



Research Article

Structural and Geochemical Characterization of Baryte
Mineralization in Liji Area, Northern Benue Trough, Northeastern
Nigeria

*H. I. Kamale¹, M. K. Muhammad¹, M. S. Maigana², U. L. Dalorima³, A. S. Sa'ad¹, I.A. Yerima¹ and
A. I. Lawan¹

¹Department of Geology, Faculty of Physical Sciences, University of Maiduguri, Nigeria

²Department of Geophysics, King Fahad University of Petroleum and Minerals, Dhahran, Saudi Arabia

³Zenith Bank Nigeria PLC, Maiduguri Main Branch, Nigeria

*Corresponding author's Email: hikamale@unimaid.edu.ng, doi.org/10.55639/607.07060501

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ABSTRACT

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Geological and structural mapping of the Liji area was conducted while the objective of the study is to geologically map and assess the structures and characterized the geochemical properties of the baryte and their host rocks of the Liji area. The result show that granite, pegmatite, Bima Sandstone, Yolde Sandstone, Pindiga Formation and Gombe Sandstone constituting the geology of the area. Structurally controlled vein-type epigenetic baryte mineralization is located within fractures in the granites, pegmatites and Bima Sandstone. Tectonic structures deduced from aeromagnetic data show lineaments trending in NE-SW, E-W and N-S directions while the field structures largely trends in NNE-SSW, N-S and E-W with minor trends in NW-SE directions. Average specific gravity of baryte has value that qualifies it for utilization in manufacture of drilling mud for oil-well drilling among other industrial applications. Ten (10) representative samples were selected and analyzed for trace elements using inductively coupled plasma mass spectrometry technique. The results show progressive increase in Ba and Sr contents from the distal samples through the proximal samples to the mineral separates with corresponding depletion of Rb from the distal to the proximal samples but with extremely low content in the baryte separates. The baryte separates show abnormally high Ba (>50,000 ppm) and Sr (10, 540.5 ppm) values indicating mineralization of baryte (BaSO₄) and Celestine (SrSO₄).

Corresponding author: H. I. Kamale, Email: suleibrahim@umaid.edu.ng

Department of Geology, University of Maiduguri, P.M.B. 1069, Maiduguri, Nigeria

INTRODUCTION

The Liji area is part of Gombe inlier a geological entity in northeastern Nigeria characterized by outcrops of Precambrian basement rocks that are exposed and surrounded by younger sedimentary formations (Nwajide, 2003). The area showcased litho-structural and stratigraphic sequences that have been affected by the mid-Santonian syn-sedimentary strike-slip faults movement with initial upthrust of the Precambrian basement along the Gombe fault system (Zaborski *et al.*, 1997). These Santonian deformation produced subsidiary fractures and fissures that later became conduit for transport, migration and depositional sites for baryte, fluorite and pyrite mineralization (Joseph *et al.*, 2007; Kamale *et al.*, 2019; Kamale *et al.*, 2020; Dalha, 2023).

The Liji baryte occurrences have not been studied on account of aeromagnetic and field structures, specific gravity study and industrial application as well as trace element geochemistry hence this study. The study is aimed at geologically mapping and determining the structural features of the area, characterizing the tectonic settings and analyzing the geochemical properties of the baryte deposits along with the host rocks as well as assessing the baryte mineral deposits thereby ascertaining their industrial applications.

Geological Setting

The Liji area lies within topographic sheet 152 Gombe NW and NE constitute parts of the Gongola arm of the Northern Benue Trough (Fig. 1). The Benue Trough is a geological feature in Nigeria, forming part of the West African Rift System (Benkhelil, 1989). It stretches for about 1000 Km striking NE-SW from the Gulf of Guinea in the south to Lake Chad in the north (Nwajide, 2013). The trough contains up to 6000m of Cretaceous –Tertiary sediments of which those that predate mid-Santonian have been compressionaly deformed exhibiting folding, faulting and upliftment in different localities (Nwajide, 2013). The compressional folding of mid-Santonian tectonic events affected the entire Benue Trough and was pervasive and intense; producing more than 100 anticlinal and synclinal structures (Benkhelil, 1989). Some of the deformational structures are large-scale in outline such as Abakaliki anticlinorium and Afikpo synclinorium in the southern Benue Trough, the Giza anticlinorium and Obi synclinorium in the Central Benue Trough and the Lamurde anticlinorium and Dadiya synclinorium in the Northern Benue Trough (Obaje, 2009). The interplay of these structural features initiated the enhancement of aqueous hydrothermal fluids which leached metals including barium and sulfur from the sedimentary host rocks and the adjacent basement rocks where it deposits the baryte and other metals in favourable structural sites (El-Nafaty, 2015).

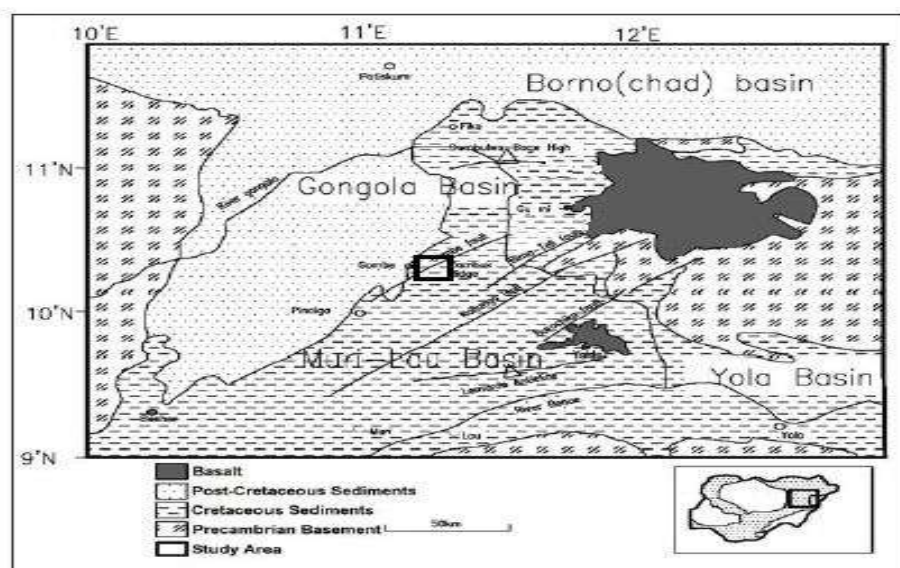


Figure 1: Geological map of the Northern Benue Trough showing the study area (Modified from Zaborski *et al.*, 1997).

MATERIALS AND METHODS

Materials

Equipment used include compass-clinometer, geological hammer, Global Positioning System (GPS), digital camera, measuring tape, field note book, pen, pencil, indelible marker, masking tape, acid bottle, sample bags, ruler, aeromagnetic data, computer softwares, ICP-MS machine, torch, calibration curve, acids, nebulizer and topographic maps.

Methods

Methods adopted during the course of this study are grouped into field and laboratory methods: Field methods: The Liji area was mapped on a scale of 1:50,000 using the topographic map as base map. A total area of 144 Km² was covered using traverse compass mapping technique. Representative rock samples were systematically collected from exposed outcrops and are described on the spot as hand specimen. Samples were then labelled the locations (exact coordinates of sample points in terms of latitudes and longitudes) noted and plotted on base map with the aid of the GPS. The megascopic features and characteristic field relationships with adjacent formations, as well as possible mode of occurrence of the various rocks and formations in the areas were measured, described and recorded in the field note book. The megascopic features described include: colour, texture, mineral composition, structure, fossil content and any other relevant features that may assist in proper description of the rocks under study. Strike and dip of beds, veins, baryte and other linear structures were measured by compass-clinometer while thickness and length of beds, veins and other structures were determined by the measuring tape. All these information gathered from the field were recorded in the field notebook while photographs of relevant structures and outcrops were taken using a digital camera. In areas of mineralization, more detailed mapping was carried out on a scale of 1: 7.5 to 1: 333.2m, to reveal boundary zones between distal rocks (Fresh unaltered), Proximal rocks (hydrothermally altered) and mineral separates (baryte).

Laboratory Methods

The rock and mineral samples collected in the field were taken to the petrology/mineralogy laboratory of the Geology Department, University of Maiduguri for determination of specific gravity and final preparations for

geochemical analysis. Ten (10) samples from the mineralized zones were selected and sent to Bureau Veritas Minerals Laboratories Ltd (ACMELAB) at Vancouver, Canada for trace element geochemical analysis which includes distal and proximal samples (granite, pegmatite and sandstone) and baryte separates.

Geochemistry

Ten representative rocks and mineral samples were carefully selected and subjected to trace element geochemical analysis following the method developed by Hoffmaan and Stroubant, (2007). The samples were broken to smaller fragments and packaged in a bag weighing 70 g – 80 g and sent for analysis. Each of the samples were crushed and then pulverized to atleast 85% passing through the 200 mesh size. Five grams (5g) each of the pulverized samples was fused with lithium metaborate/tetraborate which was rapidly digested in a weak nitric acid solution. The resultant solutions were used for the trace element analysis using the ICP/MS method. The ICP analysis involves plasma that is energized (ionized) by conductively heating the gas with an electromagnetic coil that contains sufficient concentration of ions and electrons to make gas electrically conductive. A flow of argon gas (13-18 l/m) is introduced between two outer tubes of a torch and an electric spark is applied for a short time to introduce free electrons into gas stream (Hoffmaan and Stroubant, 2007). These electrons interact with radio –frequency magnetic field of the induction coil and are accelerated first in one direction, then in the other, as the field changes at high frequency (27.12 MHz). The accelerated electrons collide with argon atoms, and the collision causes an argon atom to part with one of its electrons. The released electron is in turn accelerated by the rapidly changing magnetic field. The process continues until the rate of release of new electrons in collisions is balanced by the rate of recombination of electrons with argon ions. This produces “fireball” that consists mostly of argon atoms with rather small fraction of free electrons and argon ions (Hoffmaan and Stroubant, 2007). The temperature of the plasma is very high, of the order of 10,000 K. Samples to be analysed are introduced into central channel usually as a mist of liquid formed by passing the liquid into nebulizer where evaporation and dissociation occur and constituent atoms ionize (Hoffmaan

and Stroubant, 2007). The plasma produces light directed to a diffracting grating where wavelengths are analyzed and recorded.

RESULTS

Structures Deduced From Aeromagnetic Data

The Total Magnetic Intensity (TMI) maps show effect of both deep seated as well as shallow rocks represented by various tones. The lower values represented by blue tone are interpreted to be the effect of rocks with low magnetic minerals while the higher values marked by red tone are considered to reflect magnetic bodies in some rocks. The Total Magnetic Intensity (TMI) maps (Fig. 2) were obtained from Geological Survey of Nigeria Agency consists both deep and shallow features with values that ranged from 179.2 nT

to 216.1 nT. The TMI map was separated using Oasis Montaj software to obtain the regional anomaly map which represent the deep seated features and residual anomaly maps that depicts the shallow features represented in various tones, the blue tones with low magnetic values are the effects of rocks characterized by absence of magnetic minerals while the red tones with high magnetic values are that of rocks having abundant magnetic minerals (Fig. 2). The Residual Magnetic Anomaly map gave values that vary from -9.3 nT to 11.7 nT (Fig. 3). The lineament map of the study area is presented in Fig. 4 while the rose plots of the lineaments for Liji area is given in Fig. 5. The lineaments are oriented mainly in E-W and NE-SW with minor N-S (Fig. 5).

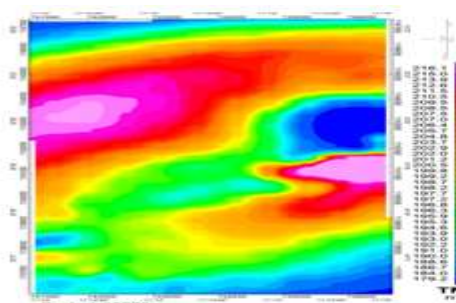


Figure 2: TMI map of part of Liji area

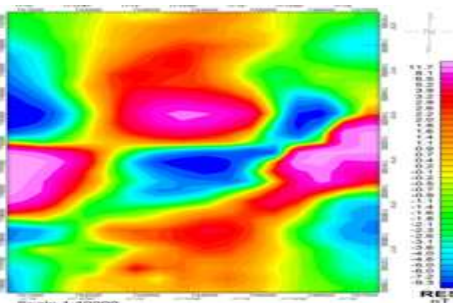


Figure 3: RMI map of Liji area

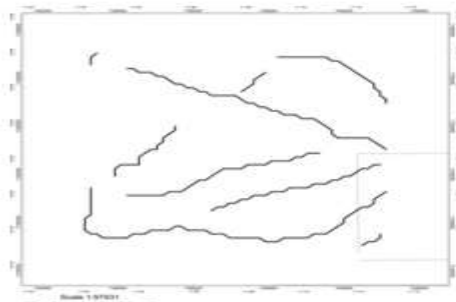


Figure 4: Lineament map of Liji area

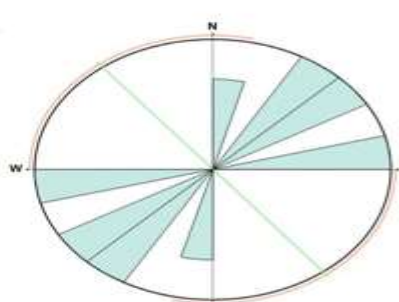


Figure 5: Rose plot of lineament for Liji Study Area

Structures Deduced From Field Measurements

Field structural measurements were obtained during the mapping exercise which involved the use of compass-clinometer to determine the strike direction of sedimentary beds, bedding planes, veins of pegmatites and quartz, veins of baryte and joints. The data obtained were imported into Rosenet software and rose diagrams were generated which show

the trending directions of the structures. However, the main trending direction of baryte veins, fractures, joints, sedimentary beds and bedding planes are the NNE-SSW, N-S and NW-SE directions with minor trends being in E-W, NW-SE and ENE-WSW directions (Fig. 6). It can be observed that the dominant trend of lineaments deduced from aeromagnetic data is in agreement with the trend of structures obtained from the field.

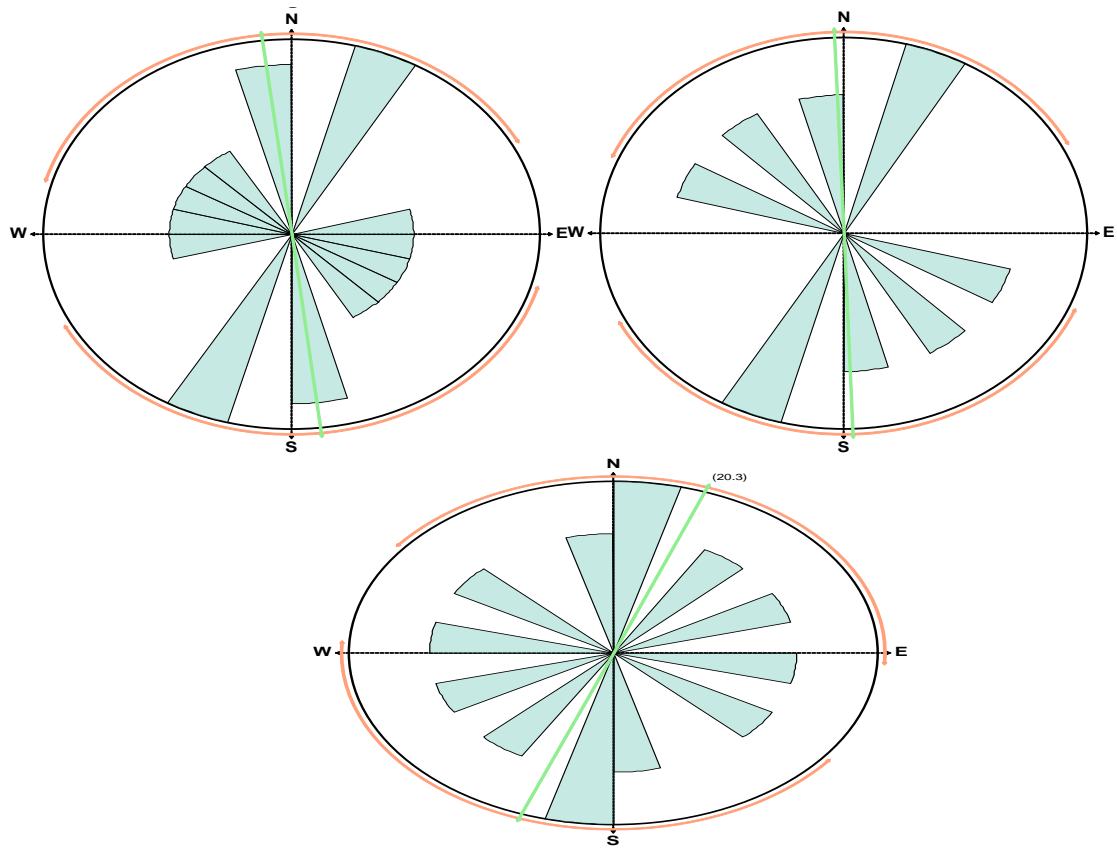


Figure 6: Rose plot of structures of Liji study area.

LITHOLOGIC UNITS OF LIJI AREA

Geological mapping indicates that Liji area is underlain by Basement Complex rocks and Cretaceous sedimentary deposits (Fig. 7). The Basement Complex rocks are members of the Older Granite suites and occur as an inliers

surrounded by the Cretaceous sedimentary rocks of the region. Detail geological and petrography of the Liji area is given in (Kamale *et al.*, 2019).

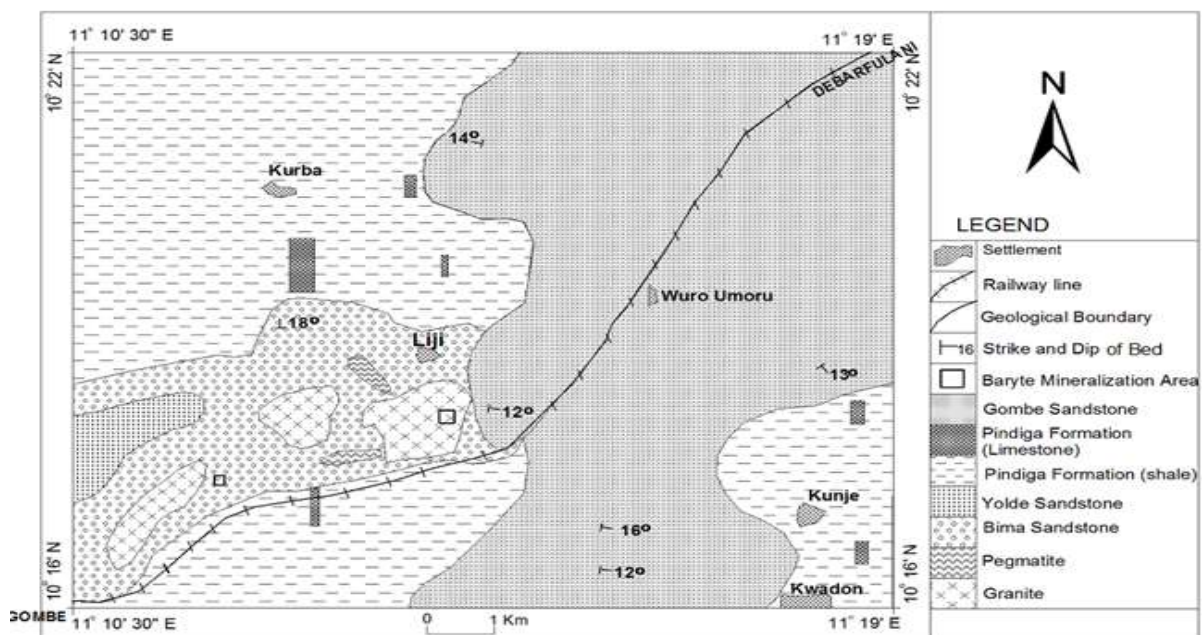


Figure 7: Geological map of the Liji area

GEOLOGY OF THE MINERALIZATION AREAS

The areas of baryte mineralization were mapped in detail to establish the relationships between host rocks and baryte mineralization. The mineralization areas are outlined as:

- i. Liji baryte mineralization Area (LBM)
- ii. Gombe baryte mineralization Area (GBM)

Liji Baryte Mineralization Area (LBM)

The LBM occur as structurally-controlled mineralization within fracture systems that trends E-W direction hosted by granite and pegmatite (Fig. 8). Four baryte veins of short dimensions were mapped in the area. The proximal rocks appears dark rusty brown, fine-

grained and crumpled due to effect of hydrothermal solution that concentrated the mineral (Kamale *et al.*, 2019) (Plate 1). Veinlets of baryte were observed filling tiny fractures in the proximal rocks believed to be randomly injected into the host rock. The baryte is granular and massive which has specific gravity value that ranged from 3.746 – 6.427 g/cm³ with an average of 4.714 g/cm³ indicating good quality baryte which has the capacity to be used in the manufacture of oil-well drilling mud among other industrial applications that varies from rubber and paints, chemical, radiation shield, medical, pharmaceutical, cosmetic and construction (Otoijamun, 2021).

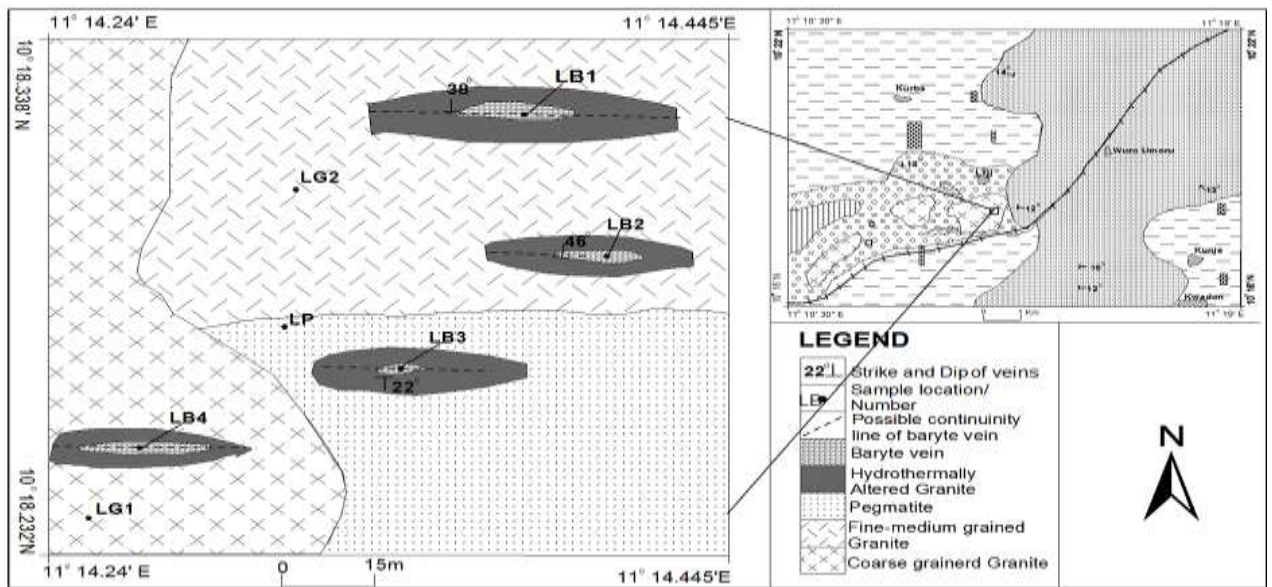


Figure 8: Geological map of Liji mineralization area



Plate 1: Hydrothermally altered granite hosting baryte (N10°18.332' and E11°14.422')

Gombe Baryte Mineralization Area (GBM)

The GBM occurs within structural features that trends N – S direction in the Bima Sandstone and extends for a distance of more than 500m in extent (Kamale *et al.*, 2019). The rocks hosting the baryte have been altered by the heat of the hydrothermal solution which converts the proximal sandstone to rusty brown to reddish coloured rock which is deformed and crumpled. The baryte is white to

creamy-white in colour having specific gravity values that varies from 3.672 – 4.281 g/cm³ with an average value of 3.941 g/cm³ indicating low quality baryte which requires beneficiation before it could be utilized for industrial application especially the manufacture of oil-well drilling mud (Otoijamun, 2021).

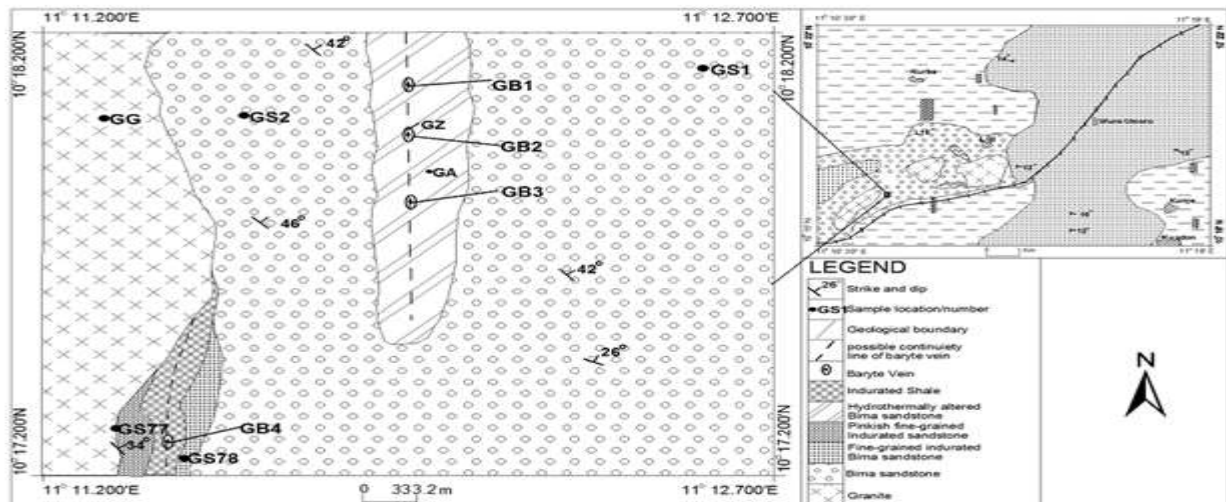


Figure 9: Geological map of Gombe mineralization area



Plate 3: Baryte vein within within altered sandstone (N10°18.117' and E11°12.388')

GEOCHEMISTRY

Geochemical results for trace elements compositions of rocks and baryte separates of the Liji area is presented in Table 1. A total of ten samples (10) were selected and analyzed comprising five from Liji baryte mineralization area (LBM) and the remaining five samples were obtained from Gombe

baryte mineralization area (GBM). The LBM consists of two distal rocks of granite and pegmatite, two proximal hydrothermally altered granites and baryte separate. The GBM has two distal rocks of pegmatite and sandstone, two proximal hydrothermally altered sandstones and one baryte separate.

Table 2: Trace Elements Composition of the Rocks and baryte in Liji Study Area

Trace Element (ppm)	Liji Baryte Mineralization Area (LBM)					Gombe Baryte Mineralization Area (GBM)				
	Distal Granite and Pegmatite		Proximal Zoned and Altered Granite		Baryte Separate	Distal Pegmatite and Sandstone		Proximal Zoned and Altered Sandstone		Baryte Separate
	LG	LP	LZ	LA	LB1	GP	GS	GZ	GA	GB1
Ba	3846	15456	50000	50000	50000	465	1477	50000	50000	50000
Sr	114.0	204.0	465.4	1248.7	10540.5	38.3	89.4	1648.6	2377.2	10433.9
Rb	159.0	157.7	40.8	164.2	0.4	329.1	101.0	134.0	169.3	1.3
Sc	2	2	2	2	n.d	7	n.d	2	1	1
Be	6	3	1	3	n.d	2	n.d	n.d	n.d	2
V	10	8	10	29	8	8	8	21	15	8
Y	10.6	9.1	15.9	17.1	5.3	11.7	2.5	13.9	3.8	4.8
Zr	19.9	31.1	161.2	282.6	1.2	12.3	101.6	205.3	60.0	1.7
Co	2.0	0.5	0.8	3.8	0.8	0.6	0.7	1.7	0.8	0.6
Ni	20	20	20	20	20	20	20	20	20	20
Cu	4.5	7.6	6.0	35.2	5.7	4.6	4.0	3.8	9.8	9.6
Zn	21	12	4	23	4	6	3	16	8	6
Ga	17.5	28.0	17.8	17.3	1.5	40.9	5.3	6.7	7.9	2.4
As	n.d	n.d	8.3	21.1	1.0	n.d	n.d	n.d	3.0	0.6
Nb	6.6	15.4	20.3	16.2	0.8	25.8	2.0	6.3	2.8	0.8
Mo	0.2	0.2	3.3	0.4	0.2	4.1	0.3	0.3	3.8	0.1
Ag	0.1	0.1	0.1	5.3	0.3	0.1	0.1	0.1	0.7	0.1
Sn	3	9	4	6	1	26	n.d	n.d	n.d	n.d
Cs	4.1	1.9	0.9	5.1	n.d	3.9	0.6	3.1	1.5	n.d
Hf	0.9	2.3	6.1	7.8	2.1	0.8	2.6	5.5	2.6	3.4
Ta	1.2	1.5	2.1	1.9	2.3	1.8	0.2	1.6	3.4	6.2
W	n.d	n.d	n.d	1.8	n.d	0.8	n.d	n.d	0.7	n.d
Au	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	0.7	n.d
Hg	0.06	0.01	0.11	0.08	0.13	n.d	0.01	0.02	0.43	n.d
Tl	0.1	0.1	0.1	2.4	0.1	0.1	0.1	0.6	0.5	n.d
Pb	8.1	9.3	18.5	37.6	2.7	4.8	5.3	10.8	12.7	5.9
Bi	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	n.d
Th	1.9	1.5	17.4	15.9	0.2	7.5	2.0	5.0	6.0	n.d
U	1.4	2.5	2.4	2.9	n.d	3.6	2.2	1.1	1.9	n.d

Note: n.d = not detected.

Trace Element Distribution Patterns in the Mineralization Areas

The trace element compositions in the study area consisting of LBM and GBM are shown in Table 2.

Trace elements are significant in studying the petrogenesis of rocks as they provide vital information relating to the crystallization behaviour of magma (Rollinson, 1993). The most important trace elements used in this study are the large ion lithophile elements (LILE) such as Ba, Sr, and Rb and inter-lithophile elements ratios such as Sr/Ba, Rb/Ba and Rb/Sr.

In the LBM, the Ba contents are 3846 ppm and 15456 ppm in the distal granite and pegmatite respectively with average of 9651 ppm. The values for both the proximal samples and baryte separate were similar i.e 50,000 ppm. This value is the maximum detectable by the equipment and hence the values of the samples especially the baryte separate are much higher than 50,000 ppm. El-Nafaty (2014) reported Ba contents of over 500,000 ppm for the baryte separates of Gulani area. The average crustal value of Ba is 456 ppm (Rudnick and Gao, 2003). Therefore the distal granite and proximal samples are enriched in Ba contents with more enrichment in the proximal. In the GBM, the Ba contents are 465 ppm and 1477 ppm for the distal pegmatite and sandstone respectively. In the same vein the values for the proximal samples and baryte separate are similar (50,000 ppm), but the values could be much higher especially in the baryte separate as in the case of LBM.

The Sr contents of distal granite and pegmatite of the LBM are 114 ppm and 204 ppm respectively. In the altered proximal granites it ranged from 465.4 ppm to 1248.7 ppm with average of 857.1 ppm but in the baryte mineral separate the Sr value is 10,540.5 ppm. These

indicate a progressive enrichment in the Sr content from the distal granite through the proximal to the baryte which is much higher than the average crustal value of 320 ppm given by Rudnick and Gao (2003). In the GBM, the Sr contents of distal pegmatite and sandstone are respectively 38.3 ppm and 89.4 ppm. It increases in abundance to values varying from 1648.6 ppm to 2377.2 ppm with average of 2012.9 ppm in the hydrothermally altered sandstones and further increased in abundance in the baryte separate (10,433.9 ppm). There is a positive correlation between Sr and Ba as the Ba contents increase, Sr also increases from the distal through proximal to the baryte separate in both Liji and Gombe mineralization areas signifying that there is isomorphous substitution of Ba^{2+} by Sr^{2+} to form Celestine ($SrSO_4$) in the two mineralization areas.

The Rb content of the LBM has values of 159.0 ppm and 157.7 ppm for the distal granite and pegmatite respectively. In proximal granites the values vary from 40.8 ppm to 164.2 ppm with average of 102.5 ppm and further depleted to 0.4 ppm in the baryte separate. These trends indicate a negative correlation between Rb and Ba in this mineralization area. In the GBM, the Rb content follows a similar trend to the Liji mineralization area with distal pegmatite and sandstones having values of 329.1 ppm and 101.0 ppm. Rb became enriched to values ranging from 134.0 ppm to 169.3 ppm with average of 151.65 ppm. There is an enrichment of Rb from the distal sandstone through the proximal sandstones and much further depletion in the baryte separate to a value of 1.3 ppm. The average crustal concentration of Rb is 49 ppm (Rudnick and Gao, 2003).

Table 2: Average values of some trace elements and large ion lithophile (LILE) ratios of the LBM and GBM (ppm)

Mineralization Area	Liji Baryte Mineralization Area (LBM)			Gombe Baryte Mineralization Area (GBM)			
	Distal Granite	Proximal Granites	Baryte Separate	Distal Sandstone	Proximal Sandstones	Baryte Separate	Crustal Average
Ba	3,846	50,000	50,000	1,477	50,000	50,000	425
K	24,233.08	24,814.01	82.99	32,532.08	34,938.79	165.98	25,000
Rb	159.0	102.5	0.4	101.0	151.65	1.3	90
Sr	114.0	857.05	10,540.5	89.4	2,013	10,433.9	375
K/Rb	152.41	242.09	207.48	322.10	230.39	127.68	285
K/Ba	6.30	0.50	0.00166	22.03	0.70	0.0033	36
Ba/Rb	24.19	487.805	125,000	14.62	329.707	38,461.538	7.8
Rb/Sr	33.74	0.119	0.0000379	1.13	0.0753	0.000125	0.12

Crustal average for elements (After Mason, 1966)

Crustal average of elemental ratios (After Holland, 1978; Taylor and McLennan, 1985)

In the LBM the average K content is slightly enriched from 24,233.08 ppm to 24,814.01 ppm in distal granite and proximal granite respectively, and is 82.99 ppm in the baryte separate (Table 2). In the GBM, the average K values are 32,532.08 ppm and 34,938.79 ppm for the distal and proximal sandstones respectively, the baryte separate has 169.98 ppm K. This trend is similar to average K values obtained by El-Nafaty (2014) with values of 25,644 ppm, 8,175 ppm and 4,270 ppm for distal, proximal and baryte separate of Wuyaku mineralization area respectively. The average crustal value for K is given as 25,000 ppm (Taylor and McLennan, 1985).

Average K/Rb ratio of the LBM show value of 152.41 ppm in distal rock and 242.09 ppm in proximal and 207.48 ppm in baryte samples, while in GBM the values of 322.10 ppm in distal, 230.39 ppm in proximals and 127.68 ppm in baryte were recorded. Crustal average of K/Rb is given as 285 ppm (Holland, 1978; Taylor and McLennan, 1985). In both areas depletion was observed compared to crustal average in distal, proximal and baryte except in the distal sample of GBM. El-Nafaty (2014) reported average K/Rb ratios of 254 ppm in distal, which slightly increased to 266 ppm in proximals and reduced to 145 ppm in barytes of Wuyaku sandstones, while 234 ppm in distals which increased to 308 ppm in proximals and reduced to 262 ppm in mineralized granites of Garin Gero area.

The average K/Ba in LBM gave values of 6.30 ppm, 0.50 ppm and 0.00166 ppm for distal, proximal and baryte while values of

22.03 ppm, 0.70 ppm and 0.0033 ppm were recorded for distal, proximal and baryte of GBM. These values for both LBM and GBM are comparatively greatly depleted compared to average crustal value of 36 ppm of Holland, (1978); Taylor and McLennan, 1985) and GCM of El-Nafaty, (2014).

In respect of Ba/Rb the following were obtained for distal, proximal and baryte in LBM and GBM respectively: 24.19 ppm, 487.81 ppm and 125,000 ppm and 14.62 ppm, 329.71 ppm and 38,461.538 ppm all are greater than the crustal average of 7.8 ppm (Holland, 1978; Taylor and McLennan, 1985) indicating enrichment compared to crustal average in distals, proximals and baryte separates of both mineralization areas suggesting same origin of baryte despite variation of host lithologies. This pattern was also shown by the values obtained by El-Nafaty (2014) for the distal (1,049 ppm), proximals (16,703 ppm) and barytes (131,558 ppm) of WBM.

The values of Rb/Sr ratios in LBM are 33.74 ppm in distal decreasing to 0.119 ppm in proximal and further decreases in baryte to 0.000379 ppm. In the GBM the distal value is 1.13 ppm which decreases to 0.0753 ppm in proximal and further decreased to 0.000125 ppm in baryte. The average crustal value of Rb/Sr ratio is given as 0.12 ppm indicating significant increase in distal, slight decrease in proximal and further decrease in baryte in LBM compared to crustal average value. In the same vein slight increase recorded in distal, which diminishes in proximal and more diminished in baryte for the GBM. The same

diminishing pattern were reported by El-Nafaty (2014) for the distal (0.6055ppm), proximals (0.0081 ppm) and baryte (0.0045ppm) of WBM

DISCUSSION

The orientation of structures deduced from the interpreted aeromagnetic data shows that the Liji area is typified by NE-SW, E-W and N-S trends. These structural orientations are synonymous to those shown on the structural map of Nigeria (Dalha, 2023). However, field structural measurement depicts that LBM trend in E-W direction and GBM trend in N-S direction (Kamale et al., 2019). The NE-SW dominant orientation in the Liji area can be associated with the Gombe fault system which Guiraud (1991) described as the major structural feature in the area which runs through the Gombe hill and beyond, forming a flower structure. The field structural measurements of sedimentary beds, bedding planes, fractures and joints are dominated by trends in NNE-SSW, N-S, NW-SE, E-W and ENE-WSW directions.

The geologic mapping of the Liji study area was carried out and a geological map of the area was produced (Fig. 2). The mapping exercise revealed the occurrence of crystalline basement complex rock and Cretaceous sedimentary rocks. The basement rocks occur as inlier in two parts of the study area forming the prominent Liji and Gombe hills. Detail geological mapping was conducted in the two mineralization areas the Liji Baryte Mineralization Area (LBM) and the Gombe Baryte Mineralization Area (GBM) (Kamale, et al., 2019).

Geological field mapping and characteristic field relationships revealed that the two baryte mineralization areas were formed by injection of hydrothermal fluids into the pre-existing fractures which precipitated the baryte minerals in fractures that runs N-S and E-W. These fractures are sub-parallel to the Gombe fault system (Kamale et al., 2019). The baryte veins in the two areas occur as structurally controlled vein-type, epithermal deposit of hydrothermal origin. The LBM is hosted within the basement rocks of granitic and pegmatitic composition. The baryte is creamy white to brownish gray and have average specific gravity of 4.714 g/cm³ which indicate high quality which meets the requirement for production of drilling fluid and is suitable for other industrial applications that include

production of chemicals, rubber, paper, paints, cosmetic, aggregate for construction, radiation shield in nuclear plants, pharmaceutical and medical application (Otoijamun *et al.*, 2021).

The GBM is concentrated within fracture system that trends N-S for about 500m. The baryte is creamy white, granular and massive with average specific gravity of 3.941 g/cm³ indicating lower quality baryte compared to the baryte of LBM. Both the LBM and GBM are being mined (Kamale et al., 2019). The baryte of GBM falls short of the requirements for utilization in the production of oil-well drilling mud until it undergoes rigorous beneficiation procedure to improve the quality but have met all the requirements for being used by other industries (otoijamun et al., 2021).

The result of trace element geochemistry for LBM and GBM is given in Table 1. The most abundant and significant trace elements in the mineralization areas are Ba, Rb and Sr. In both mineralization areas Ba is highly enriched to a level greater than 50,000 ppm in the proximal and baryte separates. The baryte separate and even the proximal samples might be much more than 50,000 ppm owing to the fact that El-Nafaty (2014) obtained values for baryte separates in Gulani area of over 500,000 ppm in baryte separates.

The LBM and GBM are characterized by remarkable enrichment of Ba and Sr in proximal and baryte separates (Table 2) due to baryte mineralization. The K and Rb are greatly depleted in baryte which may suggest that the two elements couldn't replace Ba in the separates. Additionally there are significant enrichment of Ba/Rb with consequent depletion of K/Ba, K/Rb and Rb/Sr in proximal and baryte samples compared to distal samples these most probably signify hydrothermal style of mineralization (El-Nafaty, 2015). These characteristics is in close agreement with the baryte sub-system of Gulani area as reported by El-Nafaty (2014) and is in contrast to those of magmatic hydrothermal deposits which are characterized by enriched K/Ba and Rb/Sr with depleted K/Rb and Ba/Rb as reported by Kerrich (1989). However, the average continental value for K/Rb and K/Ba are respectively 285 ppm and 36 ppm (Holland, 1978; Taylor and McLennan, 1985).

The metal component, Ba responsible for the baryte mineralization could have been leached

from the granite, pegmatite and sandstone host rocks. The values of Ba in the distal granite and pegmatite are 3,846 ppm and 15,456 ppm respectively in LBM while distal sandstone of GBM gave Ba contents of 1,477 ppm (Table 3). This suggests that the Ba involved in the formation of the baryte deposit might have been released through the scavenging of Ba from the host granite, pegmatite and diagenetic sandstone by invading hydrothermal fluid thereby reacting with sulphur in the fluid in an oxidizing environment to precipitate and concentrate the barytes in the pre-existing E-W and N-S trending structural features of the Liji and Gombe hills. This is in line with the views of Daspan and Imagbe, (2010); Griffith and Paytan, (2012) and El-Nafaty, (2014).

CONCLUSION

The Liji area was geologically mapped, the structures in the area were identified and delineated. Tectonic and sedimentary structures were characterized while the geochemical properties of the baryte and their host rocks were analyzed.

Structurally controlled vein-type epigenetic baryte mineralizations were located in two different locations confined within N-S and E-W striking fractures. Specific gravity studies showed that the baryte in LBM is good quality baryte compared to that of GBM and can be profitably utilized in the oil-well and other industries. Fluid inclusion and reserve estimation studies are recommended to be carried-out to determine the temperature of formation and economic worth of the Liji baryte mineralization.

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