TECHNICAL ASSESSMENT OF MINING SITE AND BARITE QUALITY IN NIGERIA

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by

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CERTIFICATION

This is to certify that the thesis titled “Technical Assessment of Mining Site and Barite Quality in Nigeria” submitted to the school of postgraduate studies, African University of Science and Technology (AUST), Abuja, Nigeria for the award of Master's degree, is a record of original research carried out by Ebunu Abraham Ighoro in the Department of Materials Science and Engineering.

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ABSTRACT

Barite is an exceptional non-metallic mineral composed of barium sulphate and it is used mainly by the oil and gas industry as drilling mud in deep drilling, where high pressure is encountered. The specific gravity of barite should range from 4.2 to 4.6 in order to be used as drilling mud. In Nigeria, barite deposits are found in veins and cavities hosted by varieties of rocks. In this work, barite deposits in various troughs of Nigeria have been sampled and analysed for the purpose of assessing their chemical composition and industrial quality. The specific gravity of barites in the following states, coded as: A (Zamfara), B (Nasarawa), C (Benue), D (Plateau), E (Cross River) and G (Taraba), were determined using the Pycnometer method, and their values were found to range from 2.9 to 4.3. The sedimentation process showed that the particle size distribution of the barite samples were good for drilling-mud application. The results of XRF and SEM analysis of the samples showed a predominance of BaO, Fe_2O_3 and SiO_2. Samples C and G met the API standard for drilling mud, while samples E, B and D need to beneficiated to be comparable to commercial barite for drilling mud.

Keywords: Barite, Quality Assessment, Benue Trough

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DEDICATION

This thesis is dedicated to the almighty God Jehovah, and to my parents for their loving support and encouragement.

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CHAPTER ONE: OVERVIEW

1.1 INTRODUCTION

Nigeria holds a rich abundance of solid mineral deposits. Various kinds, such as barites, gold, bentonite, gypsum, etc., are mined by artisanal miners, and have not been explored or exploited to their fullest potential. One of the objectives of the new National Policy of Nigeria on Solid Minerals is to ensure the orderly development of the mineral resources of the country. In Nigeria, mining contributes only between 0.5%-0.6% to the country's GDP (Ministry of Mines and Steel Development, 2016) because the focus is on oil resources. The underdevelopment of the mining industry means Nigeria imports the minerals that the country could be producing domestically (Ministry of Mines and Steel Development, 2016).

There are about 44 different types of minerals that have been identified in more than 500 locations, and one of them is the solid mineral barite. Barite is an exceptional non-metallic mineral and is composed of barium sulphate with a specific gravity ranging from 4.2 to 4.6, depending on the industrial application. It is commonly white to light-grey, blueish to brown, or nearly black. Generally it is opaque with hardness values of between 2.5 and 3.5. Different localities are said to produce hard or soft barites (Nigeria Geological Survey Agency, 2011). It naturally occurs with a range of accessory minerals, such as quartz, chert, dolomite, calcite, siderite and metal sulphides. The mineral occurs in veins, stratiform beds and residual deposits. The largest global deposits currently mined are stratiform beds in China, India and the US.

Barite is used primarily for its high specific gravity, in addition to its chemical and physical inertness, relative softness and very low solubility. World production of barites increased from 6.0 million tonnes per annum (tpa) to 6.5 million tpa in the early 2000s and went up to 9.7 million tonnes in 2014. In 2015, it dropped to 8 million tonnes and to 7.3 million tonnes in 2016 due to low oil prices and reduced drilling activity. China accounts for 40% of barite world production; with India, Morocco, USA, Turkey, Russia, Mexico, Iran, Kazakhstan and Thailand accounting for around 50%.

The USA was only the second largest consumer at around 1.6 million tpa in 2016 – down from nearly 2 million tonnes in 2014; the Middle East used 1.7 million tonnes, and China used 1.5 million tonnes. In 2004, Nigeria produced 7,800 tonnes (Nigeria Geological Survey Agency, 2011) and imported 13,678 tonnes in 2012, and 17,406 tonnes in 2015 (Industrial Mineral Forum and Research, 2017). Estimated world barite consumption was about 7.3 million tonnes in 2016 (The Baryztes Association, 2017a).

In Nigeria, barite deposits are found in veins and cavity fillings hosted by a variety of rocks. They are largely used by the oil and gas industry as drilling mud in high-pressure deep drilling at depths where heavy circulating fluid is required to control the reservoir pressure and prevent blow outs. Barites are also used by chemical industries in the manufacture of barium compounds or chemicals, and by paint- and glass-making industries. Barite deposits can be found in nine states in Nigeria, viz, Adamawa, Gombe, Zamfara Plateau, Cross River, Benue, Nasarawa, Taraba and Ebonyi. Between 2005 and 2009, the Nigeria Geological Survey Agency carried out a comprehensive appraisal of Nigeria's barites resources. It gave a reserve estimate of eight states to be 22,298,843 tonnes for an average vein depth of 20 meters and specific gravity of 4.2 (Nigeria Geological Survey Agency, 2011). However, in 2010, the Raw Materials Research Development Council (RMRDC) gave a reserve estimate of over two million (2,000,000) tonnes of barite ore scattered in different parts of the country (Onwualu et al., 2013).

1.2 OBJECTIVES

The objectives of the research were to:

- obtain data on reserve estimates of barite in Nigeria;
- identify some barite mining sites in Nigeria;
- characterize barite ore samples from some locations in Nigeria;
- compare barite from Nigeria with that of the global standard;
- assess research and development needs for optimizing Nigeria's barite.

1.3 STATEMENT OF PURPOSE

This project work will endeavour to estimate the available barite reserves, gauge the quality of barite in some parts of Nigeria, and compare barites in Nigeria with those from other parts of the world.

The aim is to understand barite use in Nigeria, and find out why barite is imported when there are abundant, unexploited barite reserves in the country.

1.4 SCOPE OF WORK

The barite deposits are located in the north-east, specifically along the Benue Trough, which includes states like Benue, Taraba and Adamawa; towards the north (Nasarawa, Plateau and Gombe states) and to the south fringe of Cross River. In addition, barite deposits are also found in Zamfara and Katsina in the north-west.

- Chapter two presents the occurrence of barite deposits in Nigeria, previous work on barites, research and development gaps, and the global standard for barites.
- Chapter three presents research methods that include survey, sampling, and laboratory analysis of barites samples from different locations in Nigeria.
- Chapter four presents and discusses the result of the laboratory analysis of barites samples.
- Chapter five provides a conclusion and recommendations.

1.5 JUSTIFICATION FOR THE STUDY

The major source of income for the Nigerian economy is the oil and gas industry and, as long as the activities of the petroleum industry are maintained, barite will be essential for its success. It is one of the raw materials needed for drilling mud in deep drilling in order to control reservoir pressure and prevent blow out. Barite is a non-metallic solid mineral with a minimum specific gravity of 4.2 and forms part of the circulating fluid required for drilling. In Nigeria, most of the barites used by the oil and gas industries are imported. For example, 17,406 tonnes were imported from China, USA, and UK in 2015; while 13,678 tonnes were imported from the Netherlands in 2012 (Industrial Mineral Forum and Research, 2017).

Hence, to change this, it becomes necessary to give data and information on barites in Nigeria, with respect to the occurrence, reserves estimate, mining sites and the processing and quality of barites in the country. It is hoped that this will attract investors, especially the oil exploration industries, since they are the major consumers of barites. It is our wish that they explore and exploit the large reserves of barite deposits in Nigeria.

CHAPTER TWO: LITERATURE REVIEW

2.1 BARITES

Barite is a solid mineral made up of barium and salt of sulphur. It is composed of barium sulphate ($BaSO_4$). The word barite is derived from the Greek “barys” which means “heavy”. It is with regards to its high specific gravity which makes it exceptionally suitable for its many applications in areas of medicine, manufacturing and industry. Barite is the principal ore of barium. Pure barite contain the following (http://www.webmineral.com/data/Barite, retrieved August 11, 2017):

Chemical Formula:	$BaSO_4$	
Composition:	Molecular Weight = 233.39 gm	
Barium:	58.84 % Ba	65.70 % BaO
Sulfur:	13.74 % S	34.30 % SO_3
Oxygen:	27.42 % O	
	______	____
	100.00 %	100.00 % = TOTAL OXIDE

Barites appear in nature as granular or crystalline masses, nodules, rosette-like aggregates, and also in laminated massive beds of fine crystallinity. Specific gravity, crystallinity, and its cleavage distinguish barites from other minerals. It is also insoluble and chemically inert. Barite occurs in different forms of deposit such as vein and cavity filling, residual deposits and bedded deposits. Grades of barite ores differ from location to location and within deposits. It is also a common gangue in other ore deposits such as lead, fluorite, zinc, gold, and rare earth minerals. In Nigeria, most barite deposits are vein and cavity filling types of deposits and may be hosted by different rock types such as sandstone, limestone magmatite, shale, mudstone and granite (porphyritic). Barite is often associated with fluorite, calcite, siderite, dolomite, quartz, galena, magnetite, etc. The quality of barite is measured based on the specific gravity (SG). A specific gravity of 4.2 and above is generally preferred in the oil industry.

There are basically two grades of barites. They are the high specific gravity and low specific gravity grades (low SG). A grade falling below 4.0 (SG) is classified as low-grade barite, whereas a grade that rises between 4.2 and 4.5 (SG) is classified as high-grade barite.

2.2 BARITE DEPOSITS

There are different kinds of barite deposits, and each unique kind determines the processing methods and economics of these methods. Barite vein deposits can be extracted both by surface or underground mining, and also as a co-product of zinc and lead mining. Residual deposits can usually be mined with shallow machinery such as excavators, dozers and front-end loaders. Bedded deposits are worked by open pit methods. The deposits are usually extensive with consistent barite grades.

Barite is mined either on the surface or underground and physical processing methods remove the gangue materials to produce the required product. Floatation can be used to beneficiate barite from gangue materials (Scogings, 2014).

2.2.1 Vein and cavity filling deposits

These types of deposits consist of a thin layer of barites contained in rocks and usually scattered and irregular. They range from a few centimetres to tens of centimetres in width and a few meters to hundreds of meters in length.

2.2.2 Residual deposits

Residual deposits are derived from other forms of deposits. The weathering of vein and cavity filling deposits and bedded barite deposits give rise to residual deposits. Residual barites are usually dense fine-grained masses that are translucent to opaque. The mineral is commonly associated with siderite, pyrite, chalcopyrite, galena, sphalerite, calcite and dolomite.

2.2.3 Bedded deposits

A bedded deposit occurs in a sequence of sedimentary rocks characterized by abundant chert and black siliceous shale and siltstone. It is the most commercially valuable and sought-after because of its large tonnage deposits and high-grade barites (50%-95% barites). Bed thickness ranges from a few centimetres to 30 meters and could extend up to several hectares. Barite in this deposit is usually associated with galena, sphalerite and pyrite, and occurs in marine rocks of Devonian age precipitated out of sea water (Nigeria Geological Survey Agency, 2011).

2.3 BARITE OCCURRENCE IN NIGERIA

Barite occurs in nine states of Nigeria and these are Adamawa, Zamfara, Taraba, Gombe, Plateau, Benue, Nasarawa, Cross River and Ebonyi (Nigeria Geological Survey Agency, 2011). The locations shown in pink in Figure 2.1 give the occurrence of barite in Nigeria.

Table 2.1 gives a comprehensive list of barite occurrence, the host rocks, associated minerals, and specific gravity of barite in Nigeria. Table 2.2 from Inyang (2013) shows the characterization of barites samples from different local governments in Nigeria using the American Petroleum Institute (API) standard.

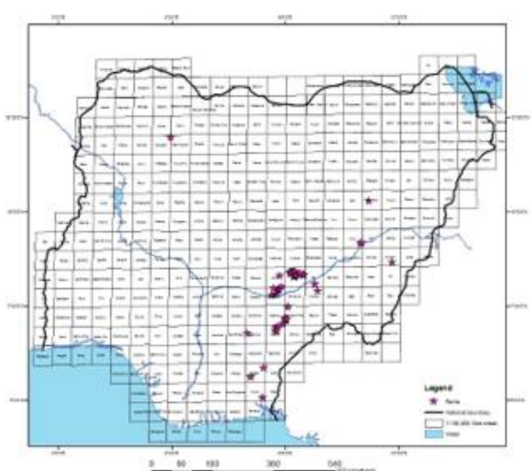


Figure 2.1: Locations of barite mineral deposits in Nigeria (Nigeria Geological Survey Agency, 2011)

Table 2.1: Barite mineralization in Nigeria (Nigeria Geological Survey Agency, 2011)

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
4	Barite	Industrial	11° 59' 00''	05° 58' 00''	Dareta	Anka	Zamfara	Occurring as vein in pelitic schist	Prospect	Vein type	N/A	N/A	N/A	N/A	N/A	Verified	N/A	N/A
14	Barite	Industrial	09° 10' 08''	10° 59' 04''	Didango South	Karim Lamido	Taraba	Clayey siltstone of the Benue Valley	Active mine	Vein type and nodules	N/A	N/A	N/A	Pitting and Trenching by local miners over past decades	N/A	Verified	Lead Zinc lodes	N/A
11	Barite	Industrial	08° 05' 48''	09° 47' 00''	Gidin Waya	Wukari	Taraba	Barite occurring in clayey sandstone	Abandoned	Vein type	N/A	N/A	N/A	Past trenching by artisanal miners	N/A	Verified	Feldspathic clay	N/A
9	Barite	Industrial	08° 05'	09° 47' 04''	Bakyu	Ibi	Taraba	Pure Barite in	Abandoned	Massive	N/A	N/A	N/A	Trenching by	N/A	Verified	N/A	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
			53''					compacted sandstones within the Benue Valley						artisanal miners				
2	Barite	Industrial	07° 55' 12''	09° 51' 18''	Wukari	Wukari	Taraba	Black shales and siltstone of Ezeaku Formation	Prospect	Vein type	N/A	N/A	N/A	N/A	N/A	Verified	Lead - Zinc sulphides	N/A
1	Barite	Industrial	09° 11' 46''	11° 01' 05''	Didango South	Karim Lamido	Taraba	Sandstone, siltone and shales of Awgu Ndeabor Formation	Occurrence	Vein type	N/A	N/A	N/A	N/A	N/A	Verified	Pb/Zn Sulphides and quartz	Small mines operated by local people
3	Barite	Industrial	08° 22' 19''	09° 18' 42''	Wuse	Awe	Nassarawa	They occur as hydrother	Active Mining	Vein type, fissure filling.	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
								mal deposit forming veins fissure filling in sandstone										
10	Barite	Industrial	08° 20' 46''	09° 29' 43''	Kumar	Awe	Nassarawa	They occur as hydrothermal deposit forming veins fissure filling in sandstone	Active Mining	Vein type, fissure filling.	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A
9	Barite	Industrial	08° 17' 29''	09° 13' 26''	Azara	Awe	Nassarawa	They occur as hydrothermal	Active Mining	Vein type, fissure filling.	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
								deposit forming veins fissure filling in sandstone										
8	Barite	Industrial	08° 22' 00''	09° 09' 17''	Agana	Awe	Nassarawa	They occur as hydrothermal deposit forming veins fissure filling in sandstone	Active Mining	Vein type, fissure filling.	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A
7	Barite	Industrial	08° 20' 44''	09° 29' 43''	Kumar	Awe	Nassarawa	They occur as hydrothermal deposit	Active Mining	Vein type, fissure filling.	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
								forming veins fissure filling in sandstone										
6	Barite	Industrial	08° 20' 07''	09° 28' 33''	Kumar	Awe	Nassarawa	They occur as hydrothermal deposit forming veins fissure filling in sandstone	Active Mining	Vein type, fissure filling.	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A
11	Barite	Industrial	08° 22' 18''	09° 18' 41''	Gidan Agana	Awe	Nassarawa	They occur as hydrothermal deposit forming	Active Mining	Vein type, fissure filling.	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
								veins fissure filling in sandstone										
4	Barite	Industrial	08° 20' 52''	09° 22' 23''	Dogon Daji (Wuse)	Awe	Nassarawa	They occur as hydrothermal deposit forming veins fissure filling in sandstone	Active Mining	Vein type, fissure filling	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A
14	Barite	Industrial	08° 18' 22''	09° 14' 46''	Sauni	Awe	Nassarawa	They occur as hydrothermal deposit forming veins	Active Mining	Vein type, fissure filling.	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
								fissure filling in sandstone										
5	Barite	Industrial	08° 20' 19''	09° 27' 58''	Kumar	Awe	Nassarawa	They occur as hydrothermal deposit forming veins fissure filling in sandstone	Active Mining	Vein type, fissure filling.	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A
25	Barite	Industrial	08° 23' 30''	09° 22' 22''	Azara - Wuse - Akiri	Adudu	Nassarawa	Vein deposit within sequence of sandstone, limestone	Deposit	Vein type, fissure filling.	N/A	N/A	S. G. 3.64 average (max 4.25)	Trenching, diamond drilling, 192 samples	N/A	Verified	Pb/Zn/Cu sulphides, limonite, siderite, ankerite iron hydroxide quartz	Operated by Nigerian Barites Mining & Processing Co

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
								, siltstone, mudstone and shale of the Eze Aku Group and the Asu River Group						chemically analysed and 475 samples tested for S.G.				Ltd. in 1980s
33	Barite	Industrial	08° 25' 47''	09° 11' 36''	Arugagwu	Awe	Nassarawa	They occur as hydrothermal deposit forming veins fissure filling in sandstone	Abandoned	Vein type, fissure filling.	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A
32	Barite	Industrial	08° 24' 56''	09° 07' 30''	Ribi	Awe	Nassarawa	They occur as hydrother	Prospect	Vein type, fissure filling.	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
								mal deposit forming veins fissure filling in sandstone										
12	Barite	Industrial	08° 18' 13''	09° 14' 10''	Jobe	Awe	Nassarawa	They occur as hydrothermal deposit forming veins fissure filling in sandstone	Active Mining	Vein type, fissure filling.	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A
26	Barite	Industrial	08° 18' 50''	08° 51' 27''	Keana	Keana	Nassarawa	Black shale and siltstone of Ezeaku	Deposit	Vein type	N/A	N/A	N/A	N/A	N/A	Verified	Lead - Zinc sulphide	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
								Formation										
13	Barite	Industrial	08° 18' 12''	09° 13' 23''	Jara	Awe	Nassarawa	They occur as hydrothermal deposit forming veins fissure filling in sandstone	Active Mining	Vein type, fissure filling.	N/A	N/A	4.20 - 4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A
18	Barite	Industrial	08° 25' 00''	09° 09' 17''	Akiri (Dutsen Akin)	Awe	Nassarawa	They occur as hydrothermal deposit forming veins fissure filling in sandstone	Active Mining but later abandoned due to communal crisis	Vein type, fissure filling.	N/A	N/A	4.20 - 4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
17	Barite	Industrial	08° 26' 06''	09° 13' 28''	Gidan Soja	Awe	Nassarawa	They occur as hydrothermal deposit forming veins fissure filling in sandstone	Active Mining	Vein type, fissure filling.	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A
16	Barite	Industrial	08° 25' 33''	09° 14' 38''	Gidan Soja	Awe	Nassarawa	They occur as hydrothermal deposit forming veins fissure filling in sandstone	Active Mining	Vein type, fissure filling.	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A
1	Barite	Industr	08°	09° 15'	Apeben	Awe	Nassara	They	Active	Vein type,	N/A	N/A	4.20-	Pitting/	N/A	Verified	N/A	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
5		ial	18' 33''	46''	e		wa	occur as hydrothermal deposit forming veins fissure filling in sandstone	Mining	fissure filling.			4.45	Trenching				
31	Barite	Industrial	08° 22' 14''	09° 08' 03''	Ribi	Awe	Nassarawa	They occur as hydrothermal deposit forming veins fissure filling in sandstone	Active Mining	Vein type, fissure filling.	N/A	N/A	4.20-4.45	Pitting/ Trenching	N/A	Verified	N/A	N/A
1	Barite	Industrial	10° 18'	11° 12' 34''	Ligi Hill	Gombe	Gombe	Granite gneisses	Artisanal	Disseminated	N/A	N/A	N/A	N/A	N/A	Verified	Chalcopyrite	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
2			03''															
20	Barite	Industrial	05º 05' 01''	08º 23' 15''	Iyametite	Obubra	Cross River	Veins occurring within shale	Active mine	Vein type	N/A	N/A	N/A	Actively mined	N/A	Verified	N/A	N/A
17	Barite	Industrial	05º 56' 27''	08° 31' 44''	Ekukunela	Ikom	Cross River	Vertical veins with strike of 155/335 occurs within shale intercalations	Active mine	Vein type	N/A	N/A	N/A	Actively mined for over 10 years	N/A	Verified	Shale	N/A
18	Barite	Industrial	06º 57' 03''	08º 45' 19''	Gabu	Yalla	Cross River	Veins occurring within shale	Active mine	Vein type	N/A	N/A	N/A	N/A	N/A	Verified	Shale	N/A
19	Barite	Industrial	06º 57' 40''	08º 47' 23''	Oshina	Yalla	Cross River	Veins occurring within shale	Active mine	Vein type	N/A	N/A	N/A	Actively mined for over 10	N/A	Verified	Shale	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
														years				
22	Barite	Industrial	05º 39' 00''	08º 05' 00''	Akpet No 1	Biase	Cross River	Vein in schist and sandstone trend E-W, age-519Ma (Pan African)	Active mine	Vein type	N/A	N/A	N/A	Actively mined for over 5 years	N/A	Verified	N/A	N/A
31	Barite	Industrial	06° 51' 00''	08° 44' 11''	Gabu	Yalla	Cross River	Sandstone	Mine	Vein type	N/A	N/A	N/A	N/A	N/A	Verified	N/A	Mine. Ephraim keys Int. Ltd. With EPL11734
35	Barite	Industrial	05° 38' 08''	08° 05' 01''	Akpet	Biase	Cross River	Sandstone, siltstone	Mine.	Vein type	N/A	N/A	N/A	N/A	N/A	Verified	N/A	N/A
21	Barite	Industrial	05º 52' 00''	08º 25' 00''	Edondo / Ochong	Obubra	Cross River	Vein occurring within shale and	Active mine	Vein type	N/A	N/A	N/A	Actively mined for over 5 years	N/A	Verified	N/A	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
								sandstone										
33	Barite	Industrial	06° 52' 30''	08° 46' 30''	Osina	Yalla	Cross River	Sandstone	Occurrence	Vein type	N/A	N/A	N/A	N/A	N/A	Verified	N/A	N/A
28	Barite	Industrial	07° 50' 32''	08° 45' 08''	Tse-Ande	Guma	Benue	Sandstones	Artisanal	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A
4	Barite	Industrial	07° 50' 30''	08° 44' 28''	Iye	Guma	Benue	Sandstones	Artisanal, Open cast	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A
5	Barite	Industrial	07° 54' 30''	08° 47' 32''	Tidza	Guma	Benue	Sandstones	Artisanal mine, Open Cast	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A
6	Barite	Industrial	07° 56' 22''	08° 50' 08''	Ukaa	Guma	Benue	Sandstones	Artisanal mine, Open Cast	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A
7	Barite	Industrial	07° 57' 09''	08° 50' 01''	Nyam Uka	Guma	Benue	Sandstones	Artisanal mine ,Open	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
									Cast									
8	Barite	Industrial	08° 01' 32''	08° 53' 34''	Torkula Akaaza	Guma	Benue	Sandstones	Artisanal mine, Open Cast	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A
9	Barite	Industrial	07° 13' 05''	08° 59' 28''	Lessel	Ushongo	Benue	Shales sandstones of Awgu Indicator Formation	Prospect	Vein type	N/A	N/A	N/A	N/A	N/A	Verified	Galena	N/A
22	Barite	Industrial	07° 59' 20''	08° 41' 51''	Lukor/ Tse-Ande	Guma	Benue	Sandstones	Artisanal mine ,Open Cast	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A
23	Barite	Industrial	07° 30' 24''	09° 04' 16''	Fada	Buruku	Benue	Sandstones	Artisanal mine, Open Cast	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A
24	Barite	Industrial	07° 07' 55''	09° 00' 53''	Mbashabu	Ushongo	Benue	Granite - gneiss	Artisanal mine, Open	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
									Cast									
25	Barite	Industrial	07° 08' 57''	09° 01' 05''	Mbato-Girim Nbatoo	Ushongo	Benue	Granite - gneiss	Artisanal mine, Open Cast	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A
27	Barite	Industrial	07° 09' 10''	09° 00' 55''	Mbatoo	Ushongo	Benue	Granite - gneiss	Artisanal	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A
29	Barite	Industrial	07° 02' 12''	08° 56' 16''	Orgba	Ushongo	Benue	Granite - gneiss	Artisanal	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A
30	Barite	Industrial	07° 02' 18''	08° 56' 14''	Orgba	Ushongo	Benue	Granite - gneiss	Artisanal	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A
31	Barite	Industrial	07° 47' 42''	08° 38' 21''	Tyodugh-Uni Agric	Makurdi	Benue	Sandstones	Artisanal	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A
32	Barite	Industrial	07° 48' 05''	08° 38' 07''	Tyodugh-Uni Agric	Makurdi	Benue	Sandstones	Artisanal	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A
33	Barite	Industrial	07° 28'	09° 04' 15''	Pilla-Yandev	Gboko	Benue	Granite	Artisanal	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A

ID	Commodity	Class	Latitude	Longitude	Location	LGA	State	Geology	Status	Types	Resource	Reserve	Grade	Explore History	Info Source	Verification	Associated Minerals	Remarks
			49''															
35	Barite	Industrial	06° 47' 00''	07° 59' 25''	Igumale	Ado	Benue	Sandstones	Artisanal	Massive	N/A	N/A	N/A	N/A	N/A	Verified	N/A	N/A
26	Barite	Industrial	07° 09' 20''	09° 01' 37''	Bunde	Ushongo	Benue	Granite - gneiss	Artisanal	Vein type	N/A	N/A	N/A	Pitting	N/A	Verified	N/A	N/A
14	Barite	Industrial	08° 40' 01''	11° 49' 26''	Gambe	Mayo-Belwa	Adamawa	Granite-gneiss and migmatite terrain. Barite occur in association with dolerite dyke	Prospect	Vein type	N/A	N/A	N/A	N/A	N/A	Verified	N/A	South of Gambe

Table 2.2: Characterized barites samples from some Nigerian locations (Inyang et al., 2013)

S/N	Sample Identity	Specific Gravity (Mg/cm^3)	Water Soluble Alkaline Earth Metals (Mg/kg)	Residue Greater than 75 Micro-Meters (% by wt)	Particles Less than 6 Micro-Meters in Equivalent Spherical Diameter (% by wt)
1.	IBI	4.35	220	1.8	20
2.	MAYO BELWA	4.16	235	2.5	28
3.	AFUZE	4.34	230	1.5	21
4.	MARKURDI	4.23	245	2.0	23
5.	MUBI	3.20	285	3.8	33
6.	NTAK	4.13	252	3.0	29
7.	OBUBRA	3.94	290	3.4	36
8.	P/H	3.84	298	3.7	38
9.	NTAK	3.86	275	3.6	36
10.	BUNDIN KWAJ-ALI	4.33	220	1.6	21
11.	IGARA	4.54	210	1.4	19.8
12.	PILA YANDEV	4.16	232	3.0	29
13.	IBI	4.44	210	1.8	21
14.	OBUBRA	4.08	254	3.01	30
15.	AFUGO	4.44	214	2.0	22

2.3.1 Barite in Adamawa State

Barite deposits in Adamawa occur in vein and cavity fillings hosted by different kinds of rocks such as migmatites, basalts, granites, and feldspathic sandstone in Demasa and Mayo-Belawa local government areas. The length of the vein ranges from 15 to 180 meters, the width from 1.2 to 4.3 meters, and the depth to a maximum of 10 meters (Nigeria Geological Survey Agency, 2011). The barite colours in these areas vary from white to pink with a specific gravity of 4.0-4.36. Estimated reserve barite in Adamawa is 332,130 tonnes (Ministry of Mines and Steel Development, 2010).

2.3.2 Barite in Benue State

Barites deposits in Benue State are found in the form of vein and cavity fillings that occurred as a result of hydrothermal solutions during Santonian deformation when barite was deposited in the fissures formed (Nigeria Geological Survey Agency, 2011). These deposits can be found in the Makurdi, Gboko, Ushongo, Vandeikya and Guma local government areas of Benue State. They are housed by igneous to metamorphic rocks of Pre-Cambrian origin, as well as in shale and sandstones. Barite in the Guma local government areas is white and reddish-brown in colour, as shown in Figure 2.2, with a specific gravity of 3.7 to 4.4. The vein deposit is not long, but the width is 3 meters and depth is about 20 meters. Chemical analysis of barite samples from Benue state shows an ore composition of 76%-86% $BaSO_4$, 5%-21% silica, and about 3% iron oxide. The reserve estimate is about 307,657 tonnes. (https://www.howwemadeitinafrica.com/opportunity, 2010).

Figure 2.2: White and reddish-brown barites in Guma local government area (Ebunu Abraham, fieldwork, 2017)

2.3.3 Barite in Cross River

Hard and soft rocks host the barite vein deposits in Cross River state. Cross River state has 35 mineralized locations of which 11 occur in sedimentary host rocks. The mineralized locations are divided into two areas – the north and the south. In the north, the deposits are found in the local government areas of Ikom, Obubra and Yala. In the south, these deposits occur in the Biase and Yakkur local government areas. There are 18 barite locations, but only two are hosted in sedimentary rocks.

The width of the veins varies between 2.5–5.3 meters, and length between 1000–6000 meters with a specific gravity ranging from 3.5–4.4. The reserve estimate for Cross River is 8,612,880 tonnes distributed between the north and south zones of Cross River (Ministry of Mines and Steel Development, 2010). It is pertinent to note that barite exploration in the north is easier because of soft host rocks, and new veins are likely to be discovered in the future (Ministry of Mines and Steel Development, 2010).

2.3.4 Barite in Nasarawa

The barite vein in Nasarawa state is hosted by different kinds of sedimentary rocks (siltstone, shale, alluvial sand, mudstones and limestone). Initial inspection indicated 18 veins of barites in places like Azara, Aloshi, Akiri, Wuse and Keana in the Awe local government area. Out of these 18 veins, detailed exploration works were carried out in only five of them. Thus, there is a need for further evaluation of the remaining 13 veins (Saintmoses Eromosele, 2017). Vein width varies from a few centimetres to 5.8 meters, and length varies from about 30 meters to 1.05 kilometres with a specific gravity of 3.9-–4.4. Figure 2.3 shows barite veins filled with water, some of which are within the specifications of the American Petroleum Institute (API) standard. However, some samples have high silica content resulting in a low specific gravity of about 3.6; and the impurities associated with barite in this location are quartz, celestite and iron oxide (Ministry of Mines and Steel Development, 2010). The estimated barite reserve of 3,243,376 tonnes has a vein thickness of 20 meters and average specific gravity of 4.0 (Nigeria Geological Survey Agency, 2011). Barites found in Azara, Nasarawa state appear to have had carbonate subjected to chemical weathering resulting in two distinctive types of barite, namely:

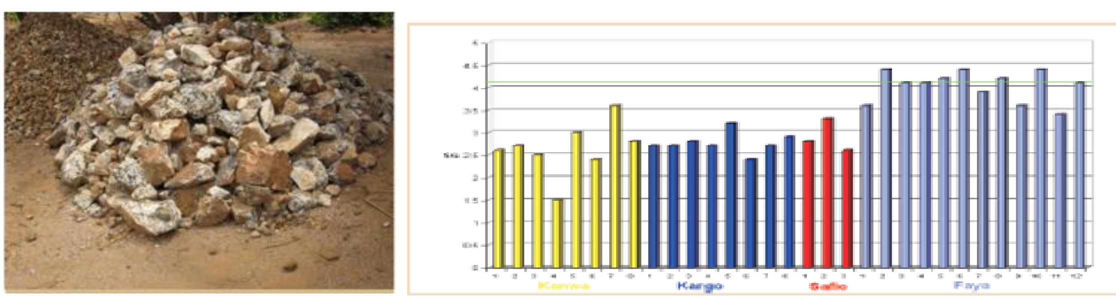
- Barite with quartz and limonite as gangue; and
- Barites with siderite and ankerite as gangue.

The former type is found at the surface while the latter occurs deep below the oxidation surface. Some of the companies beneficiating barites are the Nigerian Barite Mining and Processing Company and Delta Processor Limited Lafia, Nasarawa state (Onwualu et al., 2013).

Figure 2.3: Barite vein filled with water at Ribi (Ebunu Abraham, fieldwork, 2017)

2.3.5 Barite in Plateau state

Kargo, Faya, Safiyo Karwa, Yama, Angwar and Gimbi are villages in the Langtang South and Wase local government areas of Plateau state. The barite veins there are hosted by sandstones of the Keana Formation of Cenomanian age and their colours vary from pure white to milky white. Specific gravity ranges from 4.0–4.39 as shown in Figure 2.4. Faya has the best barite vein with an estimated reserve of about 500,000 tonnes. Figure 2.4 shows a heap of barites from Faya (Ministry of Mines and Steel Development, 2010).



(a) (b)

Figure 2.4: (a) A heap of barites from Faya; and (b) specific gravity for different locations in Plateau state (Ministry of Mines and Steel Development, 2010)

2.3.6 Barite in Taraba state

Sardauna, Yoro, Lau, Ibi and Karin-Lamido are the local government areas where barite veins are seen to be hosted in fine-grained sandstones and porphyritic granites. The vein width is of about 3.5–5 metres; vein length of about 3,500–5000 metres; and specific gravity is close to 4.2.

Impurities associated with the vein are galena and sphalerite at a depth of 20 metres, while the estimated reserve is 8,960,000 tonnes (Nigeria Geological Survey Agency, 2011).

2.3.7 Barite in Gombe state

Gombe Hill and Liji Hill are two locations both 10 kilometres north-east of Gombe town where irregular cluster veins are hosted in gnesis/magmatite basement complex rocks. Here, the specific gravity of barite is 4.09–5.3, and colours vary from cream to grey. The width of the vein is between 0.3–1.2 metres and part of the vein could be traced to about 400 metres. Impurities associated with it are fluorite, quartz and chalcopyrite. The BaO content is between 45.00–59.5% from elemental analysis. The estimate reserve for the two locations is 352,800 tonnes (Ministry of Mines and Steel Development, 2010).

2.3.8 Barite in Zamfara state

Vein deposits in Zamfara are a result of epigenetic hydrothermal fluids that leached barium from adjacent rocks, which then precipitate in the vein. The properties of the vein deposits show great variation in depth and width – from a few centimetres to several metres (0.6–2 metres) depth and about 100 metres width. The colours vary from white to reddish brown with massive to granular uneven fractures (Nigeria Geological Survey Agency, 2011). Deposits of barites are found in the following local government areas and samples from these areas are shown in Figure 2.5:

- Dareta near Anka, Anka local government;
- Rekebu near Chafe, Chafe (Tsafe) local government;
- Yarkatsina (Gidan Saro), Bungudu local government; and
- Tofa forest reserve, Gusau local government.

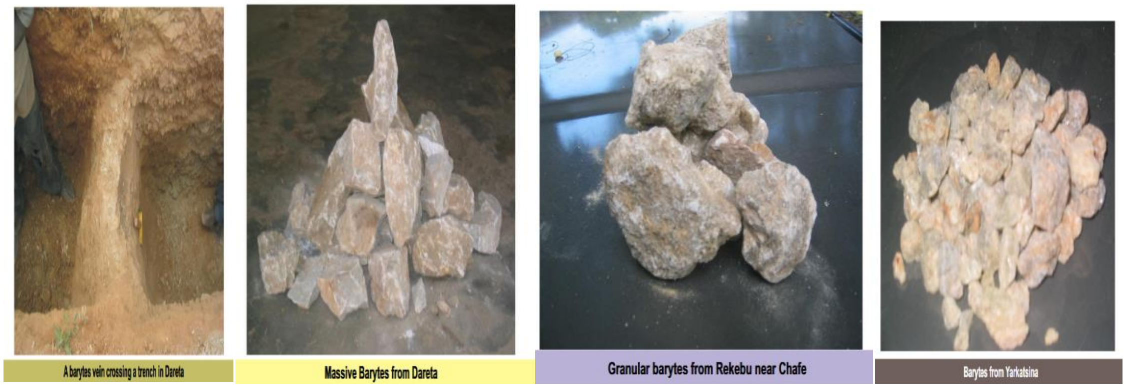


Figure 2.5: Barite samples from Dareta, Chafe and Yarkatsina in Zamfara state (Ministry of Mines and Steel Development, 2010)

2.3.9 Barite in Ebonyi state

Significant deposits of barite veins have been identified (but not quantified) in the Ishiagu area of Ebonyi state, but there is no mining activity there. Ishiagu requires further exploration as do the Afikpo North, Afikpo South and Oshaozaba local government areas because they contain minerals associated with barites (Onwualu et al., 2013).

2.4 USES OF BARITES

Barite is a solid mineral that has many economic and industrial uses. The applications are as follows:

2.4.1 Oil-well drilling

The majority of the barite mined is used in the oil and gas industry as a weighting material in drilling-mud formulation. Since high gas pressure is experienced in deep drilling, it requires a heavy circulating fluid that will compensate for high-pressure zones in order to control the reservoir pressure and prevent blowout. Pulverized barites are added to the clay-water mixture to form the drilling mud. The softness of the mineral also prevents it from damaging drilling tools during drilling, and enables it to serve as a lubricant while confining the oil and gas pressure at depth (http://imformed.com/barite-miners-in-nigeria-receive-government, 2017).

Barite used as a drill mud should, according to the American Petroleum Institute (API), have a specific gravity of at least 4.2; about 92/94 $BaSO_4$; less than 1% soluble salt (250 ppm max); and a few percent iron oxide; and 95% pulverized barite should be passed through 325 mesh (Nigeria Geological Survey Agency, 2011). According to the Nigeria Geological Survey Agency (2011), the Oil Company Materials Association (OCMA) has the following specifications for barite used in drilling mud operations:

Specific gravity of minimum 4.2;
Apparent viscosity of 250 cp;
Wet screen analysis residual at 3% max;
Soluble alkaline earth metals of 250 mg/lit; and
Residue on sieve (number 325) of 5-10% by weight.

2.4.2 Medical industry

Opaque barite is the primary ore of barium and its compounds used for X-ray shielding. It is used in hospitals, power plants and laboratories to block X-ray and Gamma-ray emissions. Barite compounds are also used in diagnostic medical tests to determine normal and abnormal anatomy (http://geology.com/minerals/barite.shtml, 2017).

2.4.3 Glass making

Coarse, sand-size barite is added to the mixture in glass making. It serves as flux, enhances the brilliance of glass, and makes the mixture workable.

2.4.4 Paint and rubber industry as fillers and extenders

Barite is used as a pigment in paints and as weighted filler for paper and cloth. In rubber it is used to make ‘anti-sail’ mud flaps for trucks.

2.4.5 Industrial chemicals

Barite is the source of most barium chemicals that are widely used as reagents and catalysts. For example: barium carbonate, barium chloride, barium nitrate, barium sulphide, etc.

Barium chloride is used in leather and cloth manufacture; oxide of barium is used in glass-making and electric furnace metallurgy; carbonate is a component of ceramic glazes and enamels; hydroxide is used in sugar recovery; and nitrate is an ingredient of detonators and flares (Nigeria Geological Survey Agency, 2011). Barium chemicals must meet the following specification: 95% $BaSO_4$; less than 1% iron oxide; 1% strontium sulphate; and some traces of fluorine (Nigeria Geological Survey Agency, 2011).

2.4.6 Other uses

Barite is also used for other applications including plastics, clutch pads, mould release compounds, television and computer monitors, sound-deadening material in automobiles, traffic cones, brake linings, and golf balls (http://imformed.com/barite-miners-in-nigeria-receive, 2017).

In 1988, the estimated national demand for barite by the chemical industry was about 13,400 tonne; by the petroleum industry for the production of drilling mud was about 70,500 tonnes; and consumption of white barite in liquid paint in the UK alone amounted to about 1,000 tonnes (Onwualu et al., 2013).

2.5 FLAME TEST AND MINERALOGY ANALYSIS

A method to identify barite is carried out using a flame test. When a chip or bit of barite powder is put in a gas flame and burns or turns a yellowish-green colour, then barite (barium) is present. Another way to test for barite is to carry out the specific gravity test. Barite is an exceptional mineral because of its high specific gravity (Al-Awad et al., 2000).

2.6 PREVIOUS WORKS ON BARITES

The Nigeria Geological Survey Agency was the first to report on barite mineralization in Nigeria, but no interest was shown with regards to its exploration (Nigeria Geological Survey Agency, 2011).

However, between 1975 and 1980, the Nigerian Mining Corporation carried out exploration work on barite deposits in the Azara district, a part of Nasarawa state in north-central Nigeria. It has a reserve estimate of about 730,000 tonnes of barite (Maiha, 1996). In 2004, the Federal Ministry of Solid Minerals Development (FMSMD, 2004) reported only two states with barite mineralization. But today additional states with barite mineralization have been identified.

Barite ($BaSO_4$), the major source of barium, usually occurs 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 inter-grown appearance (Bulatovic & Bulatovic, 2015).

Barites vein deposits were geologically mapped by 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 10–12.2 metres, but which may occur up to 40 metres if exposed in an open pit mine. Horizontal resistivity profiling results indicated that the lateral extent of the veins ranged from 4–65 metres, and were traced from the field mapping to about 950 metres. The general direction of the barite mineralization is NE-SE. The reserve estimate result showed that the Agoi village of Oban Massif has 1,981,177.0 tonnes of reserves; these are greater than the reserve estimate for the Mamfe embayment villages of Ekukunela and Nkarasi with reserve deposits totalling about 865,684 tonnes. These reserves are greater than those in the lower Benue trough villages of Osina and Okpoma (Ogoja) with about 774,345 tonnes of reserve deposits. An estimated reserve of over nine (9) million tonnes of barite have been calculated and documented for Cross River state for the first time. This has unarguably put Cross River at the pinnacle of reserve barite in Nigeria (Dominic et al., 2014).

Barite ore samples from Azare in the Plateau state of Nigeria were analysed using jigging and magnetic separation beneficiation techniques, chemical analysis, and atomic absorption spectrophotometric analysis.

The beneficiation study results 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%, according to the results of a 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 valve for jigging is in agreement with the range of values for barium sulphate of 94–98%, as required by the petroleum, paint and chemical industries (Ministry of Mines and Steel Development, 2010).

The barite vein in the Benue trough is not the only source of barite mineralization. There are at least 10 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 were formed from different post-sedimentary deformation phases in the trough. The veins have a simple block profile ranging in width from a few centimetres to as high as 6 metres, although widths are usually between 50 centimetres and 1 metre. This implies that $BaSO_4$ concentrations in hydrothermal fluids in the trough were probably low during the Cretaceous period. The top of the vein has low-quality barite, but deeper down the vein contains a high-quality barite. Hence, mining in veins of low-quality barite should be proceeded by vertical stripping (Oden, 2012).

The Okurike barite deposits in Calabar Cross River State were investigated using Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT). Geophysical data were acquired and barite samples were analysed in the laboratory in order to determine 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; 29.4 kN/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 occurrence of other elements was less than 1%. BaO, Fe_2O_3 and MnO dominate the ore composition of the samples with a 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 south-eastern Nigeria have been sampled and analysed 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 Pre-Cambrian 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 varies from 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 the Lessel and Ihugh areas of the lower Benue trough, Nigeria, was carried out using ICP-AES and ICP-MS to chemically characterize barite ore samples. The vein at Lessel area contains 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 are enriched in Ba, Sr, while there is depletion in major oxides and trace elements. Trace element data indicates that 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 epochs.

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 (3.65–4.01). Based on the geochemical and geotechnical characteristics of barites in this study, the Lessel-Ihugh barites fall below international standard specifications, and are therefore of relatively moderate quality or Grade II barites (Labe, 2015).

For 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. The direct flotation of barite, and the effect of the collectors on flotation, was also studied. An assay of 96% $BaSO_4$ with SiO_2 less than 1% was obtained using cationic collectors. The interaction of the collectors on silica and barite was also investigated using the Zeta-potential process, which showed that fatty amines are adsorb onto silica by electrostatic interaction and cationic collectors (oleic acid) adsorb onto 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, which were strata-bound and in two main-vein sets. The geotechnical properties of barite ores in these locations were: specific gravity of 3.1–4.5; water absorption (2–12%); porosity (0.1–0.5%); uniaxial compressive strength (11 and 43 N/mm^2); and geochemical composition 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 depending on factors such as mining depth, quantity of associated minerals, and location of the barite field (Godwin, 2012).

Land degradation, landscape disruption, loss of economic deposits, dearth of mining data, and contamination of ground and surface water sources are the result of abandoned surface mining 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 in geological and geotechnical issues that render excavations derelict (Ene & Okogbue, 2016).

Normal drilling fluid can control pressure formation during drilling up to 10–12 ppg. In oil and gas drilling operations, 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 cost, which is usually one half of the entire mud cost. Therefore, barite samples from the 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 et al., 2000).

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

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

Gravity pre-concentration and direct flotation beneficiation methods were conducted using barite samples in the south-west area of China. Results from both beneficiation methods showed that direct flotation is preferred to gravity pre-concentration in terms of obtaining the valuable mineral from the gangue.

The floatation experiment gave an assay of 98.21% $BaSO_4$ with a recovery of 80.71%. The collector used was sodium oleate and water glass depressant (Zhao et al., 2014).

Marine Sediments contain barite ($BaSO_4$) which is used for paleo-productivity reconstructions. Sediment samples collected from tropical North Atlantic and central North Pacific oceans were analysed using a scanning electron microscope (SEM) with an energy dispersive spectrometer (EDX). Results showed that the marine sediment contains barites and detrital aluminosilicates with ratios of 0.005 to 0.008, averaging around 0.0066 (Robin et al., 2003).

Modelling of beneficiation plants 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. This was processed with the help of a computer to find the ideal setting for each segment and 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 analysed 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 had BaO greater than 64%, silica lower than 3.3%, and a recovery of 79% BaO (Leite & 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 was analysed using a scanning electron microscope (SEM) furnished by an EDX in order to study the barite crystal morphology and elemental analysis. The XRD helped to identify crystalline phases. The SEM result showed barite with a star-like morphology and pure barite crystal formation.

2.7 BARITE FIELDS IN NIGERIA

2.7.1 Nasarawa state

The Azara field in Nasarawa state includes Azara, Ribi, Wuse and Akiri. It has a large number of barite veins and the quality of barite is generally low, except at Ribi. Currently, this field is managed by EMO Ashapura Energy and Mining Ltd (Oden, 2012). Figure 2.6 shows barite veins in the Azara area.

Figure 2.6: Barite vein in the Azara area (Oden, 2012)

The Keana field includes Aloshi, Ambua, Chiata and Kuduku. The challenge of this field is accessibility and, thus, many of the barite veins lie abandoned and there is no impetus for exploration of new veins. Figure 2.7 shows the Aloshi main vein, where barite (B) is sandwiched between microcrystalline quartz (Q). The barite is 60 cm wide and has a block profile.

Figure 2.7: Aloshi main vein in Nasarawa State (Oden, 2012)

2.7.2 Benue state

The Guma field includes Torkula, Kaseyo, Zanzan and Iye, but the barite veins in the Guma field are not as prevalent as those in the Azara field. The Guma field, Torkula, has the highest concentration of barite veins and, because of its size, this field holds a lot of promise (Oden, 2012). Lessel field include Lessel Bunde, Lessel Mbato and Lessel Mbagwa. North and south of the Gboko and Azara fields there is a large number of barite deposits with over 20 veins currently in production (Oden, 2012). The Ihugh field, in southern Benue state, is a relatively new field and the quality of the barite may not be high because of the relatively near-surface level of the workings (Oden, 2012).

2.7.3 Taraba state

The Didango field in Karim Lamido has only one barites vein. It has a width of 1.5 m and a length of 2 km. The disadvantage of this field is that the barite vein has a high concentration of galena as gangue, and accessibility to this field is difficult due to the terrain.

The Ibi field in the Ibi local government area includes the Gidan Waya, Kauyen Isa, Bakuyu and Ibua areas where barite deposits are found. At Bukuyu village, veins of 0.02–0.08 metre width stretch for 5–6 kilometres (Edu, 2006).

The Kumar field in the Ibi local government area has up to 40 barite veins and new ones have been discovered. The major problem here is access to the field.

2.7.4 Cross River state

The Yala field in northern Cross River cuts across Gabu, Osina and Alifokpa villages. The largest single barite vein passes through Gabu and Osina, and stretches to Benue state. The vein is 2 kilometres long and 6 metres wide. Alifokpa deposits are a result of stratiform mineral flats. This field contains barite deposits in Lefin and Bitol. While Bitol is a new find with barites, Lefin has been officially associated with the occurrence of barite since 1957. Figure 2.8 shows a 6 metres wide barite vein in Guma-Osina (Minerals and Industry in Nigeria, 1987) and Tables 2.3 and 2.4 indicate the Geotechnical and Geochemical properties of barite ores from the Gabu-Alifokpa barite fields (Godwin, 2012).

Figure 2.8: Gabu-Osina mother vein, a 6 m wide barite vein of a very high quality, is one of the most majestic in the Benue Trough (Ene & Okogbue, 2016)

Table 2.3: Geotechnical properties of barite ores from Gabu-Alifokpa barite fields (Godwin, 2012)

Sample location	Vein depth (m)	Specific gravity	Porosity (%)	Water absorption capacity (%)	Moisture content (%)	Uniaxial compressive strength (N/mm^2)
Gabu						
A	0–32	3.1*	0.3	8	0.3	43
B	33–36	3.2	0.2	2	0.8	38
C	37–45	3.6	0.2	7	0.5	23
D	46–48	4.2	0.1	6	0.2	20
Alifokpa						
A	0–29	2.9	0.5	12	0.4	40
B	30–34	3.3	0.3	10	0.6	34
C	35–43	3.9	0.2	9	0.4	14
D	44–47	4.5	0.1	2	0.2	11
Osina						
A	0–24	3.1	0.2	5	0.24	39
B	25–35	3.7	0.4	11	0.34	31
C	36–37	3.7	0.4	11	0.45	18
D	38–39	4.3	0.3	4	0.21	12

* Average measurement for five samples for the depth rang

Table 2.4: Geochemical properties of barites ores from Gabu-Alifokpa barite fields (Godwin, 2012)

Sample location	BaO (%)	Fe_2O_3 (%)	SiO_2 (%)	F (%)	Al_2O_3 (%)	CaO (%)	SrO (%)	Hg (ppm)	Cd (ppm)
Gabu									
A	49.64	24.54	3.43	19.8	0.87	1.07	0.12	0.01	0.1
B	53.45	34.87	1.05	9.67	0.56	0.04	0.19	0.03	0.1
C	79.76	5.76	0.45	13.56	0.51	0.01	0.13	0.02	0.4
D	75.54	8.06	1.38	12.98	0.43	0.01	0.13	0.05	0.2
Alifokpa									
A	37.23	27.98	3.09	23.93	8.34	0.05	0.16	0.012	0.12
B	43.56	35.13	2.36	13.87	1.99	0.03	2.17	0.018	0.23
C	65.65	15.65	0.04	17.46	1.43	0.01	0.12	0.016	0.37
D	74.87	10.53	0.07	13.73	0.52	0.02	0.11	0.011	0.25
Osina									
A	44.51	35.51	3.06	10.45	2.88	1.09	2.13	0.01	0.22
B	54.75	22.43	2.31	14.61	5.65	0.03	0.12	0.017	0.19
C	62.56	24.56	0.45	9.67	1.67	0.03	0.13	0.019	0.34
D	73.26	20.08	0.07	6.98	0.43	0.01	0.15	0.014	0.42

2.7.5 Gombe state

The Gombe field and Liji Hill are both situated in the north-east of Gombe state. About 10 barite veins are worked around Liji Hill by three companies, and the prospects of discovering new veins around there are quite good.

Table 2.5 shows barite from the Aloshi, Azara and Wuse mines. This must be beneficiated and then blended with materials from other mines to deliver a useful batch of API grade. On the other hand, deliveries from Ibi, Alifokpa, Gabu, Osina, Kumar, Konshisha and Didango mines tend to have high specific gravities (above 4.2) and, as such, are useful for blending to upgrade lower-grade materials. This scenario ensures Nigeria does not actually need to import high-grade barite from foreign countries. Altogether, there are more mines producing above API grade materials than those producing below API grade barite. Whatever grade of barite is required in Nigeria can actually be produced locally (Oden, 2012).

Table 2.5: Barite deposits and associated qualities or grade (Oden, 2012)

Low quality (SG: 3.6-4.0)	Medium quality (SG: 4.0-4.2)	High quality (SG: above 4.2)
Aloshi	Ribi	Ibi
	Ambua	Alifokpa
	Yandev	Gabu
Azara	Lessel	Osina
Wuse	Kornya	Konshisha
		Didango
Kuduku		Kumar
Pupule		
Apawa	Kumar	
Tombu	Ihugh	
Bunde Lessel	Orgba	

2.8 BARITE MINING COMPANIES IN NIGERIA

Table 2.6: Barite mining companies in Nigeria (Even, 2009)

COMPANY	STATE	LOCAL GOVERNMENT AREAS
Optimum Mineral Resources Ltd	Nasarawa	Awe, Obi
Rimco Mining Comp Ltd	Nasarawa	Keana
Usaled Bros Nigeria Ltd	Nasarawa	Awe
Forward Ever Global Ventures Business Ltd	Nasarawa	Awe
Hadman Resources Int'l Ltd	Nasarawa	Awe
Delphi Earthworks Ltd	Nasarawa	Awe
EMO Ashapura Energy and Mining Ltd	Nasarawa	Awe
Maifata Nigeria Ltd	Nasarawa	Ribi
Ussalis Bros Nigeria Ltd	Nasarawa	Wuse

Mairuwa Farms Nigeria Ltd	Nasarawa	Azara
Pyro Mines and Property Nigeria Ltd	Nasarawa	Keana & Azara
Unique Elmao Nigeria Ltd	Nasarawa	Keana & Azara
Almakura Nigeria Ltd	Nasarawa	Kumra
Korofi Ventures	Nasarawa	Kumra
Rimco Mining Comp Ltd	Benue	Ushengo
Ferajog Masterming Nig Ltd	Benue	Guma
Polyguard Investment Nig Ltd.	Benue	Guma
Ummah International Nigeria Ltd	Benue	Lessel
Rockfield Ltd	Benue	Gboko
Rimco Mining Comp Ltd	Taraba	Karim Lamido
Ebullient Earth Resources Ltd	Taraba	Zing
Amisua Worldwide Investment Ltd	Gombe	Yemaltu Deba
Lana Security & Investment Ltd	Kastina	Dan- Musa
Sapid Agencies Ltd	Cross River	Obubra
Nephews Concepts	Cross River	Obubra
Brigo Mining Company Ltd	Plateau	Wase
Unique EL MAO Nigeria Ltd	Plateau	Wase
Manalex Nig Ltd	Plateau	Langtang South
Noblegate Project Ltd	Adamawa	Song, Fufore
Balmo Global Resources Ltd	Adamawa	Ganye & Mayo Belwa
Jandutse Investment Ltd	Bauchi	Bauchi

There are some artisanal miners in Nigeria producing barites mainly for local consumption (Nigeria Geological Survey Agency, 2011). Notable amongst these are:

1. Global Gems Limited
2. Fermace Nigeria Limited
3. Kaffo Mines Limited
4. Alfa Distilleries and Food Processing Industry Limited
5. Ummah International Nigeria Limited
6. Lamdy Gatos Earth Products Limited

7. Al Makura Nigeria Limited
8. Sanzara Investment Nigeria Limited
9. Shotek Nigerian Limited
10. Azara Mines Limited
11. MYA Minerals and Metals Mining Company Limited
12. Universal Treasure Mines Limited

2.9 QUALITY OF BARITE VEINS

The quality of barite varies from location to location and with depth. For example, Ribi is a site a few kilometres south of Azara. The barite quality is poor at Azara, but much better at Ribi. In the Lessel area, in Ushongo LGA of Benue state, barite quality is higher in Lessel Mbagwa and Lessel Mbato than in Lessel Bunde. In all the cases studied by Oden (2012), the quality of material from the top part of a vein (0–5m depth) tested lower than that from the deeper parts of the same vein. That means that much of the touted barite reflects the characteristics of the field in question, and the level of mining in the veins. At a depth of 7–10m, higher quality barites are obtained. For large-scale barite mining in the trough, 10 fields have been identified and include the Gombe, Didango, Kumar, Ibi, Azara, Keana, Guma, Lessel, Ihugh and Yala fields. There are more veins of low quality in Nigeria producing medium- to high-quality barite than that producing low-quality barite in the trough. If oil service companies practised proper batching, there would indeed be no need to import high-grade barite for blending.

2.10 RESERVES, PRODUCTION, CONSUMPTION AND GLOBAL STANDARD FOR BARITES

The world's identified barite resource is about 740 million tonnes of which the total reserve is about 2 billion tonnes (Mcrae, 2017). A good barometer for barite production is associated with oil well drilling activity. World production of barites increased from 6.0–6.5 million tpa in the early 2000's and 9.7 tonnes in 2014; but dropped to 8 million tonnes in 2015 and to 7.3 million tonnes in 2016 due to low oil prices and reduced drilling activity.

China accounts for 40% of barite world production with India, Morocco, USA, Turkey, Russia, Mexico, Iran, Kazakhstan and Thailand accounting for around 50%. The USA was the second largest consumer at around 1.6 million tonnes in 2016, down from nearly 2 million tonnes in 2014. The Middle East used 1.7 million tonnes and China used 1.5 million tonnes in date (see Table 2.7). In 2004, Nigeria produced 7,800 tonnes (Nigeria Geological Survey Agency, 2011). Estimated world barite consumption was about 7.3 million tonnes in 2016 (The Barytes Association, 2017b) while estimated world barite production decreased by approximately 12% from 8.39 million tonnes in 2014 to 7.41 million tonnes in 2015. China, India, Mexico and the United States accounted for most of the decrease. Despite decreased world production, barite development projects, particularly the construction of processing plants, continued in several countries (https://minerals.usgs.gov/minerals/pubs/commodity/barite/, 2017).

Table 2.7: World consumption of barite (The Barytes Association, 2017b)

Middle East	1.70 Mt
US	1.60 Mt
China	1.50 Mt
Europe	0.65 Mt
Russia/CIS	0.45 Mt
S America	0.28 Mt
India	0.25 Mt
Africa	0.17 Mt
Iran	0.17 Mt

China, Morocco and India are the main barite exporting countries. They account for about 80% of all export. Incidentally, none of the main exporters of barite are major oil producing countries. Most of the barite importing countries have domestic production that is not sufficient to meet their needs, e.g., UK, USA, Canada, etc. The USA is the largest importer, mostly from China.

In 2015, 17,406 tonnes of barite in Nigeria were imported from China, the USA, the UK, and the Netherlands (see Figure 2.9). This figure exceeded the 2012 import figure of 13,678 tonnes. The Nigerian Geological Survey Agency carried out explorative studies in 2011. These studies showed that the inferred resource estimate of barite was about 22,298,843 tonnes covering about eight states of the Federation.

There is a mineralized vein depth of 20 metres and average specific gravity of 4.2. There are indications that this figure can be doubled if more deep seated drilling is undertaken and if underground mining is encouraged at such locations as Azara in Nasarawa state and Dareta in Zamfara (Nigeria Geological Survey Agency, 2011).

The latest data recorded by the US Geological Survey and the British Geological Survey lists Nigerian barite production at 10,000 tonnes in 2013 and 6,000 tonnes in 2015, respectively. A Nigerian news report in 2016 claimed the country produced more than 80,000 tpa barite and that domestic consumption was in the order of 75,000 tpa (Industrial Mineral Forum and Research, 2017). In 2017, from the barite world production as shown in Table 8, no data was given for Nigeria barite production by the US geological survey.
(https://minerals.usgs.gov/minerals/pubs/commodity/barite/myb1, 2017).

However, in 2011 barite production by Nigeria was 20,000 tonnes as shown in Table 2.9 (https://minerals.usgs.gov/minerals/pubs/commodity/barite/, 2011).

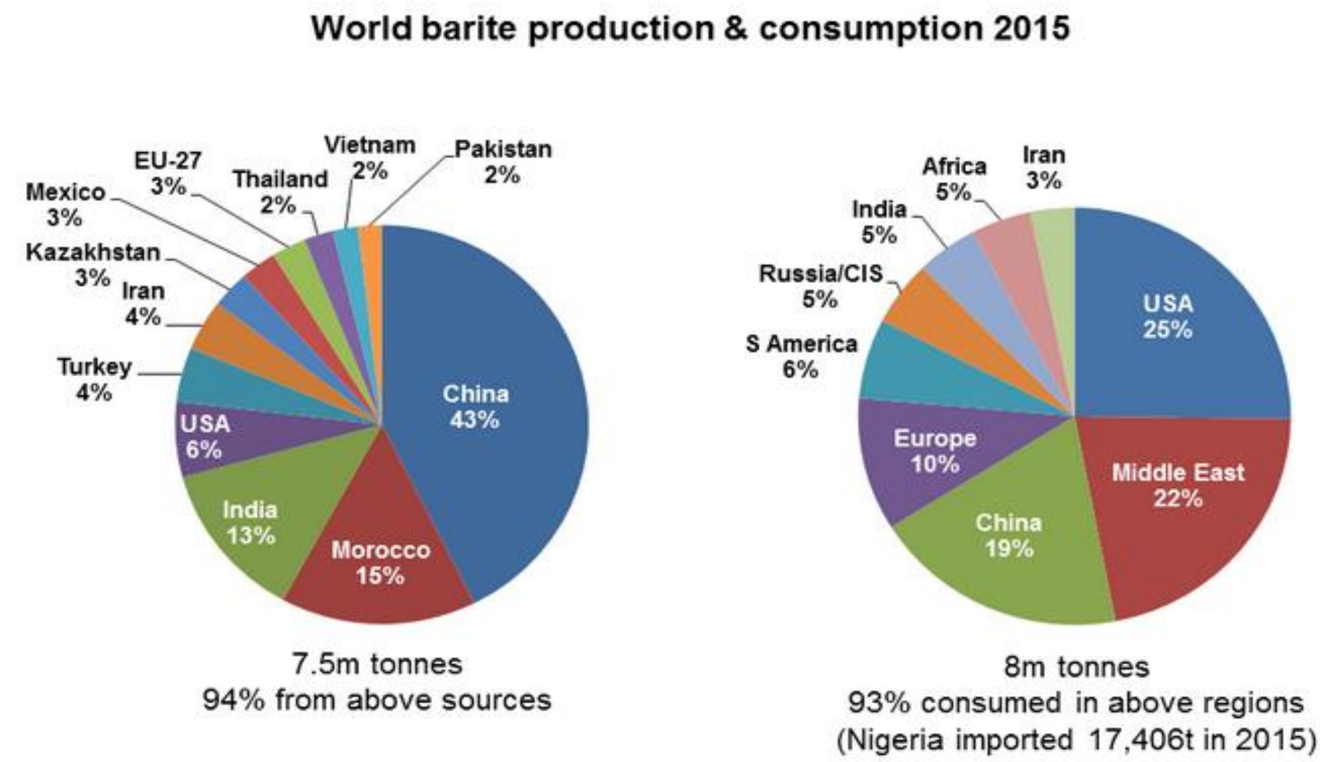


Figure 2.9: World production and consumption, 2015 (Industrial Mineral Forum and Research, 2017)

Table 2.8: Barite world production by country

(https://minerals.usgs.gov/minerals/pubs/commodity/barite/myb1, 2017)

(Metric tons)

Country[3]	2011	2012	2013	2014	2015[e]
Algeria	40,000	30,587	30,245	56,829	50,000
Argentina	5,528	9,416	26,792	16,265 [r]	17,000
Australia[4]	10,569 [r]	12,373 [r]	13,176 [r]	14,676 [r]	6,017 [5]
Bolivia[e, 6]	22,000	22,000	31,000	27,000	47,000
Brazil, beneficiated	7,039	3,025	--	--	--
Bulgaria[e, 6]	120	--	--	20,000 [r]	60,000
Burma[7]	30,000	15,339	31,295	23,060	23,000
Canada[e]	22,000	22,000	22,000	35,000	32,000
China[e]	4,100,000	4,200,000	3,200,000	3,108,300 [r, 5]	3,000,000
Germany	55,342	52,030	45,446	70,665	70,000
India	1,350,000	1,670,000 [r]	1,320,000 [r]	1,183,000 [r]	700,000
Iran[e]	300,000	314,769 [5, 8]	300,000	300,000	300,000
Kazakhstan[e]	200,000	250,000	250,000	300,000	300,000
Laos	2,500	21,900	10,500	30,610	95,000
Liberia[e, 6]	--	-- [r]	-- [r]	13,000 [r]	25,000
Malaysia	--	--	500 [r]	14,456 [r]	16,624 [p, 5]
Mexico	134,727	139,997	343,585	420,000 [e]	265,598 [5]
Morocco	769,504	1,021,400	1,094,470	1,006,600 [r]	1,000,000
Pakistan	35,959 [r]	109,415	87,165 [r]	153,808 [r]	121,575 [5]
Peru	87,848	79,451	52,491	106,071	28,407 [5]
Russia[e]	67,000 [r]	180,000 [r]	180,000 [r]	220,000 [r]	210,000
Slovakia[e, 6]	8,000 [5]	8,000	11,000	11,000	10,000
Thailand	67,703	64,499	107,437	134,961	170,661 [5]
Turkey	175,532 [r]	187,111	257,116 [r]	320,754 [r]	300,000
United Kingdom	31,000	30,000	30,000	44,000	40,000 [p]
United States[9]	710,000	666,000	723,000	663,000	425,000 [5]
Vietnam[e, 6]	135,000	110,000	75,000	100,000	100,000
Other[e, 10]	613	119	371	43	--
Total[e]	8,370,000 [r]	9,220,000 [r]	8,240,000 [r]	8,390,000 [r]	7,410,000

Table 2.9: Barite world production by country (https://minerals.usgs.gov/minerals/pubs/commodity/barite/myb1, 2011)

(Metric tons)

Country	2007	2008	2009	2010	2011[e]
Algeria	63,098	60,088	38,000	42,000 [r]	40,000
Argentina	37,979	3,170	3,416	2,944 [r]	3,000
Armenia[e]	600	600	500	550	600
Australia[e]	16,000	21,000	20,000	21,000 [r]	22,000
Bolivia	8,245	10,900	2,069	7,845	21,297 [3]
Brazil, beneficiated	13,311	23,276	49,847 [r]	41,385 [r]	41,400 [p]
Bulgaria[e]	51,000	40,000	14,300	500 [r]	500
Burma	6,813	5,679	7,623	8,975	9,000
Canada	9,000	12,000	15,000 [e]	22,000 [e]	22,000
China[e]	4,400,000	4,600,000	3,000,000	4,000,000	4,100,000
Germany	88,265 [r]	78,941	45,606	55,887 [r]	70,000
India[e]	1,000,000	1,100,000	1,200,000	1,300,000 [r]	1,350,000
Iran[4]	249,495	226,590	361,217 [r]	400,000 [r, e]	350,000
Italy[e]	5,000	5,000	3,500	3,500	3,500
Kazakhstan	130,000	170,000	170,000	200,000 [e]	200,000
Laos[e]	29,000	29,000	29,000	29,000	29,000
Mexico	185,921	140,066	151,791	143,225 [r]	156,645 [3]
Morocco	664,700 [r]	725,060 [r]	586,937 [r]	572,429 [r]	600,000
Nigeria[e, 5]	5,000	5,000	19,400 [r, 3]	19,000 [r]	20,000
Pakistan	48,044	56,500 [r]	60,000 [r]	55,000 [r]	58,000
Peru	27,372 [r]	45,213 [r]	27,881 [r]	50,942 [r]	86,790 [3]
Russia[e]	63,000	63,000	63,000	60,000	62,000
Slovakia, concentrate	11,000	12,950	8,000 [e]	10,000 [e]	10,000
Spain	26,770 [r]	11,100	2,814 [r]	2,814 [r]	3,000 [p]
Thailand[6]	8,631	9,180	51,895	33,465 [r]	35,000
Turkey	184,041	482,740	213,187	250,000 [e]	230,000
United Kingdom[e]	55,000	50,000	50,000	50,000	50,000
United States[7]	455,000	648,000	396,000 [r]	662,000	710,000 [3]
Vietnam[e]	120,000	90,000	75,000	85,000	85,000
Other[8]	2,620 [r, e]	3,934 [r]	3,617 [r]	3,660 [r, e]	3,610
Total	7,960,000 [r]	8,730,000 [r]	6,670,000 [r]	8,130,000 [r]	8,370,000

2.11 INDUSTRY SPECIFICATIONS OF BARITE

Barite is used in the well-drilling industry primarily as a weighting agent in drilling muds to suppress high formation pressures and to prevent blowouts. During drilling operations, the drill bit passes through various formations, each with different characteristics. Deeper wells require a higher percentage of barite in the mud mix. Most barite has to be ground to a uniformly small size, based on specifications set by the API, before it can be used as a weighting agent in drilling mud. (https://minerals.usgs.gov/minerals/pubs/commodity/barite/myb1, 2017).

The most important property of barite used in drilling mud is its specific gravity (SG). The American Petroleum Institute (API) sets the required standard in terms of barite characteristics. A specific gravity of 4.2 minimum is required according to API specification. However, because of concerns about dwindling reserves of 4.2-SG barite, and to provide the end-user with choices as to which material to use, the API issued a new edition of API Specification (API Specification 13A; effective August 1, 2010). These specifications, for drilling fluid materials, adding specifications for 4.1-SG barite (except for SG, other specifications for 4.1-SG barite remain the same as for 4.2-SG barite as shown in Table 2.10a). They require that the barite be finely ground so that at least 97% of the material, by weight, can pass through a 200-mesh (Tyler) (75 micrometer (μm)) screen; and that no more than 30%, by weight, can be less than 6 μm effective diameter, which is measured using sedimentation techniques. Lastly, the ground barite may contain no more than 250 ppm water soluble alkaline earth metals such as calcium (Scogings, 2014).

Table 2.10a: Industrial specification for barite (Scogings, 2014)

API 13A - Barite physical and chemical requirements	
Requirement	Standard
Density (Clause 7)	4.20 g/ml, minimum
Density (Clause 20)	4.10 g/ml, minimum
Water-soluble alkaline earth metals, as calcium	250 mg/kg, maximum
Residue greater than 75 m	Maximum mass fraction 3.0%
Particles less than 6 m in equivalent spherical diameter	Maximum mass fraction 30%

Source: API Specification 13A, August 2014

Table 2.10b: Drilling grade barite prices, December 2014 (Scogings, 2014)

	Low $	High $
Barite, Drilling grade, ground SG 4.22, bagged, FOB Morocco, $/tonne	110	170
Barite, Drilling grade unground lump, OCMA/API, Bulk, SG 4.20, FOB Chennai, $/tonne	138	145
Barite, Drilling grade, API unground lump, SG 4.20, FOB China, $/tonne	112	128
Barite, Drilling grade unground lump, OCMA/API bulk, SG 4.10 FOB Chennai, $/tonne	110	125
Barite, Drilling grade, API unground lump, SG 4.10, FOB China, $/tonne	109	113
Barite, unground lump, OCMA/API bulk, SG 4.20, FOB Morocco, $/tonne	115	127
Barite, API, lump, CIF Gulf Coast, Chinese, $/tonne	145	160

2.12 PRICE, MARKET AND ECONOMICS

The market for barite depends largely on the oil well drilling market. An increase or decrease in barite sales is proportional to the increase and decrease in oil well drilling activities. The price for barites is determined by the purity, specific gravity and mining sites. The major key players in the market that influence the price are China, Indian, Morocco and the USA. The price was steady in 2006, increased rapidly in 2012, and fell in 2014. Drilling grade barite was valued at approximately $182 per tonne, unchanged from 2014. But in 2015, according to year-end published price ranges for crude barite from major exporting countries, the price for barite from China (API grade, lump, including cost, insurance, and freight (c.i.f.), US Gulf Coast, SG 4.2) was $140 to $155 per tonne, a decrease from $145 to $160 per tonne on figures reported in 2014. The import price for barite from India (API grade, lump, c.i.f., US Gulf Coast) remained mostly unchanged at $158 to $171 per tonne. Unground lump, API bulk, SG 4.2, free-on-board barite from Morocco increased from $130 to $140 per tonne as compared with $115 to $127 per tonne at year end in 2014. The import price of chemical grade barite from China (c.i.f., US Gulf Coast) still remains the same at $161 to $180 per tonne; and barite paint grade from China (lump, c.i.f., US Gulf Coast) in 2014 increased from $235 to $275 per tonne, and then from $260 to $310 per tonne.

In Nigeria, between 1998 and 2001, barites production was about 245,000 tpa and fell to about 65000 tpa between 2002 and 2003. The Nigerian government banned the importation of barites in 1996 in an attempt to support local production, and this resulted in widespread mining of barites by artisanal miners. Today, there are barite occurrences in about twelve states in Nigeria. The main production areas are Azara in Nasarawa state; Guma, Gboko and Ushongo in Benue state; Chafe in Zamfara state; and Gabu, Osina in Cross River state. The barite prices in Nigeria differ between mine sites for logistical reasons and because of quality. Buyers from the milling cartel in Port Harcourt paid about 26,000 Naira per tonne, or 188 US dollars in year (Nigeria Geological Survey Agency, 2011).

The purchasing price of the milling companies for barites lumps is was:

9,500 Naira per tonne	SG 4.0- 4.09
10,500 Naira per tonne	SG 4.10-4.14
15,000 Naira per tonne	SG 4.20- 4.29

2.13 INVESTMENT POTENTIAL OF BARITE

While oil well activities determine the demand for barites, there is no doubt that oil exploration activities will continue throughout the globe. About 88% of world barite production is consumed by the oil and gas industries; 6% by chemical industries as fillers, extenders and aggregates; and about 6% is used by ceramic and glass industries. Demand for barite usually leads to strongly elevated prices in paint and micronized-grade barites as supplies became hard to get. Barite production industries have a bright future and will continue to expand. This is because many countries are increasing their oil exploration and drilling activities. In countries where most of the internal production is not enough, additional supplies come mostly from imports (Nigeria Geological Survey Agency, 2016).

2.14 MINING AND PROCESSING OF BARITE

Mining methods depend on the type of deposit:

- Stratiform deposits are worked by open pit;
- Vein deposits are worked by shafts and adits, as well as by shallow open pits; and
- Residual deposits are worked mainly by hand due to the variable and irregular nature of the mineral.

Beneficiation of barite ore involves the following methods: flotation, heavy media, and magnetic separation. In processing, initial crushing is carried out if there are contaminants, such as waste rock or other minerals such as fluorite, quartz, galena or pyrite. These may be separated from the barite by gravity separation, magnetic separation, and froth floatation. The barite is then either dried and sold as powder, or processed further for particular applications (Nigeria Geological Survey Agency, 2011).

The crushed ore is transferred to the processing plant by a truck where it is washed by trommel screen or log washer to remove gangue materials, such as adhering clay and low-grade fines, before reduction to 25 cm or finer by a jaw or impact crusher for further processing.
(http://www.miningcrushing.com/mineral/barite-processing-plant.html, Retrieved September 9, 2017).

2.14.1 Hand picking

The hand picking method is used where there is a small amount of mineral ore. The barite is sorted by colour and density difference from the associated minerals.

2.14.2 Flotation separation

This method is used to beneficiate barite from sulphide ore, fluorite, and a hydrothermal type of barite ore. This is done using the surface chemical and physical properties of the associated minerals and the barite by adding an anionic collector. Froth flotation is a process that selectively separates hydrophobic materials from hydrophilic. After treatment with reagents, such differences in surface properties between the minerals within the flotation pulps become apparent and, for flotation to take place, an air bubble has to attach itself to a particle and lift it to the water surface. The process can be applied to only relatively fine particles. If they are too large, the adhesion between the particle and bubble will be less than the particle weight, and the particle drops its load (Adetunji, 2016).

2.14.3 Gravity separation

In this method, barite is separated from the associated minerals by means of a density difference. The barite grades are usually greater than 88%, and beneficiation methods include washing, desliming, sieving, jigging, and a shaking table. These are the main concentration techniques for iron and tungsten ores, and also for tin ores. Gravity separation is used to treat about 85% of the current world production of barite. In some cases, gravity separation may be cheaper than flotation techniques because of the prohibitive cost of flotation reagents.

Gravity separation can handle ores with particle sizes in the range of 50–10 μm, and may also supplement flotation techniques (Adetunji, 2016).

2.14.4 Magnetic separation

This method uses the magnetic property difference of the associated mineral to separate the barite minerals. This method is used mainly to isolate iron oxide mineral impurities. Only a few minerals are commonly separated magnetically, although many more are moderately susceptible to magnetic attraction. The occasional extension of the range of practice, to include some of these, is not impossible. Magnetic fields may be obtained from permanent magnets, but the most intense fields require electromagnets. When a mixture of magnetic and nonmagnetic particles is carried on a conveyor belt into a magnetic field, the magnetic particles tend to remain in the field while the others pass through. Magnetic separators simply provide two paths, i.e., a gravitational path for nonmagnetic particles and a magnetic path for magnetic material (Adetunji, 2016). Figure 2.10 gives a flow chart for barite processing.

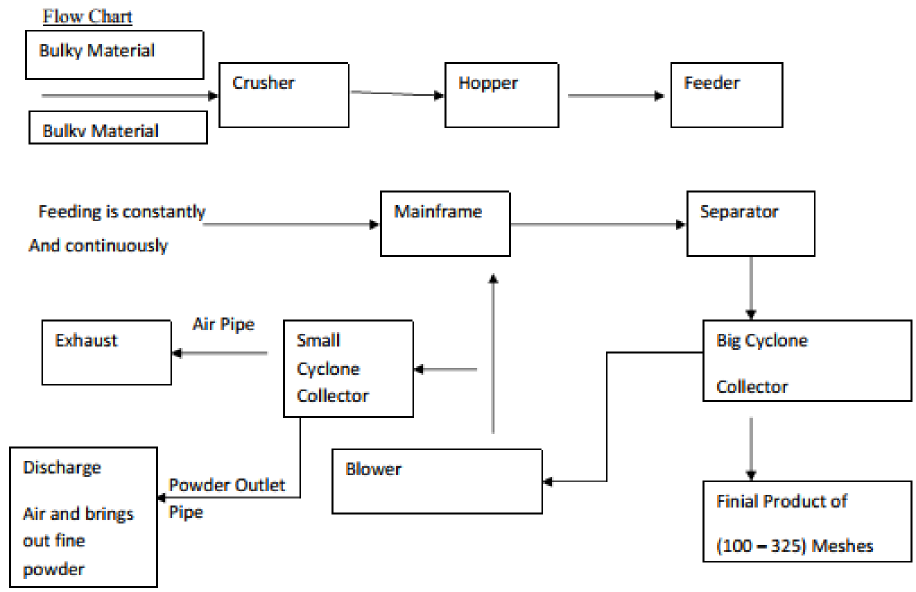


Figure 2.10: Fine Stone Processing Co Ltd (a barite processing plant in Calabar) consists of crusher, milling, separation, blower, and cyclones (Onwualu et al., 2013)

2.15 MACHINERY/EQUIPMENT FOR BARITE PROCESSING

The major pulverizing machinery/equipment for processing barite include jaw crushers, roll mills, separators, hoppers, blower cyclones (big and small) and crushers.

2.16 BARITE CRUSHING AND CONVEYING

The crusher breaks down the barites ores into small pieces; the screen divides the barites materials into four grades, i.e., 0-8 mm, 5 mm, 8-30 mm and 30-50 mm. Materials greater than 50 mm return to the crusher for further crushing. Hand picking is used to sort the 30-50 mm size or coarse barite particles. A bucket elevator is used to transport the crushed barite into the hopper which serves as a secondary storage.

2.17 ROLL MILL-MAINFRAME

From the hopper, the raw barite is transported by feeder into the roll mill, where the raw barite is milled into powder about (100-325) meshes.

2.17.1 Separator

In the separator, the air-blast is introduced by the blower and the particles receive different gravitation, collusion and centrifugal force. In this way, separation and classifying is achieved.

2.17.2 Blower

The blower introduces air into the system to create a different gravitation, collusion and centrifugal force, and the final product is collected through the big cyclone collector. The final product of about (100-325) meshes is collected into the bags.

2.18 POLICY ISSUES

National policy on minerals and metals is developed in order to improve the contribution of mining to national earning by the government. The policy focus is to "address the neglects of the past, respond to the new and global development in the sector, and consider possible areas of future action" (Elder, 2012).

Hence, the aims of the policy are as follows:

- Achieve a substantial increase in GDP contributions from the minerals sector;
- Generate quality Geoscience data;
- Establish a transparent licensing regime;
- Formalize artisanal and small-scale mining operators;
- Poverty eradication through artisan small-scale mining (ASM) operations;
- Employment generation;
- Wealth creation through value addition;
- Increase capacity of mineral-based industries; and
- Attract private investment capital.

2.19 LEGAL AND REGULATORY FRAMEWORK

The Act is the principal legislation that regulates the Nigerian mining sector. The Act vests the control, regulation and ownership of all mineral resources in the Federal Government of Nigeria (FGN). National minerals and metals policy and the minerals and mining regulations designed by FGN regulate the sector. The mining regulations contain specific provisions with respect to royalties, fees and compensation payable by holders of mining rights. The administration of the mining industry is vested in the Ministry of Mines and Steel Development (MMSD), operating through the following departments (KPMG, 2012):

2.19.1 Mines Inspectorate (MID)

- Responsible for operations in exploration, evaluation, mine development and production activities;
- Responsible for enforcement of mining laws and collection of revenues; and
- Ensure safety in operations; and maintain a database of operators and of production records.

2.19.2 Mines Environmental Compliance (MEC)

- Responsible for the enforcement of environmental best practices in mining;
- Establish environmental procedures and requirements applicable to mining operations and the review of all plans, studies and reports required to be prepared by holders of mineral titles; and
- Monitor and enforce compliance of all environmental requirements and obligations.

2.19.3 Mining Cadastre Office (MCO)

- Responsible for the administration of mineral titles;
- An autonomous institution and the sole agency regarding all matters relating to mineral titles;
- Responsible for interfacing with investors in respect of granting and processing of mineral titles; and
- Responsible for the maintenance of a cadastral atlas and title registers.

2.19.4 Metallurgical Inspectorate and Raw Material Development (MIRMD)

- Responsible for metallurgical inspectorate matters and the development of mineral raw materials for the metallurgical industry, and advises the ministry on both
- Set up standards of steel produced in the country, in liaison with appropriate bodies

2.19.5 Artisanal and Small Scale Mining Department (ASM)

- Organise, support and assist small scale mining operations;
- Provide extension services to mining cooperatives on exploration, exploitation, mineral processing, entrepreneurial training, environmental management; and
- Improve sustainable livelihood in ASM communities.

2.19.6 Steel and Non-Ferrous Metals (SNFM)

- Regulate tariffs on metal commodities and products;
- Monitor developments in other sectors of the economy that may have adverse effects on the metals sub-sector and recommend appropriate actions; and
- Ensure compliance by the metals industry operators with environmentally friendly and technically safe operation (Ministry of Mines and Steel Development, 2016).

CHAPTER THREE: EXPERIMENTAL PROCEDURES

3.1 SAMPLING AND ANALYTICAL METHODS FOR BARITE FROM NIGERIA

Site visits were conducted to Benue, Nasarawa, and Plateau states for site inspection on processing. Samples were collected from these locations and then procured from an additional three other locations, making a total of six. The collected samples were prepared for geochemical analysis as well as for specific gravity determination. All the materials were obtained as lumps, crushed or ground to powder. The six samples were coded as follows: A = Zamfara (Anka), B = Nasarawa (Azara), C = Benue (Guma), D = Plateau (Kanam), E= Cross River state (Baise) and G = Taraba (Karim Lamido).

Both the sample preparation and analyses were carried out in the chemical and physical laboratories of the Nigeria Geological Survey Agency (National Geosciences Research Laboratory, Kaduna) and the Nigeria Building and Road Research Institute, Abuja. The following analyses were carried out:

3.2 X-RAY FLUORESCENCE SPECTROMETRY

X-ray fluorescence spectrometry is a method of quantitative analysis that uses x-ray energy. The x-rays obey the law of electromagnetic radiation, which states that a body surface can absorb incident radiation and reflect the incident radiation as a mirror with spherical symmetry that can transmit incident radiation and emit the radiation. The origin of x-rays is from the loss associated with the interaction of high energy electrons with atoms. The electrons coming from the x-ray tube move towards the electronic field of the electrons, in the various shells of the atoms, of the targeted material. The incident electrons are decelerated and loose energy. Incident high energy electrons penetrate the outer orbital of the atoms and collide with an electron in the inner orbital. These inner electrons may be completely removed, leaving the atom in an unstable state. Electron rearrangement to restore stability takes place, leading to the release of energy in the form of x-rays. X-rays generated in this way have discreet wave-lengths, which are related to the atomic number of the atoms producing them.

They are called “characteristic x-rays”. The detection and measurement of the characteristic x-rays are the basis of x-ray spectrometry.

3.1.1 Sample preparation

Pulverization: The samples were pulverized (ground to fine powder) using an arget pulverizing machine (planetary micro mill pulverisette 7). The samples were ground to ensure that they passed through 150 micro mesh sieves. This was to ensure homogeneity of the samples.

Palletisation: 5 g of the pulverized sample was weighed into a beaker, with 1 g of binding aid (starch soluble). The mixture was thoroughly mixed to ensure homogeneity, and then pressed under high pressure to produce pellets. The pellets were labelled and packaged ready for the analysis.

3.1.2 Procedure for the analysis

An 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 analysed were in powder form (pellet);
    - Voltage: The voltages used were 14 kv for major oxides and 20 kv for the trace elements/rare earth metals; and
    - Filters: Selected filters used were “kapton” for major oxides and 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. The time of measurement for each sample was 100 seconds and the medium used was air.

The machine was then calibrated, after which the respective samples were measured by clicking the respective positions of the sample changer.

3.3 LOSS ON IGNITION

LOI was determined gravimetrically by heating 1 g of the powdered sample in a cleaned weighed crucible at 1000 ^{o}C. After this, the crucible and the content were weighed to get the difference in weight before and after heating:

LOI = (a-b/1) x 100% = H_2O^+

Where: a = weight of crucible + 1 g of the sample before heating
b = weight of crucible + 1 g of the sample after heating.

3.4 SCANNING ELECTRON MICROSCOPIC ANALYSIS

A scanning electron microscope (SEM) model "fei inspect S50" was used to show the morphology of the barites samples. SEM uses a beam of electrons (rather than light) to magnify the image of the samples. The magnification can be as high as 100,000 times (3 nm resolution). A metallic filament (A) generates the beam of electrons (B) which strike the surface of the samples (F) to be viewed. As the electrons are knocked off the barite sample surface, a detector (G) captures the knocked-off electrons and amplifies the signal, which is sent to a monitor (H). The electron beam operates in a vacuum and scans back and forth over the barite sample thereby building up a 3D image from the electrons emitted from each spot on the sample.
(http://www.wwu.edu/scitech/sem-competition/SEM_Basic Operating Principles, 2016).

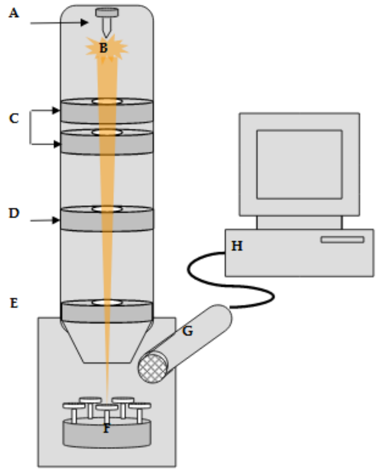


Figure 3.1: Illustration of a SEM

3.4 DETERMINATION OF SPECIFIC GRAVITY

Specific gravity is a measure of the density of a mineral. This is done by comparing the weight of the mineral to the weight of an equal volume of water (Ariffin, 2004). In the oil and gas industry the specific gravity can be determined in different ways, which are: effusion and weighing methods (gravity balance); direct weighting in submerged water; kinetic energy; vibrating element; gas chromatography; displacement of water; and the pycnometer method (Mcdonough, 2001; Verwaal, 2004). In this work, the pycnometer method was used.

3.4.1 Determination of specific gravity using the pycnometer method

Apparatus used:

- Two 50 mL density bottles (pycnometers) with stoppers;
- A rod small enough to go through the neck of the density bottle;
- A constant temperature water bath in the range of 20–30 ^{o}C ± 0.2 ^{o}C;
- A desiccator containing anhydrous silica gel;
- Balance accurate to 0.001 gr;
- Oven (24 hr at 105 ^{o}C ± 5 ^{o}C);
- Vacuum system;
- A wash bottle containing air-free distilled water; and
- A small riffle-box.

3.4.2 Sample preparation

Barite samples of 15.36 g and 15.38 g, respectively, were obtained by riffling according to the size of the density bottle. The samples were then oven dried at 105 ^{o}C and stored in an airtight container.

3.4.3 Execution of the test

- The density bottles were washed, dried, cooled and weighed to the nearest 0.001 g (M_1).
- The samples were transferred to the density bottle and weighed with the stopper to the nearest 0.001 g (M_2).
- Enough air-free distilled water was added to cover the samples in the bottle. The bottle was placed without a stopper in the vacuum desiccator so as to reduce the pressure gradually to about 25 kpa. The bottle was left for at least one hour in a vacuum until no further loss of air was apparent.
- The vacuum was released and the desiccator lid was removed. The sample in the bottle was stirred before removing the stirring rod, and any sample particles were washed off with a few drops of air-free water. This procedure was repeated until no more air evolved from the sample.
- The density bottle was removed from the desiccator and air-free water was added until full. The density bottle filled with water was placed in a constant water bath for one hour so that the bottle attained the temperature of the bath. If an apparent decrease in the volume of the liquid appeared, the stopper was removed and more water added to fill the bottle.
- The bottle was removed from the bath and wiped dry. Then the bottle with the sample and water were weighed to the nearest 0.001 g (M_3).
- The bottle was cleaned of the sample and of water; then de-aerated water was used to fill the bottle before it was immersed in the constant water bath. The bottle with water was taken out of the bath, wiped dry and weighed to the nearest 0.001 g (M_4).

Calculations:

Specific gravity (Ɋs) = $\frac{M2-M1}{(M4-M1)-(M3-M2)}$

Where:

M_1 = mass of density bottle

M_2 = mass of bottle and dry sample

M_3 = mass of bottle and sample and liquid

M_4 = mass of bottle and liquid

3.5 SEDIMENTATION TECHNIQUE

Hydrometer analysis using the sedimentation technique obtains the distribution of particle sizes in the silt range (63–2 μm), and the percentage of clay minerals < 2 μm. The test is usually not performed if less than 10% of the material passes through the 63 μm sieve. The hydrometer analysis uses the relationship among the following variables: the velocity of fall of spheres in a fluid; the diameter of the sphere; the specific weights of the sphere and of the fluid; and the viscosity of the fluid as expressed by Stokes' law (Verwaal, 2004).

3.5.1 Apparatus used

- Soil hydrometer;
- Two 1000 mL glass measuring cylinders, with rubber stops;
- Thermometers;
- High speed stirrer;
- Sieves 200 mm diameter, 63 μm, 212 μm, 2 mm and a receiver;
- Balance readable to 0.01 g;
- Drying oven, 105–110 ^{o}C;
- Stopwatch readable to 1 s;
- Steel rule;
- Four evaporating dishes;
- 1000 mL beaker;
- Two measuring cylinders, 100 mL and 500 mL;

- Washed bottle and distilled water;
- Constant temperature bath;
- Glass rod: 12 mm diameter, 400 mm long; and
- Standard dispersant solution: 33 g sodium hexametaphosphate and 7 g of sodium carbonate in distilled water to make a 1 litre solution.

3.5.2 Sample preparation

The sample was dried in an oven at 65 ^oC, weighed to 0.01 g and then placed in a 1000 mL beaker.

3.5.3 Executing the test

3.5.3.1 Dispersion

- 100 ml of the standard dispersant solution was added to the sample.
- The mixture was shaken thoroughly until all the samples were in suspension.
- The sample, with some distilled water, was transferred into a high-speed cup and stirred for about 1 hour.
- The suspension was transferred to the 63 μm sieve and placed on a receiver.
- The sample was washed in the sieve with a maximum of 500 mL distilled water.
- The suspension was also transferred in the receiver into a 1000 mL sedimentation cylinder.
- The material retained on the 63 μm sieve was placed on an evaporating dish and dried in an oven at 105 ^oC.
- When cooled, the material was sieved on 2 mm, 600 μm and 63 μm sieves.
- The material retained on each sieve was dried and weighed to the nearest 0.01 g.
- The material passing through the 63 μm sieve was added to the sedimentation cylinder.

3.5.3.2 Sedimentation

- The sedimentation cylinder was filled to the 1L gradation mark with distilled water, and then placed in a constant-temperature water bath set at 25 ^oC.

- A second cylinder containing 100 mL of the dispersant solution was filled with distilled water to exactly 1L and placed in the constant temperature bath for calibration readings of the dispersant solution and for storage of the hydrometer between the readings.
- The cylinders were allowed to stand in the bath until they reached the bath temperature (for one hour).
- A rubber stop was inserted in the sedimentation cylinder and the cylinder was shaken vigorously to obtain a uniform suspension; as well as stirred with a glass rod so that all the material went into suspension. The cylinder was inverted for 10 seconds, and placed in the constant temperature bath. Without delay and as soon as it was in the upright position, the stop watch was started (zero time).
- The rubber bung was removed and the hydrometer inserted steadily and allowed to float freely. Care was taken such that it was not allowed to bob up and down, or to rotate. However, a quick rotational twist with the fingers on the top of the hydrometer dislodged any air bubbles which may have adhered to the side.
- Readings of the hydrometer were taken at the top of the meniscus level at the following times from zero: 0.5 minutes, 1 minute, 2 minutes and 4 minutes using a stopwatch.
- The hydrometer was removed slowly, rinsed in distilled water, and placed in the separate cylinder of distilled water in the constant temperature bath.
- The top of the meniscus reading was observed and recorded.
- The hydrometer was inserted for further readings at the following times from zero: 8 minutes, 30 minutes, 2 hours, 8 hours and 24 hours; and twice during the following day using a stop watch. The hydrometer was inserted slowly about 15 seconds before a reading was due.
- The hydrometer was inserted and withdrawn very carefully to avoid disturbing the suspension.
- The temperature of the bath was observed after every recording. If the temperature varied by more than 1 ^{o}C, another reading was taken.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 MINERALIZATION OF BARITE IN NIGERIA

The Nigeria Geological Survey Agency (2011) gives the occurrence and deposits of barite in the following states: Adamawa, Benue, Cross River, Ebonyi, Nasarawa, Plateau, Gombe, Taraba and Zamfara. It shows that the current mineralization of barite in Nigeria is across the NE-SE axis. Other axes may be worked in order to investigate occurrence. Mineralization is the formation of ore bodies or lodes through hydrothermal deposition (Mineralization; Wikipedia, 2017). The mineralization may exist as vein fissures in sedimentary and fracture fillings in gneisses and migmatite rocks displaying distinct features suggestive of open-space deposition and cavity fillings such as large, interlocked, euhedral crystal growths, cocks-comb structures and mineral inclusions. Host rock to the mineralization is the ubiquitous sandstone, shale, siltstone, and pelitic schist. In addition to these, basement gneisses have been observed to host barite and fine-grained granite. The persistence of barite veins into the basement complex beneath the Cretaceous cover is an indication of both the depth and width of the Cretaceous deformation, resulting in residual or bedded deposits. In Nigeria barite is found as vein fissures and cavity fillings in sedimentary rocks. Extensive bedded deposits have not be found in the country (Nigeria Geological Survey Agency, 2011).

4.2 SITE VISIT

Nasarawa and Plateau site were visited. In the Azara mine site in Nasarawa state there are 18 veins (see Figure 4.2a, b, c and d). Vein 17 is said to be the largest in West Africa. However, most of the barites are of low quality. Hence, they need to be upgraded through beneficiation processes, although most of the barite is mined by artisanal miners. Despite the lack of machinery, the depth mined in some of the sites in Azara is more than 30 metres. In Kanam, Plateau state (see Figure 4.2e) the site is a virgin site. There are no active mining operations taking place. However, barite in this area is of low quality because the barite vein is dominated by calcite.

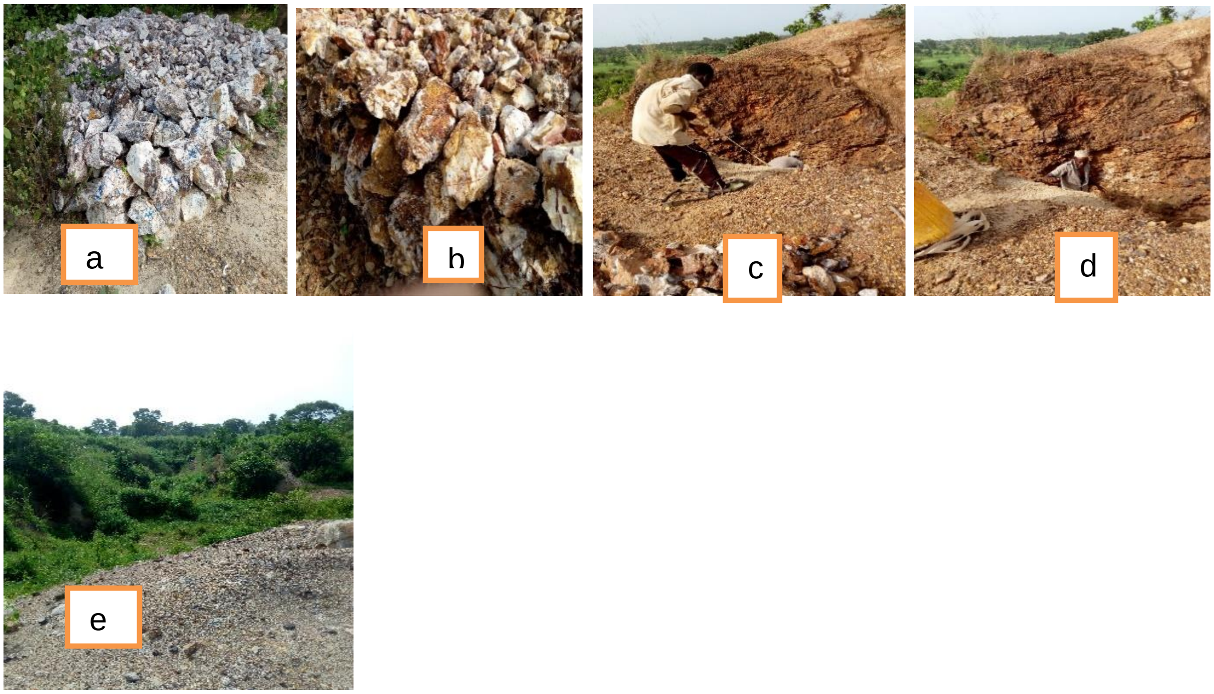


Figure 4.1: Low quality (a) and high quality (b) barite at vein 17 Azara vein 18 (c) and (d) in Azara. The vein depth is more than 30 meters.

4.3 X-RAY SPECTROMETRY

Table 4.1 shows the analysis results from X-ray spectrometry. The oxide composition of the barite samples analysed showed that the samples were dominated by BaO, Fe_2O_3 and SiO_2 with the exception of sample A. Sample A did not contain BaO, hence it is not barite, but was rich in silica (SiO_2) and alumina (Al_2O_3). Therefore, it could be mica or feldspar, which are aluminosilicate minerals that can be used as refractory materials in the metallurgical and aerospace industry. Sample B had $BaSO_4$ of 77.76%, and gangue materials such Fe_2O_3 (4.72%), SiO_2 (15.20%), and celestite ($SrSO_4$). The Ministry of Mines and Steel Development (2010) reported similar results of the impurities present in samples obtained from the same state. Hence, in order to improve the barite composition, gravity concentration should be done to remove the silica content followed by magnetic separation to eliminate the Fe_2O_3 content. Sample C contained $BaSO_4$ (89.54%), SiO_2 (6.49%), and Fe_2O_3 (4.72%). This is similar to the results obtained by *How we made it in Africa* (2010). Gravity concentration and magnetic separation beneficiation methods will improve the sample.

Sample D was a very low-grade barite dominated by calcite (49.91%), $BaSO_4$ (10.88%), and Fe_2O_3 (2.37%). Most of the locations in the state previously reported by the Ministry of Mines and Steel Development (2010) have barite mineralization in veins of calcite and celestite (SrSO) with lower SG values. The latter may be an impurity in the barites thus lowering the specific gravity. The gravity concentration method is required to eliminate the calcite; and the magnetic separation method to remove the presence of hematite. Sample E contained $BaSO_4$ (83.16%), SiO_2 (10.2%), and Fe_2O_3 (4.34%). The sample was rich in silica and hematite. Hence, gravity concentration and magnetic separation can be used to improve the quality of the sample. Sample G had the highest oxide composition of $BaSO_4$ (96.5%), and SiO_2 (1%), and as such met the API standard required for drilling mud. The silica content is still high and this can be removed by gravity concentration.

Table 4.1: XRF results for the six barites samples

Oxide Composition (%)	A	B	C	D	E	G
SiO_2	40.89	15.20	6.49	ND	10.20	1.00
TiO_2	0.018	ND	ND	ND	ND	ND
Al_2O_3	57.70	ND	ND	ND	ND	0.003
Fe_2O_3	0.264	4.72	1.42	2.37	4.34	0.13
CaO	0.02	ND	0.653	49.91	ND	ND
MgO	0.01	ND	0.113	ND	ND	ND
MnO	0.022	ND	ND	1.07	ND	ND
SO_3	ND	20.08	21.76	1.50	19.06	33.10
Na_2O	ND	0.07	0.02	ND	ND	ND
K_2O	ND	0.06	0.005	ND	ND	ND
NiO	ND	ND	ND	ND	0.006	ND
SrO	ND	0.997	0.467	1.07	0.869	0.60

CuO	0.007	0.064	0.057	0.027	0.051	0.074
ZnO	ND	0.024	0.097	ND	ND	ND
BaO	ND	57.68	67.78	9.38	64.10	63.40
Ga_2O_3	ND	ND	ND	ND	ND	0.008
OsO_4	ND	ND	ND	ND	ND	0.02
WO_3	ND	ND	ND	ND	ND	0.03
L.O. I	1.06	1.10	1.13	34.67	1.37	1.20

ND = Not Detected

4.4 MICROSTRUCTURAL ANALYSIS

Figure 4.2 shows the micrographs results from the samples analysed, which consist of well-connected dark regions with sharp edges. The dark region in Sample A, according to the Haq et al. (2009) report and the XRF result in Table 3.1, may likely be dominated by alumina with 50% irregular silica fibre. Hence, the sample is not barite and cannot be used for drilling-mud application. Sample B consists of both fine and large irregular particles. The lighter dark regions may suggest the presence of barium, sulphur and strontium, while the dark black region may indicate the presence of quartz (Haq et al., 2009). Hence, Sample B is predominantly barite, according to the XRF result in Table 11, and may contain about 70% $BaSO_4$ and less gangue materials. However, for it to meet the API standard for drilling-mud application, it needs to be upgraded through beneficiation processes to remove the gangue. Sample C, according to the Haq et al. (2009) report, appears dominated by $BaSO_4$ and, from the result of the XRF, the sample may contain as much as 90% $BaSO_4$ with a limited number of associated minerals and irregular particle sizes. Sample D consists of both coarse and granular irregular shape particles. These predominant granular shaped particles may show the presence of calcite (http://particledetective.com/blog, 2018). The sample is high in calcite hence the specific gravity will be very low. Sample E contains both coarse and fine particles. From the XRF result, the silica content (as shown in Table 11) is relatively high (about 10%) with $BaSO_4$ at 80%.

However, to be used for a drilling-mud application, the $BaSO_4$ should be about 95% (Shah Ariffin, 2017) (Purchasing Guidelines Handbook API, 2017). Sample G had the best oxide composition from the XRF result (see Table 11) and with more lighter-dark regions suggesting that the $BaSO_4$ content is high at about 95% (Haq et al., 2009). Hence, sample G meets the API specification for drilling mud.

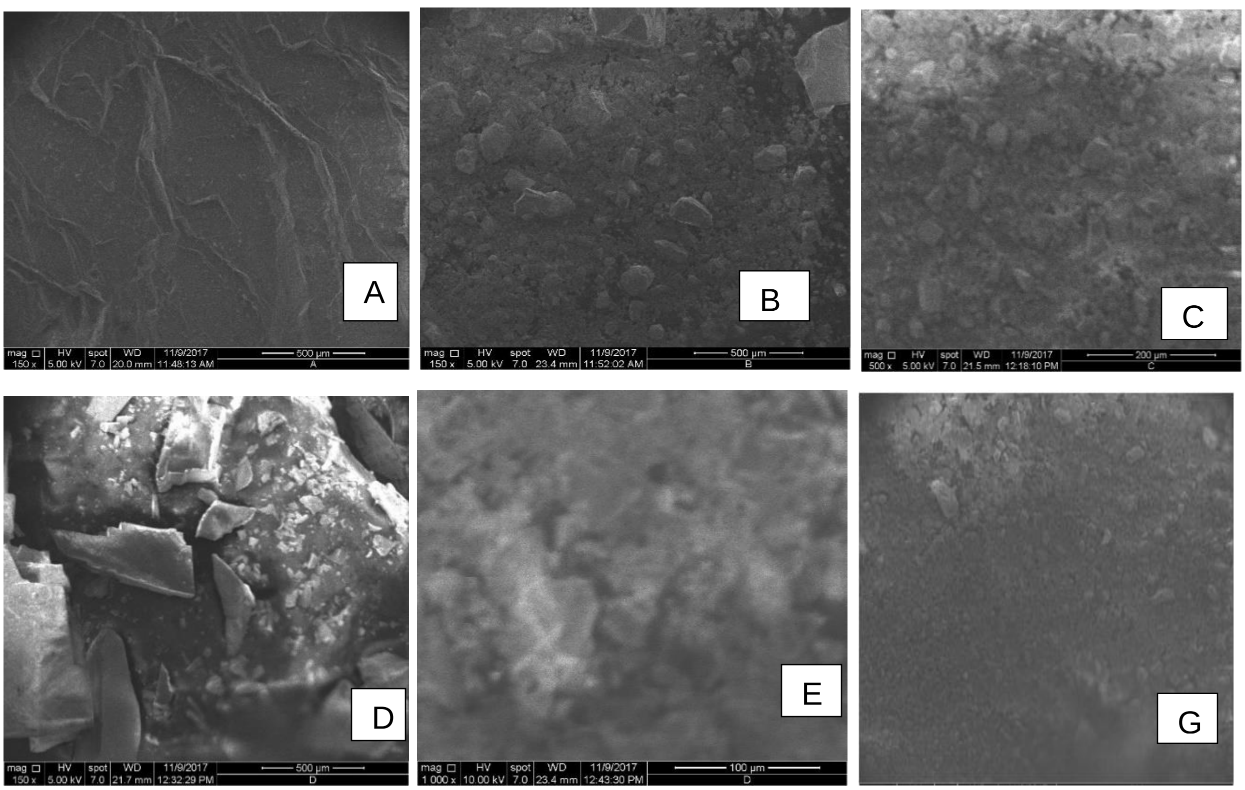


Figure 4.2: The micrographs of the samples from different locations

4.5 SPECIFIC GRAVITY DETERMINATION

Specific gravity was determined using the pycnometer method because it is simple and accurate. According to the report from the pycnometer analysis for sample B (Azara in Nasarawa state):

$M_1 = 50.78$

$M_2 = 66.16$

$M_2 - M_1 = 15.38$

$M_3 = 162.33$

$M_3 - M_2 = 96.17$

$M_4 = 150.91$

$M_4\text{-}M_1 = 100.13$

Specific gravity (Ꝗs) = $\frac{M2-M1}{(M4-M1)-(M3-M2)} = \frac{15.38}{100.13-96.17} = 3.8838$

$M_1 = 54.99$

$M_2 = 66.35$

$M_2\text{-}M_1 = 15.36$

$M_3 = 162.34$

$M_3\text{-} M_2 = 95.98$

$M_4 = 150.93$

$M_4\text{-}M_1 = 99.94$

Specific gravity (Ꝗs) = $\frac{M2-M1}{(M4-M1)-(M3-M2)} = \frac{15.36}{3.96} = 3.878$

The average value of the SG of the samples $\frac{3.8838+3.878}{2} = 3.9$

Table 3.2 shows the specific gravity of the six sample locations. The specific gravity values for the barite samples ranged from 3.6-4.3. Samples C, F and G meet the API standard of 4.1 minimum for drilling mud. Samples B, D and E were below the API standard, but can be improved through beneficiation. Comparing the values with results of the Ministry of Mines and Steel Development (in Table 3.3 and Figure 3.4) shows that barites in Nigeria meet the API standard and bear comparable properties with resources in other parts of the world, especially when beneficiated. Investors could seek investment by either partnering with existing title holders, or by directly obtaining titles and supplying mining equipment and underground mining technology.

Table 4.2: Barite SG of the six samples locations

Samples	States	LGA	SG
A	Zamfara	Anka	3.6
B	Nasarawa	Azara	3.9
C	Benue	Guma	4.3
D	Plateau	Kanam	2.9
E	Cross River	Baise	3.8

F	Nasarawa	Ribi	4.3
G	Taraba	Karim Lamido	4.2

Table 4.3: Reserve estimates and barite SG in Nigeria (Ministry of Mines and Steel Development, 2010)

State	Reserve Estimate	Barite specific gravity
Adamawa	332,130 tonnes	4.0–4.36
Benue	307,657 tonnes	3.7–4.4
Cross River	8,612,880 tonnes	3.5–4.4
Ebonyi	Yet to be Determined	
Gombe	352,800 tonnes	4.09–5.3
Nasarawa	3,243, 376 tonnes	3.9–4.4
Plateau	500,000 tonnes	4.0–4.39
Taraba	8,960,000 tonnes	4.2
Zamfara	Yet to be determined	
Bauchi	Yet to be determined	
Katsina	Yet to be determined	

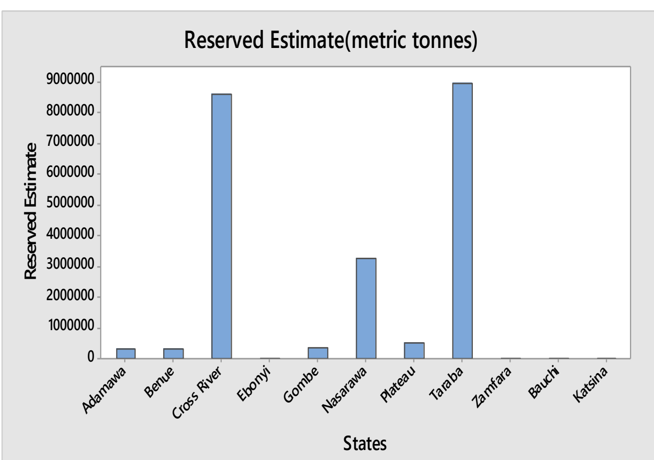


Figure 4.3: Bar chart showing reserve estimate of barite in Nigeria (Ministry of Mines and Steel Development, 2010)

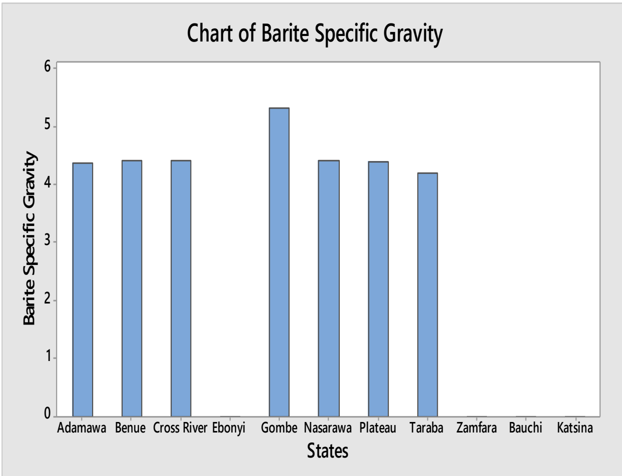


Figure 4.4: Bar chart showing specific gravity of barite in Nigeria (Ministry of Mines and Steel Development, 2010)

4.6 SEDIMENTATION

This technique looks at the distribution of the barite particle size when passed through a 75 µm sieve, and particles less than 6 µm. Particle size is important because the finer the particle the more easily a homogenous solution will be formed for drilling-mud operations (Crecelius et al., 2007). Sedimentation uses sieve analysis to monitor material quality based on particle size. Sieve analyses are usually carried out dry. However, when the sample to be analysed is a very fine powder, generally less than 45 µm, particles tend to agglomerate in a dry sieving process and this tendency leads to a clogging of the sieve meshes making further sieving process impossible. Dry sieving is less accurate for very fine materials because of an increase in the energy required to make the particles pass through the openings, and an increase in surface attraction between particles and the screen.

Therefore, if the material to be used is affected by liquid wet sieving, it is preferable, because liquid transports fine materials through the sieve far more efficiently than shaking the dry material.
(http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm, 2013); and
(https://ftp.dot.state.tx.us/pub/txdot-info/cst/TMS/200-F_series/pdf, 2016).

The dried barite samples were poured onto the top sieve and shaken by hand to retain the weight. The cumulative weight of all materials larger than each sieve size was determined and divided by the total sample weight to obtain the percent retained for that sieve size. This value was subtracted from 100% to obtain the percent passing that sieve size. Results were displayed by plotting the percent passing (on a linear scale) against the sieve opening size or particle size (on a log scale) and connecting the plotted points with a smooth curve referred to as a grain-size distribution curve.
(http://www.ce.memphis.edu/1101/notes/filtration/sieve, 2017); and
(http://www.chem.mtu.edu/chem_eng/faculty/, 2017).

Figure 4.5 shows the particle size distribution of Sample A. The particle size was constant, but thereafter continues to increase with increase in percentage passed. For particles less than 6 micrometre, the maximum mass fraction of particles is zero. Table 14 shows the particle size distribution of dry Sample A showing percentage mass retained and passing. At 75 micrometer nothing was retained. API requires that the barite be finely ground so that at least 97% of the material, by weight, can pass through a 200-mesh (Tyler) [75-micrometre (μm)] screen, and that no more than 30%, by weight can be less than 6 μm effective diameter, which is measured using sedimentation techniques. Table 15 shows that, as the particle diameter continues to reduce and the finer the barite sample, the more easily a homogenous solution will be formed for drilling-mud application.

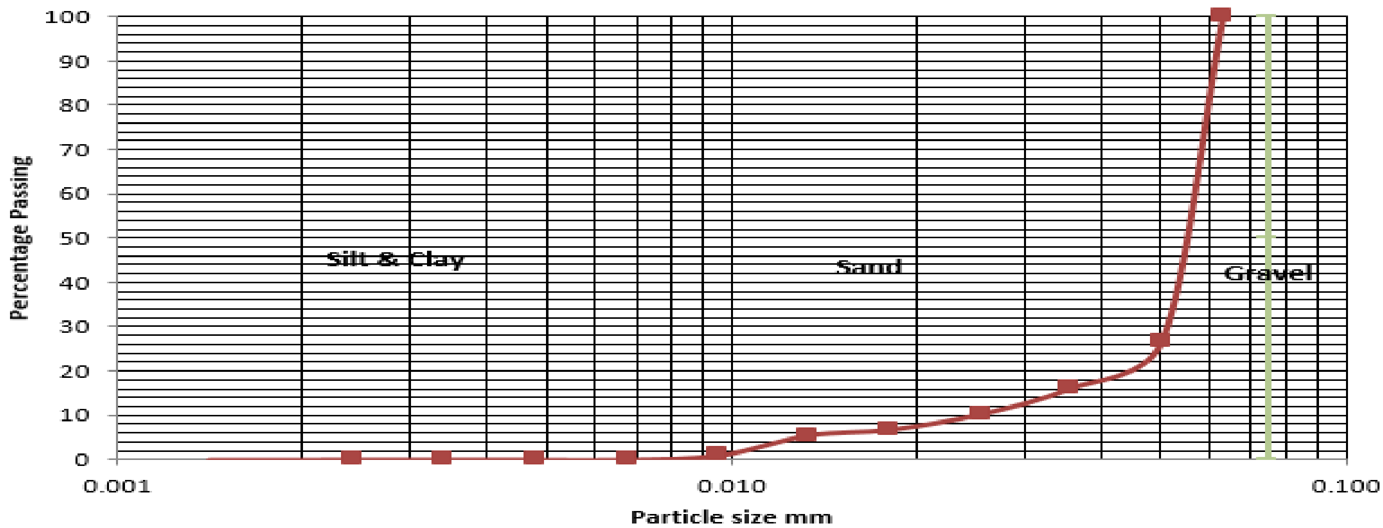


Figure 4.5: Particle size distribution chart of Sample A

Table 4.4: Particle size distribution of dry Sample A showing percentage mass retained and passing

Total mass of dry sample 40.1 g			
sieve size	Mass retained g	Percentage retained %	Percentage passing %
10.00 mm	0.00	0.00	100.00
5.00 mm	0.00	0.00	100.00
4.75 mm	0.00	0.00	100.00
3.35 mm	0.00	0.00	100.00
2.36 mm	0.00	0.00	100.00
2.00 mm	0.00	0.00	100.00
1.18 mm	0.00	0.00	100.00
600 µm	0.00	0.00	100.00
425 µm	0.00	0.00	100.00
300 µm	0.00	0.00	100.00
150 µm	0.00	0.00	100.00
75 µm	0.00	0.00	100.00
63 µm	0.02	0.05	99.95
Passing 63 µm	41.00	99.95	
Total	41.02		

Table 4.5: Hydrometer reading for wet sieving analysis for Sample A

Elapsed time t (min)	Hydrometer reading R_h'	True reading R_h	Effective depth H_R	Modified reading R_d	Particle diameter	Percentage finer
0						
0.5	17.5	17.8	136.5	16.5	0.069	53.274
1	14.9	15.2	146.7	13.9	0.050	44.879
2	11.2	11.5	161.3	10.2	0.037	32.933
4	10	10.3	166.0	9.0	0.027	29.059
8	7.5	7.8	175.9	6.5	0.019	20.987
15	6.3	6.6	180.6	5.3	0.014	17.112
30	5.5	5.8	183.7	4.5	0.010	14.529
60	3.2	3.5	192.8	2.2	0.007	7.103
120	3	3.3	193.6	2.0	0.005	6.458
240	2.2	2.5	196.7	1.2	0.004	3.875
480	1	1.3	201.5	0.0	0.003	0.000
1440	1	1.3	201.5	0.0	0.002	0.000

Sample B

Figure 4.6 shows the particle size distribution chart of Sample B. At about 6 micrometre the percentage by weight retained is 38%. Table 4.6 shows particle size distribution of dry Sample B showing percentage mass retain and passing. At 75 micrometre nothing was retained. Table 4.6 shows that as the particles' diameter reduces with time, the finer the particles. Hence, Sample B meets the API standard for sieve analysis.

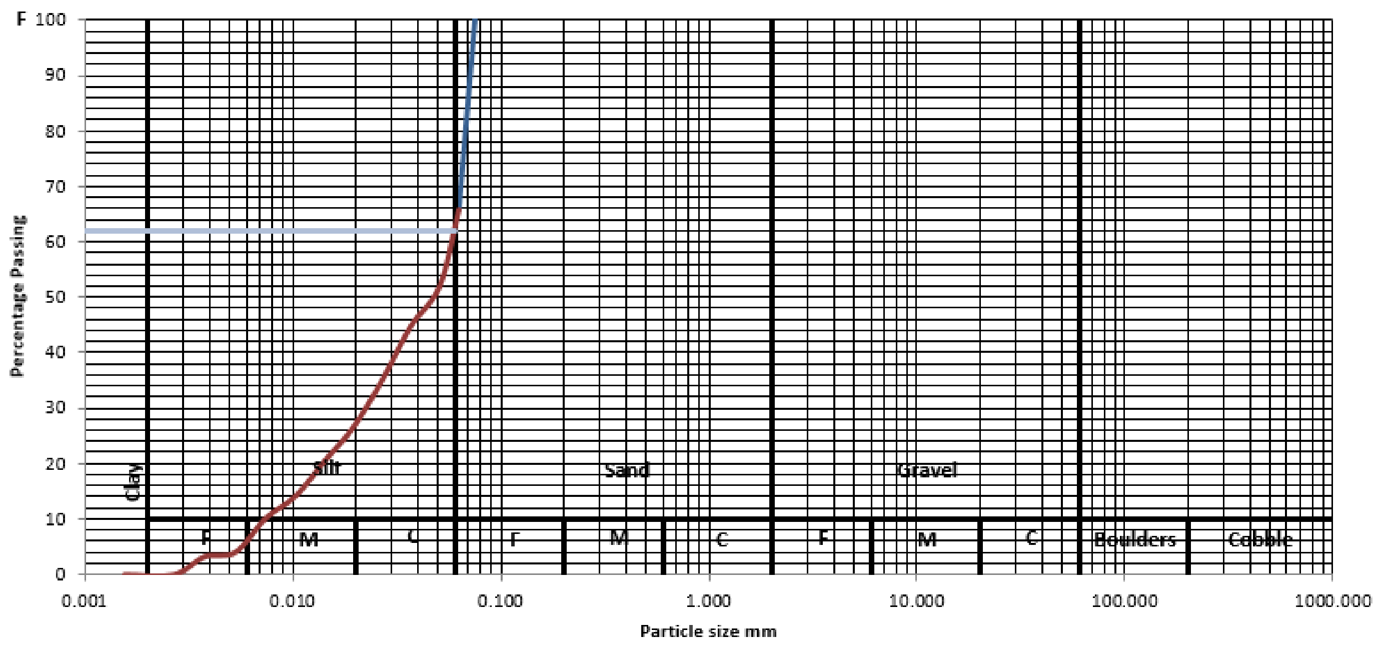


Figure 4.6: Particle size distribution chart of Sample B

Table 4.6: Particle size distribution of dry Sample B showing percentage mass retained and passing

Total mass of dry sample 40 g			
sieve size	Mass retained g	Percentage retained %	Percentage passing %
14.00 mm	0	0.00	100.00
10.00 mm	0	0.00	100.00
5.00 mm	0	0.00	100.00
3.35 mm	0	0.00	100.00
2.36 mm	0	0.00	100.00
2.00 mm	0	0.00	100.00
1.18 mm	0	0.00	100.00
600 µm	0	0.00	100.00
425 µm	0	0.00	100.00
300 µm	0	0.00	100.00
150 µm	0	0.00	100.00
75 µm	0	0.00	100.00
63 µm	13.7	34.25	65.75
Passing 63 µm	26.30	65.75	
Total	40.00		

Table 4.7: Hydrometer reading for wet sieving analysis for Sample B

Elapsed time t (min)	Hydrometer reading R_h'	True reading R_h	Effective depth H_R	Modified reading R_d	Particle diameter	Percentage finer
0						
0.5	15.1	15.4	145.9	14.1	0.071	57.282
1	13.8	14.1	151.0	12.8	0.051	52.000
2	12	12.3	158.1	11.0	0.037	44.688
4	9.6	9.9	167.6	8.6	0.027	34.938
8	7.5	7.8	175.9	6.5	0.019	26.407
15	6.1	6.4	181.4	5.1	0.014	20.719
30	4.5	4.8	187.7	3.5	0.010	14.219
60	3.5	3.8	191.6	2.5	0.007	10.157
120	2	2.3	197.5	1.0	0.005	4.063
240	1.8	2.1	198.3	0.8	0.004	3.250
480	1	1.3	201.5	0.0	0.003	0.000
1440	1	1.3	201.5	0.0	0.002	0.000

Sample C

Figure 4.7 shows the particle size distribution chart of sample C. At about 6 micrometre, the percentage by weight retained is zero. Table 4.8 shows that at 75 micrometre nothing was retained. Table 4.9 shows that the barite particles are finer as the diameter of the particles reduces. Hence, Sample C meets the API standard for sieve analysis.

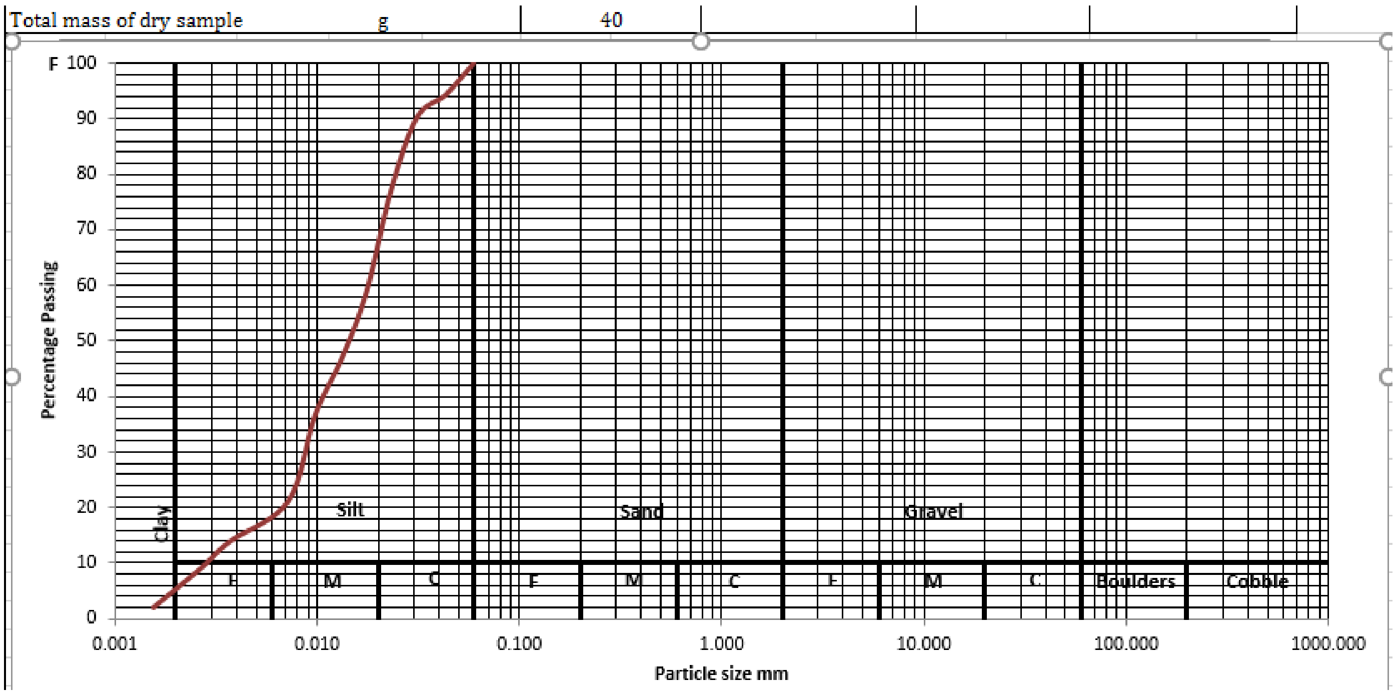


Figure 4.7: Showing particle size distribution chart of Sample C

Table 4.8: Particle size distribution of dry Sample C showing percentage mass retained and passing

Total mass of dry sample 40 g			
sieve size	Mass retained g	Percentage retained %	Percentage passing %
14.00 mm	0	0.00	100.00
10.00 mm	0	0.00	100.00
5.00 mm	0	0.00	100.00
3.35 mm	0	0.00	100.00
2.36 mm	0	0.00	100.00
2.00 mm	0	0.00	100.00
1.18 mm	0	0.00	100.00
600 µm	0	0.00	100.00
425 µm	0	0.00	100.00
300 µm	0	0.00	100.00
150 µm	0	0.00	100.00
75 µm	0	0.00	100.00
63 µm	0	0.00	100.00
Passing 63 µm	40.00	100.00	

Table 4.9: Hydrometer reading for wet sieving analysis for Sample C

Elapsed time t (min)	Hydrometer reading R_h'	True reading R_h	Effective depth H_R	Modified reading R_d	Particle diameter	Percentage finer
0						
0.5	25.6	25.9	104.5	24.6	0.060	99.938
1	24.2	24.5	110.0	23.2	0.044	94.250
2	23.2	23.5	114.0	22.2	0.031	90.188
4	20	20.3	126.6	19.0	0.023	77.188
8	15.5	15.8	144.3	14.5	0.018	58.907
15	12.6	12.9	155.8	11.6	0.013	47.125
30	10	10.3	166.0	9.0	0.010	36.563
60	6.2	6.5	181.0	5.2	0.007	21.125
120	6.2	6.5	181.0	5.2	0.005	21.125
240	4.4	4.7	188.1	3.4	0.004	13.813
480	3.2	3.5	192.8	2.2	0.003	8.938
1440	1.5	1.8	199.5	0.5	0.002	2.032

Sample D

Figure 4.8 shows the particle size distribution chart of sample D. At about 6 micrometer the percentage by weight retained is 54%. Table 4.10 shows that at 75 micrometer 42.65% was retained. Table 4.11 shows that the barite particles are finer as the diameter of the particles reduces. Sample D, in terms of sieve analysis, does not meet the API standard.

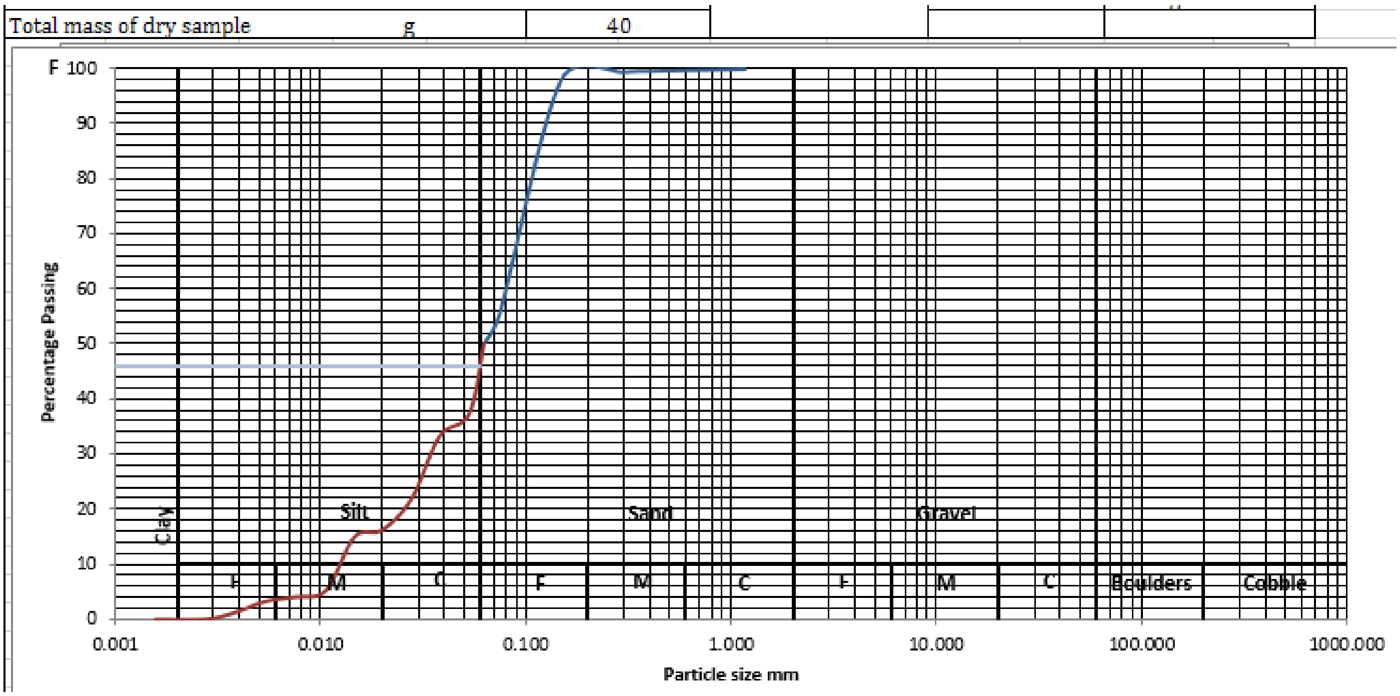


Figure 4.8: Particle size distribution chart of Sample D

Table 4.10: Particle size distribution of dry Sample D showing percentage mass retained and passing

Total mass of dry sample 40 g			
Sieve size	Mass retained g	Percentage retained %	Percentage passing %
14.00 mm	0	0.00	100.00
10.00 mm	0	0.00	100.00
5.00 mm	0	0.00	100.00
3.35 mm	0	0.00	100.00
2.36 mm	0	0.00	100.00
2.00 mm	0	0.00	100.00
1.18 mm	0	0.00	100.00
600 µm	0.1	0.25	99.75
425 µm	0.05	0.13	99.63
300 µm	0.08	0.20	99.43
150 µm	0.55	1.38	98.05
75 µm	17.06	42.65	55.40
63 µm	2.1	5.25	50.15
Passing 63 µm	20.06	50.15	
Total	40.00		

Table 4.11: Hydrometer reading for wet sieving analysis for Sample D

Elapsed time t (min)	Hydrometer reading R_h'	True reading R_h	Effective depth H_R	Modified reading R_d	Particle diameter	Percentage finer
0						
0.5	11	11.3	162.1	10.0	0.075	40.6254
1	10.2	10.5	165.2	9.2	0.053	37.3754
2	9.2	9.5	169.2	8.2	0.038	33.3129
4	6.4	6.7	180.2	5.4	0.028	21.9379
8	5	5.3	185.7	4.0	0.020	16.2504
15	4.7	5.0	186.9	3.7	0.015	15.0317
30	2.3	2.6	196.4	1.3	0.011	5.2817
60	2	2.3	197.5	1.0	0.008	4.0629
120	1.8	2.1	198.3	0.8	0.005	3.2504
240	1.3	1.6	200.3	0.3	0.004	1.2192
480	1	1.3	201.5	0.0	0.003	0.0004
1440	1	1.3	201.5	0.0	0.002	0.0004

Sample E

Figure 4.9 shows the particle size distribution chart of sample E. At about 6 micrometer, the percentage by weight retained is zero. Table 4.12 shows that at 75 micrometer 0% was retained. Table 4.13 shows that the barite particles are finer as the diameter of the particles reduces. Sample E, in terms of sieve analysis, does meet the API standard.

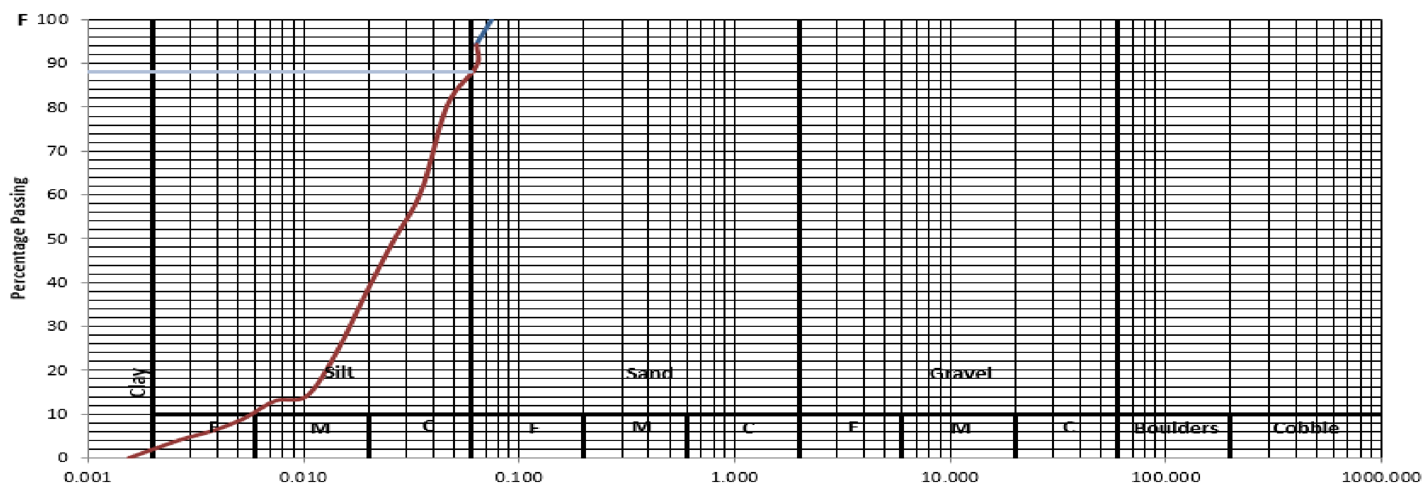


Figure 4.9: Particle size distribution chart of Sample E

Table 4.12: Particle size distribution of dry Sample E showing percentage mass retained and passing

Total mass of dry sample 40 g			
sieve size	Mass retained g	Percentage retained %	Percentage passing %
14.00 mm	0	0.00	100.00
10.00 mm	0	0.00	100.00
5.00 mm	0	0.00	100.00
3.35 mm	0	0.00	100.00
2.36 mm	0	0.00	100.00
2.00 mm	0	0.00	100.00
1.18 mm	0	0.00	100.00
600 µm	0	0.00	100.00
425 µm	0	0.00	100.00
300 µm	0	0.00	100.00
150 µm	0	0.00	100.00
75 µm	0	0.00	100.00
63 µm	2.27	5.68	94.33
Passing 63 µm	37.73	94.33	
Total	40.00		

Table 4.13: Hydrometer reading for wet sieving analysis for Sample E

Elapsed time t (min)	Hydrometer reading R_h'	True reading R_h	Effective depth H_R	Modified reading R_d	Particle diameter	Percentage finer
0						
0.5	23	23.3	114.8	22.0	0.063	89.3754
1	20.8	21.1	123.4	19.8	0.046	80.4379
2	16	16.3	142.4	15.0	0.035	60.9379
4	13.1	13.4	153.8	12.1	0.026	49.1567
8	10	10.3	166.0	9.0	0.019	36.5629
15	7	7.3	177.8	6.0	0.014	24.3754
30	4.5	4.8	187.7	3.5	0.010	14.2192
60	4.2	4.5	188.9	3.2	0.007	13.0004
120	3.2	3.5	192.8	2.2	0.005	8.9379
240	2.5	2.8	195.6	1.5	0.004	6.0942
480	2	2.3	197.5	1.0	0.003	4.0629
1440	1	1.3	201.5	0.0	0.002	0.0004

Sample G

Figure 4.10 shows the particle size distribution chart of Sample G. At about 6 micrometer, the percentage by weight retained is 28%. Table 4.14 shows that at 75 micrometer 0% was retained. Table 4.15 shows that the barite particles are finer as the diameter of the particles reduces. Sample G, in terms of sieve analysis, meets the API standard.

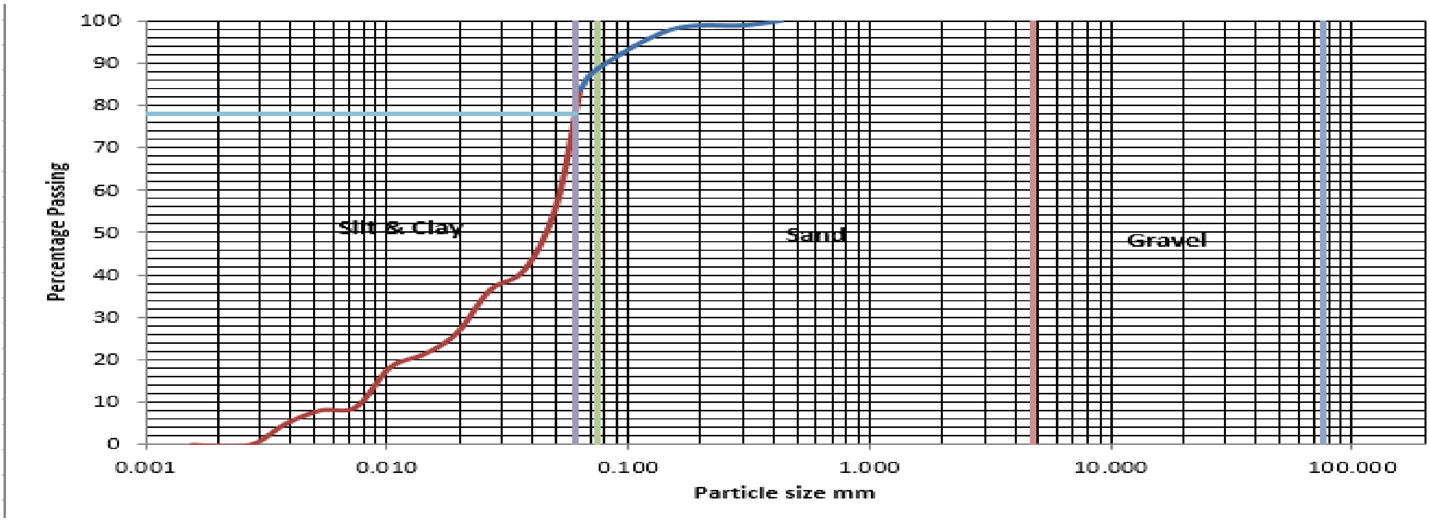


Figure 4.10: Particle size distribution chart of Sample G

Table 4.14: Particle size distribution of dry Sample G showing percentage mass retained and passing

Total mass of dry sample 40.2 g			
Sieve size	Mass retained g	Percentage retained %	Percentage passing %
10.00 mm	0.00	0.00	100.00
5.00 mm	0.00	0.00	100.00
4.75 mm	0.00	0.00	100.00
3.35 mm	0.00	0.00	100.00
2.36 mm	0.00	0.00	100.00
2.00 mm	0.00	0.00	100.00
1.18 mm	0.00	0.00	100.00
600 µm	0.00	0.00	100.00
425 µm	0.00	0.00	100.00
300 µm	0.00	0.00	100.00
150 µm	0.00	0.00	100.00
75 µm	0.00	0.00	100.00
63 µm	0.02	0.05	99.95
Passing 63 µm	40.18	99.95	
Total	40.20		

Table 4.15: Hydrometer reading for wet sieving analysis for Sample G

Elapsed time t (min)	Hydrometer reading R_h'	True reading R_h	Effective depth H_R	Modified reading R_d	Particle diameter	Percentage finer
0						
0.5	17.5	17.8	136.5	16.5	0.069	53.274
1	14.9	15.2	146.7	13.9	0.050	44.879
2	11.2	11.5	161.3	10.2	0.037	32.933
4	10	10.3	166.0	9.0	0.027	29.059
8	7.5	7.8	175.9	6.5	0.019	20.987
15	6.3	6.6	180.6	5.3	0.014	17.112
30	5.5	5.8	183.7	4.5	0.010	14.529
60	3.2	3.5	192.8	2.2	0.007	7.103
120	3	3.3	193.6	2.0	0.005	6.458
240	2.2	2.5	196.7	1.2	0.004	3.875
480	1	1.3	201.5	0.0	0.003	0.000
1440	1	1.3	201.5	0.0	0.002	0.000

In summary, samples A, B, C, E and G meet the API specification in terms of the particle size distribution. Sample D does not meet API specification because it has high calcite content as shown in Table 4.16.

Table 4.16: Summary of the entire work

State	LGA	Specific gravity	Residue greater than 75 µm (% by weight)	Particle less than 6 µm (% by weight)	Water soluble alkaline earth metals (mg/kg)
Benue (C)	Guma	4.3	0	0	
Cross River (E)	Baise	3.8	0	12	
Taraba (G)	Karim Lamido	4.2	0	28	
Nasarawa (B)	Azara	3.9	0	38	
Plateau (D)	Kenam	2.9	42.65	54	
Zamfara (A)	Anka	3.6	0	0	

CHAPTER 5: CONCLUSIONS AND RECOMMENDATION

This study presents the analysis of barite sampling from six mine sites in Nigeria. The results of XRF and SEM analyses of the samples showed a predominance of BaO, Fe_2O_3, and SiO_2. Specific gravity values of the barite samples ranged from 2.9–4.3. Samples C and G met the API standard for drilling mud, while samples E, B and D will need to be beneficiated to be comparable to commercial barite for drilling mud. Samples B and F are from the same state but from different locations. Sample F had an SG of 4.3 and Sample B had an SG of 3.9, showing that the quality of barite varies from location to location and by depth. There are currently more than 200 barite sites that have been, or are being, worked in the Benue Trough alone. Outside the Benue Trough there are also many barite occurrences, such as, from Aloshi, Azara and Wuse in Nasarawa state. Mine deposits must be beneficiated and then blended with materials from other mines to deliver a useful batch of API grade. There is a need to document all barite occurrences and encourage a study of these deposits with a view to development and sustainable production. The literature review shows that barite veins in Cross River, Benue and Nasarawa state have been investigated, but that little or no work has been done on their geophysical characteristics, geotechnical and geochemical properties, and reserve estimates in states such as Ebonyi, Zamfara, Kastina and Bauchi. There is a need for the further investigation of more deposits of barite veins in the country, especially in the Benue Trough.

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