

## Geophysical signature of felsic intrusions in the Toumodi-Fêtêkro belt (evidence from Akakro, Côte d'Ivoire): Insights into the Birimian basement evolution

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### Abstract

The Toumodi-Fêtêkro Belt in central Côte d'Ivoire is a Paleoproterozoic volcano-sedimentary basin intruded by granitoids and granodiorites. Despite its recognized geological importance, subsurface characterization of felsic intrusions has remained limited. This study applies to integrated magnetic and electrical geophysical methods to investigate the geophysical signatures of felsic rocks in the Akakro sector. Magnetic surveys revealed strong positive anomalies, with vertical gradients delineating shallow intrusive bodies and contact zones. Electrical resistivity measurements conducted using Schlumberger and dipole-dipole configurations, distinguished fresh felsic formations from altered and fractured domains. Fresh granitoid and granodiorite bodies were identified as high-resistivity zones ( $>1000 \Omega \cdot m$ ), while altered felsic formations showed reduced resistivity values ( $<300 \Omega \cdot m$ ) and an average alteration thickness of 15 m. Sounding analyses highlighted fracture-controlled conductive corridors-oriented NE-SW and NNE-SSW, consistent with regional tectonic lineaments. Synthesis maps quantified reserves, showing 54.09 ha of fresh felsic rocks and 31.47 ha of altered domains, with mafic units limited in extent. These results confirm that felsic intrusions dominate the Akakro sector, producing distinctive geophysical signatures characterized by elevated magnetic susceptibility and high resistivity. The findings extend earlier geological observations by providing subsurface quantification and highlight the role of felsic magmatism and tectonic fracturing in the evolution of the Birimian basement.

**Keywords:** Magnetic anomalies; Electrical resistivity; Felsic intrusions; Alteration zones; Fracture networks; Toumodi-Fêtêkro Belt

### 1. Introduction

The Toumodi-Fêtêkro Belt, located in central Côte d'Ivoire, represents a geologically complex region where magmatic, metamorphic, and sedimentary formations coexist. Felsic intrusions, particularly granitoids and granodiorites, are central to understanding the tectonomagmatic evolution of the Paleoproterozoic basement. Despite nearly a century of geological investigations, the geophysical characterization of these felsic intrusions remains incomplete. Early geological missions conducted between 1934 and 1938 by Bouige, Archambault, and Donnault led to the first geological maps of the belt, identifying volcanic lenses and metamorphic aureoles (Archambault et al., 1938). Subsequent work by Baud (1944) confirmed the presence of numerous volcanic rock indices along the Fêtêkro corridor. These pioneering studies provided a descriptive framework but lacked systematic analysis of the physical properties of the intrusions. In the following decades, research expanded to include petrographic and geochemical approaches. Yacé (1976) produced a detailed geological map of the southern Toumodi-Divo segment, identifying andesitic to basaltic rocks,

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metapyroxenites, metagabbros, and orthoschists, while emphasizing zones of contact metamorphism around volcanic intrusions. Mortimer (1990) proposed a lithostratigraphic classification into three groups, including the Toumodi volcanics and intrusive granitoids of type S, but his work remained focused on lithology and stratigraphy rather than geophysical properties. Recent work examined the petrography and structural evolution of the Anikro syncline, highlighting conglomeratic formations within rhyolites and dacites affected by strike-slip fractures (Ouattara et al., 2009). More recent studies have mapped deep geological formations in the Akakro locality using integrated approaches (Assie et al., 2024a), reinforcing the importance of this sector for subsurface characterization. Although these contributions enriched the geological and structural understanding of the belt, they did not address the specific geophysical signatures of felsic intrusions. Parallel to geological investigations, geophysical studies conducted by ORSTOM between 1953 and 1986 provided additional insights. Gravimetric surveys by Jean and Buffard (1960) revealed positive anomalies associated with volcanic zones and negative anomalies over the Toumodi granodiorite. Rechenman and Ramiot (1965) established a network of magnetic bases across West Africa, producing the first regional magnetic maps. While these studies were valuable, their interpretations remained broad and did not establish precise correlations between geophysical anomalies and local felsic intrusions. Later developments, including the IGRF models proposed by Peddie (1982) and the WMM programs developed by NOAA and NGA (2015), refined global geomagnetic understanding, but their application to the Toumodi-Fêtékro Belt has been limited.

The scientific problem therefore lies in the lack of integration between geological and geophysical data for the characterization of felsic intrusions in the Toumodi-Fêtékro Belt. Previous studies have been predominantly descriptive, with limited focus on the magnetic susceptibility and electrical resistivity of granitoids and granodiorites. Geophysical interpretations have remained general, without establishing direct links to felsic intrusions at the local scale. This gap restricts our ability to fully understand the tectonomagmatic processes that shaped the Birimian basement of Côte d'Ivoire. In this context, the objective of the present study is to highlight the geophysical signature of felsic intrusions in the Akakro area of the Toumodi-Fêtékro Belt. By integrating geological data with measurements of magnetic susceptibility and electrical resistivity, this research aims to overcome the limitations of previous work and provide a more comprehensive understanding of the physical characteristics of felsic intrusions. Ultimately, this study contributes to an integrated geology-geophysics approach, refining interpretations of the role of granitoids and granodiorites in the tectonomagmatic evolution of the Ivorian Birimian basement.

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## 2. Methodology

### 2.1. Study area and geological context

The study was carried out in the Toumodi-Fêtékro Belt, specifically in the Akakro locality of the Béliér region, central Côte d'Ivoire (Fig. 1). This area lies between latitudes 6°–7°N and longitudes 4°–5°W, approximately 15 km from Toumodi and 30 km from Yamoussoukro. The geological framework of the belt is part of the Paleoproterozoic Baoulé-Mossi domain of the West African Craton, characterized by granitoids, granodiorites, metasediments, schists, and felsic to mafic volcanics (Tagini, 1972; Yacé, 1976). Akakro is located at the boundary between metamorphic units and felsic volcanic intrusions, which makes it a suitable site for investigating the geophysical signatures of granitoids and granodiorites.

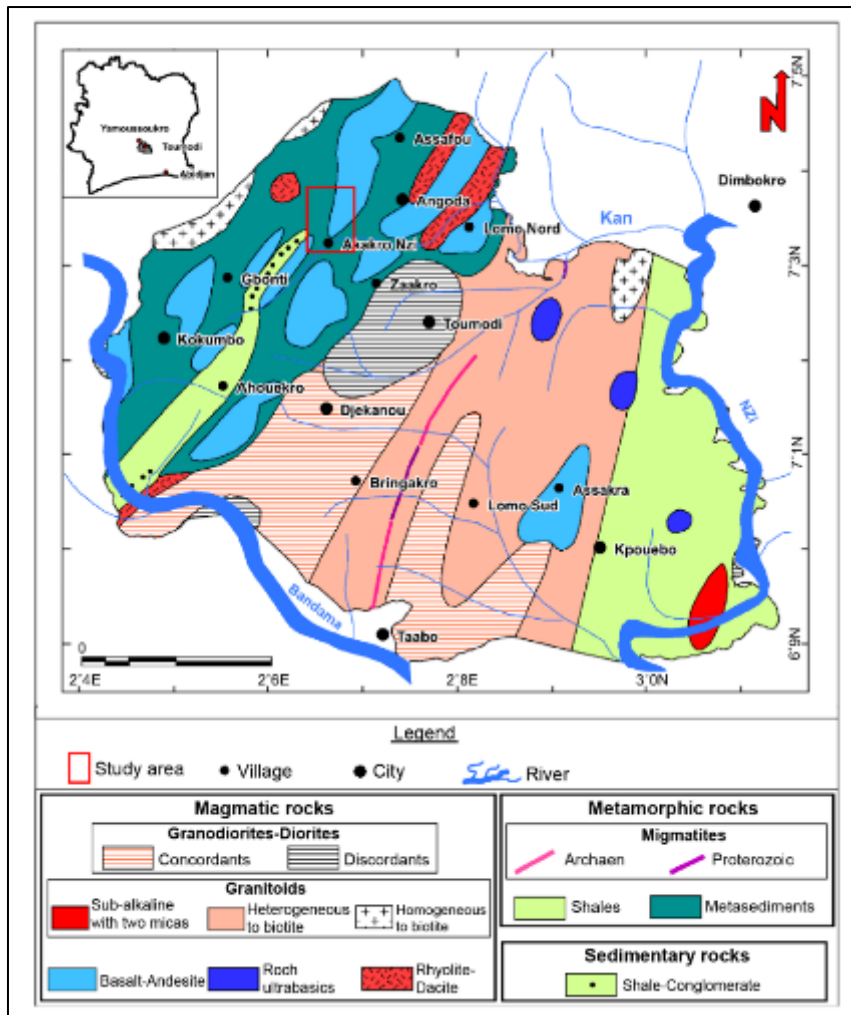


Figure 1 Geological map of the study area

## 2.2. Materials and data collection

Fieldwork involved systematic sampling of granitoid and granodiorite outcrops in the Akakro area. Each sample was oriented and documented using GPS coordinates to ensure reproducibility and spatial accuracy. Geological mapping was updated through direct field observations and compared with existing cartographic data (Tagini, 1972; Mortimer, 1990). Petrographic descriptions were performed to classify the sampled rocks into felsic, mafic, and ultramafic categories based on mineralogical composition (Best, 2003). In addition to geological sampling, geophysical measurements were conducted to determine magnetic susceptibility and electrical resistivity, which are key parameters for identifying the physical signatures of felsic intrusions. Magnetic susceptibility was measured using a portable susceptibility meter, while resistivity data were acquired through Schlumberger and dipole-dipole configurations, widely applied in mining exploration and hydrogeology.

## 2.3. Analytical procedures

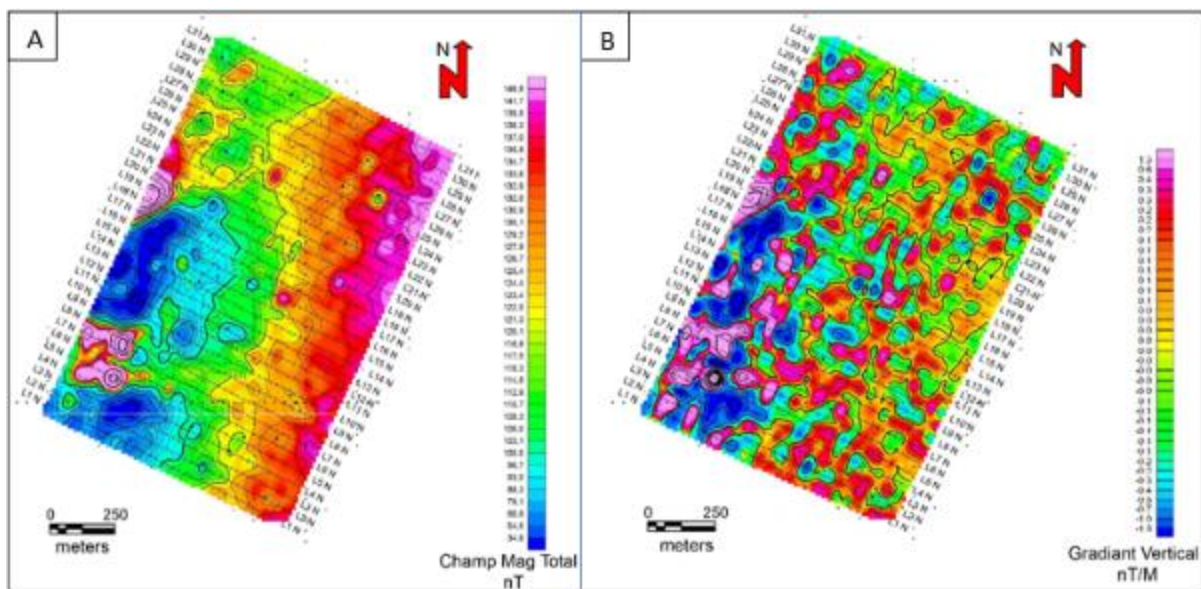
Magnetic susceptibility was calculated according to the relation ( $I = K \cdot H$ ), where ( $I$ ) is the intensity of magnetization, ( $K$ ) the susceptibility coefficient, and ( $H$ ) the applied magnetic field. This allowed quantification of the degree of magnetization of the samples, directly linked to the abundance of ferromagnesian minerals and magnetite. Electrical resistivity was derived from Ohm's law, ( $R = V/I$ ), and converted into apparent resistivity using geometric factors specific to the Schlumberger and dipole-dipole arrays. Data processing focused on identifying anomalies and correlating them with lithological units. The integration of geological mapping, petrographic analysis, and geophysical measurements provided a comprehensive framework for characterizing the geophysical signatures of granitoids and granodiorites in Akakro. This methodological approach was designed to overcome the limitations of previous studies, which were largely descriptive and lacked systematic geophysical analysis, thereby offering new insights into the tectonomagmatic evolution of the Ivorian Birimian basement.

### 3. Results

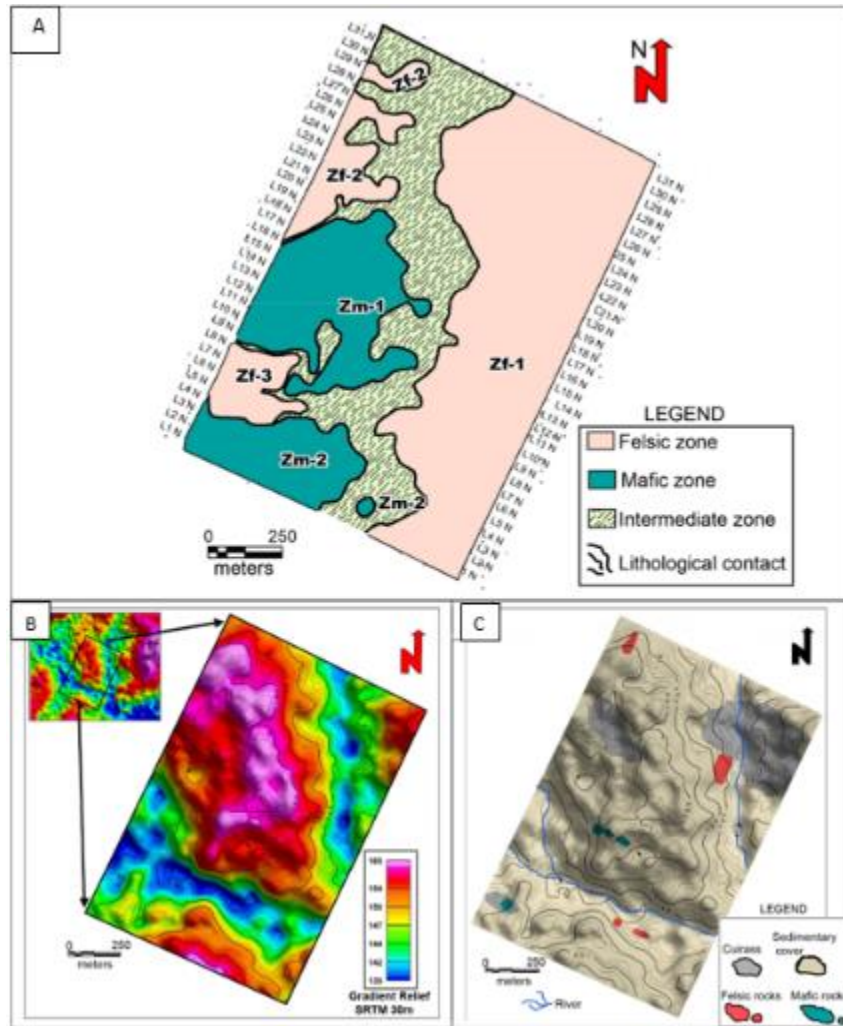
#### 3.1. Magnetic prospecting

The magnetic survey conducted in Akakro produced several maps that highlight the distribution and intensity of anomalies linked to felsic intrusions. The total magnetic field map (Fig. 2A) reveals zones of strong positive anomalies, particularly concentrated in the central and northeastern portions of the study area. These anomalies are expressed as elongated bands and circular highs, which correspond spatially to mapped granitoid and granodiorite intrusions. The intensity of the anomalies varies between 200 nT and 600 nT, suggesting significant contrasts in magnetic susceptibility between felsic intrusions and surrounding lithologies. The southern sector shows weaker anomalies, reflecting less magnetized formations.

The vertical gradient map (Fig. 2B) provides a refined view of shallow structures. This representation emphasizes the rate of change in the magnetic field, allowing the identification of near-surface intrusive bodies and contact zones. Steep gradients are observed along NE–SW and NNE–SSW orientations, consistent with structural lineaments in the Toumodi-Fêtékro Belt. These gradients delineate the boundaries of felsic intrusions, highlighting zones where intrusive bodies intersect volcanic and metamorphic formations. The magnetic anomaly interpretation map (Fig. 3) integrates the total field and gradient data to produce a lithological correlation. Resistant anomalies are associated with felsic formations, while weaker anomalies correspond to mafic and metasedimentary units. The map shows that felsic intrusions dominate the central Akakro sector, forming continuous resistant zones, while mafic formations are restricted to smaller, isolated domains. This interpretation confirms the spatial distribution of felsic intrusions and their geophysical imprint within the study area.



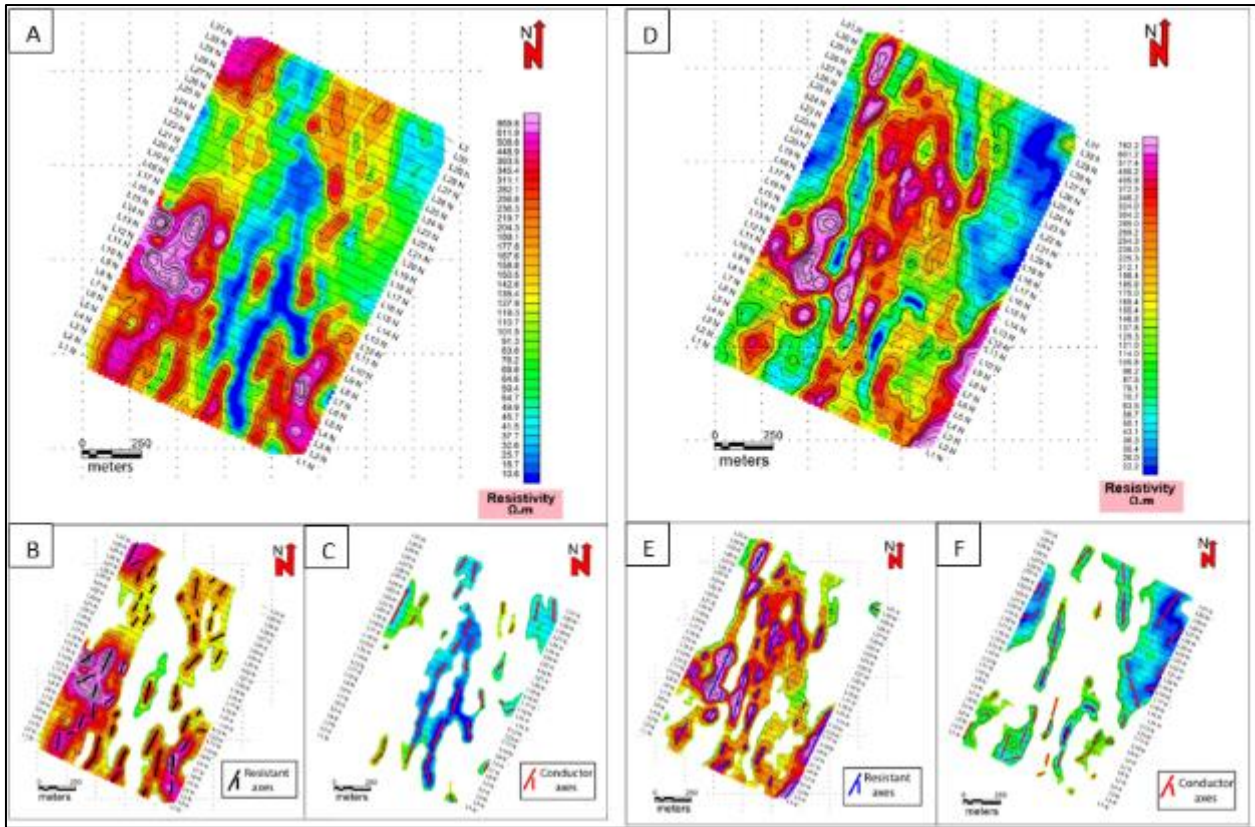
**Figure 2** Magnetic survey maps of the Akakro sector: (A) Total magnetic field map showing strong positive anomalies; (B) Vertical gradient map highlighting shallow intrusive bodies and contact zones



**Figure 3** Lithological interpretation of magnetic anomalies: (A) Felsic potential map; (B) Relief of the study site; (C) Outcrop distribution map

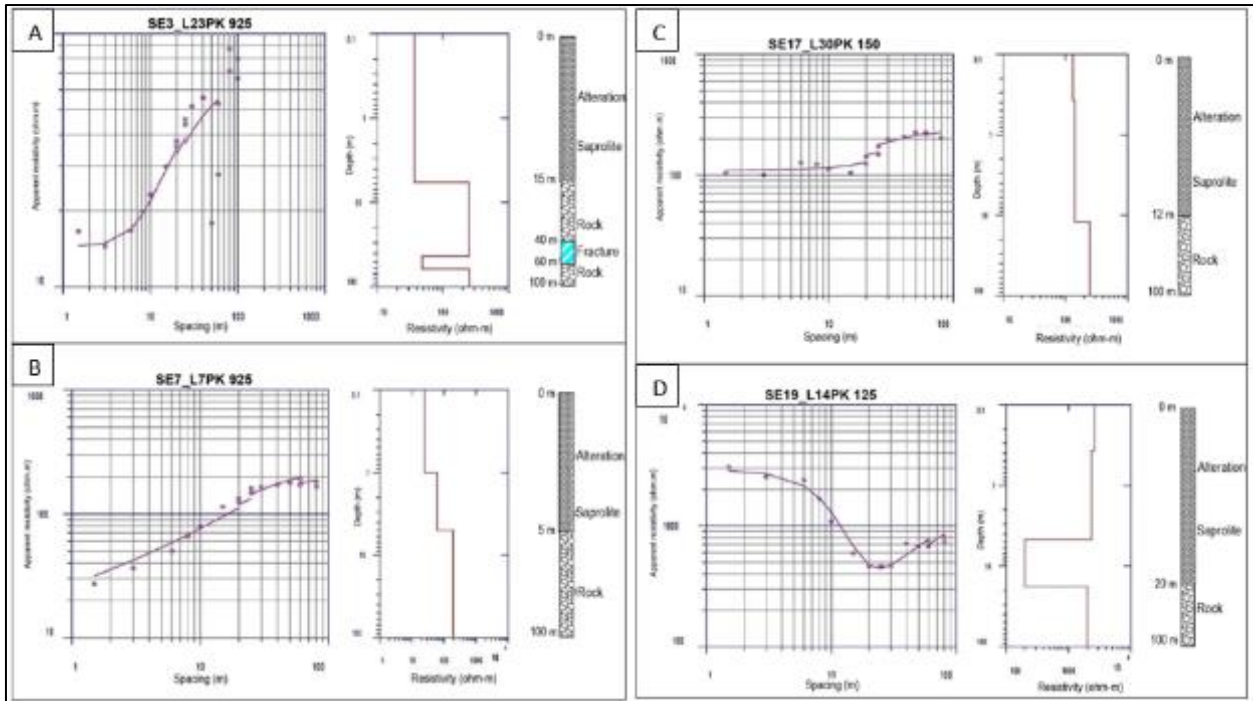
### 3.2. Electrical prospecting

The electrical resistivity survey provided complementary information to the magnetic data, allowing the characterization of subsurface formations in Akakro. The resistivity map at level 1 (Fig. 4A) highlights shallow resistivity variations across the study area. High-resistivity zones ( $>1000 \Omega\cdot\text{m}$ ) are observed in the central and northeastern sectors, corresponding to fresh granitoid and granodiorite intrusions. Lower resistivity values ( $< 300 \Omega\cdot\text{m}$ ) are concentrated in the southern and western portions, reflecting conductive lithologies such as schists and altered metasediments. At greater depth, the resistivity map at level 3 (Fig. 4B) confirms the persistence of high resistivity anomalies. These zones extend vertically, indicating that felsic intrusions are not superficial but continue into deeper levels of the subsurface. The contrast between resistant felsic domains and conductive mafic/metasedimentary units becomes sharper at this depth, reinforcing the distinction between lithological units.

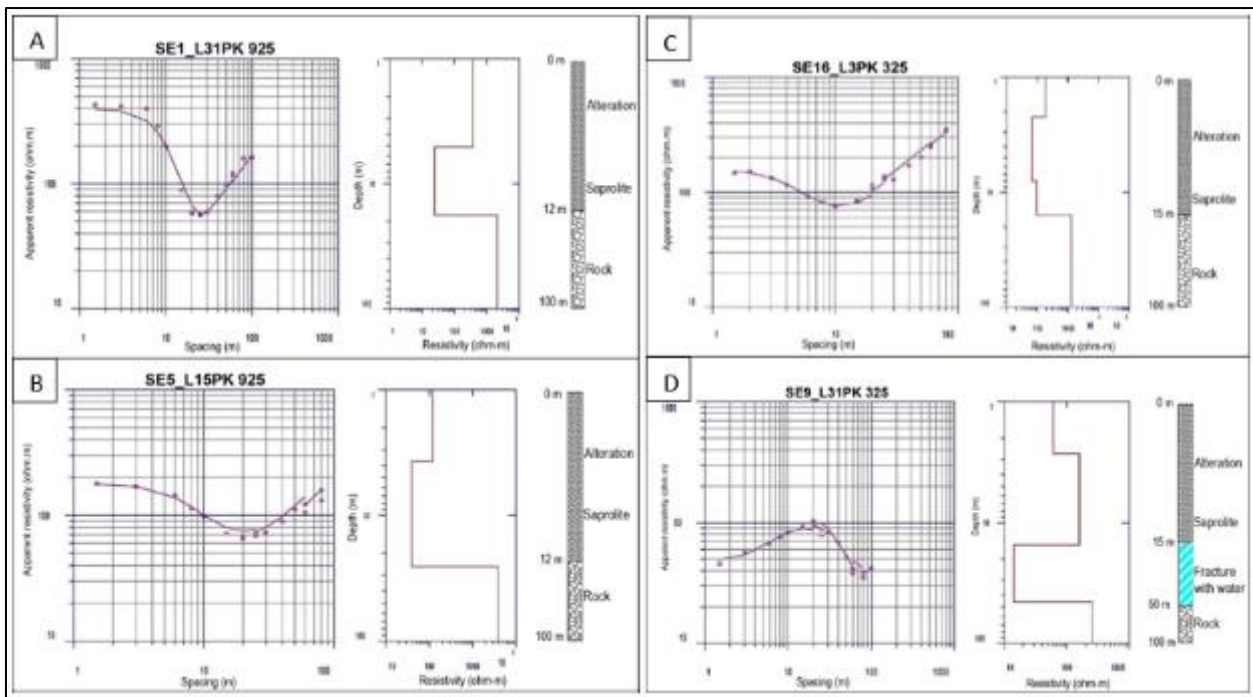


**Figure 4** Level 1 resistivity analysis: (A, D) Resistivity map; (B) Resistive anomalies (blue axes); (C) Conductive anomalies (red axes); (E) Conductive anomalies; (F) Resistive anomalies

Sounding analyses provided more localized insights into subsurface layering. The type A soundings in resistant domains (Fig. 5A, B) show a monotonic increase in resistivity with depth, consistent with thick, unaltered felsic formations. These profiles suggest massive granitoid bodies with minimal fracturing. The type H soundings in resistant domains (Fig. 5C, D) reveal a layered structure, with a conductive horizon overlying a resistant substratum. This pattern indicates felsic formations overlain by weathered or altered material, possibly clay-rich horizons or fractured zones. In contrast, the type H soundings in conductive domains (Fig. 6A, B) display decreasing resistivity with depth, highlighting zones of alteration within felsic formations. These conductive anomalies are associated with fracture networks and hydrothermal alteration, which reduce resistivity by increasing porosity and fluid content. Finally, the type K soundings in mixed conductive domains (Fig. 6C, D) illustrate complex subsurface conditions. These profiles show alternating conductive and resistant layers, reflecting felsic intrusions intersected by conductive fractures. Such heterogeneity suggests structural complexity, with felsic bodies disrupted by tectonic processes.



**Figure 5** A and H-type electrical soundings in resistive domains: (A) Profile SE3; (B) Profile SE7; (C) Profile SE17; (D) Profile SE19



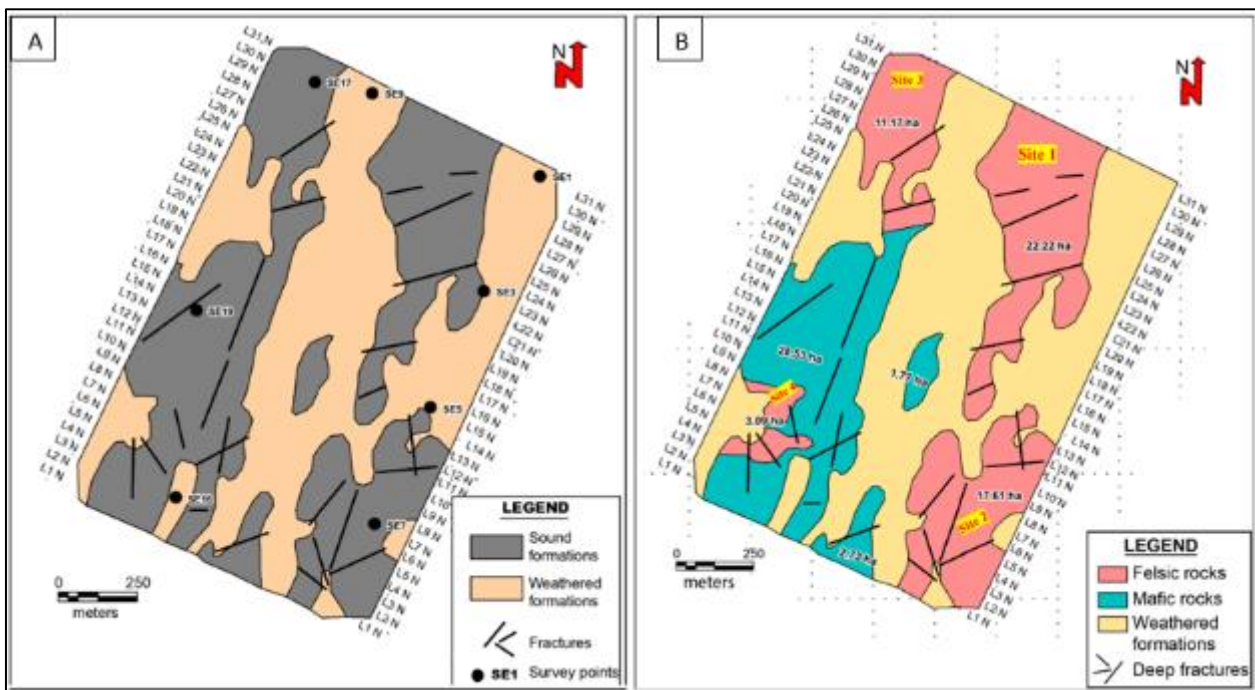
**Figure 6** H-type electrical soundings in conductive domains: (A) Profile SE1; (B) Profile SE5; (C) Profile SE16; (D) K-type electrical sounding analysis in mixed conductive domains: Profile SE9

### 3.3. Synthesis of magnetic and electrical data

The integration of magnetic and electrical datasets allowed a comprehensive delineation of felsic intrusions in the Akakro sector. The map of fresh and altered formations (Fig. 7A) provides a spatial overview of the distribution of resistant and conductive domains. Fresh felsic formations, characterized by high resistivity and strong magnetic

anomalies, occupy approximately 54.09 hectares of the study area. These zones correspond to unaltered granitoid and granodiorite bodies, identified by their consistent geophysical signatures. In contrast, altered felsic formations extend over 31.47 hectares, with an average alteration thickness of 15 m. These zones are marked by reduced resistivity and subdued magnetic responses, reflecting weathering processes and the presence of clay-rich horizons. The map also highlights the transition zones between fresh and altered domains, where resistivity values decrease progressively, indicating gradational alteration fronts.

The map of felsic and mafic reserves (Fig. 7B) quantifies the relative proportions of lithological units in the Akakro area. Felsic intrusions dominate the subsurface, forming continuous resistant domains that align with the anomalies observed in Figures 2A and 4B. Mafic formations, in contrast, are limited in extent and appear as isolated conductive pockets within the broader felsic framework. This reserve map integrates both magnetic and resistivity data, providing a volumetric estimate of felsic versus mafic resources. The felsic reserves are spatially associated with NE-SW and NNE-SSW structural orientations, consistent with the fracture networks identified in the electrical soundings.



**Figure 7** (A) Map of fresh (sound) and altered (weathered) formations across the study area; (B) Map of felsic and mafic reserves in the Akakro sector, integrating magnetic and resistivity data

## 4. Discussion

### 4.1. Tectonomagmatic evolution of the Toumodi-Fêtêkro belt

The magnetic anomalies and resistivity contrasts demonstrate that the Akakro sector is dominated by felsic intrusions, particularly granitoids and granodiorites. Their geophysical signatures—high magnetic susceptibility and elevated resistivity—are consistent with intrusive bodies emplaced during the Paleoproterozoic Eburnean orogeny (ca. 2.1–2.0 Ga). The NE-SW and NNE-SSW orientations of anomalies correspond to regional fracture systems, suggesting that felsic magmas exploited pre-existing tectonic weaknesses during emplacement. This interpretation aligns with Tagini (1972), who described the Toumodi-Fêtêkro Belt as a volcano-sedimentary basin intruded by granitoids, and Yacé (1976), who emphasized the role of felsic magmatism in the tectonic evolution of central Côte d'Ivoire. More recent work by Ouattara et al. (2009) confirmed that the belt records multiple intrusive phases, with felsic bodies marking key stages of crustal reworking. The geophysical evidence from Akakro provides subsurface confirmation of these tectonomagmatic processes, showing that felsic intrusions are not isolated but form continuous resistant domains.

#### 4.2. Alteration processes and fracture networks

Electrical soundings (Figs. 5A and 6D) reveal significant alteration within felsic formations. Conductive anomalies correspond to zones of weathering and fracturing, with average alteration thickness reaching 15 m. These altered domains are characterized by reduced resistivity, reflecting clay-rich horizons and increased porosity. The fracture networks-oriented NE–SW and NNE–SSW correspond to tectonic lineaments that facilitated hydrothermal circulation and chemical alteration. Such processes are consistent with the findings of Coulibaly et al. (2017), who reported intense alteration in felsic volcanics of the Akakro–Anikro sector, linked to hydrothermal fluids and tectonic stress. Similar structural features have been reported in the meridional Fettekro sector (Assie et al., 2024b). The geophysical evidence here extends those petrographic observations by quantifying alteration thickness and mapping fracture-controlled conductive zones. Alteration is not uniform but localized along structural corridors, confirming the interplay between tectonics and fluid circulation in the Birimian basement.

#### 4.3. Regional context and implications for the Birimian basement

Earlier geological studies (e.g., Yacé, 1966; Mortimer, 1990; Ouattara et al., 2009) described the Toumodi-Fettekro Belt as a complex of volcano-sedimentary units intruded by granitoids and granodiorites. However, most of these works relied on surface observations and petrographic descriptions. The present geophysical results extend this understanding by quantifying the spatial extent of felsic intrusions (54.09 ha of fresh formations and 31.47 ha of altered domains; and distinguishing them from mafic reserves. This quantitative approach bridges the gap between geological mapping and geophysical evidence. For example, Mortimer (1990) emphasized the structural complexity of the belt but lacked subsurface data. The resistivity and magnetic surveys presented here provide direct evidence of subsurface continuity, confirming that felsic intrusions dominate the Akakro sector and validating earlier geological interpretations with geophysical precision. The dominance of felsic intrusions in Akakro supports the interpretation that the Birimian basement of Côte d'Ivoire underwent significant tectonomagmatic reworking during the Paleoproterozoic. The emplacement of granitoids and granodiorites along regional fracture systems reflects the interplay between magmatism and tectonics during the Eburnean orogeny. Alteration zones and fracture networks identified geophysically suggest that these intrusions not only contributed to crustal evolution but also influenced subsequent hydrothermal processes and resource distribution. This interpretation is consistent with broader regional studies (e.g., Bonhomme, 1962; Daouda, 1998) that highlighted the importance of felsic magmatism in the Birimian terranes of West Africa. The Akakro results add a local-scale perspective, showing how geophysical methods can delineate felsic intrusions, quantify alteration, and identify fracture-controlled conductive zones.

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### 5. Conclusion

This research has demonstrated the effectiveness of integrating magnetic and electrical geophysical methods to investigate felsic intrusions in the Akakro sector of the Toumodi-Fettekro Belt. The magnetic survey revealed strong anomalies that delineate granitoid and granodiorite bodies, while resistivity measurements distinguished fresh felsic formations from altered and fractured domains. Together, these datasets provided a detailed subsurface characterization, showing that felsic intrusions occupy extensive areas, with fresh formations covering more than fifty hectares and altered domains extending over thirty hectares. Felsic intrusions in the study area are resistant, and structurally controlled, while alteration is localized along fracture corridors. The identification of fracture-controlled conductive zones further highlighted the structural complexity of the Birimian basement and the role of tectonic lineaments in guiding alteration processes. By quantifying reserves and mapping alteration thickness, this study extends earlier geological observations with geophysical precision, confirming that felsic intrusions are not only surface features, but also continuous subsurface bodies emplaced during the Eburnean orogeny. Beyond its academic contribution, the work underscores the value of combining magnetic and electrical methods for exploration in Côte d'Ivoire, offering a methodological framework for resource evaluation and providing new insights into the tectonomagmatic evolution of the West African Craton.

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### Compliance with ethical standards

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### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

### *Statement of informed consent*

All participants involved in this research provided informed consent prior to data collection. The authors confirm that consent was obtained in line with ethical standards and institutional requirements.

### *Author's contribution*

The first author conceived and designed the study, carried out the fieldwork and data collection, performed the data analysis, and prepared the manuscript. Co-authors were involved in fieldwork and critically reviewed the manuscript

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