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Integrated Airborne Geophysical and Mineralogical Analysis for Lead-Zinc Exploration in Futuk Sheet 172 SE, Upper Benue Trough

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Abstract

This research is aimed at assessing and synthesis of mineralogical data and airborne geophysical surveys to identify prospective areas for lead and zinc exploration within Futuk Sheet 172 SE of the Upper Benue Trough. By integrating multi-source geological data, we aim to delineate new exploration targets, thereby enhancing the efficiency and success rate of mineral prospecting in this region. The findings of the study revealed that there is potential site that lead-zinc can be explore in commercial quantity at Futuk village of Alkaleri LGA of Bauchi State. The following recommendation were made; the government can explore the area in larger quantity this will in turned bring about economic development of Bauchi State and neighboring state, the government can provide job opputurnity for the teaming unemployed youth in and within the nation.

Keywords: Lead-Zinc Exploration, Mineralogy, Airborne Geophysics, Upper Benue Trough, Prospecting, Geophysical Surveys, Mineral Prospecting, Exploration Targets

Introduction

Lead and zinc are critical industrial metals with a wide range of applications that underscore their significance in modern economies. Lead is primarily used in the manufacturing of batteries, accounting for approximately 85% of its global consumption. It also finds applications in radiation shielding, cable sheathing, and as an additive in certain types of glass and ceramics due to its high

density and malleability (ILA, 2022). Zinc, on the other hand, is crucial in galvanization, which protects steel and iron from corrosion, thus prolonging the lifespan of structures and products. Additionally, zinc is essential in the production of alloys such as brass and bronze, in die-casting industries, and as a component in various chemical compounds, including fertilizers and pharmaceuticals (IZA, 2023).

The economic importance of discovering new lead and zinc deposits cannot be overstated. These metals play a vital role in the infrastructure, automotive, and energy sectors, which are foundational to economic development and technological advancement. For instance, the increasing demand for electric vehicles (EVs) has intensified the need for lead-acid batteries, despite the rise of lithium-ion technologies, due to their reliability and cost-effectiveness in specific applications ((Mohr, *et al,* 2018 and Mudd, *et al, 2017*). Moreover, zinc's role in protecting critical infrastructure from corrosion is pivotal, especially in regions with aggressive environmental conditions (Mohr, *et al,* 2018, and Belov, *et al,* 2022).

Exploration for new lead and zinc deposits is essential to sustain their supply and meet future demand. The Upper Benue Trough in Nigeria, particularly the Futuk Sheet 172 SE area, is of significant interest for such exploration efforts. This region's geological framework suggests a potential for significant mineralization, given its historical and structural context within the broader Benue Trough, known for its diverse mineral deposits. The Upper Benue Trough, part of the larger Benue Trough in Nigeria, is an extensive intracontinental rift system that formed during the Early Cretaceous period. This geologic structure is characterized by a series of NE-SW trending fault-bounded basins filled with a complex sequence of sedimentary and volcanic rocks. The trough is divided into three main sectors: Lower, Middle, and Upper Benue Trough, each exhibiting distinct stratigraphic and structural features. The Upper Benue Trough is particularly noteworthy for its thick sequences of marine and continental sediments, which have been subjected to multiple phases of deformation and mineralization events.

The focus on Futuk Sheet 172 SE within the Upper Benue Trough is strategically significant due to several factors. Firstly, the area's geological characteristics suggest it could host substantial mineral deposits, mirroring other parts of the Benue Trough that have yielded economically viable concentrations of lead and zinc. Secondly, the application of integrated geophysical and mineralogical techniques in this region could serve as a model for similar exploration projects in other underexplored or challenging terrains globally.

The Upper Benue Trough, part of the larger Benue Trough in Nigeria, is an extensive intracontinental rift system that formed during the Early Cretaceous period. This geologic structure is characterized by a series of NE-SW trending fault-bounded basins filled with a complex sequence of sedimentary and volcanic rocks. The trough is

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This region holds significant potential for lead-zinc mineralization, largely due to its geological history and structural configuration. Previous studies have indicated the presence of extensive mineral deposits within the trough, including lead, zinc, barite, and fluorite. The mineralization in the Upper Benue Trough is often associated with hydrothermal fluids that have interacted with the host rocks, leading to the formation of ore bodies within favorable structural traps such as faults and folds. The favorable geological conditions make this area a prime target for further exploration and detailed geological studies.

The primary objective of this study is to integrate mineralogical and airborne geophysical data to identify new prospective areas for lead and zinc exploration within Futuk Sheet 172 SE of the Upper Benue Trough. By combining detailed mineralogical analyses with advanced geophysical survey techniques, this study aims to enhance the accuracy and efficiency of exploration efforts, thereby increasing the likelihood of discovering economically viable mineral deposits. Integrating mineralogical data with advanced airborne geophysical techniques represents a cutting-edge approach in modern exploration strategies. This integrated method enhances the accuracy and efficiency of identifying viable exploration targets, reducing the economic risk associated with mining ventures. Advanced geophysical surveys, will provide comprehensive subsurface images, revealing anomalies indicative of mineral deposits. When combined with detailed mineralogical assessments, these techniques can pinpoint areas with the highest potential for lead and zinc mineralization.

Methodology

This study utilizes mineralogical and airborne geophysical data to identify prospective areas for lead and zinc exploration in Futuk Sheet 172 SE. Mineralogical data were sourced from field samples collected across various outcrops and abandon mining pits, analyzed using X-ray spectrometer (XRF), and scanning electron microscopy (SEM), to determine their mineral composition and geochemical profiles. Airborne geophysical data, obtained from regional surveys conducted by geological agencies to detect subsurface anomalies indicative of mineralization. The integration of these datasets involves processing raw geophysical data to correct for noise and standardizing mineralogical data. Geophysical anomalies are spatially correlated with mineralogical data points using Geographic Information System (GIS) software, creating composite maps that overlay mineralogical and geophysical data layers to highlight regions where favorable mineral compositions coincide with significant

geophysical anomalies. Advanced analytical methods are employed to interpret the integrated data, including geostatistical analysis (variography and kriging) to model spatial continuity and variability of mineral concentrations, spatial data modeling (3D geological modeling and multivariate analysis) to visualize subsurface structures and identify patterns within the dataset, and anomaly detection techniques (threshold and cluster analysis) to distinguish significant geophysical anomalies from background noise and group similar geophysical and geochemical signatures. This comprehensive approach aims to enhance the identification of prospective exploration targets, improving the efficiency and success rate of lead and zinc exploration in the Futuk Sheet 172 SE area of the Upper Benue Trough.

RESULTS

The Total Magnetic Intensity (TMI) and Reduce to Magnetic Equator map of Futuk Sheet 172 SE reveals several significant geophysical anomalies that are indicative of subsurface mineralization, potentially associated with lead-zinc deposits. The map, which depicts variations in the Earth's magnetic field, highlights areas with varying magnetic intensities, ranging from low (blue and green shades) to high (red and pink shades).

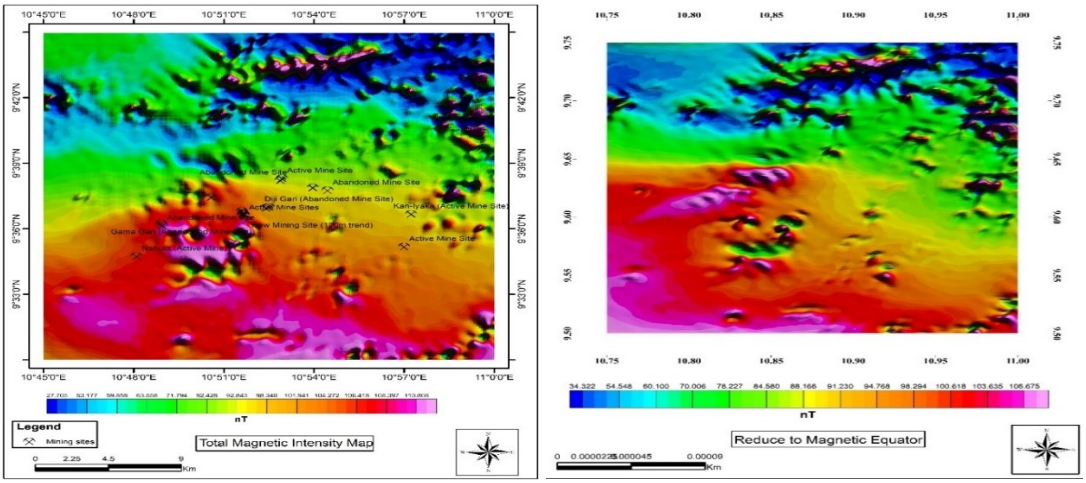


Fig. 1: (a), Total magnetic intensity map and (b), Residual magnetic map of the study area

Analysis of Regional Residual and Source Parameter Imaging Maps

Regional Residual Map

The Regional Residual Map of Futuk Sheet 172 SE presents a smoothed depiction of the magnetic field, emphasizing large-scale magnetic anomalies and regional trends. The map illustrates a gradient of magnetic intensity values, ranging from low (blue shades) to high (red and pink shades). This gradient suggests a significant regional magnetic structure, likely related to variations in the subsurface geology. Areas of high magnetic intensity, primarily located in the southeast portion of the map (coordinates

approximately 10°48'0"E to 10°57'0"E and 9°36'0"N to 9°39'0"N), may indicate the presence of magnetic minerals such as magnetite, which are often associated with hydrothermal processes that can form lead and zinc deposits (Fig. 2a).

Source Parameter Imaging Map

The Source Parameter Imaging (SPI) map provides detailed information on the depth and configuration of subsurface magnetic sources. The SPI technique enhances the visualization of magnetic anomalies by estimating the depth to magnetic sources. This map reveals a complex pattern of magnetic anomalies, with intensity values ranging from highly negative (blue shades) to highly positive (red and pink shades), indicating varying depths and concentrations of magnetic materials (Fig. 2b).

Magnetic Anomalies and Subsurface Structures

The SPI map identifies several key magnetic anomalies, particularly in the central and southern parts of the study area (coordinates approximately 10°48'0"E to 10°57'0"E and 9°36'0"N to 9°39'0"N). These anomalies are characterized by high magnetic gradients and are indicative of significant subsurface structures. The estimated depths of these magnetic sources vary, with some anomalies suggesting shallow subsurface structures (represented by higher positive values) and others indicating deeper sources (represented by highly negative values).

Areas of High Prospect for Lead-Zinc Mineralization

Combining the Regional Residual and SPI maps, the most prospective areas for lead-zinc mineralization are those with high magnetic intensity anomalies and significant subsurface structures. The central and southeastern portions of the study area, where high magnetic gradients and shallow depth estimates converge, emerge as prime targets for exploration. Specifically, the regions around coordinates 10°48'0"E to 10°57'0"E and 9°36'0"N to 9°39'0"N should be prioritized for detailed ground surveys and drilling to validate the presence of lead and zinc mineralization.

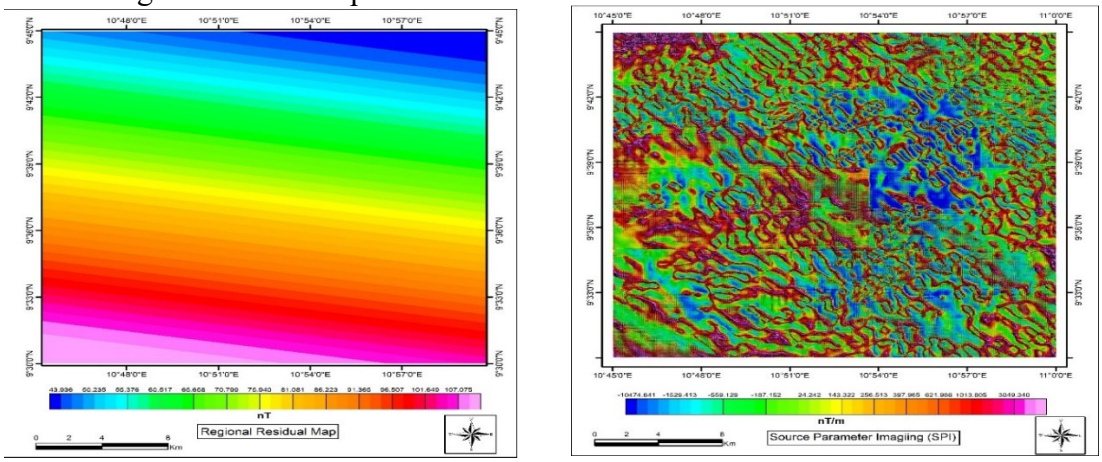


Fig. 2: (a), Regional Residual map and (b), Source Parameter Imaging map of the study area

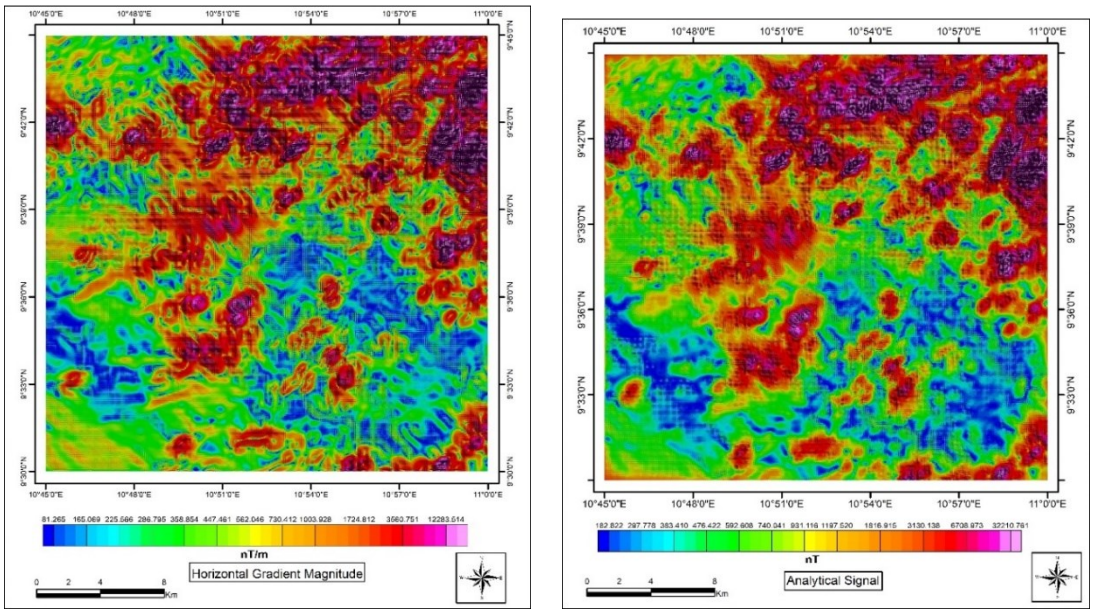


Fig. 3: (a), Horizontal Gradient Magnitude map and (b), Analytical Signal map of the study area

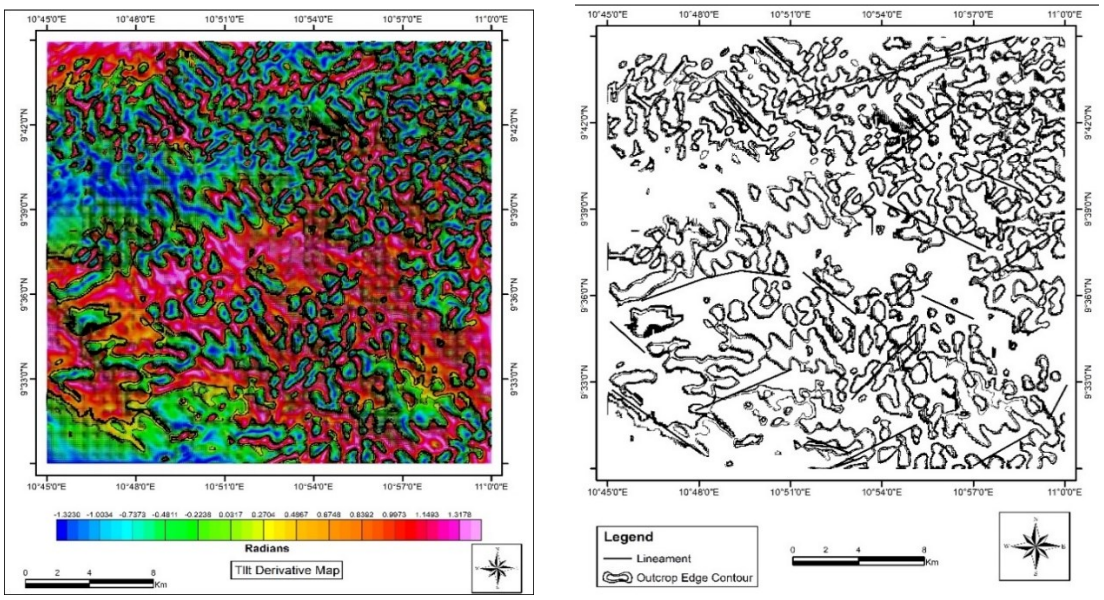


Fig. 4: (a), Tilt Derivative map and (b), Lineament superimpose on the outcrop contour edge map of the study area

Analysis of First Vertical Derivatives Map

The First Vertical Derivatives (FVD) map of Futuk Sheet 172 SE provides a detailed view of subsurface structures by emphasizing the edges of magnetic sources and delineating geological features with higher precision. This map is instrumental in identifying key structural controls that may influence mineralization (Fig. 5a).

The pronounced vertical gradients, depicted by rapid color transitions, indicate the presence of shallow subsurface magnetic sources. These are primarily located in the

central and southeastern portions of the map (around coordinates 10°48'0"E to 10°57'0"E and 9°36'0"N to 9°39'0"N). The high-gradient areas suggest the presence of fault lines, folds, and lithological contacts which are critical in understanding the structural control over potential mineralization (Fig. 5a).

The FVD map reveals several significant geological structures within the study area. The regions with the most pronounced vertical gradients indicate the presence of shallow subsurface structures, such as fault lines and folds. Fault lines are characterized by sharp changes in magnetic intensity and are essential pathways for mineralizing fluids. In the central region, a network of intersecting faults could create favorable conditions for lead and zinc deposition. These linear features are indicative of fault lines, which act as conduits for mineralizing fluids and are often associated with mineral deposits.

Areas with curved or sinuous magnetic anomalies suggest the presence of folds and lithological contacts. These features can concentrate mineral deposits by trapping mineralizing fluids within the folds or along the contacts. The southeastern region, with its complex magnetic patterns, indicates significant folding and varied lithology, making it a prime target for exploration. The identified structural features, such as fault lines and folds, are essential in localizing mineralizing fluids, thereby controlling the distribution of lead and zinc deposits.

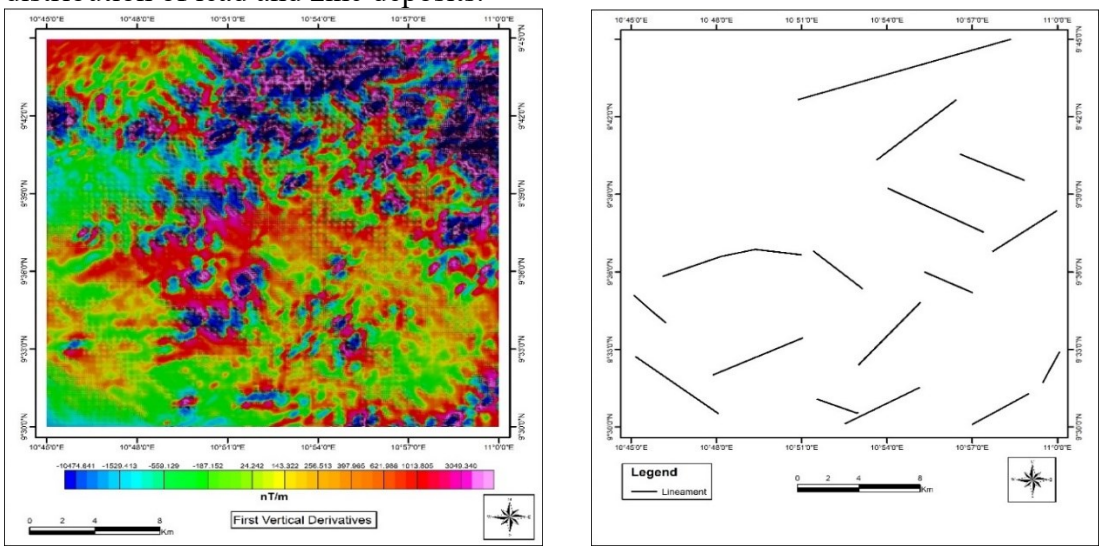


Fig. 5: (a), First Vertical Derivative map and (b), Lineament map of the study area

Discussions Findings

Prospective Areas for Exploration

Based on the maps, the most prospective areas for lead and zinc exploration within Futuk Sheet 172 SE are located in the central and southern parts of the sheet, where high magnetic intensity anomalies coincide with existing mining sites. The region around Nahuta (10°45'0"E to 10°48'0"E, 9°36'0"N to 9°39'0"N) and the area extending towards Kan-Iyaka (10°54'0"E to 10°57'0"E, 9°36'0"N to 9°42'0"N) stand out as primary targets for further exploration. These areas should be prioritized for detailed ground surveys and drilling to confirm the presence of lead and zinc mineralization and to delineate the extent of the ore bodies.

Significant Geophysical Anomalies

Notably, the southern and central portions of the map exhibit high magnetic intensity anomalies, characterized by red and pink shades. These anomalies are particularly prominent around the coordinates 10°48'0"E to 10°57'0"E and 9°36'0"N to 9°39'0"N. Such high-intensity anomalies often suggest the presence of magnetic minerals, which could be associated with hydrothermal processes that form lead and zinc deposits. The concentration of these anomalies around active and abandoned mine sites further underscores their potential significance for mineral exploration.

Mining and Non-Mining Sites

The TMI map also marks several mining sites, both active and abandoned, providing valuable context for interpreting the geophysical anomalies. Active mining sites, such as those at Nahuta and Kan-Iyaka, are situated within or near areas of high magnetic intensity, suggesting that these locations may have been selected based on similar geophysical indications. Conversely, abandoned mine sites like those at Gama Gari and Diji Gari are also located within regions of significant magnetic anomalies, implying historical exploration efforts were guided by similar geophysical evidence.

In contrast, non-mining areas, particularly those in the northern and eastern sections of the map, exhibit relatively lower magnetic intensities (blue and green shades). These regions might be less prospective for lead-zinc mineralization, as indicated by the absence of notable geophysical anomalies and mining activities

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