Romanian Journal of Earth Sciences, vol. 86 (2012), issue 1, p. 27-40

Structural styles and economic potentials of some barite deposits in the Southern Benue Trough, Nigeria

Ezekwesili Godwin ENE*, Celestine Obialo OKOGBUE, Chidozie Izuchukwu Princeton DIM

Engineering and Applied Geology Unit, Department of Geology, University of Nigeria, Nsukka

Abstract: Field and laboratory studies of barite ores and their associated rocks from the Gabu, Alifokpa and Osina barite fields allowed the evaluation of their genesis and economic potential. Results show that ores occur as disseminated nodules, stratabound as well as in two main vein sets, namely: the NW-SE trend that is orthogonal to the main axis of the Benue Trough and a comparatively younger, N-S trend, crosscutting the other one, with steep dips (generally >80^{o}). These structural arrangements not only predispose the ore deposits to vertical stripping using open pit method but also indicate epigenetic and epithermal processes for the ore formation that relate closely with basin tectonic history. Ore has the following geotechnical properties: specific gravity is 3.1-4.5, porosity is 0.1-0.5%, water absorption capacity ranges from 2 to 12% and uniaxial compressive strength varies between 11 and 43 N/mm^2. Geochemical investigations indicate the following composition: BaO = 37.23-97.54%; Fe_2O_3 = 1.06-37.98%; CaO = 0.01-1.09%; SrO = 0.11-2.17%; Hg = 0.01-0.019 ppm and Cd = 0.042-0.1 ppm. These properties, when compared to standard industrial specifications, indicate that some barites are of high grade while others are of low quality. Ore quality appears to depend on such factors as mining depth, presence of certain gangue minerals and location within the barite field.

***Keywords*: barite ore; structural styles; geotechnical properties; geochemical properties; mineral variability; economic geology; Nigeria

1. Introduction

The importance of barite ($BaSO_4$) as an economic mineral is seen from its invaluable utilization as a major constituent of drilling mud, in production of industrial wares such as glass, radiation shields and as source for barium-based chemicals. The efficient and economic use of barites in any of these civil and industrial applications necessitates that the ores possess desirable qualities and properties comparable to generally acceptable specification standards. Furthermore, its inherent properties and geologic disposition are pertinent considerations to justify economic exploitation.

The Benue Trough of Nigeria hosts more than eleven barite fields (Fig.1) that are being scavenged by small-scale and artisanal miners. Despite the earlier reports on the presence of these barite fields, (e.g. Farrington, 1952), their field characteristics, grade, dimensions, and abundance are not known and documented well enough. The paucity of these pertinent data on the mineral deposits continues to constitute a major impediment towards their economic exploitation and utilization. Indeed, almost all previous works on sulphate ore mineralization in the Benue Trough have, hitherto, largely focused on the origin/genesis of the ore veins or their associated saline waters or igneous bodies (Ezepue, 1984; Akande and Abimbola, 1987; Akande et al 1989; Akande and Mucke,1989; Uma, and Leohnert, 1992; Ekwere and Ukpong, 1994; Tijani, et al,1996). In this

* Corresponding author
email: ezekwesiliene@yahoo.com

paper, we present the results of field studies and laboratory analysis of barite ores from Gabu, Alifokpa and Osina fields. The structural patterns relative to ore host rocks and inherent properties of the barite ores are used to evaluate and highlight their economic potentials and ore genesis.

2. Physiographic framework

The Benue Trough is often described as an elongate shaped, intracratonic basin which is underlain by a thick succession of Cretaceous sedimentary rocks that is punctuated by economic ore veins, volcanic and intrusive rocks and deposited on undulating basement (Cratchley and Jones, 1965; Uma and Leohnert, 1992). The basement rocks are exposed in the south-eastern and north-western extremities of the trough where their peaks generally coincide with the major hydrologic boundaries. The principal area of investigation, Gabu- Osina-Alifokpa barite field, falls within the southern part of the Benue Trough and is located in Yala Local Government Area of Cross River State. It is bounded by latitudes 6º45'N and 6º57'N, and longitudes 8º40'E and 8º55'E (Fig. 2) and spans an approximate area of about 250 km^2.

The topography, which is part of the major regional land form, the Cross River plains (Bygott and Money, 1975), shows a gradual ascent from the plains, to the south, to highlands, in the central north. Whereas the northern part of the area is characterized by gentle sloping high lands that can attain up to 300 m to 500 m above sea level, the terrain in the southern part of the area is dominated by low lands with elevation well below 300 m**.** In terms of the climate, the area falls within the geographical region that experiences two major distinct seasons namely, the rainy and dry seasons (Duze and Ojo, 1993). Balogun (2000) noted that the climate of the area is controlled by the seasonal movement of the inter-tropical convergence zone (ITCZ) that leads to contrasting dry and wet seasons. The dry season which extends from November to February, is characterized by high mean temperatures of about 32ºC (Gates, 1978) with the period of December to January witnessing some large diurnal variation in temperature due to the harmattan, during which temperatures may fall below 28ºC. The mean temperatures may vary widely from the month of January reaching a maximum about May.

The rainy season usually commences in the month of March and ends in October. Rainfall is heaviest during the months of June to September, with dry spell of two to three weeks duration in late July to early August (Monamu, 1975). The annual total rainfall in the region ranges between 1375 mm and 2560 mm (Gates, 1978). The area is drained by four major rivers, namely, Konshisha, Oruaba, Okpauku and Kpa and their tributaries. These major rivers and their tributaries show dendritic and occasionally trellis drainage patterns and flow into the Cross River drainage system. Whereas some of the streams are perennial, others are ephemeral and usually dry up during the dry season. They commonly originate as surface flows from springs that indent the relatively higher elevations from the north towards the southern part of the area. Igbozuruike (1975) attributed the drainage pattern to structural inequalities in rock hardness/texture, recent diastrophism and geologic/geomorphic history.

The vegetation is typically mangrove overlapping into the rain forest belt (Gates, 1978) and is characterized by scattered trees with low covering shrubs and grassland. It can be classified as grassland and rainforest types (Igbozurike, 1975) or Guinea savanna (Iloeje, 1965). The vegetation is generally controlled by geology, climatic condition and the distribution of rivers in the area. Areas that are underlain by unconsolidated sandstone and shale are covered by giant green trees and plants, while areas that are underlain by consolidated sediments are characterized by grasses and shrubs. Tall trees and evergreen plants follow the pattern of the major and minor river channels in the area. Surfacial soils in the area classify as interior zone of laterite soils following the classification scheme of Iloeje, (1965). The soils are deeply ferruginized with colour grading from dark grey to mottled red. They are generally sticky when wet with some zones of alluvium.

3. Geology

The Benue Trough of Nigeria occupies the major re-entrant into the West African continental margin and its extent is about 80-150 km wide and 800 km long (Uma, and Leohnert, 1992). It extends in the NE-SW direction from the Niger delta, Nigerian part of the Gulf of Guinea to Chad basin in the interior of the West African Precambrian shield. The trough has often been described as an elongate, partly fault-

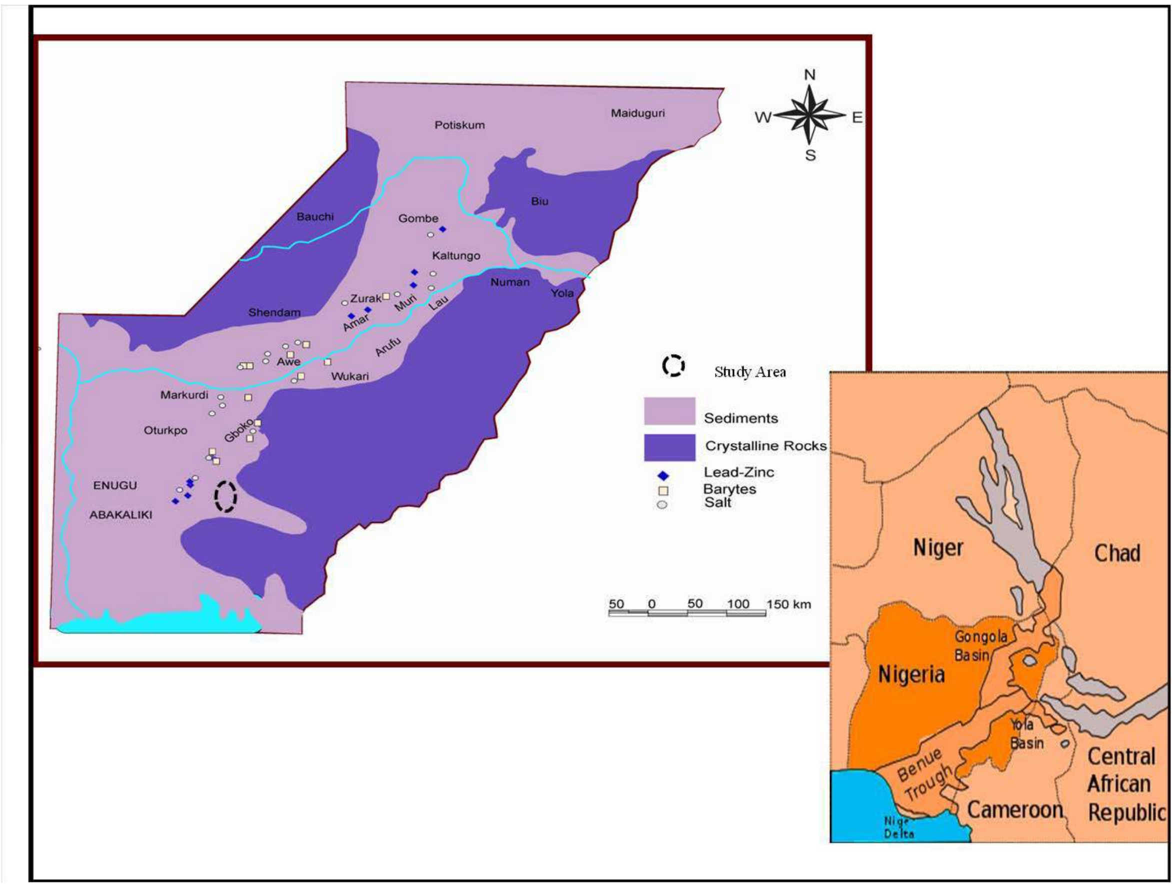

Fig. 1. Distribution of lead-zinc-barite and salt mineralization along the Benue Trough (Modified after Cratchley and Jones 1965). Insert sketch map of Nigeria showing the Benue Trough)

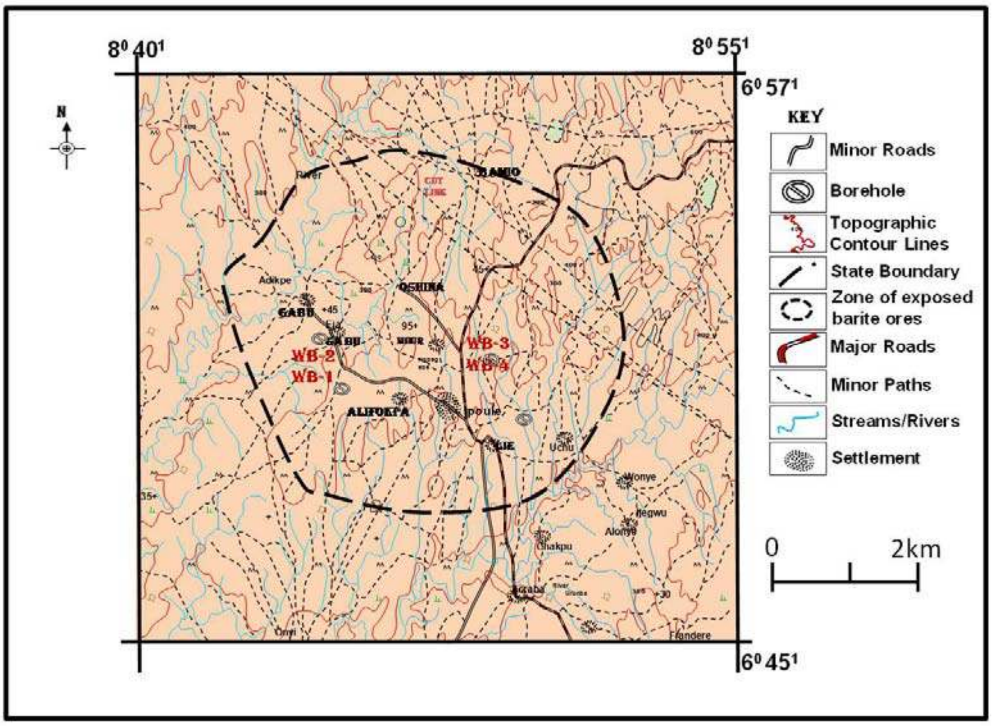

Fig. 2. Geomorphic Map of Gabu – Alifokpa – Osina barite field.

bounded depression occupied by up to 6000 m thick marine and fluvio-deltaic sediments (Benkhelil, 1989). The sediments in the trough are thought to have been compressionally or extensionally folded in a non-orogenic shield environment (Wright, 1976, Ugwuonah and Obiora, 2008). Offodile (1989), apparently for the purpose of clarity and convenience, subdivided the Benue Trough into lower/south, middle/central and upper/north geomorphic regions. In the southern (lower) region, there are many structural and depositional elements that include the Abakaliki anticlinorium, Afikpo and Anambra synclines or rift systems. These structural elements inadvertently control and dominate the geologic evolution and litho-stratigraphic architecture of the southern part of the trough.

The tectonic evolution and stratigraphic history of the Benue Trough have been extensively studied, reviewed and discussed and are fairly well known. The discussion that follows attempts to synthesize the presentations of Reyment (1965), Grant (1971), Burke et al. (1972), Olade (1975), Wright (1976), Offodile (1976), Uzuakpunwa (1980), Benkhelil (1989), Kogbe (1989), Ojo (1992), Akande and Mucke (1989) and Akande (1999). These authors agree that the application of Y-shaped triple rift model (RRR) to the break-up of the Afro-Brazilian plate, in early Cretaceous times, best explains the final configuration of the Benue Trough. They argue that the Benue Trough originated as an aulacogen consequent upon the separation of the African and South American plates sequel to the opening of Southern Atlantic in the early Cretaceous. The tectonics and the accompanying depositional processes led to the on-land reactivation of the equatorial oceanic fracture zones, particularly the Chain and Charcort zones, which probably generated successive tensional and compressional stresses in the basement rocks as well as in the overlying sedimentary successions.

During the Santonian, such crustal instability is believed to have been accompanied by widespread and spectacular magmatism, folding, and faulting, which resulted in the creation of the relatively elevated Abakaliki anticlinorium (in the Southern Benue Trough), flanked by two synclines: the Anambra to the west and Afikpo to the east. The Abakaliki anticlinorium then became a positive geomorphic feature, and sedimentation was transferred laterally to the adjoining synclines. The sedimentary infill in the lower Benue Trough (Fig. 3) (the Abakaliki Basin) records the first tectono-sedimentary cycle that inundated the southeastern Nigeria rift basins. The cycle which probably started with the Alptian-Albian transgression deposited the oldest marine sediments with shelf environment, designated as the Asu River Group (ARG). The ARG consists of mainly thick laminated shales, arkosic sandstones, and subordinate limestones and later with associated volcanics, intrusions and pyroclastics. It represents the first cycle of shallow marine and brackish water terrigenous clastic sediments that lie unconformably over the Precambrain to lower Paleozoic Basement Complex rocks. The Cenomanian is characterized by a regressive continental to transitional marine environment with high clastic sediment influx (e.g., Keana/Markurdi Sandstone in the central Benue Trough), which may have created a wide coastal plain predominantly to the west of the basin (Anambra syncline). This may have led some earlier workers (e.g., Reyment, 1965; Nwachuklwu, 1972) to suggest the absence of Cenomanian deposits in the Abakaliki basin. The subsequent Turonian transgressive phase is dominated by the Benue-Trans-Sahara Seaway (Tethian) and accounts for the deposition of extensive fossiliferous black to grey shales, the Ezeaku Group, which consists of marine shales with subordinate limestone (Benkhelil, 1989), as well as several sand bodies ranging from fluvial to marine (Hoque and Nwajide, 1985). The Abakaliki basin is said to have evolved into a (stable) platform with subsidence localized to the western shelf during the period of Turonian transgression. The localized subsidence and gradual migration of the basin axis to the west, coupled with continuous rise in sea level into the Coniacian, led to the creation of the Anambra rift with the deposition of thick upper Turonian-Coniacian Agwu Group. The Santonian folding, and uplifting of the Abakaliki basin displaced the axis of sedimentation and limited the deposition of Santonian to Maastrichtian sediments to the Anambra and Afikpo basins.

The sedimentary packages in the Benue Trough have been affected by, at least two major sets of tectonic features, namely, the pre-Turonian and Santonian. In the lower Benue Trough, the latter tectonic set involved compressional movement along an established NE-SW trend. This may have resulted in the folding, faulting and uplift of the Abakaliki Anticlinorium. The tectonic episode was not

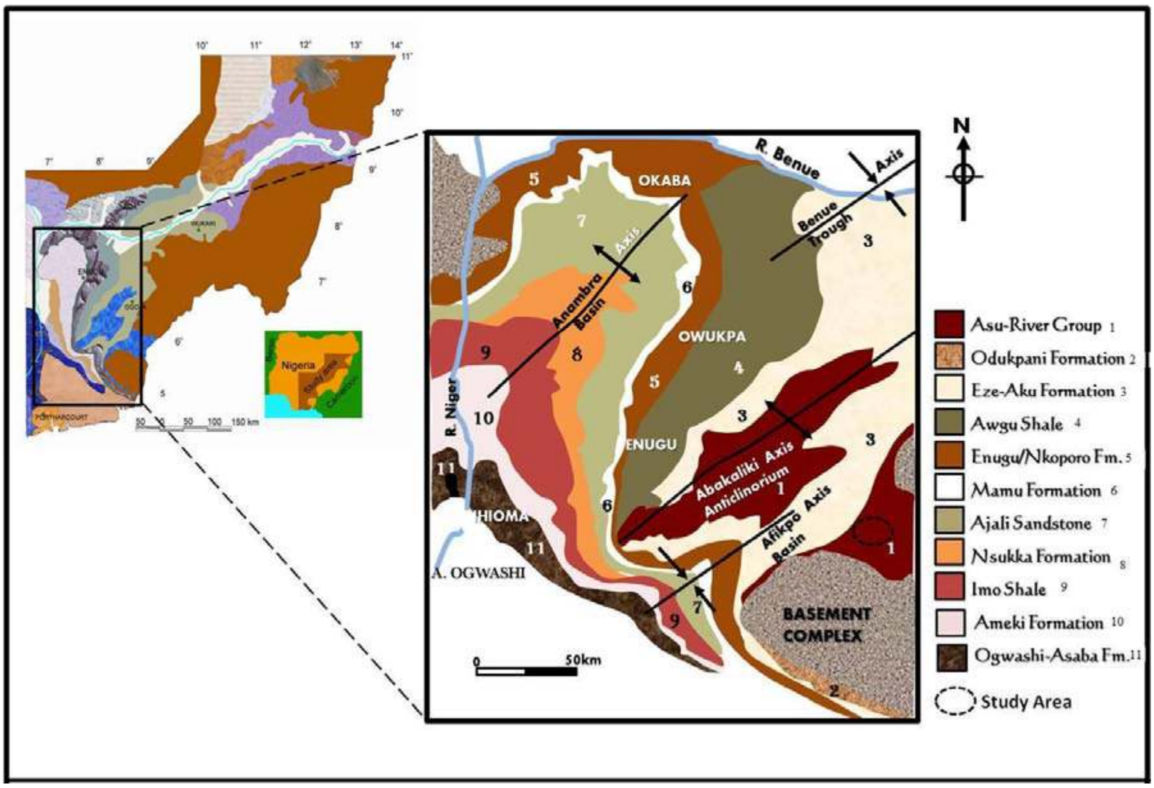

Fig. 3. Regional stratigraphic sequences in Southeastern Nigeria (Modified from geologic map of Nigeria, 1994)

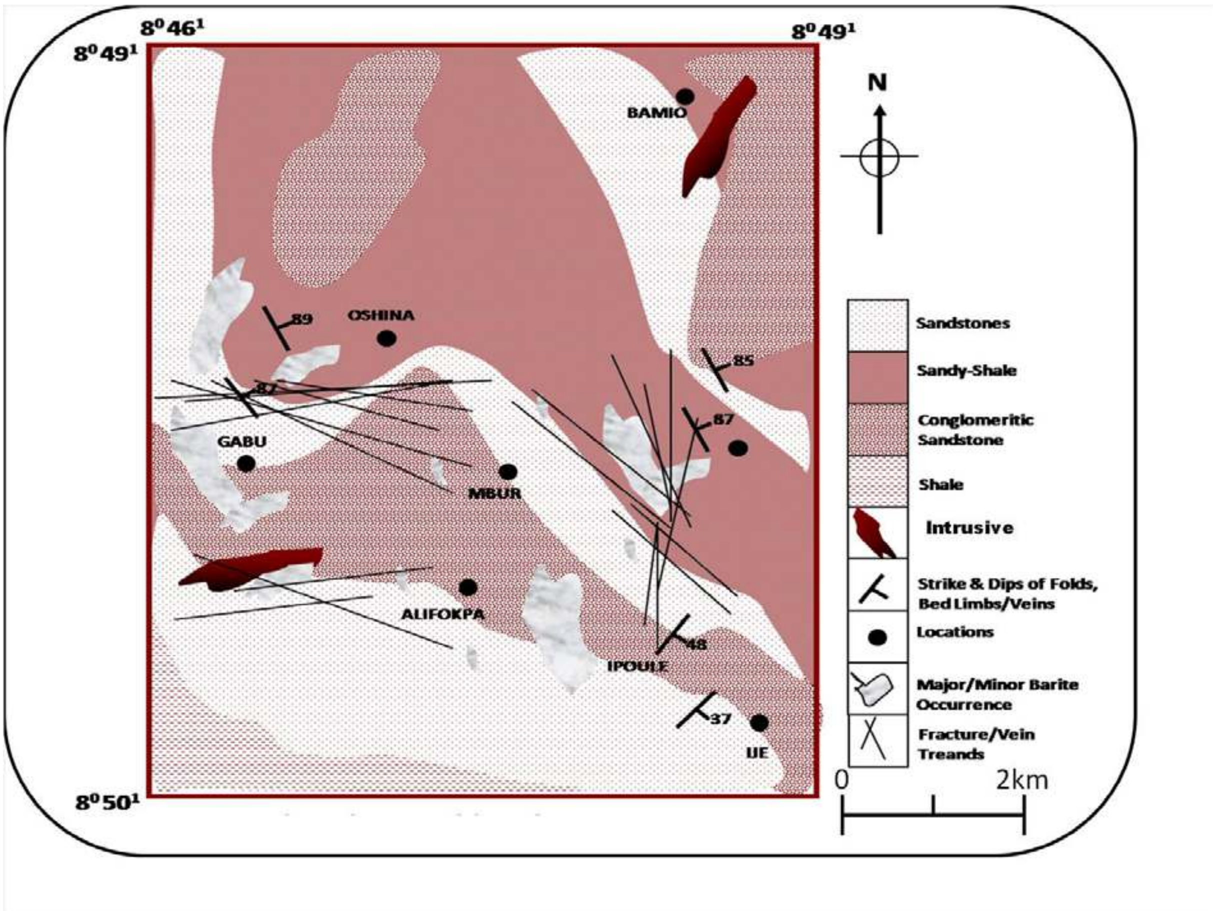

Fig. 4. Geologic map of the study area

only characterized by contemporaneous subsidence of the Anambra platform and displacement of the depositional axis westwards, but also is thought to have been marked by a number of minor intermediate intrusions as well as associated lead-zinc mineralization. The folded and fractured ARG rocks (shales, limestone, sandstone, and their equivalents in the central and northern Benue Trough) are hosts for associated lead-zinc, and fluorite-barite mineralization.

4. Methodology

Field mapping of the area was conducted and it involved the location, description, measurement and sampling of various exposed ores and the associated lithologies, geologic structures (fractures) along mine pits and river channels. Barite ore samples were subjected to geotechnical and geochemical tests in the laboratory to evaluate the grade of the barite ore. The geotechnical tests included specific gravity, porosity, water absorption capacity, and uniaxial compressive strength while the geochemical investigations involved major and trace element analysis of the ore samples. The geotechnical tests were carried out in accordance with the procedure outlined in British standard (BS, 1378, 1990). The geochemical analyses were performed by inductively coupled plasma mass spectrometry techniques (ICP-MS) using Perkin Elmer SCIEX ELAN 6100 instrument and calibration with certified reference materials from National Institute of Standards and Technology (NIST, USA). Appropriate sample preparation for the analysis was carried out on pulverized ore samples by digestion and fusion with aqua regia and wet acid (HNO_3+HCl) treatment following the procedure given in Balcerzak (2002).

5. Results and discussion

5.1. Structural styles

Detailed field studies of the barite field show that three major rock types coexist with barite veins in the area (Fig. 4). These rocks include arkosic, conglomeratic sandstone, intrusive bodies and fractured weathered shales. The sandstone is truncated by intrusives and saline water pools are restricted in the shale regions. The contact between barite ore and the sandstone host rock is sharp and devoid of observable wall-rock alterations. There is a notable absence of the host rock fragments in the barite ore samples, despite their crosscutting field relations. The lithologic association of the different rock types and barite ores indicates that barite veins, as well as stratabound concordant barite beds are widely distributed in the indurated sandstone (Fig. 5A-E). The ores are also occasionally disseminated as swarms of veins and/or globular concretions in weathered/fractured shales. In terms of their spatial and temporal appearance, veins occur predominantly in swarms but occasionally depict block profile and their lateral extents vary widely ranging between 10 cm and 8 m with mean of 1 m. The barite ores occur in association with other minerals such as quartz, galena, sphalerite and feldspar (Fig. 6).

Detailed records of the mineralogy and geochemistry of igneous bodies and of the composition of the saline waters that are known to associate with base metal mineralization in the lower Benue Trough are contained in the works of Ezepue (1984) and Uma and Leohnert (1992). Whereas the felspathic, conglomeratic coarse-grained sandstone, which trends on 310º-130º azimuth with dip of about 43º, plays host to the barite ore veins in the Gabu-Alifokpa-Osina fields, mineralization of predominantly lead-zinc sulphides and fluoride ores have been reported to occur in shales of the ARG in similarly close geographic association with saline waters and intrusives (Akande and Mucke, 1989 and Akande, 1999). The lithofacies association and occurences in the ore fields tend to suggest that ore genesis is intricately related to both magmatic activities and hydrodynamics of the associated hydrothermal fluids. A closer examination of the veins relative to the host rock indicates that open (cavity) space filling as opposed to replacement phenomena is the dominant mode of ore precipitation and concentration, a situation that explains the absence of the host rock fragments in the barite ores, despite their crosscutting field relations. Back and Clark (1993) thought that the paucity of host rock fragments in ores found in such host rocks predicates the near surface position of the host prior to deep burial during ore genesis. A further support to the open (cavity) space filling is the fact that the ore-host rock contact is devoid of observable wall-rock alterations. According to Paradis et al (1998), the seemly minimal nature or complete non-existence of wall-rock modification obviously points to the low thermal conditions that prevailed during ore mobilization and precipitation from hydrothermal fluids

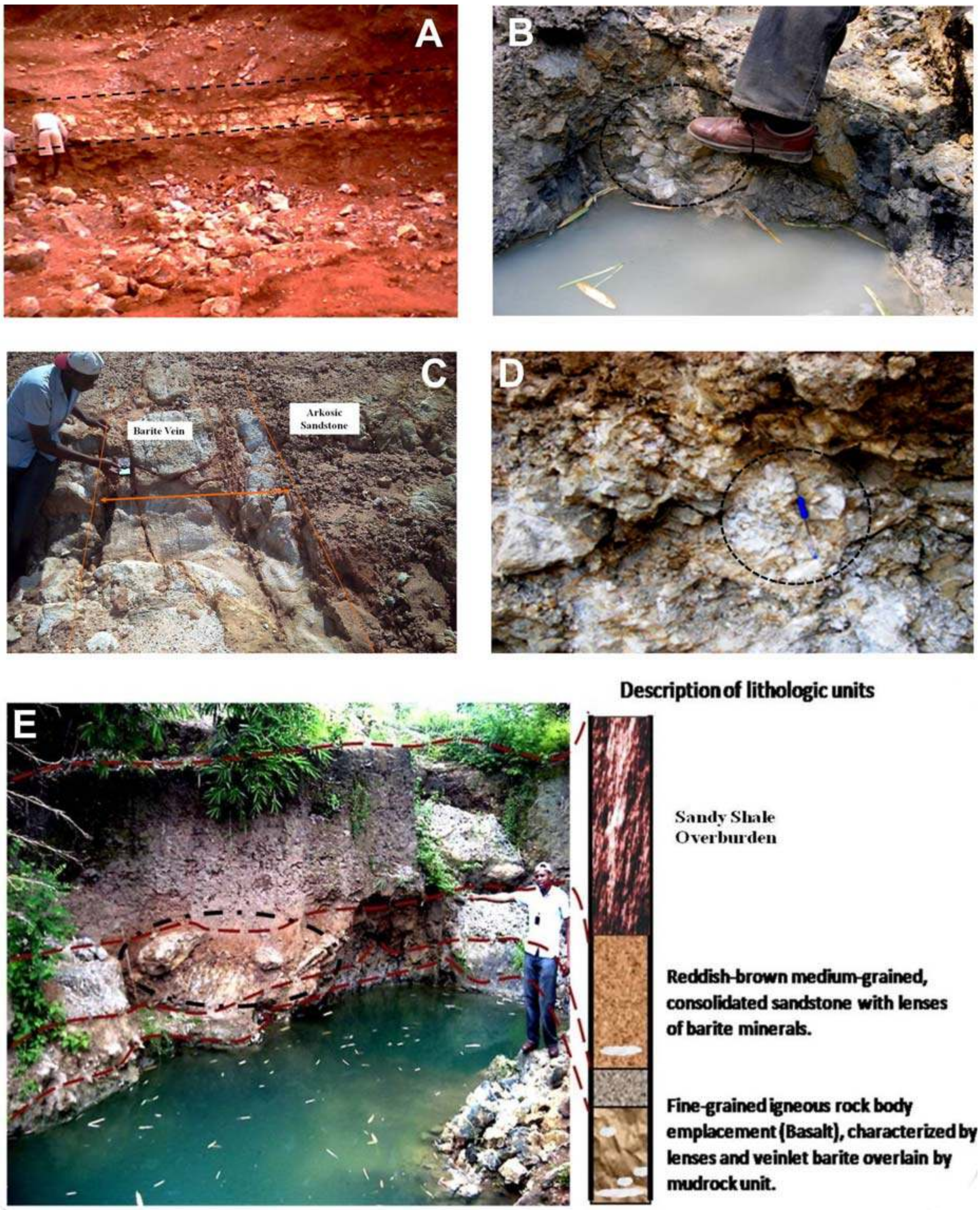

Fig. 5. A. Fractured stratabound barite ores (delimited by the dash lines) occurring as 2-5 m thick beds in sandy shale at Alifokpa (active mine pit). B. Fractured barites and barite nodules (dashed circles) occurring in shales at Oshina (abandoned mine pit due to groundwater flooding). C. Mining pit face showing fractures and associated barite-mineralized vein in the conglomeratic sandstone unit at Alifokpa site; the first author is measuring the attitude of the ore vein and fractures. D. Mining pit face showing fractures and associated barite-mineralized vein in the conglomeratic sandstone unit at Alifokpa site. E. Composite photograph and lithologic section in an abandoned mine pit at Gabu. Note the disseminated barite ores in the basal sandstone units (in dash circles).

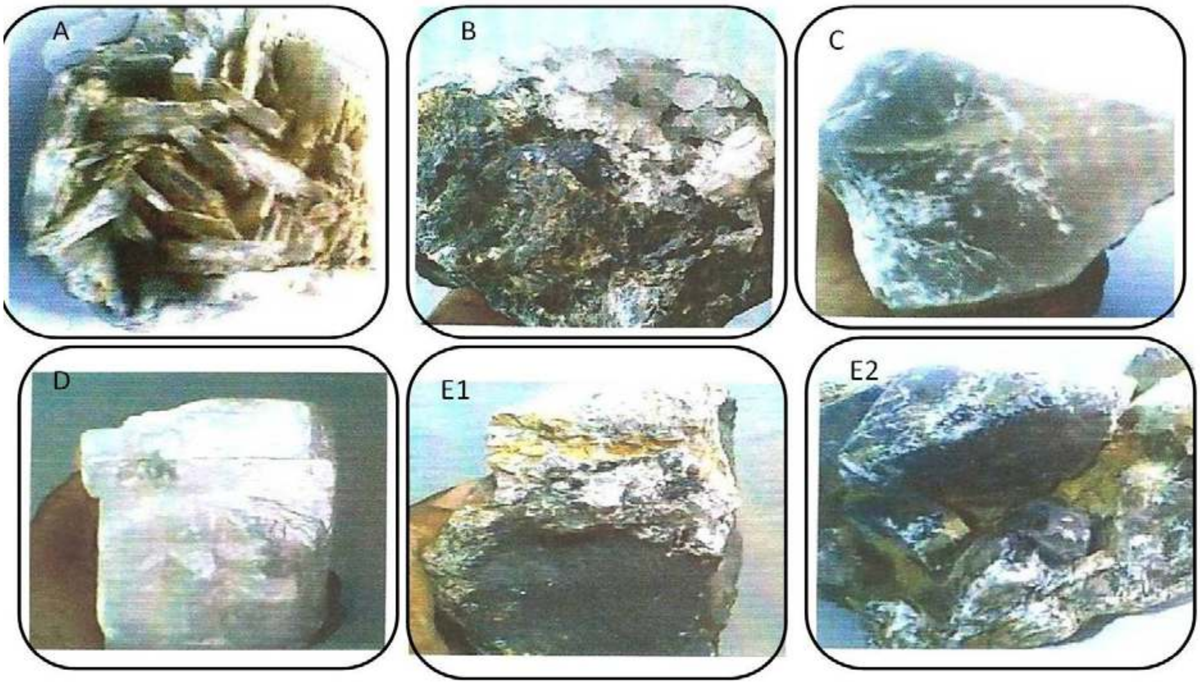

Fig. 6. Barite ore samples from Gabu/Alifokpa/Osina fields; Cross-River State, Nigeria. (A). Bladed barite matrix on sphalerite from Gabu mine, Ogoja. (B) compact yellowish dark brown metallic crystals of sphalerite intermixed with galena and quartz crystals; Gabu mine, Ogoja. (C) Tabular, clear/transparent crystals of barite from Alifokpa mine, Ogoja. (D) Tabular crystal of barite characterized by well-defined cleavage planes; Gabu/Osina mine, Ogoja. (E1) crystals of barite occurring in association with quartz and galena and (E2) crystals of barite occurring in association with feldspar.

Trend analysis of the ore veins (Fig. 7A-B) reflects two dominant fracture direction sets, namely, NW-SE trend that is orthogonal to the main axis of the Benue Trough, and a comparatively younger, crosscutting N-S trend. The NW-SE-trending ore veins predominate over N-S trending veins, and the dips of the barite veins are generally steeper than 80º. The near vertical dip of the veins predisposes the ore deposits to manual extraction and vertical stripping using open pit method. Similar observation of the spatial distribution of rock-types and association, vein morphology and presence of brines has been noted by other workers, who studied other fields in the Trough. These observations as well as fluid inclusion studies have generated a lot of controversy in the past with respect to ore or saline water genesis and two contrasting hypotheses have emerged.

The first one (e.g. Orajiaka, (1964); Ezepue, (1984); Uma and Leohnert, (1992); Tijani, et al, 1996) believes that igneous intrusions caused changes in the geochemistry of the surrounding rocks, releasing important masses of volatiles. Changes in pressure and temperature conditions probably entrained precipitation and concentration from fluids to form the ore. The authors supporting this hypothesis apparently came to this conclusion in an attempt to explain the presence of igneous bodies in close vicinity to the ore veins. The proponents of the second hypothesis, such as Olade and Morton (1985), Ekwere and Ukpong (1994), Akande and Abimbola (1987), Akande et al. (1989), think that the brine was contemporaneous with deposition of the host rocks, prior to the magmatic processes and to the concentration and precipitation of ores and that ore concentration and precipitation occurred in response to basinal fluid expulsion induced by gravity compaction and hydromechanics and subsequent fluid interaction with the arkosic sandstone which provided the source of base metal concentrates. While these authors accept the epigenetic formation model, they absolutely disagree with the magmatic hydrothermal brine source. They, however, opine that much of the brine was contemporaneous with the deposition of the host rocks, prior to the magmatic processes and concentration and precipitation of ores. Such

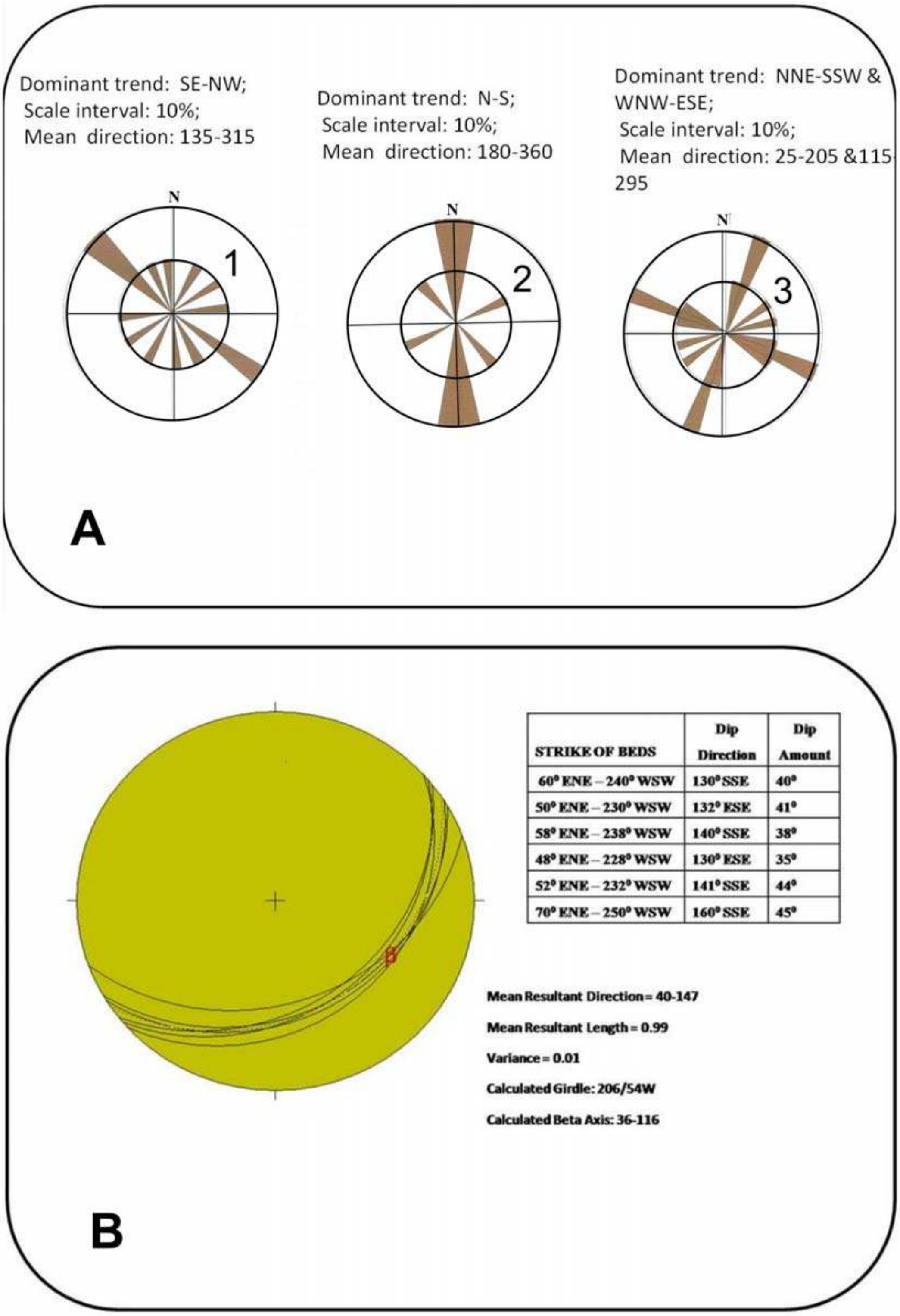

Fig. 7. A Rose diagram plots of barite veins and major fractures (joints) for: (A) Gabu, (B) Alifokpa and (C) Osina barite fields. B. Stereonet plot of ore veins and major fractures (joints) attitudes for Gabu, Alifokpa and Osina barite fields

opinion attempts to invoke plausible explanation for the continuous presence of brines within the geographic location of the veins.

From this study, it is adduced that the intrusive rocks are not in themselves mineralized and the migration pathway of the supposed magma-derived hot fluid is yet to be resolved. Also, there has not been any known igneous body directly correlated or linked to a particular mineralization. Again, there seems to be disagreement, even among the proponents of the magmatic-hydrothermal concept on the provenance and migration pathway of ore-forming fluid. For example, Farrington (1952) believes that intrusive rocks induced the formation of the ore directly, while Reyment (1965) thinks that volcanic rocks generated the hydrothermal fluids from which the ore was deposited and Orajiaka (1962) consideres either of the two rock types (sedimentary and magmatic) as possible sources of fluid. It can be considered that the basinal expulsion genesis model is more favoured. However, the indications of magmatic processes, such as the presence of igneous bodies, add yet another question to the model. Indeed, the contending models to explain the mineralization in Benue Trough reflect the complex history of basin formation and dynamics. It follows, therefore, that a holistic genetic model, however, has to account for the coexistence of the mineralization with igneous bodies and brines and the varied morphology and mode of occurrence of the ores. Such model has to be in line with the tectono-sedimentological evolution of the southern Benue Trough. It is then concluded that the Santonian tectonic event mobilized the base metals contained in the Asu River Group sediments due to magmatic intrusions that generated hot brines. The flow of the hydrothermal fluid through fissures and fractures, which may have been created by pre-Santonian tectonic events concentrated and precipitated the ores. Alternatively, the magmatic activity may have, as well, served as the source of the base metals, which, in the case of flow through the rocks witnessed ionic differentiations that led to the concentration and formation of the ores. The remnant hydrothermal fluids generated the brine ponds. Irrespective of the source of the base metals, the present structurally-controlled occurrences of the ores in varied vein trends as well as stratabound mineralization, are indications that ore genesis may have followed closely the tectonics and deformations of basin evolution in the Cenomanian (Benkhelil, 1989; Ojo, 1992), Turonian and Santonian (Nwachukwu,1972).

5.2. Economic potential

The physical appearance of the ore samples show that the ores exhibit several colours, ranging from colourless-white, for samples that occur at greater depths (more than 30 m from the ground surface), to light yellow and greenish, for those found closer to the ground surface. In addition, some ore samples show variegated colours (Fig 6) apparently due to the presence of the accompanying minerals such as galena, feldspar and quartz. On the other hand, the colours shown by samples closer to the surface could be attributed to the oxidation and alteration of the sulphates. All samples generally display typical transparent, glassy luster.

Results of the geotechnical testing of the ore samples are presented in Table 1. From the table, it can be seen that the specific gravity, porosity, and water absorption capacity vary from 3.1 to 4.5 g/cm^3, 0.1 to 0.5%, and 2 to 12%, respectively. The uniaxial compressive strength is in the range 11-43 N/mm^2. It is obvious from Table 1 that there is a general increase in the value of the specific gravity of the ores with increasing depth of occurrence. Such contrasting property at increasing mining depth, perhaps demonstrates the occurrence of higher grade ores as mining proceeds to greater depth. It can also be noted from Table 1 that the uniaxial compressive strength (UCS) of the ores varies widely. However, there is a decreasing trend in values with increasing depth, which is obviously contrasting with the specific gravity trend. A closer look at the high strength barites indicates that they are admixed with associated minerals (Fig 3) and occur closer to the ground surface in the veins, while the low strength types occur at greater depths and are devoid of gangue minerals. The higher strength recorded for barite samples that are richer in the gangue minerals is attributed to increased frictional resistance to compression due to co-recrystallization of barite with relatively harder minerals such as quartz. It would appear therefore, that ore quality (when judged from the point of view of specific gravity values and presence/absence of gangue), is higher at increasing depth in the barite fields.

The results of the geochemical tests (Table 2) lend support to the improvement of barite quality with increasing depth in the veins. For example,

Table 1. Geotechnical properties of barite ores from Gabu-Alifokpa barite fields

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

*Average measured value of five samples for the depth range

Table 2. Geochemical properties of barites ores from Gabu-Alifokpa barite fields

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

some of the chemical components, such as BaO, mimic the trend of specific gravity values showing consistent increase in grade with increasing depth. In contrast, the contaminants, such as Fe_2O_3 and SiO_2 show decreasing contents with increasing depth similar to the trend exhibited by UCS values. The increase in the specific gravity of the ore samples with increasing depth of occurrence is thus, attributed to the increasing content of barium (atomic mass: 137) and other heavy elements and decreasing content of comparatively lighter elements such as silicon (atomic mass: 28) and iron (atomic mass: 56).

The industrial specifications for different use of barites vary widely (Table 3), even among manufacturers or industries. In order to assess the quality of barite ores from the studied fields, the measured geotechnical and geochemical properties are compared with some generally acceptable standards for processed barite as there are no standards for mineral ore. The comparison shows that the geotechnical properties of some of the ore samples compare reasonably well with the American Petroleum Institute (API) specification standard for barite used as a weighting agent in oil well drilling mud, which requires at least a specific gravity of about 4.2. For example, the ore samples that occur at greater depths in the veins have specific gravity above 4.2 and thus, are suitable for oil well drilling applications. In addition, the ores with high specific gravity show lower concentration of heavy metal contaminants. For example Hg (0.01-0.019ppm) and Cd (0.042-0.1 ppm) are well within the permissible limits for barites used in drilling mud. In contrast, some of the ore samples particularly those that occur close to the ground surface and/or are contaminated with gangue minerals, fall short of this requirement as their specific gravity values fail to attain the recommended values of 4.2, and hence, are of low quality.

Table 3. API and ASTM general specification standards for various uses of barite ores.

Standard	Specific gravity	$BaSO_4$ (BaO)	Soluble alkaline content (Sr and Ca)	Heavy metals	Fe_2O_3	SiO_2	Al_2O_3	Moisture Content
API(mud)	4.2(min)	92%(min)	250ppm max	N/A	N/A	N/A	N/A	N/A
ASTM:								
Glass	N/A	95%(min)	N/A	N/A	0.15% (max)	1.5% (max)	0.15% (max)	N/A
Pharma-ceuticals	N/A	97.5% (min)	<0.01ppm	<0.001ppm (max)	N/A	1.5% (max)	N/A	N/A
Paint	N/A	95% (min)	0.2% (max)	N/A	0.05% (max)	N/A	N/A	0.5%(max)
Chemicals	N/A	92% (min)	1% (max)	N/A	1% (max)	N/A	N/A	N/A

N/A – Not applicable

The results of the geochemical analysis lend support to the varied grades of ores in the barite field as shown by the wide variations in the concentrations of the geochemical facies. Whereas the ore with low concentrations of water soluble elements: CaO (0.01-1.09%), SrO (0.11-2.17%), and heavy metals: Hg (0.01-0.019ppm) and Cd (0.1-0.42ppm) have desirable qualities of good grade barites for drilling mud and others that have higher concentration of these elements need beneficiation to attain acceptable limits. Also, the concentrations of BaO (37.23-97.54%) and Fe_2O_3 (1.06-37.98%) indicate that some of the barites classify as high grade when compared to the ASTM specification for barites utilized in pharmaceuticals, paints, glass and chemicals and therefore have good potential for use as source of barium-based chemicals and in the production of industrial goods. The low grade ores, which fail to meet API and other specifications, occur close to the surface and are characterized by the presence of gangue and ore minerals such as galena, quartz, feldspar and sphalerite. It would appear that ore quality is dependent on mining depth and is impaired by the presence of the associated minerals. In addition to mining depth, ore grade distribution within the barite field varies with location as higher grade ores appear to predominate towards the northern part of the prospect around Gabu/Osina area while ores of comparatively lower quality and contaminated by the associated minerals occur southwards, in the Alifokpa area (Fig 2 and Table 1).

6. Conclusions

Field studies and laboratory analysis of ore samples from Gabu, Osina, and Alifokpa barite field allowed for the assessment of ore morphology and occurrence, as well as the industrial properties in order to evaluate the economic potential and usability of the ores. From this study, the following conclusions are drawn:

1. Barite occurs predominantly in steeply dipping NW-SE trending veins and less frequently in N-S trending veins as well as concordant stratabound deposits spread in arkosic sandstone and shales.
2. The barite ore shows the following geotechnical properties: specific gravity: 3.1-4.5, porosity: 0.1-0.5%, water absorption capacity: 2-12% and uniaxial compressive strength: 11-43 N/mm^2.
3. The analyses of ore chemistry indicate the following concentrations: CaO (0.01-1.09%), SrO (0.11-2.17%), Hg (0.01-0.019 ppm), Cd (0.1-0.42 ppm), BaO (37.23-79.76%) and Fe_2O_3 (5.76-35.51%).
4. Whereas the geotechnical and geochemical properties of some of the barites compare fairly well with API and other industrial specifications implying that the ores are of good grade, others fail to meet the requirements and hence, will require processing and beneficiation.
5. Ore quality is controlled by the depth of occurrence, presence or absence of associated minerals and the geographic location of the vein within the ore field.

Acknowledgements

The authors are grateful to Mr Okwuolise, B.O., Dim, C. and Okeke, C. G who assisted in the field work and Anardarko Oil for the grant and the School of Civil Engineering and Geo-sciences, The University of Newcastle Upon Tyne, for the laboratory works. The manuscript benefited from the remarks and suggestions of two anonymous reviewers.

References

Akande S.O., Abimbola A.E., 1987. Aspect of the genesis of lead-zinc-fluorite-barite mineralization in the Nigeria Benue Trough. In: Matheis G., Schamelimier H. (Eds.) Current research in African Earth Sciences. Balkema Press, 365-369.

Akande S. O., Zentilli M., Reynolds P. H., 1989. Fluid inclusions and stable isotope studies of Pb – Zn – fluorite – barite Mineralization in the Lower and Middle Benue Trough, Nigeria, Mineralium Deposita, 24, 183 – 191.

Akande, S.O., Mucke, A.,1989. Mineralogy, textural and paragenetic studies of the lead-zinc-copper mineralization, lower Benue Trough and their genetic implications. Journal of African Earth Sciences, 9, 23-29.

Akande, S. O., (1999). Fluid flow Histories in the Cretaceous Sediments of the Benue rift

Basins, Nigeria: Fluid inclusions, Isotopes and Alteration Mineralogy Constraints. Nigerian Association of Petroleum Explorationist Bulletin, 14 (2),112 – 129.

Back, J.M., Clark, S.H.B., 1993. Preliminary results of petrographic studies of the Barite Hill gold deposit in the southern Carolina state belt, South Carolina. South Carolina Geology, 23, 67-78.

Balogun, C.K., 2000. Senior Secondary school Atlas. University of Calabar Press, Calabar,45pp.

Balcerzak, M. 2002. Sample digestion methods for the determination of traces of precious metals by spectrometric techniques. Analytical Sciences, 18, 737-750.

Benkhelil, J., 1989. The Origin and Evolution of the Cretaceous Benue Trough, Nigeria. Journal of African Earth Sciences, 8, 251-282.

Burke, K. C., Dessauvagie, T. F. J., and Whiteman, A. J., 1972. Geological History of the

Benue Valley and Adjacent Areas, In: Dessauvagie, T. F. J. and Whitman, A. J. (Eds) Africa Geology, Department of Geology, University of Ibadan, 482-491.

Bygott J., Money D.C., 1975. Landforms. In: Ofomata, G.E.K. (Ed.) Nigeria in Maps: Eastern States. Ethiope Publishing House, Benin City, 86-98.

Cratchley C.R., Jones J., 1965. An interpretation of the geology and gravity anomaly of the Benue Trough.Nigeria Oversea Geological Survey Geophysics paper 11, 26-35.

Duze M., Ojo A., 1993. Macmillan Senior Secondary School Atlas, Macmillan. Lagos, 207 pp.

Ekwere S. J., Ukpong E.E., 1994. Geochemistry of saline groundwater in Ogoja, Cross-River State, Nigeria. Journal of Mining and Geology, 29, 23-30.

Ezepue M.C.,1984. The geologic setting of lead-zinc deposits at Ishiagu, Southeastern Nigeria. Journal of African Earth Sciences. 2, 97-101.

Farrington J.D., 1952. A preliminary description of the Nigerian Lead-Zinc field. Economic Geology, 47, 583-608.

Gates I. J., 1972. Climatology and meteorology, Cambridge University Press, U. K. 407 pp.

Geological Survey of Nigerian Agency, 1994. Geologic Map of Nigeria, Abuja.

Grant N. K., 1971. South Atlantic, Benue Trough and Gulf of Guinea Tripple Junction. Geological Society of America Bulletin, 22, 2295 – 2298.

Hoque M., Nwajide C.S., 1985. Tectono-sedimentological evolution of an enlongate intracratonic basin(aulacogen): the case of the Benue Trough of Nigeria. Journal of Mining and Geology, 21, 19-26.

Igbozurike M.U., 1975. Vegetation types. In: Ofomata, G.E.K.(Ed) Nigeria in Maps. Ethiope Publishing House, Benin City, 35-48.

Iloeje N.P., 1965. A new geography of Nigeria. Logman Nigeria Ltd, Lagos, 187 pp.

Kogbe C. A., 1989. The Cretaceous Paleocene Sediments of Southern Nigeria. In: Kogbe C.A., (Ed.) Geology of Nigeria, Rock view Ltd., Jos., 356-363.

Monanu P.C., 1975. Rainfalls. In: Ofomata, G.E.K.(Ed) Nigeria in Maps. Ethiope Publishing House, Benin City, 56-78.

Nwachukwu S.O., 1972. The tectonic evolution of the southern portion of the Benue Trough, Nigeria. Geological Magazine, 109, 411-419.

Offodile M.E., 1976. A review of Geology of the Cretaceous of the Benue Valley. In: Kogbe,C.A. (Ed.) Geology of Nigeria, Rock View Ltd., Jos. pp. 364-376.

Ojo K.A., 1992. The Southern of the Benue Trough Cretaceous Stratigraphy, Basin Analysis, Paleo – oceanography and Geodynamic Evolution in Domain of the South Atlantic, Nigerian Association of Petroleum Explorationists Bulletin, 7, 131-152.

Olade M.A., 1975. Evolution of Nigerian Benue Trough (Aulacogen): A tectonic model. Geological Magazine, 112, 575-583.

Orajiaka S., 1964. Geology of the southern Obudu Plateau, Ogoja Province, Eastern Nigeria. Le Naturaliste Canadian, 3, 72-85.

Paradis S., Simandi G., Maclntyre D., Orris G.J., 1998. Sedimentary-hosted, stratiform Barite, In Geologic Fieldwork, 1997, British Columbia Ministry of Employment and Investment Paper1998-1, 24F-1-24F-2.

Reyment R. A., 1965. Aspect of the Geology of Nigeria. Ibadan University Press, Ibadan 145 pp.

Tijani M.N., Leohnert E.P., Uma K.O., 1996. Origin of Saline groundwaters in the ogoja area, lower Benue Trough, Nigeria. Journal of African Earth Sciences, 23, 237-256.

Ugwuonah E.N., Obiora S.C., 2008. Futher evidence for extensional rather than compressional tectonic origin for the Benue Trough using the igneous rock association. Abstract volume, 44th annual int. conf. of the Nigerian Mining and Geosciences Society, Abuja, 2008.

Uma K.O., Leohnert E.P., 1992. The brine fields of the Benue Trough, Nigeria: a comparative study of geomorphic, tectonic and hydrochemical properties. Journal of African Earth Sciences, 26, 23-29.

Uzuakpunwa A.B., 1980. Petrography differentiation of tectonically controlled Cretaceous sedimentary cycles. Southeastern Nigeria. Sedimentary Geology, 17, 235 – 245.

Wright J.B., 1976. Origin of the Benue Trough a critical review. In: Kogbe,C.A. (Ed.) Geology of Nigeria, Rock View Ltd., Jos, 234-244.