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(RESEARCH ARTICLE)

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Contribution of Induced Polarization to the Identification of Mineralization in the Agnibilékrou Department (Eastern Côte d'Ivoire)

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Abstract

The chargeability maps of the Siakakro, N'Guessankro, and Mossikro sites (Agnibilékrou Department, in the east of Côte d'Ivoire) are established from induced polarization (IP) measurements. These maps reveal both polarizable and weakly polarizable structures, with anomalies primarily oriented NE-SW. These orientations, influenced by geological faults, facilitate the migration of hydrothermal fluids and the potential formation of mineral deposits. The zones with high chargeability are mainly located in the center and east of the sites, suggesting the presence of sulfides and representing promising targets for mining exploration. The weakly polarizable areas are associated with sandy-clay formations and non-conductive materials, limiting their mining potential. However, their proximity to faults, especially at N'Guessankro, justifies further investigations to identify potential hidden mineralization. In summary, the zones with high chargeability, particularly at Siakakro, should be prioritized for exploratory drilling. Further exploration, particularly around geological contact zones, is necessary to assess the economic potential of these anomalies.

Keywords: Induced Polarization; Chargeability; Mineralization; Geophysical data; Agnibilékrou

1. Introduction

The application of geophysical methods, such as induced polarization (IP), for the identification of mineralized deposits is increasingly used. This technique makes it possible to detect areas rich in metallic minerals, even in complex geological environments where deposits may be hidden by non-conductive formations. The Agnibilékrou department, located in the east of Côte d'Ivoire, presents favorable geology for mineralization. The presence of tectonic structures and geological faults promotes the circulation of hydrothermal fluids, which play an essential role in the concentration of metallic minerals.

In this context, the use of induced polarization helps optimize mining exploration by identifying areas with high mineralization potential. The sites of Siakakro, N'Guessankro, and Mossikro, located respectively in the south, center, and northwest of the Agnibilékrou department, were chosen for this study due to their geological potential and the presence of structural anomalies, often associated with mineralization. The IP method, by highlighting chargeability variations, will efficiently guide exploration efforts in these strategic areas. The objective of this study is to target favorable areas for further investigations, particularly through exploratory drilling.

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2. Presentation of the Study Area

The Agnibilékrou Department, located 270 km east of Abidjan (Côte d'Ivoire), is part of the Indénié-Djuablin region. It lies between latitudes 6°46' N and 7°22' N, and longitudes 3°04' W and 3°40' W. The geological history of the Agnibilékrou area is closely tied to that of the West African Craton, of which it forms an extension.

The geological formations of this region were shaped during the Eburnean orogeny, a significant geological event of the Proterozoic era, which played a crucial role in structuring the area. Earlier studies, have investigated the geology, focusing on petrography and tectonics (Géomines, 1982; Delor et al. 1995). These studies revealed that the region is characterized by polyphase tectonics, with several successive phases of deformation (Figure 1).

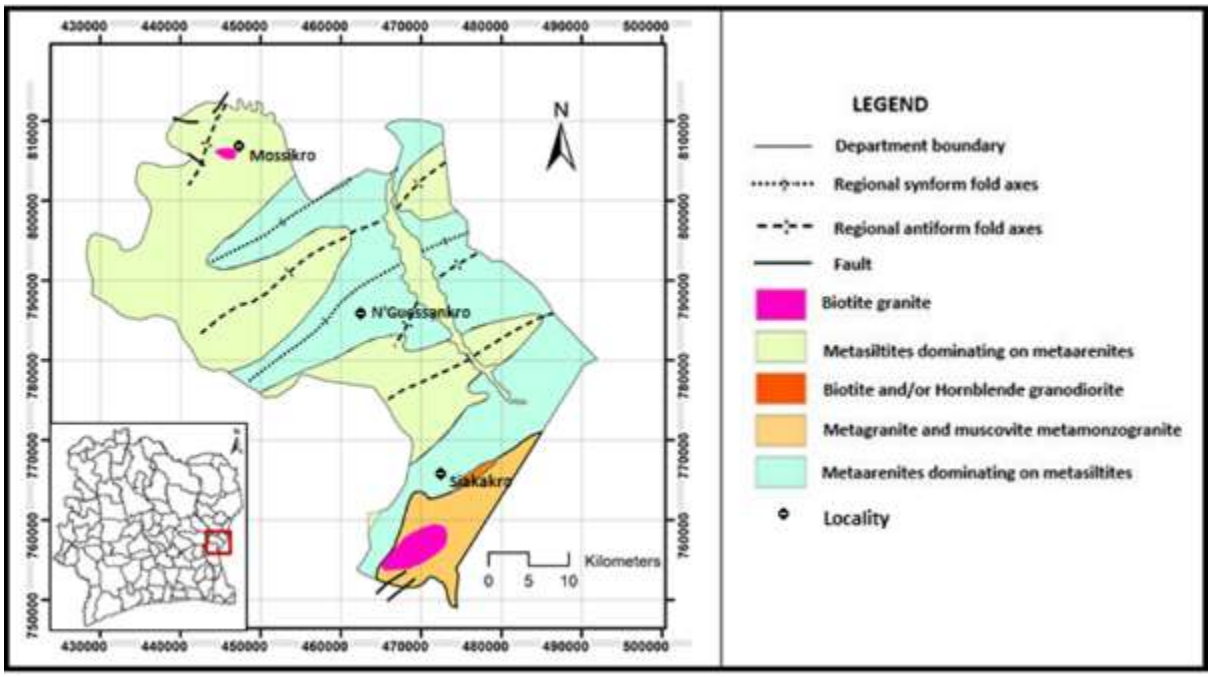

Figure 1 Geological Map of the Agnibilékrou Department (Delor et al., 1995)

These tectonic processes have resulted in numerous fractures, varying in size from a few meters to several kilometers, indicating intense structural activity. The region's geological formations also underwent regional metamorphism, transforming certain rocks and altering their internal structures.

From a petrographic perspective, two primary types of formations dominate the region: granitoids and volcano-sedimentary formations. Granitoids account for about 9% of the formations, while volcano-sedimentary formations, primarily composed of schists, represent nearly 80%. These schists are oriented along a NE-SW axis, reflecting the direction of tectonic forces that acted on the area.These geological features make the Agnibilékrou region a complex terrain, where the diversity of rocks and tectonic structures reflects a rich and dynamic geological history.

3. Methodology

The acquisition of chargeability geophysical data in the Agnibilékrou Department, specifically in the localities of Siakakro, N'Guessankro, and Mossikro, required the use of specialized geophysical equipment. This equipment consisted of a current generator, a transmission module (TxII transmitter from GDD Instruments), a receiving module (Elrec 6 from Iris Instruments), electric cables, and stainless steel electrodes.

The time-domain or transient induced polarization (IP) method was applied in this study. This technique involves injecting a direct current (DC) into the ground. After abruptly cutting off the current, the decay curve of the ground potential is measured within 10 ms to 2 seconds. Following the current cutoff, the potential does not immediately return to zero but decays rapidly to a value V, then continues to decrease quasi-exponentially over time.

This decay or relaxation is observed and recorded to calculate the apparent chargeability of the medium. The chargeability (M) in mV/V is defined as the ratio between the secondary voltage (Vs) measured at a given moment after the current cutoff and the primary voltage (Vp) measured just before the current cutoff, as shown in Equation 1:

$$M = \frac{Vs}{Vp} \quad \text{.....(Equation 1)}$$

Chargeability data, which is influenced by various factors such as mineralogical composition, permeability, and porosity, is processed and represented in map form using Geosoft 6 software.

4. Results and Discussion

4.1. Siakakro Site

The apparent chargeability map of the Siakakro site reveals polarizable structures with values ranging from 2.5 to 10.8 mV/V (Figure 2). High-chargeability structures, ranging from 6.6 to 10.8 mV/V, are represented by yellow to magenta shades. These appear as elongated corridors aligned along three main axes oriented NE-SW, alternating with low-chargeability zones (2.5 to 4.3 mV/V) shown in blue. This alternating pattern creates a complex structure stretching from the northwest to the southeast.

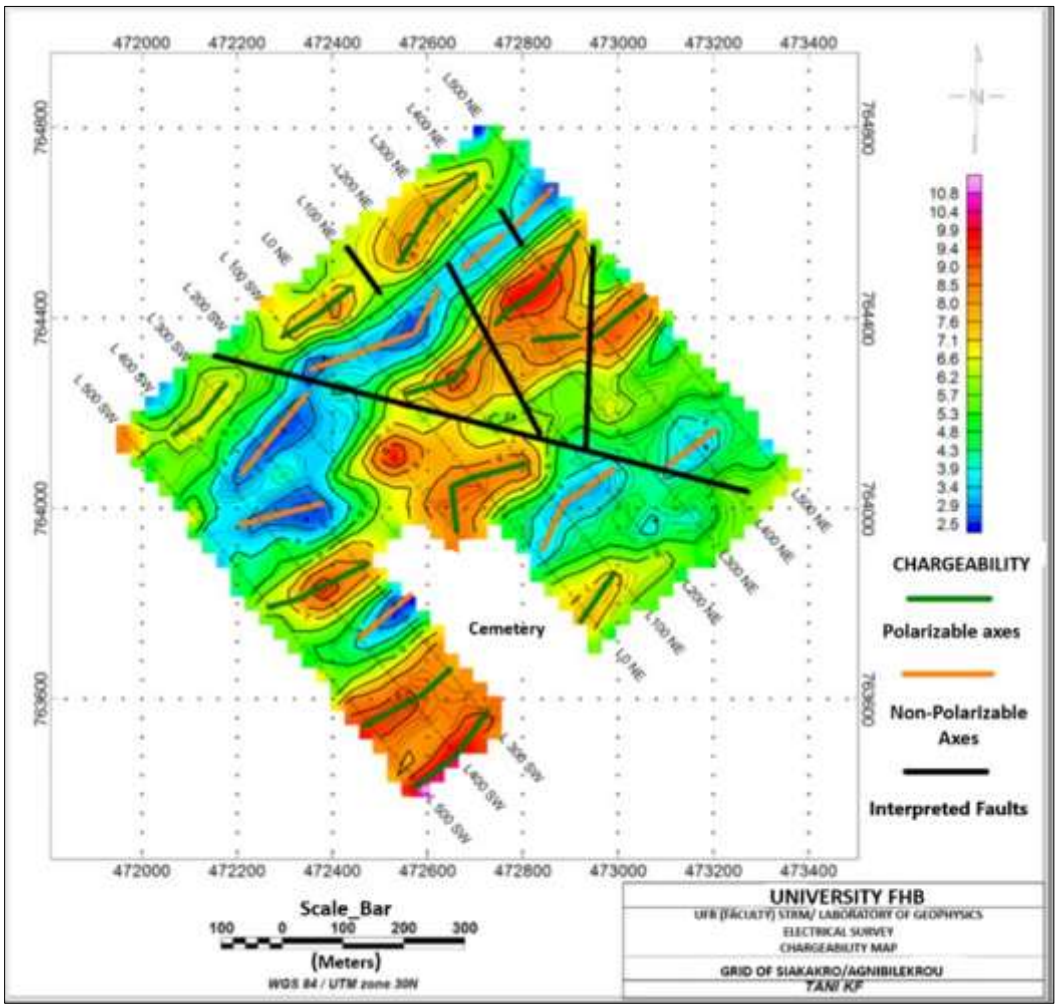

Figure 2 Apparent Chargeability Map of the Siakakro Site

Low-chargeability areas correspond to two elongated structures associated with sandy-clay formations, exhibiting low to intermediate resistivities (2.5 to 6.6 mV/V). These formations are not favorable for the concentration of metallic minerals. However, the high-chargeability zones reveal three significant polarizable corridors primarily located at the center, northwest, and southeast of the site.

The central high-chargeability anomaly, the most significant on the site, extends across all profiles with a pronounced width and well-defined boundaries. This anomaly shows distortions, indicating the presence of metallic particles in metamonzogranites and muscovite-bearing metagranites. The northwestern high-chargeability anomaly is narrower than the central one and shows discontinuities across certain profiles, reflecting the impact of multiple geological distortions. As for the southeastern anomaly, although it shares a comparable width with the central one, it does not appear on all profiles, particularly in the eastern part of the site.

4.2. N'Guessankro Site

The chargeability map of the N'Guessankro site reveals a complex distribution of polarizable and weakly polarizable structures, with chargeability values ranging from 3.8 to 9.3 mV/V (Figure 3). The identified anomalies predominantly follow a NE-SW orientation and are influenced by faults, which play a key role in the distribution of minerals.

High-chargeability zones (6.7 to 9.3 mV/V), represented by colors ranging from yellow to magenta, are concentrated in the northern, central, and eastern parts of the map. These areas, associated with polarizable axes (in green), suggest the potential presence of metallic minerals or sulfides, making them valuable targets for mining exploration. A prominent central high-chargeability anomaly crosses several profiles with well-defined contours, indicating the influence of hydrothermal fluids, which may have facilitated mineral concentration.

Conversely, low-chargeability zones (3.8 to 6.7 mV/V), depicted in blue and green, are primarily located in the southwest and around the cemetery and sacred forest. These areas are linked to non-metallic geological formations, such as sandy-clay deposits, which are less favorable for the accumulation of metallic minerals.

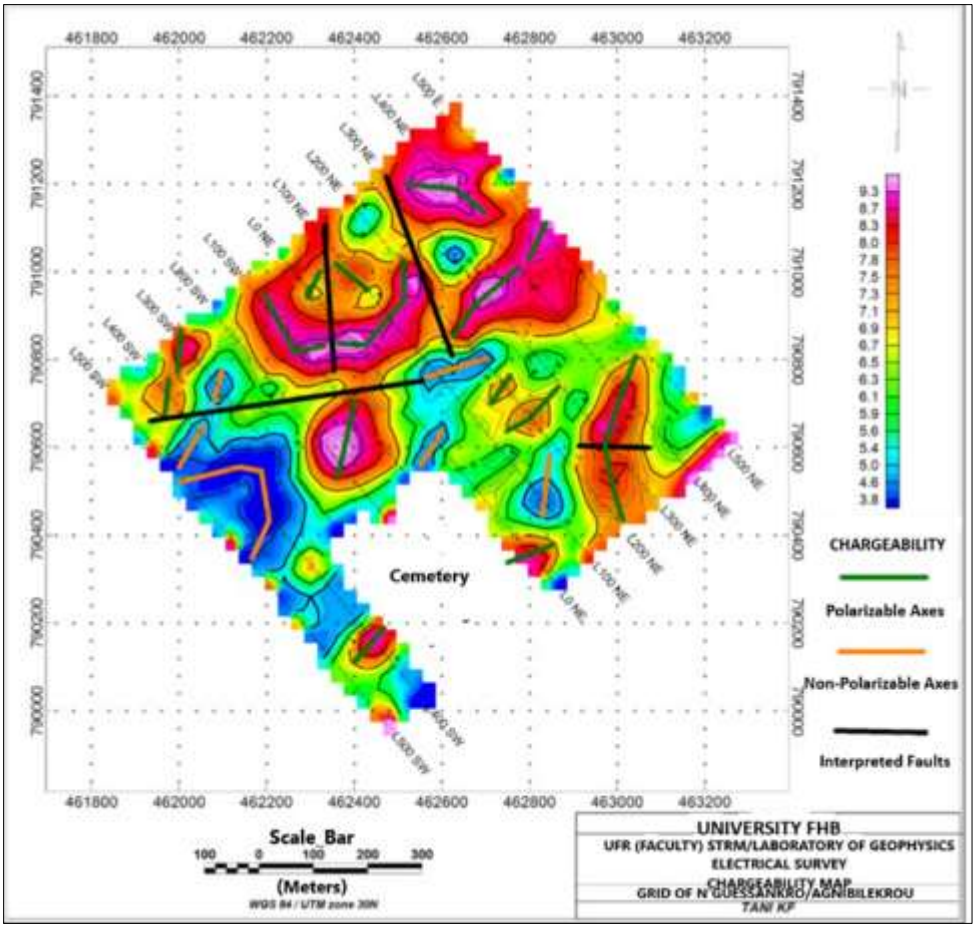

Figure 3 Chargeability map of the N'Guessankro site

The interpreted faults traverse several regions of the map, playing a crucial role in the movement of hydrothermal fluids and the potential formation of deposits. The alternation between polarizable and non-polarizable axes, following a NE-SW orientation, creates significant geological alignments. Crossings of these structures or areas near faults should be prioritized for further studies to assess their mineralization potential.

4.3. Mossikro Site

The chargeability map of the Mossikro site presents values ranging from 2.9 to 5.5 mV/V, with a clear distinction between low and high chargeability zones (Figure 4). Low values (2.9 to 4.1 mV/V), represented in blue and green, correspond to structures unlikely to contain metallic minerals, often associated with sandy-clay formations or non-conductive materials. In contrast, high values (4.1 to 5.5 mV/V), shown in yellow to magenta, indicate areas with a probable concentration of metallic sulfides, making them promising targets for mining exploration.

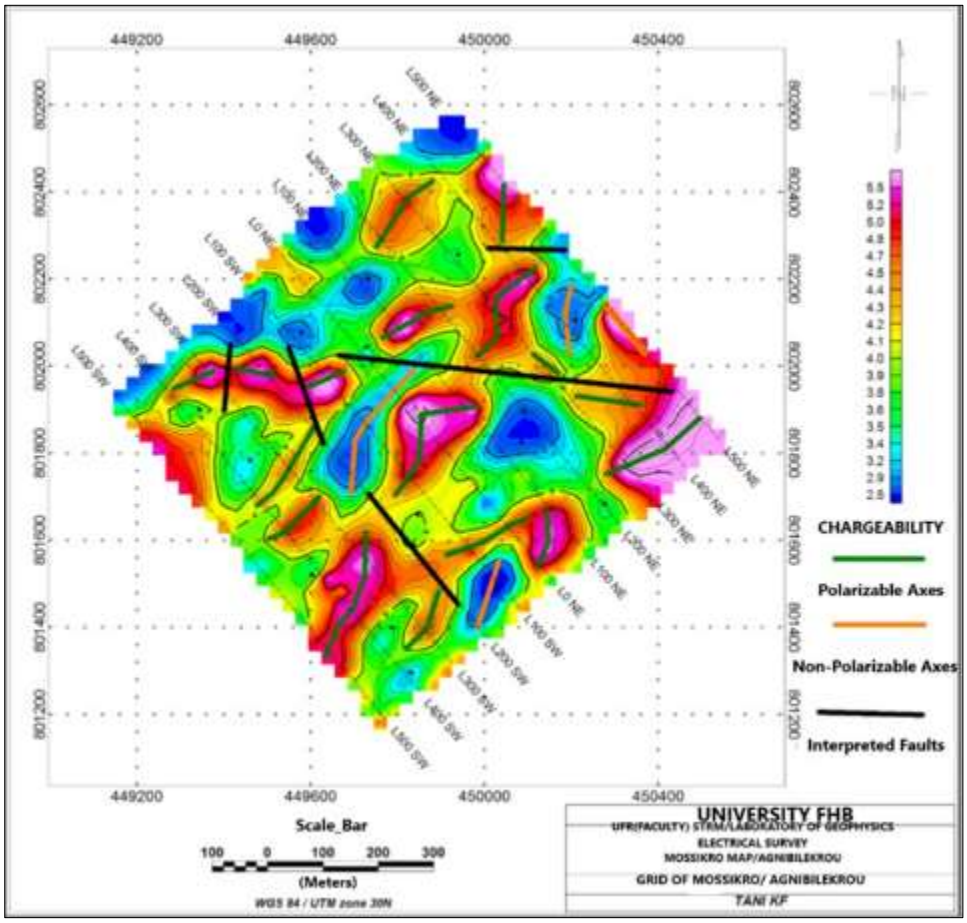

Figure 4 Chargeability Map of the Mossikro Site

Additionally, the map highlights several faults crossing different regions, which can play a critical role by serving as pathways for hydrothermal fluids, thereby influencing the distribution of minerals. These faults may also cause discontinuities in the observed anomalies. The NE-SW and NW-SE faults align with geological structures that could concentrate mineral deposits, particularly at the intersections of these axes. These intersections represent strategic targets for further exploration.

4.4. Comparison of the Results from the Sites

The comparative analysis of the chargeability maps from Siakakro, N'Guessankro, and Mossikro reveals both similarities and differences in the distribution of polarizable and non-polarizable structures, as well as in the identification of geophysical anomalies.

In all three sites, anomalies align along a NE-SW orientation, reflecting similar geological alignments. This orientation is often influenced by faults, which play a key role in the concentration of metallic minerals and the movement of hydrothermal fluids. High-chargeability zones are present across all sites, indicating the potential presence of metallic sulfides and forming promising targets for mining exploration. These zones are often located in the central and eastern parts of the maps and are associated with polarizable axes. Additionally, geological faults impact the distribution of chargeability anomalies at each site by acting as channels for hydrothermal fluids, which promotes the formation of mineral deposits, making these areas a priority for exploration.

However, key differences emerge between the sites. The chargeability values at Siakakro range between 2.5 and 10.8 mV/V, reflecting greater variability compared to Mossikro (2.9 to 5.5 mV/V) and N'Guessankro (3.8 to 9.3 mV/V). This broader range at Siakakro suggests more pronounced geological heterogeneity. Additionally, the distribution of anomalies differs. At Siakakro, a large central high-chargeability anomaly spans multiple profiles, suggesting significant mineral concentrations in metamonzogranites. At N'Guessankro, although a similar central anomaly exists, it is influenced by faults, which could indicate mineral concentrations driven by more intense hydrothermal activity. At Mossikro, the anomalies are less pronounced in amplitude, but the structural orientation and fault presence still provide interesting exploration targets.

4.5. Interpretation

The chargeability maps of Siakakro, N'Guessankro, and Mossikro reveal both geophysical similarities and notable differences, underscoring the specific geological influence of each site and offering valuable insights for targeted mining exploration. NE-SW alignments, observed across all three sites, highlight geological structures that promote hydrothermal fluid circulation, typically concentrated along geological faults. These faults facilitate the accumulation of metallic sulfides in high-chargeability zones, making their proximity a priority for mining exploration due to their potential to host economically viable mineral deposits.

High-chargeability zones are present throughout the sites, particularly in the central and eastern parts of the maps. These anomalies suggest the possible concentration of metallic sulfides, such as pyrite, chalcopyrite, and other sulfide minerals, making them highly attractive for mining exploration. In some deposits, pyrite and chalcopyrite may contain trace amounts of gold as fine inclusions, presenting opportunities for gold extraction. Pyrite serves as a key economic source of sulfur, essential for producing sulfuric acid used across industries such as fertilizers, oil refining, and metallurgy. Chalcopyrite, the most common copper ore, is a major source of copper, critical for cables, electronics, and infrastructure production.

The presence of polarizable axes within these zones enhances their potential, establishing them as promising targets for future exploration efforts. However, variability in chargeability values reflects the geological heterogeneity unique to each site. Siakakro exhibits a broader range of values (2.5 to 10.8 mV/V), indicating greater geological complexity, with structures favorable for significant mineral concentration. The central anomaly at Siakakro, extending across several profiles with substantial width, may suggest the presence of minerals within metamonzogranites and metagranites. At N'Guessankro, while the central anomaly is prominent, it appears more influenced by fault activity, indicating mineralization associated with hydrothermal processes. In Mossikro, although the anomalies exhibit lower amplitude, the presence of faults and favorable structural orientations still make the site an interesting target for exploration.

5. Discussion

The NE-SW-oriented anomalies observed at the Siakakro, N'Guessankro, and Mossikro sites correspond to regional tectonic alignments, often associated with the formation of metallic deposits (Cox, 1995). According to Sillitoe (2010), geological faults act as conduits for hydrothermal fluids, promoting metal precipitation within fractures. Across all three sites, these faults influence the distribution of anomalies and facilitate the formation of potential deposits, emphasizing their crucial role in mineralization. The identified high-chargeability zones suggest the presence of metallic sulfides, consistent with Sumner's (1976) findings that link high chargeability with significant sulfide concentrations (e.g., copper, lead, zinc). As noted by Telford et al. (1990), chargeability anomalies near faults are prime targets for mining exploration, often indicating economically viable minerals.

The differences between the sites reflect significant geological heterogeneity. Siakakro, with a chargeability range of 2.5 to 10.8 mV/V, shows greater variability, likely due to the presence of metamonzogranites and metagranites, known to host hydrothermal mineralization (Deb & Thorpe, 2004). In N'Guessankro, anomalies are more influenced by fault activity, reflecting mineralization related to intense hydrothermal processes, similar to epithermal deposits studied by Pirajno (2009). Although the anomalies at Mossikro are less pronounced, the structural orientation and the presence of faults make it a promising site. This aligns with Phillips and Powell's (2010) assertion that even low-amplitude anomalies may indicate deep-seated deposits or disseminated mineralization.

The low-chargeability zones correspond to sandy-clayey formations, which generally have low conductivity and are less favorable for mineralization (Sumner, 1976). However, Telford et al. (1990) caution against disregarding these zones, as they may conceal deep-seated mineralization. The proximity of these zones to faults, particularly at N'Guessankro (near the cemetery and sacred grove), justifies further investigation through exploratory drilling.

6. Conclusion

The analysis of the chargeability maps of Siakakro, N'Guessankro, and Mossikro highlights similar geophysical structures with anomalies primarily oriented NE-SW, influenced by geological faults. These structures facilitate the movement of hydrothermal fluids and the precipitation of metallic minerals, making high-chargeability zones key targets for exploration. These zones, often located in the central and eastern parts of the maps, suggest a potential presence of sulfides, particularly in areas associated with polarizable axes.

However, Siakakro stands out due to more pronounced variability in chargeability values (2.5 to 10.8 mV/V), reflecting geological heterogeneity linked to metamonzogranites and metagranites. In N'Guessankro, the distribution of anomalies appears more influenced by faults, indicating active hydrothermal mineralization. Although the anomalies in Mossikro are less prominent, the presence of faults and favorable geological alignments maintains its potential for further exploration.

Low-chargeability zones, associated with sandy-clayey formations, show limited mining potential but deserve particular attention due to their proximity to faults. These areas may conceal deeper mineralization requiring additional investigations. In summary, high-chargeability zones, especially in Siakakro, should be prioritized for exploratory drilling and further analysis to confirm the presence of exploitable minerals and refine the geological model of the sites.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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