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Geology, Geochemistry and Economic Potentials of Lead-Zinc Mineralization in Nahuta, Gongola Sub-Basin Upper Benue Trough, Nigeria

Shem, T. M., and Haruna, I. V.

Department of Geology, Modibbo Adama University, Yola Nigeria.

Lead-Zinc mineralization in Nahuta is hosted within the Cretaceous sediments as veins and veinlets. The ore range in colour from shining gray indicating PbS, orange brown indicating ZnS and white indicating quartz as seen in hand samples. Fracture is the major structural feature that controls mineralization in the study area, which trend NW-SE and NE-SW direction. The geochemical analysis of the samples collected shows the following ranges of the oxide, NaO 0.337 wt% - 3.24 wt%, MgO 0.0429 wt% - 0.666 wt%, Al₂O₃ 1.66 wt% - 23.6 wt%, SiO₂ 64.8 wt% - 99.19 wt%, P₂O₅ 0.149 wt% - 5.48 wt%, K₂O 0.031 wt% - 0.45 wt%, CaO 0.0586 wt% - 0.45 wt%, TiO₂ 0.158 wt% - 1.33 wt%, MnO 0.0024 wt% - 0.105 wt% and Fe₂O₃ 0.11 wt% - 3.76 wt%. The order of abundance of oxide is SiO₂, Al₂O₃, K₂O, Fe₂O₃, Na₂O, P₂O₅, TiO₂, MgO, CaO and MnO. The low amount of MgO, CaO, and MnO shows that the environment is siliciclastic and non-carbonate. This confirms the high amount of silica (SiO₂) recorded in the rocks. Texturally, Sandstones in the study area range from Arkose through Lithic arenite to Arenite. The calculated Al₂O₃/TiO₂ ratio shows an intermediate to felsic source rocks (10–48%). There is also high significant concentration of the following trace elements in all the samples analyzed Cl, S, Cu, Zn, Zr, Rb, Sr, Y, Ba and Pb. The high amount of Cr, Co, Ni and V suggest significant contributions from mafic source rocks. These variations in the geochemical characteristics of the sandstones might have been as a result of tectonic activities that affected the Bima during its formation which may lead to remobilization of the minerals and elemental composition of the sandstones. Based on the geochemical result, it is evident that the ore meets the typical standard requirement of 1 – 5% Pb and 1 – 10% Zn for exploration of a mine field for this particular mineral, hence could be explore in large scale for the economic growth of the nation

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INTRODUCTION

In Nigeria most of the Lead-Zinc deposits occur in the Benue Trough. The Trough is arbitrarily sub-divided into three portions; Lower, Middle and Upper portion (Figure 1) and lead-zinc-barytes mineralization occurs in almost the entire length of the Trough. Nigerian Lead-Zinc Mining Company in 1956 gave conservative indicated reserves of 693,000 tonnes with 9.0% lead and 7.0% zinc.

The mining of galena and sphalerite for their metal content has been possible owing to the high cost of transport and low metal prices Fatoye *et al.* (2014). Mining of the lead-zinc ores have long been in place for the past 9 decades in all districts of the Benue Trough. Studies have shown that the genesis of the lead-zinc-barite-flourite deposit is still a controversy Ogundipe (2018).

Among the sections of the Benue Trough the Upper Benue Trough have been less studied. Most of the studies were carried out on the lower Benue Trough centered on the geology and origin mostly through fluid inclusion and stable isotope geochemical studies (Akande, *et al.* 1988; Ogundipe, 1987, 2018; Olade and Morton 1985; and Isabella *et al.* 2018), which was always projected to the Zurak-Wase lead-zinc deposit in the upper Benue Trough. The Mining operation in Alkaleri, Gongola sub-basin

of the Upper Benue Trough started as far back in 1990, and the initial mining state was carried out by local miners, which was later sponsored by Chinese based company. In spite of these exploration activities, there is an absence of a systematic study of the lead-zinc deposit in terms of their geology, mineralogy and geochemistry. Hence, is of importance to the study.

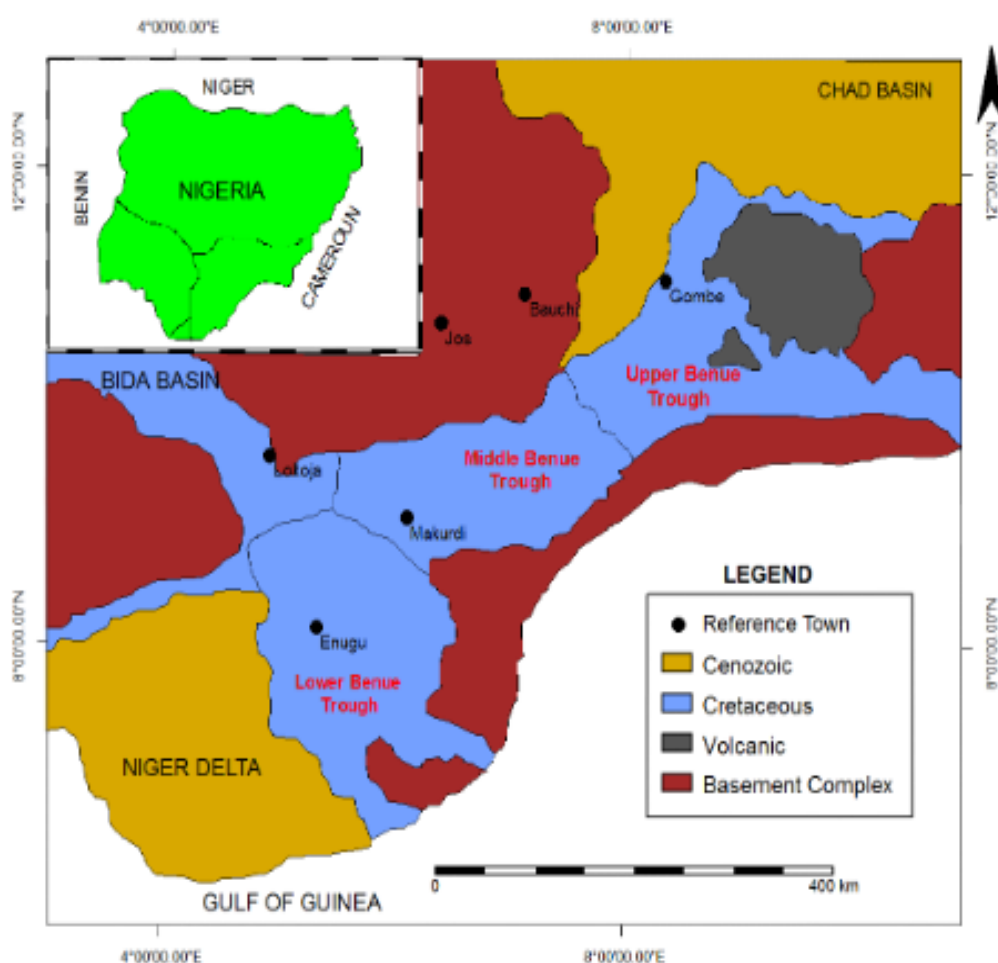


Figure 1 Geology of the Benue Trough of Nigeria (Fatoye and Gideon 2013)

2. Geological Setting

The study area is part of the Gongola Arm of the Upper Benue Trough, N.E Nigeria. The trough is generally accepted as a trough that is formed due to the rifting (Carter *et al.* 1963). The Benue Trough is an intra cratonic basin with a total length of about 1000 km and a width of 150 km and elongated which trends north east to south west (Guirand *et al.* 1989). The basin is filled with Cretaceous to Tertiary rocks. Its southern limit forms its northern boundary with the Chad basin separated by an anticlinal feature termed the Dumbulwa- Bage High. The Benue Trough is a sedimentary basin running north east from about the present confluence of the Niger and Benue rivers to roughly the most reaches of the Gongola River in Nigeria (Figure 1). The Northern end is Y-shaped made up of the east west trending Yola Basin and north-south trending Gongola Basin. The striking elongated appearance of the Benue Trough tends to propose some kind of structural control for the sedimentary area and has led to number of prepositions on its origin. King (1950) gave the first hypothesis on its origin where he considered it as a rift basin opened in response to the break-up of the Gondwanaland Carter *et al.* (1963) and Burke *et al.* (1970) contended that the Benue rift opened in the Cretaceous and was then followed by subduction and a closing episode. The Benue Trough is believed to have originated as a failed arm of an aulacogen at the time of the opening of the South Atlantic Oceans during the separation of the African plate and the South American plate. The Trough contains as much as 6,000 m of Cretaceous–Tertiary sediments, including those predating the Middle Santonian which have been compressionaly deformed, faulted, and uplifted in several places. Compressional folding during the Middle Santonian tectonic episode affected the whole of the Benue Trough and was quite intense, producing more

than 100 anticlines and synclines (Benkhelil 1989). The Benue Trough is sub divided into three main domains which are: the Upper Benue Trough, The Middle Benue Trough and the Lower Benue Trough (Obaje *et. al.*, 2004).

The upper Benue Trough is located at the northeastern end of the Benue Trough (Figure 1). It is made up of the three arms: The East-West trending Yola Arm (Yola Basin), the North-South trending Gongola Arm (Gongola Basin) and the Northe ast-Southwest trending Lau or Muri- Lamurde Arm (Main Basin) (Abubakar, 2006). The Middle Benue Trough is a linear part of the Benue Basin. The Keana Anticline is the major structural element in this basin. It is surrounded by Kadarko Basin to the North and Southwards by the Wukari Basin, both of which are slightly deformed (Benkhelil, 1982). The lower Benue Trough has two main structural Units: The N60°E trending Abakaliki Anticlinorium and the N30°E trending Anambra syncline (Offodile, 1989). No concrete line of subdivision can be drawn to demarcate the individual portions of the Benue Trough but major localities which comprises depocentres for the different portions have been documented (Peter, 1982).

3. Materials and Method

Due to the thick superficial deposits and scarcity of out crops in the study area, the choice of sampling was randomly based on the presence of rock outcrops and well-exposed sections. Observations of lithologies were noted down, photographs were taken and sketches drawn. Topographical features were identified from an existing 1:50,000 topographic map of Futuk (sheet 172 SE). Coordinates and elevations of sample points were taken using a Germin Global Positioning System (GPS), dipping angles and strikes of outcrops were measured using Brunton compass, rock samples were collected for the Pb-Zn ore, host rock and environs of the study

area, sample description were recorded in a field note book. Eight samples including one Pb-Zn ore selected were impregnated with araldite and heated on electric plate till consolidation is achieved, after which it was allowed to cool and dry. The consolidated products were then cut into thin sections, after which it was then mounted on a glass slide, using Canada balsam. They were then polished till the thinnest layer was attained, after which the thin section were viewed under cross polarized light (XPL) and plane polarized light (PPL) with a total magnification of X40. The analysis was carried out at the geologic laboratory Modibbo Adama University Yola. While XRF analyses was conducted on eight rock samples and one Pb-Zn ore at the Geological laboratory unit, department of Geology, Faculty of science Gombe State University. The XRF method was used to quantitatively determine the elemental composition of the lead-zinc ore and rocks around Nahuta. Ten major oxides and trace elements were analyzed. XRF is been used due to its simplicity, versatility and has a very good sensitivity as several elements can be determined at the same time.

Samples were first grounded into a homogenous powder approximately 100-200 mesh, and then about 5g of each samples were weighed into 32 mm sample cups with a polypropylene X-ray film of 4 μm thickness and were hydraulically pressed. Sample heights were measured in millimetres and sample cups were capped. The EDXRF analysis was performed using a Rigaku NEX DE EDXRF spectrometer equipped with a fifteen-place sample changer with spin function using slow and steady spinning mode. EDXRF measurements were carried out under helium (He) atmosphere using a palladium (Pd) X-ray tube at a voltage of 60 kV and current 10 μA with 10 mm beam spot size, and silicon (Si) drift detector comprised of Peltier electronic circuit cooling system. Standardless calibration was employed using Fundamental Parameters (FP) methods software (Rigaku RPF-SQX) to allow

for elemental quantification of completely unknown. The software can automatically estimate elemental concentration and provide appropriate corrections. Rigaku NEX DE EDXRF spectrometric analysis can be employed to measure a wide range of atomic elements, from sodium (11) through uranium (92), while providing elemental detection limits from low parts-per-million (ppm) to high weight percent (%wt). The analytical uncertainties were generally within 0.1-1% (RSD).

4. Result and Discussion

4.1 Geology/petrography

Based on the field investigation, the study area is dominantly covered with Bima sandstone (Figure 2) which is intercalated with thin laminar bedding of siltstone and mudstone. The Bima sandstone is the oldest Cretaceous sediments in the Upper Benue Trough which lies unconformably on the basement. Bima Sandstone in the study area is white to gray or buff in colour also light brown to reddish brown where it's weathered, and fine to medium grained in texture. It is highly indurated and cemented which confirms the high amount of quartz in the sandstone been the main constituent of the rock, followed by feldspar and rock fragment. Silica and iron oxide tends to be the cementing materials, indicating diagenetic alteration. Silica cement is present especially in Figure 4e in the form of quartz overgrowth and appear as the first authigenic precipitate. Sediments rich in quartz are considered mineralogically 'mature' because they have been subjected to a longer interval of physical and chemical modifications during erosion to deposition. This is supported by the sub-rounded grain observed in Figure 4a. Matured sandstones are clay free and grains are sub-angular, but well sorted. Generally, the rocks in the study area are poorly to moderately sorted. The rocks exhibits various structural features that include planer bedding, joints and micro quartz veins (figure3b and c). Fracture development in the Cretaceous

sedimentary rocks is more related to individual rock types and is controlled by their competence. The highest densities of fractures are found in the Bima sandstone (Okezie, 1976). Fractures are the major structural feature that controls the mineralization, the supposition of structural control and circulation of fluid can be supported by this discussion “the flow of fluids into favorable loci of mineralization is governed by fluid-flow thermodynamics and mechanics. That is fluids flow from zones of higher pressure and temperature to zones of lower pressure and

temperature. However, fluid flow is dispersive rather than focused. The geological setting which is favorable for mineralization conform to the mineralization at Isimiya, where quartz veins hosted by sandstone striking N-W host the mineralization (Fatoye *et al.*, 2014). Silicification exist in the study area. The silica may have been introduced through hydrothermal processes or as a byproduct of the alteration of feldspars and other minerals during leaching of bases. Silicification is usually a reliable indicator of minerals.

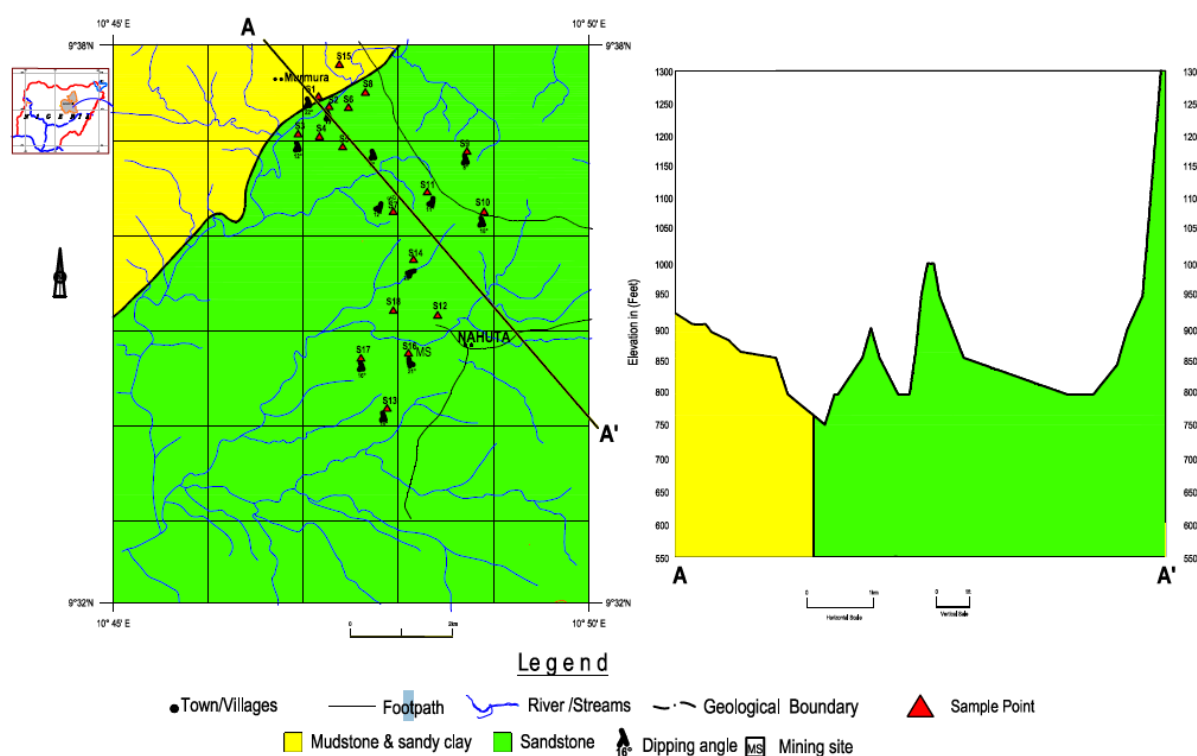


Figure 2 Geology of Nahuta and environs



Figure 3a. Sandstone occurring as boulders of low-lying hills at the Northern part of the study area b. Highly fractured sandstone intercalated with grey mud stone along stream channel located along the Eastern part of the map c. Quartz veins d. Pb-Zn vein

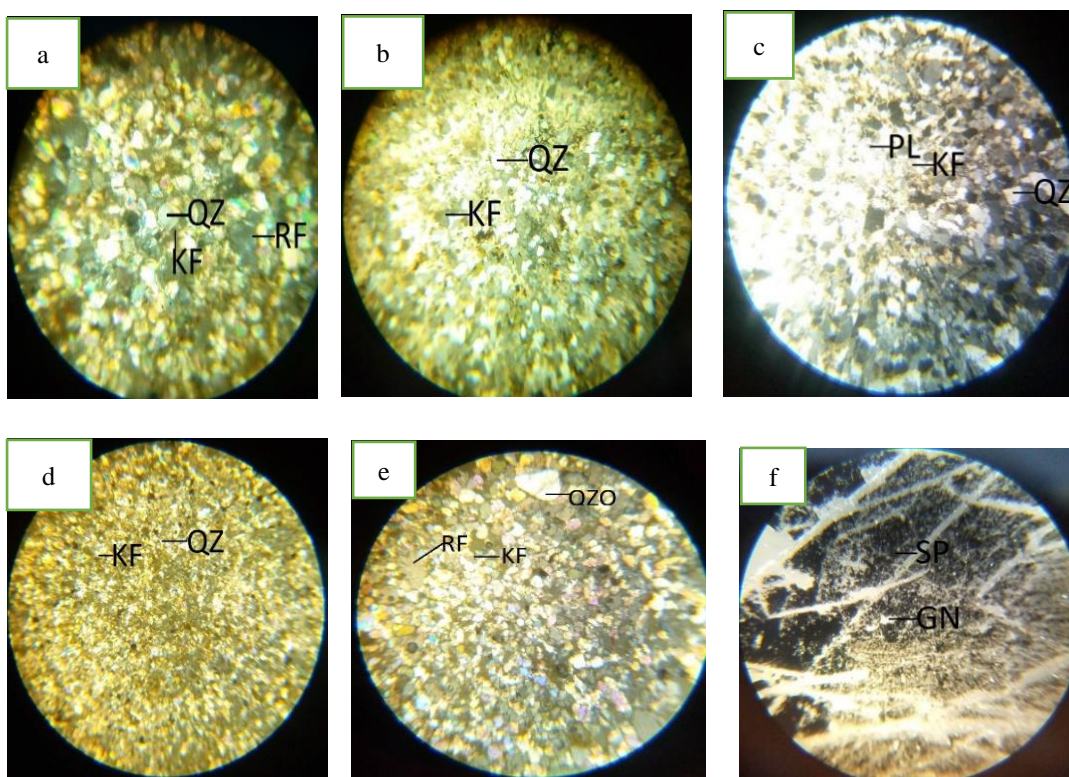


Figure 4 Photomicrographs of Rock Samples (sandstone) a, b, c, d, e(host rock) and f (lead-Zinc ore)

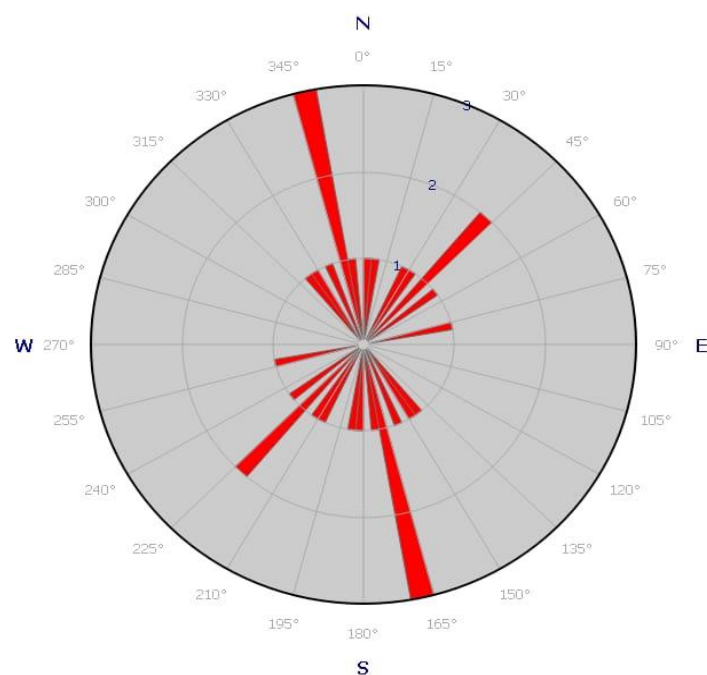


Figure 5. Rose Diagram of the fractures in the Study Area.

4.2 Environment of Deposition

The XRF analysis result for major oxide (Table 1) shows high amount of SiO_2 (quartz) in all the analyzed rocks which indicates sandstone maturity and might also indicates moderate or high amount of weathering under humid condition. These depict that the Bima sandstones has been subjected to long period of transportation and intense weathering which might have resulted in the destruction of some minerals. Low MgO (0.33 wt%), MnO (0.05 wt%) and P_2O_5 (0.83 wt%), might indicates deposition under fresh water continental condition (Pearce *et al.* 2010 and Mucke 2000). Rollins (1993) stated that alkali content ($\text{NaO} + \text{K}_2\text{O}$) is an important index of chemical maturity, < 2 indicates little or no feldspar which notes

high maturity whereas > 2 shows presence of feldspar and low chemical maturity. Based on the above statement, the rocks in the study area with the exception of L14 and L4 (Sandstones) indicates low chemical maturity due to alkali content ($\text{NaO} + \text{K}_2\text{O}$) > 2 (Table 2). Generally, the sandstones are depleted in MgO , CaO , P_2O_5 and MnO , which might be due to weathering or alteration, the low amount of MgO , CaO and MnO shows that the environment is siliciclastic and non-carbonated, (Glasby 1977). Concentrations of Al_2O_3 and K_2O may relate to the presence of k-feldspars (orthoclase and microcline), illite and mica. The high amount of K_2O to Na_2O indicates that potassium feldspar is more than plagioclase according to Nath *et al* (2002).

TABLE 1: Percentage oxides (wt. %) of rocks and ore in the study area

Oxide	Sample L4	L8A	L8B	L9	L10	L14	L15	L16A	L16B (ore)	Max.	Min.	Ave.
Na ₂ O	ND	0.348	2.33	0.978	0.799	0.337	0.563	3.24	49.6	3.24	0.337	1.07
MgO	0.0429	0.12	0.249	0.368	0.666	ND	0.677	0.216	ND	0.677	0.0429	0.33
Al ₂ O ₃	5.43	9.6	14.3	13.8	23.6	1.66	15.7	11.9	1.21	23.6	1.66	11.9
SiO ₂	93.1	86.8	77.7	78.1	64.8	95.9	75.4	80.2	1.21	95.9	64.8	81.5
P ₂ O ₅	0.114	0.149	0.0988	0.0149	0.137	0.104	0.105	0.105	ND	0.149	0.0149	0.83
K ₂ O	0.855	2	3.96	1.89	5.48	0.031	1.66	2.75	ND	5.48	0.031	2.33
CaO	0.0586	ND	0.194	0.289	0.377	ND	0.451	0.162	ND	0.451	0.0586	0.26
TiO ₂	0.158	0.521	0.292	1.33	1.1	ND	1.33	0.331	ND	1.33	0.158	0.72
MnO	0.0024	0.0154	0.105	0.0315	ND	ND	0.0736	ND	ND	0.105	0.0024	0.05
Fe ₂ O ₃	0.11	0.297	0.628	2.59	2.58	1.04	3.76	0.375	0.484	3.76	0.11	1.42
Total	99.86	99.85	99.86	99.39	99.54	99.07	99.72	99.28	52.50	134.7	67.21	100.4

* Note: ND = Not detected

Table 2: Calculated Ratios of Oxides and Logs for Chemical Classification

Samples	Na ₂ O+K 2O	K ₂ O/ Na ₂ O	Al ₂ O ₃ /T iO ₂	LogSiO ₂ / Al ₂ O ₃	LogK ₂ O/ Na ₂ O	LogFe ₂ O ₃ +MgO/ K ₂ O+Na ₂ O
L4	0.06	-	34	1.2	-0.1	-0.8
L8A	2.35	5.75	18	1.0	0.8	-0.15
L8B	6.29	1.69	48	0.7	0.2	0.5
L9	2.87	1.93	10	0.8	0.3	0.01
L10	6.28	6.86	21	0.4	0.8	-0.3
L14	0.37	0.09	-	1.8	-1.0	0.5
L15	2.22	2.95	11	0.7	0.5	0.3
L16A	5.99	0.85	35	0.8	-0.1	-1.0
Min.	0.06	0.09	10	0.4	-0.1	-0.15
Max.	6.29	6.86	48	1.8	0.8	0.5
Ave.	3.30	2.87	25.29	0.9	0.3	-0.1

Results of Trace elements concentration (Table 3) shows a considerably enrichments of the following elements in all the samples analysed, Cl, S, Cu, Zn, Rb, Sr, Zr, Y, Ba, and Pb, with the following average concentration as follows; 180.9 ppm, 522.6 ppm, 329.3 ppm, 923.5 ppm, 108.8 ppm, 80.1 ppm, 518.1 ppm, 36.2 ppm, 202.4 ppm and 794.6 ppm respectively. While for the Ore deposit the following high concentrations were recorded in S (143000 ppm), Zn (284000 ppm), and Pb (35400 ppm), as the useful mineral content of the ore, and also depict their abundance in nature hence could be explored in large scale. There is also relatively high amount of Cd (582 ppm). Ga, Zr and Tb shows appreciable abundance in the ores at 57.7 ppm, 54.7 ppm and 54.1 ppm respectively. In both the rocks and ore

vein analysed, there is considerably high concentration of Pb and Zn which are the primary elements of interest. The LREE (Ce, Pr, and Nd) and HREE (Tb, Dy, and Tm) abundances in the studied samples showed evidence of variable fractionation and also depicts a felsic source. The biplot of the trace elements produced (Figure 6) from the Principal Component Analysis (PCA) result, shows the clustering and trends of the trace elements around the two components. The results show that, Pb, Tb, Zn, S, Ga, Cu and Cd are clustered with high negative loadings in the third quadrant of the two components. The results also indicates that the Lead- Zinc mineralization is associated with the following trace elements Tb, S, Ga, Cu and Cd.

Table 3: Trace element concentration (ppm)

Elements	Sample L4	L8A	L8B	L9	L10	L14	L15	L16A	Min.	Max.	Ave.	L16B (Ore)
Cl	119	124	219	157	309	107	183	229	107	309	180.9	ND
S	188	254	219	141	92.7	1570	166	1550	92.7	1570	522.6	143000
V	ND	ND	47.8	276	147	ND	155	ND	47.8	276	156.1	ND
Cr	ND	ND	ND	135	18.3	ND	64.6	ND	18.3	135	72.6	ND
Co	ND	ND	ND	57.5	ND	ND	23.8	ND	23.8	57.5	40.7	ND
Ni	15.8	10.9	7.47	59.8	ND	14	21	ND	7.47	59.8	21.5	ND
Cu	57	44.6	22.7	29.9	27.3	2410	30.6	12	12	2410	329.3	ND
Zn	37.2	64.3	29.1	1940	1780	739	38.1	2760	29.1	2760	923.5	284000
Ga	3.58	1.6	9.45	ND	18.7	ND	14.2	ND	1.6	18.7	9.51	57.7
Ge	1.23	ND	ND	ND	ND	ND	ND	ND	1.23	1.23	1.23	ND
As	8.53	ND	9.37	19.7	ND	177	ND	ND	8.53	177	53.7	ND
Se	ND	ND	ND	ND	ND	20.9	ND	ND	20.9	20.9	20.9	ND
Kr	ND	ND	ND	18.1	ND	114	1.96	84.5	1.96	114	54.6	ND
Rb	24.5	44.4	109	62	294	ND	116	112	24.5	294	108.8	ND
Sr	42.6	27	57.5	112	160	4.81	137	100	4.81	160	80.1	ND
Zr	68.8	262	249	2240	359	19.6	653	293	19.6	2240	518.1	54.7
Y	8.86	27.4	16.3	94.4	49.1	12.4	66	15	8.86	94.4	36.2	ND
Nb	3.79	6.36	3.47	13.8	18.5	ND	20.4	5.56	3.47	20.4	10.3	ND
Ag	4.29	5.04	5.01	ND	ND	10.4	4.41	3.89	3.89	5.04	5.51	ND
Cd	ND	ND	ND	ND	ND	ND	ND	6.04	6.04	6.04	7.61	582
Sn	ND	1.94	ND	ND	1.7	ND	6.14	ND	1.7	6.14	3.26	ND

Ba	75.9	85.4	236	150	445	98.2	299	230	75.9	445	202.4	ND
Hf	ND	ND	ND	77.6	ND	ND	ND	ND	77.6	77.6	77.6	ND
Ta	ND	ND	ND	30.1	ND	ND	ND	ND	30.1	30.1	30.1	ND
Os	ND	ND	ND	36.3	ND	ND	ND	ND	36.3	36.3	36.3	ND
Ir	ND	ND	ND	37.5	ND	ND	ND	ND	37.5	37.5	37.5	ND
Pt	ND	ND	ND	26.3	ND	ND	ND	ND	26.3	26.3	26.3	ND
AU	ND	ND	ND	21.1	ND	ND	ND	ND	21.1	21.1	21.1	ND
Pb	20.4	114	20	169	941	3440	34.5	1770	20	1770	794.6	35400
Po	ND	ND	ND	ND	ND	5.43	ND	ND	5.43	5.43	543	ND
Fr	ND	ND	ND	ND	ND	ND	523	ND	523	523	523	ND
Ra	ND	ND	ND	ND	ND	17.2	ND	ND	17.2	17.2	17.2	ND
La	ND	21.1	ND	59.8	51.6	ND	45.7	18.2	18.2	59.8	39.3	ND
Ce	ND	34.9	39.8	113	99.5	ND	71.1	33.8	33.8	113	65.4	ND
Pr	ND	ND	10.8	ND	ND	ND	ND	ND	10.8	10.8	10.8	ND
Nd	ND	ND	14.9	52.9	40.1	ND	40.4	16.9	14.9	52.9	33.1	ND
Tb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	54.1
Dy	ND	ND	ND	ND	ND	ND	45	ND	45	45	45.0	ND
Tm	ND	ND	ND	44.4	ND	ND	ND	ND	44.4	44.4	44.4	ND
Ac	15.2	14	18.3	ND	71.3	33.5	ND	90.4	14	90.4	40.5	ND
U	262	ND	ND	ND	ND	ND	ND	ND	262	262	262	ND

* Note: ND = Not detected

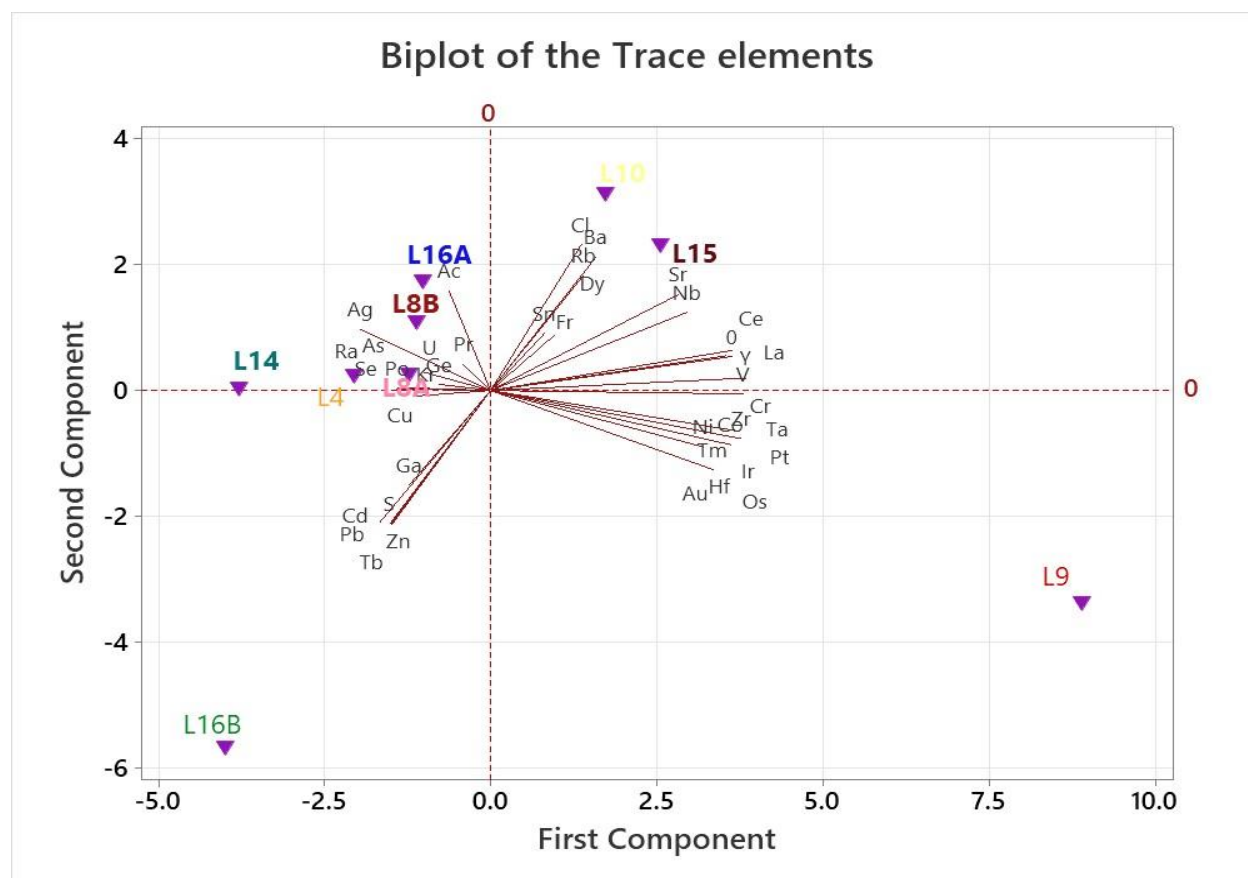


Figure 6: The bi-plot of the two components observed accounting for 58.0% information for the trace elements.

Provenance

According to Lindsey, (1999) classification guideline: $\log (\text{SiO}_2/\text{Al}_2\text{O}_3) \geq 1.5$ is for quartz arenites; $\log (\text{SiO}_2/\text{Al}_2\text{O}_3) < 1$ and $\log (\text{K}_2\text{O}/\text{Na}_2\text{O}) < 0$ is for greywackes. $\log (\text{SiO}_2/\text{Al}_2\text{O}_3) < 1.5$ and $\log (\text{K}_2\text{O}/\text{Na}_2\text{O}) \geq 0$ and $\log (\text{Fe}_2\text{O}_3+\text{MgO}) / (\text{K}_2\text{O}+\text{Na}_2\text{O}) < 0$ is for arkoses (including sub-arkose); while $\log (\text{SiO}_2/\text{Al}_2\text{O}_3) < 1.5$ and either $\log (\text{K}_2\text{O}/\text{Na}_2\text{O}) < 0$ or $\log (\text{Fe}_2\text{O}_3+\text{MgO}) / (\text{K}_2\text{O}+\text{Na}_2\text{O}) \geq 0$ if $\log (\text{K}_2\text{O}/\text{Na}_2\text{O}) < 0$ is for lithic arenites (sub-greywacke, including protoquartzite). According to the above classification the sandstones in the study area can be said to be Arkose (L8A), lithic arenite (L4, L8B and L16A) to Arenite (L14) as seen in Table 2. These generally indicates that the sandstone are quartz rich. $\text{Al}_2\text{O}_3/\text{TiO}_2$ ratio can also be used for provenance reconstruction and it increases from 3 to 8 for mafic igneous rocks, 8 to 21 for intermediate rocks and 21 to 70 for felsic igneous rocks (Sugitani *et al.*, 1996; Hayashi *et al.*, 1997; Nagarajan *et al.*, 2007; Armstrong-Altrin *et al.*, 2017, 2019; Ayala-Perez *et al.*, 2021). In this study, the calculated $\text{Al}_2\text{O}_3/\text{TiO}_2$ ratio (Table 2) range for the sandstones (10–48%) shows an intermediate to felsic source rocks. However, the high average concentrations of Zr (518.1 ppm), Ba (202.4 ppm), and Sr (108.8 ppm), observed in the studied sandstones suggests felsic source provenance (Table 3). The average concentrations of the following designated trace elements in the studied sandstones Cr, 72.6 ppm, Co, 40.7 ppm, Ni, 21.5 ppm and V, 156.1 ppm suggest significant contributions from mafic source rocks. Therefore, the Sandstones in the study area can be said to have both felsic and mafic provenance sources.

Tectonic setting

Sandstones were classified into different tectonic settings based on chemical compositions (Roser and Korsh, 1986); magmatic island arcs (average SiO_2 -58%, $\text{K}_2\text{O}/\text{Na}_2\text{O} < 1$), Andean-type continental margins (SiO_2 -68 to 74%, $\text{K}_2\text{O}/\text{Na}_2\text{O} < 1$), Atlantic-type continental margins (average SiO_2 -89%, $\text{K}_2\text{O}/\text{Na}_2\text{O} > 1$). Application of this classification for the investigated sandstones shows Atlantic-type continental margins which favorably compares with continental platform sands in term of compositional characteristics. The Atlantic type continental margin are formed under divergent plate boundary setting and is said to be characterized by relatively long period of stability. Divergent margin resulted in the diverging of North America and West Africa, north of Sierra Leone from each other during the past 180 m.a. In response to the separation, several coastal basins (50-400 km wide) have formed; these basins contain Cretaceous and Cenozoic sediments deposited over a block-faulted crust of Paleozoic and older rocks (Ayme 1965; Spengler and others, 1966). This divergent setting might be supported by the evolution of the Benue trough, which is an intra-continental rift initiated in the Cretaceous during the opening of the South Atlantic Ocean (Benkhelil. 1989). But Mustapha *et al.*, (2019) suggests that the Bima is settings on a passive continental margin (PM) indicates spreading centers island for the sediments. The area can be said to be formed on a passive continental margin (PM), which are basin on continental crust and basins associated with ocean floor spreading, failed rifts and Atlantic type continental margins.

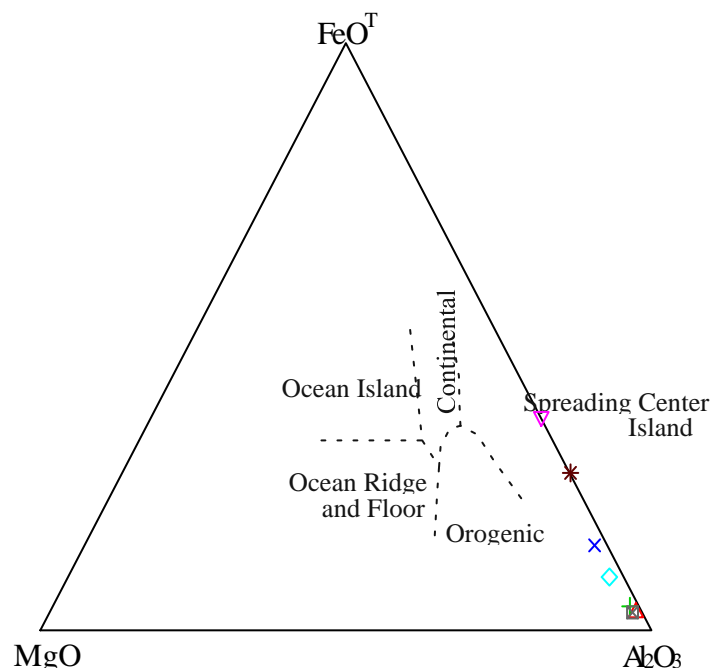


Figure 8. Tectonic discrimination diagram of $\text{MgO-FeO}^{\text{T}}\text{-Al}_2\text{O}_3$ (After Pearce *et al.* 1977)

Economic Potentials of the Pb-Zn deposit

The chemical analysis (XRF) of the study area presented in Table 3, shows that the crude lead-zinc ore contains 35400ppm Pb, and 284000ppm Zn. The ore is also associated with gangue which require beneficiation to be isolated from the mineral of interest (lead). Among these gangue minerals are S (143000ppm), Cd (582ppm), and other gangue such as Ga, Zr, and SiO_2 Na_2O etc. Based on the result, it is evident that the ore meets the typical standard requirement of 1 – 5% Pb and 1 – 10% Zn for exploration of a mine field for this particular mineral (Will, 2006).

Galena is a very vital ore for the electrical and electronic industries because of its principle constituents which is Lead and it is also because of this reason that it is mined in Nigeria, Africa and other countries of the world. Galena is a very important mineral because it serves as an ore for most of the world's lead production. The number

one use of lead today is in the lead-acid batteries, ammunition, semi-conductor material, radiation shielding etc.

5. Conclusion

Based on field observation and laboratory investigation, it can be concluded that the Pb-Zn mineralization in Nahuta occurred within the Cretaceous Bima sandstone as veins and veinlet. Besides the two major ore forming elements of Pb and Zn, which show significant concentration both in the surrounding rocks and the ore deposit, there is also significant concentration of other elements like Cu, Ga, Cd, and Tb. Fractures trending NW-SE and NE-SW seem to control the mineralization.

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