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RESEARCH ARTICLE

AN APPRAISAL OF THE BARITE RESOURCES OF CROSS RIVER STATE, SOUTHEASTERN NIGERIA: ORIGIN, DISTRIBUTION AND ECONOMIC POTENTIALS

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ABSTRACT

The occurrence of barite mineralization in both the sedimentary and basement rocks in Cross River State shows a genetic linkage in relations to source of the metal for fluids that drain the basements. This agrees with current opinion based on isotopic and fluid inclusion data obtained by previous workers who on the basis of observed strontium data, Pb isotope composition of galena and rare earth element patterns in fluorite suggested that the basement rocks in the Benue trough or their weathered equivalents are likely sources of metal for mineralizing fluids in the Benue trough. The gentle dip of the basement rocks are believed to have generated slow migration of the fluids, a condition that is necessary to prevent quick flushing thereby allowing adequate time for enough leaching of barium from the basement rocks to form the barite deposits. The NE-SW trend of the barite veins, the identified sinistral faults as well as the fact that the barites that are associated with wall rock alteration usually display well developed crystal habits are suggestive that the barite mineralization is structurally controlled. Ore fluid formation from juvenile and circulating connate brines have been proposed for the formation of the barite deposits in Cross River State and indeed in Nigeria.

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INTRODUCTION

The use of barite as a weight additive in oil drilling operation is very crucial to the oil industries and because the Nigerian barite deposits remain largely unexplored, oil companies operating in the Niger Delta mostly depend on its importation which constitutes a drain on the country's foreign reserve. This work is therefore aimed at generating a data base in terms of location, quality, quantity and ore reserve estimation of the barite deposits in Cross River State with a view to attracting both local and foreign investment for optimum exploitation of this mineral resources. The renewed interest in the exploration and exploitation of the Nation's barite deposits is uniquely important, being one of the industrial minerals required for economic and industrial revolution in the process of our Nation building. The strategic contributions of barite to the Nation's economy particularly in the upstream sector of the Nigerian petroleum and cement industries has necessitated the current efforts at developing the local content so as to improve the Nation's gross domestic product.

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More importantly, the seeming conundrum in the demand and supply gap that exists between local consumption and production expectation of barite within the framework of the Nation's strategic plan has put the mineral at the front burner of critical evaluation, hence this evaluation work. The study area covers the entire Cross River state which lies between latitudes 6° 32' and 9° 27' N and longitudes 7° 51' and 9° 28' E. The study focuses on a detailed assessment of barite which is an ore of barium sulphate with the chemical formula - $BaSO_4$, its mode of occurrence, ore paragenesis, genetic model for its formation, resource estimation and investment potentials which will, no doubt, generate the required impetus that would stimulate both foreign and local investments in the Nigeria's barite industry.

MATERIALS AND METHODS

This work commenced with a reconnaissance survey of the study area and the sensitization of the locals on the economic importance of the research on barites to the socio-economic development of the Nation. This was followed by identification of barite mineralization sites in each local government area of Cross River State. Subsequently, the study of the barite occurrences from one location to another, on local government

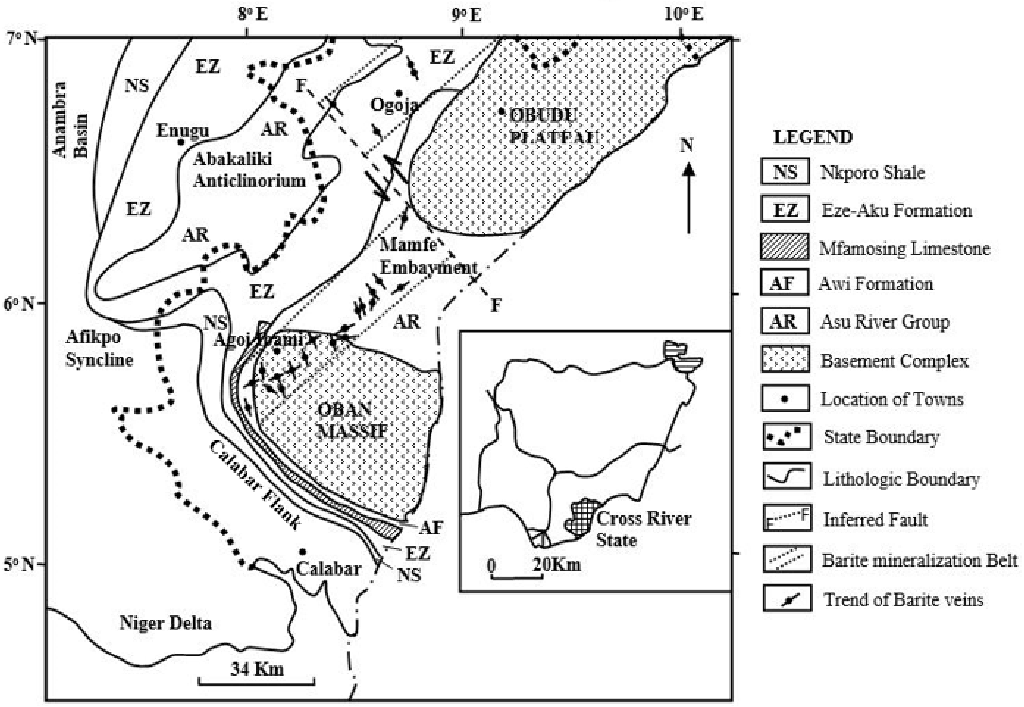

Figure 1. Location map of Cross River State showing the barite mineralization belt

Figure 2. Biotite schist around Iyamitet-Okokori-Edondon axis showing millimetric schistocity

Table 1. Tectono-Metamorphic Evolution of Southeastern Nigeria (Ekwueme, 2003)

SN	Event	Date
15	Intrusion of dolerite dykes in Obudu and Oban areas	140.5±0.7 - 204.0±9.9ma
14	Intrusion of Older granites in Obudu	507.6±10.1
13	Age of migmatization in Oban	510±11 - 527±16 Ma
12	Deformation/high grade metamorphism in Oban	546±24 Ma
11	Emplacement of charnockites in Oban and Obudu areas	584.5±1 - 574.1±1.0Ma
10	Emplacement of Uwet granodiorite	616.9±1Ma
9	Deformation and metamorphism of Obudu	605.5±1.4 - 676±26 Ma
8	Deformation and metamorphism of banded amphibolites and meta-ultramafic in Oban and Obudu	784±31 - 811±1.1Ma
7	Metamorphism of homogeneous amphibolites tholeiitic basalt protolith in Oban	1313±37Ma
6	Metamorphism of biotite-garnet schists in Obudu	1788.8±2.1Ma
5	Metamorphism of garnet-sillimanite gneisses in Obudu	1803.8±0.4Ma
4	Emplacement of granodiorite protolith of banded gneisses in Oban	1931.9±0.8Ma
3	Granulitic facies of metamorphism in Obudu	1980 - 2000Ma
2	Emplacement of tonalite protoliths of the granulites	2062.4±0.4Ma
1	Emplacement of granodiorite protoliths of biotite-garnet schist in Obudu	2505±0.5Ma

Table 2. Barite and associated Sulphide samples locations and host rocks

S/N	Sample Number	Mineralization	Associated/Host Rocks	Locations/Villages
Biase Local Government				
1	S4	Barite	Sandstone and shale	Ugbem
2	S5	Barite	Granite gneiss	Ibogo 1
3	S7	Barite	Granite gneiss	Ibogo 3
4	S8	Barite	Granite gneiss	Ibogo 4
5	S9	Barite	Ferruginized granite	Akpet 1
6	S11a	Barite	Granite gneiss	Akpet 1
7	S11b	Barite	Ferruginized sandstone	Akpet 1
8	S14	Barite	Sandstone/granite	Okurike
9	S15	Barite	Ferruginized sandstone	Okurike
Yakurr Local Government				
10	S18	Barite/galena	Ferruginized granite gneiss	Agoi Ekpo
11	S19	Barite	Ferruginized granite	Agoi Ekpo
12	S20	Barite/galena	Ferruginized migmatite	Agoi Ibami forest reserve 1
13	S21	Barite	Ferruginized granite gneiss	Agoi Ibami forest reserve 2
14	S22	Barite	Granite gneiss	Agoi Ibami forest reserve 3
15	S30	Barite	Ferruginized granite	Agoi Ibami North 1
16	S30a	Barite	Ferruginized granite	Agoi Ibami North 2
17	S30b	Barite	Ferruginized granite	Agoi Ibami North 3
18	S31	Barite	Ferruginized granite gneiss	Agoi Ibami forest reserve North
Obubra Local Government				
19	N23	Barite/galena	Ferruginized granite	Iyamitet 1
20	N23b	Barite/galena	Ferruginized granite	Iyamitet 2
21	N23c	Barite/galena	Ferruginized granite	Iyamitet 3
22	N27	Barite	Ferruginized sandstone	Edondon
23	N28	Barite	Ferruginized granite gneiss	Okokori
24	N29	Barite	Granite gneiss/schist	Iyamitet/Okokori bush
Ikom Local Government				
25	N32	Barite	Sandstone	Ekukunela 1
26	N32a	Barite/Lignite	Sandstone	Ekukunela 1
27	N33	Barite	Sandstone	Ekukunela 2
28	N34	Barite	Sandstone	Atakpa
29	N39	Barite/galena	Granodiorite/sandstone	Nkarasi
Yala Local Government				
30	N44	Barite	Sandstone	Gabu 1
31	N45	Barite	Sandstone/shale	Gabu 2
32	N46	Barite	Ferruginized sandstone	Gabu 3
33	N47	Barite	Ferruginized sandstone	Gabu 4
34	N50	Barite	Ferruginized sandstone	Omoji/Wanokpayi/Wanikade
35	N52	Barite	Ferruginized sandstone	Okpoma

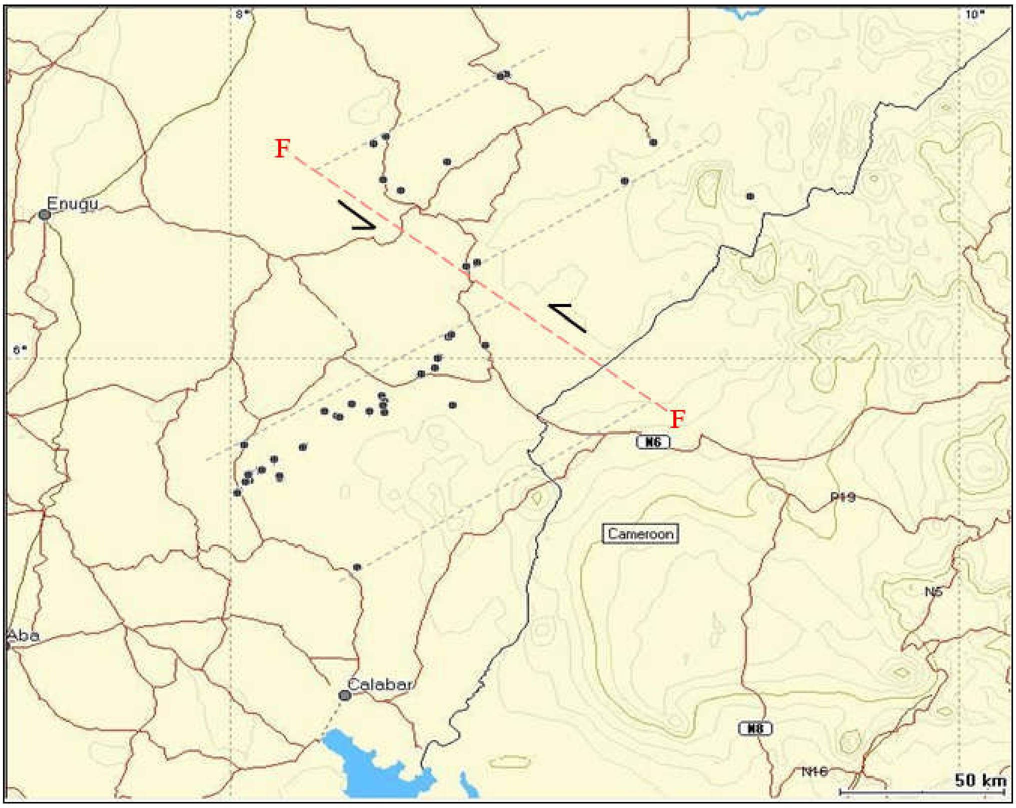

Figure 3. Composite map showing barite sample locations in Cross River State

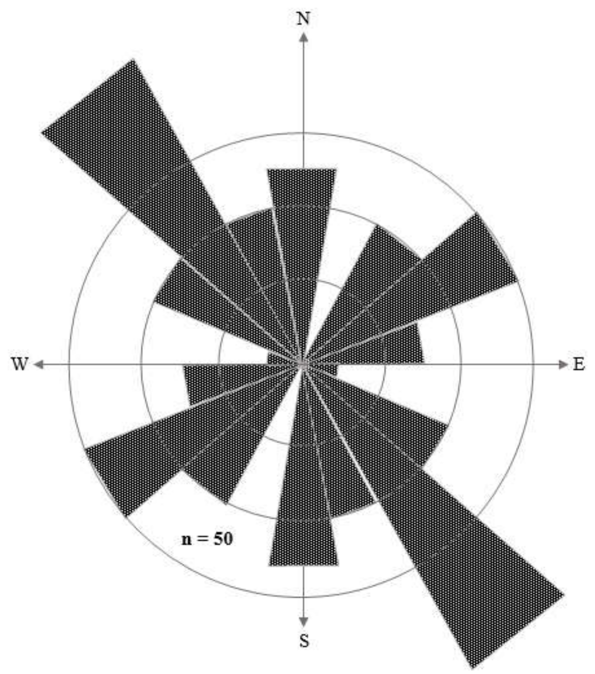

Figure 4. Rosette diagram of the trend of barite veins in Cross River State

basis which included Akamkpa, Biase, Yakurr, Obubra, Ikom, Yala, Obudu and Obanliku was undertaken. At each locality, careful observations were made on the morphology, trend, texture, area extent and depth of the barite vein with careful attention paid to the presence or absence of associated sulphide mineralization as well as host rock lithology, characteristics and contact relationships. Fresh samples of barite and host rock were collected (where possible) for further laboratory work. In areas where the barite veins are not outcropping and had not been exposed by the activities of the artisanal miners, pitting and/or trenching were carried out in order to fully study the ore morphometry of the barite veins. Systematic mapping of the areas of barite mineralization was carried out simultaneously with the assessment of the barite occurrences on a scale of 1:50,000, covering six (6) local government areas of Akamkpa, Biase, Yakurr (Ugep), Obubra, Ikom, and Yala (Ogoja). These areas covers five (5) 1:100,000 sheets comprising Ugep (Sheet 314), Ikom (Sheet 315), Bansara (Sheet 304) Ogoja (Sheet 290) and Abakaliki (Sheet 303).

Regional Geological Setting

The study area has a diverse geology which can be classified into four (4) mega structural units, namely: Calabar flank, Mamfe embayment, Oban massif and Obudu plateau. The Calabar flank and Mamfe embayment are sedimentary basins of Cretaceous-Tertiary age which lie unconformably on the Oban massif and Obudu plateau constituting part of the Pre-Cambrian basement complex of Nigeria (figure 1). The Calabar flank occurs within the southernmost region of the area and bounded in the North by the Oban massif and by the Calabar hinge line which delineates it from the Niger Delta in the west. The basin is associated with crustal block faults which resulted in a horst and graben structure trending NW –SE (Simpson, 1954). Deposition in the area was controlled by the tectonics of the horst and graben structure, and by eustatic sea level changes within the Southern Atlantic Ocean. Sedimentary rocks within the Calabar flanks include sandstones, limestones, calcareous sandstones, Shales, marls, siltstone, etc. Most of these rocks are highly fossiliferous, and this is attributed to the location of the Calabar flank on the Southern Atlantic Sea board, which was under constant marine transgression (Ekwueme, 2003). Ekwueme (1987) recognized 3 carbonate lithofacies in the Calabar flank which include basal limestone, fossiliferous limestone and dolomitic limestone associated with calcareous limestone of the area. These carbonate lithofacies are most likely members of the Albian Asu River Group, while the associated calcareous sandstone belongs to the Turonian Eze-Aku formation. Sedimentation in the Calabar flank started with the initial deposition of fluvio–deltaic cross-bedded sands of Awi formation (Adeleye and Fayose, 1978) in early cretaceous. This was followed by the first marine incursions that resulted in the deposition of the platform Mfamosing limestone (Foster, 1978; Petters 1982) during the middle Albian. During the Cenomanian and Turonian, subsidence of faulted blocks and widespread deposition of black to dark grey shales occurred with minor intercalations of marls and impure limestone (Nyong and Ramanathan, 1985). The Coniacian witnessed continued deposition of thin dark shales beds. These sediments are uncomformably overlain by a dominantly shale lithology with occasional mudstones and thin gypsum beds during the Campannian to Maastrichtian (Nyong and Ramanathan, 1985).

The Mamfe embayment is situated between the Oban massif and the Obudu plateau, and is pre-dominantly composed of fluviatile clastic sequences that exhibits point bar fining upwards cycles and over bank mudcracks. A maximum depth to basement of about 4km has been suggested for the southern flank of the Mamfe rift. The source of the sediments for the sedimentary basins in Southeastern Nigeria is thought to be the adjoining basement rocks of Oban massif, Obudu plateau and probably Mount Cameroun (Ekwueme, 2003). The Pre-Cambrian basement complex of Nigeria in the region is reflected in the Oban Massif and Obudu plateau which have been described as giant spurs forming the western prolongation of the Cameroon Mountain into Cross river plains of Southeastern Nigeria (Ekwueme, 2003 and Ephraim, 2005). The Oban massif occurs to the north of the Calabar flank and is separated from the Obudu plateau by the Mamfe embayment.
Both the Oban massif and the Obudu plateau are flanked by the Cameroon volcanic line and on the northeast by the Benue trough which is believed to be complementary structural features (Fitton, 1987). According to Ekwueme (2003), the Oban massif consists of a deeply dissected plateau which in places attains a height of 1,125 meters above mean sea levels while the Obudu plateau is more rugged and forms parts of the Pre-Cambrian Bamenda massif that stretches from Republic of Cameroon into Eastern Nigeria attaining a maximum height of 1,576 meters in the Obudu cattle ranch area. In the Oban Massif, the Basement complex is dominated by the Uwet granodiorite and charnockite masses which intruded a sequence of schists similar to those of the Southwest and Northwestern regions, while the Obudu plateau is made up of a floor of high grade quartzo-feldspathic gneisses intruded by diverse plutons of acidic-intermediate-basic compositions.

Lithological and Structural Evolution

The geology of Cross River state consists of diverse lithological units and are here-succinctly described. The sedimentary deposits are mostly sandstone, shale, marl, and siltstone found within the Calabar flank. In the Mamfe embayment, fluviatile clastic sequences that are made predominantly of pebbles, sandstones and siltstones are found associated with basaltic fragments. Migmatite-gneiss-quartzites unit are probably the most widespread and abundant, occurring within the basement terrains of Oban massif and Obudu plateau. The gneisses are medium- to coarse-grained and dissected by quartzo-feldspathic veins and dykes, resulting in migmatitic characteristics. The gneisses bear imprints of intense deformation suffered by the study area and are interbedded on a megascopic scale with quartzites thereby indicating the relevance of sedimentary processes in their evolutional history. The phyllitic and schistose rocks are abundant in the Oban Massif and in the Ekokori area of Obubra. Frequently, the schists are intensely weathered so that fresh exposures are scarce except in Ekokori area of Obubra L.G.A. where good outcrops of the schistose rock are mapped (figure 2). The plane of schistocity in biotite is millimetric and is well defined with fabrics trending in the direction N010º and dips by 62º E. Some of the quartz veins which have been boudinaged within the schist show boudins whose sizes range from 25cm by 5cm to 75cm by 15cm. In Obudu cattle ranch area, a schistose rock referred to as ultramafic schist by Ekwueme (2003) occurs as pods within garnet-hornblende gneiss of the area. Generally, phyllites occur frequently with the schists and are fine-grained weakly foliated rock while the schists are medium-grained and soapy/greasy to touch.

Amphibolites and dolerites occur mostly as dismembered enclaves and irregular lenses within the gneisses of the basement area. They are medium-grained in texture, varying in color from black to dark gray and are associated with dolerite stocks (Ekwueme 2003). Like in other parts of the Nigerian basement, the amphibolites in the basement complex of southeastern Nigeria bears imprints of several generations of deformation and are highly tectonized. Unlike the amphibolites, the dolerites in the area occur mostly as undeformed NE-SW trending dykes and cross-cut rocks in both the Oban Massif and Obudu plateau. In the Obudu, the dolerite dykes occupy mostly the flanks and topmost part of the plateau, commonly exhibiting ophitic textures. Charnockites and granulites, both magmatic and metamorphic, occur in abundance in the Obudu plateau area. The igneous charnockites outcrop around Bebi, Bogene and River Metu. They occur mostly as enclaves within the migmatitic gneisses and schist of the area. The metamorphic variety of the charnockites are associated with granulites and they both occur in Kanyang in eastern Boki and Okorotong area in Obudu. Granites and granodiorites outcrop as intrusives of batholiths, stocks and bosses into the gneisses of the area. Generally, they are coarse grained, weakly foliated to non-foliated and show sharp contacts with the enclosing country rock. Rocks of granodioritic composition are the dominant intrusive rocks, harboring numerous xenoliths of older gneisses in the western Oban area.

Diorite and syenite intrude the gneissic rocks of northeast Oban massif, occurring both as in-situ rock bodies and as xenolith trains in the host granite gneiss (Ekwueme, 2003). Rocks of basaltic composition are restricted to the Ugep and Ikom areas and are believed to be products of Tertiary volcanicity. Meta-ultramafics are mapped in Okure hills in Okorotong area, Shikpeshi Mountain and Obanliku–Sankwala area of the Obudu plateau (Ekwueme and Shilling, 1995). These rocks are strongly tectonized and are therefore suspected to be remnants of ophiolite complexes (Ekwueme, 2003). Pegmatites and quartz veins occur sporadically throughout the basement area especially in the Oban massif. These rocks maintain varied structural relationship with the host rocks. In some areas, the evidence of pegmatite is the presence of scattered fragment of feldspars, mica and quartz. Most pegmatite intrusions in the Oban massif have undergone considerable weathering and have formed secondary (placer) deposits worth investigating. Rocks outcropping within the study area have a general N-S to NE-SW trends which is consistent with those of other regions in the Nigerian basement and points to the fact that the area was affected by the Pan-African Orogeny. The basement rocks in this region have been subjected to intense deformation resulting in the occurrence of several generations of folds, faults, shears, fractures, etc. Linear structures identified in the basement includes pinch and swell, boudins and mineral lineation, defined by prismatic hornblende crystals as well as elongate quartz and plagioclase minerals. Some ductile structures observed are tight to isoclinal folds, asymmetrical, recumbent and ptygmatic types. Dominant trend and axial trace of these folds are in the N-S to NE-SW directions. The plunges of the folds vary from 10-15^{o}. The planar structures in the area include foliations, faults, shears and fractures. Foliation is defined by banding in the gneisses some of which are axial planar to axis of tight isoclinal folds. This foliation trends predominantly in the N-S to NE-SW directions with dips varying from 40 - 45^{0}.The banding is the product of strong deformation and migmatitic processes. Most minor faults observed in the area are found in the gneisses and schists with sinistral and dextral displacements of up to 10m. The work of Ekwueme (2003) dealt with the tectono-metamorphic evolution of southeastern Nigeria prior to the deposition of the Tertiary-Cretaceous sediments as summarized in Table 1.

Outcrop Locations and Description

A total of thirty five (35) representative samples were collected from fifty four (54) localities of barite mineralization in the study area. Barite mineralization in the southern part of the study area is found in Biase and Yakurr local government areas located in 30 outcrops that are enclosed in a belt trending NE-SW from Ugbem, in Biase local government on the right bank of the Cross river, through Okurike, Ibogo, Akpet, northeastwards to Agoi Ibami in Yakurr local government area. This belt continues northeastwards from Iyamitet in Obubra local government area northwards through Edondon and Okokori in Obubra local government area to Ekukunela, Atakpa and Nkarasi in Ikom local government area, before ending at Gabu-Okpoma area in Yala local government area, spanning about 100 kilometers in length and 50km in width. The trend of the barite mineralization was terminated by a sinistral transform fault running along a NW-SE direction while the mineralization outcrops again in Okpoma-Gabu area of Yala local government area (Ogoja province), extending for another 40 km before entering into Benue State (figure 3). Although, most of the major barite veins with considerable thickness and high quality trend NW-SE, a large number of the minor barite veins trends NE-SW (figure 4). Table 2 shows the sample location numbers and host rocks.

The Southern Barite Prospect

The mineralization belt at Ugbem exhibits barite in association with alternating fine-grained sandstone, shale, limestone and siltstone. The barite vein is traceable for about 300 meters and trends NE-SW with a thickness of between 0.8m to 1.0m. At the contact of a granite-gneiss with a massive sandstone around Okurike, about 1m thick vertical barite veins with a strike length of 400m occur within the ferruginous zone, trending N60^o within a dug trench of about 5m deep. Elsewhere around the vicinity of Okurike, a 0.8m thick barite vein trends N165^o east-west for about 300m length, and intrudes vertically into sandstone with marked ferruginization around the mineralization. The pit at Ibogo 1 reveals that the barite vein varies from 1.5 to 2.0m in thickness, with a strike length of about 500m, trending N-S within a weathered and ferruginized banded gneiss. Other minor barite veins trends NNW-SSE, with a dip angle of about 55º and trends in the direction of N75º. In another pit at Ibogo, a barite vein of about 1m thick trends vertically along N161^o, cutting across a weathered granite-gneiss whose metamorphic fabrics dips at 29º in the direction of N115º. A second barite vein of about 0.45 to 1.2m thick at this location dips nearly vertically and trends between N161º-163º. A minor barite vein was also observed around Ibogo dipping vertically with a 17cm width across the granite-gneiss. The dip and azimuth in the gneiss is 34º/110º. At Akpet, well developed crystals of barite are seen growing in fissures in the ferruginized zone which trends N115º and corresponds to the trend of the barite vein which has a width of 0.8m and a strike length of 200m. Another pit dug at Akpet reveals a 1.5m thick barite vein trending for 400m length in the direction N125º, dipping nearly vertically.

A high grade barite mineralization of about 1.2m wide, with well-developed transparent crystals, was also observed inside a dolerite dyke trending N120º and about 350m in length. At the eastern part of Agoi Ekpo in Yakurr local government area, barite mineralization of about 0.6m thick and 500m long occurs within a ferruginous zone in a consolidated sandstone along the bed of river Ruwem. The barite vein trends 060º-065º and shows isolated crystals of galena within the barite. Another barite mineralization occur at the vicinity of Agoi Ekpo where the 3m wide barite veins dip almost vertically and trend along N150º. The medium- to coarse-grained granitic host rock shows a purplish brown colour, representing the ferruginized zone that enclosed the barite vein. The barite is milky white coloured with well-formed transparent crystals which are associated with isolated crystals of galena. At Agoi Ibami forest reserve, a barite vein with galena mineralization of about 400m long and 0.8m thick occurs trending N70^o and dips nearly vertically within a ferruginous zone in a migmatitic gneiss intruded by pegmatites. To the northeastern part of this locality, lenses of barite measuring about 4m high and 2m thick trends along N70^o for a distance of 300m at a depth of about 5m in a trench dug within a partly ferruginous granite-gneiss. At another location in Agoi Ibami forest reserve, lenses of barite vein of about 0.7m thick with a 500m length occurs at a 5m depth within the ferruginous granite-gneiss trending N70º and intruded by pegmatites. The last location of barite mineralization in Agoi Ibami forest reserve where it outcrops on the ground surface with a width of 0.8m, 800m long trending N145º with a dip of 60ºSW within the medium-grained granite host rock. The barite here is purer and heavier than at the previous locations.

The Northern Barite Prospect

Around Iyamitet village in the northern part of Cross River state, barite veins occur within medium-grained granites, trending between N010^o to N160^o within a ferruginous band and about 0.06m to 0.5m in width with a vertical dip as observed in a dug pit. The barite vein which runs for about 1km along strike is closely associated with sulphide mineralization, including galena, sphalerite and chalcopyrite. Another barite occurrence in the same area is in the form of 3m thick and 40m long lenses trending N35º, occurring in association with ferruginous zone about 5m below the ground surface. A third location, in this area has a 1m thick and 300m long barite vein associated with sulphide mineralization trending N190º and dipping at 80º westerly within a partly ferruginous coarse-grained granite intruded by pegmatites. A massive sandstone, white to yellowish-brown coloured and undergoing ferruginization with well-developed thick bedding plane, trending N160º and dips 36º westerly outcrops at Iyamitet and extend northwesterly to Edondon village where 1m thick and 500m long barite veins occur within a large ferruginous zone trending N45º. Other smaller barite veins pervade the ferruginous area within the medium-grained sandstone (figure 5) with crystals of iron sulphide mineralization which are observed at the contact between the main barite veins, breaking down to release iron and native sulphur, which is seen as yellowish powder.

At Okokori village, south of Edondon, barite vein of 0.5m thick and 250m long trends N090^o and occurs within a partly ferruginized granite-gneiss host rock associated with sulphide mineralization and intruded by pegmatites. At Ekukunela in Ikom local government area, 2 major parallel barite veins occur, each about 1m wide and a 3m gap between them. 5 other smaller veins, each about 0.2m wide occur between the 2 major veins. The barite veins trend N145º and dip vertically within the host rock of fine-grained sandstone with clayey matrix. The sandstone is thinly bedded with localized trough cross beds and trends N080º with a dip angle of 23º in the direction N135º. The dip and azimuth of the bisectrix of the trough cross beds is 8º/340º while the wavelength is 1.2m with an amplitude of 0.28m. Other sedimentary structures observed are *liesegang* rings, minor discontinuous *flasers* (made up of dark gray shale) as well as minor coal seams which are concordant with the general bedding plane in the sandstone. In the southern part of Ekukunela, a barite vein of 2m thick trends N145º within sandstone while lignite seams were observed at a depth of about 30 meters below ground surface. Another veins of barite around Ekukunela trends N145º and dips vertically within a milky gray-coloured sandstone which is partly ferruginized. At Atakpa, a 1m thick barite vein trends N150º and dips almost vertically. Other subsidiary veins of barite of about 0.15m in width occur within consolidated fine-grained sandstone parallel to the major vein, exhibiting pseudomorphism on feldspar. The barite vein at Ekpokpa is 1m thick and exposed for about 200 meters in length, trending N185º and dips vertically. The barite vein is hosted within ferruginous sandstone.

At Nkarasi, a 1m thick barite vein trends N190º and dips almost vertically within a lithified partly ferruginized arkosic sandstone associated with crystals of galena occur within the barite. In the southern part of Nde, minor barite vein of about 0.06m thick trends N145º and dips almost vertically within a fine- to medium-grained sandstone, occurring 2m below ground surface. In the northern part of Yala local government area, the sinistrally displaced barite mineralization belt through a transform fault continues northeasterly, outcropping at Gabu, where thick barite veins of 1.5m to 3m trending between N070^o to N100º and dipping vertically were exposed in a pit at 5m depth intruding through both the partly ferruginized fine- to medium-grained sandstone and the overlying dark shale bed (figure 6).

Figure 5. Minor veinlets of barite within the ferruginized zone of the sandstone at Gabu

Figure 6. A dark shale bed with boulders of barite exposed within an abandoned exploration pit

Table 3. Estimates of barite resources in Cross River State

S/N	Zones	No. of veins	Dimensions (L x B x D)	Estimates (m^3)	Estimates (Tons)
S1	Okurike/Ugbem	3	1000m× 2.8m×3m	8400	2.10
S2	Ibogo	5	1500m×3.0m×3m	13500	3.38
S3	Akpet	3	2000m×3.5m×3m	21000	5.25
S4	Agoi Ekpo	2	2000m×2.5m×3m	15000	3.75
S5	Agoi Ibami forest reserve	3	2700m×3.5m×3m	28350	7.09
S6	Agoi Ibami North	6	4200m×5.3m×3m	66780	16.70
N1	Iyamitet/Okokori/Edondon	5	2090m×4.5m×3m	28215	7.05
N2	Ekukunela	3	3100m×3m×3m	27900	6.98
N3	Atakpa	3	1400m×1.4m×3m	17640	4.41
N4	Nkarasi	2	2000m×2m×3m	12000	3.00
N5	Gabu/Oshina/Alifokpa	11	6000m×6m×3m	108000	27.00
N6	Omoji(Ukelle North)	2	1000m×2.4m×3m	7200	1.80
N7	Okpoma	2	2000m×2m×3m	12000	3.00
Total		50		354,225 m^3	88.6 tons

Figure 7. Barite deposit near Gabu intruded by pegmatitic vein

The breakdown of associated sulphide mineralization leaves yellowish stains of native Sulphur within the barite veins. The barite at Gabu which are traceable for 500m are of very high quality and transparent with distinctively high specific gravity. At another barite location in Gabu/Oshina area, 2 barite veins of about 4m thick, each trending in the direction N120º and separated by 10m country are exposed within the medium- to coarse-grained sandstone. The barite veins which extend for more than 10m in depth are traceable over a distance of about 1km along strike (figure 7). A barite vein of about 1.2m thick also outcrops on the upper slope of a high ridge before the break of slope at Omoji hill within a weathered and ferruginized fine-grained granite trending N145º and dips vertically. At Okpoma, a high quality and transparent 2m thick barite of high specific gravity trends N145º and dips vertically within a partly ferruginized coarse-grained sandstone.

Estimates of Barite Resource in Cross River State

The 6 barite mineralization zones comprising of 22 major vein deposits in the southern belt of Cross River State starting from the southwestern part of Ugbem extends northeasterly for about 70km with a maximum width of about 50km. The veins constituting the various deposits range in sizes ranging in width from 0.5m to 2m and traceable strike length of up to 1.5km at an average 3m depth. There are 7 barite mineralization areas constituted by 28 major vein deposits in the northern belt of Cross River State trending northeasterly for about 6km total vein length, 1.5m to 4.5m thickness for an average 3m depth. The quality of Cross River State barite is among the best in the world as laboratory studies shows that the barites have specific gravity values from 3.7 to 4.3 depending on the deposit.

The barite deposits at Osina and Gabu in Yala local government is the purest in Cross River State with an average specific gravity of 4.30 (Akpeke, 2000; Bassey, 1988; Egeh et, al., 2002, 2004). This value is slightly above the American Petroleum Institute (API) standard value of 4.20. For a conservative reserve estimation, therefore, a uniform mineralization depth of 3m and an average specific gravity of 4.0 are used to calculate the reserve tonnage as presented in table 3.

Investment Potentials

This study has revealed that countless barite veins and veinlets occur in Cross River State and are largely unexplored for reasons of inaccessibility and terrain ruggedness. The area has been subjected to periods of tectonism, magmatism and regional metamorphism leading to the development of fractures, faults and folds creating favourable sites for mineralization. The study area therefore holds a great potential in terms of barite mineralization as presented in table 2. Exploitable barite per m^3 deposit is put at a conservative value of 354,225m³ which when converted, using an average specific gravity of 4, gives a conservative value of 88.6 metric tons. However, this reserve figure is grossly underestimated because of the rugged terrain hindering detailed investigation. The lack of adequate information and detailed investigation had in the past robbed the state of investment opportunities in this sector. It is hoped that the present findings will encourage curious investors to go into investment in the area. The barite resource of southern Cross River State is therefore more than adequate to sustain a barite beneficiation industry in terms of its size and quality. So far only illegal miners are currently mining some of the veins by pick and shovel methods and the product hand-sorted.

Ore Paragenesis

Many workers have investigated the geology of the Nigerian Pb-Zn-fluorite-barite deposits, the nature of ore-forming fluids and have in fact advanced theories for their origin (Farrington, 1954; Olade 1976; Offodile, 1975; Olade and Morton, 1985). Many of the earlier workers proposed a magmatic-hydrothermal origin since the deposits are epigenetic as suggested by vein morphology and relationship to fractures (Olade, 1976). Farrington (1952) suggested that the mineralizing solutions were derived from intrusive rocks. Olade (1976) argues that epigenesis does not necessarily imply magmatic-hydrothermal origin, and that not all epigenetic bodies are hydrothermal in origin. Moreover, according to Olade (1976), in many of the mineralized localities, no igneous rocks occur at a distance of up to 20km and no traces of the path taken by the hydrothermal fluids can be established. Akande *et al*. (1989) also argued against the formation from juvenile and connate brine sources on the basis of lack of close spatial association of igneous intrusions as well as evidence obtained from fluid inclusion data. However, the present study refutes the evidence based on lack of igneous proximity given the proximity of the Cross River barite zone to the Cameroun volcanic line, and the occurrence of barite veins in basement rocks that includes igneous rocks such as granitic gneisses and medium-grained granites. Ore fluid formation from juvenile and connate brines (Offodile; 1975), as well as from circulating connate brines have also been proposed for the deposits. This study therefore proposed a genetic model in which the precipitation of barite along permeable zones by the metal-bearing fluids which must have extracted Ba^{+} from basement sources and SO_4^{-} from seawater or evaporite as the possible source of the Cross River barite.

DISCUSSION AND CONCLUSION

Discussion

The barite resources of Cross River State is emplaced in a belt of mineralization about 50km wide. This belt could be traced from Ugbem and Okurike axis in the southwest of the State for about 100kms through Ibogo, Agoi Ibami, Agoi Ekpo, Edondon, Iyamitet, Okokori to Nkarasi near Ogoja in Ikom local government area. The displaced northern extension of the belt continues in Yala local government area (Ogoja province) from Okpoma, to Gabu, Oshinna and to Ukelle north, at Omoji. This extension spans about 50km in the State before entering into Benue State. The barite presents itself mostly in the form of veins, veinlets and, in some cases, as small lenses. These bodies are mostly hosted within shale, sandstones, granite gneiss and granites, and are nearly always have the areas intruded by the barite vein ferruginized, showing purplish brown colour. In few places, the barite host rocks are intruded by pegmatites and diorites. The barite occurs usually as vertical to near vertical veins and veinlets that are frequently associated with sulphide mineralization including galena, chalcopyrite and sphalerite. In some localities, the sulphides, especially chalcopyrite, occur at the fringes of the barite veins and are indeed responsible for the observed ferruginization in the host rock around the barite vein. In some instance where the sulphide is mostly galena, it occur in discrete fractures and cleavage surfaces within the ferruginous zone around the barite veins. The quality and quantity of the barite appear to increase in value northwards. The best values occur at Gabu, Oshina and Okpoma in Yala local government area where the barites are crystalline and transparent with an increased thickness of between 3m to 5m and a specific gravity of over 4.5. Field evidence shows that the principal mode of barite mineralization in all localities studied is open-space fillings within *en echelon* tensional gentle-dipping fracture systems that trends predominantly in the NW-SE directions with subordinate NE-SW trending barite veins. This study has clearly established that barite deposits are not restricted to the Cretaceous sedimentary basins as erroneously concluded in the past (Farrignton, 1952; Offodile, 1975; Olade, 1976; Olade and Morton, 1985; Akande *et al*., 1989). Rather, the barite veins are hosted in rocks of diverse ages; notably the Pre-Cambrian basement rocks and the Cretaceous sedimentary rocks of the lower Benue trough. It was observed that the barite veins that are surrounded by altered and ferruginized zone, where wall-rock alteration effects are significant, display well developed crystal habits.

The mineralization in some localities exhibits pseudomorphism of the barite on white feldspars especially in locations with well-formed crystals like in Akpet area. The occurrence of barite mineralization in both the sedimentary and basement rocks in Cross River State shows a genetic linkage in relations to source of the metal for fluids that drain the basements. This agrees with current opinion based on isotopic and fluid inclusion data (Akande *et al*., 1989; Olade, 1976). On the basis of observed strontium data, Pb isotope composition of galena and REE patterns in fluorite, Akande *et al*. (1989) suggested that the basement rocks in the Benue trough or their weathered equivalents are likely sources of metal for mineralizing fluids in the Benue trough. The sulphur could have been sourced from the Cretaceous evaporites in the trough while the gentle dip of the basement rocks are believed to have generated slow migration of the fluids. This condition is necessary to prevent quick flushing and to allow adequate time for enough leaching of barium from the basement rocks for the barite deposits. The NE-SW trend of the barite veins, the identified sinistral faults as well as the fact that the barites which are associated with wall rock alteration display well developed crystal habits are indications that the barite mineralization is structurally controlled.

Conclusion

Barite occurrences have been mapped and documented in many localities in Cross River State consisting of various veins of different dimensions trending predominantly NW-SE but which are confined to a mineralization belt trending NE-SW. High grade deposits are found in Oshina - Gabu and Okpoma (Ogoja sheet 290), Ekukunela (Ikom sheet 315), Akpet (Ugep sheet 314) and Agoi Ibami (Ugep sheet 314). A modest estimated reserve of 354,225m³ of barite at 88.6 metric tons has been calculated for Cross River State and this has unarguably put the State with the largest deposit of barite in Nigeria today. The occurrence of barite in Cretaceous Sandstones with wall rock alteration effects suggests that the origin of the barite deposit is intimately related to the Benue rift system. The precipitation of barite along permeable zones by the metal-bearing fluids which must have extracted Ba^{+} from basement sources and SO_4^{-} from seawater or evaporite is hereby suggested as the most probable genetic model for the Cross River barite deposits in consonance with the work of Akande *et al*. (1989). Traces of galena, sphalerite and chalcopyrite are often associated with the barite mineralization.

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