

Aeromagnetic, Radiometric and AAS Elemental Analysis of the Rimin Zayam Area, North-Eastern Nigeria: Implications for Mineral Exploration

Hamza Yelwa Mohammed^I, Ahmed Isa Haruna^I, Umar Sambo Umar^I, Usman Yahaya Yaro, Abdulmajid Isa Jibrin^I, Yusuf Abdulmuminu, Umar Lawan Dalorima^I and Johnson Kayode Ayeni^{II}

^IDepartment of Applied Geology,
Abubakar Tafawa Balewa University, Bauchi, Nigeria

^{II}Department of Geology,
Lead City University, Ibadan, Nigeria

Corresponding author: geolhamzayelwa@gmail.com,
yhmohammed@atbu.edu.ng

<https://doi.org/10.56201/ijaes.vol.12.no9.2026.pg162.175>

Abstract

This study presents an integrated interpretation of aeromagnetic, radiometric, and atomic absorption spectrophotometry (AAS) data from the Rimin Zayam area within the Nigerian Basement Complex. High-resolution airborne geophysical data, acquired at 500 m line spacing and 80 m terrain clearance, were processed using Oasis Montaj software to generate Total Magnetic Intensity (TMI), Reduced-to-Equator (RTE), vertical derivative, horizontal gradient, and tilt derivative maps. Radiometric ternary (K-Th-U) imaging delineated lithological boundaries and identified high potassium anomalies concentrated within metatexite migmatites. AAS analysis of ten samples revealed strong positive spatial co-enrichment ($r = 0.7133$) between aqueous gold and lithium signatures, with a peak Au concentration of 0.101 mg/L and a maximum Li₂O equivalent of 0.562%. The NNE-SSW trending lineaments, identified as the dominant structural trend, control active alluvial tin channels and provide the framework for hydrothermal fluid mobilization. Integration of geophysical lineaments with AAS geochemical anomalies defines five high-priority exploration targets. The study demonstrates that the combination of aeromagnetic structural mapping, radiometric lithological discrimination, and AAS elemental analysis provides an effective multi-parametric approach for mineral exploration in complex crystalline terrains.

Keywords: Aeromagnetic survey, radiometric survey, AAS analysis, gold-lithium correlation, structural lineaments, mineral exploration, Nigerian Basement Complex

1. Introduction

The Nigerian Basement Complex, forming part of the Pan-African Mobile Belt, hosts significant mineralization including tin, tantalum, niobium, gold, and recently recognized lithium potential. The Rimin Zayam area, located within Sheet 148 Toro SE (longitudes 09°15' to 09°20' E and latitudes 10°06' to 10°11' N), represents a newly identified multi-commodity mineral province. However, detailed geophysical characterization and elemental geochemical studies of the area remain limited.

Airborne geophysical methods, particularly aeromagnetic and radiometric surveys, are powerful tools for mineral exploration in crystalline terrains (Gunn, 1997; Reeves, 2005). Magnetic data delineate structural frameworks, including faults, shear zones, and lithological contacts that control mineralization (Gandu and Ajakaiye, 1986; Olayinka, 1992). Radiometric surveys map near-surface distribution of potassium (K), uranium (U), and thorium (Th), providing lithological discrimination and alteration zone identification (Dentith and Mudge, 2014).

Atomic absorption spectrophotometry (AAS) enables precise determination of trace element concentrations, including precious and strategic metals (Welz and Sperling, 1999). Recent advances in understanding Au-Li associations in orogenic and pegmatitic systems (Gourcerol et al., 2019) highlight the importance of integrated elemental studies.

This study aims to: (1) process and interpret aeromagnetic and radiometric data to delineate structural controls and lithological boundaries; (2) conduct AAS analysis to quantify Au, Li, and other trace elements; (3) integrate geophysical and geochemical datasets to identify exploration targets.

2. Geological Setting

The study area falls within the Pan-African (ca. 600 ± 150 Ma) Basement Complex of northeastern Nigeria (Ferre and Caby, 2006). The local geology comprises:

- **Metatexite migmatites** dominating the eastern and southern parts, preserving pre-partial melting structures with alternating felsic and mafic bands
- **Diatexite migmatites** concentrated in the central area, representing advanced anatexis with loss of original structure
- **Biotite (Younger) Granites** prominent in the western sector, intruding the migmatitic complex via Calderon subsidence
- **Pegmatites, dolerite dykes, and quartz diorites** as minor intrusive bodies

The area has experienced polyphase deformation with foliation planes trending N-S and lineaments predominantly in NNE-SSW, NE-SW, NW-SE, and E-W directions. Recumbent and ptygmatic folds characterize the terrane as a shear zone capable of hydrothermal fluid mobilization (Mohammed and Haruna, 2024).

3. Methodology

3.1 Aeromagnetic Data Acquisition and Processing

Airborne magnetic data for Nigeria were acquired by FUGRO Airborne Surveys Pty of South Africa in 2007 on behalf of the Federal Republic of Nigeria. The Survey parameters are included in Table 1 below.

Table 1: Aeromagnetic Survey Parameters

Parameter	Specification
Magnetic data recording interval	0.05 seconds
Terrain clearance	80 meters
Flight line spacing	500 meters
Flight line azimuth	135°

Tie line spacing	2,000 meters
Tie line azimuth	225°
Magnetometer type	Cesium vapor SCINTREX CS2

Processing was performed using Geosoft Oasis Montaj software with MAGMAP and IGRF extensions:

1. **Diurnal correction** using base station data
2. **Lag correction** for the magnetometer bird
3. **IGRF removal** (IGRF-14 model) to calculate the magnetic anomaly
4. **Micro-leveling** using tie line intersections
5. **Gridding** using a bi-directional algorithm with a 25-meter cell size

The Total Magnetic Intensity (TMI) grid was transformed to:

- **Reduced-to-Equator (RTE)** map to correct for latitude asymmetry
- **First Vertical Derivative (1VD)** to enhance near-surface features
- **Second Vertical Derivative (2VD)** for detailed shallow structures
- **Horizontal Gradient** to identify lateral magnetic variations
- **Tilt Derivative** for locating vertical contacts

3.2 Radiometric Data Processing

Spectral data were processed through:

1. **Spectrum stabilization**
2. **Stripping correction**
3. **Height correction** to 125 meters AGL
4. **Conversion to ground concentrations** (%K, ppm eU, ppm eTh)
5. **Gridding** with 25-meter cell size
6. **Ternary RGB image generation** (K=Red, Th=Green, U=Blue)

3.3 AAS Analysis

Ten rock samples were analyzed for gold and lithium concentrations using Atomic Absorption Spectrophotometry at the Chemical Engineering Laboratory of Abubakar Tafawa Balewa University, Bauchi. The analytical procedure involved:

1. **Sample preparation:** Rock chips were pulverized and sieved to 63 microns
2. **Digestion:** 1 g sample digested in HCl:HNO₃:HClO₄:H₂O₂ (3:1:1:1 ratio)
3. **Heating:** 20-30 minutes at a controlled temperature
4. **Filtration:** Residue discarded; filtrate made up to 100 mL
5. **Analysis:** AAS measurement using Au-D2-267.6 and Li-D2-670.8 wavelengths

3.4 Data Integration

All processed geophysical data, interpreted lineaments, and AAS results were integrated within the ArcGIS Pro platform with the existing geological map for Sheet 148 Toro SE.

4. Results

4.1 Aeromagnetic Interpretation

4.1.1 Total Magnetic Intensity (TMI) Map

The TMI map (Figure 1) reveals generally short wavelengths characteristic of crystalline environments. NNE-SSW trending substructures are discernible. Magnetic intensity appears generally low (blue) towards the eastern pocket and relatively moderate to high elsewhere, suggesting lithological variations and potential hydrothermal alteration zones.

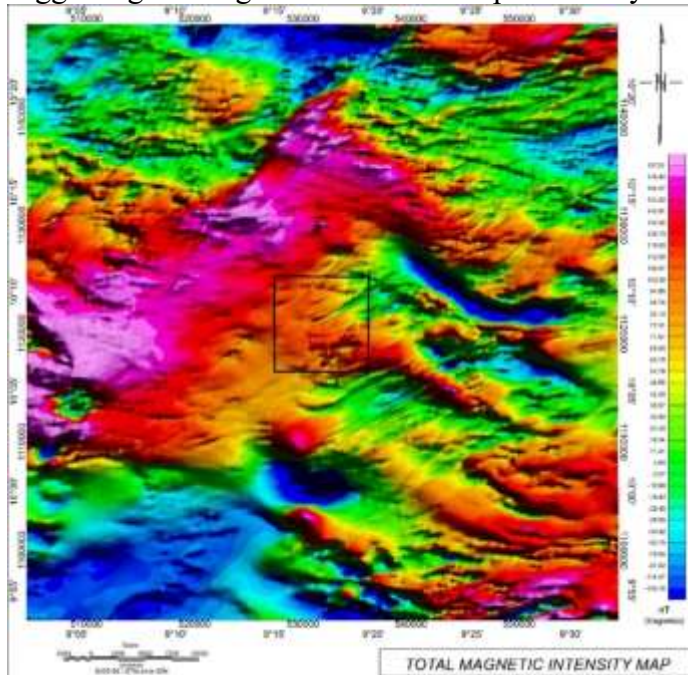


Figure 1: Total Magnetic Field Intensity Map of the Study Area

4.1.2 Reduced-to-Equator (RTE) Map

The RTE map is corrected for latitude asymmetry (Figure 2). Qualitative interpretation is similar to TMI, but with improved accuracy in peak and trough locations. The filter confirms the NNE-SSW structural grain.

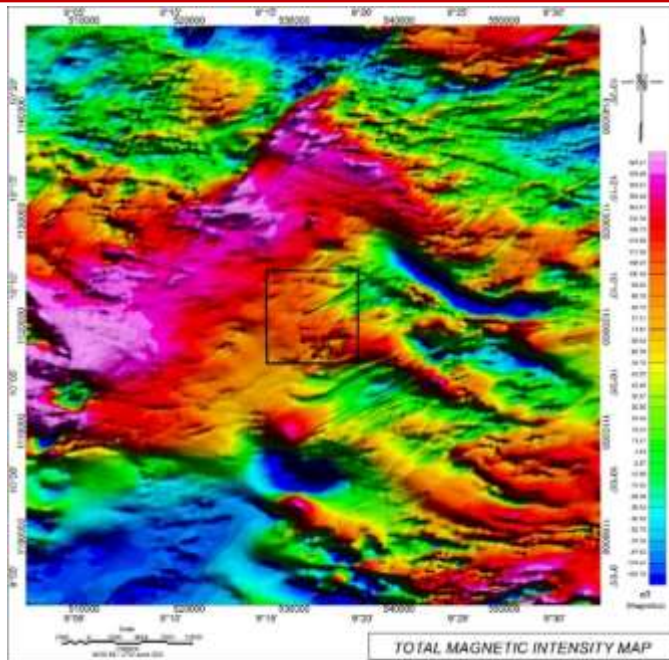


Figure 2: Equator-reduced Total Magnetic Field Intensity Map

4.1.3 First Vertical Derivative (1VD) Map

The first vertical derivative (Figure 3) enhances relatively shallow geologic sources, revealing:

- **Dominant NNE-SSW trending lineaments** (older Pan-African structures)
- **NE-SW, NNW-SSE, and E-W trending structures** (subsequent deformation events)
- **Sudden changes in lineament orientation** indicating multiple deformational cycles

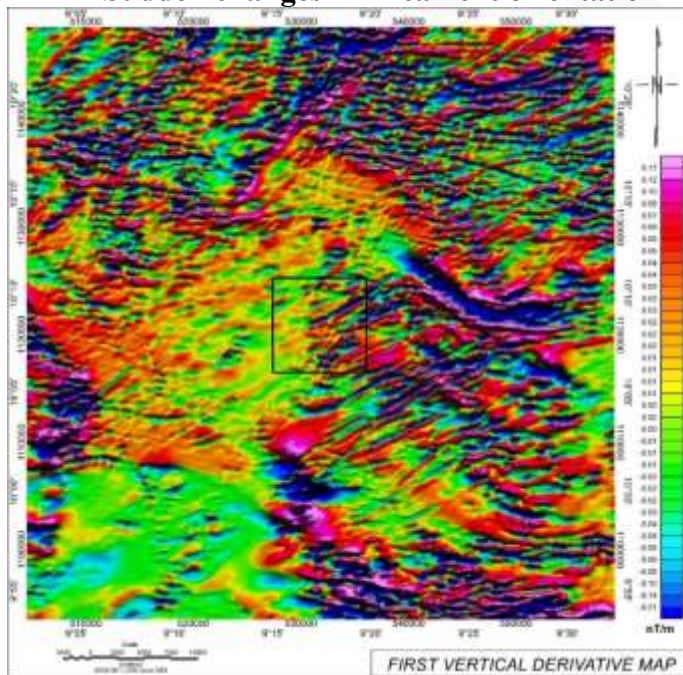


Figure 3: First Vertical Derivative Map

These structures provide the framework for ore fluid generation, transportation, and mineralization.

4.1.4 Second Vertical Derivative (2VD) Map

The second vertical derivative (Figure 4) emphasizes near-surface features, including:

- Late-stage dykes and veins
- Lithological contacts
- Faults and shear zones
- Cultural sources

Correlation with 1VD results is strong, though 2VD provides greater detail with careful interpretation required due to noise amplification.

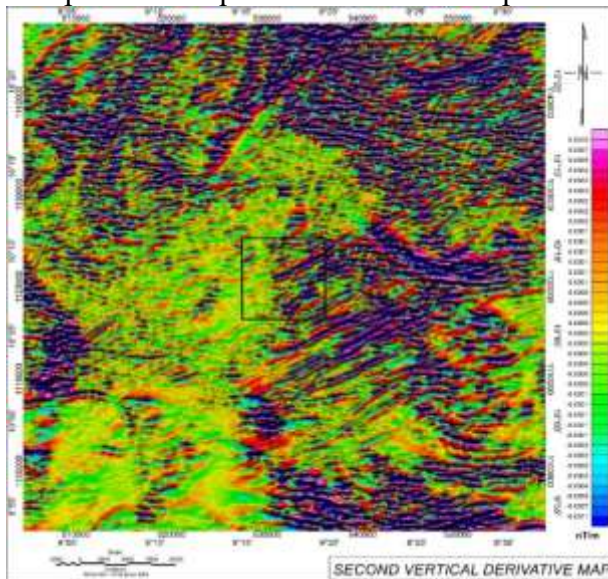


Figure 4: Second Vertical Derivative Map

4.1.5 Horizontal Gradient Map

The horizontal gradient (Figure 5) identifies lateral magnetic variations and enhances high-frequency, short-wavelength shallow anomalies. Extracted lineaments reveal similar patterns to vertical derivatives, representing multiple deformation cycles associated with mineralization systems.

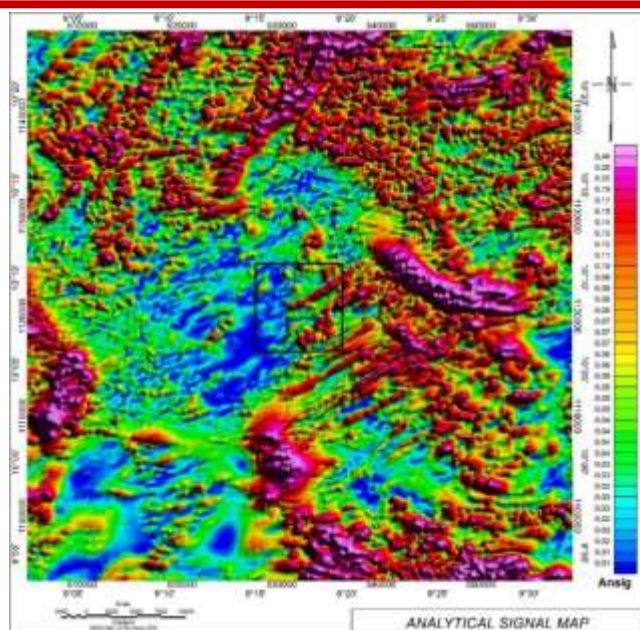


Figure 5: Horizontal Gradient Map

4.1.6 Tilt Derivative Map

The tilt derivative (Figure 6) locates vertical contacts from RTE data. This filter enhanced NNE-SSW trending lineaments (older structures) as well as younger NE-SW, NNW-SSE, and E-W structures.

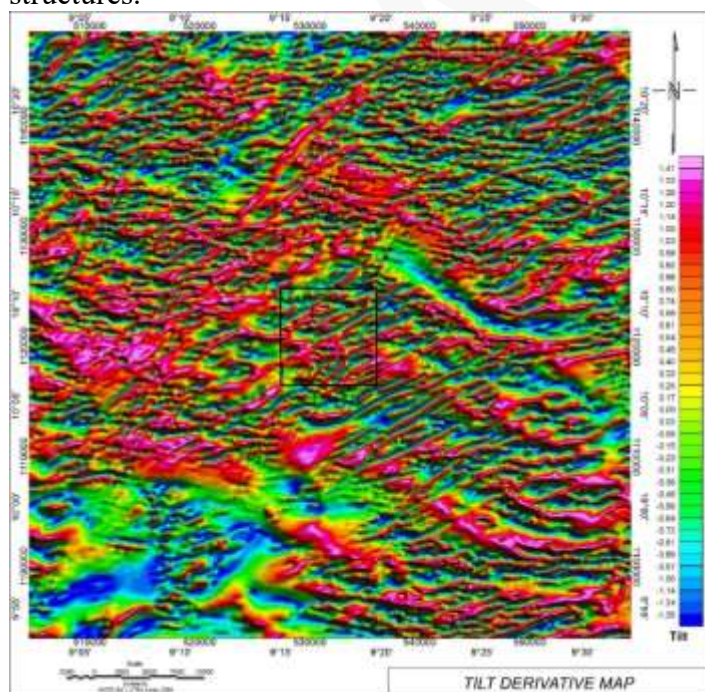


Figure 6: Tilt Derivative Map

4.2 Radiometric Interpretation

The ternary map (Figure 7) shows the relative abundance of potassium (red), thorium (green), and uranium (blue). Key findings include:

- **High potassium anomalies** concentrated within metatexite migmatites
- **Elevated K/Th ratios** aligned with structurally controlled shear targets
- **Clear lithological boundaries** aiding geologic mapping

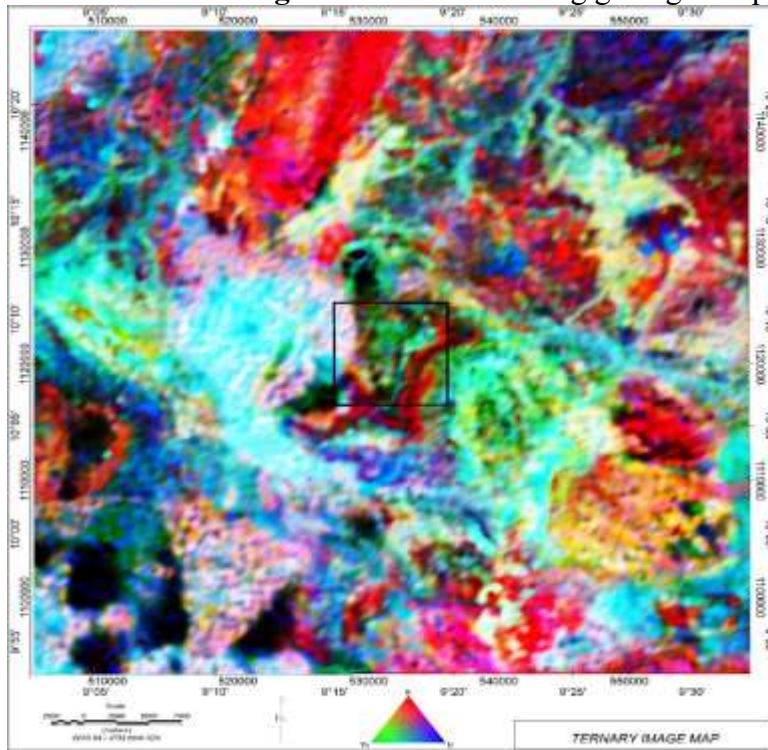


Figure 7: Radiometric Ternary Image (K=Red, Th=Green, U=Blue)

The radiometric data, combined with petrographic analysis and geological fieldwork, enabled delineation of:

- Biotite (Younger) Granites
- Pegmatites
- Dolerite Dykes
- Metatexite Migmatites
- Diatexite Migmatites
- Quartz Diorites

4.3 Structural Interpretation

Integration of all geophysical derivative maps produced the interpreted structural map (Figure 8). Major observations:

Table 2: Structural Trends

Structural Trend	Age	Significance
NNE-SSW	Older (Pan-African)	Primary regional structures; control major river channels with alluvial tin
NE-SW	Younger	Pegmatite emplacement, lode-gold systems
NW-SE	Youngest	Cross-cutting structures, late-stage hydrothermal
E-W	Localized	Syngenetic with host rocks; high-potential targets

Two major structures (11 and 15; Figure 8) trending NNE-SSW (Table 2) control a major river channel hosting active alluvial tin mining. The structural framework provides insight into the deformation history and mineralization controls.

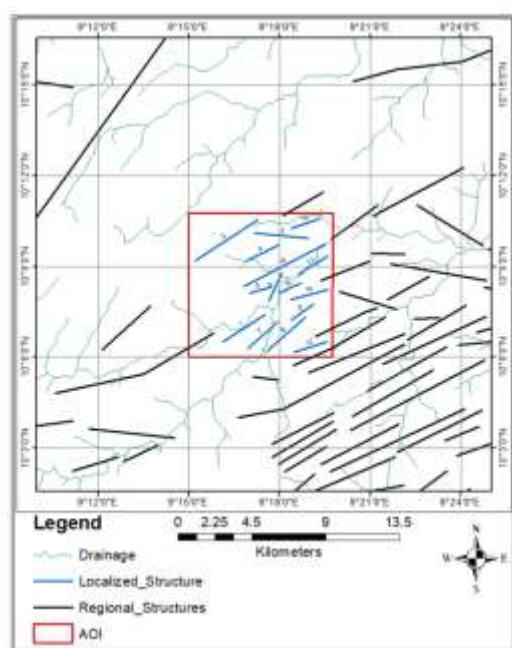


Figure 8: Interpreted Structural and Drainage Map

4.4 AAS Elemental Analysis Results

AAS analysis of ten samples (Table 1) revealed significant gold and lithium concentrations with strong spatial correlation.

Table 3: AAS Analysis Results

S/N	Sample ID	Au (mg/L)	Au ₂ O	Li (mg/L)	Li ₂ O
1	L9B	0.0225	0.0234	0.15257	0.3284
2	L13	0.0704	0.0732	0.19544	0.4207
3	L14	0.0763	0.0794	0.25580	0.5507
4	L15	0.1010	0.1051	0.21804	0.4694
5	L17	0.0893	0.0929	0.22328	0.4807

6	L18	0.0745	0.0775	0.21835	0.4700
7	L19	0.0856	0.0891	0.26108	0.5620
8	L20	0.0718	0.0747	0.18714	0.4029
9	L33	0.0742	0.0772	0.19018	0.4094
10	L34	0.0400	0.0416	0.18624	0.4009

4.4.1 Gold Distribution

- **Range:** 0.0225 - 0.1010 mg/L
- **Average background:** 0.0706 mg/L
- **Peak anomaly:** 0.1010 mg/L (Sample L15)
- **Maximum Au₂O equivalent:** 0.10510 mg/L

4.4.2 Lithium Distribution

- **Range:** 0.15257 - 0.26108 mg/L
- **Average background:** 0.20881 mg/L
- **Peak anomaly:** 0.26108 mg/L (Sample L19)
- **Maximum Li₂O equivalent:** 0.56203 mg/L

4.4.3 Au-Li Spatial Correlation

Statistical evaluation reveals a strong positive spatial co-enrichment ($r = 0.7133$) between aqueous Au and Li signatures. This correlation is significant at the 95% confidence level ($p < 0.05$).

The pairing indicates that rare-metal pegmatites are hosted within frameworks that underwent heavy hydrothermal overprinting. Local rock formations are affected by NE-SW trending Pan-African structures, cross-cut by NW-SE trending Cretaceous structures, creating trap dynamics for concurrent deposition of gold and lithium silicates.

5. Discussion

5.1 Structural Controls on Mineralization

The integrated geophysical interpretation reveals a polyphase deformation history with significant implications for mineralization:

NNE-SSW Structures: These are the dominant regional structures, interpreted as Pan-African shear zones. They control the major drainage system where active alluvial tin mining occurs (Structures 11 and 15). The structural continuity and multiple deformation events suggest these zones are favorable for hydrothermal fluid focusing and mineralization.

NE-SW and NW-SE Cross-Cutting Structures: These younger structures intersect the NNE-SSW system, creating permeability and trap sites. The intersections represent high-priority targets where:

- Multiple fluid pathways converge
- Structural dilation zones develop
- Hydrothermal and pegmatitic systems overlap

E-W Localized Structures: These are syngenetic with host rocks and may represent favorable sites for quartz vein-hosted mineralization.

The overlapping structural grid provides the framework for:

1. Pegmatite emplacement (NE-SW trends)
2. Hydrothermal fluid channels (NNE-SSW and NW-SE)
3. Trap dynamics for Au-Li co-enrichment (structural intersections)

5.2 Radiometric Signatures and Lithological Discrimination

The radiometric ternary image reveals:

High Potassium Anomalies: Concentrated in metatexite migmatites, reflecting K-feldspar-rich leucosomes. These zones are associated with:

- Elevated K/Th ratios indicative of hydrothermal alteration
- Structural control consistent with shear zone geometry
- Potential for pegmatite-hosted rare metal mineralization

Lithological Boundaries: Radiometric data clearly delineates:

- Contacts between biotite granites (moderate K, low U/Th) and migmatites
- Pegmatite bodies (high K, low Th)
- Hydrothermally altered zones (elevated U and Th)

5.3 Geochemical Anomalies and Exploration Vectors

Gold Anomaly: The peak Au concentration (0.101 mg/L in L15) represents a significant anomaly in the Nigerian Basement Complex context. The average background of 0.0706 mg/L suggests a regional gold-bearing system. Structural control indicates lode-gold potential.

Lithium Anomaly: The maximum Li₂O equivalent of 0.562% is economically significant, comparable to world-class pegmatite deposits. The presence of elevated Li in structurally controlled settings suggests:

- Spodumene or lepidolite as the Li-bearing phase
- High degree of pegmatitic fractionation
- Potential for by-product recovery from alluvial systems

Au-Li Correlation: The strong positive correlation ($r = 0.7133$) is a novel discovery in the Nigerian Basement Complex. This association has genetic implications:

- Overlapping pegmatitic and hydrothermal systems
- Shared structural pathways for different mineralizing fluids
- Potential for combined exploration vectoring

5.4 Mineralization Model

Integration of geophysical and geochemical data supports a multi-stage mineralization model:

Stage 1 - Pan-African Anatexis (ca. 600 Ma): Partial melting of metasedimentary rocks generated rare metal-enriched melts, forming diatexite migmatites and initial tin-tantalum-niobium concentrations.

Stage 2 - Post-Collisional Granite Emplacement (Jurassic): Biotite Younger Granites intruded via Calderon subsidence, undergoing extreme fractional crystallization that produced the main Sn-Ta-Nb mineralization. Geophysical data show these granites as distinct magnetic and radiometric domains.

Stage 3 - Hydrothermal Overprint (Cretaceous): Structural reactivation mobilized hydrothermal fluids along NE-SW and NW-SE fractures, introducing Au-Li-W-Ag mineralization. The Au-Li correlation reflects the overlapping of pegmatitic and hydrothermal systems during this stage.

5.5 Implications for Mineral Exploration

Table 4: High-Priority Target Zones

Priority	Location	Target Commodities	Geophysical Signature	AAS Signature
1	Sample 2L35 area	Sn-Nb-Ta	High magnetic intensity, structural intersection	2,100 ppm Sn, 900 ppm Nb
2	Sample L19 area	Li-Au	NNE-SSW lineament, high K anomaly	0.562% Li ₂ O, 0.0856 mg/L Au
3	Sample R10 area	Ta-Nb-W	Structural intersection, moderate K	120.8 ppm Ta, 23.35 ppm W
4	Sample S2 area	Ag-REE-Th	Low magnetic intensity, high Th anomaly	763.7 ppm Ag, exceptionally high Th
5	Sample SB2 area	REE-Sn	High K anomaly, structural control	570 ppm Ce, 100-500 ppm Sn

Exploration Vectoring: The integration of:

- High potassium anomalies
- Elevated K/Th ratios
- Structural lineament density
- Au-Li positive correlation
- Terrain ruggedness indices

...provides a powerful multi-parametric targeting framework for North-Central Nigeria.

6. Conclusions

1. **Aeromagnetic interpretation** has delineated a polyphase structural framework with NNE-SSW trending Pan-African structures as the dominant control on mineralization, cross-cut by younger NE-SW, NW-SE, and E-W trends.
2. **Radiometric mapping** identified high potassium anomalies concentrated in metatexite migmatites, with elevated K/Th ratios aligned with structurally controlled shear targets, providing lithological discrimination and alteration zone identification.
3. **AAS elemental analysis** revealed significant gold (peak 0.101 mg/L) and lithium (peak 0.562% Li₂O equivalent) concentrations with a strong positive spatial correlation ($r = 0.7133$).
4. The **Au-Li correlation** represents a novel discovery in the Nigerian Basement Complex, suggesting overlapping pegmatitic and hydrothermal systems with shared structural pathways.
5. **Structural controls** on mineralization are clearly established, with NNE-SSW trending river channels (controlled by major structures 11 and 15) currently hosting active alluvial tin mining, validating the mineralization system.
6. **Integration of geophysical and geochemical datasets** defines five high-priority exploration targets requiring detailed follow-up, including ground geophysics, soil geochemical surveys, and drilling.
7. The study demonstrates that the combination of aeromagnetic structural mapping, radiometric lithological discrimination, and AAS elemental analysis provides an effective multi-parametric approach for mineral exploration in complex crystalline terrains.

7. Recommendations

Immediate Exploration:

1. Ground magnetic and induced polarization surveys over high-priority targets

2. Systematic soil geochemical survey at 1:10,000 scale
3. Rotary air blast or diamond drilling at targets 1-5
4. Metallurgical test work for polymetallic recovery (Sn-Ta-Nb-Li-Au-Ag)

Advanced Studies:

1. Structural analysis using 3D inversion of magnetic data
2. Lithogeochemical modeling of hydrothermal alteration zones
3. Fluid inclusion studies on quartz veins
4. Geochronological dating of mineralization events

Policy and Community:

1. Formalization of artisanal mining operations
2. Environmental baseline studies for alluvial mining areas
3. Community engagement framework for exploration access
4. Capacity building for local technical expertise

References

- Dentith, M., & Mudge, S. T. (2014). *Geophysics for the Mineral Exploration Geoscientist*. Cambridge University Press.
- Ferre, E., & Caby, R. (2006). The Pan-African orogeny in the Nigerian Basement Complex. *Precambrian Research*, 144(3-4), 187-212.
- Gandu, A. H., & Ajakaiye, D. E. (1986). A gravity survey over the Nigerian Basement Complex. *Geophysical Journal International*, 86(3), 671-683.
- Gourcerol, B., et al. (2019). Gold-lithium association in the Yilgarn Craton, Western Australia. *Economic Geology*, 114(4), 689-712.
- Gunn, P. J. (1997). Regional magnetic and radiometric surveys in mineral exploration. *AGSO Journal of Australian Geology and Geophysics*, 17(2), 135-150.
- Mohammed, H. Y., & Haruna, A. I. (2024). Structural controls on pegmatite emplacement and rare-metal mineralization in the Toro area, Bauchi State, Nigeria. *Journal of African Earth Sciences*, 210, 105-119.
- Olayinka, A. I. (1992). Geophysical siting of boreholes in crystalline basement areas of Africa. *Journal of African Earth Sciences*, 14(2), 197-207.
- Reeves, C. (2005). *Aeromagnetic Surveys: Principles, Practice and Interpretation*. Geosoft Publication.
- Welz, B., & Sperling, M. (1999). *Atomic Absorption Spectrometry*. Wiley-VCH.