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**Review**

# Review of the occurrence and structural controls of Baryte resources of Nigeria

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**Abstract:** Baryte occurrences in Nigeria are spread across the Cretaceous Benue Trough which comprises of carbonaceous shales, limestone, siltstones, sandstones as well as in the northeastern, northwestern and southeastern parts of the Precambrian Basement Complex comprising of metasediments and granitoids. The mineralization is structurally controlled by NW-SE, N-S and NE-SW fractures. The common mode of occurrence for these barytes is the vein and cavity deposits type usually associated with galena, sphalerite, copper sulphide, fluorite, quartz, iron oxide as gangue minerals. Principal areas of baryte occurrences in Nigeria include Nassarawa, Plateau, Taraba, Benue, Adamawa, Cross River, Gombe, Ebonyi, and Zamfara. A large part of the vast baryte resources in Nigeria is still underexploited and further exploration work is needed to boost its exploitation. The inferred resource and proven reserve of baryte is put at over 21,000,000 and about 11,000,000 metric tons respectively. The economic evaluation of these barytes is viable having low (SG = < 3.5) to high (SG = 5.3) grades. The presence of associated minerals produces low quality barytes and as such blending and beneficiation is required to improve its quality.

***Keywords:*** *Baryte, Benue Trough, Cretaceous, reserve, resource, SG*

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## Introduction

Baryte also known as “heavy spar” or “spar” is the principal mineral of barium with chemical formula $BaSO_4$. It is a transparent or translucent, readily cleavable, crystalline mineral having a vitreous luster (Thrush, 1968). Baryte is a relatively dense mineral with high specific gravity (SG = 3 to 4.4) which is its most distinct feature. Baryte is an important industrial mineral which commonly occurs as gangue in most metallic (Fe, Pb, Zn, Cu, Ag, Au) ore deposits. The mineral occurs in diverse geological environments in a host of sedimentary, metamorphic and igneous rocks which span from Early Archean to Late Phanerozoic (Hanor, 2000). Most of the baryte in the Earth’s crust has been formed through mixing of fluids; one containing barium and the other fluid containing sulphate (Hanor, 2000). Baryte deposits can be classified based on the mode of occurrence into the following:

a. **Bedded and Residual Deposits** - Bedded deposits are those formed by the precipitation of barytes at or near the sea floor of sedimentary basins. Residual deposits are derived from the weathering of baryte-bearing rocks in which baryte is present as loose fragments embedded within residual soil or clay. Clark et al. (1990) further subdivided the bedded baryte deposits into five groups based on its depositional environment as follows:
   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 baryte deposits e.g. Mangampet deposit in Andhra Pradesh, India and in Nigeria Alifokpa deposit in Cross River and Gidanwaya deposit in Taraba.
v. Exogenetic baryte 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 Filling Deposits** - These are epithermal deposits which are formed by the precipitation of hot barium-enriched fluids in faults, joints, bedding planes, breccia zones, solution channels and cavities. This type of deposits are generally smaller than the bedded deposits, examples include Dreislar and Rhineland-Palatinate vein deposits in Germany, Les Arcs deposit in France, Pennine ore fields in the United Kingdom (Lorenz and Gwosdz, 2003) and vein deposits of the Benue Trough, Nigeria.

Although baryte is used for various purposes in the manufacturing industries, majority of baryte mined is consumed in the oil industry. Baryte possess certain properties that make it important to the oil industries as a weighting agent. These properties include: its high specific gravity, chemical inertness, non-corrosive, non-abrasive nature, overall abundance and relatively low cost. Hence, the exploitation of baryte goes hand in hand with crude oil exploitation. In 2003, the Federal Government of Nigeria banned the importation of baryte and since then, a lot of effort has been directed towards mining baryte locally. With the decline in oil prices in recent years, diversification of the economy is paramount and the time to develop the Nigerian solid mineral sector is now. In order to boost Nigeria's gross domestic product (GDP), the vast baryte resources/reserves in the country need to be critically looked into.

The purpose of this paper is to give concise information on the baryte resources in Nigeria which will encourage further research, investment and consequently mining/extraction. The baryte resource of Nigeria started gaining recognition as from 1951. Bogue (1951) reported on the baryte prospect near Gabu in Ogoja Province in the present Cross River State. Earlier works on the Nigerian baryte indicate that baryte occur as gangue in galena and sphalerite veins (Farrington, 1952). Occurrences of baryte was also 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 1959 reported an estimated baryte reserve of 41,000 tons at a depth of 20 meters for the Benue Valley deposits in the Azara locality.

In 2008, the Nigerian Geological Survey Agency embarked on the evaluation of newly reported deposits in the present Cross River, Benue, Nassarawa, Plateau and Taraba States. The inferred resource of baryte in these states was put at 21,123,913 metric tons (Figure 1). Further exploration activities revealed additional areas with favourable geological setting for baryte 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. In Nigeria, baryte occurs within the Precambrian Basement and Cretaceous sedimentary rocks as vein infilling materials closely associated with lead-zinc mineralization (Nwozor and Chukwunenye, 2008; MMSD, 2008; Daspan and Imagbe 2010; Ekwueme and Akpeke, 2012; Fatoye, et al., 2014; El-Nafaty, 2015).

## Baryte Occurrences in Nigeria

### *Occurrences in Precambrian basement rocks*

The geology of the Basement Complex in Nigeria has been described and reviewed by various authors including Oyawoye, (1972); Rahaman (1976); Ajibade, (1980) and Ekwueme, (1991, 2003). Three major lithological units are distinguished within in the Basement Complex of Nigeria (Fig.ure 2):

i. Polymetamorphic Migmatite-Gneiss Complex (Liberian to Pan-African)
ii. The Upper Proterozoic supracrustal rocks which include the Schist Belts with metavolcanic units.
iii. The Older Granite suite of Pan-African age intruding both the Migmatite-Gneiss Complex and the Schist Belts.

Baryte occurrences have been reported in the Northeastern, Northwestern and Southeastern sections of Nigeria's Precambrian Basement rocks.

*Northeast Nigeria*

Edu (2006) noted the occurrence of over 2 km length and width ranging from 3.5 to 5 m of baryte veins hosted in migmatitic gneiss, porphyritic and fine-grained granites at Juo (Sardauna) area of Taraba State. Quartz intergrowths are common in most baryte veins hosted within granites at Tola (Adamawa). The veins generally dip 40$^o$NE stretching over a length of about 180 m (Halilu, 2017) with SG $\leq$ 4.2 (MMSD, 2008).

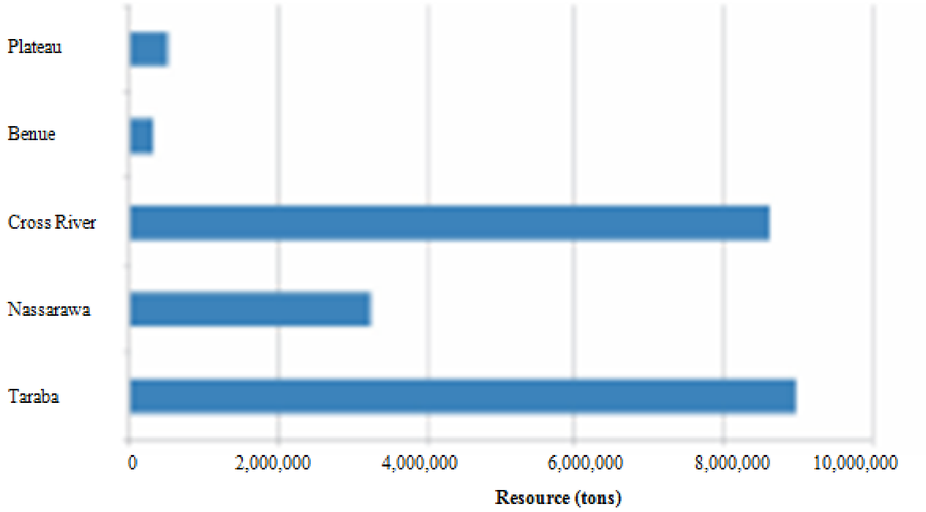


Figure 1. Inferred baryte resources of some states in Nigeria (Source: MMSD, 2008).

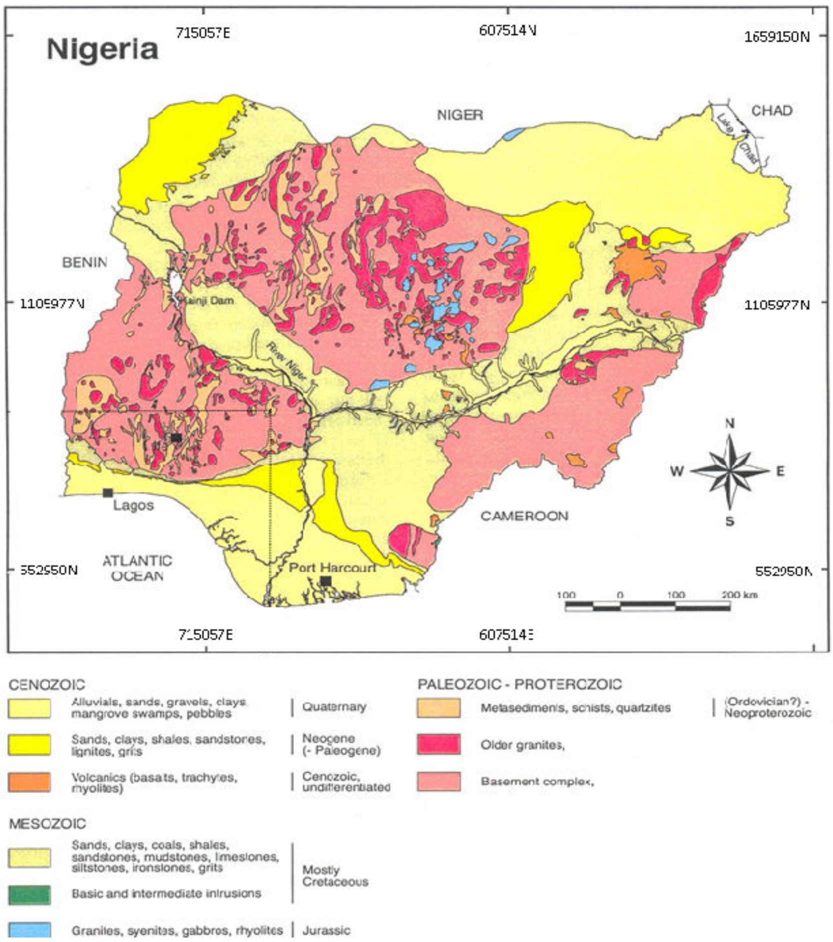


Figure 2. Geological map of Nigeria (NGSA, 2000)

*Northwest Nigeria*

The Basement Complex of Northwest Nigeria consists of low-medium grade NE-SW trending Schist Belts and metavolcanic rocks intruded by the Precambrian Granites. Baryte veins are generally hosted in phyllites measuring 1.5 meters wide, greater than 100 m in length and 4 meters deep with an average SG = 4.2. The veins are fissure filling and follow a general structural trend corresponding to the major Anka fault system in the region (Daspan and Imagbe, 2010). Baryte occurs in the following areas: Dareta (Anka), Rekebu (Tsafe), Tofa forest reserve (Gusau), Yarkatsina (MMSD, 2008) and Bukkuym (Olusegu et al., 2015) all in Zamfara state.

*Southeast Nigeria*

The Oban Massif and Obudu Plateau make up the Precambrian Basement of southeastern Nigeria. The Basement Complex is composed of phyllites, schists, gneisses, granulites, migmatites intruded by rocks of granitic, mafic and ultramafic composition overlain by Cretaceous sediments of the Calabar flank in the south and west but separated by a Cretaceous sediment filled graben (Mamfe rift) in the north (Ekwueme, 1991, 2003). Baryte mineralization is mostly localized along the boundary between the basement (gneiss, dolerite) /sedimentary rocks (carbonaceous shales, limestone, siltstone and sandstone of the Asu River and Cross River Groups). Mineralization in this area is often associated with pyrite and chalcopyrite. In some parts, baryte occurs dominantly in dolerite and granitic gneiss as vein infillings trending NE-SW, N-S and NW-SE with an average width of 2.18 m and depth ranging from 1.2 - 4.2 m with SG = 3.5 to 4.4. The barytes within the Oban Massif (Agoi area) has a total reserve estimate of 1,981,177 metric tons (Obi et al., 2014). Occurrences of baryte has also been reported at Obubra, Yakur, Akamkpa, Biase, Okpoma, Omoji areas of Cross River state (Akpeke et al., 2006; MMSD, 2008 and Ekwueme and Akpeke, 2012) in addition to Bunde, Mbatoo areas of Benue state (Oden, 2012; Labe, 2015).

***Occurrences in Cretaceous sedimentary rocks***

Most baryte occurrences in Nigeria are situated within the Cretaceous sediments of the Benue Trough and Calabar Flank and is usually associated with lead-zinc-flourite vein ore bodies as well as salt deposits (Figure 3). Baryte deposits occur as lenses and veins within the Lower Cretaceous (Albian to Turonian) carbonaceous shales, limestones and arkosic sandstones. Vein constituents include sphalerite, galena, quartz, siderite, marcasite + chalcopyrite.

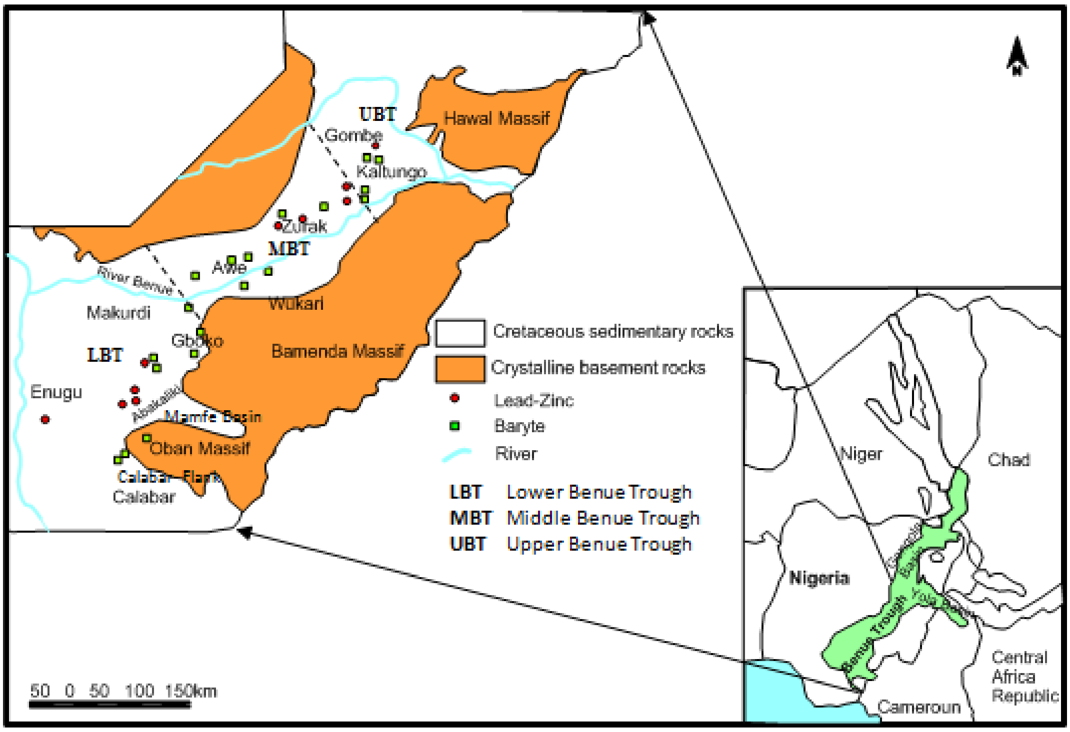


Figure 3. Distribution of lead-zinc-baryte mineralization along the Benue Trough (Inset sketch map of Nigeria showing the Benue Trough) (modified from Ene et al., 2012).

The origin of the Benue Trough is intricately linked to the opening of the Atlantic Ocean in the Early Cretaceous and several models have been proposed to explain its origin. Benkhelil (1982) described it as an elongated sedimentary basin extending over 800 km from the Niger Delta basin to the southern margin of the Bornu Basin. Cretaceous sediments filling the northeast trending Benue Trough were deposited unconformably over the Precambrian to Lower Paleozoic Basement Complex. The trough is geologically subdivided into three sub-basins known as Lower, Middle and Upper Benue Trough (Figure 3). The stratigraphy of the Benue Trough and the Calabar Flank has been reported in detail by Offodile, 1976; Petters and Ekweozor, 1982; Petters et al., 1995; Zaborski, 1998, 2000; Abubakar, 2014 (Figure 4). Oden (2012) further documented the occurrence of baryte across eight major areas within the Benue Trough (Adamawa, Benue, Cross River, Ebonyi, Gombe, Nassarawa, Taraba and Plateau States) (Table 1). Baryte deposits occur as lenses and veins within the Lower Cretaceous (Albian to Turonian) carbonaceous shales, limestones and arkosic sandstones. Vein constituents include sphalerite, galena, quartz, siderite, marcasite ± chalcopyrite.

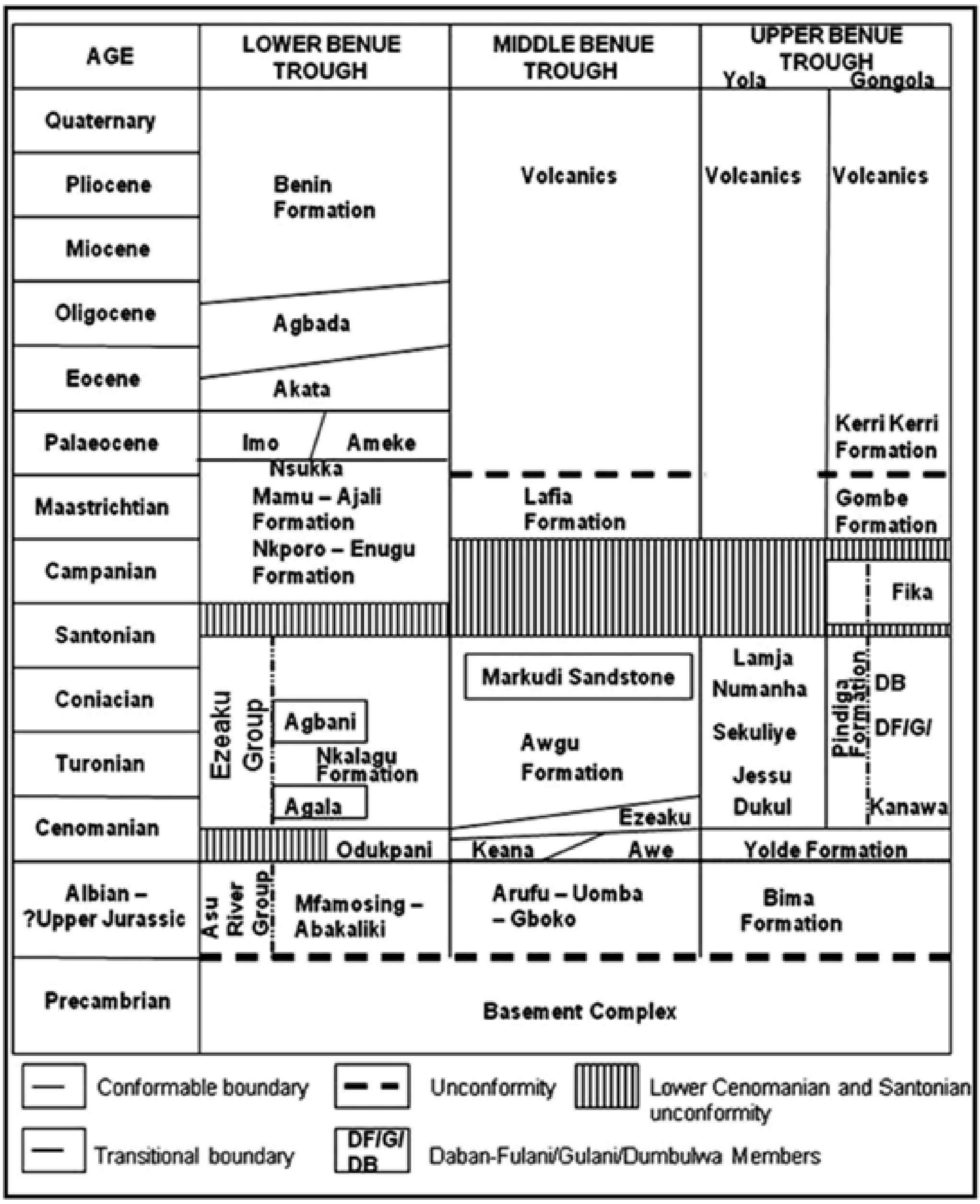


Figure 4. Stratigraphy of the Benue Trough (after Abubakar, 2014).

Table 1. Location, reserve estimation and current exploration status of barytes in some parts of Nigeria.

| State | Location | Reserve Estimation (tons) | Status | Remark |
|---|---|---|---|---|
| 1. Nassarawa* | Azara, Akiri, Aloshi, Chiata, Gidan Bera, Gidan Tailor, Wuse Kuduku, Ribi | 730,000 recorded by Nigerian Mining Corporation (NMC) at Azara, Akiri and Wuse | 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, Kumar, Pupule, Apawa 1 & 2, Didango, Suwa | Yet to be determined | Active informal and some organized mining in progress | Further exploration necessary to improve the known stock of veins and boost 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 | 9,660,306 metric tons determined by Obi et al. (2014) | 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 (Modified from Oden, 2012)

*Lower Benue Trough and Calabar Flank*

The vein-wall rock contacts are sharp and brecciated. The veins are steeply dipping trending N-S, NW-SE, NE-SW with length and width ranging from 30 –150 m and 2 – 20 m respectively having SG. = 3.5 to 4.4. Mineralized veins are distributed in the Abakaliki, Ishiagu districts on the main axis of the Abakaliki anticlinorium (Akande et al., 1989). Other principal areas of baryte mineralization include; Gboko, Buruku, Lessel, Ihugh Makurdi, Gabu (Cross River) and Ikom (Cross River) areas (Nwafor et al., 1997; Ene et al., 2012; Labe, 2015).

*Middle Benue Trough*

A large portion of baryte mineralization is found in the Middle Benue Trough, most of which are reportedly concentrated in the Azara, Arufu, Akwana, Awe and Keana areas (Offodile, 1980; Omada and Ike, 1996; Tanko et al., 2015). Baryte mineralization at Azara occurs within the Cretaceous Keana Sandstone and Awe Formation while at Arufu and Akwana, it is hosted in the Arufu limestone. The vein-type mode of occurrence is directly guided by fractures and joint patterns in the country rocks striking in the NW-SE, E-W and N-S directions. The vein system consists of baryte-quartz and thin siderite veins which cut the earlier formed baryte veins. Vein constituents include galena, sphalerite, fluorite, quartz, tetrahedrite, chalcopyrite $\pm$ native silver. Several veins in the area have an average length of 200 m, width of about 1.5 m and an average depth to about 15 m with SG = 4.0 to 4.2. The veins show a peculiar outcropping pattern; having steep slopes and sharp contacts with the wall-rock (Akande et al., 1992 and GSN, 2007).

Principal areas of mineralization have been identified at Azara, Ribi, Jobe, Sauni, Jara, Mairago, Gidan Agana, Gidan Soja, Wuse, Akiri, Dogondaji, Kumar and Keana all in Nassarawa State. Other baryte occurrences have also been reported at Sardauna, Karim, Lamido, Yoro, Lau, Ibi and Faya (MMSD, 2008). Baryte veins are hosted in the Bima Sandstone which is the lateral equivalent of Albian Asu River Group in the Lower Benue Trough.

*Upper Benue Trough*

Baryte veins are hosted in the Bima Sandstone which is the lateral equivalent of Albian Asu River Group in the Lower Benue Trough. Vein contact with wall-rock is sharp, with a general N-S trend, having widths between 1- 3 m and length of about 400 m with SG = 4.0 to 5.3 (MMSD, 2008). Baryte is associated with copper sulphide, galena, sphalerite, hematite and native silver. Appreciable deposits of barytes occur in Gombe, Liji hills, Gban and Moyo-Kpoki areas (MMSD, 2008 and El-Nafaty, 2015).

## Discussion

Apart from its major use in drilling systems where specific gravity of 4.2 is required, baryte is also used as a contrast medium, radiation shield and in the manufacture of plastics, paper, paints, enamels and leaded glass. The percentage composition of BaO and specific gravity of baryte is critical in determining its end use (Table 2). According to Aliyu et al. (1996) the total national demand for barytes in Nigeria is estimated at 10,000,000 ton per annum. The few processing plants in the country produce a little above 40,000 metric tons per annum creating a wide supply gap (Chukwunenye, 2006).

Table 2. Specifications and end uses of barytes (after Lowrenz and Gowsdz, 2003)

| PROPERTIES | SPECIFICATIONS | | | END USES | | | |
|---|---|---|---|---|---|---|---|
| | API[1] | OCMA[2] | IS[3] | Paper | | Paint | |
| | | | | Barytes | Blanc fixe | Barytes | Blanc fixe |
| **Chemical Composition (M.-%)** | | | | | | | |
| $BaSO_4$ | >92 | >92 | >94 | >94 | >97 | >94 | >97 |
| $SrSO_4$ | | | | | | | |
| $Al_2O_3$ | LCP* | LCP* | LCP* | 0.05 | 0.02 | 0.05 | 0.02 |
| $Fe_2O_3$ | | | | <2.6 [6] | | <2 [6] | |
| SiO2 | | | | | | | |
| CaO | | | | | | | |
| $CaF_2$ | | | | | | | |
| Volatile components | | | | <0.8 | <0.8 | <0.5 | <0.5 |
| Carbonate | | | <1.5 | | | 0.7-1.1 | |
| Mn (ppm) | | | | | | | |
| Fe (ppm) | | | | | | | |
| As (ppm) | | | | | | <500 | |
| Pb (ppm) | | | | | | | |
| Cd, Hg (ppm) | <3 bzw.1 [8] | | | | | | |
| Water soluble alkaline earth metals (ppm) | <200 | | | | | | |
| Water soluble substances (ppm) | | <0.1 | <0.02 | <0.2 | <0.2 | <0.2 (0.5) | <0.2 |
| **Physical Properties** | | | | | | | |
| Moisture content (M.-%) | | | | | | | |
| pH | | | | 6-8 | 8-10 | 6-8 | 8-10 |
| Density ($g/cm^3$) | >4.2 | >4.2 | >4.15 | 4.48 | 4.35 | 4.3-4.4 | 4.3-4.4 |
| Viscosity (cP) | | <125 | | | | | |
| Oil absorption (g/100g) | | | | 10-12 | | | |

*Low contents are not a problem. 1. American Petroleum Industry, 2. Oil Company Material Association, 3. Indian Standard , 6. Sulphides <0,1 ppm; colour white, odourless 8. For future applications in oil and gas drilling in deep oil-gas boreholes; Alaska-specification bsw – performance measurement

The Technical Working Group on Minerals and Metals Development in 2009 however, gave the following estimates on barytes based on data collected from 1997 to 2003; proven reserves = 1,000,000 tons, annual national demand = 140,000 tons, present annual national production = 10,000 tons. Though the report did not include estimates on baryte for the years 2000 to 2007 due to the dearth of data and incomplete status on baryte and other minerals. The price for a metric ton of baryte ranges from ₦10,000.00 ($28) to ₦ 40,000.00 ($112). The variation in price may depend on the amount of pure baryte mixed with rock overburden and gangue minerals (Plate 1). Mining baryte requires intensive mechanized and human labour; in Nigeria, the later outweighs the former. Despite the appreciable quantity of baryte mined on a daily basis the problem of quality greatly affects the demand-supply chain. It is worth noting that the American Association of Drilling Engineers in 2010 adopted API-grade 4.1-SG to meet the high demand due to dwindling API-grade 4.2-SG (Stark et al., 2014). Thus, beneficiation and blending of low grade baryte with high grade baryte to obtain specific gravity of 4.2 is unavoidable.

Plate 1. Low grade baryte heaps at Ushongo, Nigeria.

***Environmental impact related to Baryte exploitation***

Most artisanal miners usually carryout ‘wild card’ mining activities in their search for baryte which have produced pits/gullies in many areas. For the most part, these mined out pits or mine gullies do not undergo reclamation and with time, the shallow mine pits give way to deep ponds or lakes. And if this problem goes unchecked it will result to large scale degradation of the environment (Plate 2).

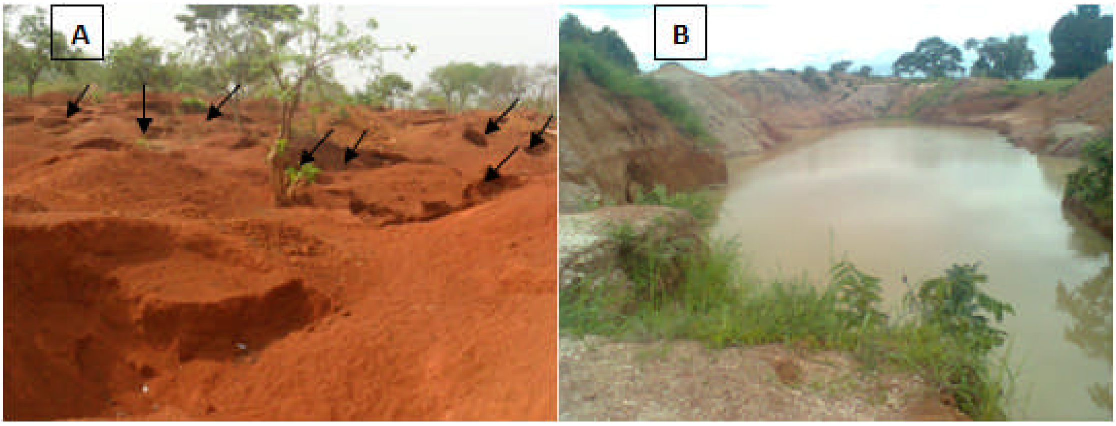


Plate 2. (A) Gullies (arrows indicate pits) and (B) lakes produced during mining activities

## Conclusion

In Nigeria, baryte occurs within the northeastern, northwestern and southeastern parts of the Precambrian Basement Complex as well as in the Mid-Lower Cretaceous sediments of the Benue Trough and Calabar Flank. It is evident that these rocks were affected by a number of tectonic activities that produced numerous structures which provided a suitable pathway for the ore fluid. The NW-SE, N-S and NE-SW structures produced aided the precipitation of baryte; thus its epigenetic mode of occurrence as veins and lenses. This study has shown that barytes from Nigerian are generally associated with gangue minerals that will inevitably lower its quality. Despite the inconsistencies and plethora of data (many of which are about a decade old) on barytes in Nigeria, much needs to be done as ninety percent of baryte reserves are still undetermined. Poor environmental attitude of miners is a growing cancer that will require drastic measures from miners, local communities, Mines

Environment and Compliance unit of the Ministry of Mines and Steel Development as well as the Federal Government of Nigeria.

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