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INTEGRATED GEOPHYSICAL METHOD FOR GOLD EXPLORATION IN BIRNIN GWARI, KADUNA STATE NIGERIA

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ABSTRACT

Birin Gwari is well recognised for having a wealth of minerals, particularly gold deposits, but its exploration efforts based on the use of single method have resulted to inaccurate results when it comes to detecting mineralisation zones and target accuracy. This problem was addressed by combining induced polarisation (IP) and electrical resistivity imaging (ERI) surveys techniques to further investigate the interpreted aeromagnetic data of the study. This combined technique improved subsurface characterization of the identified gold-mineralized zones with detail geological information. The study adopted GDD IP and electrical resistivity imaging survey equipment to probe further the selected nine IP profiles of delineated anomalous from the aeromagnetic survey. The results from the 2-D inverted IP - resistivity models revealed that 30 out of 34 of the anomalous zone with high chargeability and high to average resistivity were identified. Also, 33 of the IP profiles were highly charged, and their chargeability increased with depth. Meanwhile, 29 of the delineated anomalous has a width length less than 10 m while 5 has greater than 10 m. However, the depth to top length of the 34 anomalies varied from 5 to 81 m. Therefore, the study came to the conclusion that the geophysical parameters of each of the identified anomalous and the maps of mineral prospective priority targets should be served as a reference for core drilling of the suggested anomalous points.

Keywords: Birin Gwari, Gold mineral, Induced polarisation, Electrical resistivity, Aeromagnetic survey

INTRODUCTION

Gold exploration in Birnin Gwari, Nigeria, is vital due to the region's rich mineral deposits, which can significantly boost the local economy and contribute to national revenue. The discovery and development of gold reserves can create jobs, improve infrastructure, and attract both local and foreign investment (Ahmed, 2022). As Nigeria seeks to diversify its economy beyond oil, gold exploration represents a strategic avenue for growth and economic resilience. Studies indicate that combining IP and resistivity techniques with aeromagnetic data allows for improved subsurface characterization, especially in distinguishing between mineralized zones and barren rock, which is crucial in gold-rich terrains (Sono et al., 2021; Yusuf et al., 2022; Su et al., 2023). By adopting these geophysical techniques in the study area, exploration teams can effectively delineate subsurface structures, identify mineralization zones, and enhance target accuracy that might be missed using individual methods. The aeromagnetic geophysical studies can map out significant geological structures that suggest possible mineral deposits (Joshua et al., 2017; Almasi et al., 2017; Akinlalu et al., 2018). Meanwhile, ground-based IP measures the chargeability of materials, helping to identify areas with potential mineralization (Dusabemariya et al., 2020; Revil et al., 2022). On the other hand, electrical resistivity assesses the electrical resistance of the subsurface, revealing varying rock properties (Nthaba et al., 2020; Yusuf et al., 2022). This integration can lead to improved targeting of drilling locations, reduced exploration costs, and increased chances of discovering economically viable gold deposits, ultimately enhancing the efficiency and effectiveness of exploration efforts (Moreira et al., 2019). Multiple studies have demonstrated the effectiveness of IP and electrical resistivity imaging in mineral exploration in various regions (Han et al., 2016; Abdullahi and Alabi, 2018; Arifin et al., 2019; Gupta et al., 2019; Yusuf et al., 2022). Previous gold exploration efforts in Birnin Gwari have faced several limitations, primarily due to reliance on traditional methods such as surface mapping, soil sampling, and direct drilling. These techniques often offered limited spatial resolution and could overlook deeper or subtly mineralized areas (Martínez et al., 2019). Additionally, their dependency on surface expressions of mineralization could lead to false conclusions, missing concealed deposits entirely. Economic constraints also often restricted the extent of drilling undertaken, and the high cost of exploration made it challenging to conduct thorough and expansive studies. Furthermore, environmental concerns and regulatory hurdles sometimes impeded comprehensive exploration initiatives (Adekiya et al., 2024). As a result, many potentially promising areas remained underexplored or inadequately assessed, necessitating more advanced and integrated approaches to improve exploration success. Based on this, the study adopted the potential for improving gold exploration in the study area by combining induced polarisation and electrical resistivity imaging geophysical methods to provide a more understanding of subsurface geology. The outcomes of this study will not only lead to better identification of gold-bearing targets, but also enhance economic recovering of viable gold mineral in the study area.

MATERIALS AND METHODS

Description of the Study Areas

The Brinin Gwari gold deposit is located in the Northern Nigeria region, specifically in the Kaduna State, which is part of the larger Nigerian Shield. Figure 1 illustrates the Birnin Gwari gold deposit's geographic location in Kaduna State, Nigeria, at roughly 10.34°N latitude and 7.48°E longitude. It is located in the Birnin Gwari Local Government Area, about 120 kilometers northeast of Kaduna metropolis. The modified geological map of the Zungeru-Birnin Gwari schist belt and other explored schist belts is presented in Figure 2. This region is known for its complex geological setting and significant mineralization, including the presence of gold (Oluyede & Klötzli, 2020). The area is influenced by the West African Craton's geology and is characterized by a range of metamorphic and igneous rock formations (Mohammed *et al.*, 2021). The geology features precambrian rocks, primarily comprised of schists, gneisses, and granites, reflecting a history of significant tectonic activity (Sunkari et al., 2022; Lukman et al., 2024). The dominant rock types in the region include metasedimentary rocks (e.g. schists and phyllites that have undergone metamorphosis), granitoids (e.g. syn- and post-tectonic granites and diorites which are often associated with mineralization), and volcanic rocks (there are also occurrences of metavolcanics that can be associated with gold mineralization). Gold mineralization at Brinin Gwari is closely related to structural geology, occurring along shear zones and within quartz vein systems.

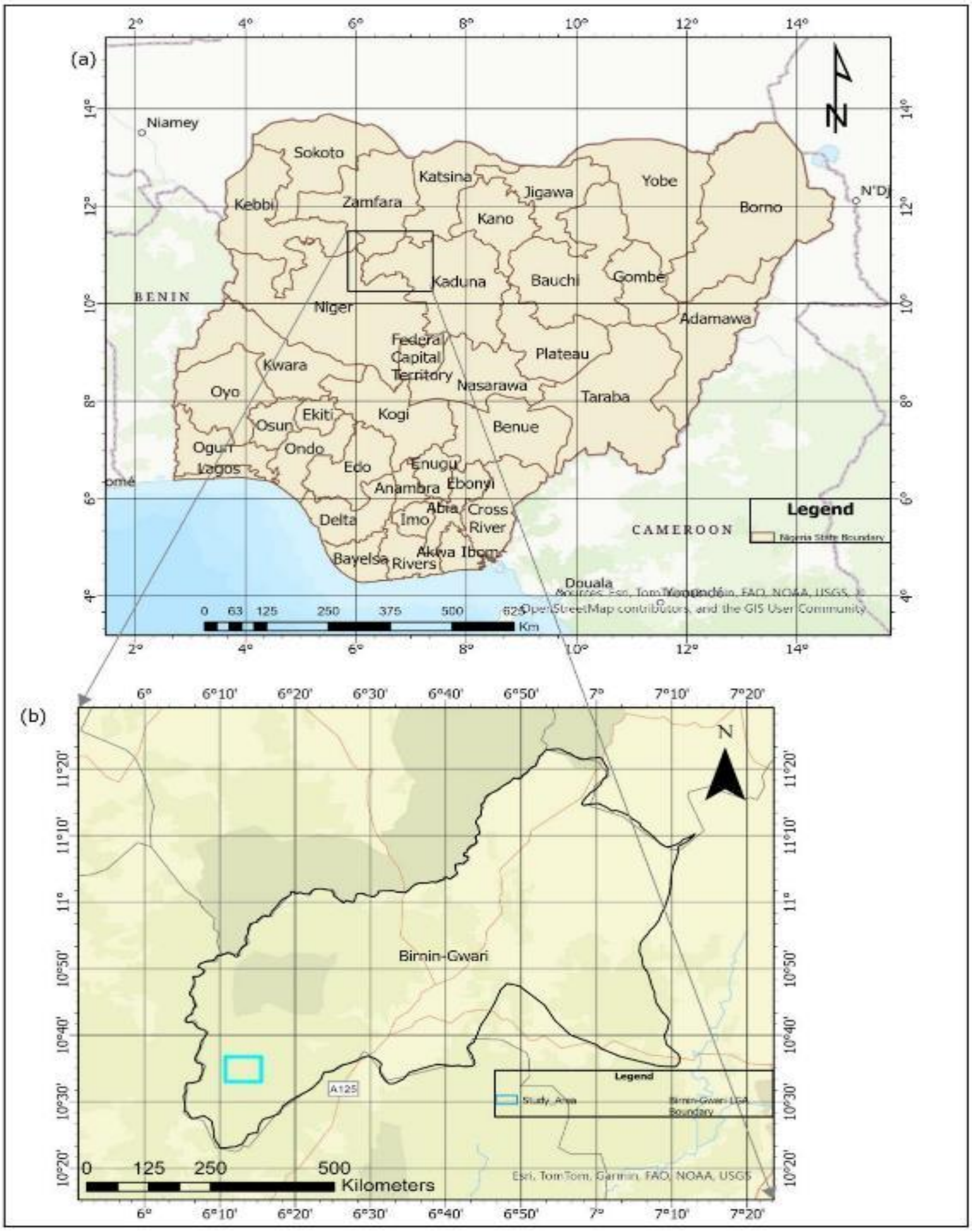


Figure 1: Map of the Study Area

The mineralization is often on or along the contact zones of different rock types, particularly where granites intrude into metamorphic rocks, creating the right conditions for hydrothermal activity (Mohammed et al., 2021). The gold deposit features in the area are both primary veins and secondary deposits, such as alluvial gold accumulations derived from weathering and erosion of the primary sources. The primary ore is generally hosted in quartz veins where gold occurs in association with sulfides like pyrite, arsenopyrite, and chalcopyrite (MMSD, 2010). This suggests that the hydrothermal fluids responsible for mineralization were rich in gold and were likely sourced from deep-seated magmatic processes. The Brinin Gwari gold area has seen various stages of exploration and artisanal mining. The gold grades can be variable, but certain intercepts have been reported to contain significant amounts of gold that make mining economically viable, especially as global gold prices remain high (Zankan et al., 2022; Zankan & Abubakar, 2024) . Like many gold mining operations, Brinin Gwari faces environmental challenges, including land degradation, pollution from mining activities, and social implications for local communities (Waziri, 2014; Ahmed, 2022).

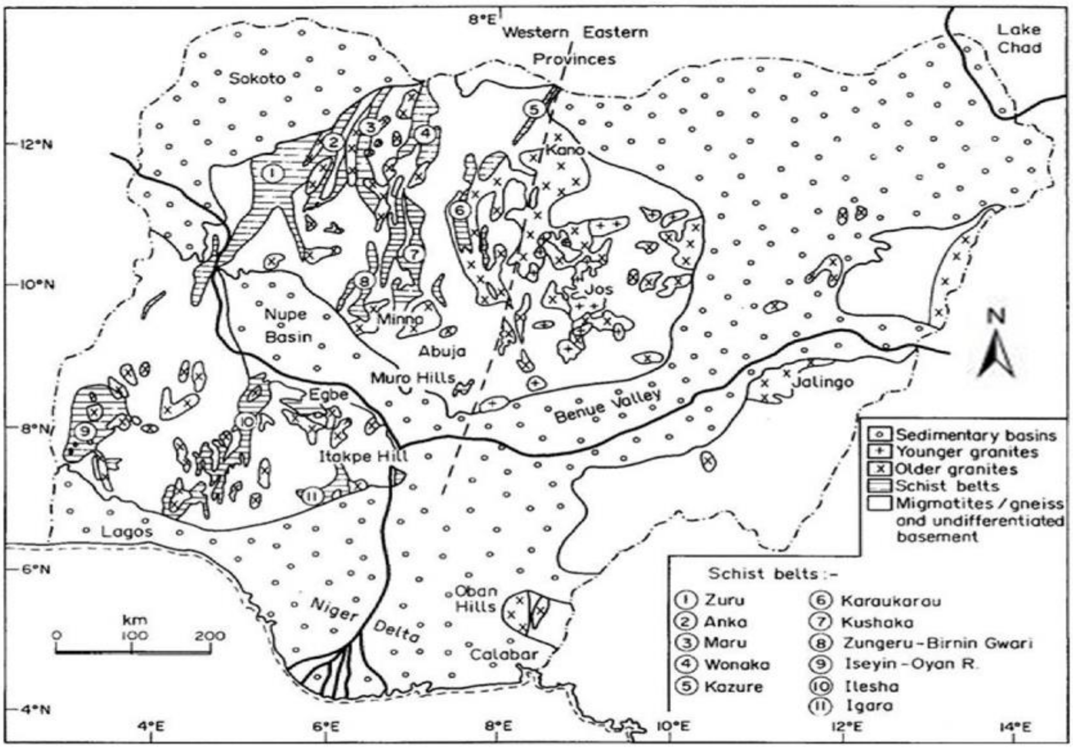


Figure 2: Generalized geology of Nigeria (modified after Obaje, 2009)

Methodology

The induced polarization (IP) and electrical resistivity imaging (ERI) were used in probing further the results of aeromagnetic survey obtained from the three prospect delineated anomalous within the study area. Figure 2(a) shows aeromagnetic survey map where prospect A covered a distance of 1.6 km with twenty-three (23) profiles, while prospect B covered a distance of 2.4 km with twenty (20) profiles and prospect C covered a distance of I.6 km with fourteen (14) profiles. A total of nine (9) IP/ERI profiles of about 1300 m each were selected from aeromagnetic survey data. The selected IP/ERI prospect profiles were chosen as a result of their distinguished magnetic responses, which are indicative of possible mineral deposition. The GDD IP and electrical resistivity imaging survey equipment that manufactured by GDD Inc. Canada was concurrently utilized to conduct the IP and ERI study. The GDD IP equipment (Figure 2b) consists of GDD 5000W-2400V-10A IP Transmitter (model TxII) unit, Model GRx8-32 IP Receiver unit, connecting cables, two electrodes (transmitter Tx1 and Tx2) and nine porous pots as receivers. The equipment has a transmission cycle of 2 seconds ON, 2 seconds OFF. It is sturdy and can operate in extreme climatic conditions (40℃ to 65℃). The QVGA screen allowed the real-time presentation of the chargeability data, resistivity, and IP decay curves. The GRx8-32 was utilised as the single channel display of graphics prior to data capture in order to continuously monitor the main voltage waveform and control the noise level. In the time domain, the IP effect developed when the current was suddenly cut off; instead of going back to zero, the primary voltage plummeted to a secondary voltage that gradually decayed. The electrical current was passed to the ground through the first pair of electrodes, while the second pair of electrodes was used to measure the resulting voltage at a reasonable distance between the electrodes. The dipole-dipole array method (Figure 2c) was used for electrical resistivity imaging to produce an image of the subsurface resistivity. The IP/ERI profiles were conducted in the directions that cutting across the general trends of the veins extracted from aeromagnetic survey data.

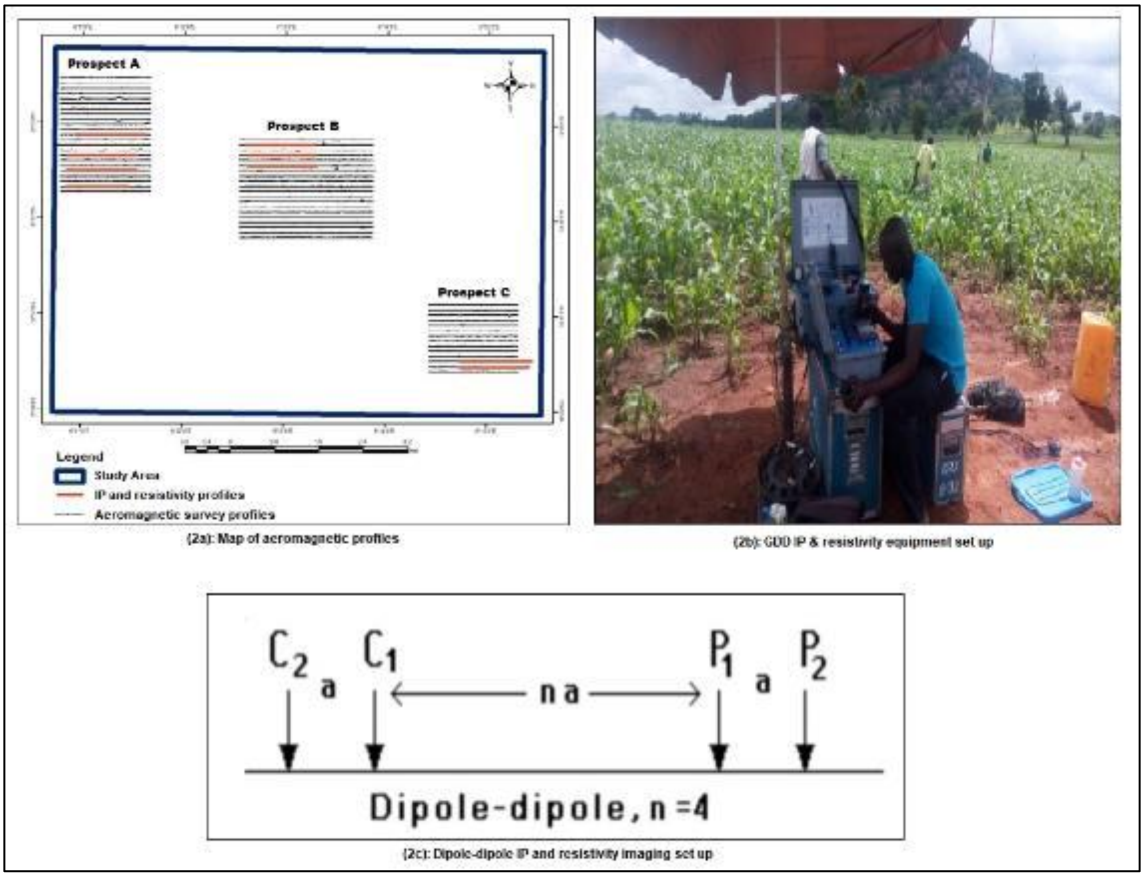
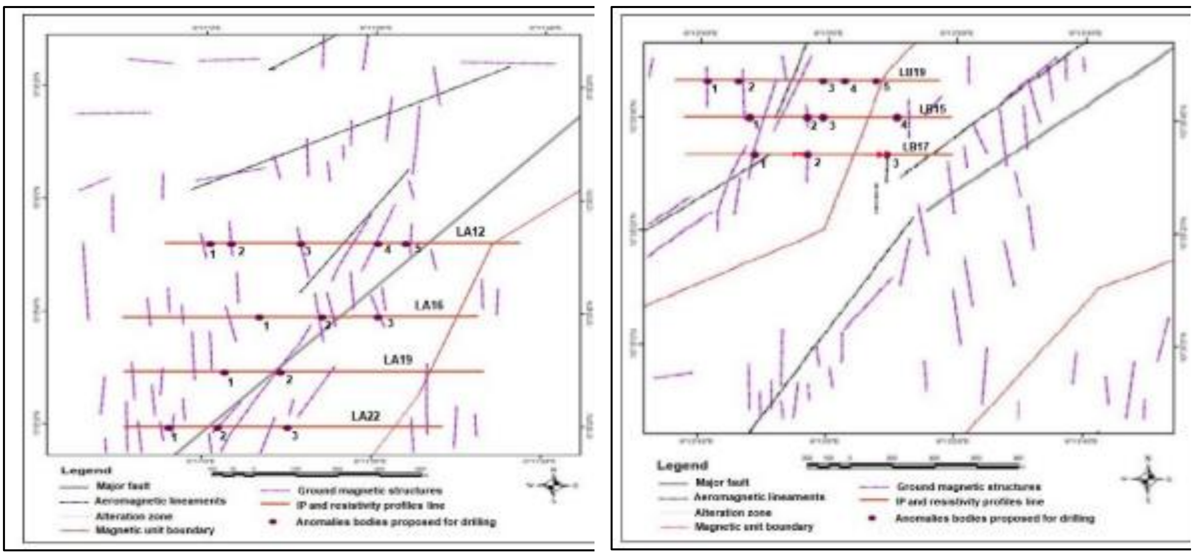


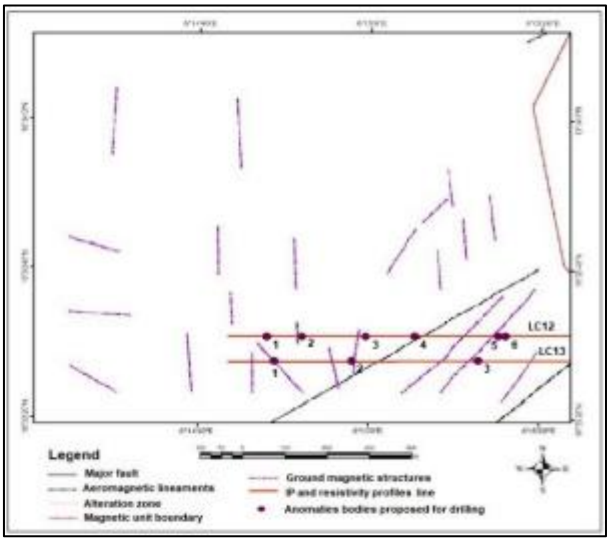
Figure 3: Geophysical data acquisition methods

Data Processing and Interpretation

Out of a total nine (9) IP/ERI profiles selected from aeromagnetic survey data, four (4) were selected from prospect A, three (3) from prospect B and two (2) from prospect C respectively. In prospect A, profile lines LA12 has 5 anomalous bodies, LA16 has 3, LA19 has 2, and LA22 has 3 (Figure 4a). Also, in prospect B, profiles lines LB19 has 3 anomalous bodies, LB17 has 3, and LB15 has 5 (Figure 4b). Meanwhile, in prospect C, profile line LC12 has 6 anomalous bodies, and LC13 has 3 (Figure 4c). The lineaments/veins on these profiles are trending mostly toward N-S, NE-SW and NW-SE with length varies from 50 m to 600 m while the width has a maximum value of 20 m.



(a): Prospect and Profile line A (b): Prospect and Profile line B



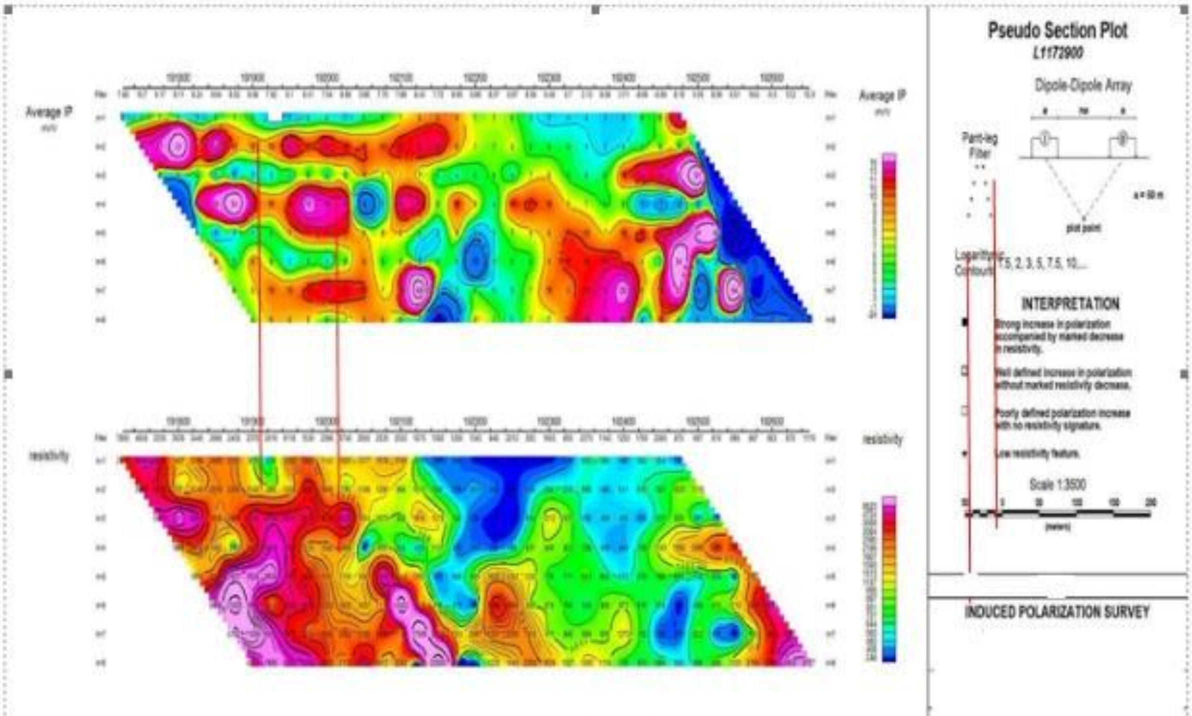
(c): Prospect and Profile line C

Figure 4: Mineral Prospective Priority Targets Map

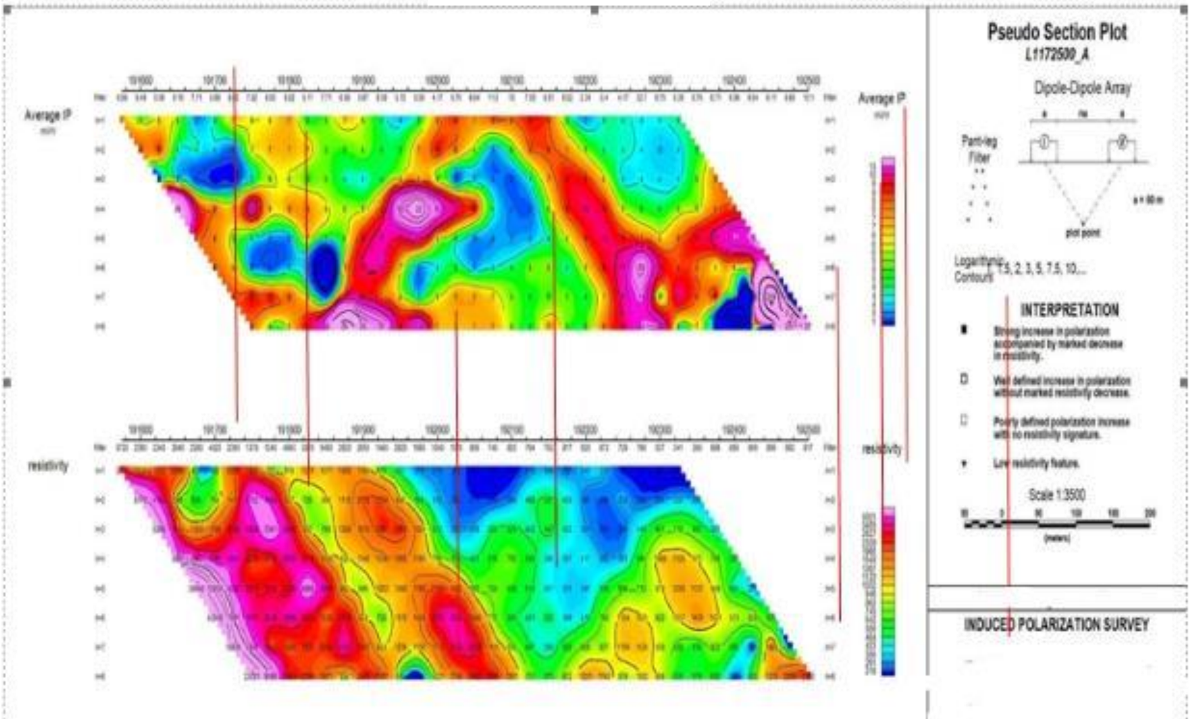
The study adopted the IP extension in the Oasis Montaj program to process and interpret the IP/ERI data obtained from the GDD IP system. The pseudo-section and 2-D inverted IP-resistivity models were used to presents the qualitative understanding of the subsurface's distribution of resistivity and chargeability data. Studies have confirmed that northern schist belt's primary gold deposit is linked to sulphide mineralisation (MMSD, 2010). Meanwhile, significant responses of chargeability especially sulphides mineralisation is an indication of potential gold mineralisation. Therefore, high chargeability is considered as one of the major parameters for prospecting and delineating gold mineralisation in the study area. On the other hand, resistivity data helps detect zones with different fluid content and mineralisation by revealing information about the conductivity of geological materials. According to the field report from previous research, the majority of primary gold mineralisation in the study area's schist belt typically occurs in quartz veins across a variety of lithologies. Therefore, the geophysical properties of the quartz veins constitute another crucial element in defining the gold potential in the study area. Since the predicted primary gold deposits in the study area are located within quartz veins associated with sulphide mineralisation, the high chargeability and high to average resistivity values were considered as anticipated zones for gold mineralisation.

RESULTS AND DISCUSSION

The results of the 2-D inverted IP - resistivity models (Figures 3 to 5) present the aeromagnetic survey profiles with high chargeability and high to average resistivity values. Twenty three (23) of the high chargeability and high to medium resistivity values were found at a very shallow depth between 5 and 50 m, while seven (7) exceeding 50 m, with a highest of 81 m. The detailed geophysical parameters (resistivity, chargeability, and magnetic response) of each of the nine IP/ERI profiles with their identified anomalous bodies is presented in Table 1. The table revealed that 30 out of 34 of the anomalous zone with high chargeability and high to average resistivity were identified. Also, 33 of the IP profiles were highly charged, and their chargeability increased with depth. Meanwhile, 29 of the delineated anomalous has a width length less than 10 m while 5 has greater than 10 m. However, the depth to top length of the 34 anomalies varied from 5 to 81 m.



Prospect A (TR12)



Prospect A (TR16)

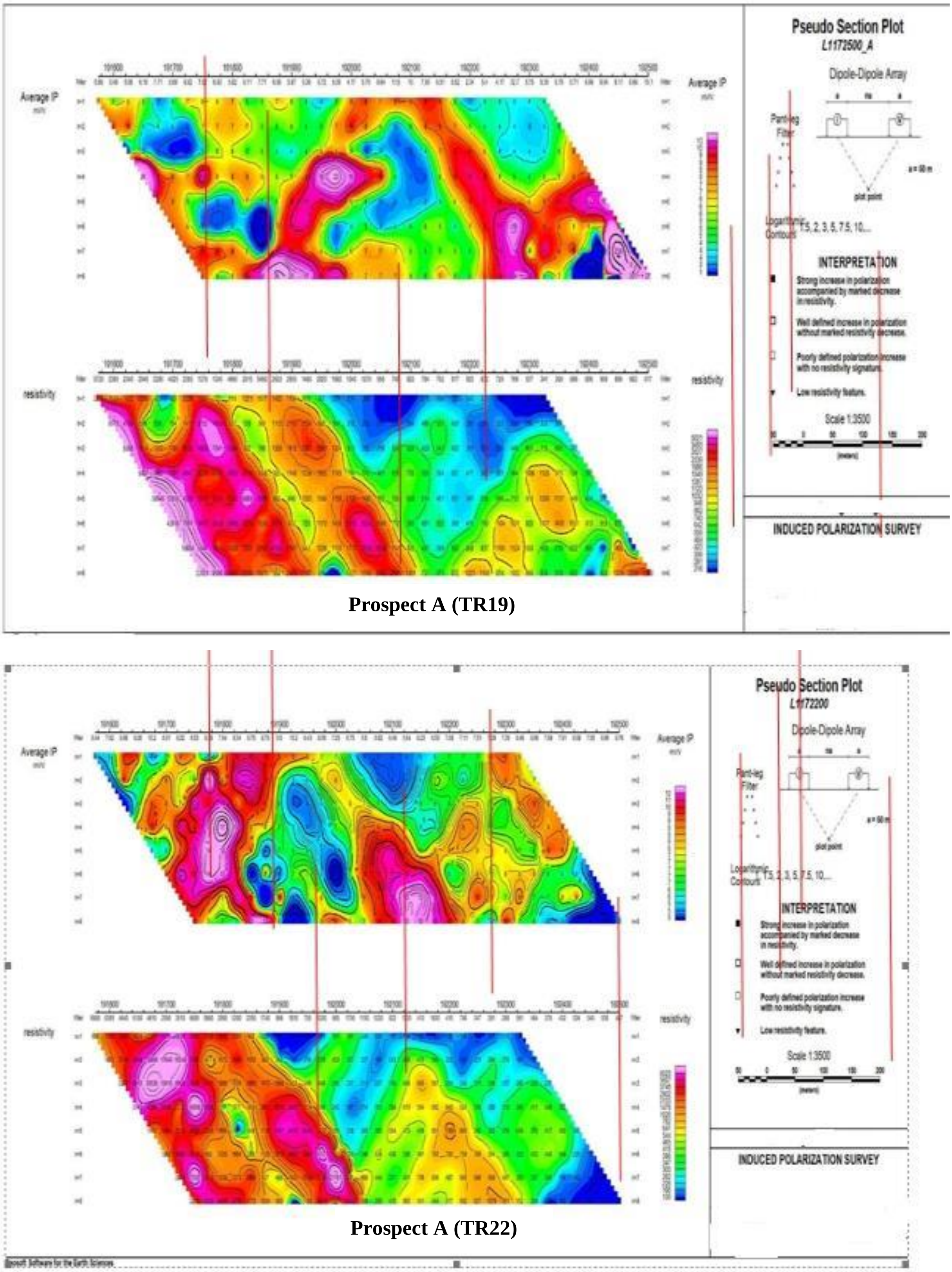
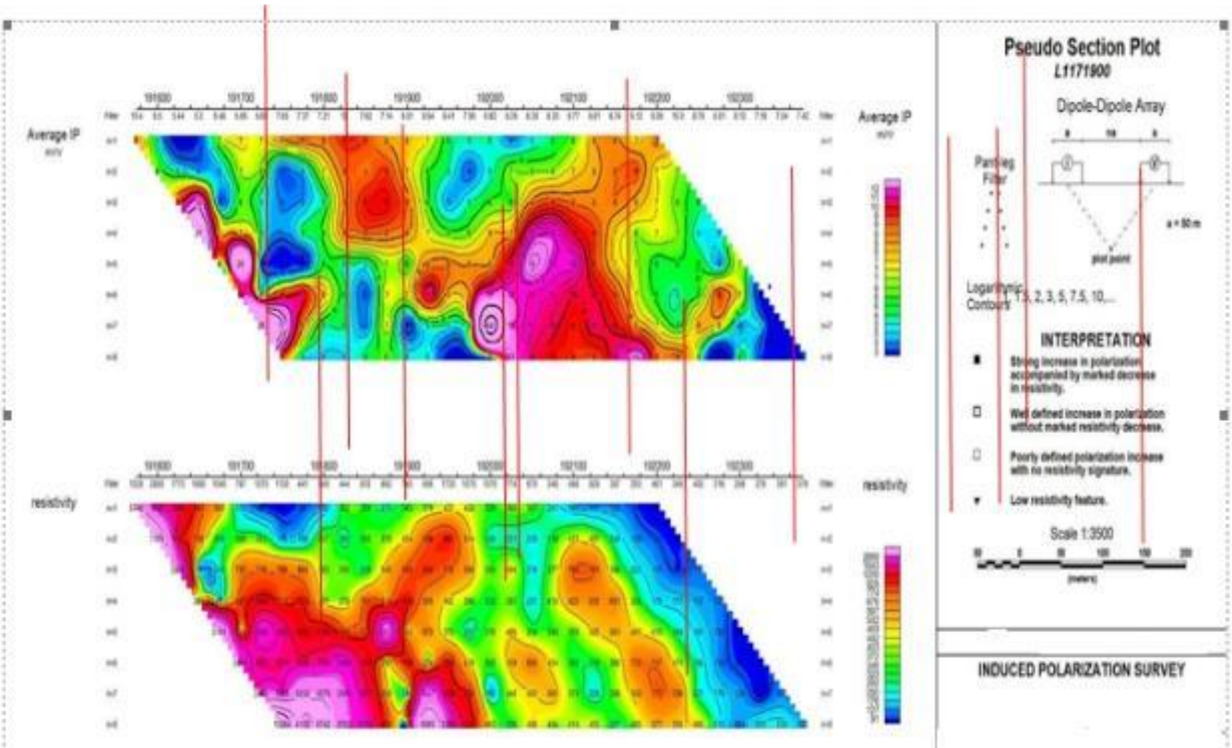
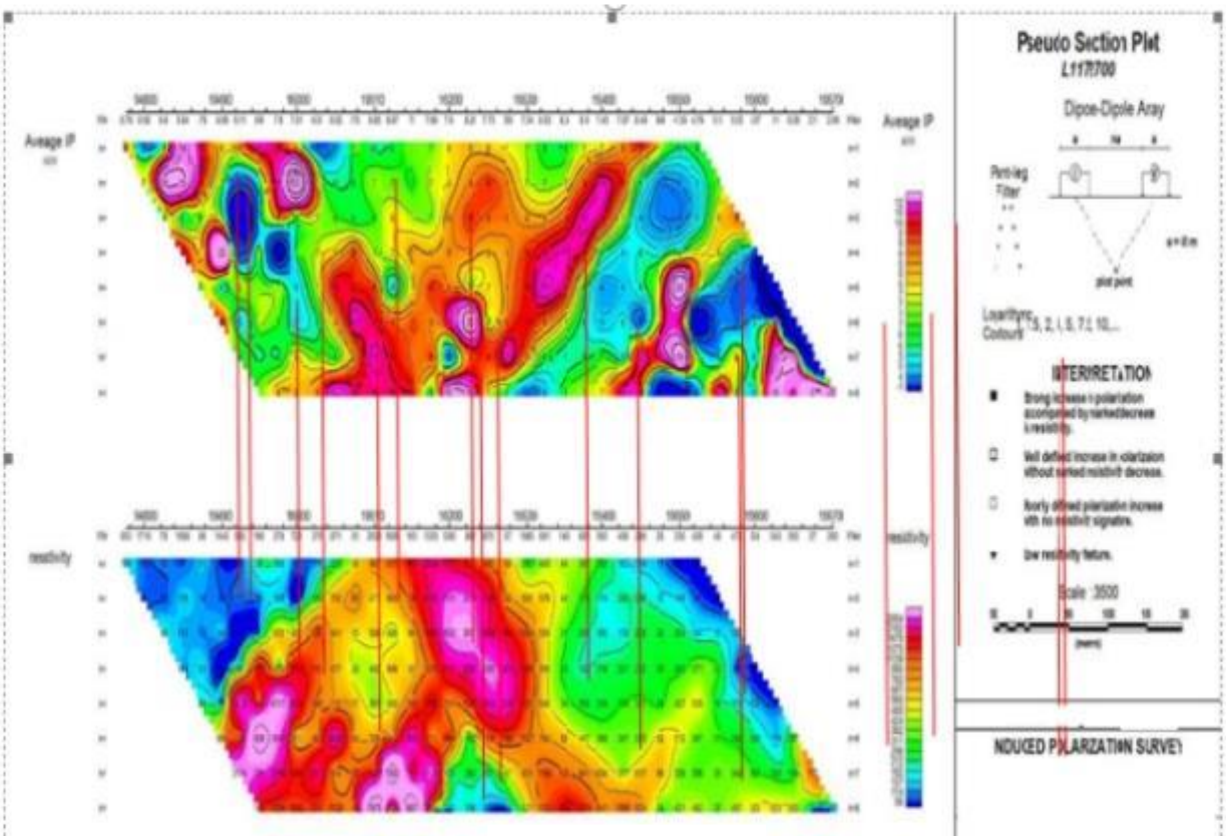


Figure 5: Pseudo-section plot of the IP and resistivity data for Prospect A



Prospect B (TR19)



Prospect B (TR17)

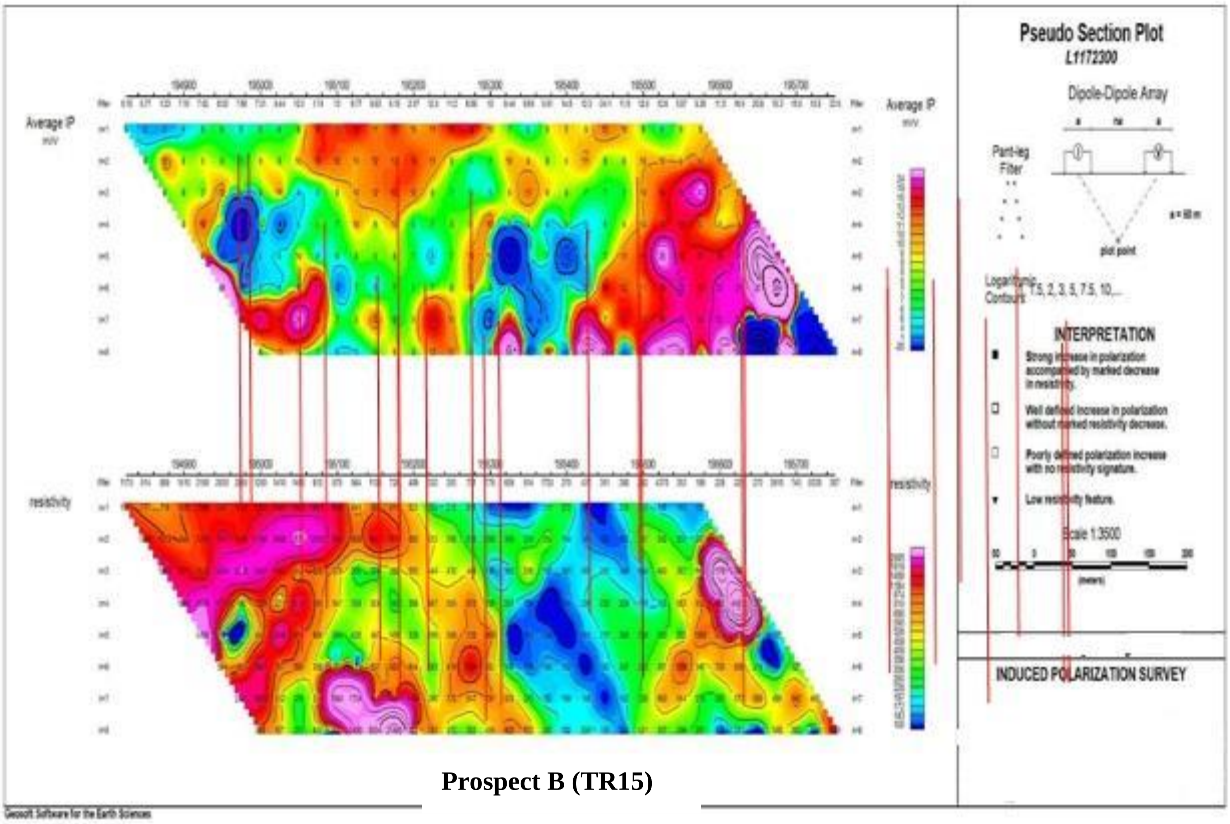
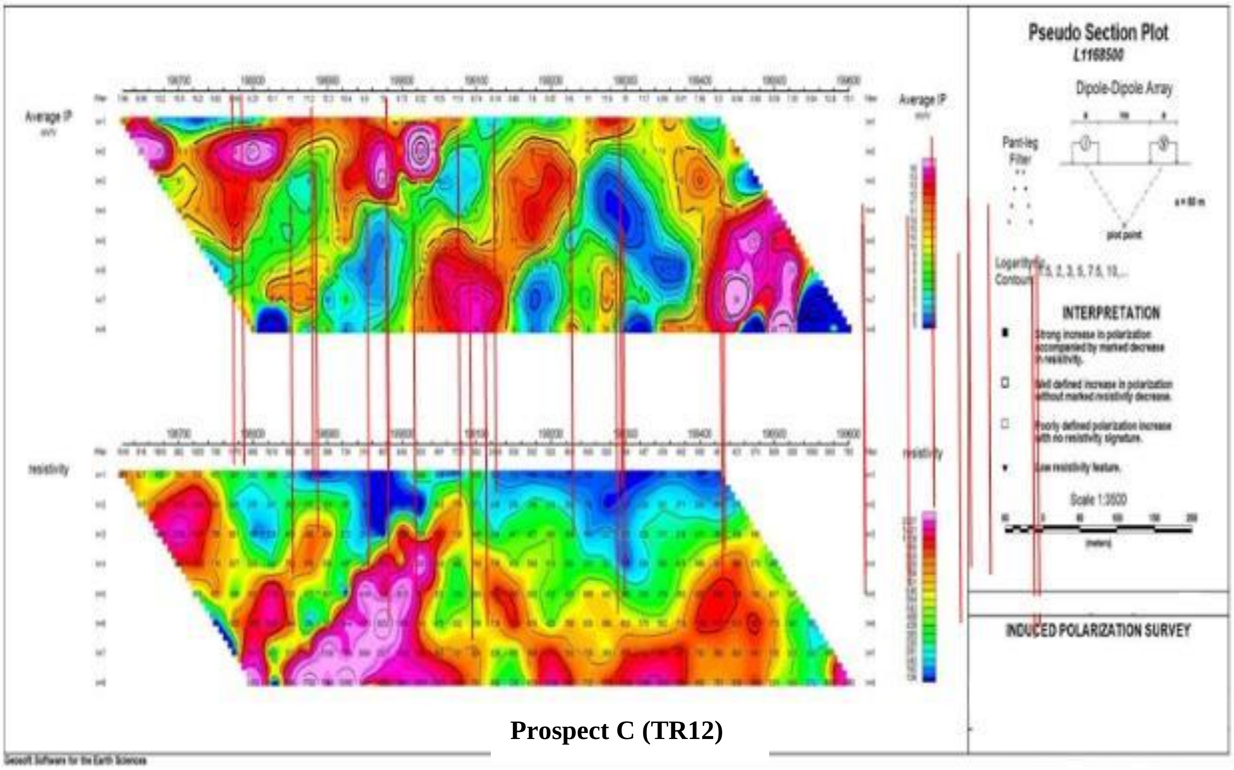


Figure 6: Pseudo-section plot of the IP and resistivity data for Prospect B



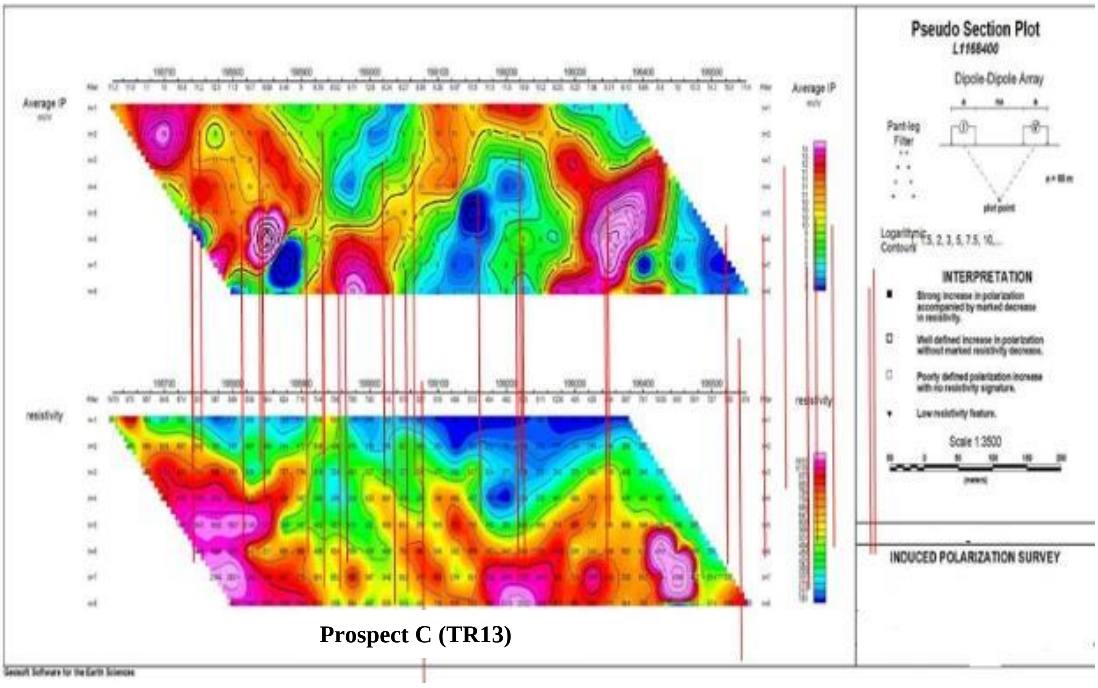


Figure 7: Pseudo-section plot of the IP and resistivity data for Prospect C

Table 1: Geophysical parameters of selected IP/ERI profiles with their identified anomalous bodies at Birni Gwari

S/N	Prospect	Profile Line	Easting	Northing	Width	Depth to top	Magnetic response	Chargeability level	Resistivity level	Occurrence on nth dipole
1	A	L22	192075	1171900	>10m	38m	Good	High	Medium	N4 to N8
2	A	L22	191650	1171900	<10m	26m	Good	High	High	N3 to N8
3	A	L22	191825	1171900	<10m	5 m	Good	Medium	Low	N1 to N6
4	A	L19	192050	1172200	>10m	38m	Good	High	Medium	N4 to N8
5	A	L19	191850	1172200	>10m	15m	Good	High	High	N2 to N8
6	A	L16	192400	1172500	<10m	50m	Good	High	High	N5 to N8
7	A	L16	192200	1172500	<10m	38m	Good	High	High	N4 to N8
8	A	L16	191975	1172500	<10m	38m	Good	High	High	N4 to N8
9	A	L12	191800	1172900	<10m	15m	Good	High	High	N2
10	A	L12	191875	1172900	<10m	38m	Good	High	High	N4
11	A	L12	192500	1172900	<10m	38m	Good	High	Medium	N3 to N8
12	A	L12	192400	1172900	<10m	81m	Good	High	High	N7 to N8
13	A	L12	192125	1172900	<10m	81m	Good	High	High	N7 to N8
14	B	L19	195650	1172700	<10m	81m	Good	High	Medium	N7 to n8
15	B	L19	195500	1172700	<10m	50m	Good	High	Medium	N5 to N8
16	B	L19	195400	1172700	<10m	15m	Good	High	Medium	N2 to N7
17	B	L19	195000	1172700	<10m	38m	Good	High	Medium	N4 to N6
18	B	L19	194850	1172700	<10m	65m	Good	High	Low	N1 to N2
19	B	L17	195400	1172500	<10m	65m	Good	High	Medium	N6 to N8
20	B	L17	195050	1172500	<10m	38m	Good	High	High	N4 to N8
21	B	L17	195325	1172500	<10m	5m	Good	High	High	N1 to N8
22	B	L15	195325	1172300	<10m	81m	Good	High	Medium	N7 to N8
23	B	L15	195675	1172300	<10m	38m	Good	High	Medium	N4 to N8
24	B	L15	195075	1172300	<10m	65m	Good	High	Medium	N6 to N8
25	B	L15	195275	1172300	<10m	5m	Good	High	Medium	N1 to N4
26	C	L13	199425	1168400	<10m	26m	Good	High	High	N3 to N8
27	C	L13	198975	1168400	<10m	65m	Good	High	High	N6 to N8
28	C	L13	198700	1168400	<10m	15m	Good	High	High	N2 to N7
29	C	L12	199500	1168500	<10m	38m	Good	High	High	N4 to N8
30	C	L12	199525	1168500	>10m	50m	Good	High	High	N5 to N8
31	C	L12	199200	1168500	>10m	26m	Good	High	High	N3 to N8
32	C	L12	198800	1168500	<10m	15m	Good	High	Low	N2 to N3
33	C	L12	199025	1168500	<10m	15m	Good	High	Low	N2 to N3
34	C	L12	198675	1168500	<10m	15m	Good	High	High	N2 to N1

CONCLUSION

The study probing further the selected aeromagnetic survey profiles that are indicative of possible gold mineralisation by utilising the GDD IP equipment. The projected primary gold deposit in the studied areas is within a quartz vein linked with sulphide mineralisation, implying that the veins are mineralised to varied degrees of characterisation. The findings from most of the 2-D inverted IP - resistivity models present high chargeability and high to average resistivity values. With a very shallow depth of less than 50 m. Out of the nine IP profiles, thirty of the anomalous zone recorded high chargeability and high to average resistivity, while twenty of the anomalies had a width of less than 10 m. However, the depth to top length of the thirty anomalies varied from 5 to 81 meters. Therefore, the study suggested that the geophysical parameters of each of the identified anomalous and the maps of mineral prospective priority targets should be served as a reference for core drilling of the suggested anomalous points.

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