EVALUATION OF SOME CHARACTERISTICS OF THE BARITE DEPOSITS IN RIBI, NASSARAWA STATE, FOR INDUSTRIAL APPLICATIONS

A Thesis Presented to the Department of
Materials Science and Engineering

African University of Science and Technology

In Partial Fulfillment of the Requirements for the Degree of

Master of Science in Materials Science and Engineering (Minerals Processing)

By

Ibrahim Habib Olanrewaju

Abuja, Nigeria

July, 2019.

CERTIFICATION

This is to certify that the thesis titled "Evaluation of Barite Deposits in Ribi, Nassarawa State, for Industrial Applications" submitted to the school of postgraduate studies, African University of Science and Technology (AUST), Abuja, Nigeria for the award of the Master's degree is a record of original research carried out by Ibrahim Habib Olanrewaju in the Department of Materials Science and Engineering.

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Ibrahim Habib Olanrewaju

A THESIS APPROVED BY THE MATERIALS SCIENCE AND ENGINEERING DEPARTMENT

RECOMMENDED:

Dr. Adelana Rasak Adetunji

Prof. Azikiwe Peter Onwualu

Head, Department of Materials Science and Engineering

APPROVED:

Chief Academic Officer

Date

DEDICATION

This project is dedicated to Al-mighty Allah the Giver of knowledge then my parents and my dearest wife Opeyemi.

ACKNOWLEDGMENTS

All praises and adorations belong to Allah my creator and special appreciations go to my indefatigable supervisor Dr. Adelana Rasak Adetunji who worked tirelessly to ensure that this project becomes a success. Also, my co-supervisor Dr. S.O Rahman for his great contribution that gave this project a good shape. In addition, I appreciate the good will of my scholarship sponsor under the World Bank's Pan African Materials Institute (PAMI) program. I am also grateful to my school, African University of Science and Technology, Abuja, for providing the avenue to study under world-class scholars from different parts of the world. Furthermore, I thank the head of department Prof. Azikuwe Peter Onwalu and Dr. Hakeem Bello who, despite their academic commitments and busy schedule found the time to provide necessary supports.

In addition, I appreciate my entire teachers in AUST including Prof. Wole Soboyejo, Prof D. Buttrey, Prof. K. Achenie, Prof. Leo Daniel, Dr. Shola Odusanya, Dr. Nelson Y. Dzade, Dr. Usman Bello, Dr. Ma'ruf and others.

Lastly, I appreciate the sacrifice of my lovely wife Ibrahim (Nee Uzamat) Opeyemi Fatimah who stood by me despite all the daunting challenges during the program. May God reward her for this great sacrifice.

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ABSTRACT

This study aimed at characterizing and evaluating the viability of barite deposits within Ribi for industrial applications. There is an inadequacy of information as regards mineralization, chemical and geotechnical properties of barite ores in the area of study. Field work was carried out to assess the various mining sites where barite deposits are being mined and also for sample collections. Ten barite samples were collected from various mining locations within Ribi and the samples were taken to the laboratory for chemical and geotechnical analysis. Specific gravity analysis was carried out in the laboratory using Pycnometer method; this was done so as to classify the barite samples' viability for industrial applications including oil drilling processes according to the American Petroleum Institute (API) standard. Elemental analyses were carried out using the Scanning Electron Microscope (SEM) in EDX mode at the AUST laboratory with model Fei Inspect S50 equipment to reveal the spatial variation in chemical properties within the barite samples. Results showed that Specific gravity values of the samples ranged from 4.13 to 4.27. Six of the samples have specific gravity values that fall above 4.2 while four of the samples have specific gravity values that fall below 4.2. In addition, EDX results revealed the spatial chemical variation within some of the analyzed samples, Ba have weight % values that ranged between 70-82 % confirming it as the dominant mineral within the sample followed by S with values that ranged from 14.4 -14.6 %. Both minerals also have the highest peak on the EDX micrograph. Other elements within the samples are Nd, Te, Ca, O, Cs, Ce, all appearing as traces within the samples. It was concluded that Barite mineralization is present in Ribi, and that Barite samples from Ribi are good enough for industrial applications especially when beneficiated. However, follow up detailed exploration is expected to be worthwhile to further reveal the various properties of these barite samples.

CHAPTER ONE

INTRODUCTION

1.1 Background

Barite is a sulphate mineral with chemical formula $BaSO_4$. It is an important industrial mineral that is used for several applications. The vast usage of this mineral is due to its excellent physical and chemical properties. Industrial applications of barite revolve around its unique specific gravity because it is rare for a nonmetallic mineral to have such a high specific gravity as barite (King, 2005). Barite is widely used in the oil and gas industries as part of the constituent of drilling mud to serve as a weighting agent to control high formation pressures and prevent blowouts during drilling operation, this is because of suitable properties of barite such as high specific gravity, chemical inertness, non-corrosive, non-abrasive and, its non-magnetic nature that prevent the drilling fluid from interfering with the formation fluids. In addition, it does not interfere with the logging from the borehole (Fatoye et al., 2014). It also cools the drilling bit and as well carries the rock cuttings in the borehole up during drilling.

Barite also finds applications in other industries such as painting, paper (where it is packed in playing cards to increase the density of the playing card to be "dealt" easily to players around a card table) (King, 2005), clothes, plastic as fillers, sound reduction in engine structures, coat of automobile finishes for smoothness and corrosion resistance, friction products for automobiles and trucks, radiation-shielding cement, glass ceramics and medical applications (Tanko et al, 2015). Barite is also one of the principal ores for producing barium compound that are used to make high-density concrete to shield x-ray emissions in hospitals, power plants, and laboratories (King, 2005).

The wide range of applications of barite has created a large market for barite. Nigeria spent about 5billion naira on barite importation whereas, she is among the countries with highest deposit of barite in Africa and the world at large. Barite occurs in commercial quantities in states such as Benue, Nassarawa, Taraba, Cross River, with an estimated reserve of about 21,123,913 metric tons in the four states (Ministry of Mines and Steel Development, 2008). According to Nigerian Geological Survey Agency, barite deposits are largely restricted to the eastern half of the country specifically within the Benue Trough, (Benue, Taraba, Adamawa States), and its fringes to the north (Nassarawa, Plateau and Gombe State) and the Southern fringe (Cross River State). A major exception is the occurrence of the commodity in Zamfara State, Northwestern Nigeria (NGSA, 2009).

One can imagine the abundance of barite in Nigeria that are yet to be properly tapped due to lack of technical know-how together with inadequate attention of government towards the development of the solid mineral sector of the country.

1.2 Problem Statement

Barite can play a significant role in the economic development of Nigeria through foreign exchange generation as well as job creation if properly managed. Nigeria being one of the countries with the largest deposits of barite is supposed to benefit from her wealth but due to lack of proper management of the solid mineral sector as a result of over dependency on crude oil, the country has not really benefited from this rare gift of nature. It was reported that Nigeria loses more than #5billion worth of foreign exchange on barite importation by the oil and gas industry every year. While the country has more than enough barite of high quality that can meet our local demand and as well serve as an export commodity, yet the nation has resulted in importation of barite (Abah, 2018). This is just in the oil and gas industry alone but barite has more industrial applications such as in plastic industry, paper-making industry, painting industry, rubber industry, cosmetics industry, pharmaceutical industry and so on. Therefore, it is pertinent to reassess the quality of Nigerian barite and compare them with the international specifications for each industrial application, hence this study.

1.3 Location and Accessibility

The area of study falls within Ribi in Awe Local Government Area of Nassarawa State (Fig.1). It is geographically enclosed within Latitudes 7^o 50’ to 8^o 30’ and Longitudes 9^o 00’ to 9^o 30’ covering a total of approximately 770 km^2. Ribi, which is one of the major communities within Awe Local Government Area, is located at about 95 km away from Lafia, the Nasarawa State Capital. The area of study is bounded to west by Lafia, Obi, and Keana LGAs, to the east by Taraba State, to the North by Plateau State and to the South by Benue State. Ribi is accessible by major roads that come from Obi and another one from Keana linking the area to other localities within the state while there are also several footpaths that are accessible.

1.4 Climate and Vegetation

The study area is characterized by tropical sub-humid climate with two distinct seasons: the wet season (May to October) and dry season (November to April). The mean annual rainfall and temperature in the area are 1550 mm and 27^{o}C respectively. The study area falls within Southern Guinea Savannah Zone. However, clearance of vegetation for farming, fuel wood extraction for domestic and cottage industrial uses as well as saw-milling has led to the development of re-growth vegetation (Alao and Amadi, 2012).

1.5 Human Activities and Settlements

The area of study has people of diverse ethnic groups, amongst them are the Tiv, Jukun, Bassa, Agatu, Fulani etc. Majority of the people living in the study area are farmers while others are artisanal miners. There is a vast of land available for farming with rich soils in the study area. The farming activity is mainly focused on yam, soya bean, cassava, maize, groundnut and vegetables. Other occupation include trading and cattle rearing.

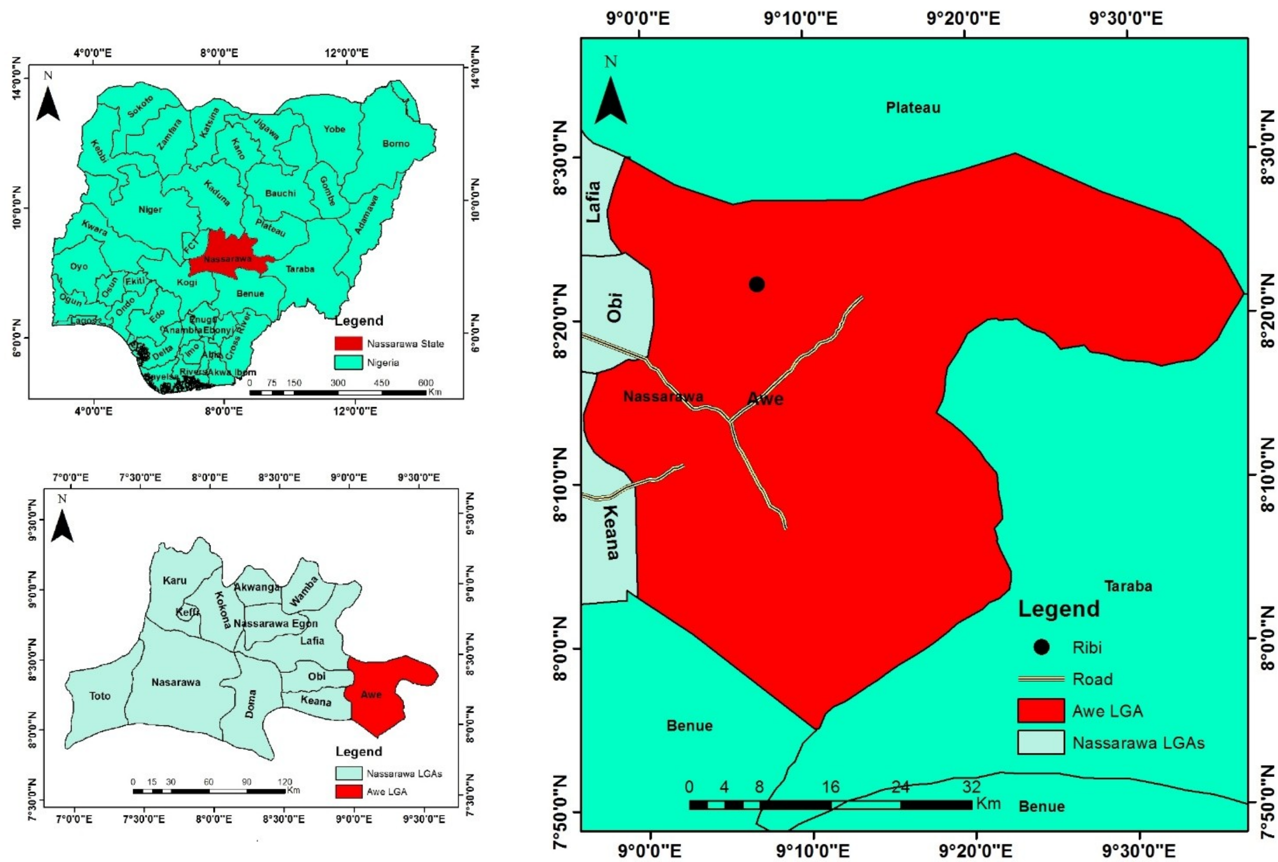

Fig. 1.1: Location Map of the Area of Study

1.6 Aim and Objectives

The aim of this research work is to characterize and evaluate the viability of the barite deposits within Ribi for industrial applications.

The major objectives are to;

- Characterize the barite ore from the study area.
- Establish geochemical data for the barite in the study area.
- Establish the appropriateness of the barite from the study area for applications.

1.7 Scope of Work

This work involves confirmation of barite deposits in the selected study area through fieldwork approach as well as site visitations and samples would be picked systematically for tests and laboratory analysis. The tests and analysis will include geotechnical tests which include; specific gravity, major and trace element analysis of the ore samples in compound and elemental forms. The whole work will be divided into chapters as follows:

- Chapter two will discuss literature review on the occurrences and characteristics of barite deposits in various states in Nigeria and their reserve estimates.
- Chapter three will address the methodology which will include sample collection and preparation, tests and analysis.
- Chapter four will present the results and discussion of the results
- Chapter five will contain the conclusions derived from the work and also give recommendations for future work.

1.8 Justification of the study

Nigeria is known to have barite in economic quantity but yet import huge amount of barite for use in industries especially the oil and gas industry. This project will verify the viability of the barite deposit in Ribi, Nassarawa State of Nigeria for industrial usage.

1.9 Limitations

The scope of this work was originally designed to include the study of the morphology, water absorption capacity and pH of the samples. However, these were no more carried out due to the dearth or malfunction of the required facilities as at the time of bench work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Barite is reported to have been found in different geological settings throughout the world and Nigeria is not an exception. The three major types of deposits of barite include; stratiform, residual and vein (Bonel, 2005). Most barite deposits in Nigeria are often associated with lead and zinc.

2.2 Types of Barite Deposits

Based on field occurrence, barite deposits are classified as follow:

2.2.1 Veins and Cavity Filling Deposits

These are epithermal deposits that occur as a result of the infilling of barium bearing fluid in faults, joints, breccia zones, bedding planes, solution channels and cavity zones, solution channels and cavities and then become precipitated to form barite deposit. They are usually fewer than the bedded deposits, examples include vein deposits of the Benue Trough, Nigeria (Labe et al., 2018), Les Arcs deposit in France, Dreislar and Rhineland-Palatinate vein deposits in Germany and Pennine ore fields in the United Kingdom (Lorenz and Gwosdz, 2003).

2.2.2 Residual Deposits

These are barites derived from the weathering of barite bearing rocks in which barite is present in form of loose fragments within residual soil or clay. This type of deposit varies considerably in size and shape but extend over a wide range of kilometers (Bonel, 2005).

2.2.3 Stratiform Deposits

These are important forms of barite deposit especially those formed by the precipitation of barite at or near the sea floor of sedimentary rocks (sedimentary exhalation or 'sedex' deposits). The salt solution is generated by migration of reduced, saline solution and is concentrated by major basin controlling faults. They are found in variety of rocks of different ages ranging from Precambrian to Cenozoic (Bonel, 2005).

2.3 States and Their Barite Deposits in Nigeria

Barite deposits in Nigeria have been found to occur majorly in the Benue trough (Benue, Taraba, and Adamawa States) and its fringes to the north (Nassarawa, Platueau and Gombe State) and the Southern fringe (Cross River State). All barite deposits in Nigeria fall within the Benue trough except that of Zamfara State deposits that occurs in the Northwestern part of Nigeria (Ministry of Mines and Steel Development, 2008). The Benue trough is a rift basin that was initiated during the Lower Cretaceous in relation with the Atlantic opening (Benkhelil, 1989). It is believed to be one of the major re-entrant into West African continental margin (Uma, 1992) and it extends NNE–SSW for about 800 km in length and 150 km in width. The southern limit is the northern boundary of the Niger Delta, while the northern limit is the southern boundary of the Chad Basin Ocean opening (Obaje, 2009).

The origin is tied to the break-up of the Gwondwana land and opening of the Atlantic Ocean in early Cretaceous times and in fact earlier workers affirmed that the idea of Y-shaped triple rift model (RRR) is the best to describe the break-up of the Afro-Brazilian plate, the early Cretaceous times best explains the final configuration of the Benue Trough (Ene *et al*., 2012). Its shape and structure are controlled by pre-existing ductile and brittle shear zones periodically reactivated in response to regional tectonism. The entire trough is filled with sediments that range from Late Aptian to Paleocene (Ministry of Mines and Steel Development, 2008). The Benue Trough is arbitrarily subdivided into a lower/south, middle/central and upper/north (Ene et al., 2012) portion based on physiographic and lithostratigraphic nomenclature differences (Petters 1982; Nwajide 1990).

The zone of mineralization which is as a result of the tectonic activities in the Benue Valley appears to run in the narrow tract extending from the southeast in the Abakaliki trough axis to the northeast. The associated intrusive are distributed from Ishiagu in the southeast to as far north as Dadiya, in the northeast, a distance of about 500 km. The barite is associated with brine spring; but this is a point of argument among scholars. However, there is the possibility of chemical interaction between the rising metal bearing hydrothermal fluid with the surrounding country rock in the saliferous or evaporitic zones, resulting in the deposition of barites and other minerals such as galena and sphalerite (Obaje, 2009).

Barite occurs widely throughout the world. It often occurs in hydrothermal ore veins with lead, and zinc minerals. It is insoluble in water and practically insoluble in the most chemical reagents under ordinary conditions. The locations of Barite deposits in Nigeria are given in Figure 2.1 and Table 2.1.

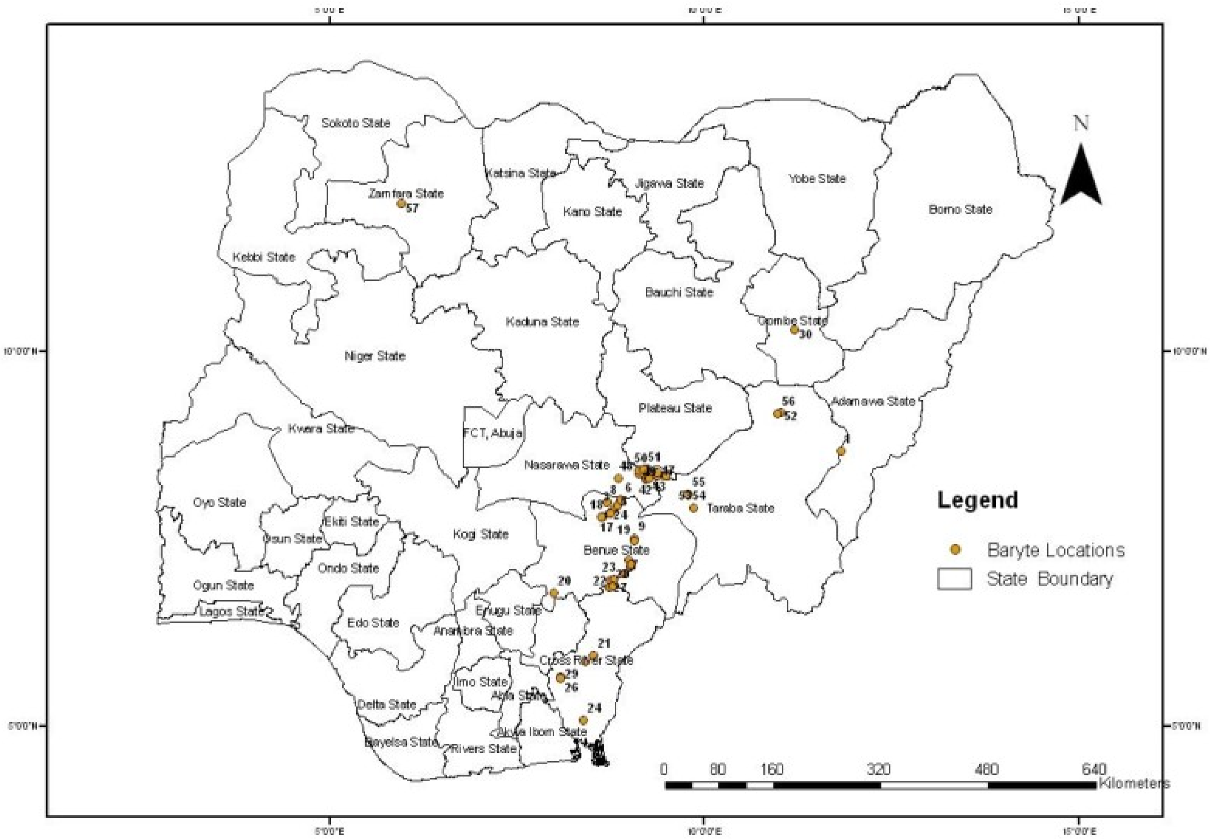

Fig. 2.1: Map of Nigeria Showing Barite Deposits in Various State (NGSA, 2009)

Table 2.1: Barite Locations in Nigeria (NGSA, 2009)

S/n	Location	Lga	State	Geology
1	Gambe	Mayo-Belw	Adamawa	Granite-gneiss and migmatite terrain.
2	Iye	Guma	Benue	Sandstones
3	Tidza	Guma	Benue	Sandstones
4	Ukaa	Guma	Benue	Sandstones
5	Nyam Uka	Guma	Benue	Sandstones
6	Torkula A	Guma	Benue	Sandstones
7	Lessel	Ushongo	Benue	Shales sandstones of Awgu Indicator.
8	Lukor/ Ts	Guma	Benue	Sandstones
9	Fada	Buruku	Benue	Sandstones
10	Mbashabu	Ushongo	Benue	Granite – gneiss
11	Mbato- Gi	Ushongo	Benue	Granite – gneiss
12	Bunde	Ushongo	Benue	Granite – gneiss
13	Mbatoo	Ushongo	Benue	Granite – gneiss
14	Tse-Ande	Guma	Benue	Sandstones
15	Orgba	Ushongo	Benue	Granite – gneiss
16	Orgba	Ushongo	Benue	Granite – gneiss

17	Tyodugh-U	Makurdi	Benue	Sandstones
18	Tyodugh-U	Makurdi	Benue	Sandstones
19	Pilla- Ya	Gboko	Benue	Granite
20	Igumale	Ado	Benue	Sandstones
21	Ekukunela	Ikom	Cross Riv	Vertical veins with strike of 155/335
22	Gabu	Yalla	Cross Riv	Veins occuring within shale
23	Oshina	Yalla	Cross Riv	Veins occuring within shale
24	Iyametite	Obubra	Cross Riv	Veins occuring within shale
25	Edondo/ O	Obubra	Cross Riv	Vein occuring within shale and sandstone
26	Akpet No	Biase	Cross Riv	Vein in schist and sandstone trend E-
27	Gabu	Yalla	Cross Riv	Sandstone
28	Osina	Yalla	Cross Riv	Sandstone
29	Akpet	Biase	Cross Riv	Sandstone, siltstone
30	Ligi Hill	Gombe	Gombe	Granite gneisses
31	Wuse	Awe	Nassarawa	They occur as hydrothermal deposit formation
32	Dogon Daj	Awe	Nassarawa	They occur as hydrothermal deposit formation
33	Kumar	Awe	Nassarawa	They occur as hydrothermal deposit formation
34	Kumar	Awe	Nassarawa	They occur as hydrothermal deposit formation
35	Kumar	Awe	Nassarawa	They occur as hydrothermal deposit formation
36	Agana	Awe	Nassarawa	They occur as hydrothermal deposit formation
37	Azara	Awe	Nassarawa	They occur as hydrothermal deposit formation
38	Kumar	Awe	Nassarawa	They occur as hydrothermal deposit formation
39	Gidan Aga	Awe	Nassarawa	They occur as hydrothermal deposit formation
40	Jobe	Awe	Nassarawa	They occur as hydrothermal deposit formation
41	Jara	Awe	Nassarawa	They occur as hydrothermal deposit formation
42	Sauni	Awe	Nassarawa	They occur as hydrothermal deposit formation
42	Sauni	Awe	Nassarawa	They occur as hydrothermal deposit formation
43	Apebene	Awe	Nassarawa	They occur as hydrothermal deposit formation
44	Gidan Soj	Awe	Nassarawa	They occur as hydrothermal deposit formation
45	Gidan Soj	Awe	Nassarawa	They occur as hydrothermal deposit formation
46	Akiri (Du	Awe	Nassarawa	They occur as hydrothermal deposit formation
47	Azara - W	Adudu	Nassarawa	Vein deposit within sequence of sands
48	Keana	Keana	Nassarawa	Black shale and siltstone of Ezeaku Formation
49	Ribi	Awe	Nassarawa	They occur as hydrothermal deposit formation
50	Ribi	Awe	Nassarawa	They occur as hydrothermal deposit formation
51	Arugagwu	Awe	Nassarawa	They occur as hydrothermal deposit formation
52	Didango S	Karim Lam	Taraba	Sandstone, siltone and shales of Awgu
53	Wukari	Wukari	Taraba	Black shales and siltstone of Ezeaku
54	Bakyu	Ibi	Taraba	Pure Baryte in compacted sandstones
55	Gidin Way	Wukari	Taraba	Baryte occuring in clayey sandstone.
56	Didango S	Karim Lam	Taraba	Clayey siltstone of the Benue Valley
57	Dareta	Anka	Zamfara	Occuring as vein in pelitic schist.

2.3.1 Barite Occurrence in Benue State

Barite has been reported to occur in five local governments in Benue State and they include; Guma, Makurdi, Gboko, Ushongo and Vandeikya. The Guma deposits occur around the following villages; Iye, Ise- Ande, Tidza, Uyam-Ukaa, Torkula, Akaaza Lukor, Zanzan, Chiata and Hugwe. The deposits in Makurdi, Gboko and Vandeikya Local Government Areas are found around Tyodough, Pila Yandev and Mbaakase- Ihugu villages respectively (Table 2.2), while the deposits in Guma and Makurdi LGAs are hosted mainly by sandstones, those of Pila Yandev have shale and limestone bands as hosts. The Ushongo and Vandeckya deposits are hosted mainly by basement rocks; granites, gneisses and migmatite. Deposits are in form of fissure filling with hydrothermal solutions depositing barites in fissures formed by the closing in of the Benue trough during the Santoninan. The mineral occurs as white, reddish-brown and clear varieties with SG varying between 3.7 and 4.4. Chemical analysis show that most samples contain between 76- 87% $BaSO_4$, impurities of between 5 and 21% silica and up to 3% iron oxide (NGSA, 2009). The distribution of barite occurrence Benue State is shown in Table 2.2.

Table 2.2: Distributions of Barites in Benue State (NGSA, 2009)

S/N	Local Government Area	Village	Coordinate	Host Rock	Sheet Number
1.	Guma	Iye	7^o50’ 34” N, 8^o44’ 28” E	Sandstone	1:50,000 sheet 251, Makurdi NW
	Guma	Tse-Ande	7^o50’ 32”N, 8^o45’ 08”E	Sandstone	1:50,000 sheet 251 Makurdi N E
	Guma	Tidza	7^o54’ 30”N, 8^o47’ 32”E	Sandstone	1:50,000 sheet 251 Makurdi N E
	Guma	Ukaa	7^o56’ 22”N, 8^o50’ 08”E	Sandstone	1:50,000 sheet 251 Makurdi N E
	Guma	Ngam- Ukaa	7^o57, 08”N, 8^o50’ 0” E	Shale	1:50,000 sheet 251 Makurdi N E
	Guma	Torkulla	8^o01’ 32”N, 8^o53’ 34”E	Sandstone	1:50,000 sheet 251 Makurdi N E

	Guma	Zan-Zan	8°00' 11"N, 8°54' 08"E	Sandstone	1:50,000 sheet 251 Makurdi N E
	Guma	Hungwe	8°01' 49"N, 8°56' 36"E	Sandstone	1:50,000 sheet 231 Lafia SE
2.	Ushongo	Mbashabu- Lessel	7°7' 55"N, 9°00 53"E	Basement rock	1:50,000 sheet 272 Katisna Ala SW
	Ushongo	Mbashabu- Lessel	7°08' 57"N, 9°01' 05'E	Basement rock	1:50,000 sheet 272 Katisna Ala SW
	Ushongo	Mbashabu- Lessel	7°09' 20"N, 9°01' 27"E	Basement rock	1:50,000 sheet 272 Katisna Ala SW
	Ushongo	Mbatoo	7°09' 10" N, 9°00' 55" E	Basement Rock	1:50,000 sheet 272 Katisna Ala SW
	Ushongo	Ongba	7°02' 12" N, 8°15' 16" E	Sandstone	1:50,000 sheet 271 Gboko SE
3.	Makurdi	Tyodough (behind Uni-Agric)	7°48' 05" N, 8°38' 07" E	Sandstone	1:50,000 sheet 251 Makurdi NW
4.	Gboko	Pila-Yan- dev	7° 28' 49" N, 9°04' 16" E	Shale	1:50,000 sheet 272 Katisna Ala NW
5.	Vandeikya-	Mbaakase- I hugh	6°55'55" N, 8°59' 39" E	Basement Rock	290 Ogoja NE

2.3.2 Barite Occurrence in Cross River State

Barite occurs as vein deposit in Cross River state in both hard rocks and soft rocks. The area of mineralization has been divided into the southern area consisting of Biase and Yakkur Local Government Areas (LGAs) and the Northern area comprising Obubra, Ikom (Ene *et al*. 2012) and Yala LGAs. Thirty-five locations have been reported, among which eleven are in sedimentary areas. Mineralized zones include Iyamitet / Okokori / Edoudon, Ekukunela, Atakpa, Nkarasi, Gabu / Oshina/ Alifo kpa, Omoji and Okpoma all within three local Government areas. Vein outcrops are exposed from Iyamitel in Obubra LGA, northwards through Edondon, Okokori to Ekukunela, Atakpo in Nkarasi in Ikom Local Government Area; terminating at Gabu Okpoma in Yala LGA (Labe, 2015; Nwafor *et al*., 1997). Out of the seventeen mineralized locations obtainable in the south, barites are found in sedimentary rocks in nine locations, and also in basement rocks in eight locations. Among the remaining eighteen mineralized locations in the north, only two locations are hosted by sedimentary rocks, and the other sixteen different locations are housed by basement rocks (Fatoye *et al*., 2014). The barite in Cretaceous sedimentary rocks of the lower Benue Trough and Tertiary dolerites are reported to contain gangue materials that are mainly galena, pyrite and chalcopyrite. Barites in veins hosted by dolerite dykes are in the forms of euhedral crystals (NGSA, 2009).

The veins width is often between 2.5 and 5.3 metres (veins with width less than 0.2 meters were not considered) and they are of traceable lengths up to 1.5km. Deposits are hosted in rocks of diverse ages notably the Precambrian basement complex rocks. Specific gravity (SG) ranges between 3.5 and 4.4. Inferred Resource for the entire State is 8,612,880 metric tons distributed almost evenly between north and south (Ministry of Mines and Steel Development, 2008).

2.3.3 Barite Occurrence in Nassarawa State

Barites in Nassarawa State are hosted by several types of sedimentary rocks as shale, mudstones siltstones, limestones as observed in Azara, Wukari, Wuse and so on. They occur in form of veins with width varying between a few centimeters to 3.5 metres. These veins are found to persist along strike for distances ranging between just under 1000 to over 4,000 metres. The laboratory studies carried out on samples from the state revealed that they contain between 76% and 87% $BaSO_4$ and specific gravity that varies between 3.9 and 4.4; this grade range is within the 4.2 minimum specification of the American Petroleum Institute (API) (API, 2010). However, some samples have SG values of less than 3.6. These samples are silica rich varieties and not suitable for use as drilling constituents unless beneficiated but can find applications in other areas of industrial applications of barite minerals such as glass making, pharmaceutical industry, plastic, coating and paint industry (Labe et al., 2018). The estimated barite reserve is with a vein thickness of 20 meters and average specific gravity of 4.0 is 3,243, 376 metric tons (NGSA, 2009).

2.3.4 Barite Occurrence in Taraba

Barites in Taraba State are located in five LGAs; Karim Lamido, Yoro, Sardauna, Lau and Ibi as shown in Table 2.3. The mineral is hosted in porphyritic granites and fine-grained sandstones. This barite resource is hosted in the igneous-metamorphic rocks of the Pre-Cambrian; also in sandstones, shale, mudstone, siltstone and limestone of the Benue Trough Sedimentary Formations (Fatoye *et al*., 2014). However, its mineralization and deposition are in form of fissure filling with hydrothermal solutions formed by the closing in on the Benue Trough, making them epigenetic deposit. Vein lengths are persistent over distances varying from 3,500 to 5,000 metres and width from 3.5 to 5 meters. Impurities consist of quartz and sulphide minerals such as galena and sphalerite. The reserve estimate for barite resource is 8,960,000 metric tons to a depth of 20 metres. Quality of resource is good with most SG values close to 4.2 (Ministry of Mines and Steel Development, 2008; NGSA, 2009).

Table 2.3: Distribution of Barite Mineralization in Taraba State (NGSA, 2009)

S/N	Local Government Area	Village	Coordinate	Host Rock	Associated minerals	Sheet Number
1.	Sarduana	Mbanga Petel	06°34.198’N 011°12.111"E	Fine grained granite	Amethyst quartz	1:250,000 sheet 76 (Mayo Daga)
		Mbang 3 corner	06°34.209N 011°12.109"E	Fine grained granite	Amethyst quartz	1:250,000 sheet 76 (Mayo Daga)
		Juo	06°43.499N 011°12.471E	Porphyroblastic gneiss	-	1:250,000 sheet 76 (Mayo Daga)
		Juo	06°43.146N 011°12.762E	Porphyroblastic gneiss	-	1:250,000 sheet 76 (Mayo Daga)
2.	Ibi	Gidin Waya	08°05.862’N 009°47.001’E	Fine grained sandstone	-	1:100,000 sheet233 (Ibi)
		Gidin Waya	08° 05.891’N 009°46.903’E	Fine grained sandstone	-	1:100,000 sheet233 (Ibi)
		Kauyen Isa	08°10.797’N 009°45.649’E	Fine grained sandstone	-	1:100,000 sheet233 (Ibi)
		Kauyen Isa	08°10.991’N 009°45.689’E	Fine grained sandstone	-	1:100,000 sheet233 (Ibi)
		Kauyen Isa	08°08.092’N 009° 48.040’E	Fine grained sandstone	-	1:100,000 sheet233 (Ibi)
		Kauyen Isa	08° 05.110’N 009° 48.012’E	Fine grained sandstone	-	1:100,000 sheet233 (Ibi)
		Bakuyu	08° 06.083’N 009°49.382’E	Fine grained sandstone	None	1:100,000 sheet233 (Ibi)
		Bakuyu	08° 05.888’N 009°49.298’E	Fine grained sandstone	None	1:100,000 sheet233 (Ibi)
		Ibua	08°07.084’N 009°47.696’E	Fine grained sandstone	Galena	1:100,000 sheet233 (Ibi)
		Kumar	08° 19.145’N 009°28.040’E	Bauxitic sandstone	Galena Amethyst quartz	1:100,000 sheet 232 (Akiri)
		Kumar	08°19.932’N 009°28.392’E	Bauxitic sandstone	Galena Amethyst quartz	1:100,000 sheet 232 (Akiri)
		Kumar	08° 20.263’N 009°29.418’E	Bauxitic sandstone	Galena Amethyst quartz	1:100,000 sheet 232 (Akiri)

3.	Yorro	Kwaliang (Pupule)	09°02.447'N 011°37.334'E	Porphyritic granite	Galena	1:250,000 sheet 47 (Lau)
4.	Lau	Apawa (I)	09°07.011' N 011°30.318' E	Porphyritic granite	Galena	1:250,000 sheet 47 (Lau)
		Apawa (II)	09°07.014'N 011°30.320'E	Fine grained granite	Galena	1:250,000 sheet 47 (Lau)
5.	Karim- Lamido	Didango	09°10.089'N 010°59.009'E	Fine grained sandstone	Galena sphalerite	1:250,000 sheet 47 (Lau)
			09°09.938'N 010°59.123'E	Fine grained sandstone	Galena sphalerite	1:250,000 sheet 47 (Lau)

2.3.5 Barite Occurrence in Adamawa

Barite occurs in this state as fissure and cavity fillings induced by faulting and fracturing in the southern part of Adamawa State and the upper Benue Trough. Barite veins are generally thin and are hosted by different rock types including granites, migmatites, basalts, and feldsphatic sandstone. The length of the vein ranges from 15 – 180 meters and the width from 1.2 to 4.3 meters while the depth is at maximum of 10 meters. They are restricted to seven prospect areas namely Gambo, Gangjari, Tola, Toungo, Dirima and Parambe, Gban/Mago-kpoki river, Waltandi and Heme as shown in Table 2.4. The barite colours in these areas vary from white to pink with a specific gravity of 4.0 - 4.36. Estimated reserve of barite in Adamawa is 332,130 metric tonnes.

Table 2.4: Barite prospect area in Adamawa (NGSA, 2009)

Digital Map No.	Prospect Area	Location	Coordinate	Sheet No 1:50,000
A	Gambe	Nyami-Warar Hill	08º 35’ 17’’N 011º 48’ 03’’E	Sheet 216 Monkin SE
B	Gangjari	Burumkusum Hill	08º 32’ 03’’N 011º 54’ 02’’E	Sheet 216 Monkin SE
C	Tola	Pela Village	08º 54’ 15’’N 011º 56’ 84’’E	Sheet 216 Monkin SE
D	Toungo	River Dasasar Bank	08º 10’ 19’’N 012º 04’ 16’’E	Sheet 238 Toungo SW
E	Dirima and Purambe	Dirima Village	08º 10’ 19’’N 012º 20’ 00’’E	Sheet 175 Shellen NE
		Koti- Dirima Village	09º 46’ 54’’N 012º 22’ 12’’E	
		Gbenre Hill	09º 47’ 54’’N 012º 18’ 41’’E	
F	Gban and Mayo-Kpoki	Gban Village	09º 50’ 02’’N 012º 15’ 31’’E	Sheet 175 Shellen NE
		Mayo-Kpoki River Village	09º 50’ 27’’N 012º 15’ 14’’E	
G	Waltandi and Leme	Waltandi Hills	09º 47’ 30’’N 012º 16’ 00’’E	Sheet 175 Shellen NE
		Leme Hills	09º 45’ 40’’N 012º 16’ 00’’E	

2.3.6 Barite Occurrence in Plateau State

Barite occurs in this area of the middle Benue Trough in the forms of veins as well as fracture filling in sandstone bodies of the Keana Formation of Cenonian age. Faya barites mineralization occurs as vein lode type deposits extending for several tens of meters both in length and in depth. The resource estimation for Faya is around 500,000 metric tons (NGSA 2009). Average purity of samples observed from Plateau State suggests Faya barytes samples have high purity and specific gravity. Colour varies from pure white to milky white. Specific gravity ranges from 4.0 to 4.39. Barite veins also seldomly contain impurities of quartz and fluorite. Exploration for barites in Plateau State by the Nigerian Geological Survey Agency targeted the country around

Faya, Karwa, Kargo, Safiyo, Angwar Yama, Gimbi Tunga villages all in Langtand South and Wase Local Government Areas (Ministry of Mines and Steel Development, 2008; NGSA, 2009).

2.3.7 Barite Occurrence in Zamfara State

Barite in this state is an exception to occurrence of barite deposit in Nigeria as other deposits are found in the Benue trough. Zamfara State barite is extensive and it is linked to epigenetic hydrothermal fluids which leaked barium from adjacent rocks to be precipitated in veins and fissures. Vein depths and widths varied remarkably from a few centimeters up to several meters (0.6m-2m) and length of up to 100meters. Barites veins were assessed by Nigerian Geological Survey Agency (NGSA 2009) in four local government areas of the state namely;

1. Dareta near Anka,Anka local government area (LGA)
2. Rukebu near Chafe, Chafe LGA
3. Yarkatsina (Gidan saro) Bugundu LGA
4. Tofa forest reserve, Gusan LGA.

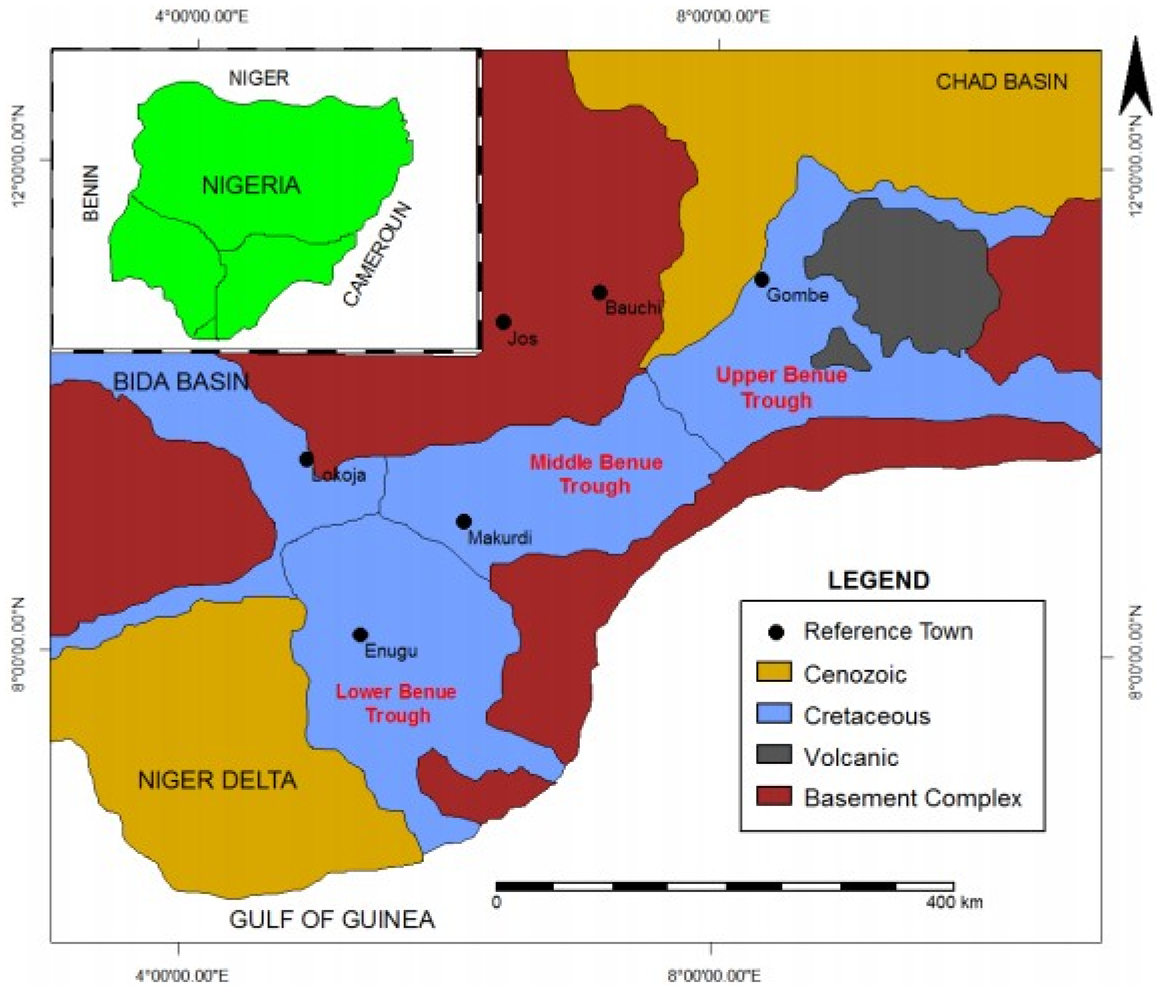

Fig. 2.2: Map of the Benue Trough Showing States with Barite Mineralization in Nigeria (Fatoye et al., 2014)

2.4 Reserve Estimate of Barite in Nigeria

The reserve estimate cannot be accurately determined by now due to the fact that there are still ongoing exploration activities. For instance, the Geological Survey of Nigeria in 1959 reported an estimated barite reserve of 41,000 tons at a depth of 20 meters for the Benue Valley deposits in the Azara locality. In 2008, the Nigerian Geological Survey Agency embarked on the evaluation of newly reported deposits in the present Cross River, Benue, Nassarawa, Plateau and Taraba States. Further exploration activities revealed additional areas with favorable geological setting for barite mineralization (Nwozor and Chukwunenye, 2008). A comprehensive appraisal of the barites resources of Nigeria was carried out by the Nigerian Geological Survey Agency between 2005 and 2009 and credited eight states with deposits of the commodity which were explored with detailed reports. An inferred resource figure of 22,298,843 tonnes was estimated based on an average vein depth of 20meters and specific gravity of 4.2. Because of the inconsistencies and plethora of data (many of which are about a decade old) on barites in Nigeria, much needs to be done as ninety percent of barite reserves are still undetermined (Labe et al., 2018). Table 2.5 and Figure 2.3 shows states with their estimated resources and specific gravity range.

Table 2.5: Barite Resource Estimates for Different Locations (adapted from MMSD 2008).

States	Resources (tons)	Specific Density Range
Benue	307, 657	3.5-4.4
Cross River	8,612,880	3.5-4.4
Nasarawa	3,243,376	3.9-4.4
Taraba	8,960,000	Mostly 4.2
Plateau	500,000	3.4-4.4
Adamawa	332,130	4.0-4.36
Gombe	352,800	4.09-5.3
Zamfara		3.1-4.5

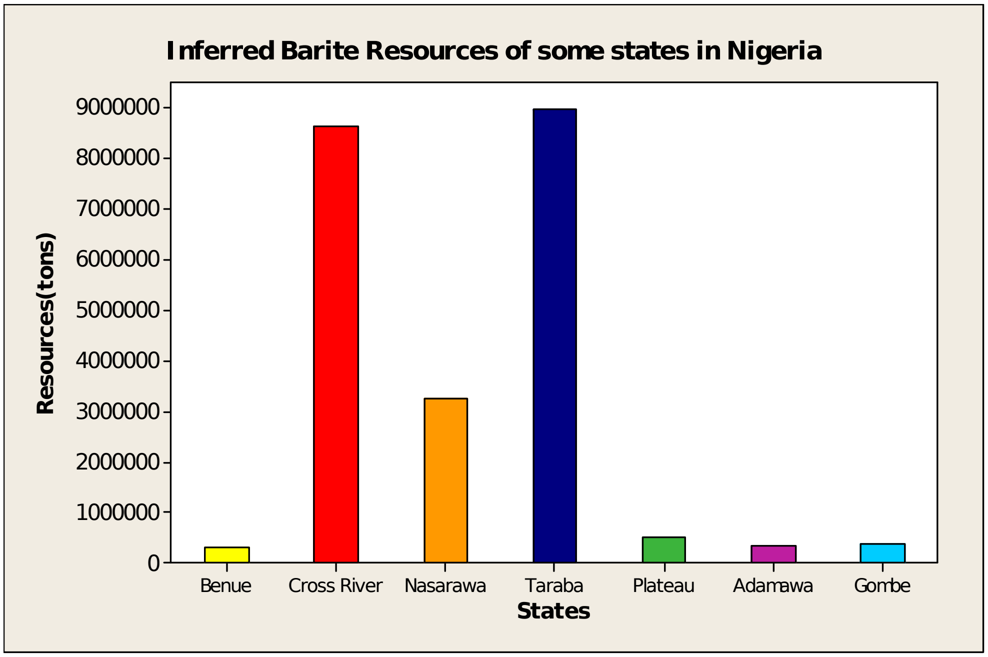

Fig. 2.3: Graph of Barite Resources in Some States (adapted from NGSA 2009).

2.5 Composition and Mineralogy of Barite

Barite is a mineral that contains about 66% BaO and 34% SO_3 as its proportion. Barites can sometimes contain strontium, and forms a complete solid solution series with the mineral celestite ($SrSO_4$) (Bonel, 2005). Complete solid solution exists between $BaSO_4$ and $SrSO_4$; most representatives of the series are either distinctly Ba-rich or Sr-rich. Hence, it is convenient to use the term *barite* to refer to not only the stochiometric $BaSO_4$ endmember but also to those $(Ba,Sr)SO_4$ solid solutions dominated by Ba.

Similarly, the term *celestine* will refer here not only to the stoichiometric $SrSO_4$ endmember but to solid solutions dominated by Sr. Such usage is in accord with standard mineral nomenclature (Encyclopedia Britannica, 2019). It also contains lead forming anglesite $PbSO_4$ or calcium forming anhydrite ($CaSO_4$) or gypsum ($CaSO_4 \cdot 2H_2O$). The substitution of Ba in barite ($BaSO_4$)

with other cations (such as K^+, Mg^{2+}, Ca^{2+}, Sr^{2+}, Ra^{2+}, Pb^{2+}, La^{3+}, Ce^{3+}, Lu^{3+}, Cu^{2+}) is because of its degree of similarity in ionic charge, ionic radius and electronegativity.

Barite is typically associated with one or more of the following minerals: celestine ($SrSO_4$), galena (PbS), sphalerite (ZnS), pyrite (FeS_2), quartz (SiO_2), calcite ($CaCO_3$), dolomite ($Ca,Mg(CO_3)$), marcasite (FeS_2), chalcopyrite ($CuFeS_2$), fluorite (CaF_2), siderite ($FeCO_3$) and witherite ($BaCO_3$). There is a very extensive solid solution amongst the barium sulphate member and two other sulphates namely; anglesite ($PbSO_4$) and celestite ($SrS0_4$) at a very low temperature of 100°C in the form of Anglesite- Barite-Celestite. A solid solution series also exists between barite and anhydrite ($CaSO_4$) even though the two are not iso-structural. Barite has hardness of 3-3.5 on Moh's scale of hardness (Milwhite, 2019) and variety of colours that range from white, light blue, light yellow, light red to light green. Its streak is white and weak pleochroism. Barite is usually associated with Fluorite, calcite, dolomite, rhodochrosite, gypsum, sphalerite, galena, and stibnite.

2.6 Industrial Applications of Barite

Barite is unarguably an industrial mineral that has enormous applications. In fact it is believed to have over two thousand uses such as oil well drilling mud components, filler and extender in paints and plastics, sound dampening in various engine compartments, smoothness and corrosion resistant powder coatings, friction products for automobiles and trucks, a weighting agent in bowling balls and other sporting goods, aggregate in preparation of heavy concrete and cement, weighting filler in rubber to make "anti-sail" mudflaps for trucks, contrast agent for medical x-rays of the GI tract, glass ceramics, and pottery (Omland *et al*., 2007).

2.6.1 Oil and Gas Industry

The bulk of barite mined are used in the oil and gas industry as one of the main constituents of the drilling fluid which is a complex chemical system that consists of several different components (Johnson *et al*., 2017). As the drilling for oil and gas proceed to higher depths the tendency of coming across a high-pressure zone is high and in order to prevent blow out that can claim a lot of live and properties, drilling mud weight must be increased (Moen, 1963). The increase in the weight of the drilling mud is achieved by the addition of barite in appropriate proportion. Pulverized barite is added to the normal clay – water mixture to form the drilling mud, the circulation of which lubricates the drill stem, cools the drill bit, seals the walls of the hole, removes cuttings and confines the oil and gas pressure at depth (Ministry of Mines and Steel Development, 2008; NGSA, 2009). Barite is used for drilling purpose because it is clean, easy to handle, relatively inexpensive, chemically inert, and non-abrasive (Kishan, 2019).

The softness of the mineral also prevents it from damaging drilling tools during drilling and enables it to serve as a lubricant. Barites for this application must have some specific properties which are specified by API.

2.6.2 Filler and Extender in Paints and Plastics Industry

Barite is used in grounded form directly as industrial filler and weighing agent chiefly in rubber and as an extender in paint (NGSA, 2009). It is also used as a white paint pigment known as Lithopone (precipitated zinc sulphate and barium sulphate) as well as to make "anti-sail" mudflaps for trucks. Lithopone is now being supplanted by titanium oxide pigment, but for economic reasons, the reagent is still considerably employed . Barite is also added to heavy printing paper, playing cards, rope finishes, brake linings, clutch facings, plastics and linoleum.

2.6.3 Paper-making Industry

Barite found application in the paper making industry due to its whiteness. it is added to heavy printing paper, playing cards, rope finishes, brake linings, clutch facings, plastics and linoleum in order to improve the whiteness of the product and also increase the percentage of coverage, thereby giving it a pure white look (Abubakar *et al*., 2015).

2.6.4 Rubber Industry

Barite is used in rubber industry to make products acid proof and alkali proof which is known to elongate the lifespan of the products. It also helps to reduce cost of production.

2.6.5 Pharmaceutical Industry

Due to its high density, barite is effective in blocking x-rays and gamma-rays emission and therefore making the digestive tract visible when taking X-ray photo of it that is, as a barium meal material for the intestines and stomach reflections. It is also used as filler and extender for plaster.

2.6.6 Glass Making Industry

Barite when crushed to coarse sand size can be used in glass making as a flux, makes the mix more workable and improves the brilliance of the glass (Ministry of Mines and Steel Development, 2008).

2.6.7 Cosmetics Industry

Due to barite’s gentle and mild effect on the skin, it finds application in the cosmetic industry. Barite is very popular in the cosmetics industry as it serves as a wonderful substitute to titanium dioxide.

2.7 Previous Works

Nasarawa State is known to be "Home of solid minerals" and the state is endowed with abundant mineral resources. The three major geological components that makeup the geology of Nigeria, namely, basement complex, younger granites and sedimentary rocks are all pronounced in the state. All known minerals that occur in the Nigerian geological environments are present in Nasarawa State (Obaje *et al*., 2007).

The rocks in Nasarawa State are the host to gold in Wamba; barite at Azara, Wuse and Aloshi; coals at Obi, Jangerigeri, Jangwa and Shankodi; tantalite at Afu, Udege Beki, and Wamba; gemstone in Keffi, Nasarawa Eggon and Kokona; salt deposits in Ribi, Keana and Awe; Limestone deposits at Adudu, and Jangwa, at Keffi, Akwanga, Nasarawa Eggon, Tudu Uku, etc. (Obaje *et al*. 2007).

Several works have been published on the occurrence of barite deposit in Nigeria. Few have also been published on the occurrence of barite within Nassarawa State.

Aladesanmi *et al*, (2018) worked on geological characterization of Azara barite mineralization, middle Benue Trough Nigeria; this study characterized Azara barite deposit using a combination of geotechnical, petrological and geochemical analysis in vein samples from the area. From their findings, it was revealed that Azara barite deposit occurred as vein infilling materials associated with Lead-Zinc lodes. The soluble alkaline earth metal test showed presence of calcium or magnesium which is good for drilling fluid. Hardness capacities of the veins mineralization were in the range of 3.0 to 3.5 with an average specific gravity of 4.2 which classify the veins as a high grade barite. Quantitative mineralogical analysis revealed barite as the main mineral with an average of 92 wt.% and quartz as an associated mineral with average of 8wt.%.

Tanko *et al*. (2015) used petrology and geochemistry to investigate the barite mineralization of Azara, Benue trough, Nigeria. The petrology and geochemical analysis were carried out on eight vein samples; four from known vein and another four from unknown vein samples. Their findings revealed that the weight percentage composition of barite in the samples are 86.39 %, 82.61 %, 81.48 %, 81.17 %, 79.82 %, 78.94 %, 76.82 % and 70.55 % respectively. It is deduced from this work that the chemical weathering of the carbonates resulted in two distinct types of barites; barite associated with mainly quartz (SiO_2) and limonite ($FeO(OH).nH_2O$) as major gangue and barite with siderite (ferrous carbonate with high amount of Mg) ankerite (Ca (Fe, Mg) (CO_3)) and calcite ($CaCO_3$). The outcomes were compared with the barite specification of 95.00 % and were found to be good for making drilling mud for use in the oil industry, paints and other chemicals.

Further, Oladapo *et al.*, (2011) investigated barite deposit in Tunga, Northeast Nigeria using geophysics. Gravity and electromagnetic methods were combined to characterize known veins and possibly unveil other concealed veins in Tunga, Northeastern Nigeria. Barite occurs in the study area as vein deposits hosted in clean sandstone rocks. Relatively high Bouguer anomalies were recorded over regions that are presumably underlain by barites. Barite mineralization potential varies from high gravity values of between 177.507 and 181.072 mGals to medium values of 174.681 and 176.801 mGals. Areas of low Bouguer anomaly were presumably barren. The variations in the Bouguer anomaly values are presumably influenced by the density contrast between the barite and the host rocks. Areas of high gravity values exhibit very low conductivity values (< 10 mS/m) and are presumed underlain by dense materials of low conductivity to which barite mineralization can be associated. Thus, according to this study, areas of high gravity values accompanied by low conductivities are associated with barite mineralization. The trend of mineralization in the area is southwest-wards in the direction of River Benue. Thus, higher barite mineralization potential probably exists beneath River Benue and its southern flank in Tunga area.

The Nigeria geological Survey Agency was the first to report about barite mineralization in Nigeria and as at that time no interest was shown with regards to its exploration (NGSA, 2011). However, between 1975 and 1980 the Nigerian Mining Corporation carried out exploration work on barites deposits in Azara District part of Nasarawa State in North Central Nigeria and a reserve estimate of about 730, 000 tonnes of barite was established over the area (Maiha, 1996). In 2004 the Federal Ministry of Solid Minerals Development (FMSMD, 2004) reported only two states with barite mineralization. But today we have more states with barites mineralization.

Barite- $BaSO_4$, the major source of barium is usually in coarse crystalline form associated with secondary minerals or gangue. Barite is not only produced from its deposit, but can also be processed from the ores of other minerals which exist as gangue with an intergrown appearance (Bulatovic and Bulatovic, 2015).

Barite vein deposits were geologically mapped with Vertical Electrical Sounding (VES) and Horizontal Resistivity Profiling (HRP). The geophysical data generated from 22 communities carried out in 52 locations showed the occurrence of barite vein deposits at a depth of 10-12.2m and can be up to 40m in an open pit mine. The lateral extent of the veins ranges from 4m to 65m from the horizontal resistivity profiling results, and could be traced from the field mapping to about 950m. The general direction of the barite mineralization is NE-SE. The reserve estimate results showed that Agoi village of Oban Massif has 1,981,177.0 metric tons of reserves; these are greater than the reserve found at Mamfe embayment villages of Ekukunela and Nkarasi with reserve deposits of about 865, 684 metric tons. These reserves are greater than those found in the lower Benue trough villages of Osina and Okpoma (Ogoja) with about 774, 345 metric tons of reserve deposits. An estimated reserve of over nine (9) million metric tons of barite have been calculated and documented for Cross River State for the first time. This has unarguably put Cross River State as having the largest reserve of barite in Nigeria (Dominic et al., 2014).

Barite ore samples from Azare in the Plateau State of Nigeria was analysed after jigging and magnetic separation beneficiation techniques, chemical analysis, and atomic absorption spectrophotometric analysis. The beneficiation study result showed that Azare barite can be beneficiated for use in the oil and gas industry and other industrial purposes. The content of barium sulphate is 98%, and this was as result of jigging operation. Comparison between jigging and magnetic separation shows that jigging produces a more satisfactory result. Magnetic separation gives 95.07% while jigging separation gives 98.95%. The valves for both jigging and magnetic separation are in agreement with the range of values of barium sulphate of 94%-98% required by the petroleum, paint and chemical industries (Ministry of Mines and Steel Development, 2008).

Barite vein in the Benue trough are not the only source of barite mineralization. There are at least ten barite fields in the trough, each containing swarms of veins of hydrothermal origin. The vein is of two trends in the trough: the NW-SE trend, which tends to be orthogonal to the axis of the trough; and the N-S to NNE-SSW trend, which is younger than the former. Both vein sets are formed from different post-sedimentary deformation phases in the trough. The veins are formed as a simple block profile whose width range a few centimeters to as high as 6m although widths are usually between 50cm and 1m. This implies that $BaSO_4$ concentrations in hydrothermal fluids in the trough were probably low during the Cretaceous period and the top of the vein has low quality barite, but deep down the vein the barite is of high quality. Hence mining in those veins of low quality barite should proceed by vertical stripping (Oden, 2012). An Okurike Barite deposit in Calabar Cross River State was investigated using Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT). Geophysical data were acquired and barite samples were analyzed in the laboratory in order to determine the ore composition and physical characteristics. The results indicated that barites occur with gravels, breccias and weathered basement materials within a very limited region. The physical characteristics of the barites are 4.4 for specific gravity, 3.64 g/cm^3 for density, 28% for porosity, 29.4kN/mm^2 for UCS (Uniaxial Compressive Strength) and 1.5% for water absorption. The barites are preferentially enriched in Ba (77.28%) and Fe (19.98%). The composition of other elements was less than 1%. BaO, Fe_2O_3 and MnO dominate the ore composition of the samples with percentage composition of 71.28, 21.40 and 6.10% respectively. These results show that the Okurike Barites are of high industrial quality with specific gravity higher than the API-specified value of 4.2 (Akpan, et al 2014).

Barite occurrences in the Calabar Flank, Oban massif, Mamfe Embayment and Obudu Plateau of Southeastern Nigeria have been sampled and analyzed for the purpose of assessing their chemical composition and industrial quality. Barite occurrences were observed mostly along faults and unconformities marking the boundaries between the Precambrian basement rocks of Oban and Obudu massifs and the Cretaceous sediments of the Calabar Flank and Mamfe embayment. Occurrences were also observed within the sediments. The chemical data show that $BaSO_4$, SiO_2 and TiO_2 are the major chemical species of the barite. The Ba and SO_4 content vary between 53.62 – 56.10 wt% and 27.57 – 39.35 wt% respectively across the sampled areas. The specific gravity is 4.45 and this combined with high $BaSO_4$ (approximately 94 wt%) shows that the mineralization is of high industrial quality and compares favourably with the Azara barite deposits of the Benue Trough. The quality of the barite meets American Petroleum institute (API) requirements for use as drilling mud (Ekwueme, et al, 2015)

Geochemical and geotechnical characterization of barite mineralisation in Lessel and Ihugh areas, Lower Benue Trough, Nigeria was carried out using ICP-AES and ICP-MS to chemically characterize barite ore samples. The veins at Lessel area contain minor amounts of quartz, galena and sphalerite as associated minerals. Geotechnical properties such as density, moisture content and uniaxial compressive strength tests were carried out. Barite veins from the Lessel-Ihugh area showed enrichment in Ba, Sr, depletion in major oxides and trace elements. Trace element data indicates Ba was leached from Ba-rich magmatic rocks. The interaction of Ba-rich fluid with sulphate-rich fluid led to the precipitation of barite under oxic and anoxic conditions in fractures during the Santonian to Campanian. Geotechnical investigations reveal that the Lessel-Ihugh barites have low uniaxial compressive strength (2.02 – 5.36 N/mm^2), moderate moisture content (0.42 – 1.18%) and specific gravity of (3.65 – 4.01). Based on the geochemical and geotechnical characteristics of barites in this study, the Lessel-Ihugh barite fall below international standard specifications, and are therefore of relatively moderate quality or Grade II barites (Labe, 2015).

In the oil and gas operations where drilling mud is required, barite is used extensively. Froth flotation as a beneficiation method was investigated using collectors (anionic and cationic) such as fatty amines and oleic acid in reverse and direct flotation of barite and effects of the collectors on flotation was studied. Assay of 96 percent $BaSO_4$, with SiO_2 less than one percent were obtained using cationic collectors. The interaction of the collectors on silica and barite were also investigated using Zeta-potential process which showed that fatty amines adsorb on silica by electrostatic interaction and cationic collector (oleic acid) adsorb on barite by chemisorption (Raju, et al, 2016).

Gabu, Alifokpa and Osina barite fields in Cross River State were studied. The research showed that barite deposits in these locations occur as disseminated nodules, stratabound as well as in two main vein sets. Barite ores geotechnical properties in these locations are: specific gravity of 3.1-4.5, water absorption (2 to 12%), porosity (0.1-0.5%), uniaxial compressive strength (11 and 43 N/mm^2) and Geochemical composition is as follows (BaO = 37.23-97.54%; Fe_2O_3 = 1.06-37.98%; CaO = 0.01-1.09%; SrO =0.11-2.17%; Hg = 0.01-0.019 ppm and Cd = 0.042-0.1 ppm). The geotechnical properties and Geochemical composition showed that barites in these locations are of high and low quality which depends on factors such as mining depth, quantity of associated minerals and location of the barite field (Godwin *et al*, 2012). Land degradation, landscape disruption, loss of economic deposits, dearth of mining data and contamination of ground and surface water sources are the results of abandoned mining surface excavation of barite ore fields. This study used field description and measurements, laboratory analysis and numerical simulation techniques to evaluate some abandoned barite fields in Nigeria with the aim of factoring geological and geotechnical issues that render excavations derelict (Ene and Okogbue, 2016).

Normal drilling fluid can control pressure formation during drilling up to 10 -12 ppg. In oil and gas drilling operation the pressure encountered could be as high as 20 ppg. Hence to control the formation pressures and prevent blow out, barite is preferred as a weighting material because of its low cost, purity, availability, non-toxicity and its expenditure is usually one half of the entire mud cost. Therefore, barite samples from Rabigh area of Saudi Arabia were collected and characterized. The analysis from the investigation showed that the local barite in Saudi Arabia is comparable to commercial barite in terms of quality (Al-Awad and Al-qusabi, 2000).

Barite samples from Hazara in Pakistan were analyzed using X-ray diffraction (XRD), scanning electron microscope (SEM) and energy dispersive spectroscopy (EDS). The result showed the presence of barium strontium sulphate with sulfur as the second phase with micro irregular shaped and small grains of quartz. The elemental composition indicated that the barite samples contains 74-76 percent weight of Ba along with small amounts (24-26 percent weight) of Sulfur and Strontium (Haq et al, 2009).

Characterization and flotation of barite concentrate in Indonesia were carried out with the aim to having $BaSO_4$ with a composition of at least 60 percent BaO and less than 6.5 percent Silica (SiO_2). The result of the study showed that the raw barite ore had a smooth texture, composed of $BaSO_4$ in barite and silica in quartz. The flotation condition gave $BaSO_4$ (93.04% grade), silica (6.3%) and 92.23% recovery (Araujo et al, 2006).

Gravity preconcentration and direct flotation beneficiation methods were conducted using barite samples in the Southwest area of China. Results from both beneficiation methods showed that direct flotation is preferred to gravity preconcentration in terms of obtaining the valuable mineral from the gangue. Floatation experiment gave an assay of 98.21% $BaSO_4$ with recovery of 80.71%. The collector used is sodium oleate and water glass depressant (Zhao et al, 2014). Marine Sediments contain Barite (BaSO4) which is used for paleo-productivity reconstructions. Sediment samples collected from tropical North Atlantic and Central North Pacific oceans were analyzed using a scanning electron microscope (SEM) that has energy dispersive spectrometer (EDX). Results showed that the marine sediment contain barite and detrital aluminosilicates which have ratios of 0.005 to 0.008 averaging value around 0.0066 (Robin et al., 2003).

Modelling of beneficiation plant for barite was done in order to optimize barite processing. Experimental field data were used for the modelling in order to determine the performance of the machinery and the characteristics of the feed material and this were processed with the help of a computer to find the ideal setting of each segment and in order to maximize profit, in respect of the type of ore fed into the beneficiation plant. Furthermore, the benefits of blending different concentrates were also presented (Ciccu et al, 1987).

Four types of barite samples were analyzed in Minas Gerais Brazil using flotation with the aim of achieving a minimum of 60% of BaO and less than 6% of silica (SiO_2) with different types of collectors. Flotation was used because the samples are rich in sulphide. The best of the four samples has BaO greater than 64%, the silica lower than 3.3% and a recovery of 79% BaO (Leite and Corrêa, 2007).

The work of Dera et al, (2017) in Indonesia investigated the formation of $BaSO_4$ scale deposit in pipes. The $BaSO_4$ scale deposit were analyzed using scanning electron microscope (SEM) furnished by EDX in order to study the barite crystal morphology and elemental analysis. XRD helped to identify crystalline phases. SEM result showed barite with a star-like morphology and the barite crystal formed is pure.

2.8 Knowledge Gap

Despite all the above previous studies, there is no known data on physic-chemical characteristics on barite mineralization in Ribi, Nasarawa State. The barite data for this study area becomes imperative for the classification of the mineral in the area for industrial applications.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

The methodology adopted in this work includes; Desk study and literature search, fieldwork, site visitation and sampling, geochemical and geotechnical sampling.

3.1 Desk Study and Literature Search

This involves assessing the literature and reports from Nigeria Geological Survey (NGSA), Nigeria mining cadastre office and other sources. Literature review of available scholastic journals relating to barite mineralization, its modes of formations, geochemical data and their industrial applications as well as checking the Oil Company Materials Association (OSMA) and America Petroleum Institute (API) standards. In addition, information about the study area such as safety, geology, accessibility, topography and feasibility of the project were obtained

3.2 Fieldwork

The fieldwork was carried out at Ribi in Awe local government of Nasarawa State and the materials used for the work are as spelt out below:

- Compass clinometer
- Hammer
- Sample bag
- Measuring tape
- Marker pen
- Notebook

- G.P.S.
- Hand lens
- Pencil and eraser

3.3 Site Visitation and Sampling

These involve visiting of barite mineralization area and sites in order to obtain data about the origin, mode of occurrence, structures and other information regarding to barite in-situ. Systematic and target sampling of barites was also carried out where samples were taken and the coordinates of the areas were recorded. Some measurements such as the vein width, trending of the minerals were also done.

3.4 Analysis

Experimental analysis such as measurement of specific gravity of the samples and EDX analysis were carried out, in order to determine some physic-chemical characteristics of various ores of barites in the study area. Also, comparative analysis in relation to global best grades of barites for drilling muds was done.

3.4.1 Determination of Specific Gravity Using Pycnometer Method

Apparatus Used

- Pycnometer.
- Thermometer
- Sensitive weighing balance
- Distilled water

- Oven
- Spatula
- Volumetric flask

Test Procedure for Specific Gravity Determination

The Specific Gravity determination was carried out according to the standard procedure as follows:

a. The weight of the empty clean and dry pycnometer was determined and recorded as *M1*.

b. Some grams of the powdered barite sample (passed through 200µm sieve) was placed inside the pycnometer and the weight of the pycnometer containing the barite sample was recorded determined and recorded as *M2*.

c. Distilled water was added to fill the pycnometer to the marked spot and the sample was soaked for 24hours.

d. The entrapped air was removed.

e. The pycnometer was filled with distilled water (to the mark) and recorded as *M4*, the exterior surface of the pycnometer was cleaned and with a dry cloth to avoid inaccurate measurement.

f. The weight of the pycnometer containing distilled water and barite sample was determined and recorded as *M5*.

g. The pycnometer was emptied and cleaned, then filled with water only to the marked spot and the external surface was cleaned with dry cloth.

Calculations

Specific gravity (SG) = $\left(\frac{M3}{M3-(M4-M5)}\right)$ {According to ASTM D854 standard procedure}

Where

M_1= weight of density bottle (pycnometer)

M_2= weight of bottle and barite sample

M_3 = weight of the barite sample only= M_2- M_1

M_4= = weight of bottle and liquid

M_5=weight of pycnometer + barite sample +water

Fig. 3.1: Apparatus Used for Specific Gravity Determination

3.4.2 EDX analysis of the Samples

Sample Preparation

Pulverization: The samples were pulverized using Arget pulverizing machine (planetary micro mill pulverisette 7). The ground samples were ensured to pass 150 micro mesh sieves. This was to ensure homogeneity of the samples.

Pelletization: 5g of the pulverized sample was weighed into a beaker, with 1g of binding aid (Starch soluble). The mixture was thoroughly mixed to ensure homogeneity, which was pelletized, labeled and packaged ready for the analysis.

Procedure of the Analysis:

Energy Dispersive x-ray fluorescence (EDXRF) spectrometer of model "Minipal 4" was used for the analysis.

The pellets were carefully placed in the respective measuring positions on a sample changer of the machine. The following condition sets were made as the machine was switched on.

- Type of Examination/Analysis: Elemental composition determination

- Form of Sample: The samples to be analyzed were in powder form (pellet)

- Voltage: The voltage used is 14kv for major oxides, 20kv for the trace elements/rare earth metals, according to the specified calibration of the equipment used.

- Filters: Selected filters were "kapton" for major oxides, Ag/Al-thin for the trace elements/rare earth metals.

The selection of filters was guided by a given periodic table used for elemental analysis. Time of measurement for each sample was 100 seconds and the medium used was air throughout. The machine was then calibrated, after which the respective samples were measured by clicking the respective positions of the sample changer.

3.4.3 Energy-dispersive X-ray Spectroscopy

Energy-dispersive X-ray spectroscopy (EDS, EDX, EDXS or XEDS), sometimes called energy dispersive X-ray analysis (EDXA) or energy dispersive X-ray microanalysis (EDXMA), is an analytical technique used for the elemental analysis or chemical characterization of a sample (Fig. 3.2 EDX mode). It relies on an interaction of some source of X-ray excitation and a sample. Its characterization capabilities are due in large part to the fundamental principle that

Fig. 3.2: Scanning Electron Microscope Instrument in EDX Mode

each element has a unique atomic structure allowing a unique set of peaks on its electromagnetic emission spectrum (Goldstein, 2003) (which is the main principle of spectroscopy).

To stimulate the emission of characteristic X-rays from a specimen a beam of X-rays is focused into the sample being studied. At rest, an atom within the sample contains ground state (or unexcited) electrons in discrete energy levels or electron shells bound to the nucleus. The incident beam may excite an electron in an inner shell, ejecting it from the shell while creating an electron hole where the electron was. An electron from an outer, higher-energy shell then fills the hole, and the difference in energy between the higher-energy shell and the lower energy shell may be released in the form of an X-ray. The number and energy of the X-rays emitted from a specimen can be measured by an energy-dispersive spectrometer. As the energies of the X-rays are characteristic of the difference in energy between the two shells and of the atomic structure of the emitting element, EDX allows the elemental composition of the specimen to be measured (Goldstein, 2003). It should be noted that Scanning electron microscope (SEM) model Fei inspect S50 has several modes that enables it carries out several analyses, and this was used to analyze the sample.

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CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Site Visitation

Several mine sites within the area of study were visited and samples were collected. This was done in order to confirm the presence of Barite in the area of study (fig. 4.1 to 4.3). The coordinates of the Barite locations are given in the Table 4.1;

Table 4.1: Locations of Barite Mines Visited

S/N	Coordinates	Locality
1	N8^{o}6’8.45028”, E9^{o}8’7.88”	Ibi and Ribi
2	N8^{o}24’58.99716”, E9^{o}8’3.99156”	Ibi and Ribi
3	N8^{o}24’24.7990”, E9^{o}8’6.96510”	Yumaco Mining Co.
4	N8^{o}24’23.25528”, E9^{o}7’58.83276”	Yumaco Mining Co
5	N8^{o}22’1.48001”, E9^{o}17’49.0218”	Azara
6	N8^{o}22’4.7062”, E9^{o}18’20.295”	Azara

Fig. 4.1: Barite Mine Pit in Ribi

Fig. 4.2: Barite Trench at Mine Site in Ribi

Fig. 4.3: Gangue Hill at Ribi Mine Site

4.2 Specific Gravity Determination

Specific gravity results of the analyzed barite samples are presented in Table 4.2.

Table 4.2: Specific Gravity Analysis Results

	A	B	C	D	E	F	G	H	I	J
M1 = (Mass of empty clean Pycnometer)	17.6988	18.1432	17.7070	19.1005	17.7141	17.0274	16.5783	18.2975	18.0158	17.7601
M2 = (Mass of Pycnometer + Barite sample)	24.2124	22.9032	22.1746	24.7453	25.2921	22.8756	25.3465	30.6907	31.6039	29.3577
M3 = (Mass of the Dry Barite sample) = M1-M2	6.5136	4.76	4.4676	5.6448	7.5780	5.8482	8.7682	12.3932	13.5881	11.5976
M4= Mass of Pycnometer + Water fill to mark	46.6225	46.9885	46.9813	47.5961	46.7395	45.8195	45.8917	46.9568	46.5677	46.6390
M5 = Mass of Pycnometer + soil + distill water fill to mark	51.5991	50.6257	50.3888	51.888	52.4887	50.2530	52.5504	56.4218	56.9707	55.5229
Specific Gravity = M3/ M3+(M4-M5)	**4.24**	**4.24**	**4.22**	**4.17**	**4.14**	**4.13**	**4.16**	**4.23**	**4.27**	**4.27**

From the specific gravity results, it can be clearly seen that the specific gravity values of the analyzed samples ranged from 4.13 to 4.27. Of all the ten samples collected, only four samples have specific gravity values that fall below 4.2 (samples D,E,F, and G), six of the ten samples have specific gravity values that fall above 4.2 (samples A, B, C, H, I, J). These results are also shown as a bar chart in Figure 4.4. The specific gravity values obtained in this work are close to those obtained in Okurike in Cross River State by Akpan et al (2014), which the authors have classified as high purity barite. They are also within the range obtained around Gabu, Alifokpa and Osina barite fields ((Godwin et al, 2012). Furthermore, with the average Specific Gravity from Table 4.2 being 4.2, there is an agreement with the early reported around the area by previous researchers especially in Azara (which is a town close to Ribi) by Aladesanmi *et al* 2018. It is believed that barite from other barite deposits would not be considerably different. The acceptable standard specified by the American Petroleum Institute (API) and department of petroleum Resources (DPR) is 4.21. As a result, samples D, E, F, and G are not suitable for use in industry while samples A, B, C, H, I, J are favourable for use in the industry. It can be inferred that 60% of the samples have specific gravity that is above the standard minimum specification for barites for oil and gas applications.

However, samples that fall below standard can further be upgraded for suitable use through the addition of suitable beneficiation processes.

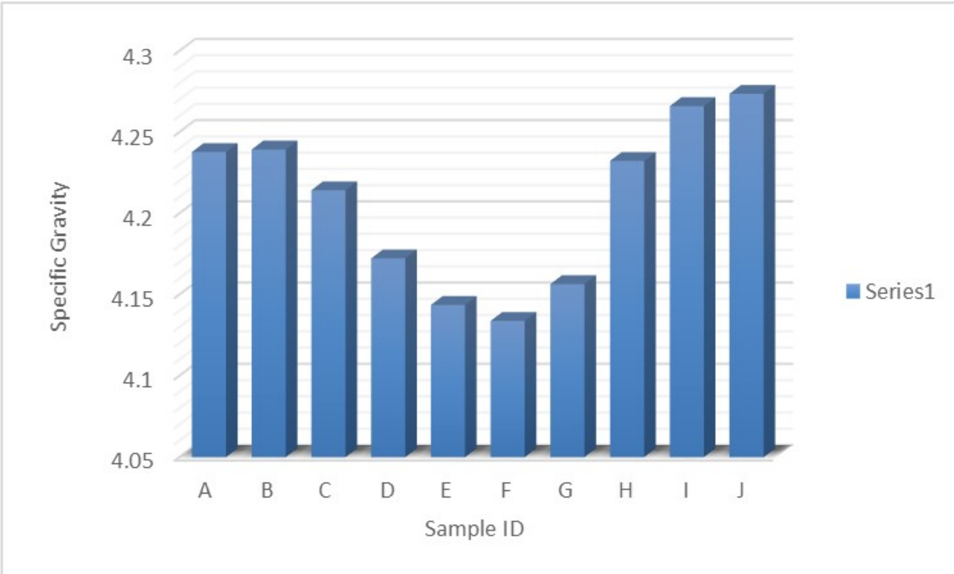

Fig. 4.4: Statistical Presentation of Specific Gravity Results of the Collected Samples

4.3 EDX Analysis

The Energy Dispersive X-ray spectroscopy results of some of the barite samples A to E are shown in Tables 4.3 to 4.7 while the EDX spectra for samples a to D are shown in Figures Figure 4.5 to 4.8.

Table 4.3: EDX Analysis Result Table for Sample A

Element	Weight %	Atomic %	Error %	Net Int.	K Ratio	Z	R	A	F
O K	0.49	2.81	29.87	5.57	0.0031	1.5183	0.7607	0.4098	1
S K	14.56	41.18	5.95	323.86	0.1395	1.361	0.8375	0.6908	1.0187
Te L	0.92	0.66	56.4	6.72	0.0097	0.943	1.0268	0.9738	1.1402
Ba L	79.24	52.31	3.98	366.1	0.7583	0.9316	1.0388	0.998	1.0293
Ce L	2.33	1.51	43.45	10.08	0.0219	0.9389	1.0433	0.9659	1.0367
Nd L	2.44	1.54	46	9.1	0.0227	0.9361	1.0466	0.9618	1.0325

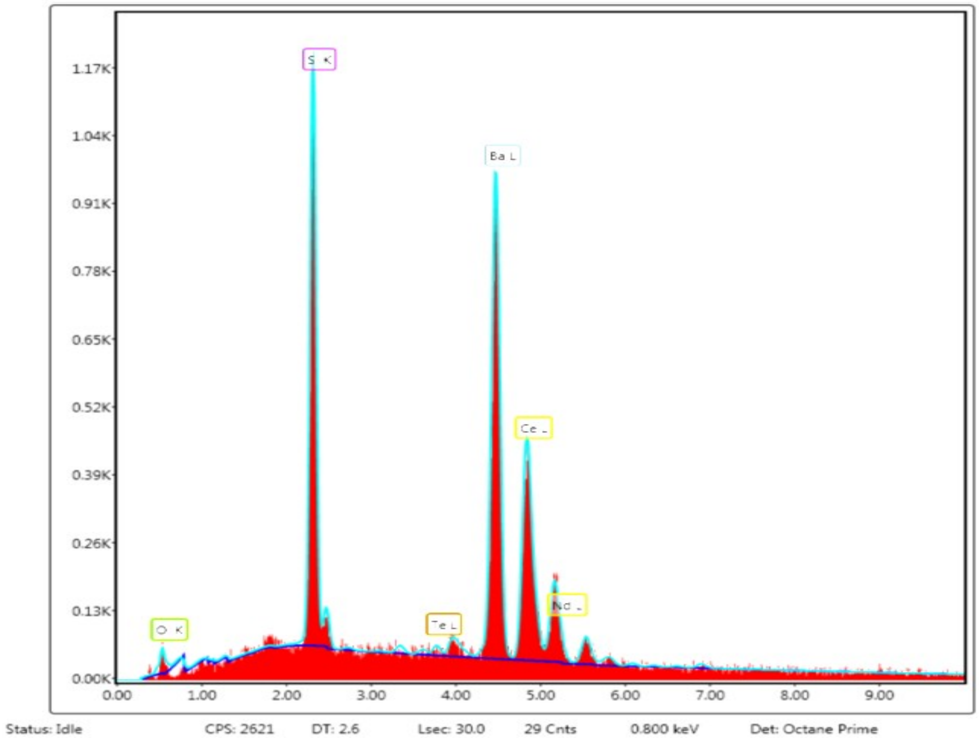

Fig. 4.5: EDX Spectrum of Sample A.

Table 4.4: EDX Analysis Result Table for Sample B

Element	Weight %	Atomic %	Error %	Net Int.	K Ratio	Z	R	A	F
O K	0.56	3.16	28.81	5.46	0.0034	1.5185	0.7609	0.405	1
S K	14.46	40.83	6.05	282.1	0.1379	1.3613	0.8377	0.6875	1.0189
Te L	0.73	0.52	56.8	4.68	0.0077	0.9432	1.027	0.9741	1.1424
Ba L	81.34	53.61	4.4	330.82	0.7787	0.9318	1.039	0.9986	1.0289
Ce L	2.91	1.88	39.98	11.04	0.0273	0.9391	1.0435	0.9648	1.0361

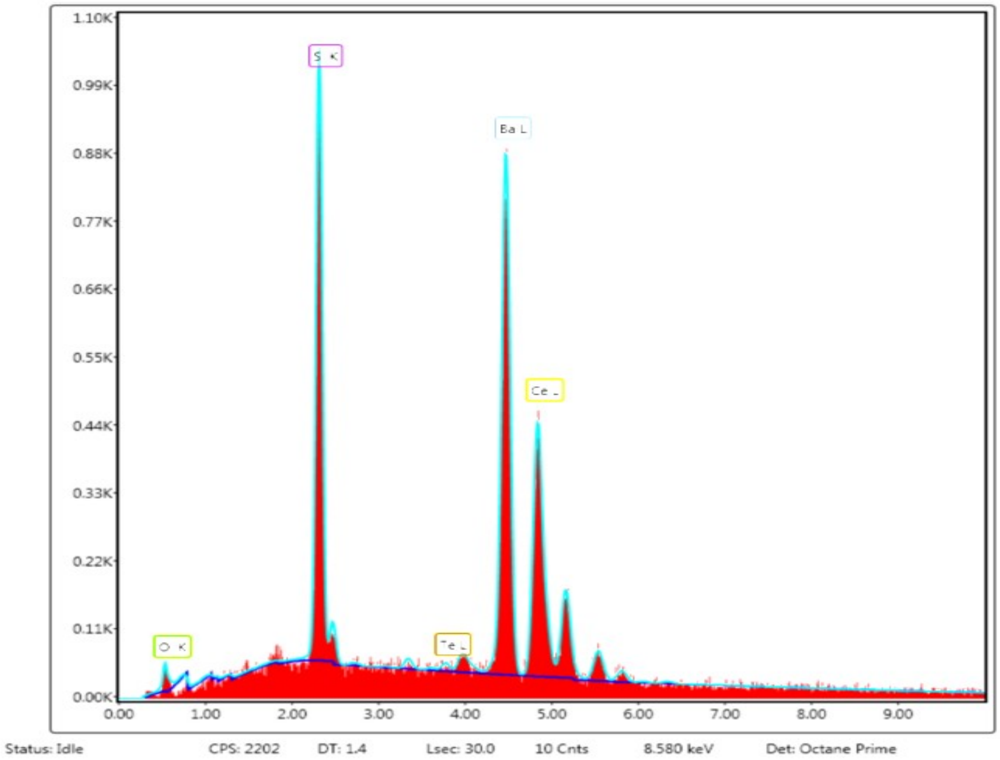

Fig. 4.6: EDX Spectrum of Sample B

Table 4.5: EDX Analysis Result Table for Sample C

Element	Weight %	Atomic %	Error %	Net Int.	K Ratio	Z	R	A	F
O K	0.48	2.7	29.27	5.89	0.0029	1.5183	0.7608	0.4033	1
S K	14.59	41.25	5.88	363.27	0.1399	1.3611	0.8376	0.6915	1.019
Te L	0.42	0.3	57.03	3.43	0.0044	0.943	1.0269	0.9742	1.1445
Cs L	0.46	0.31	61.79	3.09	0.0049	0.9487	1.0363	0.994	1.1514
Ba L	79.88	52.74	3.8	413.22	0.7652	0.9317	1.0389	0.9989	1.0293
Ce L	4.18	2.7	34.66	20.18	0.0393	0.9389	1.0434	0.9662	1.0362

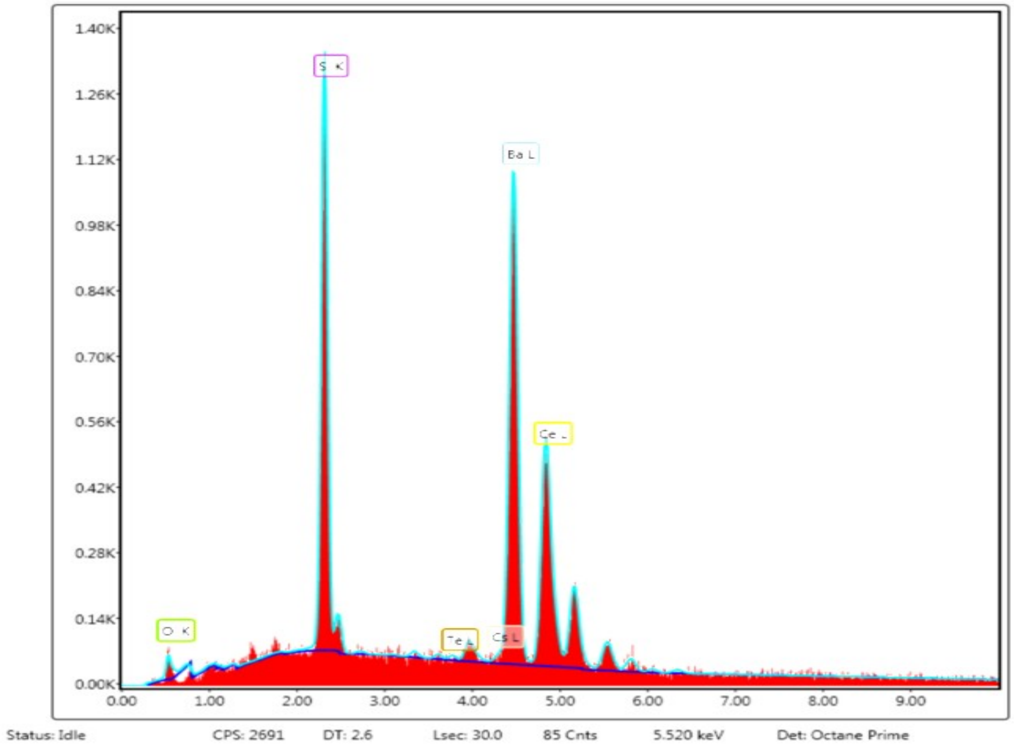

Fig. 4.7: EDX Spectrum of Sample C

Table 4.6: EDX Analysis Result Table for Sample D

Element	Weight %	Atomic %	Error %	Net Int.	K Ratio	Z	R	A	F
O K	0.52	2.82	28.37	6.2	0.0033	1.5009	0.7681	0.4159	1
S K	14.18	38.27	5.82	333.17	0.1362	1.3455	0.8451	0.7008	1.0186
Te L	0.52	0.35	56.32	3.94	0.0054	0.9317	1.0351	0.9789	1.1414
Ba L	76.52	48.21	3.9	369.97	0.7268	0.92	1.0467	1.0022	1.0301
Ce L	2.65	1.64	40.22	11.99	0.0248	0.927	1.0508	0.9713	1.0376
Cr K	0.16	0.26	68.77	1.38	0.0017	1.1868	0.9148	0.8831	1.0249
Fe K	5.45	8.45	16.04	32.97	0.0596	1.1907	0.933	0.8868	1.035

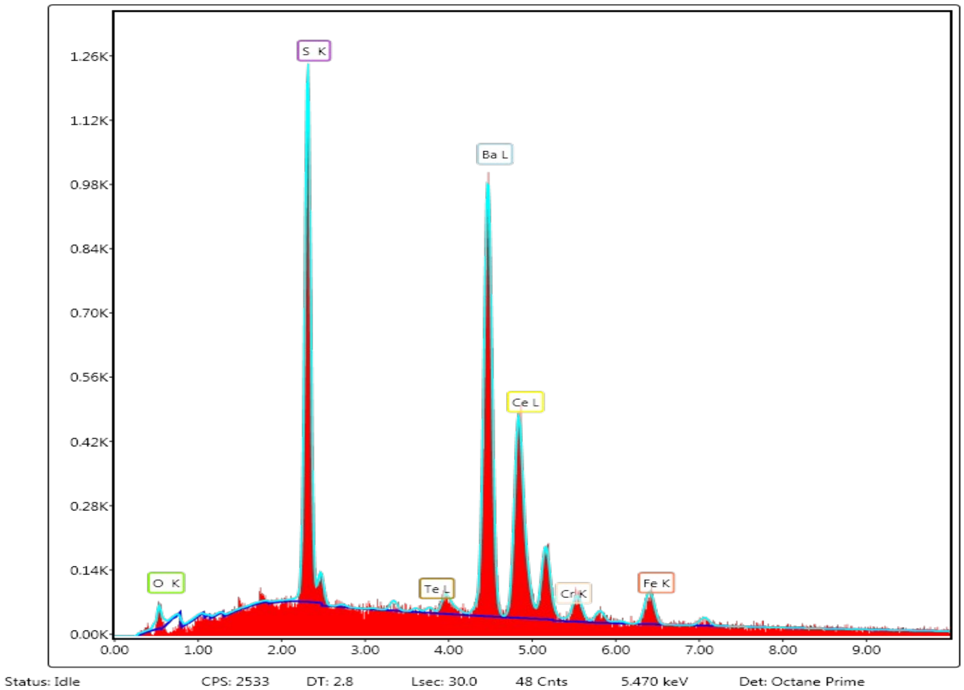

Fig. 4.8: Chemical Composition in Sample D

Table 4.7: EDX Analysis Result Table for Sample E

Element	Weight %	Atomic %	Error %	Net Int.	K Ratio	Z	R	A	F
O K	0.62	3.47	27.64	6.37	0.0038	1.5163	0.7615	0.4089	1
S K	14.65	41.04	6.01	299.7	0.1403	1.3593	0.8383	0.6913	1.0189
Ca K	0.1	0.23	70.32	1.62	0.0013	1.3206	0.8734	0.8747	1.0959
Te L	0.36	0.26	58.1	2.45	0.0038	0.9418	1.0277	0.9741	1.1442
Ba L	81.33	53.18	4.03	345.46	0.7778	0.9304	1.0397	0.9989	1.029
Nd L	2.93	1.82	43.73	10.01	0.0272	0.9348	1.0474	0.9618	1.0322

Table 4.8: API Specifications for Barite (Beroil, 2010)

Requirements	**Unit**	**Specification**
Specific Gravity	Gr/cm^3	Min 4.20

$BaSO_4$	-	90% min
Soluble alkaline earth metals as calcium	Ppm	Max 250
Extractable Carbonates	Mg/I	3000 max
Moisture	W.t%	1.00% max
Residue > 75 micrometers	w.t %	3.00% max
Less than 6µm	W.t %	Max 30
Hg	Ppm	1.00 ppm Max
Cd	Ppm	3.00 ppm Max

From Tables 4.3 to 4.7 and Figure 4.5 to 4.8, it could be seen that the concentration of Ba is very high in all the samples, with Ba being the dominant mineral in all the samples followed by Sulphur. This confirms the presence of Barite ore in the area of study, and implies that these areas can be a useful site for sourcing for barite deposits for the industries.

Further, Table 4.8 shows API specification of barite sample as drilling fluid. The barite samples contain negligible amount of Hg and Cd, making it suitable for application as a constituent of drilling fluid in the petroleum industry.

In addition, the field work reveals that barite in Ribi are hosted in sandstone as a vein deposit which according to NGSA 2009, Oladapo *et al* 2011 and Oden 2012, barite in Bakyu Nasarawa are also hosted in sandstones which implies that there is a similarity between the mode of formation earlier reported and the field mapping in Ribi. However, other areas within Nasarawa State show contrary, with them showing hydrothermal deposits as their mode of formation.

EDX analysis results of samples A, B, C, D, E revealed that the weight percent of Ba are 79.24%, 81.34%, 79.88%, 76.52%, 81.33% respectively. Although these are less than the API standard which stipulated that barite for oil and gas must contain a minimum of 90% $BaSO_4$ according to Table 4.8. However, industries such as paper, glass, paint, plastic and rubber industries which require lower grade barite can make use of it. Beneficiation of Ribi barite can also upgrade the Ba content since other parameters especially the Specific Gravity is within the stipulated standard of 4.2. The absence of Hg and Cd from the EDX results show that barite in Ribi are free from Hg and Cd or present in a very minute and negligible amount. More so, the Ba content are also close to those that have been reported by Akpan *et al* 2014 reported an average Ba content of 71.28% from Okurike and Tanko *el al* (2015) which reported 76.82%, 78.94, 81.48%, 82.61% and 86.39%. These values show that the barite in the Benue trough is very similar in their chemical characteristics.

One of the fields in China shows EDX result of Ba content of 44.11% (Dera et al, 2017), yet China is one of the greatest exporter of barite in the world. For instance, that country accounted for about 64% of the barite imported into the US in 2012 (USSA, 2016). It is believed that the barite from China is upgraded through appropriate beneficiation processes, giving rise to a quality of 98.21% $BaSO_4$ (Zhao et al, 2014). In Indonesia, the barite was also upgraded to a quality of 93.04% (Arajuo et al, 2006). In the same vein, barite from Pakistan analyzed between 74 and 76% Ba (Haq et al, 2009), but the country exported over 1.3 tonnes to the US alone in 2012 (USSA, 2016). Again, it is believed that the barite from that country has gone through appropriate upgrading processes. The commodity from other countries may have gone through similar processes to pass the API standard for use in the oil industry as well as other industrial applications.

Despite the unstable prices in crude oil, it has been predicted that demand for barite is likely to increase (USSA, 2016). Currently, China's barite exports have decrease in recent years owing to reduced mine output and increased domestic consumption (USSA, 2016). With Nigeria's vast deposit resources, the country stands a great chance in becoming one of the greatest high quality barite producers if appropriate beneficiation routes are employed. Furthermore, there are benefits derivable from blending different concentrates (Ciccu et al, 1987).

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary and Conclusion

This study aimed at characterizing and evaluating the viability of barite deposits within Ribi for industrial applications. There is an inadequacy of information as regards mineralization, chemical and geotechnical properties of barite ores in the area of study. Field work was carried out to investigate the various mining sites where barite deposits are being mined and for sample collections. Ten barite samples were collected from various mining locations within Ribi and the samples were taken to the laboratory for chemical and geotechnical analysis. Specific gravity analysis was carried out in the laboratory using Pycnometer method; this was done so as to classify the barite samples' viability for industrial application according to the American Petroleum Institute (API) standard.

From the result of the analysis, specific gravity values of the samples ranged from 4.13 to 4.27. Six of the samples have specific gravity values that fell above 4.2 while four of the samples have specific gravity values that fell below 4.2. According to American Petroleum Institute, specific gravity values of 4.2 and above are recommended for barite of industrial value. Also, EDX results revealed the spatial chemical variation within the analyzed samples, Ba have weight % values that ranged between 70-82 % confirming it as the dominant mineral within the sample followed by S with values that ranged from 14.4 -14.6 %. Both minerals also have the highest peak on the EDX graph. Other elements within the samples are Nd, Te, Ca, O, Cs, Ce, all appearing as traces within the samples.

From the above, it can be concluded that Barite mineralization is present in Ribi, and that Barite samples from Ribi are good enough for industrial applications especially when beneficiated. However, follow up detailed exploration and characterization are expected to be worthwhile in further revealing the various properties of these barite samples, not only for the Ribi fields, but also for other deposit resources across the country.

5.2 Recommendations

At the end of this study, the following are strongly recommended;

1. Detailed geological mapping of the area of study should be carried out; this will help to ascertain the host rock and style of mineralization in the study area.
2. XRF and XRD analysis to further reveal the major and minor elements and oxides present within the samples from Ribi.
3. A GIS and remote sensing approach should be used to map spectral signatures of Barite alteration across the study area; this will help to reveal the extent of mineralization in the area of study.
4. Furthermore, a geophysical investigation along with further characterization should be done to further map the structures that could play host to barite mineralization and revelation of the physic-chemical characteritics, not only the studied part of Nassarawa State, but also for other barite locations across the country.

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