ASSESSMENT OF BARITE DEPOSIT IN NASSARAWA STATE FOR OIL DRILLING APPLICATION

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CERTIFICATION

This is to certify that the thesis titled “Assessment of Barite Deposit in Nasarawa State for Oil Drilling Application” submitted to the school of postgraduate studies, African University of Science and Technology (AUST), Abuja, Nigeria for the award of the Master's degree is a record of original research carried out by Olugbemi Oluwamayowa Moses in the Material Science and Engineering Department.

ABSTRACT

Drilling fluids play sophisticated roles in the drilling process which include, keeping formation fluids at bay, stabilizing the wellbore without damaging the formation, lubricating the bit and drill-string and clearing cuttings from the bit face. Weighting agents are compounds that are dissolved or suspended in drilling fluid to increase its density. The effect of density also contributes to the stability of the borehole by increasing the pressure exerted by the wellbore fluid onto the surface of the formation down hole. There has been a very long desire in order to increase the density of wellbore fluids, and through various researches, a variety of methods exist. Barium Sulphate ($BaSO_4$) also known as barite is the prevalent weighting material but there is need to develop local barite for use in drilling fluid. This research was aimed at the investigation of some characteristics of Nigeria barite and its effect on mud density. Six barite samples were collected from different locations in the area of Wuse in Nasarawa state, Nigeria. The barite showed distinct specific gravities ranging between 4.38 SG and of 4.11 SG and compared with the American Petroleum Institute (API) standard. The characterization of these samples was carried out using the SEM/EDS which showed some traces of rare earth metals present. Six water-based mud samples were also prepared and the barite was added in different proportions of 40g, 80g and 120g to form the mud weight and this ranged from 9 lb/gal and 10.7 lb/gal which showed the effect of the specific gravity on the mud densities. Sample 1 which contains 40g of barite showed the highest yield point of 4.00 lb/100ft^2 and sample 2 which contains 80g of barite showed the lowest yield point of 0.975 lb/100ft^2 while there were 10 secs gel strengths 1.00 lb/100ft^2 and 1.5lb/100ft^2 respectively. With the specific gravity of the barite samples obtained, which meet the API standard, the weighting material in these locations would be fit for use majorly in the oil and gas industry as additives to drilling mud.

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DEDICATION

This work is dedicated to my late father Engr. Sunday Olugbemi and my mother Mrs Kehinde Olugbemi

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LIST OF ABBREVIATIONS

AfDB	African Development Bank
API	American Petroleum Institute
AUST	African University of Science and Technology
DPR	Department of Petroleum Resources
EDS	Energy Dispersion Spectroscopy
EPA	Environmental Protection Agency
GDP	Gross Domestic Product
GPS	Global Positioning System
HSE	Health Safety and Environment
MCBC	Magnet Cove Barium Corporation
MMSD	Ministry of Mines and Steel Development
OCMA	Oil Companies' Materials Association
SEM	Scanning Electron Microscope
USGS	United States Geological Survey
XRD	X-Ray Diffraction

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Drilling fluids play sophisticated roles in the drilling process which include, keeping formation fluids at bay, stabilizing the wellbore without damaging the formation, lubricating the bit and drill-string and clearing cuttings from the bit face. Weighting agents are compounds that are dissolved or suspended in drilling fluid to increase its density. These materials are also used for the control of formation pressures and thereby resist the effects of heaving shale's that may be encountered in stressed areas (Omoniyi and Mubaraq, 2014).

The density the weighting agent also contributes to the stability of the borehole by increasing the pressure exerted by the wellbore fluid onto the surface of the formation down hole. There has been a very long desire in other to increase the density of wellbore fluids, and through various researches, a variety of methods exist. One method is adding dissolved salts such as sodium chloride, calcium chloride, and calcium bromide in the form of aqueous brine to wellbore fluids. Another method is adding inert, high-density particulates to wellbore fluids to form a suspension of increased density. These inert, high-density particulates often are referred to as ‘‘weighting agents” and typically include powdered minerals of barite, calcite, or hematite (Abdou et al., 2013).

The main role of the weighting materials in the drilling fluid is to increase density and ultimately to ensure borehole stability (Akpabio et al., 2012). It also creates sufficient hydrostatic pressure in the hole and minimizes fluid loss by formation of thick filter cake on the walls of the well (Elkatatny et al., 2011).

Barite ($BaSO_4$) is chemically inert and insoluble. It occurs as a vein filling and as a gangue mineral in silver, zinc, copper, nickel and lead ores (Arcos et al., 2008). Barite with a specific gravity of 4.2–4.4 and hardness 2.3–3.5 has been the most common weight material for drilling fluids. Presently, the global barite market was valued at US$ 1,276.60 Mn in 2017 and is anticipated to expand at a CAGR of 4.8% from 2018 to 2026, according to a new report published by Transparency Market Research (TMR). The global barite market is driven by the rise in demand in the oil & gas industry (TMR, 2018). Conversely, barite is prone to sag, and so requires viscosifiers and other gellants to keep it in suspension.

Barite has high specific gravity, is relatively soft and virtually inert. The main uses of these material are based on its density, colour and radiation absorptive properties. About 90% of all barite produced goes into drilling muds used in petroleum exploration (Harben and Kužvart, 1996).

Barite occurs in diverse geological environments in a host of sedimentary, metamorphic and igneous rocks which span from Early Archean to Late Phanerozoic (Bonel, 2005). Most of the barite in the Earth's crust has been formed through mixing of fluids, one containing Ba leached from silicate minerals and the other fluid containing sulphate (Hanor, 2000). Barite ore which occurs in nature is usually associated with one or more of these minerals: Celestine ($SrSO_4$), galena (PbS), sphalerite (ZnS), pyrite (FeS_2), quartz (SiO_2), calcite ($CaCO_3$), dolomite ($Ca,Mg(CO_3)$), marcasite (FeS_2), chalcopyrite ($CuFeS_2$), fluorite (CaF_2), siderite ($FeCO_3$) and witherite ($BaCO_3$). The top leading producer of barite in the world is China with India being the second world producer with the Mangampet deposit in Cuddapah district of Andhra Pradesh being the single largest deposit in the world.

The choice of weighting agent to be used in drilling fluids is determined by the need to; provide low rheology (low plastic viscosity) particularly in high density fluids, show low settling tendency and providing low sag, to be easily removable from the reservoir by mechanical or chemical means, hard enough not to create fines during drilling which may cause formation damage or high gel values, contain a minimum of coarse particles to prevent abrasion, sustainable and readily available and in large quantities, have a good health, safety and environment (HSE) profile, be cost effective.

1.2 Problem Statement

High priority has been placed on exploration and exploitation of the barite deposits in the country since the Federal Government proposed the banned importation on barite many years ago. The bulk of the barite mined in different parts of Nigeria are used as weighting agent in oil and gas drilling operation. Furthermore, the country has put more attention on the oil and gas industry which produces the highest GDP yearly and demand for barite may probably continue to grow giving the fact that further exploration and development of wells will consequently boost barite consumption.

So far, as can be ascertained, there has not been any detailed work on the assessment and optimization of barite deposit in the South-East region of Nasarawa state. There is therefore, a need to characterize the barite mineralization in the area using major oxides and trace elements composition and other physical parameters which will serve as guide to further exploratory work.

1.3 Aim and Objectives

The aim of this project is to assess quality of the barite in the south-east of Nasarawa state, Nigeria based on its characterization and optimization of the deposits. This would be achieved with the following specific objectives;

- Identification of barite occurrence in south-east of Nasarawa state
- Partial beneficiation of the barite ore
- Characterization of the barite ore from the study area
- Determination of the physical properties
- comparison of the barite ore with the API and OCMA standards as used in oil and gas industry

1.4 Scope of Study

This study examines the use of barite ore bedded in the region of south-east Nasarawa state as substitute for weighting material which are imported from oversea and used in the Nigerian oil and gas industry. The study includes:

1. the processing of the ore (barite) with different compositions through gravity separation

2. the material characterization of the barite ore with:
    i. Energy Dispersion X-ray Spectroscopy (EDS);
    ii. Scanning electron microscopy (SEM);
3. the determination of the effect barite characteristics on mud density
4. the determination of the rheological properties
    i. apparent viscosity
    ii. plastic viscosity
    iii. gel strength
    iv. yield point

1.5 Justification

Presently, the global barite market was valued at US$ 1,276.60 Mn in 2017 and is anticipated to expand at a CAGR of 4.8% from 2018 to 2026, according to a new report published by Transparency Market Research (TMR). It is believed in the oil and gas industry that the quality of barite which is processed in nigeria is lower compared to imported barite making the imported barite preferable in the oil drilling application. This is caused by the lack of removal of some impurities which occurs in the barite ore. The low quality of Nigeria barite may be attributed to inadequate processing techniques, part of which this work will address.

CHAPTER TWO

LITERATURE REVIEW

2.1 Barite Deposit

Barite deposits can be classified based on the mode of occurrence into the following broad categories:

a. Bedded and Residual Deposits

Bedded deposits are those formed by the precipitation of barites at or near the sea floor of sedimentary basins. The ore fluid is generated by migration of reduced saline fluids and are concentrated by major basin controlling faults. Barite may occur either as a principal mineral or cementing agent associated with stratiform massive sulphide deposits (Harben and Kužvart, 1996). Most bedded deposits occur in sequences of sedimentary rocks characterized by abundant chert, black siliceous shale and siltstone referred to as "black bedded barite". Bedded deposits of barite are associated with rocks of age ranging from Precambrian to Tertiary (especially from Early to Mid-Paleozoic) (Ramos and de Brodtkorb, 1989). Individual beds are fine-grained, massive to laminated and may contain about 50 – 95% barite. The bedded deposits are the most valuable and economically most important deposit type because they are usually large and have higher grades (Lorenz and Gwosdz, 2003). Residual deposits are derived from the weathering of barite-bearing rocks in which barite is present as loose fragments embedded within residual soil or clay e.g. Georgia and Missouri barite deposits (Bonel, 2005). Clark *et al.* (1990) further subdivided the bedded barite deposits into five groups based on its depositional environment as follows:

Figure 2.1: World Distribution of Major Barite Deposits (Bonel, 2005)

i. Bedded deposits with base-metal sulphides (cratonic rift type) associated with alkali volcanic rocks, e.g. Meggen and Rammelsberg, Germany; Ballynoe and Silvermines, Ireland; Selwyn Basin, Canada and Red Dog, Alaska.

ii. Bedded deposits without base-metal sulphides (continental margin type), e.g. Arkansas and Nevada deposits, USA; Jiangnan and Qinling deposits in China.

iii. Bedded deposits associated with volcanic series, e.g. Kuroko type ore, Japan; Buchans deposit, Canada.

iv. Stratiform barite deposits e.g. Mangampet deposit in Andhra Pradesh, India.

v. Exogenetic barite deposits: These are unconsolidated alluvial or residual deposits formed by erosion or weathering processes occurring on or near the surface of the earth e.g. Krakow deposit, Poland.

b. Veins and Cavity Fillings

These are epithermal deposits which form by the precipitation of hot barium enriched fluids in faults, joints, bedding planes, breccia zones, solution channels and cavities as a result of fluid mixing or reduced pressure and/or temperature. In some cases, the ore fluid dissolves the surrounding host rocks (especially limestone and dolomite) and barite is deposited in its stead, thus forming replacement deposits. The resulting veins are characterized by sharp contacts, extensive pinching and swelling, and extreme variations in length and depth. The veins consist predominantly of barites (80% $BaSO_4$ and <5% SrSO4), sulphides (galena, pyrrhotite [FeS2 – magnetic pyrite]), iron, manganese oxides as well as fluorite, calcite and quartz. This type of deposits is generally smaller than the bedded deposits, with examples including Dreislar and Rhineland-Palatinate vein deposits in Germany; Les Arcs deposit in France and Pennine ore fields in the United Kingdom (Lorenz and Gwosdz, 2003).

2.2 Uses of Barite

According to Transparency Market Research (2018), the following are the uses of barite. Barites have high specific gravity, which makes them excellent weighting additives. These additives are required to be added to drilling fluids to counteract high-pressure zones encountered during oil and gas drilling activities and to stabilize the boreholes. Moreover, high inertness and exceptionally low oil absorption of barite make it a near-perfect weighting agent.

Also, low hardness of barite helps reduce the wear of drill bits. Drilling mud is the leading application segment of the barite market, accounting for more than 70% share of the global market. According to Brobst (1970) large increases in the use of drilling mud in the worldwide search for oil and gas can be expected. Not only will there be more wells drilled, but many targets will require deeper holes into high-pressure areas of deeply buried reservoir rocks. Such deep holes, with a greater potential for blowouts and leakage losses, will require large amounts of drilling mud. The major applications are enumerated below:

1. The high density, non-corrosive, non-abrasive, chemical inertness and non-toxic nature of barite makes it a suitable weighting agent or drilling mud which is used in drilling shafts of gas and oil wells. Barite makes the mud dense and therefore prevent blow-up ensuing from oil and gas pressure.

2. Barite is a raw material used in the production of barium chemicals such as: Ba-metal which is used to remove traces of gases in vacuum tubes. $BaCO_3$, $BaCl_2$, Ba(OH) are used to control efflorescence and scum from forming on brick and ceramic materials during its manufacture.

3. Barite is also used as an additive in the manufacture of plastics, paper, paints, enamels and leaded glass.

4. Barite significantly blocks x-rays and gamma rays hence; it is used as a contrast medium in medical x-ray examination and an aggregate in high density concrete to shield against radiation.

2.3 Barite Grade

Barite is available in various grades. Barite grade is derived from geochemical assays for barium and the assumption, supported by extensive mineralogical studies, that barium is present as barite (ASX, 2017). Based on purity and specific gravity, barite has been classified into Sp. Gr. up to 3.9, Sp. Gr. 4.0, Sp. Gr. 4.1, Sp. Gr. 4.2, and Sp. Gr. 4.3 and above. Each grade is used for certain specific applications.

• Grade 3.9: Barite grade up to 3.9 signifies specific gravity of 3.9. It is a low-grade barite formed by 50/50 ratio of barite and other alternative weighing material such as ilmenite and hematite.

• Grade 4.0: Barite grade 4.0 signifies a low-grade oilfield barite with specific gravity of 4.0. Its composition includes 85% to 90% of $BaSO_4$

• Grade 4.1: Barite grade 4.1 signifies specific gravity of 4.1. Its composition includes minimum 90% $BaSO_4$, maximum 2% SiO_2, maximum 0.25% Fe_2O_3 and moisture

• Grade 4.2: Barite grade 4.2 signifies specific gravity of 4.2. Its composition includes minimum 90% $BaSO_4$, maximum 2% SiO_2, maximum 0.25% Fe_2O_3 and 1% moisture

• Grade 4.3: Barite grade 4.3 signifies specific gravity of 4.3. Its composition includes up to 95% of $BaSO_4$, 0.5% of SiO_2, 1.2% of Fe_2O_3 and 0.15% moisture

• Grade 4.4 and above: Barite grade 4.4 and above signifies specific gravity of 4.4 and more than 4.4 g/m3. Its composition includes more than 95% of $BaSO_4$, 0.5% of SiO_2, 1.2% of Fe_2O_3 and 0.15% moisture.

2.4 Extraction Method

Barite can be mined using both surface and underground mining methods. Drill machines, loaders, dozers and dumper-trucks are used for removing overburden. Mining economics and processing complexity of the type of barite deposit is affected by the geometry of the type of barite deposit (Scogings, 2014). Major stratiform deposits are worked by open pit where this is practicable. Vein deposits are worked by shafts and adits, as well as by shallow open-pits. Residual deposits are mainly worked by hand, due to the variable and irregular nature of the mineralization. The ore is drilled and blasted and then trucked to the mill for processing. Conventional underground methods are used as appropriate to the shape and attitude of the deposit (British Geological Survey, 2005).

2.5 Processing

Physical processing methods, such as crushing, washing and jigging are used to produce correctly sized product and/ to remove gangue minerals. Flotation may be used to separate barite from finely intergrown gangue minerals. Hand sorting may be used in countries with low labor costs. Acid washing may also be used to remove iron oxide stains from white barite destined for coatings markets (Scogings, 2014). After initial crushing some pure barites is sold as direct shipping ore. Contaminant gangue materials and minerals such as fluorite, quartz, galena is separated using gravity separation, wet grinding and froth flotation. The barites are either dried and sold as a powder or processed further for particular applications (British Geological Survey, 2005).

2.6 Drilling Mud

Drilling fluid also referred to as drilling mud forms an integral part of materials used for drilling in the oil and gas industry. It can be water based or oil-based mud depending on continuous phase and internal phase. The type of fluid used depends on factors such as cost, technical performance and environmental impact. Drilling mud comprise of barite as a weighting agent which balances formation pressures in the wellbore to minimize blow outs. Besides pressure control, it helps mud to cool and lubricate the drill string and bit, transmission of hydraulic horsepower to bit, minimizes damage to the producing formations. (Essalhi et al 2017)

2.7 Specifications

The American Petroleum Institute (API) has set specifications for the barite used in the oil industry. These specifications primarily deal with specific gravity, particle size, and maximum quantities of some impurities. Most barite needs to be ground to a small uniform size before it is used as a weighting agent in petroleum-well-drilling mud based on specifications set by the API or the former Oil Companies' Materials Association (OCMA) (Essalhi et al, 2017).

In response to concerns about dwindling global reserves of 4.2 specific gravity barite used by the oil and gas drilling industry, the American Petroleum Institute issued an alternate specification for 4.1 specific gravity barite in 2010. This has likely stimulated exploration and expansion of global barite resources. Estimated reserves data are included only if developed since the adoption of the 4.1 specific gravity standard (U.S. Geological Survey, 2017). The intention was not to replace the 4.2 grade, but to provide the end-user with choice as to which material to use. Drilling-grade barite is specified by the API and must meet certain SG, chemical and sizing requirements. Although not an API specification, drilling companies have started to focus on heavy metal content in particular mercury (Hg <1ppm) and cadmium (Cd <3ppm) (U.S. Geological Survey, 2017).

Additional heavy metals may also be taken into account for example silver (Ag), arsenic (As), chromium (Cr), copper (Cu), lead (Pb), selenium (Se) and zinc (Zn), although there are no set limits for oilfield application (Scogings, 2014).

2.8 Analysis of Nigerian barite production, export and import data

Annual production, export and import data obtained from the United States Geological Survey is plotted in Figure 2.4, the data covers the period 2006 to 2015.

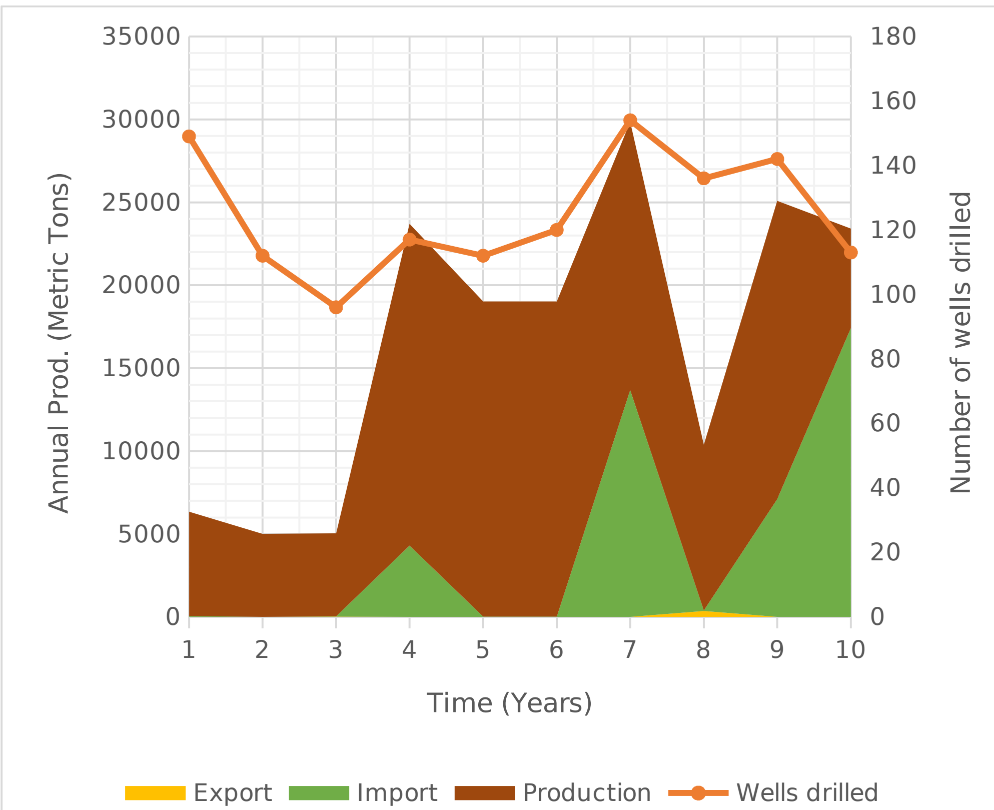


Figure 2.2: Nigerian Barite Production, Export and Import Statistics (DPR Oil & Gas Annual Report, 2016).

2.9 Barite Production in Nasarawa State

The interest in Nasarawa is due to its proximity to the oil and gas producing states and has the highest number of artisanal miners already in operation; this has created a footprint to follow in assessing the activities already in place. The state also has huge barite resource estimated to be 3.2 million metric tons with an average specific gravity of 4.0. Nasarawa State hosts some of the prominent barite fields in the Benue Trough such as the Azara field. Production over the years have not been steady due to the fact that exploration and mining activities have been dominated by artisans and small-scale miners who possess low work force with little or no mechanization utilized for operations, lack of strong technical know-how, low finance as well as lack of incentive from government to operate legally. -

Table 2.2 lists the annual production for Nasarawa State between 2015 and 2018. It can be seen from Table 2.2 that production has decreased over the four years in the record. This could be as a result of poor technical knowledge of the artisans. The nature of their work schedule could also be a factor. These artisans work periodically and usually rely on market price development for operations. Just as the name suggests, one of the major limitations of artisanal scale of mining is lack of organization and documentation. They rarely keep good records of operations such as volume of barite obtained daily or monthly. Statistics in Table 2.2 were obtained from a few small-scale miners currently in operations.

Table 2.1: Production History of Barite in Nasarawa between 2015 and 2018 (Nigerian Mining Cadastre Office, 2017)

Year	**Annual Production (Metric Tons)**
2015	3276
2016	2952
2017	2880
2018	2736

Table 2.2 Barite API physical and chemical requirements (MCBC, 1976)

Requirement	**Numerical value**
Specific gravity	4.2 minimum
Soluble alkaline earth metal	250 ppm maximum
Wet sieving analysis	
Residue on U.S. sieve no. 200	3% maximum
Residue on U.S. sieve no. 325	5% maximum
Particles less than 6 micrometers	3% maximum
Ph	7% maximum
Moisture content	1% maximum
Oil adsorption	9% maximum
Barium Sulfate	90% maximum
Water soluble Alkaline earth metals	250 mg/kg maximum

2.10 Previous Work

Earlier works on the Nigerian barite indicate that barite occur as gangue in galena and sphalerite veins (Farrington, 1952; McConnel, 1949). The barite resource of Nigeria started gaining recognition as from 1951. Bogue (1951) presented a report of barite prospect near Gabu in Ogoja Province in the present Cross River State. Occurrences of barite have been reported in 1957 edition of the "Minerals and Industry in Nigeria" yearbook at Lefin in Ogoja Province; Aba-Gbandi, Keana and Akiri in Benue Province and Dumgel in Adamawa Province (Oden, 2012). The Geological Survey of Nigeria in 2008 estimated barite reserve to be 41,000 tonnes at a depth of 20 meters for the Benue Valley deposits in the Azara locality. Nigerian Geological Survey Agency (2008) embarked on the evaluation of newly reported deposits in the present Cross Rivers, Benue, Nassarawa, Plateau and Taraba States as shown in Table 2.1. The inferred resource of barite in these states was put at 21,123,913 metric tons (Fig. 2.2). Further exploration activities revealed additional areas with favourable geological setting for barite mineralization namely: Liji Hill, Gombe Town, Ganye, Suwa and Sabin areas northeast Nigeria in addition to Dareta, Tofa Forest Reserve, Rebeku and Yarkatsina areas in northwestern Nigeria (Table 2.1).

Table 2.3: Location Of Barite Resources And Their Current Status Of Exploration In Some Parts Of Nigeria. (Oden, 2012)

STATE	LOCATION	RESERVE ESTIMATION (TONES)	STATUS	REMARK
1. Nassarawa*	Azara, Akiri, Aloshi, Chiata, Gidan Bera, Gidan Tailor, Wuse Kuduku, Rib	730,000 recorded by NMC at Azara, Akiri and Wuse alone (5 veins)	Mining in progress by private companies and artisanal miners. NMC has divested	Very rich state, grade ranges from poor to good, reserve could be improved through further exploration
2. Plateau	Panyam (Wase), Faya	Yet to be determined	Registered companies and artisanal miners at work	Further exploration could increase stock of veins
3. Taraba*	Mbanga Petel, Mbanga 3 corner, Juo, Gidan Waya, Kauyen Isa, Bakuyu, Ibua,	Yet to be determined	Active informal and some organized mining in progress	Further exploration necessary to improve the known stock of veins and boost

	Kumar, Pupule, Apawa 1 & 2, Didango, Suwa			reserve
4. Benue*	Ambua, Torkula, Makurdi, Kaseyo, Yandev, Orgba, Ihugh, Lessel, Tombu, Korinya, Iye, Zanzan, Logo	Yet to be determined	Active informal and organized mining in progress	Exploration work necessary to improve the known stock of veins and boost reserve
5. Adamawa	Ganye, Suwa, Sabin Village	Yet to be determined	Only Suwa and Sabin deposits are currently mined	Further exploration necessary
6. Cross River*	Okumurutet, Okangha, Agoi Ekpo, Agoi Ibami, Akept1, Akpet Central, Okurike, Lefin, Bitol, Ugbem	Yet to be determined	Enormous informal and organized mining in progress	Large scale operators needed and further exploratory work very necessary in this state with the highest prospect
7. Gombe	Liji Hill, Gombe Town	Yet to be determined	Mining activity started here recently	Requires further exploration
8. Ebonyi	Ishiagu	Yet to be determined	No mining activity is going on	Requires further exploration

*** Major producing states**

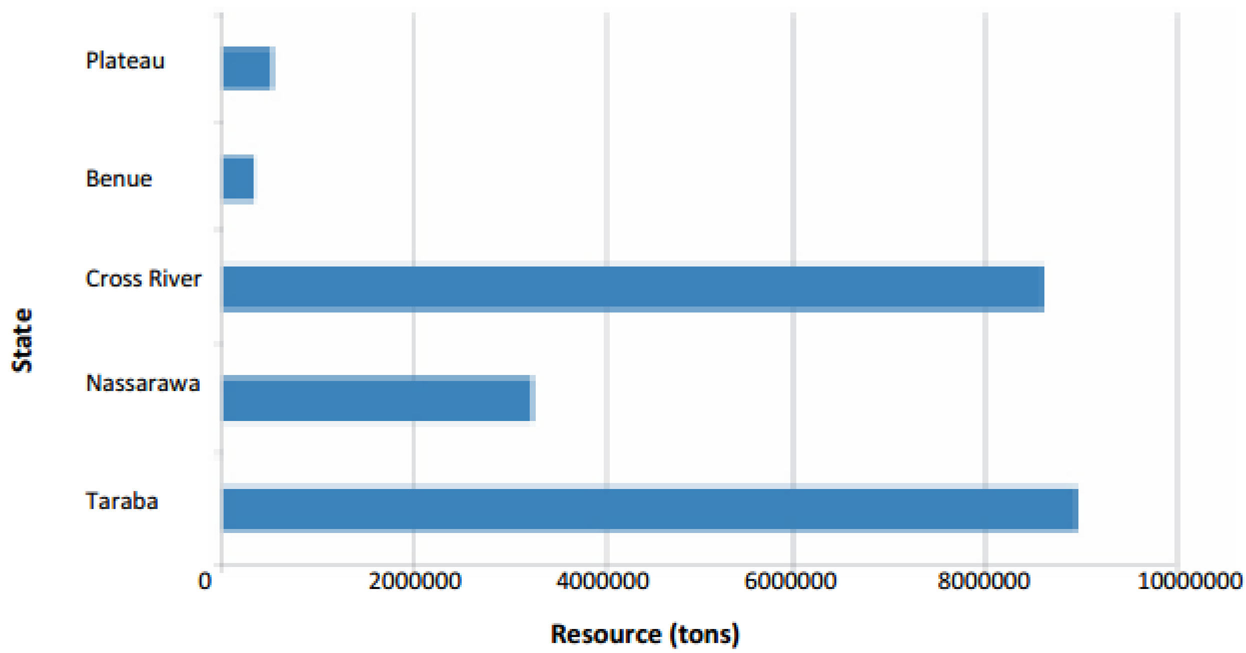


Figure 2.3: Inferred Barite Resource Of Some States In Nigeria (MMSD, 2008).

Daspan and Imagbe (2010) reported the occurrence of barite veins corresponding to the major Anka fault system in metasedimentary rocks at Dareta-Tungan Kudaku area, northwest Nigeria. According to Akpeke *et al.* (2006), MMSD (2008) and Ekwueme and Akpeke (2012) barite mineralization in Southeastern Nigeria (Obubra, Yakur, Akamkpa, Biase, Nkarasi, Okpoma and Omoji areas of Cross River state) is localized mostly along the boundary between the Basement rocks (migmatite, gneiss, granite), Cretaceous sediments (sandstone) and also in dolerite. Edu (2006) also observed that barite is hosted in basement gneisses, porphyritic and fine-grained granite in some parts of the present Taraba State, Northeastern Nigeria.

Akande *et al.* (1989) and Oden (2012) reported that most barite mineralization in Nigeria are hosted in the Cretaceous sediments of the Benue Trough and are associated with lead-zinc-flourite vein ore bodies and occasionally with salt deposits**.** Oden (2012) further documented the occurrence of barite across eight major areas within the Benue Trough (Adamawa, Benue, Cross River, Ebonyi, Gombe, Nassarawa, Taraba and Plateau States) (Table 2.1). The geology and stratigraphy of the Lessel and Ihugh areas have been captured in the works of Reyment (1965), Murat (1972), Nwachukwu (1972), Dandume (1978), Kogbe (1989), Najime (2010) and Obiora (2012). The field occurrence, mineral association and paragenesis of barite in some parts of the Benue Trough have been documented by Farrington (1952), Omada (1985, 1987), Akande *et al.* (1989, 1992), Omada and Ike (1996), Ekwueme and Akpeke (2012) and Oden (2012). Nwafor *et al*. (1997), Ministry of Mines and Steel Development (2008) and Najime (2010) reported the occurrence of barite at Lessel. In a more recent study, Oden (2012) also described their field characteristics and quality of barite occurrences in Ihugh and Lessel areas. Ajayi (1987) carried out gravity survey of the Middle Benue Trough and proposed that barite occurrence in this part of the trough was most probably formed as a result of the interplay of volcanic intrusions with brine water from buried salt domes. Oladapo and Adeoye-Oladapo (2011) recorded high gravity and low conductivity values influenced by the density of concealed barite veins at Tunga in the Middle Benue Trough. Several models have been suggested for the origin of barite in the Benue Trough; Farrington (1952) suggested a magmatic hydrothermal origin for the lead-zinc-barite mineralization in the Benue Trough. Ofoegbu and Odigi (1989) suggested that Pb-Zn sulphide, barite and other ore mineralizations in the Benue

Trough are closely associated with magmatic episodes and are mainly localized in steeply dipping faults and fracture systems of predominantly N-S, NE-SW trend. Hot mantle materials involved in the rifting of the Trough provided the thermal energy needed for upward movement of ore fluids (Ofoegbu and Odigi, 1989).

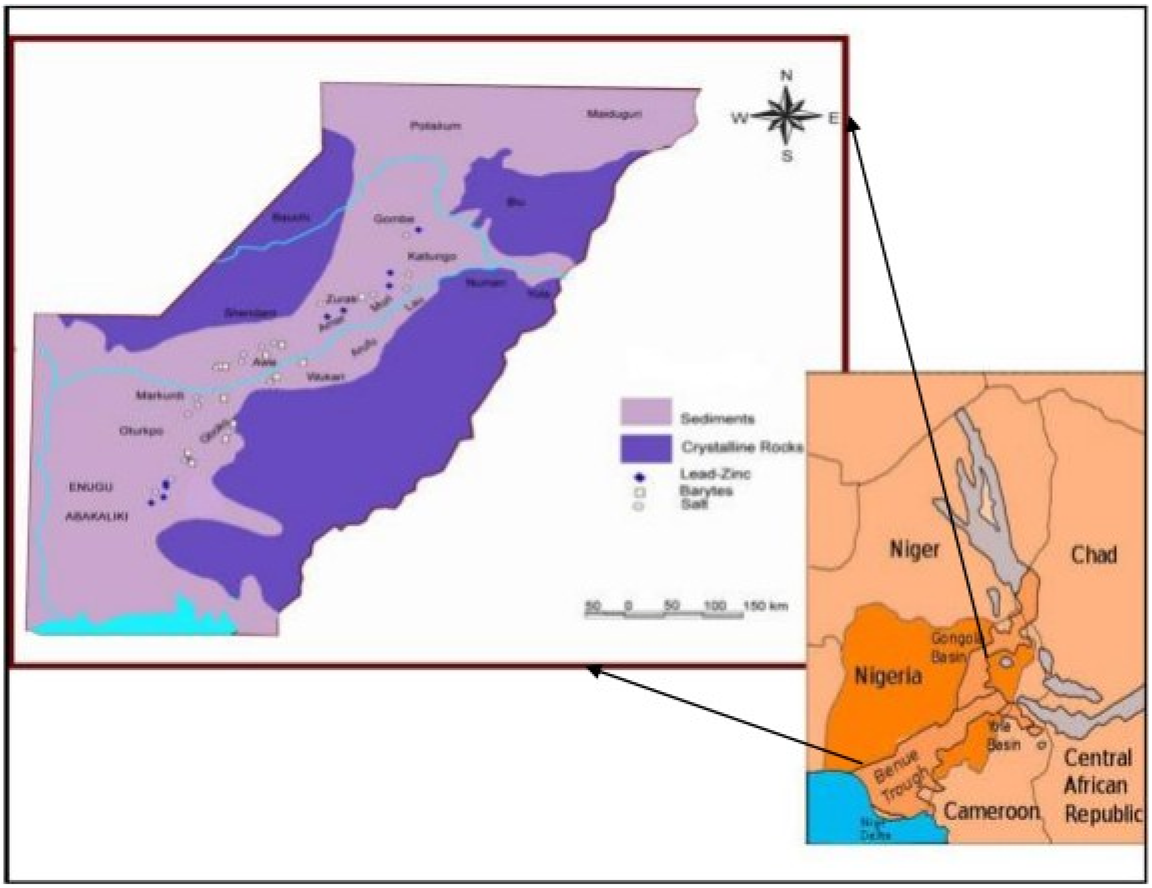


Figure 2.4: Distribution of lead-zinc-barite and salt mineralization along the Benue Trough (Inset sketch map of Nigeria showing the Benue Trough) (Ene *et al.*, 2012).

Reyment (1965) alleged that volcanic rocks generated the hydrothermal fluids from which the ore was deposited. Orajiaka (1964) considered both sedimentary and igneous rocks to be possible sources of the mineralizing fluid. Omada (1985) stated that Ba (barium) was mobilized from the host rock and then concentrated in fractures with the aid of hydrothermal fluids. Omada and Ike (1996) further reported that the geochemical signature of barite in the Middle Benue Trough was derived from hydrothermal fluids of igneous origin.

Ezepue (1984), Uma and Leohnert (1992), Tijani, *et al.* (1996) believed that igneous intrusions caused changes (pressure and temperature conditions probably entrained precipitation and concentration from fluids to form the ore) in the geochemistry of the surrounding rocks thus releasing important masses of volatiles. Juvenile and connate brine origin was proposed by Offodile (1976) advocating that the brines evolved from connate water by osmotic filtration or from meteoric water by solution of evaporites in the course of sinking to great depth in the sedimentary basin. Russell (1978) put together a circulating brine convection model for Irish base metal mineralization whose mineralization is almost similar to that of the Benue Trough. Olade and Morton (1985) suggested that brine circulation was driven by magmatic intrusions. Basinal brine source was adopted by Akande *et al.* (1989) who carried out fluid inclusion and isotope studies on barites in the Middle and Lower Benue Trough. These authors noted that the mineralizing fluids were saline brines (14 to 21 equiv. wt% NaCl) containing hydrocarbons with fluid temperatures of between 95 and 200o C. Their Sr and Pb isotopic data indicated that the metal ore components were sourced from the Lower Paleozoic gneisses and migmatites while sulphur data suggested that sulphur was derived from Cretaceous evaporite source within the trough. Sulphur isotope values reported by Akande *et al.* (1989) matches that of the Lower Cretaceous seawater sulphate of Lieben *et al.* (2000) which have been interpreted by Grandia *et al.* (2003) to be consistent with mixing of metal-rich brine with sulphur-rich fluid of Upper Cretaceous and Lower Paleocene age.

Other Alternative Weighting Materials

Walker (1983) presented experiences with mined iron oxide used as an alternative weighting material to barite. According to Saasen et al. (2001), ilmenite has been applied earlier as a weighting material. A higher drilling penetration rate was reported from the use of ilmenite, because lesser colloidal solid fractions were produced during drilling. The ilmenite used in the first two wells drilled in 1979 and 1980 in the North Sea, were finely ground materials compared to the presently used ilmenite (Blomberg and Melberg, 1984). The second trial was conducted in 1994 using a more finely ground ilmenite (Idris and Ismail, 1994). Recently, Manganese Tetra oxide (Mn3O4) has been used as a weighting material for water-based drilling fluids (Al-Yami and Nasr-El-Din, 2007). Mn3O4 and CaCO3 were prepared in the laboratory and used to conduct experiments. Polymer starch degraded at 250ºF and cellulose were contained in the drilling fluid formulation to control fluid loss and rheological properties of the drilling mud. According to Symposium (Simpson, 1985), important properties of drilling mud include: Density (which enhances borehole stability and prevents blowout); low viscosity and gel strength (which produce faster drilling and more efficient removal of drill cuttings). High filtrate will minimize chip hold-down and facilitates faster drilling (API, 2004). According to Moore and Gatlin (1960) and Eckel (1967), some of the more recognizable variables which affect penetration rate include: mud density, weight on bit, rotating speed and bit type (Blattel and Rupert, 1982; Eckel 1967). Other factors which affect rate of penetration are formation properties such as permeability, porosity and hardness, rig efficiency and personnel efficiency. The main role of the weighting materials in the drilling fluid is to increase density and ultimately to ensure borehole stability (Akpabio et.al, 2012). It also creates sufficient hydrostatic pressure in the hole and minimizes fluid loss by formation of thick filter cake on the walls of the well (Gatlin, 1960). Increase in density also results in increased penetration rate; however, when the density is excessive, it can cause differential sticking of the drill string (Darley and Gray, 1988).

2.11 Knowledge Gap

Of all the previous work, there is no data regarding the properties of barite in Wuse Nasarawa state. There is therefore, a need to characterize the baryte mineralization in these areas using major oxides and trace elements composition and other physical parameters which will serve as guide to further exploratory work.

CHAPTER THREE

METHODOLOGY

3.1 Study Area

The samples were obtained from different locations in the Southeastern region of Nasarawa state (Wuse village). Six samples were obtained from this region with locations respectively.

Table 3.1: GPS Location of Six Samples Collected from Wuse Nasarawa State

SAMPLES	1	2	3	4	5	6
LOCATION	N8°22’11’’	N8°22’12.9’’	N8°22’27’’	N8°22’29.8’’	N8°22’36.8’’	N8°22.4’37.8’’
	E9°18’25.7’’	E9°18’30.1’’	E9°18’19.6’’	E9°18’20.9’	E9°18’22.4’’	E9°18’22.4’’

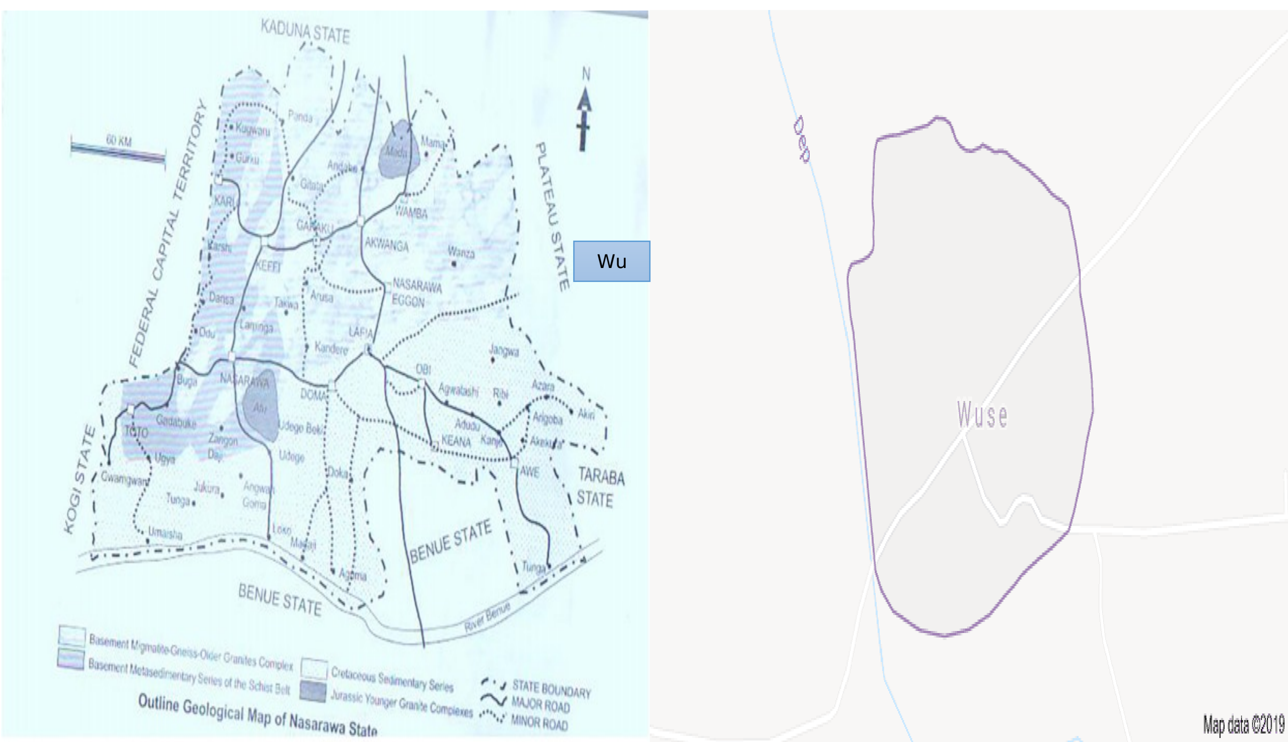


Figure 3.1: Map of study area Wuse-Nasarawa state.

3.2 Measurement and Analysis

3.2.1 Sample Preparation

The samples gotten from these locations were processed in the AfDB Mineral Processing Laboratory African University of Science and Technology, Abuja. Each sample was washed thoroughly using the gravity separation method then dried at 50°C to remove the moisture content and crushed using a jaw crusher to get an appreciable grain size. These crushed samples were then sieved with the laboratory mechanical sieve shaker to different sizes of 150 micron and 75 microns for SEM/EDS and mud density analysis respectively following the API standard.

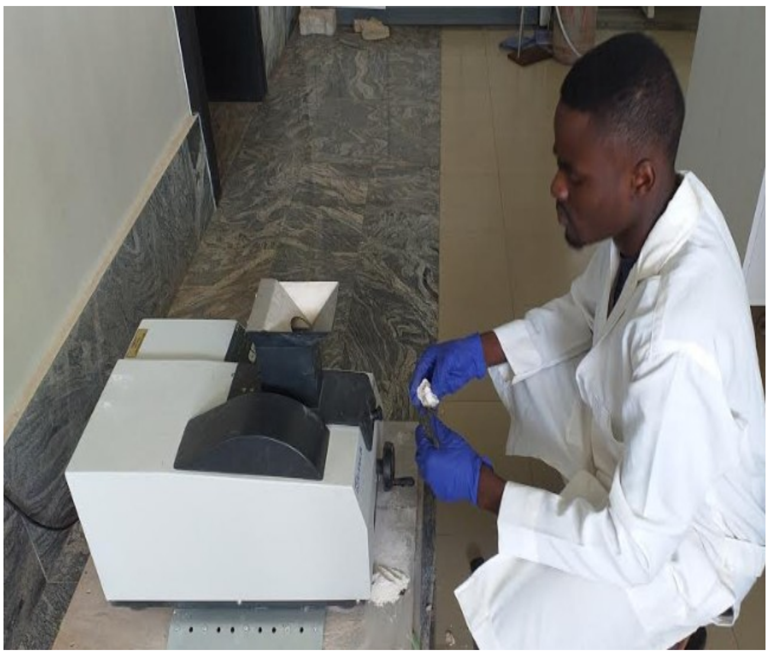


Figure 3.2: Crushing and Grinding of Barite

3.3 Characterization

The characterization comprises of the imaging and the chemical and elemental composition of each sample gotten from different locations in the study area. The scanning electron microscope, energy dispersion spectroscopy was the equipment used for the characterization of these samples carried out at the materials science laboratory African university of science and technology Abuja, Nigeria.

3.3.1 SEM/EDS Analysis

The samples that were grinded and sieved at 75microns were then taken to the scanning electron microscope in order to obtain the clearer image of the samples. The EDX also gave the elemental composition of the samples.

Figure 3.3: SEM Analysis of Barite

3.4 Specific Gravity

3.4.1 Pycnometer Method of Determining Specific Gravity

The pycnometer method was used in determining the specific gravity of these samples. The following parameters were used in this process;

Density of mineral grains $= \frac{B-A}{(D-A)-(C-B)}$ g/cm3

Specific gravity of the ore aggregate = Density of ore grain x density of liquid

Where:

A = weight of empty pycnometer.

B = weight of pycnometer + mineral grain.

C = weight of pycnometer + mineral gain + liquid.

D = weight of pycnometer + liquid.

V = volume of pycnometer.

3.5 Mud Density

The determination of mud density was carried out in the Petroleum laboratory AfDB AUST. Six different samples of particle size 75 microns following API standard which were taken from different locations were used in the determination of the mud density. Each sample varied 40g, 80g and 120g in 350ml of water and with a constant 24.5g(Fattah and Lashin, 2016) of bentonite clay for the preparation of the mud samples. Each sample was prepared one after the other and reading were taken concurrently.

Table 3.2: Formulation of drilling fluids & Six samples of water-based drilling fluids at different.

	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6
Barite	40g	40g	40g	40g	40g	40g
Bentonite	25.4g	25.4g	25.4g	25.4g	25.4g	25.4g
Water	350ml	350ml	350ml	350ml	350ml	350ml
	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6
Barite	80g	80g	80g	80g	80g	80g
Bentonite	25.4g	25.4g	25.4g	25.4g	25.4g	25.4g
Water	350ml	350ml	350ml	350ml	350ml	350ml
	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6
Barite	120g	120g	120g	120g	120g	120g
Bentonite	25.4g	25.4g	25.4g	25.4g	25.4g	25.4g
Water	350ml	350ml	350ml	350ml	350ml	350ml

Figure 3.5: Mud Density Determination

3.5 Temperature and pH

The temperatures of each samples were taken before determination of the mud densities and likewise the pH was determined to check the acidity and alkalinity of the prepared samples.

Figure 3.6: pH scale

3.6 Rheological Properties

Viscosity and Gel Strength

Apparent Viscosity, $cp=\frac{\varnothing 600}{2}$ (1)

Plastic Viscosity, $cp=\varnothing 600$-$\varnothing 300$ (2)

Effective Viscosity, $cp=\frac{300\,x\,\varnothing}{\omega}$ (3)

Yield Point YP; (Ib=100ft2)¿$\varnothing 300-\mu_p$ (4)

Shear Stress; (Ib/100ft^2) = 1:065 * $\varnothing$ (5)

Shear Rate; sec^{-1}= 1:7023 * ω (6)

where, $\varnothing$ is the dial reading, lb/100 ft^2 and ω is the Rotor Speed, rpm, μ_p is the Plastic Viscosity

Figure 3.7: Rheology Parameters Determination

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Specific Gravity

Table 4.1: Specific Gravity of Six Samples from Different Locations in Wuse-Nasarawa

Specimen Number	L1	L2	L3	L4	L5	L6
Specific Gravity	4.380688	4.144448	4.193069	4.2106408	4.3365651	4.282771739

Table 4.1 shows the increase in the specific gravity of the barite samples obtained from different locations in Wuse, Nasarawa state. With the use of the pycnometer method, the sample gotten from the first location (N8°22’11’’ E9°18’25.7’’) showed the highest specific gravity of 4.380688 and the sample obtained from the second location (N8°22’12.9’’ E9°18’30.1’’) showed the lowest specific gravity of 4.144448. The average specific gravity value of the barite obtained from Wuse in Nasarawa state is 4.26 as compared to that of Azara local government in Nasarawa state of average specific gravity value of 4.43. These figures showed that these barites obtained are within the range of the API standard for the oil and gas drilling operation.

4.2 Elemental Composition of Barite

All the samples at the different locations were analyzed using the Energy dispersion X-ray Spectroscopy to determine the elemental composition. The result below shows different elements present in the mineral. There are traces of rare earth metals, oxygen, Sulphur, carbon and alkaline metals.

	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6	
Elemen t	Weight %	Atomic %	Weight %	Atomic %	Weight %	Atomic %	Weight %	Atomic %	Weight %	Atomic %	Weight %	Atomi c %
C	0.88	5.98	0.88	5.97			2.05	13.23	0.88	6.32		
O	0.56	2.83	0.53	2.67	0.61	3.33	0.62	2.98	0.45	2.44	0.56	3.06
Al	0.84	2.54	-	-	-	-	0.69	1.97	-	-	15.32	41.88
Si	1.93	5.61	1.24	3.57	0.68	2.11	-	-	-	-	0.55	1.71
S	13.4	34.13	13.98	35.38	15.45	41.78	14.76	35.66	14.15	38.12		
Ba	74.47	44.28	77.82	45.97	79.95	50.46	78.75	44.41	81.38	51.2	82.7	52.77
Ce	7.93	4.62	-	-	-	-	2.61	1.44	-	-	-	-
Fe	-	-	3.58	5.2	-	-	-		-	-	-	-
Co	-	-	0.13	0.19	0.36	0.53	-	-	-	-	-	-
Nd	-	-	1.52	0.86	2.63	1.58	-	-	2.67	1.6	-	-
Te	-	-	0.31	0.2	0.31	0.21	-	-	0.47	0.32	-	-
Cs	-	-	-	-	-	-	0.52	0.31	-	-	0.88	0.58

Table 4.2: Elemental Composition of Barite Samples

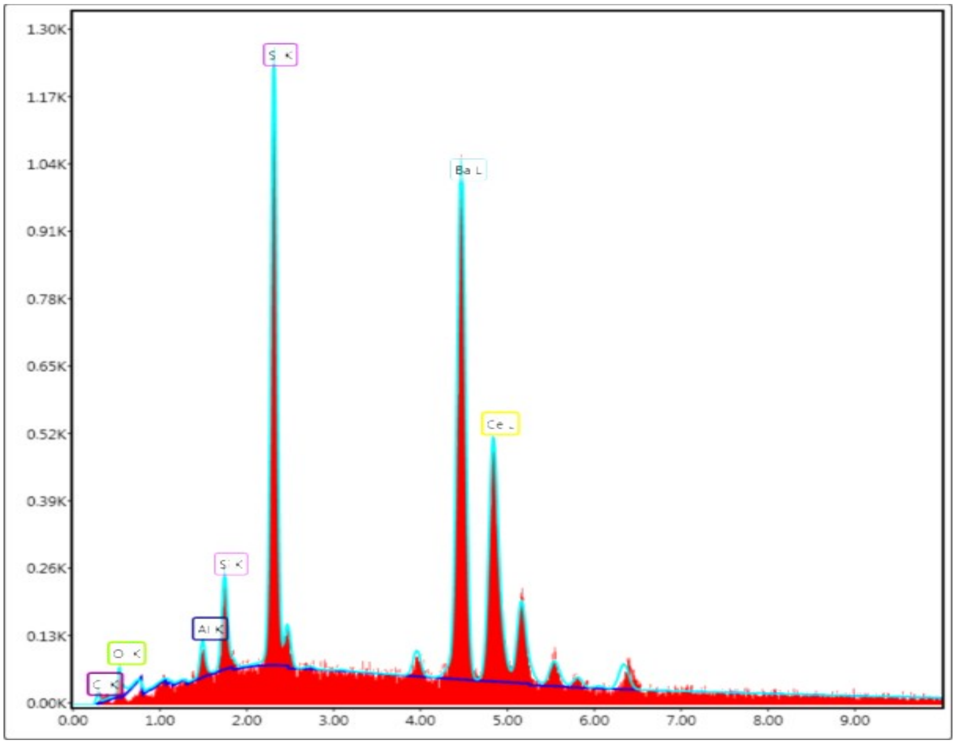


Figure 4.1: EDSIimage of Sample 1

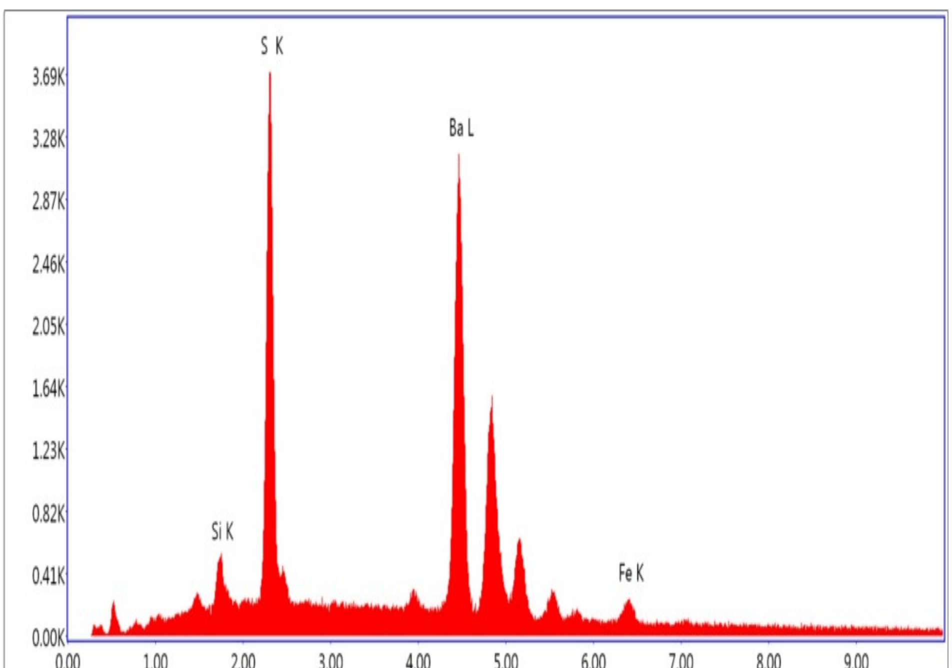


Figure 4.2: EDS Image of Sample 2

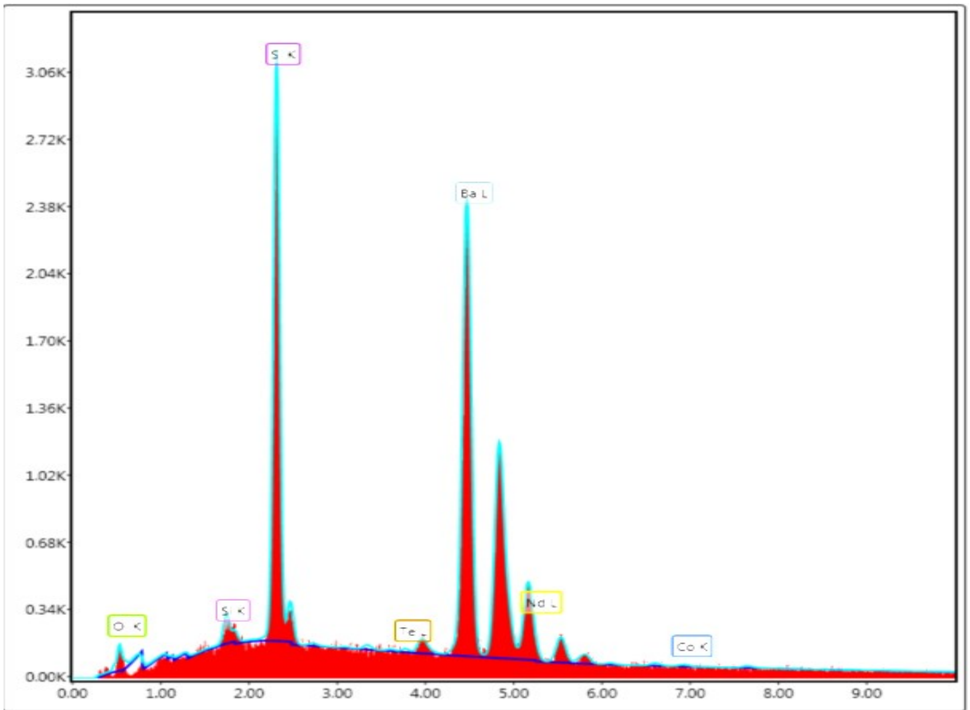


Figure 4.3: EDS Image of Sample 3

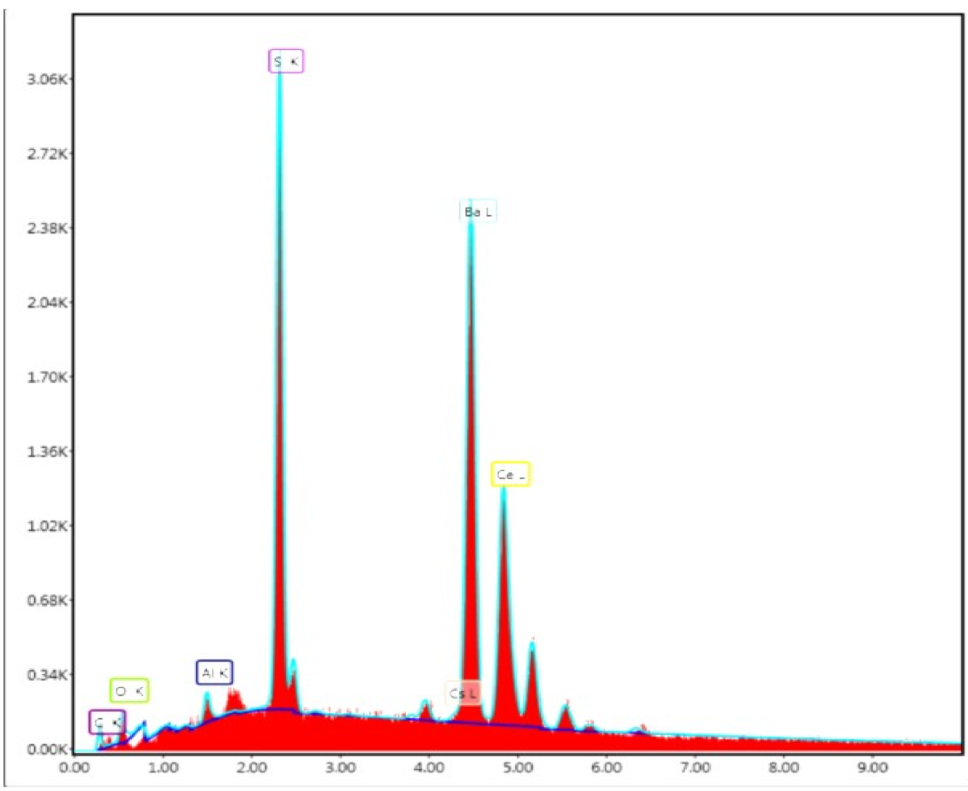


Figure 4.4: EDS Image of Sample 4

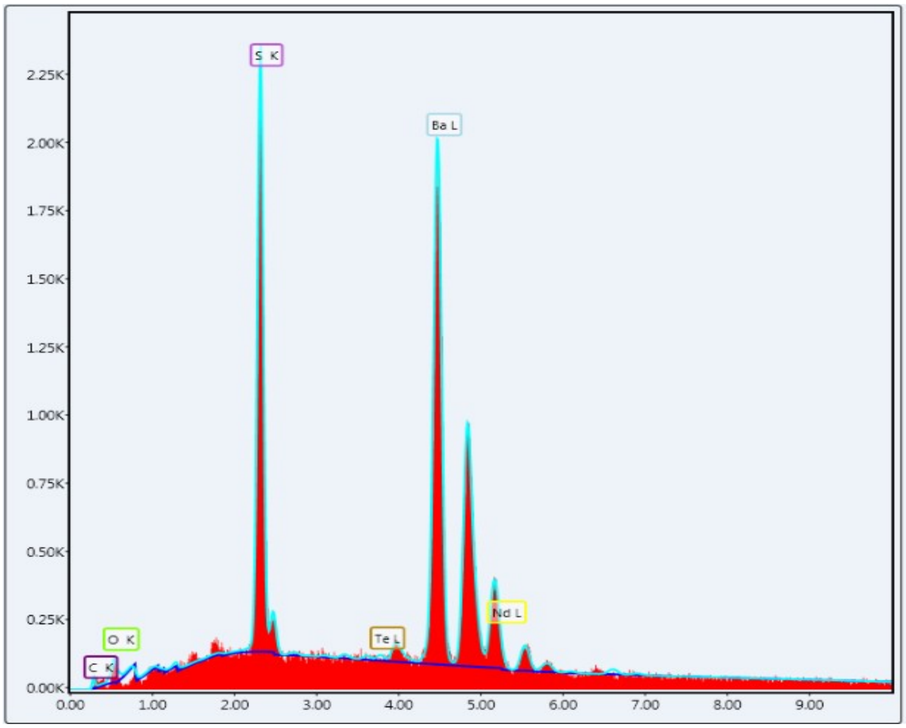


Figure 4.5: EDS Image of Sample 5

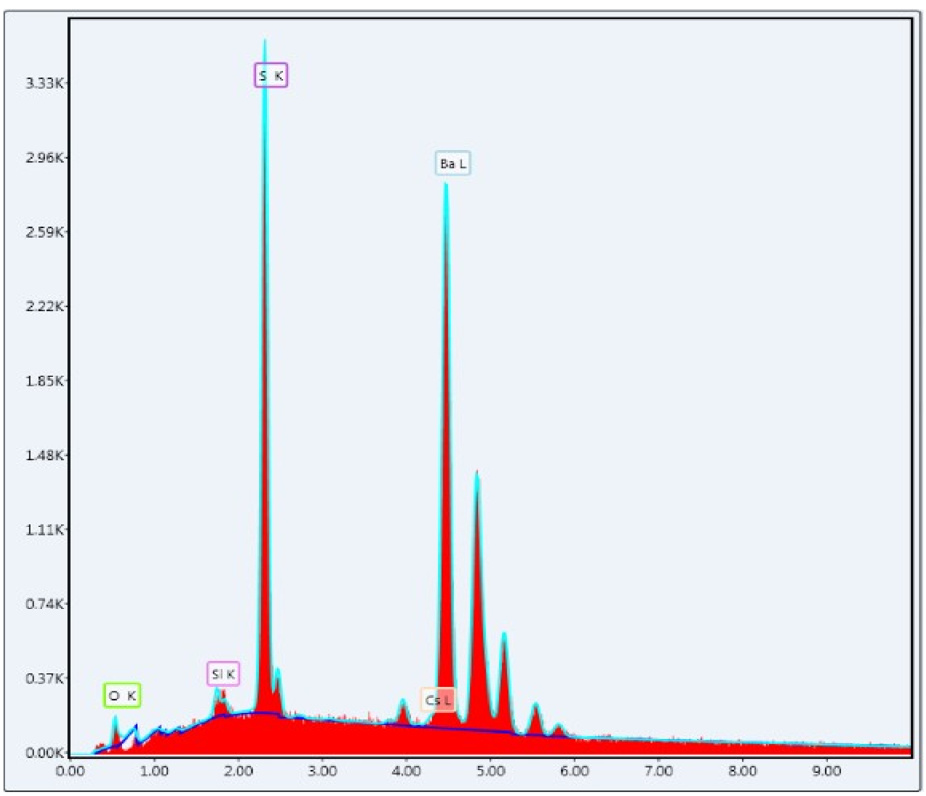
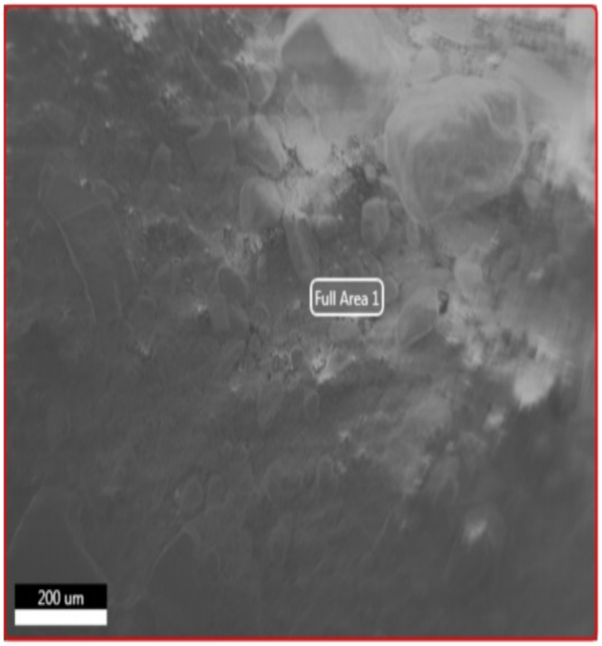
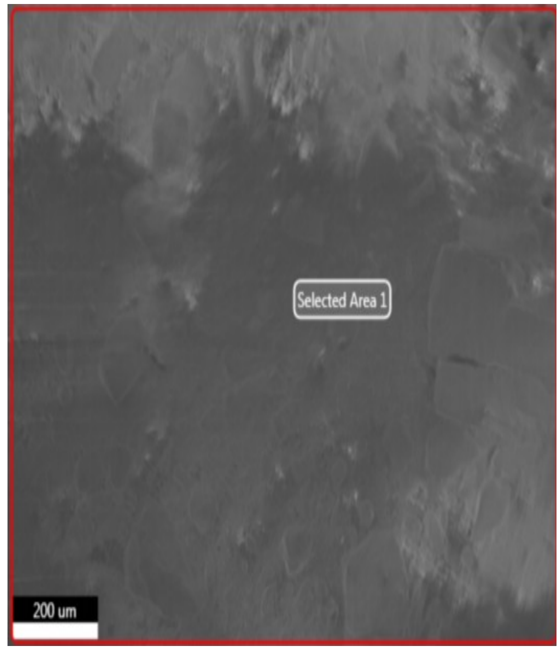


Figure 4.6: EDS Image of Sample 6

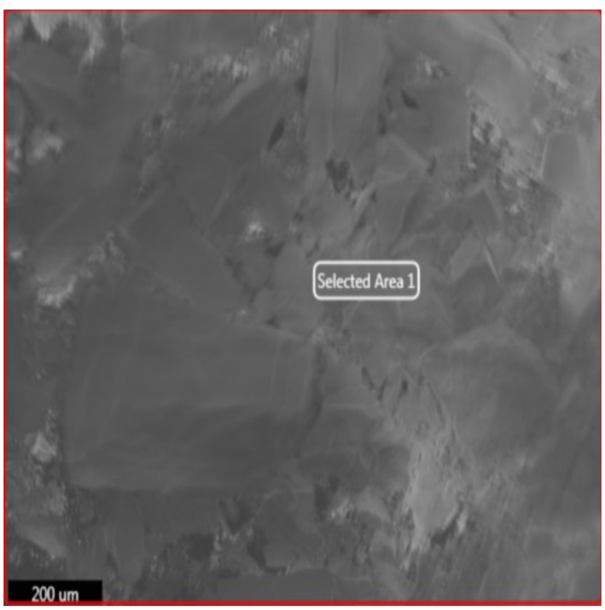
(a)



(b)



(c)



(d)

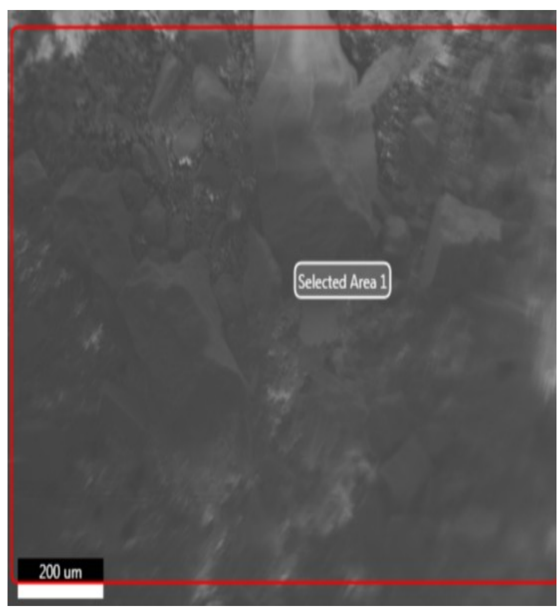


Plate (a-d) SEM Images of Selected Samples

4.3 Mud Density

All the samples were used to prepare the mud samples to obtain the results for the mud densities in proportion of 40g, 80g and 120g. the results obtained are shown below

Table 4.3.1: Drilling Fluid Density (with 40g of barite)

Fluid reference	Amount of Barite ($BaSO_4$) g	Density of Drilling Fluid lb/gal
Sample C	0	8.7
Sample 1	40	9.5
Sample 2	40	9.0
Sample 3	40	9.1
Sample 4	40	9.3
Sample 5	40	9.4
Sample 6	40	9.3

From the table 4.3 above, the weight of barite was 40g and the sample 1 showed the highest mud density of 9.5 lb/gal and sample 2 has the lowest mud density of 9.0 lb/gal. from the sample 1, it showed that there is an effect of the specific gravity of the barite in sample 1 (4.38) on the mud density which shows the increase in mud density as specific gravity increases

Table 4.3.2: Drilling Fluid Density (with 40g of barite)

Fluid reference	Amount of Barite ($BaSO_4$) g	Density of Drilling Fluid lb/gal
Sample C	0	8.7
Sample 1	80	10.5
Sample 2	80	9.2
Sample 3	80	9.4
Sample 4	80	9.85

Sample 5	80	10.2
Sample 6	80	9.85

The above figure shows 80g of barite used to determine the mud density. It showed that sample 1 gave the highest value of mud density 10.5lb/gal, which shows the effect of specific gravity on the mud density, while sample 2 which has the lowest specific gravity of 4.11 showed the lowest value of the mud density 9.2lb/gal

Table 4.3.3: Drilling Fluid Density (with 40g of barite)

Fluid reference	Amount of Barite (BaSO4) g	Density of Drilling Fluid lb/gal
Sample C	0	8.7
Sample 1	120	10.7
Sample 2	120	10.2
Sample 3	120	10.3
Sample 4	120	10.4
Sample 5	120	10.6
Sample 6	120	10.4

-

The above result in table 4.4 shows the effect of the barite specific gravity on the mud density. The amount of barite added was 120g and it showed that sample 1 which has the highest specific gravity possessed the highest mud density of 10.7lb/gal, the above graph also showed that the increase in the specific gravity caused increase in the mud density and shows sample 3 and 4 with same amount of mud density because they nearly possessed the same value of specific gravity.

The figures below show the relationship between the mud density and the amount of barite added in the formation. This implies that, as the barite content increases, therefore the mud density increases which showed that there is a weighting material present which gave rise to the increment in the mud density.

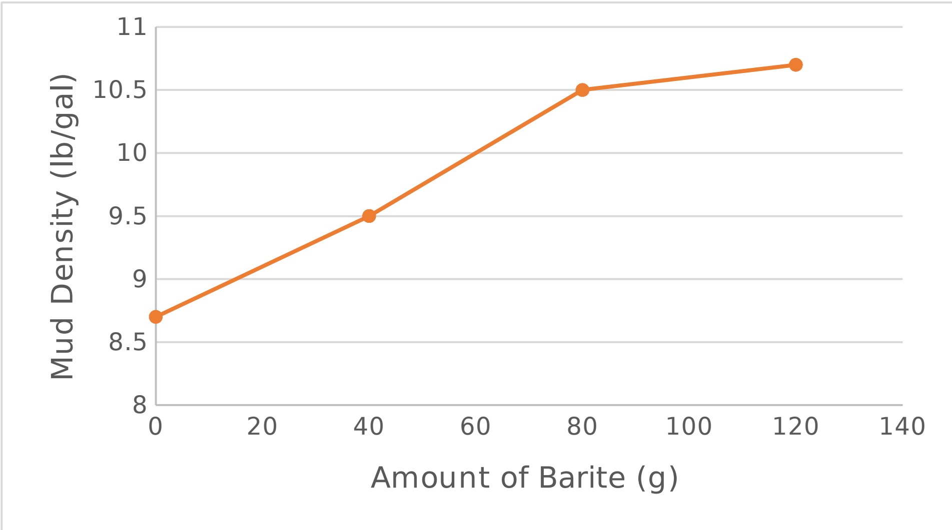


Figure 4.7: Barite from Location 1

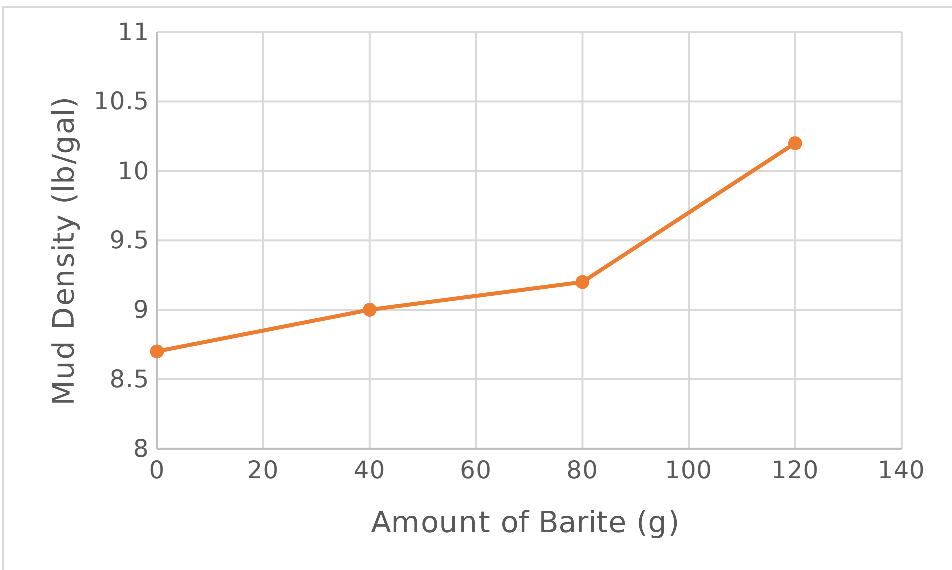


Figure 4.8: Barite from Location 2

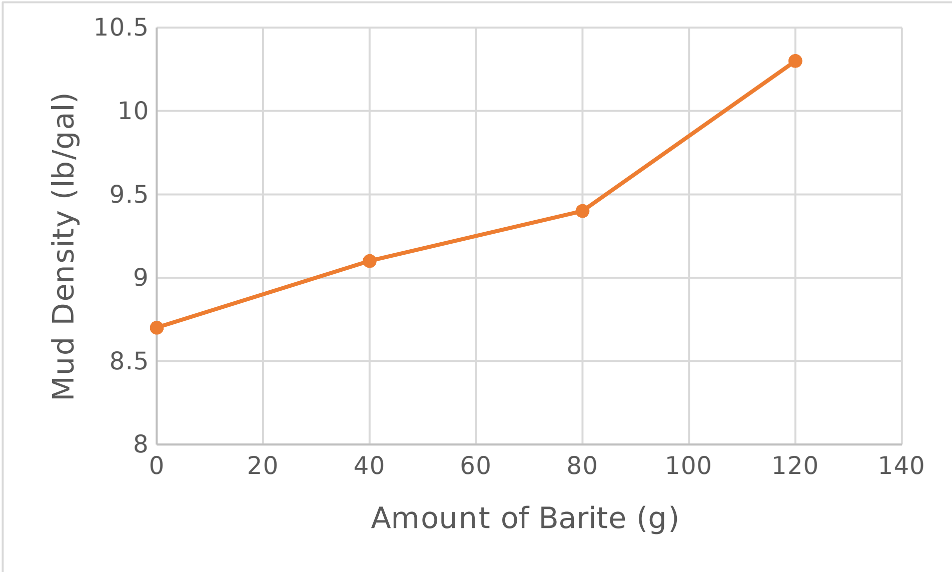


Figure 4.9: Barite from Location 3

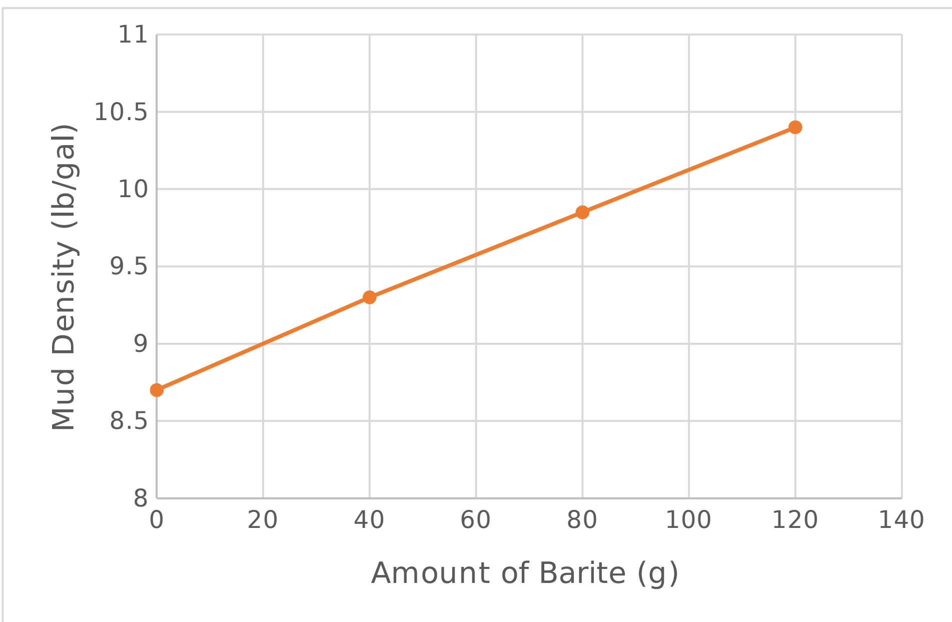


Figure 4.10: Barite from Location 4

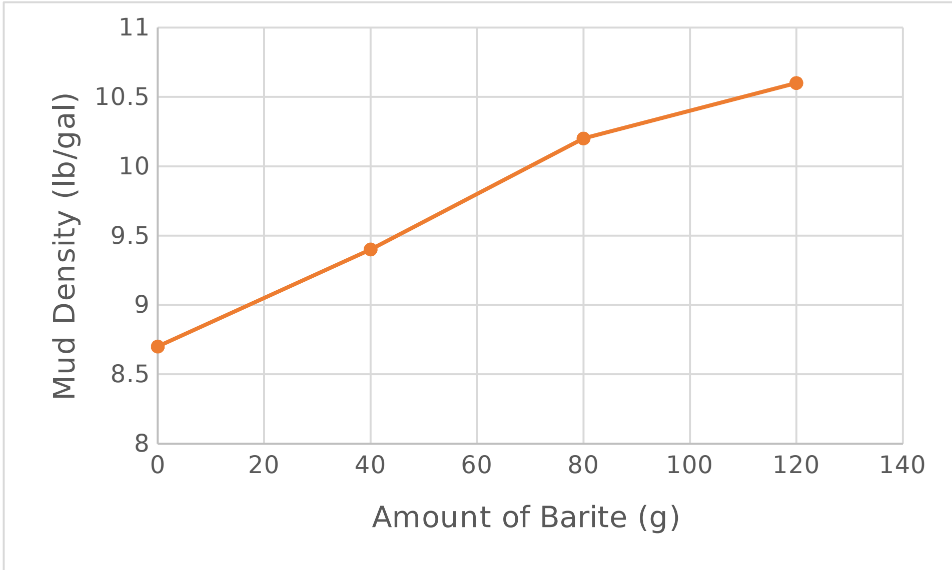


Figure 4.11: Barite from Location 5

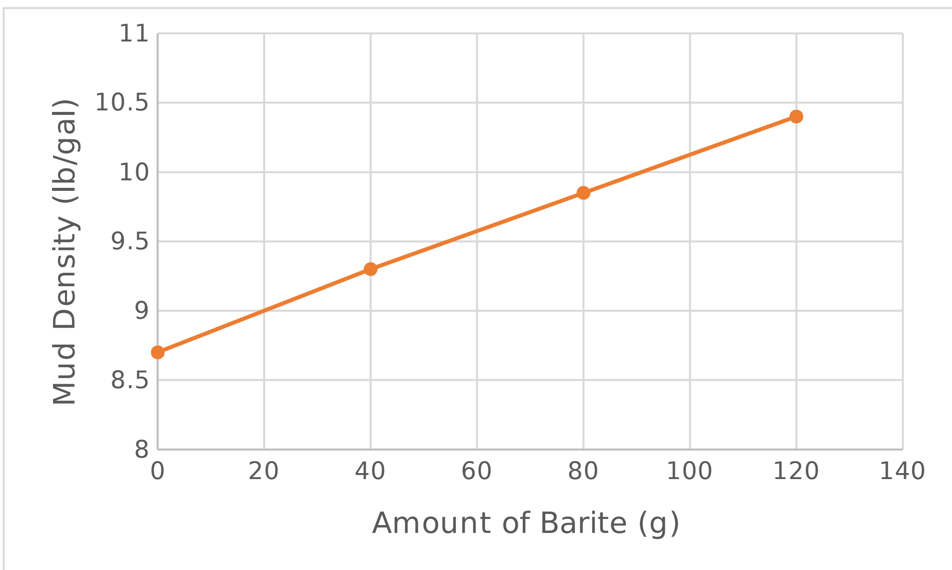


Figure 4.12: Barite from Location 6

4.4 Viscosity

The table 4.4.1 below shows the result of the viscosity on the mud samples, with sample 1 having the highest plastic viscosity of 2.75 (cp) and sample 2 and 3 showed the lowest plastic viscosity of 1.5 (cp) each. Also, the gel strength at 10 secs was high at sample 1 and 5 due to the effect of the specific gravity of the barite and the lowest is the sample 2 with 0.5 (lb/100ft^2).

Table 4.4.1 Rheology of Mud Sample by weight of 40g Barite

Rheology	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Apparent viscocity (cp)	3	3.125	2.75	2.7625	3	3
Plastic viscosity (cp)	2.75	1.5	1.5	1.525	2.5	2
Yield point (ib/100 ft^2)	4	1.5	2.5	2.475	3	2
Gel 10 s (ib/100 ft^2)	1.5	0.5	1	1	1.5	0.5
Gel 10 mins (ib/100 ft^2)	2.5	2.5	1	1	1	1
θ_{600}	6	6.25	5.5	5.525	6	6
θ_{300}	4.5	4.5	4	4	4.5	4.5
θ_{200}	3.5	3.25	3.5	3.5	3	3
θ_{100}	2.5	2.5	1.5	1.5	2	2
θ_{60}	2	2	1	1	1.5	1.5
θ_{30}	1.5	1.5	1	1	1	1
θ_{6}	1	1	0.5	0.5	0.5	0.5
θ_{3}	0.5	0.5	0.5	0.5	0.5	0.5

The table 4.4.2 below shows the result of the viscosity on the mud samples, with sample 1 having the highest plastic viscosity of 4.025 (cp) and sample 2 and 6 showed the lowest plastic viscosity of 2 (cp) each. Also, the gel strength at 10 secs was high at sample 1 and 5 due to the effect of the specific gravity of the barite and the lowest is the sample 2 and 6 with 1 (lb/100ft^2).

Table 4.4.2 Rheology of Mud Sample by weight of 80g Barite

Rheology	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Apparent viscocity (cp)	4.875	3.5	3.75	3.762	4.75	3.5
Plastic viscosity (cp)	4.025	2	2.5	2.525	3.5	2
Yield point (ib/100 ft^2)	2.5	0.975	1.7	2.525	3	2.250
Gel 10 s (ib/100 ft^2)	1.5	1	1.5	1.5	1.5	1
Gel 10 mins (ib/100 ft^2)	2.5	1.5	1.5	1.5	2.5	1.5
θ_{600}	9.75	7	7.5	7.525	9.5	7
θ_{300}	6	5	5	5	**5.725**	5
θ_{200}	5.5	4	4	4	**5.5**	4
θ_{100}	3	2.5	2	2.25	**3**	2.5
θ_{60}	2.5	1.5	1.5	1.5	**2.5**	1.5
θ_{30}	2	1	1	1	**2**	1
θ_{6}	1.5	1	0.5	1	**1.5**	1
θ_{3}	1.5	0.5	0.5	0.5	**1.5**	0.5

The table 4.4.3 below shows the result of the viscosity on the mud samples, with sample 1 and 5 having the highest plastic viscosity of 4.5 (cp) each and sample 2 showed the lowest plastic viscosity of 3.5 (cp) each. Also, the gel strength at 10 secs was high at sample 1 and 5 of 2.5 (cp) due to the effect of the specific gravity of the barite and the lowest is the sample 2 with 1.25 (lb/100ft^2).

Generally, it was observed that the rheological properties were increasing with the increase in the amount of barite added to the mud samples.

Table 4.4.3 Rheology of Mud Sample by weight of 120g Barite

Rheology	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Apparent viscocity (cp)	5.25	5.25	5.75	5.75	5	5
Plastic viscosity (cp)	4.5	3.5	4	4	4.5	4
Yield point (ib/100 ft^2)	3.5	1.5	2.5	2.5	3	2
Gel 10 s (ib/100 ft^2)	2.5	1.25	2	2	2.5	1.5
Gel 10 mins (ib/100 ft^2)	3.5	1.5	2.5	2.5	3	2
θ_{600}	10.5	10	11.5	11.5	10.5	10
θ_{300}	7	7	7	7	6	6
θ_{200}	5.5	5.5	5	5	4	4
θ_{100}	4	4	3.5	3.5	3	3
θ_{60}	3	3.25	2.5	2.5	2	2
θ_{30}	2.5	2.5	2	2	1.5	1.5
θ_{6}	2	2	1	1	1	1
θ_{3}	2.5	2.25	1	1.5	1	1

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

From the above study and results obtained, barite samples were collected from six different location in the area of Wuse in Nasarawa state, Nigeria. The following can be concluded:

1. Local barite obtained from this region has the potential to be used as weighting material in drilling fluid as there is a good range of specific gravity following the API standard.
2. The samples from Wuse in Nasarawa state, Nigeria gave high amount of specific gravity of 4.8 SG, with some traces of rare earth metals.
3. There will be an increase in the GDP of Nigeria economy if these local barites can be utilized and properly processed for use in the oil drilling industry.
4. The SEM image has revealed the shape of the plate like structure of the barite and EDS showed the elemental composition of the ore. The ore contains, Barium, Sulphur, oxygen, carbon, aluminum, iron and tracs of rare earth metals
5. There is also an effect of the specific gravity on the mud density, it implies that the higher the specific gravity, there was an increase in the value of the mud density which actualizes the claim that there is an effect of the barite specific gravity on the mud densities.

RECOMMENDATION

From the study, the following recommendations were generated:

1. This study only considered the percentage of the elemental composition of the ore. X-Ray Diffraction (XRD) or X-Ray Fluorescence (XRF) analysis should be carried out in other to know the percentage of the barite in the ore and also the percentage of other compounds present in the ore. This will help to determine whether the amount of barite present gave rise to the high specific gravity.

2. This study also showed the samples were collected from the surface with about 10 feet deep, and it is recommended that there should be an analysis on the deeper part of the locations so as to know the variations that might occur if different from samples collected just around the surface.
3. The processing of the barite should also be improved using other methods like the froth flotation, heavy media separation method. This may have great effect on the purification of the ore.

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