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Review article

Barite as an industrial mineral in Nigeria: occurrence, utilization, challenges and future prospects

Abraham Ighoro Ebunu [a,*], Yusuf Afolabi Olanrewaju [a], Oghenerume Ogolo [c], Adelana Rasak Adetunji [a,b], Azikiwe Peter Onwualu [a]

[a] Department of Materials Science and Engineering, African University of Science and Technology (AUST), Km 10 Airport Road, Galadimawa Roundabout, Abuja, FCT, Nigeria
[b] Department of Materials Science and Engineering, Obafemi Awolowo University (OAU), Ile Ife, Osun State, Nigeria
[c] Department of Petroleum, Nile University of Nigeria, Abuja, Nigeria

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ABSTRACT

Barite is a non-metallic mineral which is simply barium sulfate ($BaSO_4$) and is largely used by the oil and gas industry as a weighting agent in drilling mud during drilling operations. The specific gravity of barite should range from 4.1 to 4.6 to be applicable as a drilling mud additive. This study considered the occurrence, utilization and challenges facing the mining of barite in Nigeria. It also discussed the global reserve, production and consumption of barite and types of barite ores and associated minerals in Nigeria. With the use of data from various ministries, departments and agencies involved in the records of operations within the Nigerian solid minerals sector, the nature of occurrence of barite in Nigeria has been reviewed. The various reported deposits areas have been elucidated while the associated minerals along with the quality reserve estimates have been discussed. Reported geochemical and geological studies of the barite mineralization in Nigeria show cream to grey, reddish-brown, whitish and pinkish varieties. The quality of the Nigerian barite is moderate to high. It is often associated with dolomite, fluorite, quartz, calcite, etc. The major impurities found in the mineral are iron oxide (goethite), quartz, and carbonates of magnesium, iron and calcium. Enumeration of the challenges facing the exploitation of the mineral has been revealed to include poor infrastructural development, safety and security, insufficient geophysical and geoscience data information and crude mining techniques. The barite production industry still has a huge potential for growth if these challenges are addressed.

1. Introduction

Nigeria is richly and abundantly blessed with solid minerals of various types such as iron ore, tantalite, barites, gold, tin, bentonite, gypsum etc (Adewuyi et al., 2019; Afolabi et al., 2017; Elder, 2012; FMSMD, 2004; Ihekweme et al., 2020; Obiajunwa, 2011; Omotehinse and Ako, 2019; Orosun et al., 2020; Ramadan and Abdel Fattah, 2010). The exploration and exploitation of most of these minerals are extremely low when compared to the number of deposits and this is as a result of the artisanal mining technique being used to mine these minerals (Adewumi and Laniyan, 2020; Bello et al., 2019; Oramah et al., 2015; Taiwo and Awomeso, 2017). Hence, much of these minerals are yet to be exploited to their fullest potentials. The new National Policy of Nigeria on solid minerals addressed this challenge by ensuring the orderly development of mineral resources in the country. The mining sector in Nigeria is only contributing about 0.5%–0.6% to the country's GDP (Ministry of Mines and Steel Development, 2016) because of her dependence on oil resources. The mining industry in Nigeria is underdeveloped, resulting in the importation of minerals that could be produced domestically (Ministry of Mines and Steel Development, 2016). There are about 44 different types of minerals that have been identified in over 500 locations in Nigeria and one of such minerals is barite. Barite occurs in veins, stratiform beds and residual deposits. Stratiform beds are the largest global deposits currently mined in the United States (US), China and India (Gao et al., 2017). Barite is utilized primarily for its high specific gravity in addition to its chemical and physical inertness, relative softness and very low solubility (Bosbach et al., 1998; Crecelius et al., 2007; Das et al., 2020; Ulusoy, 2019).

Barite deposits in Nigeria are found in veins and cavity fillings hosted by varieties of rocks and are largely used by the oil and gas industry

* Corresponding author.
E-mail address: aebunu@aust.edu.ng (A.I. Ebunu).

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during drilling operations as a drilling mud weighting agent to balance the reservoir pressure and prevent blowouts (Ekwueme et al., 2012; Elkatatny, 2019; Ene et al., 2012; Labe, 2015; Kwache and Ntekim, 2016; Oladapo and Adeoye-Oladapo, 2011; and Darley and Gray, 1988). During drilling operations, the drill bit passes through several formations, each with different properties. Deeper wells require a higher percentage of barite in the mud mix (Scogings, 2014). Barites are also used by the chemical industries in the manufacture of barium compounds or chemicals, and the paint and glass industries (Tanko et al., 2015). Barite deposits can be found in nine states in Nigeria, viz, Adamawa, Gombe, Zamfara. Plateau, Cross River, Benue, Nasarawa, Taraba and Ebonyi (Adamu et al., 2015; Akpan et al., 2014; Dominic et al., 2014; Edu, 2006; Ekwueme et al., 2012; Labe et al., 2018; Maiha, 1996; Oden, 2012; Ogundipe, 2017). A comprehensive appraisal of barites resources in Nigeria was carried out by the Nigeria Geological Survey Agency between 2005 and 2009. They estimated the reserve of barite from eight states to be 22,298,843 tonnes on an average vein depth of 20 m and a specific gravity of 4.2 (Nigeria Geological Survey Agency, 2011). Although barite is one of the seven strategic minerals identified in the country, there is no published work that gives the complete data and information on the occurrence, utilization and challenges of barites as an industrial mineral in the country. The objective of this study was to appraise data and information on barite occurrence, utilization, challenges and prospects in Nigeria. This is to project the potential of the mineral's resource and increase its utilization in the country.

2. Materials and methods

The following relevant agencies were visited for the collection of data; Nigeria Geological Survey Agency, Ministry of Mines and Steel Development, Raw Materials Research and Development Council, National Geosciences Research Laboratory, Kaduna and the Nigeria Building and Road Research Institute, Abuja. Site visits were also conducted to Benue, Nasarawa, and the Plateau States for site inspection on processing to understudy indigenous mining operations and minerals processing techniques involved in the barite mineralization and other associated gangue minerals, with samples being collected from these sites. Relevant literature on the global perspective of barite as an industrial mineral was also consulted.

3. The barite mineral

Barite is a solid mineral that combines barium and sulphur. It is composed of barium sulfate ($BaSO_4$) (Arrifan, 2003; Brock-Hon and Johnston, 2014; Ehya and Mazraei, 2017; Ene et al., 2012; Robin et al., 2003; Tanko et al., 2015). Barite appears in nature as granular or crystalline masses, nodules, rosette-like aggregates and also in laminated to 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 deposit and bedded deposits (Alaminia and Sharifi, 2018; Bulatovic, 2015; Fatoye et al., 2014; Jébrak et al., 2011; Zhou et al., 2018). Barite ores of different grades vary from one location to the other and within deposits. It is also a common gangue in other ore deposits such as lead, fluorite, zinc, and gold and rare earth minerals. In Nigeria, most barite deposits are vein and cavity filling type of deposit and this type of deposit may be hosted by different rock types such as sandstone, limestone, migmatite, shale, mudstone and porphyritic granite. Barite is often associated with magnetite, fluorite, calcite, siderite, quartz, galena, dolomite etc (Chen et al., 2018; Deng et al., 2019; Liu et al., 2019; Yang et al., 2020).

3.1. Mining and processing

Different kinds of Barite deposits exist, and each determines the processing methods and economics. Barite vein deposits can be extracted either from a surface or underground mining followed by physical processing methods to remove the gangue materials and to obtain the required product (Ciccu et al., 1987; Ofor and Nwoko, 1997; Scogings, 2014; Zhao et al., 2014). The residual deposit can be mined with machineries such as excavators, dozers and front-end loaders and they are usually shallow. Bedded deposits are worked by open-pit methods. The deposits are usually extensive with consistent barite grades. Vein deposits are worked by shafts and adits, as well as by shallow open pits. 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 a powder, or processed further for particular applications (Nigeria Geological Survey Agency, 2011).

3.2. Forms of barite deposit

- Vein and Cavity Filling Deposit

This type of deposit is a thin layer of barites contained in rocks and are usually scattered and irregular ranging from few centimetres to a few tens of centimetres in width and a few to hundreds of meters in length. The host rocks are usually Precambrian to tertiary age and are a source of pure barites used in ceramics and fillers. The associated minerals include; carbonates, quartz, calcite, fluorite, siderite and pyrite or other sulphide minerals. Barites and associated minerals in vein and cavity filling occur along faults, joint and bedded planes, breccia zones, solution channels and other sink structures. Deposit in solution channel and sink structures are common in limestone (Nigeria Geological Survey Agency, 2011). This type of deposits is smaller when compared with bedded deposits and can be found in Benue Trough in Nigeria and the United Kingdom (Labe et al., 2018).

- Residual Deposit

Residual deposit is derived from other forms of deposits. The weathering of vein and cavity filling deposit and bedded barite deposits give rise to residual deposit. Residual barites are usually dense fine-grained masses which are translucent to opaque. The mineral is commonly associated with siderite, pyrite, chalcopyrite, galena, sphalerite, calcite, dolomite, quartz, unweathered rock fragments, metal sulfides, sulfide weathering and iron oxides products may also be present (USGS, 2011, and USGS, 2020, Nigeria Geological Survey Agency, 2011). A typical residual deposit can be found in Missouri, Washington some kilometres South West of Louis (Nigeria Geological Survey Agency, 2011).

- Bedded Deposit

A bedded deposit occurs in a sequence of sedimentary rocks characterized by abundant chert and black siliceous shale and siltstone. In bedded deposits, barites occur as the principal mineral or cementing agents in stratiform bodies in a layered sequence of rocks. They are the most commercially valuable and highly sought for because of its large tonnage deposits and high-grade barites (50–95% barites). Bed thickness ranges from few centimetres to 30 m and could extend up to several hectares. Barite in this deposit is usually associated with galena, sphalerite, pyrite and occurs in marine rocks of Devonian age precipitated out of seawater (Nigeria Geological Survey Agency, 2011). There are different forms of bedded deposits based on their dispositional environments. Examples include; stratiform deposits found in Gidanwaya deposits, Taraba State, and Alifokpa deposits, Cross River State, Nigeria. Bedded deposits associated with volcanic series are found in Buchan's deposit, Canada, exogenetic deposits found in Krakow deposit, Poland and base-metal sulphides found in Red Dog, Alaska (U.S. Geological Survey, Labe et al., 2018).

3.3. Uses of barites

Barite is a solid mineral which has many economical and industrial usages. The uses of barite are as follows:

- Weighting Agent in Drilling Mud

The majority of the barite mined is used in the oil and gas industry as a weighting material in drilling mud. Since high reservoir pressure is experienced during drilling operations, this requires a heavy circulating fluid that will compensate for high-pressure zones to control the pressure of the reservoir and prevent blowout. Pulverized barites are added to the clay-water mixture to form the drilling mud. The softness of the barite also prevents it from damaging drilling tools during drilling operations and enables it to serve as a lubricant. The most important property of barite considered for usage in drilling mud formulation is its specific gravity (SG) (The Barite Association, 2014).

The American Petroleum Institute (API) set the required standard in terms of barites characteristics. The specific gravity of 4.2 minimum is required by API specification (API, 1993). But because of concerns about dwindling reserves of barite with a specific gravity of 4.2, and to provide the end-user with a choice as to which material to use, the American Petroleum Institute issued a new edition of API Specification 13A, Specification for Drilling Fluids Materials, adding specifications for 4.1 specific gravity barite (API, 2010), Except for specific gravity, other specifications remained the same. The American Petroleum Institute required that the barite be pulverized so that at least 97% of it, by weight, can pass through a 200-mesh (Tyler) screen, and that no more than 30%, by weight, can be less than 6 μm, effective diameter, which is usually measured using sedimentation techniques. Lastly, the pulverised barite may contain no more than 250 ppm water-soluble alkaline earth metals such as calcium (Scogings, 2017). Barite used in drilling operation according to the America Petroleum Institute (API) should have characteristics such as specific gravity of at least 4.2, about 92/94 $BaSO_4$, less than one per cent soluble salt (250ppm max) and a few percentages of iron oxide, 95% pulverized barite that passes 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 specification for barite used for drilling mud operations:

i. The specific gravity of a minimum of 4.2
ii. Apparent Viscosity of 250 cp
iii. Wet screen analysis residual at 3% max
iv. Soluble alkaline earth metals of 250 mg/L
v. Residue on sieve number of 325 of 5–10% by weight.

- Medical Industry

The main ore of barium is barite and its compounds are used for x-ray shielding. Barite is opaque and it is used in hospitals, power plants and laboratories to block gamma rays and x-rays emissions. Compounds of barite are also used in a diagnostic medical test for determination of normal and abnormal anatomy (MMSD, 2018; Geology.com).

- Glass Making

Coarse sand size of barite is added to the mixture in glassmaking, it serves as flux, enhanced brilliance of glass and also makes the mixture workable. In glassmaking industry, barite is used to reduce bubble when melting material and it is also used in product transparency and luminosity (Nigeria Geological Survey Agency, 2011). The barium-containing glasses are more transparent than the lead glasses. Advanced ceramics that contain barium are used in the electronics industry (condenser, earphone, speakerphone, telephone, and permanent magnet).

- Paint and Rubber Industry as Filler and Extender

Barite is used as a pigment in the production of paints and as weighted filler for paper, cloth and in rubber to make "anti-sail" mudflaps for trucks. Due to its high SG and radioactive absorption characteristics, it is used as an aggregate in heavy-weight concrete production to increase density (British Geological Survey September, 2005, Tzong-Jer Chen 2017). A mixture of rubber, asphalt and 10% barite is used in the construction of stations and runways of airports. It is also used in pharmaceutical, alloy industries etc.

- Industrial Chemicals

Barite is the source of most barium compounds such as barium sulphide, barium chloride, barium nitrate, barium carbonate etc. that are widely used as reagent and catalyst. Barium chloride is used in the manufacture of cloth and leather, oxides of barium are used in glassmaking and electric furnace metallurgy, the carbonate of barium is a component of ceramic glazes and enamels, while the hydroxide is used in

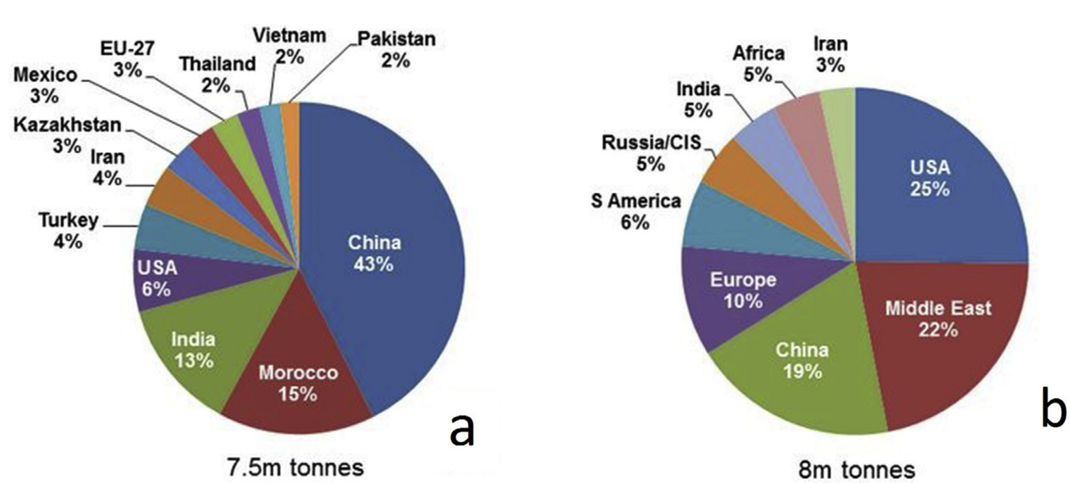

Figure 1. Global production (a) and consumption (b) of Barite in 2015 (Industrial Minerals Form and Research, 2017).

Table 1. World production of barite by country in metric tonnes from the year 2007–2015 (United States Geological Survey, 2017).

Country	Year								
	2007 (mt)	2008 (mt)	2009 (mt)	2010 (mt)	2011 (mt)	2012	2013 (mt)	2014 (mt)	2015 (mt)
Algeria	63,098	60,088	38,000	42,000	40,000	30,587	30,245	56,829	50,000
Argentina	37,979	3,170	3,416	2,944	3,000	9, 416	26,792	16,265	17,000
Australia	600	600	500	550	600	12,373	13,176	14,676	6,017
Bolivia	16,000	21,000	20,000	21,000	22,000	22,000	31,000	27,000	47,000
Brazil, Beneficiated	8,245	10,900	2,069	7,845	21,297	3,025	N/A	N/A	N/A
Bulgaria	13,311	23,276	49,847	41,385	41,400	N/A	N/A	20,000	47,000
Burma	51,000	40,000	14,300	500	500	15,339	31,295	23,060	60,000
Canada	6,813	5,679	7,623	8,975	9,000	22,000	22,000	35,000	23,000
China	9,000	12,000	15,000	22,000	22,000	4,200,000	3,200,000	3,108,300	32,000
Germany	4,400,000	4,600,000	3,000,000	4,000,000	4,100,000	52,030	45,446	70,665	3,000,000
India	88,265	78,941	45,606	55,887	70,000	1,670,000	1,320,000	1,183,000	70,000
Iran	1,000,000	1,100,000	1,200,000	1,300,000	1,350,000	314,769	300,000	300,000	700,000
Kazakhstan	249,495	226,590	361,217	400,000	350,000	250,000	250,000	300,000	300,000
Laos	5,000	5000	3,500	3,500	3,500	21,900	10,500	30,610	300,000
Liberia	130,000	170,000	170,000	200,000	200,000	N/A	N/A	13,000	95,000
Malaysia	29,000	29,000	29,000	29,000	29,000	N/A	500	14,465	25,000
Mexico	185,921	140,066	151,791	143,225	156,645	139,997	343,85	420,000	16,624
Morocco	664,700	725,606	586,937	572,429	600,000	1,021,400	1,094,470	1,006,600	265,598
Nigeria	5,000	5000	19,400	19,000	20,000	N/A	N/A	N/A	N/A
Pakistan	48,044	56,500	60,000	55,000	58,000	109,415	87,165	153,808	1,000,000
Peru	27,372	45,213	27,881	50,942	86,790	79,451	52,491	106,071	121,575
Russia	63,000	63,000	63,000	60,000	62,000	180,000	180,000	220,000	28,407
Slovakia, concentrate	11,000	12,950	8,000	10,000	10,000	8000	11,000	11,000	210,000
Spain	26,770	11,100	2,814	2,814	3,000	N/A	N/A	N/A	N/A
Thailand	8,631	9,180	51,895	33,465	35,000	64,449	107,437	134,961	10,000
Turkey	184,041	482,740	213,187	250,000	230,000	187,111	257,116	320,754	170,661
United Kingdom	55,000	50,000	50,000	50,000	50,000	30,000	30,000	44,000	300,000
United States	455,000	648,000	396000	662,000	710,000	666,000	723,000	663,000	40,000
Vietnam	120,000	90,000	75,000	85,000	85,000	110,000	75,00	100,000	425,000
others	2,620	3,934	3,617	3,660	3,610	119	371	43	100,000
Total	7,960,000	8,730,000	6,670,000	8,130,000	8,370,000	9,220,000	8,240,000	8,390,000	7,410,000

sugar recovery and nitrate, an ingredient of detonators and flares (Nigeria Geological Survey Agency, 2011). Barium chemicals must meet the following specification: 95% $BaSO_4$, less than one per cent iron oxide and one per cent strontium sulphate and some traces of fluorine (Nigeria Geological Survey Agency, 2011).

- Other uses

Barite is also used in other applications including plastics, clutch pads, mould release compounds, sound-deadening material in automobiles, traffic cones and brake linings.

The estimated amount demanded barites in Nigeria in the chemical industry is about 13,400 tonnes while that of the petroleum industry for the production of drilling mud is about 70,500 tonnes as of 1988. Consumption of white barites in liquid paint in the UK alone amounts to about 1000 tonnes per annum (Onwualu et al., 2013a, b).

4. Global reserves, production, consumption and global standard for barites

The world's barite identified resources are about 740 million tons of which the total reserve is about 2 billion tons. A good barometer for barite production is associated with oil-well drilling activity. World production of barites has increased from 6.0 to 6.5 million tpa in the early 2000s and 9.7 million tpa in 2014 - but dropped to 8 million tonnes in 2015 and 7.3 million tonnes in 2016 due to low oil price and reduced rate of drilling activities. In 2018, global mine production was about 9.18 million tpa while in 2019 there was an estimated value of about 9.5 million tpa. China alone accounts for 40% of barite production globally while Russia, India, Morocco, USA, Turkey, Mexico, Iran, Kazakhstan and Thailand account for around 50%. The US consumption rate was about 2 million tpa in 2014 and they became the second-largest consumer of barite in 2016 with a consumption rate of 1.6 million tpa. The Middle East consumed 1.7 million tonnes and China 1.5 million tonnes (The Barites Association, 2017). 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 Barites Association, 2017), while estimated world barite production decreased by approximately 12% in 2015 from 8.39 million tonnes in 2014 to 7.41 million tonnes. This reduction occurred majorly in the production capacity of China, India, Mexico, and the United States. Despite the decrease in the world production rate, barite development projects, particularly the construction of processing plants, continued in several countries.

China, Morocco and India are the main barites exporting countries, they accounted for about 80% of all export. Incidentally, none of the main exporters of barites are the major oil-producing countries. Most of the barites importing countries also have domestic production which is not sufficient to meet their needs e.g. UK, USA, Canada etc. The USA is the largest importer of barite and imports most of her barite from China.

Figure 1 shows the global production and consumption of barite in 2015. That year, Nigeria imported a total of 17,406 tonnes of barite from the following countries; China, United States of America, United Kingdom, and the Netherlands. This exceeded the amount imported in

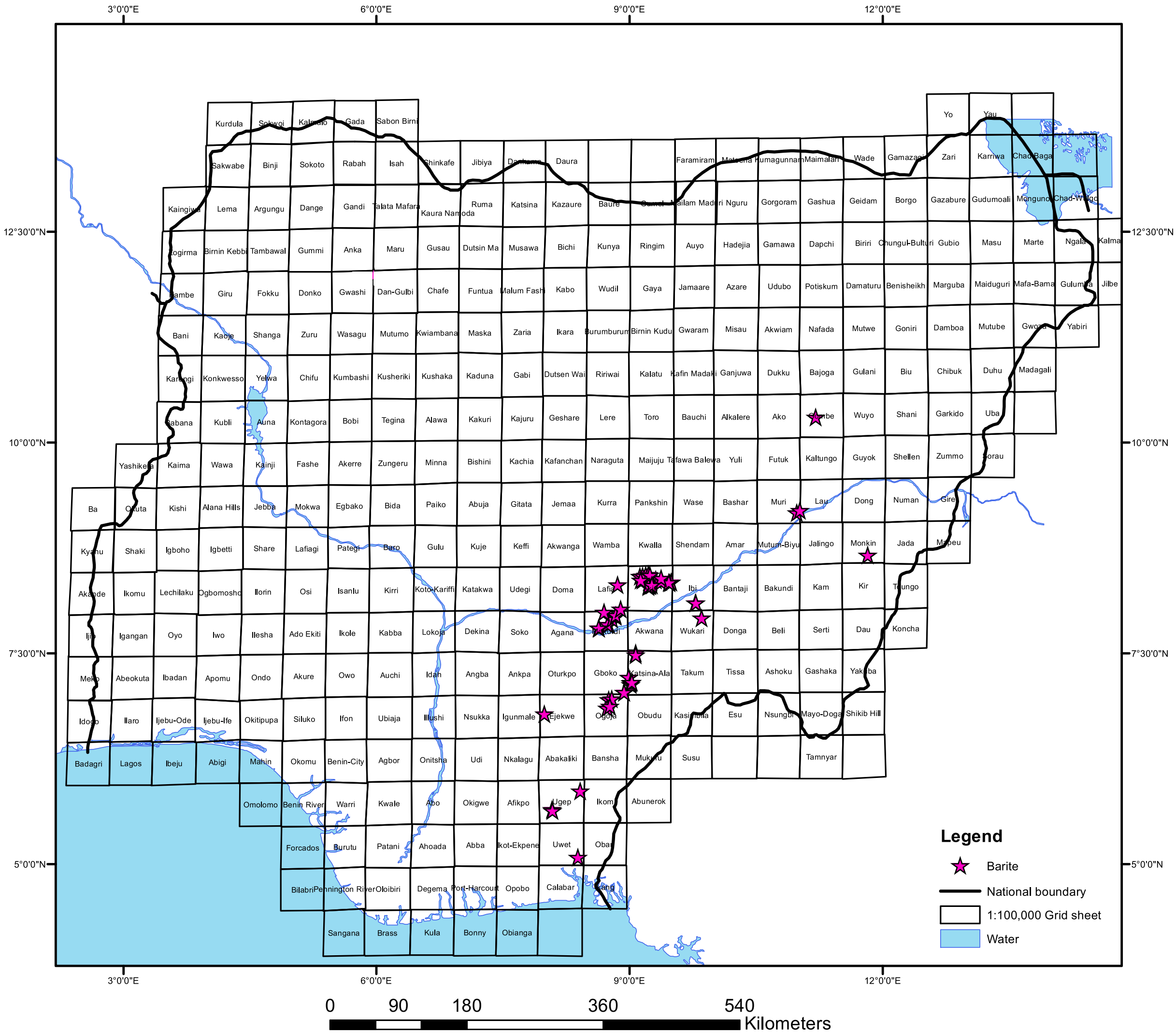

Figure 2. Mineralized location of Barite in Nigeria (Nigeria Geological Survey Agency, 2011).

2012 which is 13,678 tonnes. The Nigerian Geological Survey agency in 2011 carried out exploration studies which show that the inferred resources estimate of barite is about 22,298,843 tons covering about eight states of the Federation with mineralized vein depth of 20 m and an 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 locations such as Azara in Nasarawa State and Dareta in Zamfara State (Nigeria Geological Survey Agency, 2011). The production capacity of barite in Nigerian was 10,000 tpa in 2013 and 6, 000 tpa in 2015. Table 1 shows the production of barite by country. In 2017, no data was given of Nigeria barite production by the US geological survey but in 2011, reported barite production by Nigeria was 20, 000 metric tonnes as shown in Table 1.

A total of 7.5 million tonnes were produced in 2015, 94% of which came from the countries indicated in Figure 1(a) while 8 million tonnes were consumed the same year with 93% by countries indicated in Figure 1(b). This same year Nigeria imported a total of 17,406 tonnes.

5. Barite occurrence in Nigeria

The Government of Nigeria had banned the importation of barites in 2003 to encourage local content and use of domestic barite resources. However, the local miners were not able to meet the demand of the oil and gas companies due to poor development of the mining industry. The oil and gas companies also claimed that the local production of barite struggled to meet the American Petroleum Institute standard and the volume required by the industry. In 2014, an application for the removal of the ban on the importation of barite was made. The committee that was set up to consider the waiver of the ban placed on importing barite into the country said that the country had a shortfall of 31,318.65 tonnes of barite, against domestic demand of 70,590 tonnes (Industrial Minerals Form and Research, 2017).

For decades the Nigeria economy has depended solely on the sale of crude oil but with the recent downturn in the oil price, the economy of the country needs to diversify. This is the time to focus on the development of the solid mineral sector to boost the GDP of the country. Hence, the vast barite reserves in Nigeria needs to be critically looked into (Labe et al., 2018; Akongwale et al., 2013). Barite was first discovered in Ogoja province of Cross River State in Nigeria by Bogue (1951) in a preliminary report published by Geological Survey of Nigeria Report No. 1014 (unpublished). The occurrence of barites in some parts of Benue and Plateau was also reported by Tate (1959) in the Geological Survey of Nigeria Report No.1266. Nigeria Lead–Zinc deposits hosted by the cretaceous rock was worked by Farrington (1952) and he discovered barite as one of the associated minerals. In 1987 the Nigeria Mining Corporation, now defunct, investigated five veins out of the eighteen veins in Azara field, Nasarawa State and reported a reserve of 730,000 tonnes of barite.

Table 2. Barite mineralization in Nigeria.

a: Location, Geology and Mining Status Quo of Barite in Nigeria (Adapted from Nigeria Geological Survey Agency, 2011).

State	LGA	Location	Geology	Status	Types	Grade	Associated Minerals
Adamawa	Mayo-Belwa	Gambe	Granite-gneiss and migmatite terrain. Barite occurs in association with dolerite dyke.	Prospect	Vein type	N/A	N/A
Benue	Guma	Tse-Ande, Iye, Tidza, Ukaa, Nyam Uka, Torkula Akaaza, Lukor	Sandstones	Artisanal	Vein type	N/A	N/A
Benue	Ushongo	Lessel	Shales sandstones of Awgu Indicator Formation.	Prospect	Vein type	N/A	Galena
Benue	Buruku	Fada	Sandstones	Artisanal mine, Open Cast	Vein type	N/A	N/A
Benue	Ushongo	Mbashabu, Mbato-Grim Nbatoo, Mbatoo, Orgba, Bunde)	Granite - gneiss	Artisanal mine, Open Cast	Vein type	N/A	N/A
Benue	Makurdi	Tyodugh-Uni Agric	Sandstones	Artisanal	Vein type	N/A	N/A
Benue	Gboko	Pilla- Yandev	Granite	Artisanal	Vein type	N/A	N/A
Benue	Ado	Igumale	Sandstones	Artisanal	Massive	N/A	N/A
Cross River	Obubra	Iyametite	Veins occurring within shale	Active mine	Vein type	N/A	N/A
Cross River	Ikom	Ekukunela	Vertical veins with a strike of 155/335 occur within shale intercalations	Active mine	Vein type	N/A	Shale
Cross River	Yalla (Gabu, Oshina)	Gabu	Veins occurring within shale	Active mine	Vein type	N/A	Shale
Cross River	Biase	Akpet No 1	The vein in schist and sandstone trend E-W, age- 519Ma (Pan African)	Active mine	Vein type	N/A	N/A
Cross River	Yalla	Gabu	Sandstone	Mine	Vein type	N/A	N/A
Cross River	Biase	Akpet	Sandstone, siltstone	Mine.	Vein type	N/A	N/A
Cross River	Obubra	Edondo/Ochong	Vein occurring within shale and sandstone	Active mine	Vein type	N/A	N/A
Cross River	Yalla	Osina	Sandstone	Occurrence	Vein type	N/A	N/A
Gombe	Gombe	Ligi Hill	Granite gneisses	Artisinal	Disseminated	N/A	Chalcopyrite
Nassarawa	Awe	(wuse, Kumar,Azara, Agana, Gidan Agana, Dogon Daji, Sauni, Jobe, Jara, Gidan Soja, Apebene, Ribi, Akiri (Dutsen Akin)	They occur as hydrothermal deposit forming veins fissure filling in sandstone.	Active Mining	Vein type, fissure filling.	4.20–4.45	N/A
Nassarawa	Adudu	Azara - Wuse - Akiri	Vein deposit within a sequence of sandstone, limestone, siltstone, mudstone and shale of the Eze Aku Group and the Asu River Group.	Deposit	Vein type, fissure filling.	S. G. 3.64 average (max 4.25)	Pb/Zn/Cu sulphides, limonite, siderite, ankerite iron hydroxide quartz
Nassarawa	Awe	Arugagwu	They occur as hydrothermal deposit forming veins fissure filling in sandstone	Abandoned	Vein type, fissure filling.	4.20–4.45	N/A
Nassarawa	Keana	Keana	Black shale and siltstone of Ezeaku Formation	Deposit	Vein type	N/A	Lead–Zinc sulphide
Taraba	Karim Lamido	Didango South	Clayey siltstone of the Benue Valley. Sandstone, and shales of Awgu Ndeabor Formation	Active mine	Vein type and nodules	N/A	Lead Zinc lodes, Sulphides and quartz
Taraba	Wukari	Gidin Waya, Wukari	Barite occurs in clayey sandstone. Black shales and siltstone of Ezeaku Formation	Abandoned	Vein type	N/A	Feldspathic clay, Lead–Zinc sulphides
Taraba	Ibi	Bakyu	Pure Baryte in compacted sandstones within the Benue Valley.	Abandoned	Massive	N/A	N/A
Zamfara	Anka	Dareta	Occurring as a vein in pelitic schist.	Prospect	Vein type	N/A	N/A

b: Mineralization and Characteristics of Barite in Nigeria (Ministry of Mines and Steel Development, 2010; Nigeria Geological Survey Agency, 2011)

State	LGA	Types	Host Rock	Length (m)	Width (m)	Depth (m)	Colour	SG	Estimated Reserve (tons)
Adamawa	Demasa and Mayo-Belawa	Vein and Cavity Fillings	Magmatites, basalts, granites, and field spathic sandstone	15–180	1.2–4.3	10	White-Pink	4.0–4.36	332,130

(*continued on next page*)

Table 2 (*continued*)

b: Mineralization and Characteristics of Barite in Nigeria (Ministry of Mines and Steel Development, 2010; Nigeria Geological Survey Agency, 2011)

State	LGA	Types	Host Rock	Length (m)	Width (m)	Depth (m)	Colour	SG	Estimated Reserve (tons)
Benue	Markudi, Gboko, Ushongo, Vandeikya and Guma	Vein and Cavity Fillings	Igneous to metamorphic rocks of the Pre-Cambrian, shale and sandstone	N/A	3	20	White and reddish-brown	3.7–4.4	307,657
Cross River	Ikom, Obubra, Yala, Biase and Yakkur	Vein	Sedimentary rock	1000–6000	2.5–5.3	N/A	N/A	3.5–4.4	8,612,880
Ebonyi	Afikpo North, Afikpo South, Ivo and Oshaozaba	-	Composed of low-lying sedimentary terrain with some intrusions of different episodes. -	N/A	N/A	N/A	N/A	N/A	Not yet quantify
Gombe	Gombe	Vein	gnesis/magmatite	N/A	0.3–1.3	N/A	Cream-grey	4.09–5.30	352,800
Nassarawa	Awe	Vein	Siltstone, shale, alluvial sand, mudstones, and limestone	30–1050	few cms to 5.8	20	White and reddish-brown	3.0–4.4	3,243, 376
Plateau	Langtang South and Wase	Vein	Sandstone	N/A	N/A	N/A	Pure white-milky white	4.0–4.39	500,000
Taraba	Sardauna, Yoro, Lau, Ibi and Karin-Lamido	Vein	fine-grained sandstones and porphyritic granites	3500–5000	3.5–5	N/A	N/A	4.2	8,960,000
Zamfara	Anka, Chafe and Yarkatsina	Vein	N/A	100	0.6–2	N/A	white-reddish brown	N/A	N/A

Table 3. Characteristics of some barite samples in Nigeria (Onwualu et al., 2013a, b).

S/N	State	LGA	Sample Identity	Specific Gravity (gr/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	Adamawa	Mayo Belwa	Mayo Belwa	4.16	235	2.50	28
2	Adamawa	Mubi	Mubi	3.2	285	3.80	33
3	Benue State	Markurdi	Markurdi	4.23	245	2.00	23
4	Benue State	Gboko	Pilla Yandev	4.16	232	3.00	29
5	Benue State	Bunde, Lessel	Lessel	3.6–4.33	220	1.60	21
5	Cross River	Oruk-Ana	Ntak	4.13–4.33	252–275	3–3.6	29–36
6	Cross River	Obubra	Obubra	3.94–4.08	254–290	3.01–3.40	30–36
7	Nasarawa	Agana	Agana	4.34	230	1.50	21
8	Nasarawa	Awe	Ribi	4.54	210	1.40	19.8
9	Taraba	Ibi	Ibi	4.35–4.44	210–220	1.80	20–21
12	Taraba	Karim Lamido	Karim Lamido	4.44	214	2.00	22

Figure 3. White and Reddish-brown barites in Guma local government (Ebunu, 2017).

Earlier work by the Geological Survey Agency of Nigeria on barites reserve in Adamawa, Benue and Plateau are recorded in the Minerals and Industry yearbook of 1978. Mineralization of barites in the Oban Massif, southern Nigeria was also documented by Egeh et al. (2004), Akpeke (2006) and Oden (2012). The most detailed investigation of barites mineralization is those done by Nigeria Geological Survey between 2005 and 2009.

The mineralization of barites in Nigeria cut across the North East and South East region (Nigeria Geological Survey Agency, 2011). The region designated by a star in Figure 2 shows the occurrence of barite in Nigeria. Table 2 gives a comprehensive list of barite occurrence, the host rocks, geology, associated minerals, specific gravity and status quo of mining activities of barite in Nigeria. Table 3 (Onwualu et al., 2013a, b) shows the characterization of barite samples from different Local Governments in Nigeria using the American Petroleum Institute (API) standard. The mineralisation and characteristics of barite deposit in different states in Nigeria as shown in Table 3 are discussed in the next section.

Figure 4. Barite vein filled with water at Ribi (Ebunu, 2017).

Figure 5. Heap of Barite at Faya (Ministry of Mines and Steel Development, 2010).

5.1. Barite in Adamawa state

Barites deposit in Adamawa occurs in vein and cavity filling deposit hosted by different kinds of rocks such as migmatites, basalts, granites, and field spathic sandstone in Demasa and Mayo-Belawa Local Governments. The length of the vein ranges from 15 – 180 m and the width from 1.2 to 4.3 m and the depth at maximum 10 m (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. The estimated reserve of barite in Adamawa is 332,130 metric tons (Ministry of Mines and Steel Development, 2010).

5.2. Barite in Benue State

Barite deposits in Benue State is in the form of vein and cavity filling which occurs as a result of hydrothermal solutions during Santonian deformation, depositing barite in the fissure formed (Nigeria Geological Survey Agency, 2011). These deposits are found in Markudi, Gboko, Ushongo, Vandeikya and Guma Local Government Areas of Benue State and are housed by igneous to metamorphic rocks of the Pre-Cambrian as well as in shale and sandstones. Barite in these areas is white and reddish-brown in colours as shown in Figure 3 in Guma local Government with a specific gravity of 3.7–4.4. The vein deposit width is over is 3 m and keeps expanding as it descends to a depth of about 20 m. Chemical analysis of barite samples in Benue state shows the ore composition of 76%–86% $BaSO_4$, 5–21% silica and about 3% iron oxide and the reserved estimate is about 307,657 metric tonnes.

5.3. Barite in Cross River State

Hard and soft rocks host the barite vein deposits in Cross Rivers State. It has 35 mineralized locations of which 11 are in sedimentary areas. The mineralized locations are divided into two, the North and South. The Northern area hosted by sedimentary rocks consists of Ikom, Obubra and Yala Local Government Areas and in southern area with 18 locations, only 2 are hosted by sedimentary rocks and consist of Biase and Yakkur Local Government Areas. The width of the veins ranges between 2.5 – 5.3 m and length is between 1000 - 6000 m with a specific gravity ranging between 3.5-4.4. The reserve estimate for Cross River was 8,612,880 metric tonnes distributed between the Southern and Northern zones of Cross river (Ministry of Mines and Steel Development, 2010). Barite exploration in the North is easier compared with that of the South as a result of soft host rocks and new veins are likely to be discovered in the future (Ministry of Mines and Steel Development, 2010).

5.4. Barite in Nasarawa State

The barite vein in Nasarawa State is hosted by different kinds of sedimentary rocks (siltstone, shale, alluvial sand, mudstones, and limestone). An initial inspection by Geological survey agency indicated 18 veins of barite at areas including Azara, Aloshi, Akiri, Wuse and Keana in Awe Local Government Area and out of these 18 veins, detailed exploration works were carried out in only 5 veins (Saintmoses Eromosele, 2017). Thus, there is a need for further evaluation of the remaining 13 veins. Vein width varies from a few centimetres to 5.8 m and length varies from about 30 m to 1.05km with a specific gravity of 3.9–4.4. Figure 4 shows barite veins in Ribi filled with water, some of which is within API standard. However some of the samples have high silica content resulting in 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 with a vein thickness of 20 m and an average specific gravity of 4.0 is 3,243, 376 metric tons (Nigeria Geological Survey Agency, 2011). The barite found in Azara, Nasarawa State appears to have had carbonate subjected to chemical weathering resulting in two distinct types of barite, namely;

- Barite with quartz and limonite as gangue
- Barite with siderite and ankerite as gangue

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

5.5. Barite in Plateau State

Kargo, Faya, Safiyo Karwa, Yama, Angwar and Gimbi are villages in Langtang South and Wase Local Government Areas of Plateau State where barite veins are hosted by sandstone of the Keana Formation of Cenomanian age and the barite colour varies from pure white to milky white. The specific gravity ranges from 4.0 – 4.39. Faya has the best

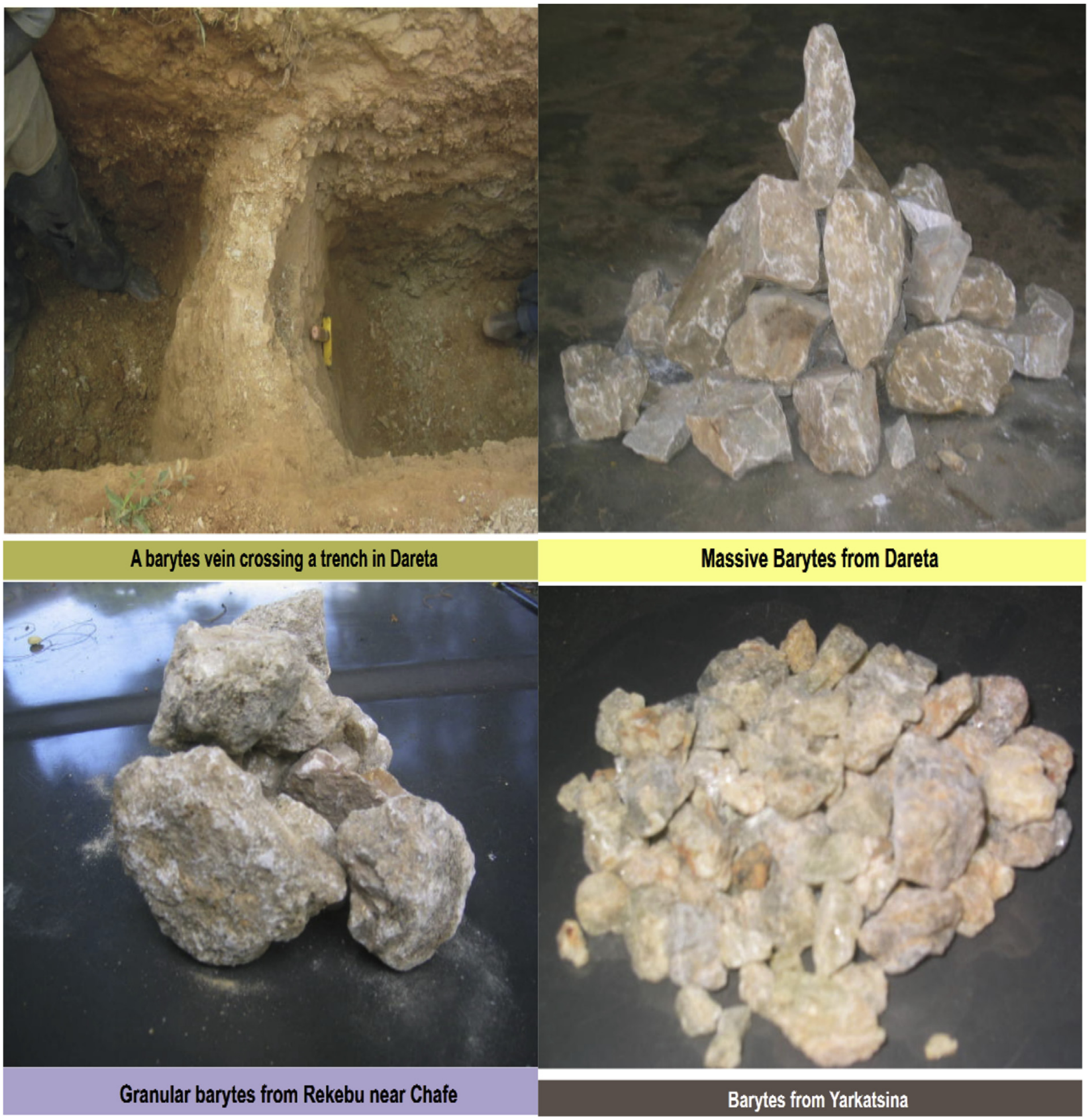

Figure 6. Barites samples in Dareta, Chafe and Yarkatsina in Zamfara State (Ministry of Mines and Steel Development, 2010).

barite vein with an estimated reserve of about 500,000 metric tons. Figure 5 shows a heap of barite from Faya (Ministry of Mines and Steel Development, 2010).

5.6. Barite in Taraba State

Sardauna, Yoro, Lau, Ibi and Karin-Lamido are local government areas where barite veins are found hosted in fine-grained sandstones and porphyritic granites with vein width of about 3.5 m to 5m, vein length of about 3,500 m–5000 m and specific gravity close to 4.2. Impurities associated with the vein are galena and sphalerite and it has a depth of 20 m while the estimated reserve is 8,960,000 metric tons (Nigeria Geological Survey Agency, 2011).

5.7. Barite in Gombe state

Gombe Hills and Liji Hills are two locations both 10 km North-East of Gombe town where irregular cluster veins are hosted in gnesis/migmatite basement complex rocks. The specific gravity of barite is in the range of 4.09–5.3 with the colour varying from cream to grey. The width of the vein is between 0.3m to 1.2 m and some of the barite could be traced to about 400 m. Impurities associated with it are fluorite, quartz, and chalcopyrite and BaO contents are between 45.00%-59.5% from elemental analysis. The estimated reserve for both locations was 352,800 metric tonnes (Ministry of Mines and Steel Development, 2010).

5.8. Barite in Zamfara State

Vein deposits in Zamfara State are as a result of epigenetic hydrothermal fluids that leached barium from adjacent rocks and precipitated it in the vein. The properties of this deposits show great variation in depth and width from a few centimetres to several meters (0.6m–2m) and length to about 100 m. The colour varies 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 6.

5.9. Barite in Ebonyi State

Significant deposits of barite veins have been identified (but not quantified) in Ishiagu area of Ebonyi State. No mining activity is going on. Further exploration is required in this location and also in Afikpo North, Afikpo South, and Oshaozaba Local Government Areas because these local government areas contain barite with associated minerals (Onwualu et al., 2013a, b).

6. Challenges of barite mining and utilization in Nigeria

6.1. Poor infrastructural development

One of the main challenges to the development of the barite mining sector is the poor infrastructural adequacy within Nigeria. Also, inadequate electricity supply and roads to sites of mineral deposits affect the development of this mineral. For the barite mining industries to thrive, there should be a good transportation network to and fro the barite mining sites. This will help in the movement of machinery and equipment to the barite mining sites. Having good roads to the sites will also create a local market for small and medium enterprise. Water is needed in the mining sites to ensure that the minerals are mined efficiently. Processes that are automated needs electricity to function. The epileptic power supply in the country is among the major challenges affecting the large scale mining of barite.

6.2. Safety and security

Risks are involved in the mining of barite and other valuable minerals. Explosion in the mining sites have been recorded in Nigeria. Barite is mined in the country majorly by artisanal and small scale miners. These artisanal miners have exposed themselves to high risk from dangerous metals. There have been report of cases where miners were exposed to these metals beyond the limit of exposure to humans. For example, very high values of manganese and chromium have been recorded which exceeds the maximum admissible concentration in some mine ponds that were abandoned in Jos, Plateau State. Most of the barite rich states in Nigeria are affected by the terrorist group, occasional religious and communal crises especially in the middle belt region and these have hindered production and scared both local and foreign investors.

6.3. Geophysical and geoscience data information

The Geological and Geoscience data for barite are out of date in Nigeria. This affects the integrity of the resource information and has impacted the bankability of barite mining projects. For instance, significant deposits of barite veins have been identified (but not quantified) in some states in Nigeria and no mining activity is going on. A good geological data can aid in the approval of a business plan or the release of funds by the government for the exploration and development of minerals. Sufficient geophysical and geoscience data and information with the Nigerian Geological Survey Agency (NGSA), M.Sc and PhD theses and published work on barite in Nigeria are available but not accessible both by local and foreign investors.

6.4. Artisanal mining

Barite mining in Nigeria is mostly carried out by artisanal miners and this affects the production output, exposure to uncontrolled risk, erosion, pollution and environmental degradation. There are many illegal barite miners in the barite rich states in Nigeria and as a result of this, barite mining is done informally at production levels that may be as high as eighty per cent. The government needs to ensure that the legal framework under the Mining Act (Cadastral Office) is implemented for artisanal miners. Furthermore, because most of the activities are illegal, barite is exported to the international markets without any value addition, leading to a loss of considerable revenue by the Government.

7. Conclusion

Barite occurrence in Nigeria is majorly in veins and cavities and it occurs in large deposits in the Benue Trough. It exists along with gangue minerals. It is found in nine states in the country with an estimated reserve of 22,298,843 tonnes on an average vein depth of 20 m and a specific gravity of 4.2. There is still a huge amount of barite deposit that has not been discovered and some of the discovered deposit still needs further exploratory work to ascertain the quantity of barite found in the country. Geochemical and geological studies of the barite mineralization in Nigeria show cream to grey, reddish-brown, whitish and pinkish varieties. Some of the barite deposits found meets API standard in terms of specific gravity and should be exploited for drilling operations in the country.

The challenges facing the production of barite in the country range from poor infrastructural development to crude mining techniques being employed in the sites. The barites production industry in Nigeria still has a bright future; it will expand if the challenges listed are addressed. Nigeria is among one of the largest oil-producing countries in the world, with an abundant barite reserve. Hence there is a potential business in barite production to increase the country's GDP. With the setting up of the Mining Cadastral Office and relevant mining laws, investors are encouraged to participate in the production of barite by either partnering with existing titleholders or outrightly obtaining titles to improve the production output by a cost-effective mining technology especially in areas where the barite vein lies below 20 m. There should be easy access to barite mining licenses and provision of equipment, tools, machinery and good transport network system and infrastructure for barites miners and investors. Finally, for better barite recovery and turn-over, there should be a provision of technical manpower in advanced mining technology.

Declarations

Author contribution statement

Abraham Ighoro Ebunu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Yusuf Afolabi Olanrewaju, Oghenerume Ogolo: Analyzed and interpreted the data.

Adelana Rasak Adetunji, Azikiwe Peter Onwualu: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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