COMPOSITIONAL FEATURES AND ECONOMIC POTENTIALS OF BARYTES OCCURRENCES AROUND ALIFOKPA – GABU – OSINA AND ENVIRONS, LOWER BENUE TROUGH OF NIGERIA.

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ABSTRACT

This work discusses the compositional features and economic potentials of the barites from Alifokpa-Gabu-Osina and environs in the Lower Benue Trough of Nigeria, with a focus to unravelling the economic potentials of the deposit. Results of the geochemical analysis show that $BaSiO_4$, SiO_2, and TiO_2 are the major chemical species of the baryte. The Ba and SO_4 content vary between 53.62 – 56.10 wt.% and 27.57 – 39.35% respectively across the sampled areas. The results of geotechnical tests show the porosity ranges between 0.1 – 0.5 percent. Uniaxial strength varies between 11 and 43 N/mn2, and Water Absorption Capacity ranges between 2 and 12 %. Other parameters include specific gravity (2.8 – 4.3 g/cm^2, and Moisture content (0.2 – 0.4). These values compared very well with American Petroleum Institute (API), American Society for testing and Material (ASTM) and Niger Delta Petroleum Resources (NDPR) specifications, which in turn groups the baryte ores in the study area as good ores for oil and industrial purposes. The FeO content (0.1 – 0.5%) of the barytes also suggests baryte mineralization of hydrothermal fluid of low temperature. The BaO and API trend maps increases north-westerly to the central parts of the study area, which should be considered as target for further studies. This study has provided data driven empirical information for a better understanding of the physical and chemical compositions and industrial potentials of the baryte deposits in Alifokpa-Gabu-Osina and Environs, and will thus contribute to its increased availability worldwide.

Keywords: Baryte field, Compositional features, Geotechnical tests, , Hydrothermal fluids, Economic Potentials

1.0 INTRODUCTION

Baryte is a very important economic mineral that can be used as an additive in the production of drilling muds, paints, x-ray materials, electrical wares in television and computer equipment's as well as gemstones. An evaluation of barites is therefore necessary to be carried out so as to make sure that these materials possess the acceptable quality required to meet the minimum standard for its industrial utilization. Nevertheless, an evaluation of its physical and geologic features will be guide towards a proper economic exploitation of the resource. Several baryte fields occur within the Nigerian Benue Trough system, but is mainly quarried by local artisanal miners. McConnel (1949) and Farrington (1952) reported the presence of barites in the Ogoja Province, but did not give a detailed description of ranking, extent and quantity. The economic exploration and utilization of this mineral resource is being hindered by lack of the required physical characterization necessary for its development. Most previous studies on the barites concentrated on the formation of ore veins, its accompanying saline waters and igneous structures (Ezepue, 1984; Akande *et al*, 1989; Uma and Leonart, 1992; Tijani *et al*, 1990). This study is therefore aimed at highlighting the geotechnical and geochemical qualities of barites in Yala Local Government Area of Cross-River State of Nigeria. The study area (Figure

1a) lies within the Abakaliki Basin in Southern part of the Benue Trough (Figure 1b). The area is bounded by Longitudes 008˚30΄E and 009˚00΄E and Latitudes 06˚30΄N and 07˚ 00΄N and covers about 250 km$^{2.}$ (Figure 1a.)

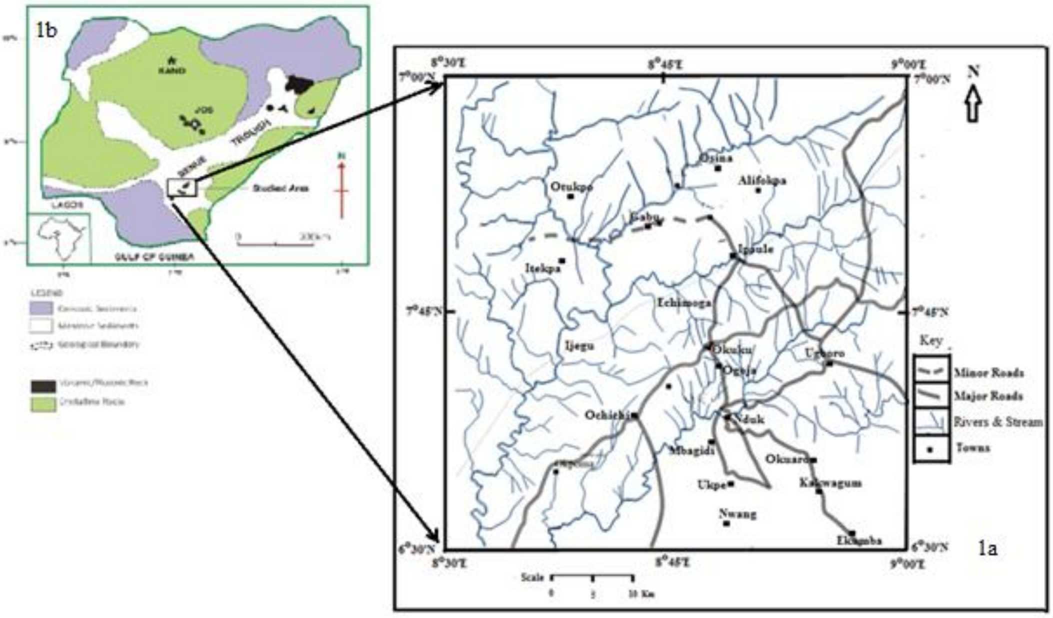

Figure 1: Map of the (a) Study Area as an inset within (b) the Benue Trough

2.0 TECTONIC AND GEOLOGIC SETTING

The study area (Figure 1a) lies within the lower part of the Benue Trough (Figure 1b), with length of about 1000 km in the northeast direction and a width of about 90 – 100 km. The trough is generally divisible into the Lower, Middle and Upper parts (Benkhelil, 1986), with a N-S trending arm (Gongola arm) and an E-W trending arm (Yola arm). Offodile, (1989) also divided the Benue Trough into the Lower/Southern, Middle/Central and Upper/Northern regions. The Benue Trough runs through the West African Pre- Cambrian shield in a NE – SW direction from the Chad Basin to the Niger Delta in the Gulf of Guinea. The trough is fault bounded and houses about 6000m of marine and fluvio-deltaic sediments (Benkhelil, 1987).

The structural and tectonic history of the Benue Trough has been widely studied and documented by several authors including Burke *et al* (1971), Olade (1975), Wright (1976), Offodile (1976), Benkhelil (1989), Kogbe (1989)). A Y-shaped triple rift model has been postulated to explain the origin / breakup of the Afro-Brazilian plate at the Early Cretaceous times (Petters,1978; Hoque and Nwajide, 1985; Offodile; 1989). The Benue Trough was said to have developed into an Aulacogen, which is a result of the detachment of the African and South American plates and formation of the South Atlantic Ocean in the Early Cretaceous times. The Abakaliki Benue Trough which originated as a failed arm of the triple junction rift – edge system had its tectonic history dated back to the pre-Albian times (Burke *et al* 1972) and Nwachukwu (1972). The Abakaliki failed arm of the triple junction/rift edge system led to the separation of Africa from the South America during the Aptian/Albian. The tectonism and its associated sedimentation caused an on-land resuscitation of the equatorial fracture zones for example, the Chain and Charcot fracture zones. The tectonism, thus caused a series of tensional and compressional stresses affecting both the basement and overlying sediments.

Three main tectonic phases in the Benue Trough took place and these phases controlled the filling of the basin (Murat, 1970). The first phase took place during Albian and the movement was along the major NE – SW trending Benue Abakaliki Trough. During this phase saw the emergence of the Anambra Platform and the Afikpo Syncline on the West and East of the Benue Abakaliki Trough respectively. The second phase which spanned from Campanian to Paleocene recorded compressional movements along the established NE – SW trend, caused a generalized folding that affected the Cretaceous sediments in the Benue Trough (Benkhelil, 1986). The compressional movement led to a series of NE – SW trending folds that resulted in the Abakaliki Anticlinorium and the subsequent down-warping of the Anambra Basin to the west, and the Afikpo syncline to the east of the Abakaliki Anticlinorium. These depressions became the main depositional targets.

In the Santonian, the tectonism is thought to have been complemented by extensive and remarkable magmatism as well as folding and faulting, which gave rise to the relatively high Abakaliki anticlinorium, bordered by the synclines of the Anambra Basin to the west and Afikpo to the east. Sedimentation became shifted from the positive geomorphic feature of the Abakaliki anticlinorium to the contiguous synclines. The first sedimentary infill in the Lower Benue Trough (the Abakaliki Basin), is the Albian-Aptian Asu River Group (ARG) sediments. It consists of thick laminated shales, feldspathic sandstones and subordinate limestone’s, associated with volcanic intrusions and pyroclastics. The Asu River Group rests unconformably on top of the Precambrian to Paleozoic Basement Complex rocks. During the Cenomanian, a regressive to continental clastic sediments, such as the Keana / Makurdi sandstones of the Ezeaku Group were deposited. The Turonian was marked by a transgressive phase which caused the deposition of widespread fossiliferous black to dark gray shales and limestones of the Ezeaku Group.

The sediments are thought to be compressionally or extensionally folded in an unorogenic environment (Wright, 1976, Ugwuonah and Obiora 2008). The Benue Trough have been affected by at least two major sets of tectonic events which includes the pre-Turonian and the Santonian episodes. The Santonian episode in the Lower Benue Trough comprises of compressional movement along the NE-SW trend. The event led to the folding, faulting and uplift of the Abakaliki Anticlinorium, causing a contemporaneous subsidence which affected the Anambra Platform and also moved the depositional axis westwards. The tectonism is marked by some minor intermediate intrusives and associated Lead-Zinc mineralization. The Lead-Zinc and Fluorite-Barite mineralization are emplaced in the sediments of the Asu River Group (shales, limestone’s, sandstones) as well as in the overlying Ezeaku Group rocks. Aulacogens are generally characterized by the presence of fluorites, barytes, which are deposited by hydrothermal process.

Reyment (1965) proposed many of the lithostratigraphic units in the study area. He did the first detailed study of the stratigraphy of the southern Nigeria sedimentary basins. The three tectonic activities, shifts in the basin axis coupled with sedimentation after the tectonic activities led to three depositional phases in the Abakaliki - Benue stage (Aptian – Santonian), the Anambra – Benue stage (Campanian – Middle Eocene) and the Niger Delta stage (Paleocene – Recent). The scope of this study lies on the Abakaliki – Benue stage. Deposited during the first stage of Abakaliki – Benue and Calabar Flank valley regions were the Asu River, Ezeaku and Awgu Formations. The Anambra Basin was installed simultaneously as a flexural basin relative to the Abakaliki Anticlinorium after the squeeze during the Santonian.

The southwestern part of the Benue Trough is filled with an accumulation of up to 7 km of lower Cretaceous (Aptian) to Palaeogene predominantly clastic sediments. Works on stratigraphic division of the units was carried out by Reyment and Ojoh (1992). In the Albian to Santonian phase, the depositional center was the NE – SW trending Abakaliki - Benue Trough, a graben like structure flanked by the Anambra platform to the east and Ikpe/Afikpo platforms to the southwest. With the folding of the southern Benue Trough into the Abakaliki Anticlinorium, Afikpo and Anambra syncline, deposition shifted southernly. The third phase was the formation of the proto–Niger Delta during the Upper Eocene. The geologic map of the study area is shown in Figure 2a and as an inset in the Geological map of Southeastern Nigeria in Figure 2b. The stratigraphic succession in the study area is given in Table 1.

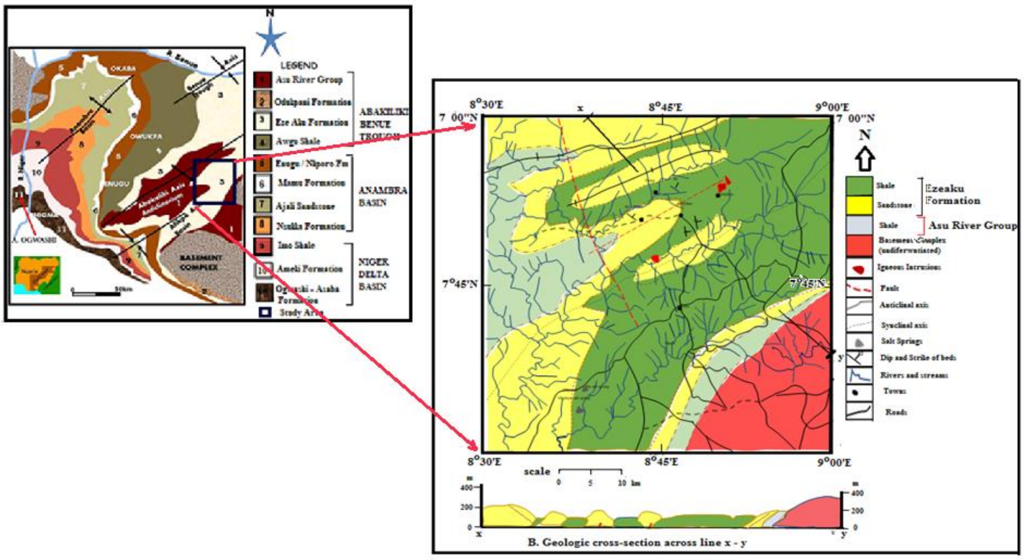

Figure 2a: Geological map of the study area showing its location within the (b) Geological map of Southeastern Nigeria.

Table 1: Stratigraphic subdivision of the Southern Benue Trough – Benue Trough, Anambra Basin and Niger Delta (Modified from Reyment (1965)

AGE		FORMATION	LITHOLOGY	DEPOSITIONAL ENVIRONMENT	BASIN
Quarternary		Benin Formation	Sandstones, clays, shales,	Continental	NIGER DELTA BASIN
Tertiary	Pliocene				
	Miocene	Ogwashi-Asaba Formation	Clays, shales, Sandtones, lignites	Continental	
	Oligocene				
	Eocene				
		Ameki Group	Sandstones,clays,shales,	Estuuarine, marine	
	Paleocene	Imo Formation	Clays, Shales, Limestones, Sandstones, Marl	Shallow Marine, Deltaic	
		Nsukka Formation	Sandstones, Clay, Shales, Coal, Marl	Fluvio-Deltaic	ANAMBRA BASIN
Upper Cretaceous	Maastrichtian	Ajali Formation	Sandstones, Claystones	Fluvio-Deltaic	
		Mamu Formation	Sandstones, Clays, Coals	Shallow Marine, Deltaic	
	Campanian	Enugu/Nkporo/Owelli Fm.	Shales, Sandstone, Clay, Ironstones,,	Shallow Marine, Deltaic	
		Major Unconformity			
	Santonian	Awgu Formation	Sandstones, Limestones, Clays, Coals, Siltstones	Shallow Marine, Deltaic	BENUE TROUGH
	Coniacian				
Middle Creta-ceous	Turonian	Eze-Aku Group	Shales, Limestones, Sandstones	Shallow Marine	
	Cenomanian	Odukpani Formation	Sandstones, Limestones,	Shallow Marine,	
Lower Cretaceous	Albian	Asu River	Shales, Limestones,	Shallow Marine,	
Lower Paleozoic		Major Unconformity			
		Basement	Granites, Gneisses, Schists, Migmatites	Igneous, Metamorphic	

3.0 METHODOLOGY

Field geological studies were carried out in the study area. The field work involved location, description, measurement and sampling of the barite veins, associated lithologies and fractures. These measurements were taken at the outcrops located at mine pits and stream channels. The barite samples collected were selected and subjected to geochemical and geotechnical analysis to understand the grade of barite samples. The geochemical analysis carried out include X-ray fluorescence (XRF) analysis, Atomic Absorption Spectrometer (AAS) Analysis and X-ray Diffraction (XRD) Analysis. Geotechnical tests carried out include moisture content, specific gravity, porosity and uniaxial compressive strength (UCS). Geotechnical tests were conducted following the procedure as defined by British Standard (BS, 1378, 1990). The required sample treatments were carried out before the samples were utilized for the various analysis.

4.0 RESULTS

4.1 GEOCHEMISTRY

Results of Geochemical analysis of some major and trace elements of the Aliforkpa-Gabu-Osina barytes are shown in Table 2. Graphic plots of the various metal oxides for Osina, Alifokpa, Gabu and the Study area are shown in Figures. 3, 4, 5 and 6 respectively. The $BaSO_4$ ranges from an average value of 54.16 % to 65.77 %. The Osina baryte has the highest $BaSO_4$ percentage. Following closely is the Gabu baryte, with Aliforkpa having the lowest value of 54.16 %. Fe_2O_3 % is lowest on the Aliforkpa ores with a value of 0.007 % as against the values of 0.02 % and 0.04 % recorded respectively on the Osina and Gabu ores. The values of TiO_2, Na_2O and K_2O reduces from Aliforkpa 0field to Osina – Gabu with values of 0.02 % - < 0.001 %, 0.04 % – 0.02 % and 0.04 % – 0.02 % respectively. SiO_2 values in wt% from Osina to Alifokpa are 0.24, 0.26 and 0.31 respectively. The CaO content of the baryte is higher on the Gabu field and reduces from Aliforkpa to Osina with values of 0.22 % to 0.081 %. MgO content records the lowest value at Aliforkpa with a value of 0.01% to 0.05% at Gabu.

The trace element analysis records values ranging from 39.56 ppm - 53.59 ppm and 75.79 ppm for the element Pb at Aliforkpa, Gabu and Osina as against Zn with higher value at Aliforkpa of 26.43 ppm and 9.31 ppm at Osina. Cu appears to be higher at the ores of Gabu with a value of 51.47 ppm, followed by 16.00 ppm for Osina and was not detected at all at the Aliforkpa ore. Cd has the highest value at Osina and Gabu, and records its lowest value at Alifokpa, with values of 0.6 ppm,0.2 ppm and 0.18 ppm respectively. The values recorded for Hg element from Osina, Gabu to Aliforkpa are as follows; 0.03 ppm, 0.03 ppm to 0,017 ppm.

Table 2. Geochemical composition of the Major and Trace oxides of barytes of the Study

% oxide Composition	*Loc 19 Osina*	*Loc 11 Osina*	*Loc 20*	*Loc 10A Alifokpa*	*Loc 32 Alifokpa*	*Loc 4*	*Loc 12*	*Loc 13*	*Loc 14 ..Gabu*	*Loc 17 ..Gabu*
SiO_2	0.29	0.18	28.50	0.29	0.22	0.62	59.01	0.27	0.30	0.32
TiO_2	<0.001	0.002	0.10	0.01	0.03	<0.001	0.11	Nd	0.01	0.013
Al_2O_3	<0.001	<0.001	3.18	<0.001	0.65	0.39	3.89	<001	<001	<001
Fe_2O_3	0.011	0.02	0.01	0.01	0.003	0.43	0.17	0.01	0.04	0.04
CaO	0.07	0.081	1.64	0.08	0.14	55.45	2.28	0.084	0.23	0.21
MgO	0.01	0.03	0.12	0.013	0.01	0.17	0.94	0.010	0.04	0.05
Na_2O	0.019	0.018	0.86	0.04	0.03	0.04	0.12	0.05	0.019	0.017
K_2O	0.025	0.020	0.22	0.062	0.011	0.07	0.05	0.059	0.021	0.024
MnO	Nd	Nd	Nd	Nd	<0.00	0.22	0.001	Nd	Nd	Nd
BaO	64.98	65.80	10.20	65.77	42.55	<0.001	15.70	65.53	65.42	65.32

SO_3	33.87	33.81	5.38	33.61	25.50	<0.001	10.25	33.87	33.90	33.88
SrO	0.02	0.03	0.003	0.003	0.15	<0.001	Nd	0.011	0.011	0.02
L.O.I.	0.70	Nd	Nd	0.10	Nd	42.40	2.30	Nd	Nd	0.10
Cu (ppm)	4.14	27.67	Nd	Nd	Nd	Nd	Nd	Nd	Nd	51.54
Mn (ppm)	Nd	Nd	Nd	Nd	4.26	1674.31	11.43	Nd	Nd	Nd
Pb (ppm)	71.47	80.11	49.72	48.22	30.90	313.25	4.12	1074.24	59.67	47.51
Ni (ppm)	3.89	5.17	6.58	2.30	3.96	37.04	60.71	0.73	2.88	8.96
Zn (ppm)	11.01	7.60	283.86	6.41	46.44	36.97	1.05	7.29	12.36	43.74
Cd (ppm)	0.43	0.74	0.80	0.35	0.015	0.27	0.008	Nd	0.1	0.3
		0.033	0.005	0.016	0.018	0.006	0.05	0.003	0.02	0.04
Nd = Not determined, LOC = Location, LOI = Loss on ignition.										

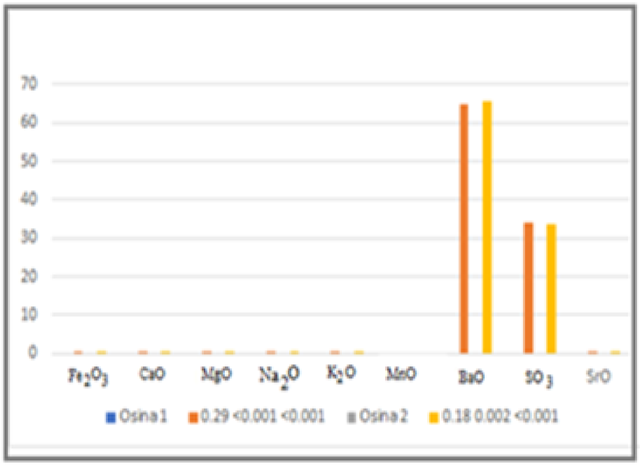

Figure 3: Major / Trace metal oxides chart for barytes from Osina

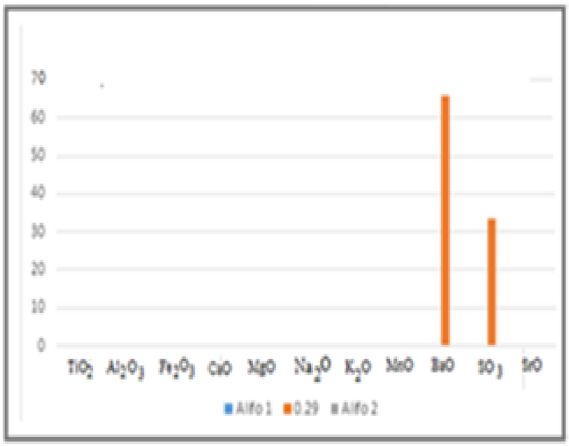

Figure 4: Graph of Metal Oxide for Baryte samples from Aliforkpa

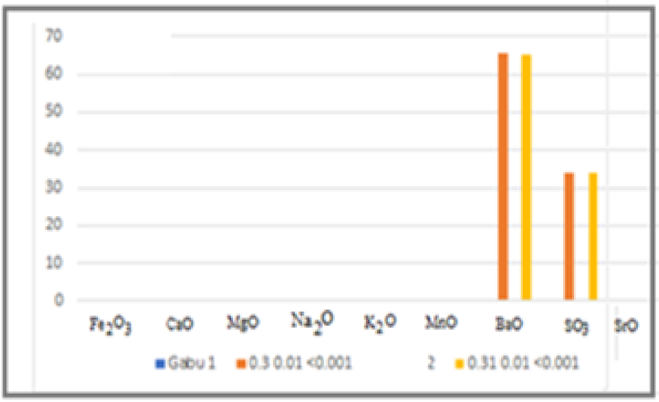

Figure 3: Graph of Metal Oxide for Baryte samples from Gabu

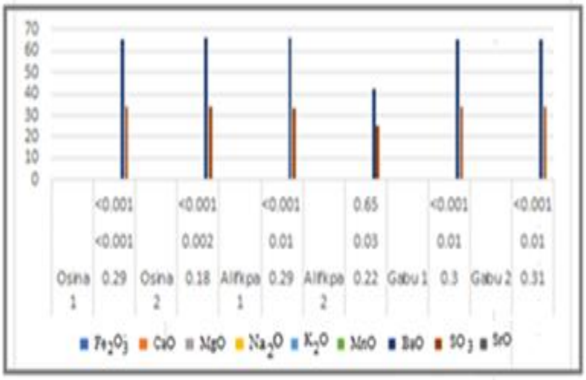

Figure 6: Graph of major Metal Oxides in the Study area

Table 3 is a similarity and comparison table of the barytes in the study area with other barytes of the Middle Benue Trough. The Azara, Dareta and Lessel barytes have $BaSO_4$ wt % values of 89.00, 87.92 and 91.85, whereas Lessel Mbagwa, Bunde and Ihugh have of values 79.20, 80.90 respectively. Values for SiO_2 in wt% are as follows 3.08 and 1.26 for Azara and Dareta ores. 20.50, 18.90 and 13.30 for Lessel Mbagwa, Bunde and Ihugh ores. The Fe_2O_3 content values are 1.51, 2.35 and 0.51 for the Azara, Dareta, Lessel while Lessel Mbagwa, Bunde and Ihugh have recorded values of 0.10, 0.04 and 1.20. The values for SrO in wt% is as follows 0.88 and 0.56 for Azara and Dareta ores respectively. The Lessel Mbagwa, Bunde and Ihugh barytes have SrO values of 0.50,0.30 and 0.60.

The trace oxide values for Pb, Cu and Zn from Azara, Dareta and Lessel are as follows; Pb has a recorded value of 26.67 ppm in the Azara field (Omada, 1985; Omada and Ike, 1995). Values of 12.94 ppm and 25.60 ppm are recorded for Pb of Bunde and Ihugh fields, (Labe, 2015).

Cu in Azara field has values of 46.67 ppm while Lessel Mbagwa, Bunde and Ihugh ores have Cu values of 25.10 ppm, 66.40 ppm and 7.00 ppm respectively. The values for Zn of Lessel Mbagwa, Bunde and Ihugh are as follows; 93.00 ppm, 37.64 ppm and 54 ppm.

Table 4 is a comparison table between the metallic content of the ores of the area under study and Torkula baryte (Middle Benue Trough). The industrial accepted and API max limit values for the different metals are given. The values of the Gabu – Aliforkpa – Osina barytes Zn of 9.31 mg/kg to 28.05 mgkg is higher than the Torkula content with a value of 3.9 mg/kg. Torkula ores has Ca and Mg content of 34 and 8.5 mg/kg respectively whereas the barytes under the study area are deficient in Ca and Mg. Cu content tends to be higher in Gabu, Osina with values of 51.47mg/kg, 16.00mg/kg as against 0.302mg/kg value of Torkula.

Table 3: Major oxides, Trace Elements, geochemical parameters of barytes from the study area compared with those of other parts of Nigeria.

Sample Location	**BaO (wt%)**	**SiO_2 (wt%)**	**SrO (wt%)**	**Fe_2O_3 (wt%)**	**CaO (wt%)**	**Pb (ppm)**	**Zn (ppm)**	**Cu (ppm)**	**Cd (ppm)**	**Specific Gravity**	**Uniaxxial Compressive Strength**	**Moisture Content**	**Literature**
GABU	65.37	0.31	0.013	.0.04	0.22	53.59	28.05	51.47	0.40	3.65	31.5	0.25	**Study Area**
ALIFOKPA	54.16	0.26	0.05	0.007	0.11	39.56	26.43	Nd	0.01	3.5	25.5	0.3	**Study Area**
OSINA	65.77	0.24	0.03	0.02	0.08	75.79	9.31	16.00	0.63	3.7	21	0.26	**Study Area**
AZARA	89.00	3.08	0.88	1.51	1.07	26.67	-	46.67		4.17	-	-	**Omada ,1985, Omada & Ike, 1996**
DARETA	87.92	1.26	0.56	2.35	0.86	-	-	-		4.20	-	-	**Daspan & Imagbe, 2010**
LESSEL	91.85	-	-	0.51	1.96	-	-	-		4.35	-	1.15	**Nwafor *et al*, 1997**
LESSEL MBAGWA	79.20	20.50	0.50	0.10	0.04	-	93	25.10		4.01	5.36	0.42	**Nkposo & Labe, 2015**
BUNDE	80.90	18.90	0.30	0.04	0.03	12.94	37.64	66.40		3.65	2.02	0.77	**Nkposo & Labe, 2015**
IHUCH	83.70	13.30	0.60	1.30	0.10	25.60	54	7.00		3.95	2.07	1.18	**Nkposo & Labe, 2015**

Table 4: Metallic Content of the baryte of the Study area and Torkula (Middle Benue Trough). Concentration (mg/kg) (mg/L).

S/N	Metals	Gabu Baryte	Aliforkpa	Osina	Torkula	Industrial accepted baryte	API max. limit
1	Ca	-	-	-	34.0135	415.00	250
2	Zn	28.05	26.43	9.31	3.9051	44.60	140
3	Mg	-	-	-	8.5726	65.00	250
4	Pb	53.59	39.56	75.79	113.8127	193.00	1000
5	Cd	0.20	0.24	0.29	0.0008	1.60	5
6	Fe	-	-	-	15.6094	62.20	zero
7	Cu	51.47	Nd	16.00	0.3024	160.00	36

4.2 GEOTECHNICAL RESULTS

Results of Geotechnical properties of the baryte ore in the study area are shown in Table 5. Graphic Plots showing the specific gravity and average specific gravity of barytes in the study area and in the Middle Benue Trough are shown in Figures 7 and 8 respectively. Specific Gravity values are as follows from Osina and Aliforkpa to Gabu, 3.1 - 4.3, 2.8 - 4.2, 3.1-4.2. Porosity values on the Aliforkpa, Gabu and Osina barytes are 0.1 – 0.5 %, 0.1 – 0.3 % and 0.2 – 0.3 %. Moisture content values are 0.2 – 0.4 for Aliforkpa, 0.2 – 0.3 for Gabu and 0.21 – 0.24 for the Osina barytes. The values for water absorption capacities of the ores are as follows; 2 – 12 %, 6 – 8 %, 4 – 5 % for Aliforkpa, Gabu and Osina respectively.

The geotechnical results of the Middle Benue Trough on Specific Gravity, Moisture Content and Uniaxial Compressive strength are as follows; specific gravity analysis of Azara, Dareta and Lessel have the values of 4.17, 4.20 and 4.35. The Lessel Mbagwa, Bunde and Ihugh barytes have specific gravity values of 4.01, 3,65 and 3.95 respectively. The moisture content values in percentage of Lessel, Lessel Mbagwa, Bunde and Ihugh are 1.15, 0.42, 0.77 and 1.18 respectively. Uniaxial compressive strength values of Lessel Mbagwa, Bunde and Ihugh are 5.36, 2.02 and 2.07. (Labe, 2015).

Table 5; Geotechnical Result

Locations	Specific Gravity	Water Absorption Capacity%	Porosity%	Moisture Content	Uniaxial Compressive Strength Nm^{-2}
Osina					
A	3·1	5·0	0·2	0·24	30
B	4·3	4·0	0·3	0·21	12
Gabu					
A	3·1	8·0	0·3	0·3	43
B	4·2	6·0	0·1	0·2	20
Aliforkpa					
A	2·8	12	0·5	0·4	40
B	4·2	2	0·1	0·2	11

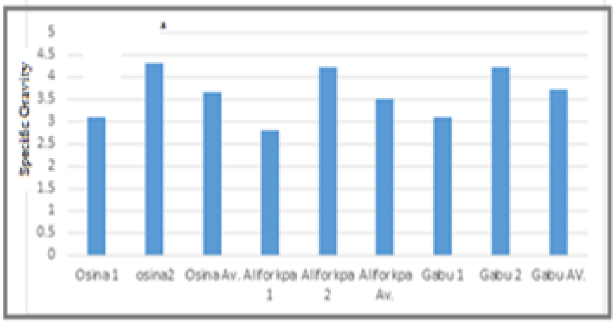

Figure 7: Plot of Specific Gravity and Average specific Gravity for various Baryte deposits in the Study area

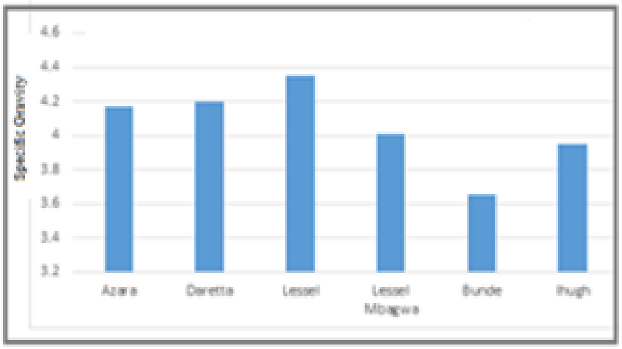

Figure 8 : Plot of Specific Gravity for smoe Baryte deposits in the Middle Benue Trough

5.0 DISCUSSION OF RESULTS

5.1 GEOLOGY

Field studies revealed that barytes veins in the study area are structurally controlled by majorly the NW – SE trending fractures as shown in Figure. 9. The NE -SW fractures occur but less frequently. The veins run mainly as strata bound ores in the fractured shales of the Asu River Group and the coarse-grained sandstones of the Ezeaku Group. Close to the barytes veins are the saline water ponds. The ores also appear as cluster of veins in the weathered/fractured sandstone and shale unit. The barytes exhibited different colors that range from colorless to white, light yellow and greenish. Ores at greater depth tend to be whiter in color. Different colors shown by the ores on the surface as a result of the gangue minerals (mainly galena, sphalerite and hematite) could also be attributed to weathering, leading to alteration of the sulphate minerals.

The factors that encourage the formation of deposits include depositional environment, fluid movement component, source of water (Misra, 2000). In the study area, barytes mineralization was controlled by source of water which probably was from trapped seawater or hydrothermal source. The required heat needed for fluid circulation probably came from the igneous intrusions in the area during magmatism. The banded gneiss and granite provided the Pb and Zn. The basaltic rocks in the studied area (N 06˚39′, E 008˚23′ and environs) provided the much-needed Ba. Fluid temperature was relatively low as indicated by low concentrations of high temperature elements such as Ti(Titanium), Fe(Iron) and Cu(Copper). Precipitation occurred probably as barium leached from the basalts into the joints and was mixed with rich sulphate seawater giving rise to precipitation of barytes.

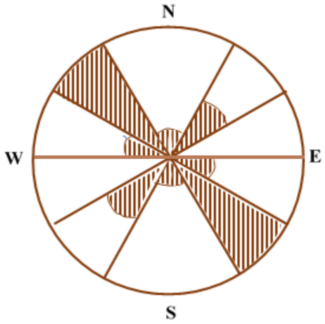

Figure 9: Rose Diagram showing the general structural trend of the baryte veins in the Conglomeritic arkosic Sandstones

5.2 GEOCHEMISTRY

The geochemical composition of the major elements and trace metal oxides in Alifokpa-Gabu-Osina and Environs gave the following values; BaO (42.55 – 65.77 %), Fe_3 (0.01 – 0.20 %), CaO (0.07 – 0.23 %), MgO (0.01 – 0.17 %) and Al_2O_3 (< 0.00 – < 0.001). Following Oden (2012), the BaO values of 42.55 to 65.80 (av. 61.63%) suggests a medium grade quality barytes for the study area but generally from the above results the quality of the barytes is low and thus the ore can be upgraded for industrial purposes. Kurt *et al* (1998) attributed high values of TiO_2 (0.1 – 1.6%), Cu (109 – 161 ppm) in barytes from Turkey to mineralizing fluid of magmatic origin. Values of < 80 ppm of Cu in the barytes of the study area with those of Azara, Daretta, Lessel, Ihugh and Torkula suggests a hydrothermal origin for the barytes ores of the Lower and Middle Benue and not of magmatic origin. Barytes ores with low concentration of water-soluble elements such as Ca (0.07 – 1.09 %), Sr (0.11 – 2.17 %) and heavy metals such as Hg (0.01 – 0.019 ppm), Cd (0.1 – 0.42 ppm) have qualities of good grade barytes for drilling mud, (Ene *et al*, 2012). Values of CaO (0.08 - 0.23 %), SrO values of (0.008 – 0.15 %), Cd values of (0.20 – 0.40) ppm thus makes the Alifokpa – Osina – Gabu ores good for use as drilling mud.

A barytes oxide trend map prepared for the study area (Figure 10) suggests a northwesterly increase of the oxide from Alifokpa to the central parts of the study area, which should be considered as target for further exploration. An API gravity trend map as shown in Figure 11 confirms this proposition. Plots of BaO versus major oxides and minor elements (Figure 12) shows an enrichment trend in SiO_2, Fe_2O_3, MgO, K_2O, Pb, and Cd as BaO increases, and depletion trend in TiO_3, Al_2O_3, CaO, Na_2O_3, SrO, Ni and Zn as BaO increases. The low iron content of barytes in the study area which varies from 0.001 to 0.04% falls within the range used Kurt *et al* (1998) to characterize barytes mineralization occurring at low temperatures. This implies that the Alifokpa – Osina – Gabu barytes ore mineralized from a hydrothermal fluid of low temperatures.

The barytes from the study area can be attributed to have mineralized from hydrothermal fluid from volcanic and intrusive materials because of its TiO_2 and Cu content of – to -. Kurte *et al* (1998) using high values of TiO_2 (0.1 – 1.6%) with Cu (109 ppm – 161 ppm) in barytes from Turkey to infer mineralizing hydrothermal fluid as being sourced from volcanic and intrusive materials. Ortigoza-Cruz et al (1994) as well as Kurt *et al* (1998) suggested that high Sr (9605 – 13,603 ppm) content suggests some connections between barytes and volcanic activities. Werner (1958), Starke (1964) and Kurt *et al* (1998) also reported that high Ba\Sr (60 – 100) as being related to epithermal hydrothermal origin.

The chemical and physical parameters values were compared with the American Petroleum Institute (API), (Table 6) and the Nigerian Department of Petroleum Resources (NDPR) set limits.

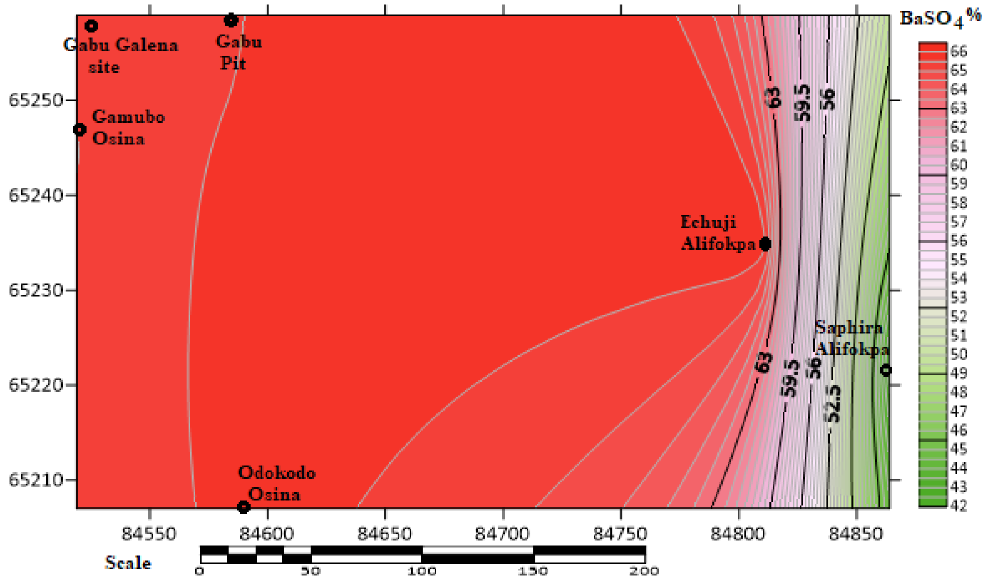

Figure 10: Barium Oxide Trend Map of the Study Area

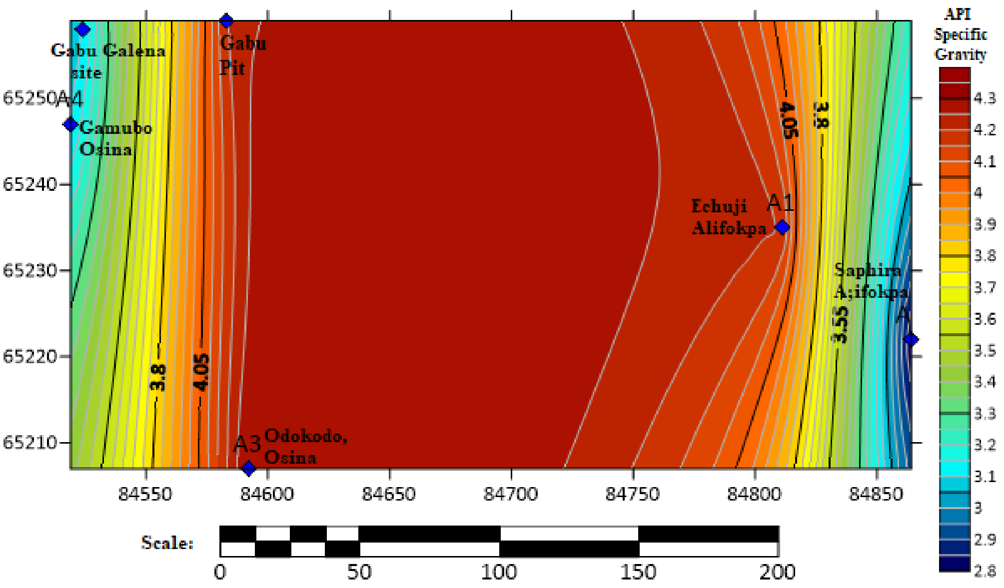

Figure 11: API Gravity Trend Map of the Study Area

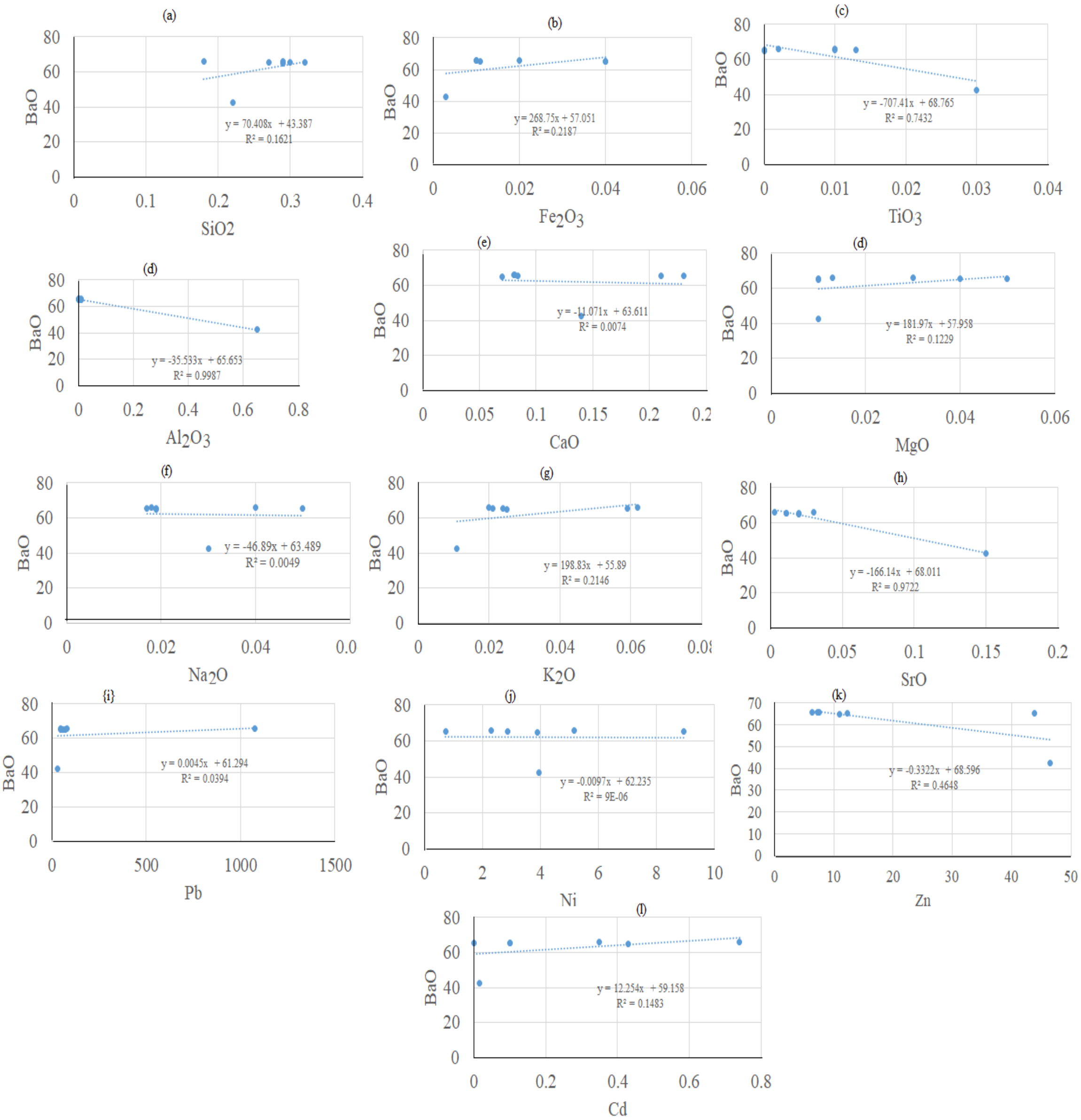

Figure 12: Plot of Barium Oxide versus Major Oxides and Trace Elements

Table 6: Standard Barite Specification Table for various uses of baryte ores in the study area.

Standard	API Specific Gravity	$BaSO_4$	Soluble Mineral content	Heavy Mineral	Fe_2O_3	SiO_2	Al_2O_3	Moisture Content
Oil/Gas well drilling	4.1-4.6	95	250 ppm	minimal	minimal	minimal	-	-
Water well drilling	4.2		250 mg/kg	minimal			minimal	-
Paint Industry	4.2	95	-	minimal	minimal			0.5%(max)
Medical/ Pharmaceutical Industry	4.2	97	-	<0.001ppm	minimal	1.50% (max)	minimal	-
Paper Industry	4.2	> 90	-	-		minimal	minimal	-
Rubber Industry	4.2	95	-	-	< 1% (max)	minimal	0.15% (max)	≤1%(max)
Glass Industry		95	-	-	0.15%	1.50% (max	-	-
Alifokpa	3.5	59.2	-	-	0.007	0.26	-	0.3
Osina	3.7	65.4	-	-	0.02	0.24	-	0.3
Gabu	3.7	65.4	-	-	0.04	0.31	-	0.3
Azara	4.17	39.0	-	-	1.51	3.08	-	-
Dareta	-	37.92	-	-	2.35	1.26	-	-
Lessel	4.38	91-65	-	-	0.51	-	-	1.15
Lessel Mbagwa	-	79.20	-	-	0.10	20.50	-	-
Bunde	3.65	80.90	-	-	0.04	18.90	-	0.77
Ihugh	3.95	33.79	-	-	1.20	13.30	-	1.18

5.3 INDUSTRIAL ASSESSMENT OF BARYTES FROM THE STUDY AREA

An assessment of the barytes from the study area compared with the acceptable standard baryte specifications is detailed in Table 6. Results of the chemical and physical properties of the barytes from the study area gave values of barium sulphate ($BaSO_4$) of 59.2 – 65.4%, iron oxide (Fe_2O_3) of 0.007 – 0.02, Silicon Oxide (SiO_2) of 0.24 – 0.31, and specific gravity of 2.8 – 4.3 and moisture content of 0.3 respectively. Some of the specific gravity values in the study area compare well with the standard API specific gravity values required for oil/gas well drilling. The barium sulphate ($BaSO_4$) values of 59.2 – 65.4 % falls below the acceptable API standard of 95 % required for utilization in oil /gas well drilling. The iron oxide (Fe_2O_3) and silicon oxide (SiO_2) values of 0.007 – 0.02 and 0.24 – 0.31 respectively fall almost within the minimal API standard for utilization in oil / gas well drilling. The specific gravity values of 2.8 – 4.3 for the barytes in the study area compares favorably with the acceptable API standard required for water well drilling.

The specific gravity values of 2.8 – 4.3, moisture content of 0.3%, barium sulphate ($BaSO_4$) of 59.2 – 65.4 %, iron oxide (Fe_2O_3) of 0.007 – 0.02 compare favorably with the acceptable standard values for utilization in the paint industry, with the exception of barium sulphate, with lower values. The chemical and physical parameters of barytes from the study area compare well with the acceptable standard for its utilization in the medical / pharmaceutical industry, with the exception of barium sulphate, with lower values of 59.2 – 65.4 % as against the standard value of 97 %. The chemical and physical properties of barytes from the study area compare favorably for its utilization in the paper industry, with the exception of barium sulphate, with values of 59.2 – 65.4 %, as against the standard value of 90 %. The same is applicable to the Rubber and Glass industries, but their acceptable standard specifications are 95%. This major deficiency of the barytes in the study area is the lower content of the barium sulphate which can be upgraded through beneficiation for its use as stated above.

6.0 SUMMARY AND CONCLUSION

Barytes occurrence in Nigeria is in parts of the northeastern, northwestern and southern part of the Precambrian complex and also in the middle to lower cretaceous sediments of the Benue Trough. It is in existence with gangue minerals. A number of tectonic activities that produced numerous structures took place in the trough (Nwachukwu, 1992). These structures formed a suitable pathway for the ore fluid. The NW – SE, N- S and NE – SW structures facilitated the precipitation of barytes, thus its epigenetic mode of occurrence as vein deposits. The barytes mineralization occurs as veins in sandstones and shales of Osina and Gabu. In Alifokpa, the ores occur as lenses.

The purity percentage of barytes is measured using the percentage of barium concentration. High content of SiO_2, SrO, Zn and Pb is a suggestion of the nature of the gangue minerals in association with the barytes ores. The geochemical and geotechnical properties of these ores have proved that the ores can be used for other industrial purposes and upon beneficiation is good as weighting agent in oil drilling. Moisture content of 0.2 – 0.3% is within the API standard and specification, also other geotechnical parameters clearly describe the nature of the studied barytes which permits it to be used for numerous purposes. The metallic content such as Ca, Pb, Zn, Mg, Cu minerals fall within the limits set by API, NPDR. Values of <100 ppm and <0 001 percentage of Cu and TiO_2 respectively on the study area with barytes of Azara, Daretta, Lessel and Torkular proves that the barytes of the lower and central Benue are of hydrothermal and not magmatic origin.

Conclusively, barytes from Aliforkpa – Osina – Gabu from its dense milky color, geochemical and geotechnical parameters fall below the API, ASTM and DPR specification standard and are thus of grade 11 group but can be beneficiated for upgrading.

6.1 RECOMMENDATIONS

i. Further studies should be carried out in the central parts of the study area, which is shown by the BaO and API trend maps to have higher percentage of BaO and API specific gravity.
ii. Magnetic and gravity survey should be carried out in this area to actually delineate hidden barytes veins.
iii. A GIS and remote sensing exercise should also be carried out in order to map spectral signatures of veins. This will help to reveal the extent of the vein mineralization.
iv. Studies on sulfur isotopes of barytes should be carried out to properly characterize the major and trace elements.
v. Detailed analytical technique to ascertain the REE elements of the study area is recommended.

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