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MINERALOGICAL AND CHEMICAL ANALYSIS OF ORE RESOURCES IN NASARAWA STATE FOR PROCESSING APPLICATION

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ABSTRACT

Investigation of the geological, mineralogical and chemical content of some ore resources in Nasarawa state was carried out using XRD and XRF techniques. The data obtained suggest that the geology of the area is responsible for the deposits and chemical characteristics of the ore. The mineralogy indicated that the ore contained variable concentrations of minerals according to the nature of the ore type. The chemical analysis of the ore showed that baryte samples contained a very high concentration of (60.1-70.1%) as the major metal while the galena from adudu and Nasarawa Eggon contained Pb and Zn (41.2-86.8%), and (1.43-39.11%) as the predominant metals in recoverable quantities. XRD analysis of ore revealed the presence of some other metals that include; Ti, Cd, Mg, and Cu in the minerals in the form of $(Ca_2AlSiO_4)(SiO_7)(OH)$, $Zn_2AlSiO_5(OH)_4$. A strong occurrence association of other minerals formed as a product of weathering of Zn was observed. Although the major gangue content is silicate, these associated metals could also be considered as gangue or waste based on the economy of mineral recovery. The recovery of the minerals through novel processing techniques will attract economic benefits to the state and country at large.

Keywords: Geology, chemical, mineral, analysis, Ore

INTRODUCTION

Minerals occur in different forms in the earth's crust depending on their type, nature and location of occurrence. The composition of the ore matrix varies with the elements and gangue which are chemically combined together (Akande *et al.,* 1990). On the other hand, mineral bearing ores are mostly mixtures of extractable minerals and extraneous rocky materials which are often described as gangue. The processing of the minerals from the ore matrix for application sometimes requires crushing and grinding followed by either physical or chemical treatment (Barbery, 1986; Amos *et al.,* 2020). The ores are frequently classified according to the nature of the valuable mineral they contained. Some of these minerals are present as sulphide, silicate, oxidic, carbonate or in hydrated forms with variable amounts of waste and valuable minerals which are usually recovered (Baba and Folahan, 2010). The geological formations where these minerals are found differ. For instance galena (PbS), the chief ore of lead and one of the most widely distributed metallic sulphides, occurs in both igneous and sedimentary rocks in varying amounts in Nigeria (Amos *et al.,* 2012). The minimum metal content (grade) required for a deposit to qualify as an ore varies from metal to metal (Runge, 1998; Rudenno, 2008). Many non-ferrous ores containing as little as 1% metal and often much less is often considered. However, different strategies are usually adopted in upgrading such minerals called beneficiation. Due to the growing population expansion coupled with advancements in technology, mineral ores or deposits hitherto considered uneconomical are now been considered for exploration to match the growing demand for their applications (Baba and Adekola, 2010; Amos *et al.,* 2020; Ihekweme *et al.,* 2020).

Most countries of the world are continuously devising ways of exploring and harnessing their natural resources through the application of geochemical studies to ascertain the viability or otherwise of the resource for possible exploration (Dorin *et al.,* 2014). The Nigerian situation is not different. However, the sector has been neglected due to the emergence of petroleum in the mid-nineteen seventies as a major foreign exchange earner, before the discovery of oil the solid minerals sector ranked second only to the agricultural sector as a source of export earnings. During the period, Nigeria was known for the production of coal as an energy source of electricity, railways and for export. The country was a major producer of tin and columbite, accounting for 94% of world production at a certain point. The sector contributed substantially to national output, accounting for about 10% of gross domestic product (GDP) and employed an average of about 49 thousand workers per annum over the period 1958-1970. In recent times things changed with the discovery of oil which made Nigeria a mono-product economy, a situation where the nation's fate is tied to the vagaries of international market price of crude oil (Lukman, 1983; Orazulike, 2001; Obaje, 2008).

The current excessive borrowing by government to fund its budget due to falling prices in the oil global market exacerbated by oil theft and global economic crises has now led to the need for diversification of the revenue base of the country. Therefore, there is the need for the development, exploitation, beneficiation and export of solid minerals such as; Pb, Zn, Ta, Ag, Au, Ba and other noble metals that occur in Nigeria (Thomas *et al.,* 2019). These minerals occur in abundance in Nasarawa state due the geological nature of the state which comprises of sedimentary basin. The presence of these valuable minerals in the state is what led to the state being tagged the home of solid minerals (Obaje and Ligouis, 1996; Obaje *et al.,* 2006). Despite the abundant mineral resources of the state, the complexity of the Nigeria Mineral Act and the poor knowledge of the geology of the state coupled with low technical capacity to properly asses the minerals have continued to elude the state of its potentials. The location of the state in the Benue-trough that is rich in abundant solid minerals is an added advantage to it as a potential source of revenue that government can take advantage in its effort towards economic advancement.

Lead and zinc ores occurrences are well known in Nigeria, such as those of Ameka, Ameri and Enyigba near Abakaliki, at Benue and Zurak to name only a few. It is estimated that there are at least 30 lodes within an aggregate length of about 6000 m (Obaje *et al.,* 2006). The different values can be accounted for by the variation in geochemical and environmental effects (Alafara and Folahan, 2012). Despite the million tons of barytes (Abraham *et al.,* 2021) and complex sulphide ores occurring in the geology of Nasarawa state comprising galena and sphalerite with traces of pyrite, siderite, quartz, and chalcopyrite. Not much attempts have been made towards developing a suitable process for the optimal extraction of these minerals and other precious metals present in these ores. In most cases these minerals are extracted and sold without value addition there by resulting in huge revenue deficit. The understanding of mineralogy is important in the liberation of associated minerals and in explaining mineral behaviour during processing. This is important in identifying opportunities for improvements (Evans and Morrison, 2016; Fandrich *et al.,* 2007; Albijanic *et al.,* 2014; Whiteman, Lotter, and Amos, 2016).

Therefore, this study which is targeted at the analysis of some ore sources in Nasarawa state would create an understanding of the chemical content and mineralogical composition for further geochemical investigation and assessment. This will enhance the development of these solid local raw materials for industrial application and or for export as a source of foreign earnings.

MATERIALS AND METHOD

Study area

The study area is Nasarawa State, located in the North–Central Geo–political zone of Nigeria otherwise known as the middle belt region and covers an area of $300km^2$. The state lies between latitude 70 45I and 90 251 'N of the equator and between Longitude 70 and 90 37'E of the Greenwich meridian (Agidi *et al.,* 2018). The State is accessed by road through Kaduna–Plateau State, Taraba–Benue States and Kogi State – Abuja road (Fig. 1). The State is blessed with abundant mineral resources and for this reason, it is tagged, "The Home of Solid Minerals in Nigeria". Prominent among the mineral deposits of the State are coal, barytes, salt, limestone, clays, glass sand, tantalite, columbite, cassiterite, iron ore, lead, and zinc. (Fig.2). The minerals are distributed in ores in association with copper and other precious metals in the form of ZnS, FeS_2, $CuFeS_2$ and FeAsS (Alafara and Folahan, 2012). The mining of the minerals is carried out by small artisanal miners who do not have an understanding of the chemical nature of the ore for possible upgrades. Processing of the ore sometimes requires liberation of associated minerals depending on the nature of gangue (Evans and Morrison, 2016; Fandrich *et al.,* 2007; Albijanic *et al.,* 2014; Whiteman *et al.,* 2016).

Geology of the Study Area

The geology of the entire area falls within the middle Benue Trough, as the name infers the middle portion of the Nigerian Benue Trough. The Benue Trough itself is a rift basin in Central West Africa that extends NNE–SSW for about 800km in length and 150km in width. The Trough contains up to 6000M of Cretaceous Tertiary Sediment of which those pre–dating the mid–Santonian Compressionally deformed (Benkhelil, 1989). Specifically, the study area is situated around Nassarawa Eggon, Obi (Adudu) and Awe (Wuse/Azara). Geologically (Fig.2), Nassarawa Eggon is made up of Basement complex rocks of migmatite gneisses, Younger Granite series and sandstones of sedimentary series of the Central Benue trough. Obi and Awe are overlaid by sedimentary rock series with intrusions of tertiary volcanic rocks (Evans, 1980; Obaje *et al.,* 2006).

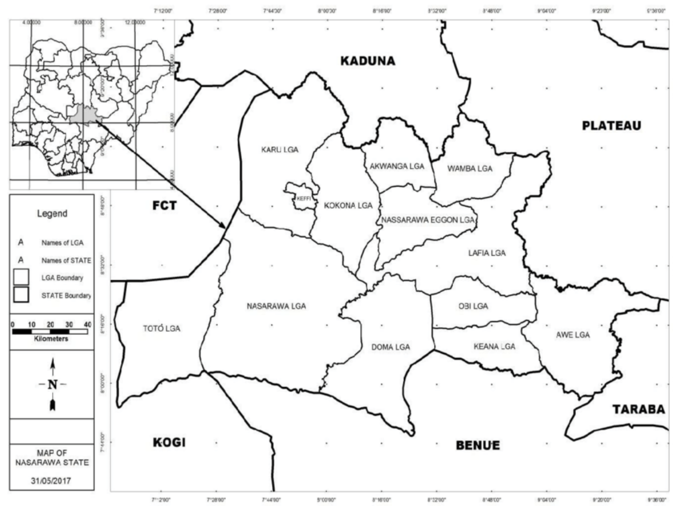

Fig. 1: Map of Nasarawa State
Source: Agidi *et al*. (2018)

Sample Collection

Mineral ores for this analysis were collected from active mining sites in three towns cutting across different sites (Azara, Adudu and Nasarawa/Eggon towns) in Nasarawa State with the assistance of miners. The baryte ore samples were obtained from Azara while the galena samples were collected from nine mining locations in Adudu and Nasaraw/Eggon. The study areas are known for mining-related activities as a result of the geological nature of the area. In each case, the point of collection of each ore sample differs from the other in a particular mining site (Fig. 2).

Sample Preparation and Analysis

The ore samples (2.0 kg) were crushed using a Retsch steel jaw crusher (to -3mm), then milled using a tungsten–carbide Tema pot and ground to obtain the desired particle size. 20.0g of the finely ground sample was sieved through a 200-250 mm mesh sieve and dried in an oven at 105 ˚C for 1h and cooled. Thereafter, the sample was intimately mixed with a binder in the ratio of 5.0g sample: 1.0g cellulose flakes binder and palletized at a pressure of 10-15 tons/inch in a palletizing machine. The prepared sample was then advanced for chemical analysis. The analysis was carried out using Energy Dispersive x-ray fluorescence spectrometry (ED-XRFS) (mini PAL 4 model (c) 2005 at the National Metallurgical Development Centre, Jos, Plateau State. X-Ray Diffraction (XRD) of ground samples was determined for mineralogical content using Siemens/Bruker D5000. The XRD measurements were matched with known signatures using the EVA software.

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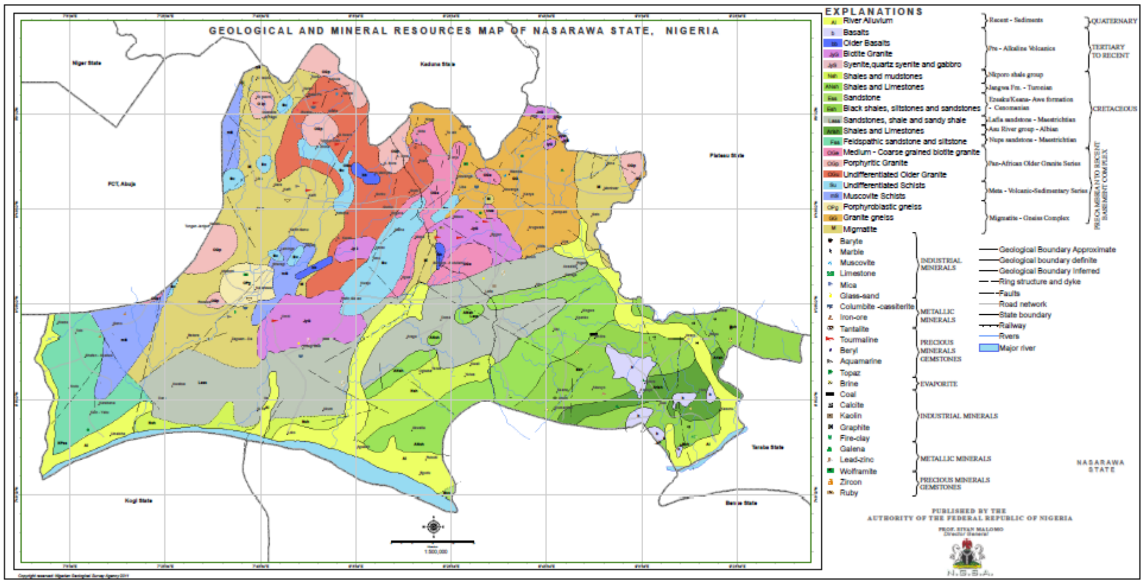

Fig. 2: Outline Geological map of Nasarawa state after Ambo *et al.* (2013)

RESULTS AND DISCUSSION

Geological and Mineralogical Assessment

Ores containing minerals of economic benefits such as Ba, Pb, Zn, Cu were determined from Wuse, Adudu and Nasarawa/Eggon areas. The Ba were obtained from the sedimentary basin in the southern part of Nasarawa state cutting across Abuni, Azara and wuse which are known to host significant economic deposits of minerals. The Baryte were of high grades (Table 1) obtained 4km North of Azara town where economic deposits are mined. The investigation revealed that minerals are located in veins traversing Awe-keana formation Northeast-Southwest direction. The mineralized vein suggests slight alteration as seen in the sandstone indicating that the vein was probably of hydrothermal origin and its movement through the sandstone altered the mineralogy slightly. Conservative estimates undertaken in four rich veins within the locality indicated a huge reserve of up to 130,000 tonnes with the major mineral as $BaSO_4$ at a depth of 10m as (Offodile, 1980).

As shown in the XRD analysis (Figs 3-5), there is strong association of other minerals in the baryte ore in the studies area. The peak where $ZnSO_4.6H_2O$ (Hydrated zinc sulphate) appear suggest good source of electrolytic material for zinc plating and as a mordant in dyeing, $Ca_2(Al_3SiO_4)(Si_2O_7)(OH)$ is a complex mixture of sorosilicate of calcium and aluminium and silicate (Al_2O_3) which can be useful as refractory mineral in the glassmaking industry. Traces of tridymite were also detected in the baryte samples (Table 1) and are believed to have been transported during the weathering process of volcanic rocks in the Middle Benue-trough and deposited in the vein of mineralization. The high concentrations of Ba (60.1-70.1%) in the investigated ores infer the mineralogical location as a good source of baryte. The presence of iron oxide in the samples further suggests possible occurrence of hematite around the study area. Although the result of Fe metal is low, the deposit contained the metal in low concentration. Thus, iron oxide could be a constituent of sandstone as a cementing material in the vein. The presence of zinc aluminium silicate mineral chemically known as zinalsite ($Zn_2AlSiO_5(OH)_4$) (Fig.4) in the samples is a product of weathering of zinc a key component of the deposit. This is reflected in the metallic content of Al and Zn in the ore (0.37-0.55%). With the occurrence of Pd-Zn in the Middle-Benue Trough (Table 2), there is strong indication of the inclusion of the mineral in the deposits with SiO_2 as quartz acting as impurity. Other traces of minerals in the ore (Table 1), such as Nb, Cr, Ti, Mn, Cu, Sr may exist in the ore matrix as niobium oxide, calcium silicate hydroxide constituent contained in the baryte vein are inclusions which occurred during the mineralization process. The presence of this mineral is strategic to the oil and gas industry due to its potential application as a weighting agent in petroleum drilling mud. The mineral could also be explored for application in the manufacturing of paints and paper due to its high quality. Although the usage depends on its beneficiation level, intense physical processing such as grinding and micronising could be integrated to improve whiteness and brightness of the mineral.

Table 1: Results of Baryte Samples from Wuse

Location							Elements								
BA1	Al	Si	S	K	Ca	Ti	Cr	Mn	Fe	Ni	Cu	Zn	Sr	Ba	Nb
BA2	0.55	TR	8.01	0.10	0.20	0.76	ND	0.01	0.15	0.01	0.01	0.05	0.87	70.1	0.12
BA3	0.37	2.37	7.21	ND	0.10	ND	ND	0.01	0.12	0.01	0.10	ND	0.20	60.1	0.11
BA4	ND	0.31	6.50	ND	0.14	0.64	0.02	0.02	0.81	0.02	0.12	0.10	0.40	66.2	0.13
BA5	ND	1.51	5.51	0.10	0.12	0.68	0.01	0.01	2.70	0.01	0.01	ND	0.50	65.1	0.14

Tables 2 and 3 present the result of the lead-zinc ore investigated. Results indicated a higher probability and concentration of the mineral in most of the geological locations spanning through Nasarawa/Eggon through Adudu area. The mineralization in the

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Benue Trough occurs as sulphides of Pb and Zn in the form of galena (Offodile, 1980; Obaje *et al.,* 2006). Occasionally traces of Cu are known to occur as a result of the Pb-Zn-Cu association. The observation of the high concentration of minerals within the mineralization zone in the form of galena in the area conforms to their geological nature. This corroborates the findings by Ambo *et al*. (2012). As shown in the results (Table 2 and 3), the ores obtained from seven mining locations in Nasarawa state revealed significant concentrations of Pb with values that ranged from 63.4-86.8 in Nasarawa Eggon mining sites and 0.2- 82.47 in Adudu mining sites. While only two locations were assessed from Adudu, the geology of the area support the mineralogical composition of the area to contained significant Pb-Zn concentration in the deposit. Although some of the ore samples contained Zn only in small quantities, the economic exploitation of the mineral is probable (Table 2 and 3). This shows the variability of minerals in the ore. Mineral content in an ore depends on mineralogy and location of samples as seen from the results. Although for economic purposes all the locations are viable for exploitation of both minerals (Pb-Zn). The results suggest the occurrence and association of the two minerals in the form of galena.

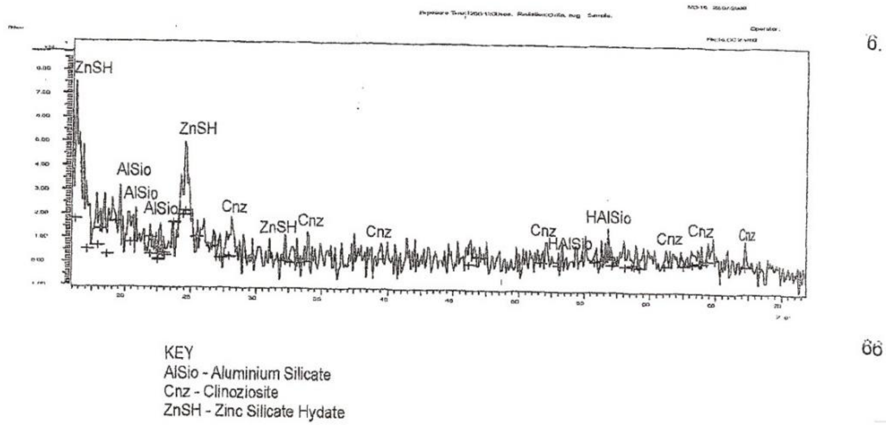

Fig.3: X-ray diffraction diagram of Baryte sample containing gangue content of zinc silicate, aluminium silicate, clinoziosite

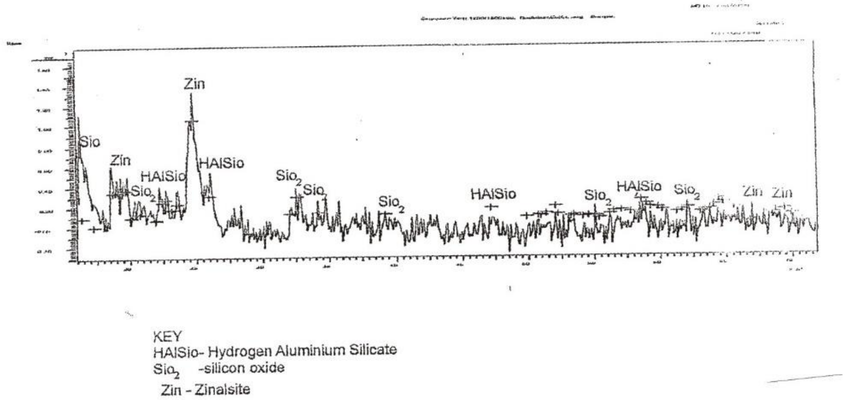

Fig.4: X-ray diffraction of sample containing silicate, hydrogen aluminium silicate, zinalsite in the baryte ore

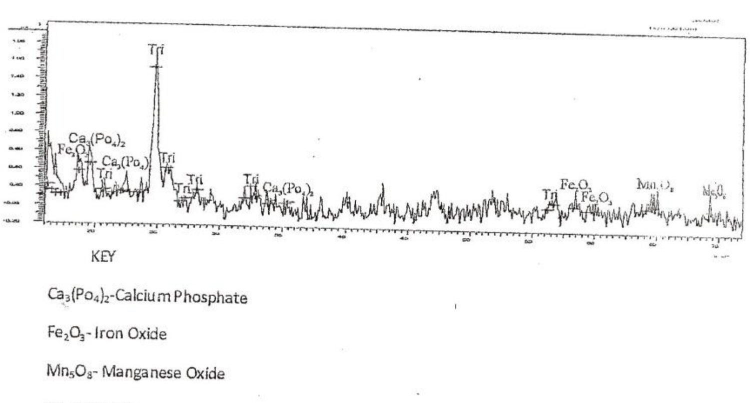

Fig.5: X-ray diffraction of sample depicting the presence of iron oxide, calcium phosphate, manganese oxide in the ore.

Table 2: Results of Analysis of Galena Ore from Adudu town

Location	Metals														
	Pb	Zn	Ni	Cu	Mn	Ba	Cr	Ti	Fe	Ca	K	S	Si	Al	Sr
A	82.47	0.07	0.02	0.10	0.06	0.34	0.04	0.05	0.68	0.22	ND	ND	ND	ND	ND
B	ND	39.11	0.02	0.14	0.25	ND	ND	0.06	7.27	0.14	0.02	8.89	8.89	0.42	0.06
Mean	41.2	19.5	0.02	0.12	0.15	0.17	0.02	0.05	3.97	0.18	1.01	4.44	4.44	0.21	0.05
SD	±8.48	±1.92	±0.02	±0.12	±0.19	±0.07	±0.02	±0.06	±3.98	±0.18	±0.01	±4.45	±4.45	±0.21	±0.03
CV%	20.5	9.80	100	1.26	1.26	2.00	2.00	2.0	100	1.00	100	1.00	1.00	100	1.00

Table 3: Results of Analysis of Galena Ore from N/Eggon

	Metals								
Location	Pb	Zn	Ni	Cu	Mn	Ba	Cr	Ti	Fe	Cd
A1	86.8	7.4	0.05	0.25	0.03	0.31	0.02	0.02	0.32	8.4
B1	72.4	5.6	0.06	0.32	Nd	0.32	0.10	0.02	0.58	6.5
C1	63.4	2.80	0.02	0.38	0.09	0.30	0.10	0.02	0.42	3.2
D1	65.2	2.50	00.23	0.25	0.02	0.30	0.12	0.02	0.82	2.8
E1	67.8	1.43	1.40	0.20	0.03	0.40	0.12	0.02	2.26	2.50

Although some minerals that include Cu and Fe are strategic minerals, they are present in the ore in low quantity. However, Cu could be recovered from the ore after beneficiation especially from Nasarawa/Eggon (Table 3) depending on the processing method. These metals were also detected in the ore (Ni, Mn, Ba, Cr, Ti, Fe, Cd, Si, Ca, K, S, Al and Sr) in low concentration except Cd (Table 3). This explains the dominance of Pd as the major mineral in the ore samples. The availability of Ba (Table 1), Pb and Zn (Table 2 and 3) in the areas studied relates to the geological history of Nasarawa state located in the rich Middle Benue-trough which is along the north-south east belt cutting through the eastern flank of the country where Pb-Zn is known to occur (Akande *et al.,* 1990). Although galena is a raw material for storage battery, pencils, paints and other useful materials. Currently, the exploitation of the mineral is done through artisanal miners without any form of processing to remove the gangue and other minerals. Thus most of the ore resources are yet to be considered for local applications despite their huge potential for economic exploration. Therefore, there is the need to explore the option of processing of the ore for domestic application and or for export as value-added product.

CONCLUSION

The geological and chemical investigation of some ore resources in Nasarawa state was carried out. The analysis showed that the geological locations contained minerals in variable concentrations that include: Ba, Pb, Zn and Cu in exploitable quantities. Nb, Cr, Fe, Ti, Ca, K, Al Sr and Mn are found in the matrix of the ore in complex assembly. These minerals could be considered as gangue components. However, for economic recovery Cu could be considered a probable resource. The application of appropriate processing techniques would lead to the recovery of these minerals from the ore in appreciable quantities to match their requirement for export as value added products. The investigation also revealed that the geological nature of the locations where the ores were collected is responsible for the mineralization. On the other hand the location of the state within the Benue trough and the sedimentary environment confers certain advantages to it in terms of revenue earnings. The exploitation and development of these ore resources alongside an integrated processing approach will enhance the maximization of the minerals for application and as an alternative source of revenue earning.

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Conflicts of Interest

There are no conflicts of interest relating to the publication of this paper.

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