Nigerian Journal of Physics (NJP)
ISSN online: 3027-0936
ISSN print: 1595-0611
DOI: https://doi.org/10.62292/njp.v32i4.2023.159
Volume 32(4), December 2023

Geophysical Anomaly Indicators for Mapping Lead-Zinc (Pb-Zn) in its Metallogenic Province, Southern Benue Trough, Nigeria

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ABSTRACT
One of the major challenges facing the mineral industry in Nigeria and Africa at large is insufficient geophysical information. The cost of geophysical equipment is rising geometrically. However, most of these countries have archives of geophysical data that are underutilized. Secondary (Magnetic, gravity and radiometric) data were collected, filtered and interpreted to generate anomaly indicators for exploring Lead-Zinc ores in southern Benue Trough province. Algorithms were tested using the existing mining sites to constrain the interpretation. It can be deduced that the high response of the magnetic analytic signal, residual gravity, and potassium in the western part of the area are mineralization indicators. Therefore, the magnetic analytic method was used to extract the probable depth to the top of the minerals in the area, which ranges from 47 to 113m and corresponds with the field measurements. The mineralization potential map of the area was developed. High mineralization dominated the western part of the area where the mining sites are concentrated. Therefore, the Pb-Zn ores are delineable using aeromagnetic, gravity, and radiometric datasets.

Keywords:
Mapping,
Anomaly,
Magnetic,
Gravity,
Radiometric.

INTRODUCTION

The economic growth and development of any nation depend on the availability and utilization of natural resources. Besides oil and gas, Nigeria is richly blessed with abundant solid mineral resources that if properly utilized will transform it from an underdeveloped to a developed country. The mineral industry is therefore a feasible area through which Nigeria can diversify her economy. Lead-Zinc is an important mineral used in batteries as electrolytes, as an alloy with other metals, in construction as a roof, in the military as a chemical weapon, and as a chemical compound in the rubber and paint industry. This has however necessitated the need for its exploration.

One of the major challenges of the solid mineral industry among others is limited geoscience data and information (Vecent, 2018). Geophysical Methods have played a significant role in mineralization potential mapping (Amr *et al*., 2023; Solomon *et al*., 2022; Olawuyi *et al*., 2016). To identify, quantify and characterize deposit extension, geophysical campaigns play a major role before embarking on mine exploration and exploitation (Hubs *et al*., 2022; Boszczuk *et al*., 2011).

Researchers (Dube *et al*., 2007; Ford *et al*., 2007; Isife *et al*., 2000; Mammah *et al*., 2000; Thomas *et al*., 2000;) have successfully applied electrical and electromagnetic prospecting methods in sulfide mineralization potential mapping. Also, gravity, magnetic and radiometric methods have been successfully applied in mineralization potential mapping (Anyanwu and Mammah, 2013; Eze, 2011; Obi *et al*., 2010; Ugbor and Okeke, 2010; Airo, 2007; Mcintosh *et al*., 1999; Oliveira *et al*., 1998; Shieves *et al*., 1997). Despite radiometric, gravity, and magnetic methods being important tools for evaluating the mineralization potential of a province. Previous studies of the Southern Benue Trough were commonly limited to the magnetic method (Leke *et al*., 2023; Daniel *et al*., 2018; Anyanwu and Mammah, 2013; Eze, 2011; Obi *et al*., 2010; Mammah *et al*., 2000). They relied mostly on the Baranov pseudogravity transform to get the gravity equivalent and/or reduction to the pole which is unstable at low magnetic inclination such as the study area (Richard, 1996). In the pseudogravity, magnetization is assumed to be uniform in all directions which is not true for a mineralized zone (Michael and Stephen, 2014). It is on this premise that, this study integrates readily available high-resolution aeromagnetic, land gravity, and airborne radiometric data sets using different filtering algorithms to identify unique signature patterns for delineating Lead-Zinc mineralization in its metallogenic province. Therefore, it will serve as a reconnaissance technique for mineralization potential zonation before detailed geophysical and geochemical exploration.

Description and Geologic Setting of the Area

It lies within latitude 6^0 00′ to 6^0 30′ N and longitude 8^0 00′ E to 8^0 30′ E (Nigeria Geological Survey Agency (NGSA) Sheet 303). The area of the location is about 3,000 km^2. It is accessible through a network of roads and footpaths (Figure 1).

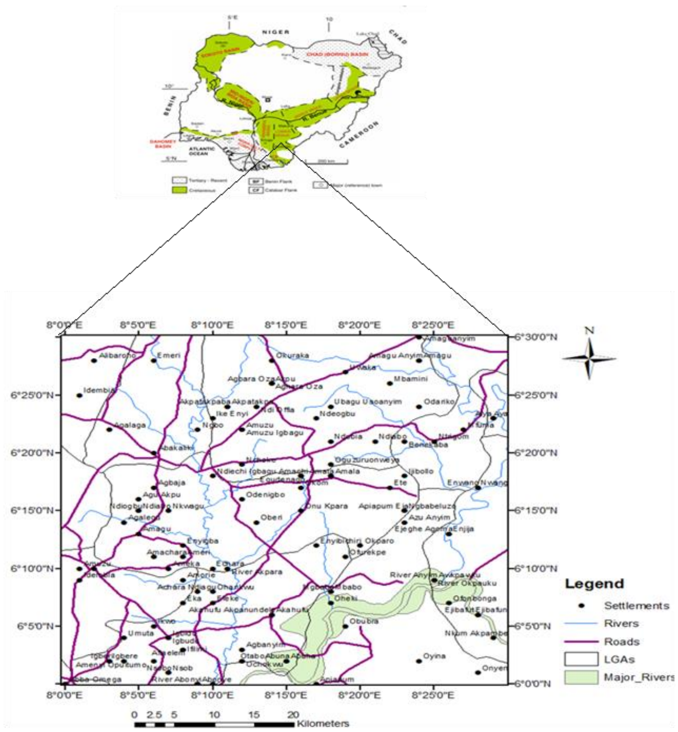


Figure 1: The Study Area Base Map

The drainage pattern is dendritic (Anyanwu and Mammah, 2013) and its climate is tropical (Itita, 2014). The disconnection of the African and South American plates led to a fault that was filled with sedimentary material.

The geology of the area is that of a complete inland basin (Burke et al., 1971; Nwachukwu, 1972; Olade, 1975; Benkhelil, 1988). The Albian Asu-River Group (Figure 2) is majorly black shale with slight sandstone components (Ukaegbu and Akpabio, 2009; Nwanjide, 2013). Solomon *et al*., 2022 opined that the Lead-Zinc minerals in the Benue Trough are of hydrothermal origin.

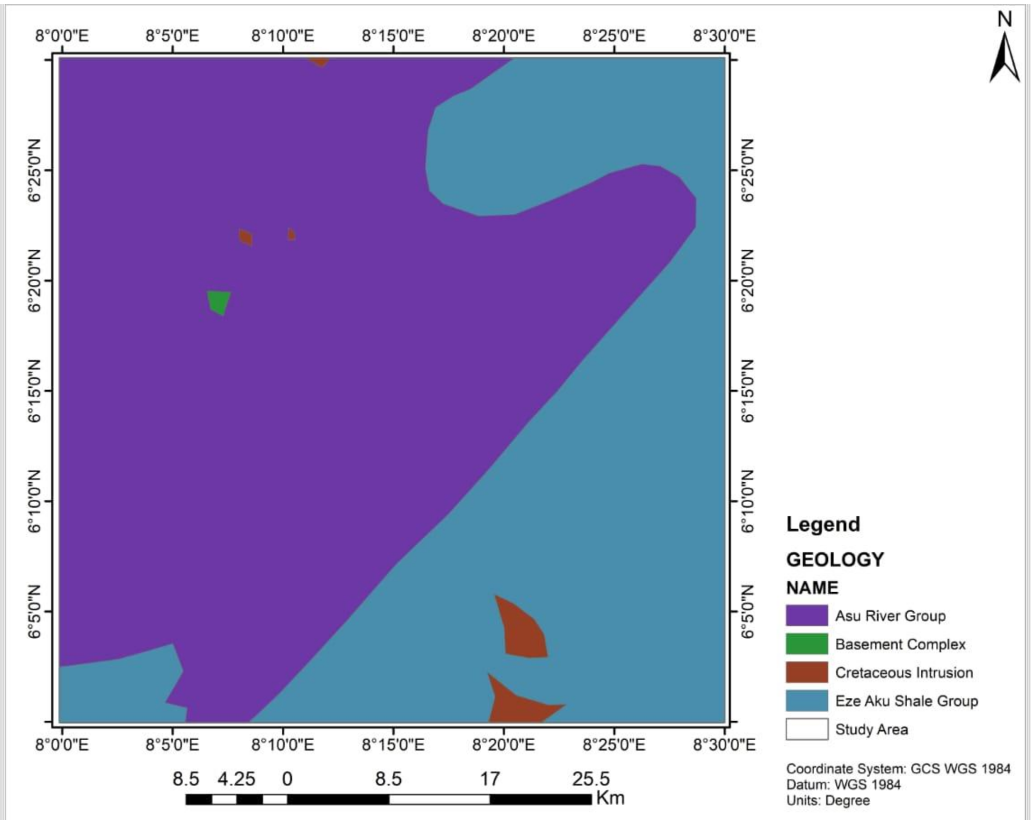


Figure 2: The Study Area Geological Map (Modified after Daniel *et al*., 2018)

MATERIALS AND METHODS

The digitized Airborne Magnetic (TMI), airborne radiometric, and land gravity datasets used for this study were sourced from the NGSA. TMI was reduced to the equator to reposition the anomaly and deduction of the International Geomagnetic reference field (IGRF) was done to remove the effects of long-wavelength regional components. An analytic signal filter was applied to inspect the effects of remanent magnetization and map possible geological structures that could host Lead-minerals. The probable depth of the mineral head within the location was determined using the analytic depth method.

Reductions such as latitude correction, drift correction, free air correction, and Bouguer correction were also carried out on gravity data. The density contrast of the mineral (lead-zinc) and the host rocks was delineated using Bouguer gravity, residual gravity, and Bouguer analytic signal. Airborne radiometric data were interpreted in conjunction with the digital elevation model (DEM) to isolate pseudo anomalies due to elevation from real radiometric anomalies. Composite, ratio, and ternary maps were generated to map hydrothermal alteration zones within the area. The mineralization potential map was generated from magnetic analytics, residual Bouguer gravity, and potassium responses which were validated by georeferencing the existing mining sites.

RESULTS AND DISCUSSION

Interpretation of Aeromagnetic Method

The TMI values range between 21.1 and 95.3 nT after IGRF correction, which is a typical area of high magnetic heterogeneity (Dainel *et al*.,2018). As shown in the TMI map (Figure 4), Agalegu and Igbudu areas are of relatively high amplitude magnetic intensity while Nchoke and Idembla areas are of relatively low amplitude magnetic intensity. The drastic nature of magnetic intensity over the Eze Aku group may be due to identified folding and facie changes (Nwajide, 2013).

The low anomalies dominated the middle part of the area could be a response of the host rock (black shale) which is a diamagnetic material. The positive isolated magnetic anomalies in the western part of the study area could be a signal to the lead-zinc mineralization since it occurred in association with siderite and chalcopyrite which are high magnetic susceptibility minerals (Ogundipe and Obasi, 2016). Also, hydrothermal alteration increases chemical remanent magnetization (Michael and Stephen, 2014) which perhaps could give a positive response to Pb-Zn Mineralization.

The TMI result is reduced to the equator (RTE) to properly position the anomaly and reduce the effects of shallow inclination. The correlation of the TMI map (Figure 4) with the RTE map (Figure 5) shows the same trend but the image was enhanced in the RTE and the anomaly was blown north-south direction. The signatures in the SE part of the study area were also enhanced (Figure 5). The rock boundaries are demarcated on the maps to correlate the magnetic results with the local geology which shows that surface geology has little or no effect on the magnetic filtering output.

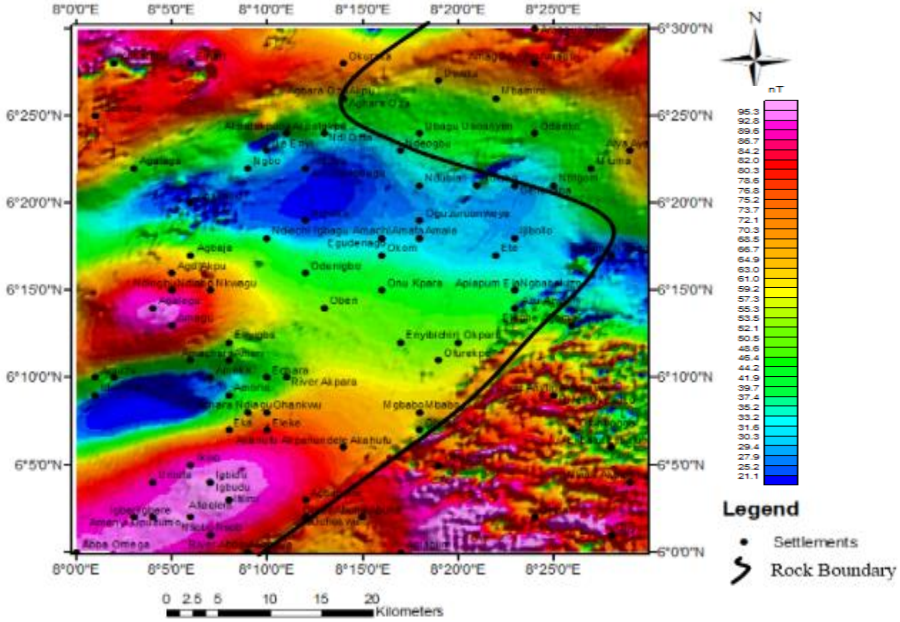


Figure 4: The Area's TMI map

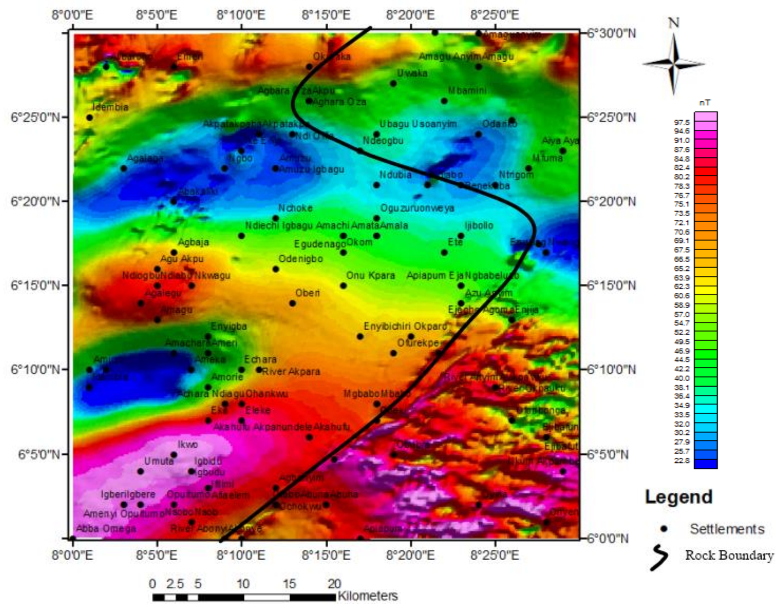


Figure 5: The Area's Reduction-to-Equator Map

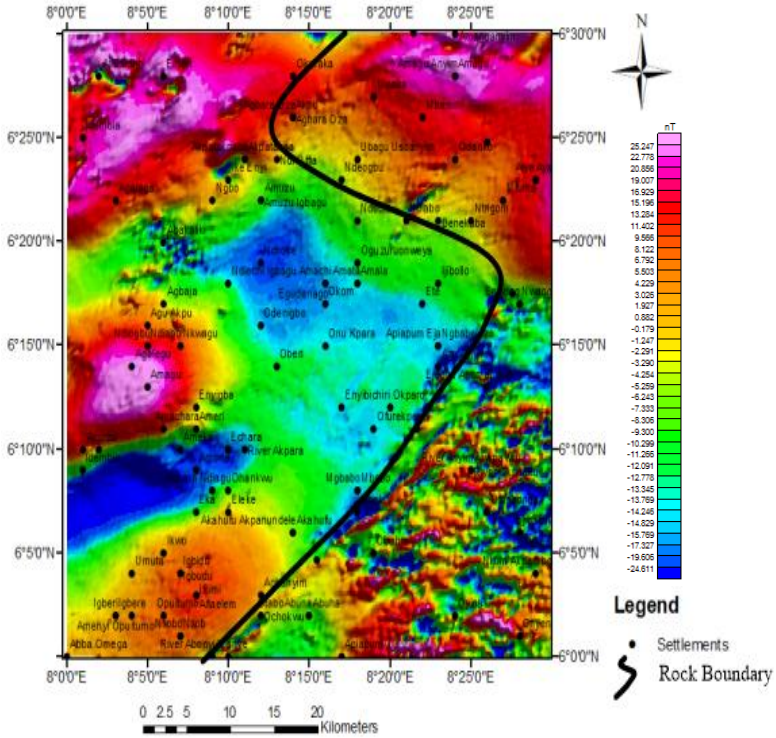


Figure 6: The Area's Residual Magnetic Map.

The Magnetic Anomalies of Agalegu, Igbudu, Nchoke and Idembla are near surface anomalies because of their enhancement in the residual map. The Agalegu and Igbudu areas are of relatively high magnetic intensity, while the Nchoke and Idembla areas are of relatively low amplitude magnetic intensity (Figure 6).

As shown in Figure 7, the magnitudes of the analytic signal ranges from 0.01 to 0.047 nT/m. The analytic signal is used in mapping the edge of the magnetic source. The top of the magnetic bodies coincides with the peak of the analytical signal, especially where low magnetic latitude complicates interpretation (Michael and Stephen, 2014). The peak analytic signal in the SW part of the area contradicts previous filtering results which implies that they must have been polluted by strong remanent magnetization. Therefore, response of analytic signal should be held.

The highly folded and structured Eze Aku group in the SE part of the area is also enhanced in the analytic signal map. Pb-Zn minerals occurred in conjunction with high magnetic sulphide minerals such as chalcopyrite resulting in significant magnetic anomalies (Lisa, 2010) and it occurs within the Asu River group (Nwajide, 2013). Hence, High amplitude analytic signal areas within the Asu River formation could be the mineralizing zones. As shown in Figure 8, the depth to the suspected Pb-Zn mineralized zones as estimated by the analytic signal method ranges from 30 to 112 m.

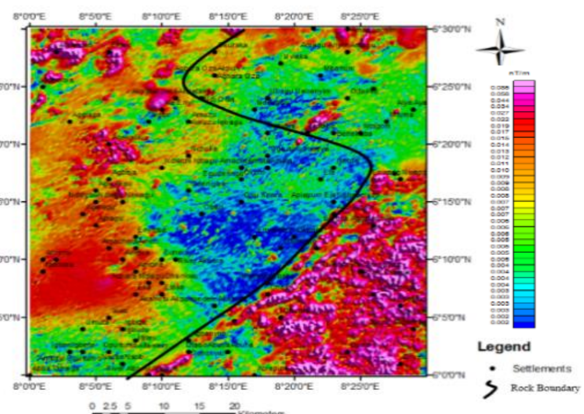


Figure 7: The Analytic Signal Map of the Area

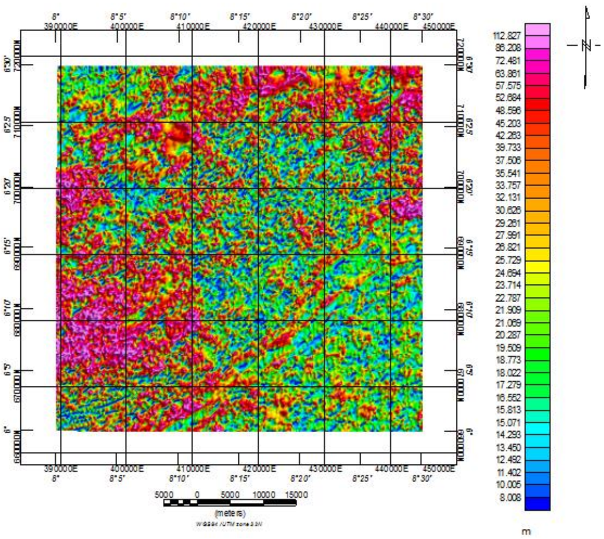


Figure 8: Depth Classification Map (Using Analytic signal)

Interpretation of Land Gravity Data

Minerals found in Pb-Zn Mineral deposits have a comparatively higher density than the host rock (Fallon et al., 1997). Gravity highs are typical anomaly patterns in the Pb-Zn mineralization terrains and centre over the ore body since they occur in association with baryte (Solomon *et al*., 2022). The Bouguer anomaly of the area varies from 8.0 to 34 mGal (Figure 11) though, it does not cover the entire study area but covers the area underlain by the suspected mineralized Asu River group. The gravity-high area in the western part of the area is likely to be the mineralized zones by sulfide ores. The Bouguer gravity map contains the superposition of anomalies from different depths i.e., both shallow and deep anomalies. Hence, there is a need for anomaly separation.

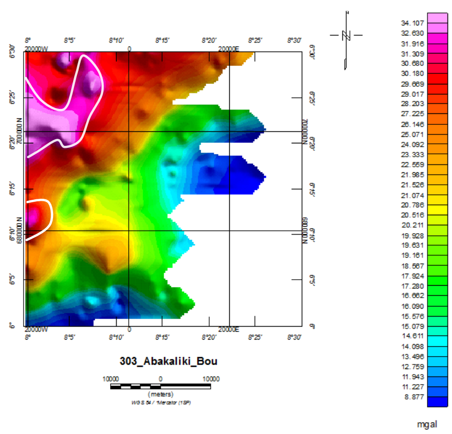


Figure 11: Map of the Bouguer Gravity of the Area

Figure 12 shows the long wavelength component of the gravity anomalies when it was upward continued to the height of 800 m (when uniformly varying field was achieved). The upward continued grid is removed from the Bouguer anomaly grid to get the residual anomaly grid. The residual gravity map (Figure 13) which values ranging from -5.671 to 5.825 mGals. The most paramount are the ones corresponding to the three major high positive gravity values ((5.8 mGals) in Agalaga, Idenla and Eleke (Figure 13).

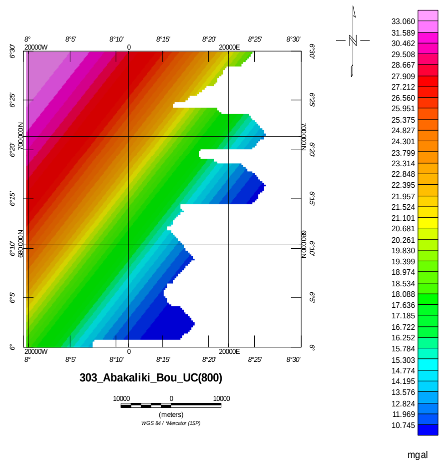


Figure 12: Upward Continuation Map (Bouguer Anomaly) to the height of 800 m

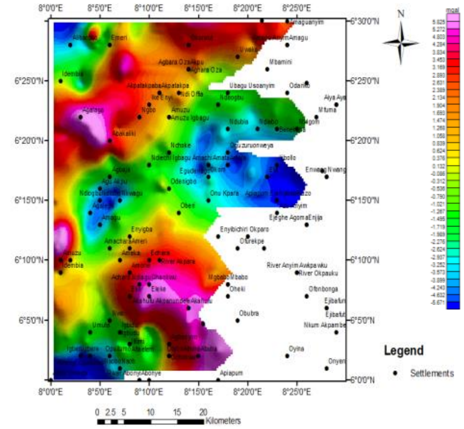


Figure 13: Map of the Residual Gravity of the Area.

Notably, the identified positive anomalous bodies fall within the mineralized Asu River group (Figure 2) which could be an indication of lead-zinc mineralization in the study area, because of its high-density contrast with the host. The gravity values (residual) are not constrained to their source alone. Consequently, there is a need for an analytic signal.

Analytic signal enhances near-surface anomaly in the potential field data (Michael and Stephen, 2014). The anomalies shown in Agalaga and Idenla in the residual anomaly have been enhanced in the analytic signal (Figure 14). The ridges in the analytic signal map are suspected to be mineralized zones within the area.

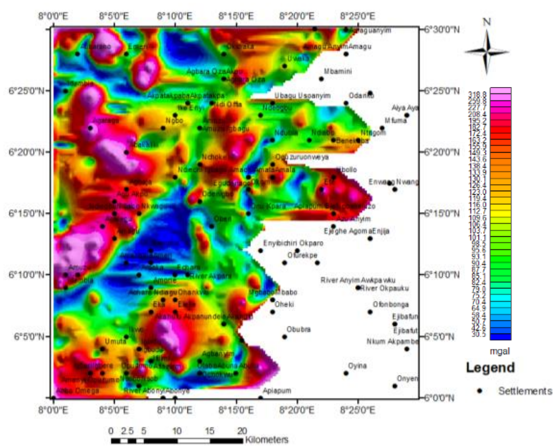


Figure 14: Analytic Signal Map (Bouguer) of the Area

Digital Elevation Map of the Area (DEM)
Relief of an area corrupts radiometric interpretation since, it is a near-surface event (Michael and Stephen, 2014). Consequently, the radiometric data is interpreted in conjunction with the Digitized Elevation Map (DEM). DEM shows that the NW part and the edge of the SW part of the area are high-elevation environments ranging from 47 to 133 m (Figure 15). In between this highland in the NE part, there is a valley labelled ‘V’. River Obubra coincides with the lowland in the SE part of the area which is a densely structured area in the magnetic derivatives maps. Therefore, the river is structurally controlled. There is also a ridge labelled ‘R’ in the northern part of the area.

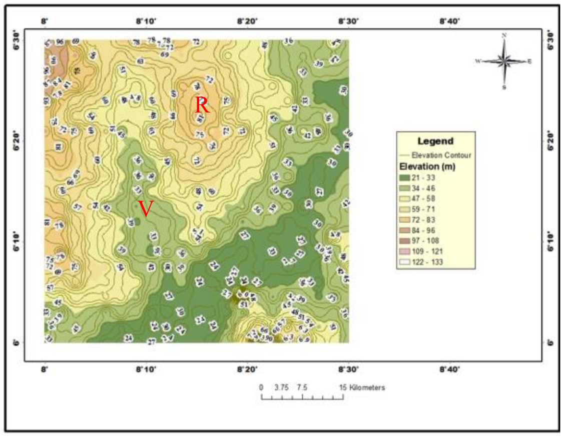


Figure 15: Digital Elevation Map of the Area.

Radiometric Data Interpretation

The Potassium (K), Thorium (Th) and Uranium (U) anomalies are generated from radioactive measurements. The magnitude of potassium is high in the western part of the area (Figure 16). There are variations of radioactive elements across the area. Potassium concentration ranges from 0.2 to 1.2%; Thorium concentration ranges from 6.6 to 21.6 ppm (Figure 17); Uranium concentration ranges from 1.71 to 5.34 ppm (Figure 18).

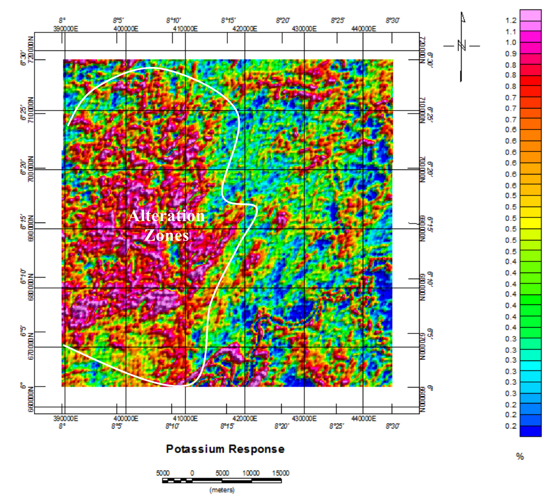


Figure 16: The Potassium Response Map of the Area

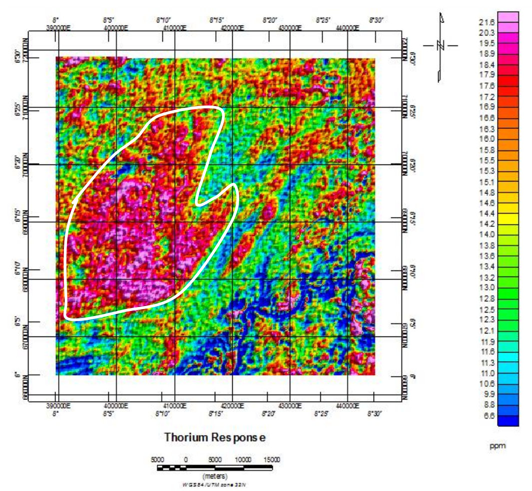


Figure 17: Map of the Thorium Response of the Area

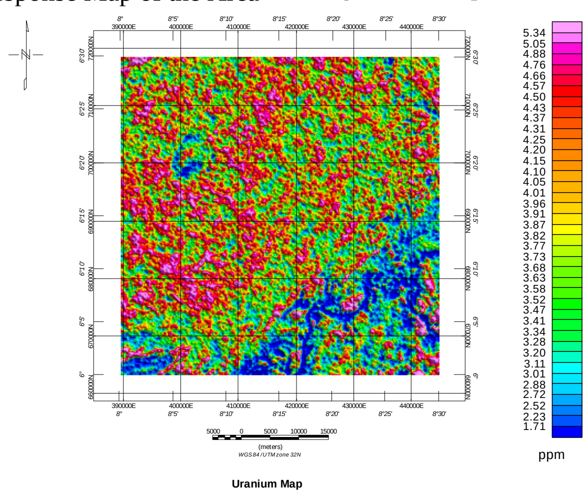


Figure 18: The Uranium Response Map of the Area

Comparing and contrasting both radiometric and DEM maps shows that elevation has no significant effect on the radiometric responses in the area. The eastern part of the study area has relatively low Potassium and Thorium anomalies while the western part contains relatively high potassium and Thorium anomalies. Potassium content is higher in alteration zones. Hydrothermal alteration triggered potassium enrichment (Michael and Stephen, 2014). Therefore, this confirmed the previous studies that the mineralization in the study area is of hydrothermal origin. Thorium is also concentrated in the western part of the area which implies that the deposit is unweathered (Silva *et al*., 2003). Uranium is randomly distributed across the study area as shown in figure 18. Therefore, mineralization in the area is not of radioactive or radioactive origin. The existence of River Obubra masked the response of Potassium, Thorium and Uranium (Figures 16, 17, 18) in the SE part of the area.

The ternary map of the area is shown in Figure 19. Alteration zones are represented by the white/near white portion of the map where the three elements have the highest magnitude in the western part of the area signalling mineralization.

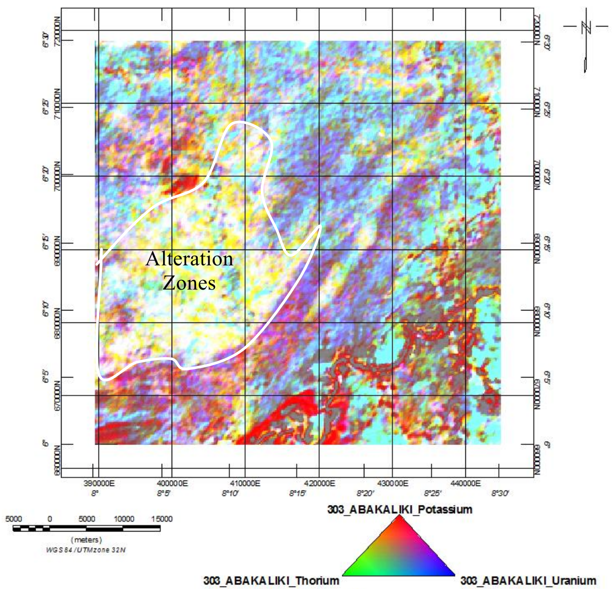


Figure 19: Ternary Map of the Area

Figure 20 shows the potassium-to-thorium ratio map of the area. It varies from 0.0 to 0.1. The high ratio in the western part of the area is an indication of alteration zones (Silva *et al*., 2003). The high ratio in the southeastern part of the area coincides with the path of river Obubra (Figure 2). Therefore, river Obubra may contain placer deposits of lead-zinc mineralization.

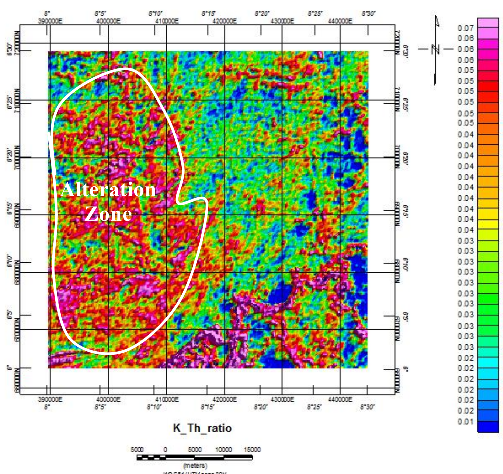
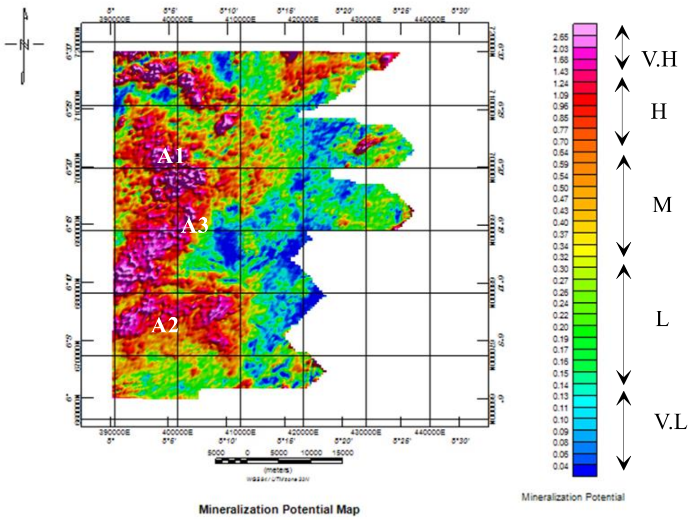


Figure 20: Potassium to Thorium Ratio Map

To produce a geologically meaningful, statistically valid, and practically useful mineralization potential map; the suspected effects of Pb-Zn minerals on representative maps from magnetic (Analytic grid), gravity (Analytic grid), and radiometric (potassium grid) are multiplied using multiplication tools of Oasis Montaj software. The mineralization potential map is zoned into very high mineralization (V.H) dominated the western part of the area; high (H), medium (M), low (L), and very low (V.L) mineralization as shown in Figure 21.

The mineralization potential map (Figure 21) was verified by georeferencing the existing mining site on the map which shows the existing mining sites correspond to the peak amplitude of the mineralization potential map.



V.H: Very High; H: High; M: Medium; L: Low; V.L: Very low

Figure 21: Mineralization Potential Map of the Area.

CONCLUSION

Geophysical interpretation of airborne magnetic, land gravity and airborne radiometric data was carried out at the Lead-Zinc metallogenic province of southern Benue to generate geophysical anomaly indicators for mapping Pb-Zn minerals in the area and area of similar geology. The geophysical data were processed to enhance high-frequency anomalies using various enhancement techniques such as gradients, upward continuation, analytic signal, ratio map and ternary maps as applicable to each method. The interpretation of the results was guided by the location of the existing mining sites in the Pb-Zn metallogenic province of southern Benue Trough. It was deduced that high analytic signal anomaly in the western part of the study area can be used as an indicator for Pb-Zn Mineral. The probable mineral head in the area ranges from 40 to 120 m as revealed from the depth to the top of magnetic bodies using analytic signal depth which is consistent with the field observation. The lead zinc mineral in the area has a high density contrast with the host which resulted in its high Bouguer gravity anomaly in the western part of the study area. The study revealed that high radiometric anomalies of ^{40}K, eTh, eTh/^{40}K, and ternary map are also in the western part of the area which buttress their origin as hydrothermal minerals. This also coincides with the area of high magnetic intensities. Therefore, potassic alteration occurred in the area. The mineralization potential map of the study area was developed from AS, RG and ^{40}K. It was zoned into high mineralization, medium mineralization and low mineralization. High mineralization dominated the western part of the study area where the mining sites are concentrated. Therefore, the Pb-Zn anomaly pattern is delineable using aeromagnetic, gravity, and radiometric data.

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