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Reserve Estimation of Barite Deposits using Geological and Geophysical Investigations in Cross River State South Eastern, Nigeria.

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Abstract
Barite deposits occur mostly as concealed mineralization dominantly in shales and sandstones of Cretaceous age in Cross River State. Vertical Electrical Sounding (VES) and Horizontal Resistivity Profiling (HRP) have been carried out in areas with less mining activities. Also, field geological mapping in which the lengths and the widths of barite veins were measured has been undertaken.The geophysical data collected within 22 communities was done in 52 locations and the results indicate that the barite occurs in veins located at 10 – 12.2m depth and could be up to 40m in open mine pits. The lateral extent of the veins range from 4m to 65m from the from the horizontal resistivity profiling results, and could be traced from the field mapping to about 950m . The general direction of the barite mineralization is NE-SW . The result of the reserve estimate indicate that the Agoi village of Oban Massif has 1,981,177.0 metric tons of reserves, these are greater than the reserve found at mamfe embayment villages of Ekukunela and Nkarasi with reserve deposits of about 865, 684 metric tons. These reserves are also greater than those found in parts of the lower Benue trough villages of Osina and Okpoma (Ogoja) with reserve deposits of about 774, 345 metric tons. An estimated reserve of over nine (9) million metric tons of barite have been calculated and documented for Cross River Stat for the first time. This has unarguably put Cross River State as having the largest reserve of barite in Nigeria.
Keywords: Barite, VES, HRP, Reserve, geophysical, mineralization , resistivity

1.0 Introduction

Barite can occur in three forms, which include stratiform or bedded, residual and in veins. Barite veins occur in many parts of the world and they are the most productive. For example, such veins yielded 900 tons of barite in North Africa in 1994; 2,400 tons of barite in Middle and Far East in the same year and 355 tons barite in South Africa.(Kaiser et al. 1987) described barite deposits in veins mostly metamorphosed in rocks of the Piedmont belt, Virginia U.S.A. Barite veins occur widely in the United States of America and other parts of the world.

Residual deposits are formed when disseminated barite or barite veins in pre-existing rocks accumulate on a basement as the previous host rock is eroded and weathered. The important deposits of Washington County occur in residual clay derived from Cambrian dolomite in which primary deposits occur (Bateman, 1950)

Barite mineralization in Nigeria was first reported by the Geological survey of Nigeria. No interest was shown then towards its exploration. Detailed exploration work on barite deposit located at Azara District part of Nasarawa State in northcentral Nigeria was carried out by the Nigerian Mining corporation between 1975 and 1980 and a reserve of about 730, 000 tonnes of barite was established over the area (Maiha, 1996). As at 2004 the Federal Ministry of Solid Minerals Development (FMSMD 2004) has documented only two States with barite mineralization in Nigeria. Cross River State, this study area, was not listed. Only Plateau State (Azara) and Taraba State (Iba and Dumgel) both in north central Nigeria were listed.

This study reports abundant occurrence of barite deposits in Cross River State of Nigeria. Geophysical Survey was employed to unravel most of the barite deposits which occur as concealed vein mineralization. The geophysical technique has made it possible to estimate the reserve in the area which is up to 9 million metric tonnes greater than barite reserves for the well-known Azara occurrence which has a reserve of 730,000 tonnes.

2.0 Geological Setting

Two giant spurs make up the Precambrian basement of southeastern Nigeria, namely the Oban massif and the Obudu Plateau (Fig 1). These spurs are the western prolongation of Cameroon Mountains into the Cross river plains of Southeastern Nigeria. The basements are overlain by Cretaceous sediments of the Calabar Flank in the south and west but separated by a Cretaceous sediment filled graben or Mamfe rift (Embayment) in the north (Fig 2).(Orajaka 1964), (Umeji 1988), (Ekwueme 1990),(Ekwueme & Onyeagocha 1982), (Ekwueme 2003),(Ukwang 1998),(Ukaegbu 2003),(Ephraim 2005), and(Obioha & Ekwueme 2011) have studied in detail the Precambrian basement rocks in the area. These are composed of phyllites, schists, gneisses, granulites and migmatites intruded by rocks of granitic, mafic and ultramafic composition. They range in age from NeoArchaean to Pan-African (Ekwueme & Kroener 1997, 1998).

A dolerite in Obudu yielded $^{40}Ar/^{39}Ar$ plateau age of 140 ± 0.7Ma (Ekwueme 1994a). The basement has undergone polyphase deformation and polymetamorphism and several generations of folding, faulting, shearing and fracturing have been reported (Ekwueme 1987, 1994b). The dominant trend of the structural features comprising of planar and linear types is N-S to NE-SW (0-30^0). Minor trends in the NW-SE and E-W also occur and have been interpreted as relicts of pre-Pan African deformation episodes (Grant 1972; Onyeagocha & Ekwueme, 1982; Ekwueme 1987, 1994b). Bassey (1998) had suggested that the Oban massif and Obudu plateau could have been continuous prior to the formation of the Mamfe Basin which lies between them (Petters et al. 1982).

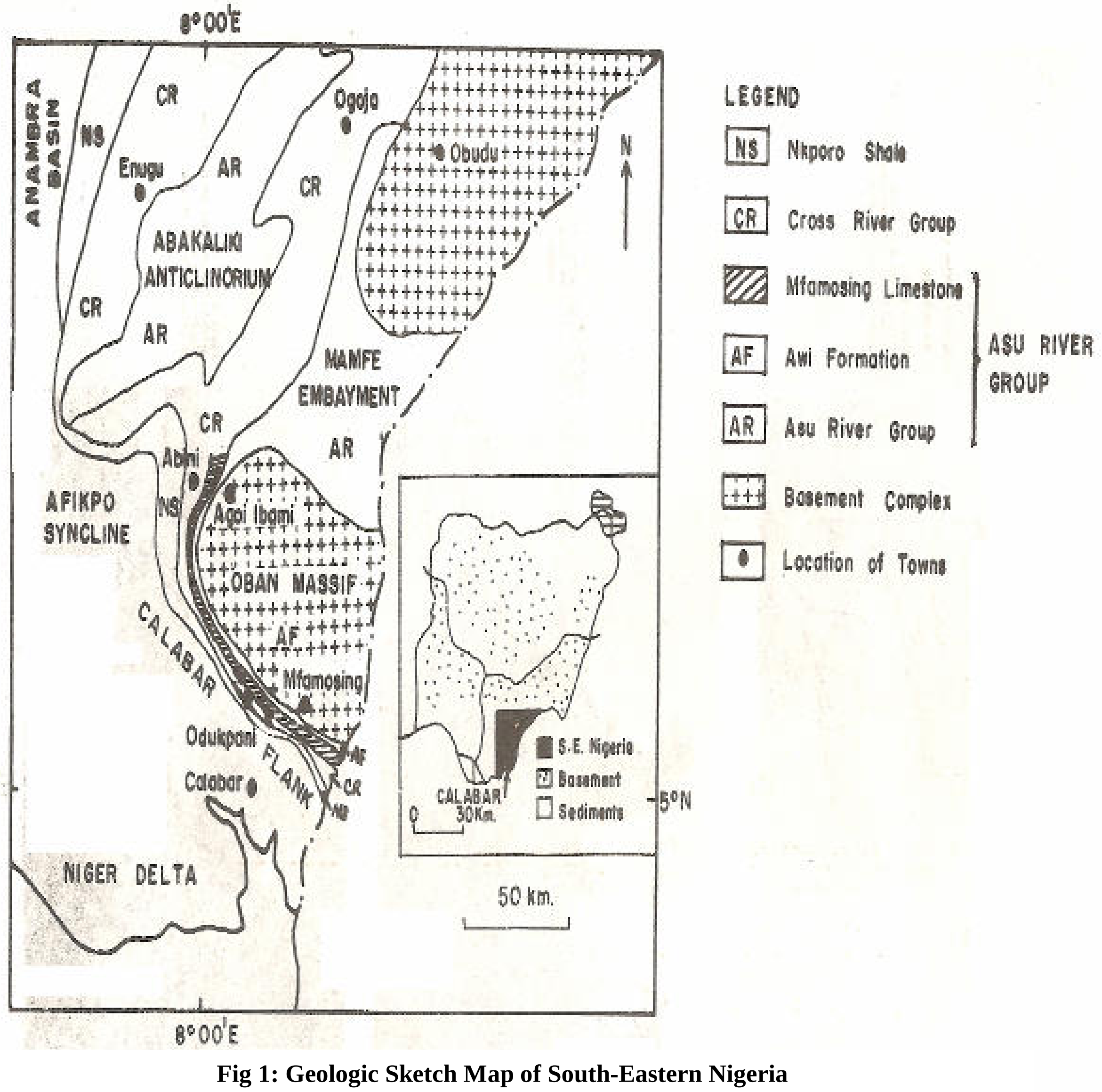

Fig 1: Geologic Sketch Map of South-Eastern Nigeria (After Ekwueme et al. 1995).

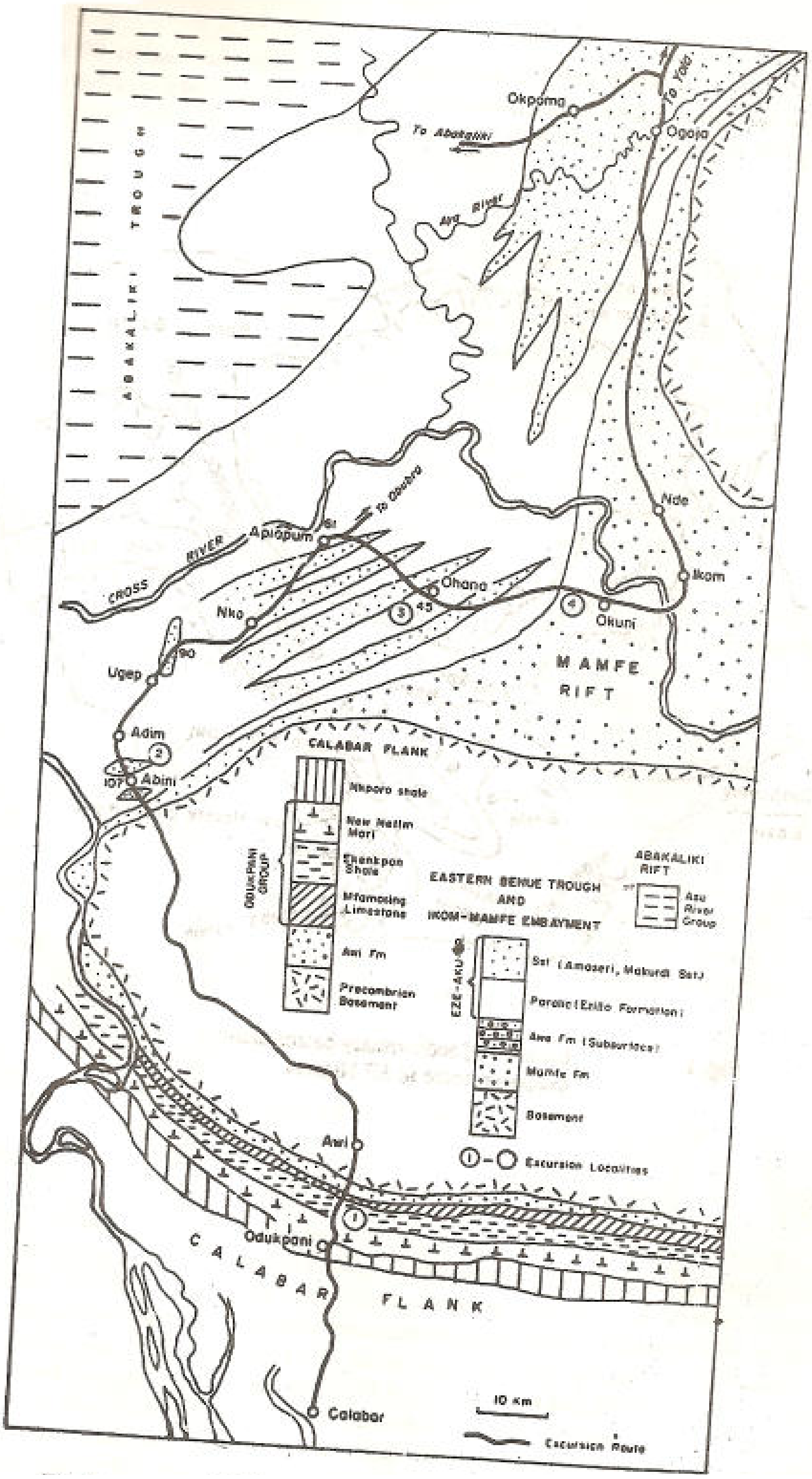

Fig 2: Geological Map of Calabar Flank, Oban Massif and Mamfe Embayment (After Ekwueme *et al*., 1995)

The Mamfe Embayment (Fig 2) situated between the Oban massif and Obudu Plateau is predominantly a fluviatile clastic sequence that exhibits point bar fining-upward cycles and over bank mudrocks (Ekwueme, 2003). This formation has been described as the Asu River Group of Albian age. Associated with the sedimentary rocks of Mamfe rift are basaltic rocks which exhibit excellent columnar joints in the middle of the lava flow. The type locality of the Mamfe Formation is on the bank of Cross River at Mamfe in adjoining Cameroon Republic where 800m of massive arkosic sandstones with marl, sandy limestone and shale intercalations are exposed (Reyment 1965). The sequence in the Nigerian part of the Mamfe Basin comprises conglomeritic immature mudstones (Petters, 1982, Ekwueme 1994) have shown evidence of faulting at the edge of the Mamfe Basin.

The Calabar Flank (Fig. 2) comprises of lithologies such as sandstone, limestone, marl and shale. The oldest formation in the Flank is a sandstone shale sequence which is folded and lies unconformably on the Precambrian basement at Awi. This is the Awi formation of Aptian-Albian age described by (Petter, 1982). Overlying these rocks is the Mfamosing Limestone Formation. The Eze-Aku shale lies on the Mfamosing limestone. It has been described as Ekenkpon shale by Petters (2003). Associated with these shales are bioturbatred marls which are overlain by Nkporo shale of Campanian-Maastritchtian age. The youngest formation in the Calabar Flank is the unconsolidated sand belonging to Benin Formation of Tertiary age. It is deltaic.

2.1 Field Occurence And Distribution Of Barite Minerilization

Structural features are most important in the localization of the barite ore and have greatly influenced barite mineralization in the study area. The detailed features discovered to determine the immediate localization of barite in the area are mainly unconformities and major faults. These are features that come under daily observation of the mining geologists. They become well exposed in mining operation and are observed slowly but destroyed rapidly.

The major faults of the Benue Trough and the unconformities along the boundary between the basement and the sediments are favourable sites for the accumulation of the barite deposits in the study area. This is why some deposits are found to occur in lenses and impervious covers. Due to tectonic events that took place in the study area, layers of rocks have been folded into curves that are lower in the middle than at the end known as geosyncline. Obviously in a geosyncline, accumulation of sediments was followed by uplifting, faulting and folding. This is evident from the location of barite vein within the generalized stratigraphic chart at Agoi Ibami (Fig 3) in which the mineralization is concentrated within the sediments at the boundary between the basement and the sediments. These sediments are the carbonaceous shales, limestone, siltstone, and sandstone with the Cross River and Asu River Groups of the Albian sequence in the lower Benue Trough (Fig 4). The Cenomanian was a period of uplifting and non-deposition in the most part of the Benue Trough and at this time the Albian sediments in the Trough axis were slightly deformed, fractured, brecciated and intruded by mafic dykes (Nwachukwu 1972, Benkhelil 1987). In the Turonian, the Asu River Group was covered by sediments of the Eze-Aku Formation consisting of carbonaceous shales, limestones and siltstone which grade into sandstone (Akande et al. 1992). Hence, it is hereby suggested that the mineralization episodes were in pulses occurring in basement, in cross-cutting intrusive and in sediments.

For instance, barite deposits found in Agoi Ibami occur in calcareous sandstones and carbonaceous shales with high permeability that helped to localize the mineral in these areas. The calcareous sandstone therefore allowed the mineralizing fluids to form barite deposits in this area. Overlying the basement complex in some parts of the study area are Cretaceous sediments of the Benue Trough within which the barite mineralization occurs (Fig 5). The sketch of typical barites bearing dolerite dyke that occupies the boundary between sandstone and basement is shown in Fig 6.

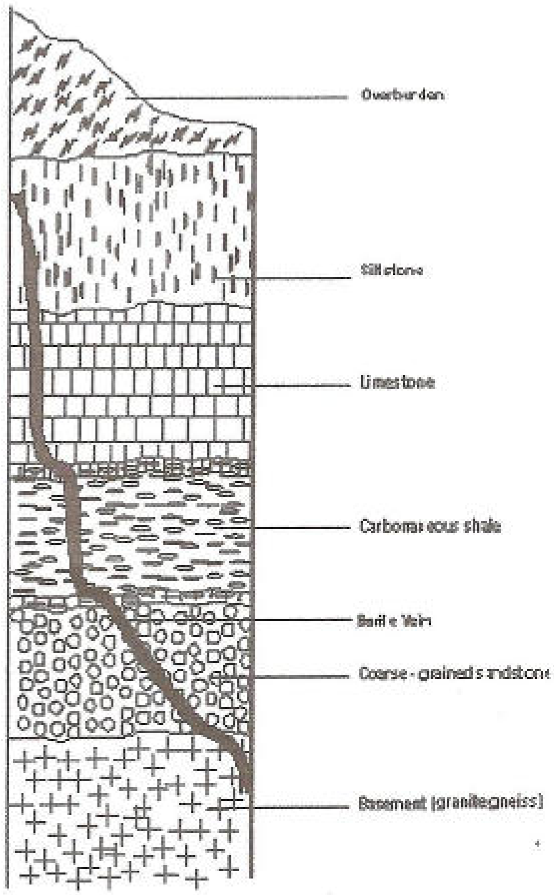

Fig 3: Location of barite vein in a generalized stratigraphic chart at Agoi Ibami (050 43'27" N, 080 12' 22"E)
(Scale; 1cm=0.1m for stratigraphic sequence
1cm=50m for barite vein length)

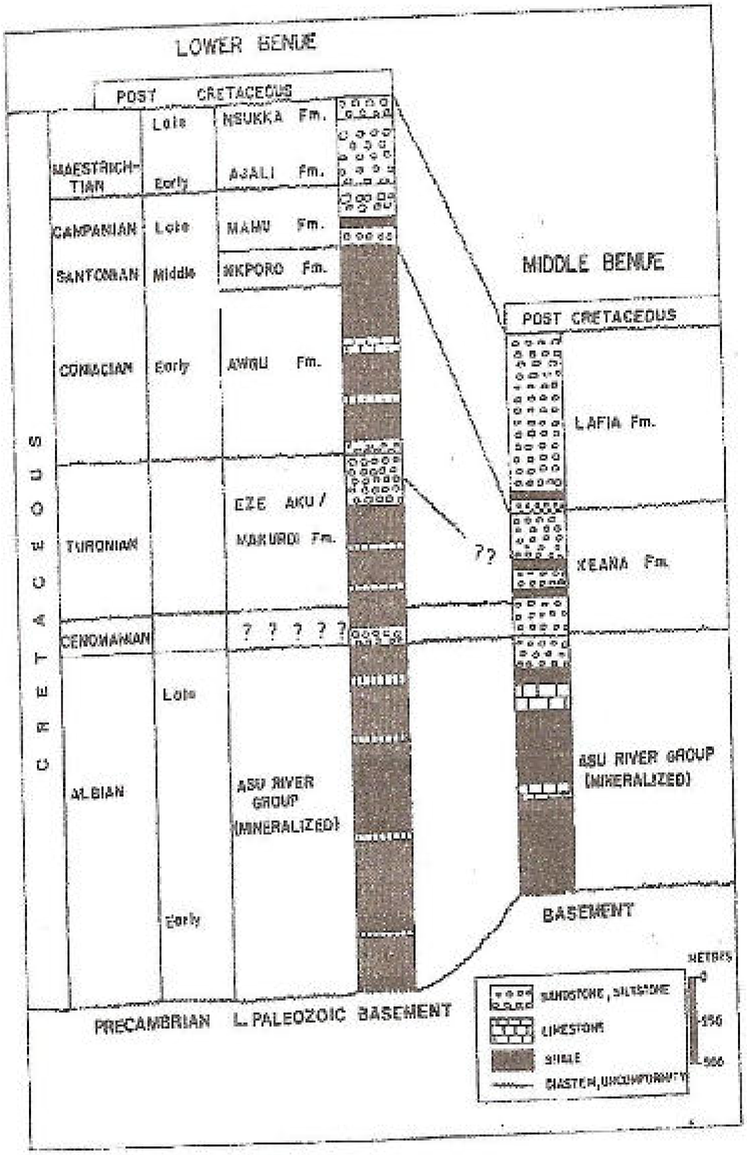

Fig 4: Generalized Cretaceous Stratigraphy of the Lower Benue Trough (Simplified from Akande *et al,* 1989)

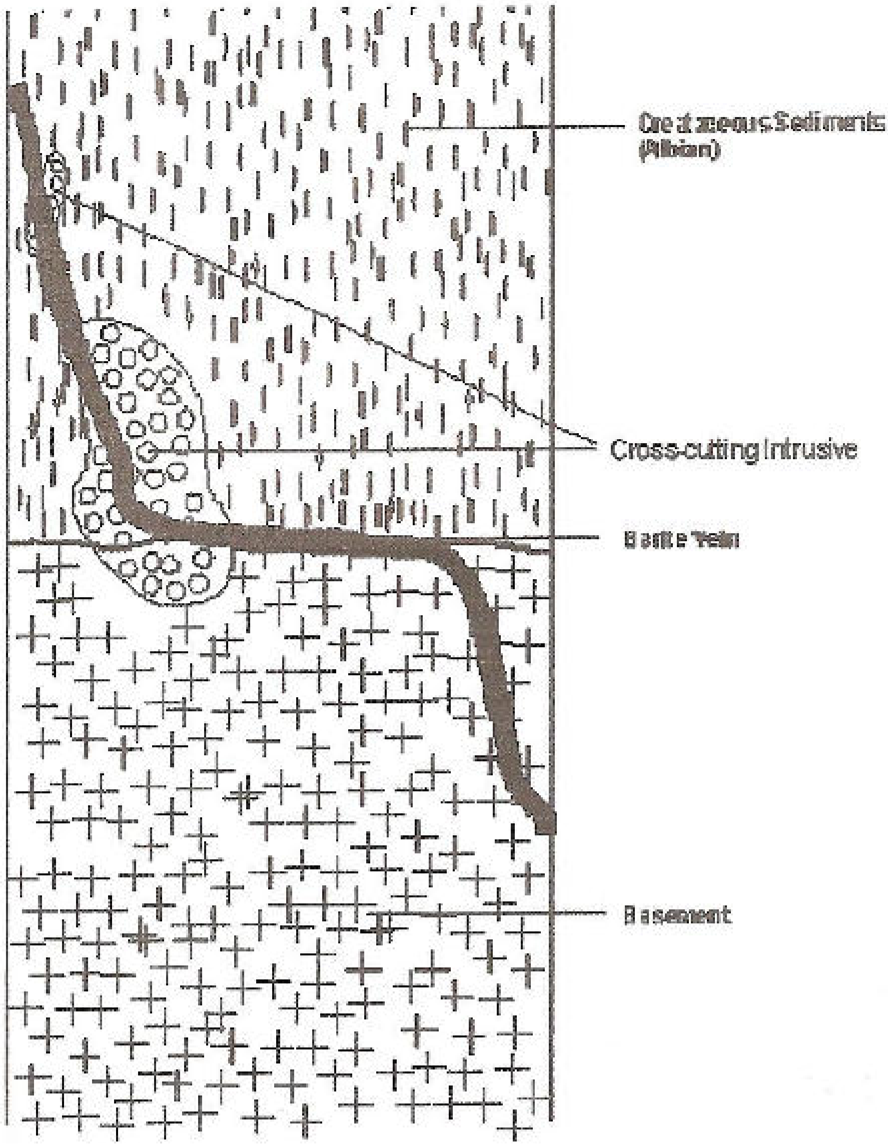

Fig 5: Generalized model of Barite Mineralization in Cross River State
(Scale: 1cm = 50m for barite vein length)

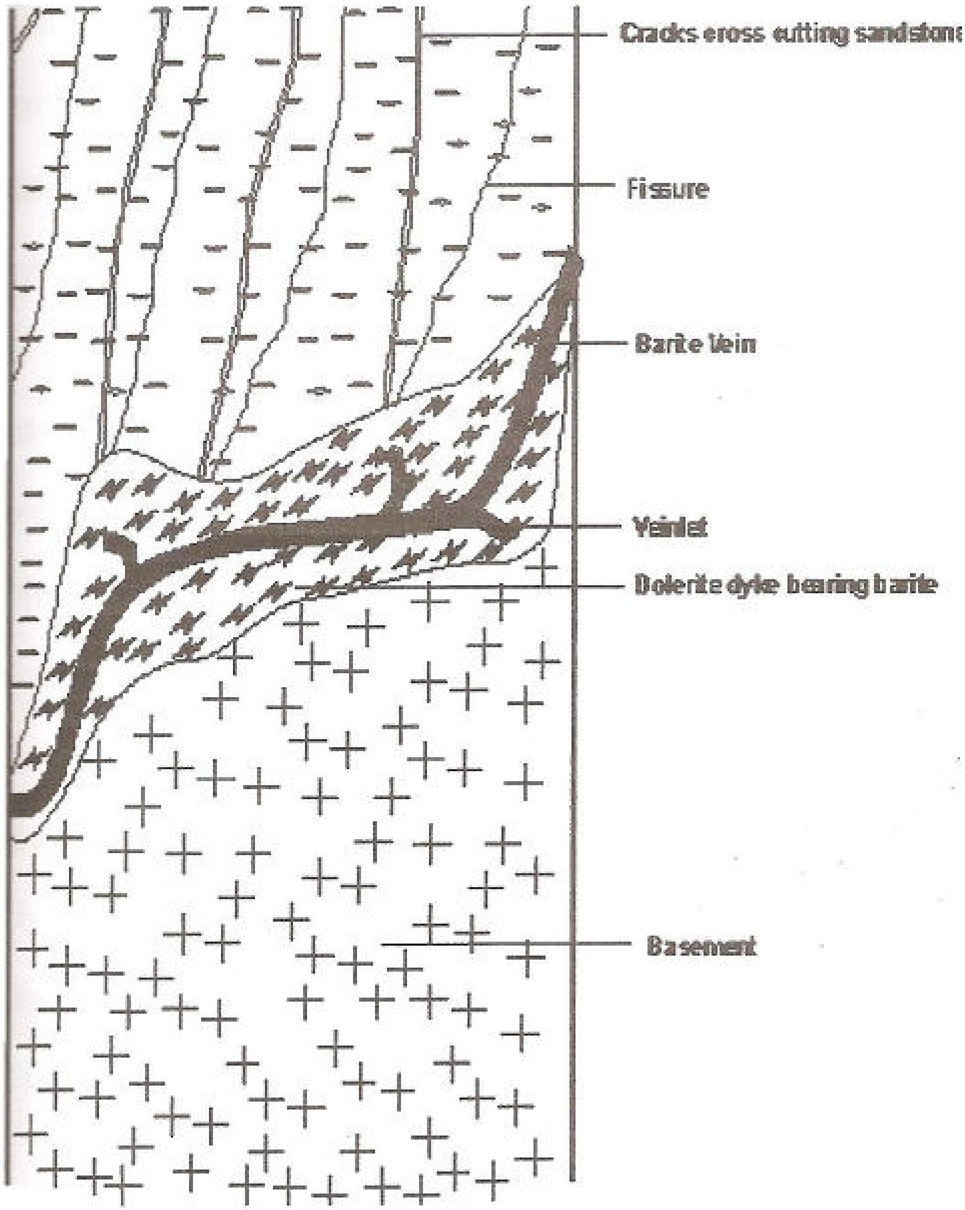

Fig 6: Sketch of barite bearing dolerite dyke occupying the boundary between sandstone and basement at Okurike (05^0 37^1 07"N, 08^0 31" 25"E) (Scalae: 1cm = 50m for barite vein length)

3. Geophysical Survey

Geophysical survey was carried out in areas with minimal interference by mining activities, whilst some physical parameters were used to evaluate barite deposits in other areas where mining activities could not permit geophysical survey. Electrical Resistivity of Gabu, Osina and Alifokpa areas was carried out using an Abem Terrameter (300 SAS model) and employing the Vertical Electrical Sounding (VES) and Horizontal Resistivity Profiling (HRP) techniques.

The apparent resistivity of each subsurface rock layer can be calculated from the following relationship:

$$\rho_2 = k \cdot R \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

Where k is the geometric factor and R is the resistance of the rock layer (dobrin et,al 1988) from Ohm's Law,

$$R = \frac{V}{I} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

Where V is the potential difference measured across the two potential electrodes and I is the current through the two current electrodes. If half current electrode spacing $AB/2$ which is usually the same as the depth of investigation is given as L, and half the potential electrode spacing $MN/2$ is given as a, then for the Schlumberger array , the geometric factor, K can be calculated from the relationship, (Telford et, al 1990).

$$k = \frac{\pi}{a}\left(\frac{(L)^2 - (a)^2}{2}\right) \cdots\cdots\cdots (3)$$

and 3.

$$\rho_a = \frac{\pi}{a}\left(\frac{(L)^2 - (a)^2}{2}\right) \bullet R \cdots\cdots (4)$$

The Schlumberger configuration was employed in carrying out the vertical electric sounding (VES) and the horizontal resistivity profiling (HRP).

The VES and HRP traverses were made in a more or less NE-SW direction in both areas. The VES technique was based on Schlumberger electrode array using a maximum half current electrode spacing of 215m. The current electrode spacing (AB/2m) was varied from 1.5 – 215m at logarithmically equal intervals giving a depth of investigation of 100m or more. In each case, the expansion of the current electrodes was in a direction parallel to the average strike (NE-SW), of the outcrops. The apparent resistivities (pa) versus (AB/2) were plotted digitally and the resultant sounding curves were smoothened and then interpreted by curve matching techniques.(Griffith et, al 1981).

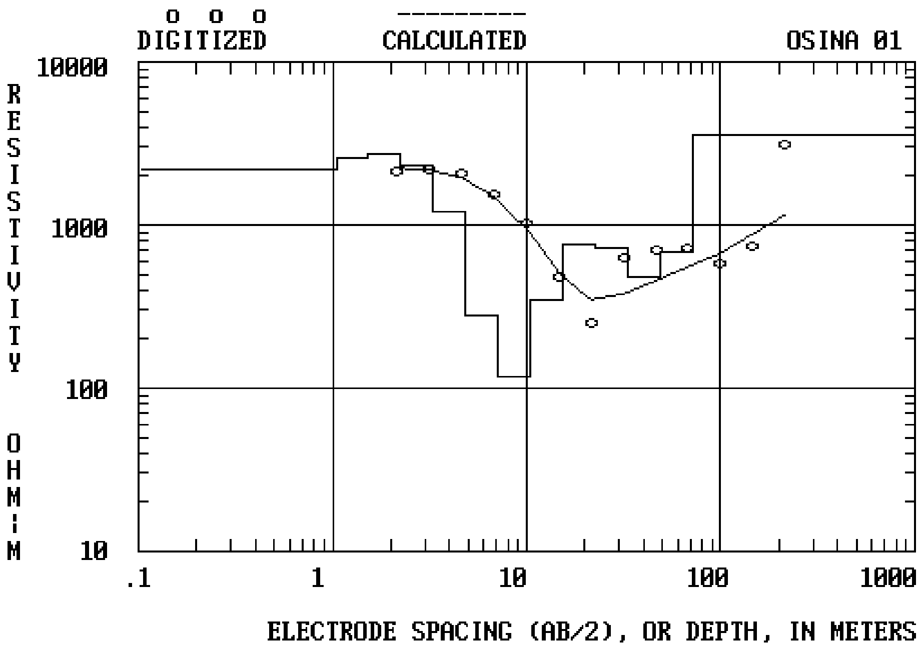

Fig. 7 Modelled Resistivity Sounding Curve for Osina (VES)

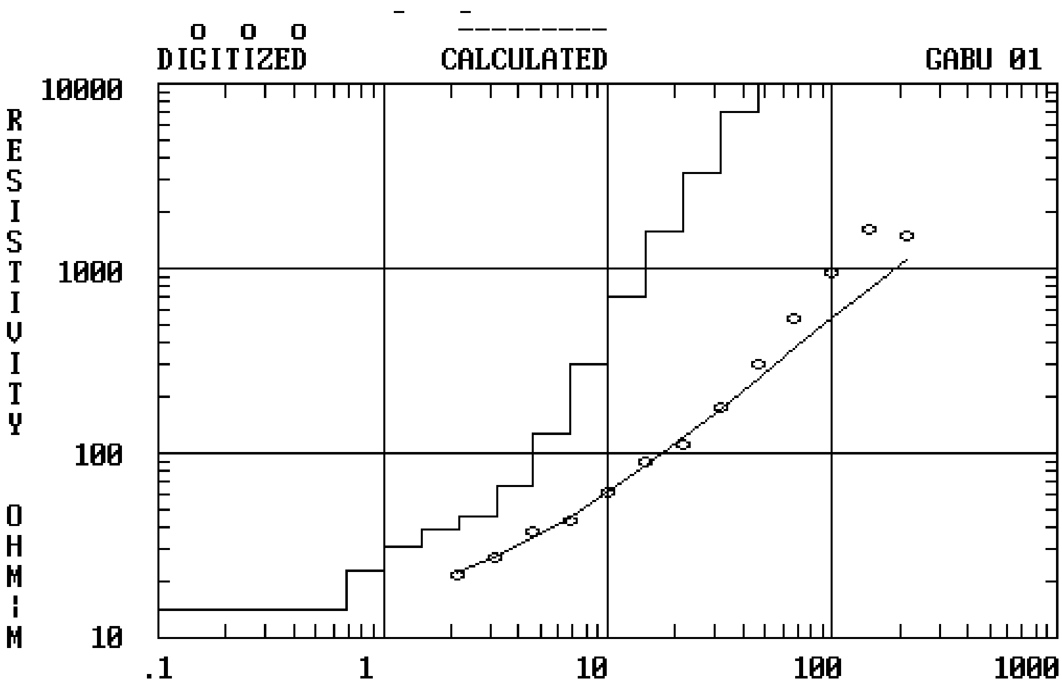

Fig.8 Modelled Resistivity Sounding Curve for Gabu (VES)

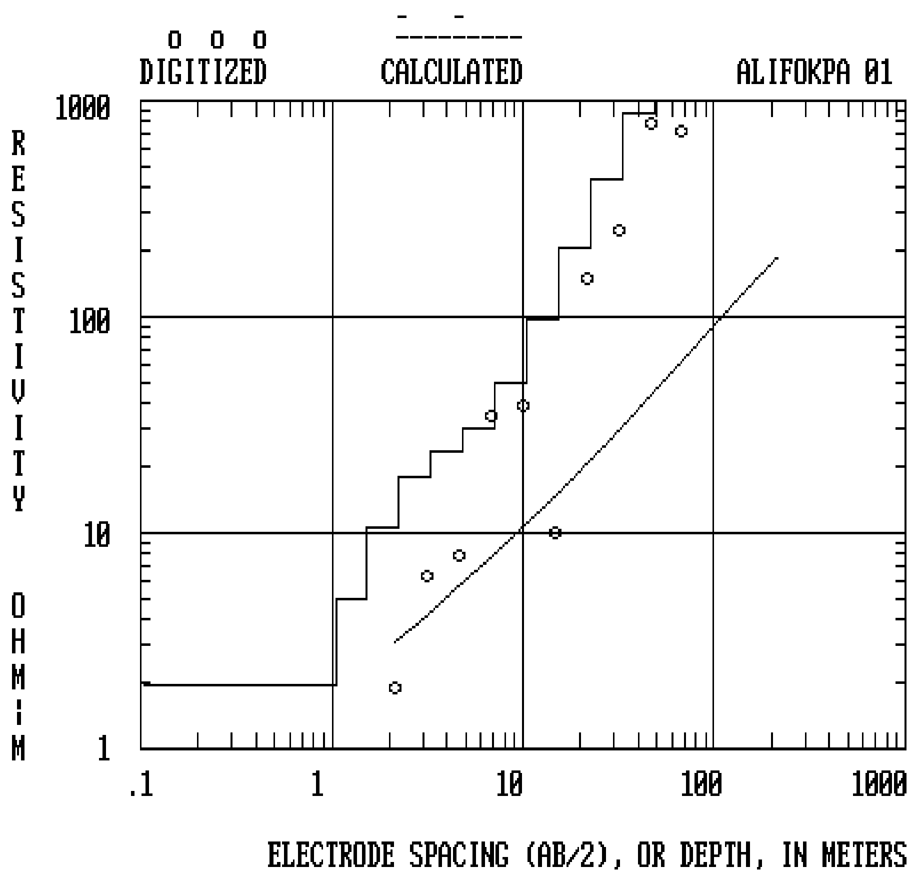

Fig.9 Modelled Resistivity Sounding Curve for Alifokpa (VES)

Table 1: Result of modeled VES Layers showing depth and Resistivities values

OSINA 01
METERS

13	Resistivities
1.0449	2170.191
1.533703	2546.944
2.251169	2691.606
3.304264	2310.382
4.849997	1224.446
7.118822	277.3622
10.449	117.8323
15.33704	344.0837
22.51169	760.2642
33.04265	717.569
48.49998	481.3149
71.18823	677.3372
99999	3576.635

GABU 01
METERS

13	Resistivities
.6855587	14.29782
1.006263	23.22025
1.476992	31.324
2.167927	38.59795
6.855589	128.7409
10.06263	302.1616
14.76992	711.1782
21.67928	1573.674
31.82083	3336.19
46.70659	7067.4
99999	15442.08

ALIFOKPA 01
METERS

13	Resistivities
1.0449	1.98425
1.533703	4.9536
2.251169	10.65595
3.304264	17.96812
4.849997	23.8057
7.118822	30.61906
10.449	48.77957
15.33704	97.36834
22.51169	207.1921
33.04265	428.9928
48.49998	870.5688
71.18823	1791.314
99999	3897.891

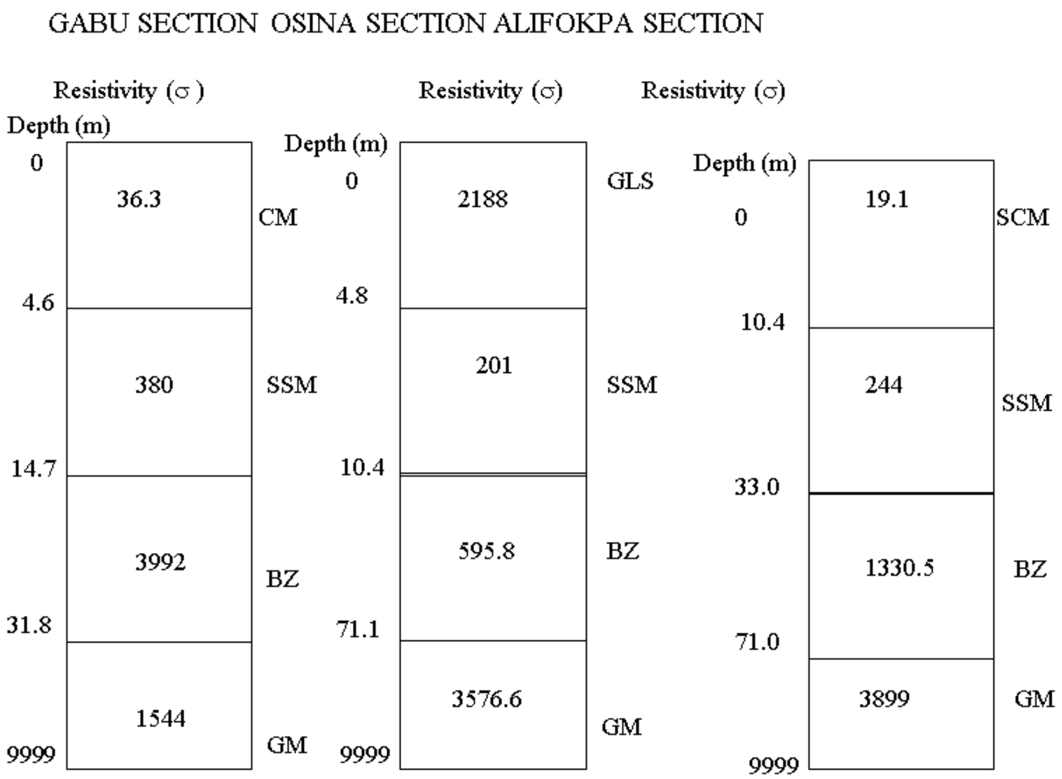

Fig 10 Geoeletric sections showing depths of zones of suspected Barite Mineralization at Osina, Gabu, and Alifokpa (BZ – barite zone, GLS = Gravel / Laterite soils, CM = clayed material, GM = Granite material SCM = saturated clayed material) SSM = saturated sand material Number represent apparent resistivities in Ohm –m.

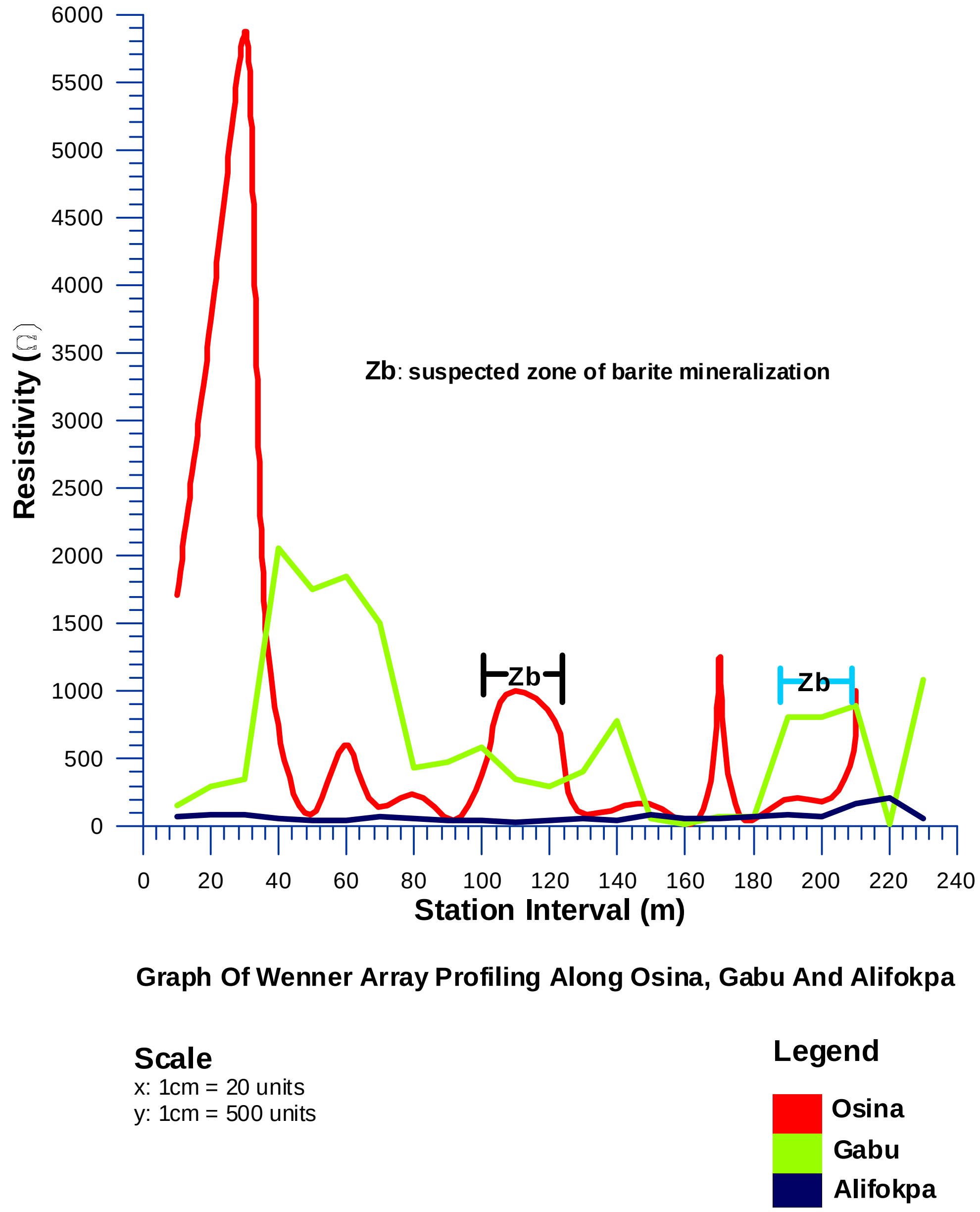

Fig 11: Graph of Wenner Array Profilling along Osina, Gabu and Alifokpa

The VES measurements were carried out to determine the variation of rock resistivity with depth and then the top and bottom surface of the concealed barite mineralization. The HRP was carried out using Wenner electrode array with a constant station interval of 10m. Twenty two (22) stations spaced at an interval of 10m were occupied along the HRP lines at Gabu, Osina and Alifokpa. The choice of the electrical resistivity method was based on the anomalous high resistivity (Egeh, et al, 2004) usually associated with most mineralized ores like barite, which generally exhibit high densities and extremely low porosities. The resistivity measuresments made in the field were then subjected to interactive computer modeling, as well as manual interpretation to delineate zones with anomalous resistivity in relation to the geology of the area.

3.1 Geophysical Interpretation

Resistivity measurements were made in the field at 22 location using the vertical electric sounding VES and horizontal resistivity profilling HRP. However only three locations of Osina, Gabu and Akofakpa are displayed for illustration on how the data was processed. The field measurements are analysed using the Zoody Software in processing the VES data and grapher 2.0 in processing the HRP data.

The values for AB/2 and MN/2 were manually keyed into the programme and subjected to iterative computer modeling (Figs 7, 8 and fig 9 respectively).

The result of iterative curve matching of the observed curve and the calculated curve is displayed in table 1.0. Which is used to produce the geoelectric sections fig.8. The results of the geomodels indicates that the three modeled sections has four subsurface layers each as shown in fig.10 There is a correlation in the resistivities values within the subsurface layers. Low resistivity values indicates areas with clays moderality high values represent sandy clay's with possible saturation of ground water while areas of moderately high resistivity values represent possible barite refrailtored granites with barites. Intrusives while very high resistivity values represent fresh basements of granitic origin.

The Gabu section has a top layer clay materials with resistivity of 36.3Ωm to depth of 4:6m, below this unit is the sandy – day materials with resistivity values of 380Ωm at depth α 14.7m, this unit is underlain by possible fresh barite of high resistivity value of 3992Ωm at depth of 31.8m, below this zone is the fresh granite materials with resistivity values of 15444Ωm.

The Osina model section has a top layer of consolidated gravels and lateritic soils with a high resistivity value of 2188Ωm, this is followed by a moderately high saturated sandy clayed layer with a resistivity value of 210Ωm, this layer is followed by a possible weathered barite zone with a resistivity of 595.8Ωm which is underlain by a granitic basement with a resistivity value of 3576.6Ωm .

Also the Alifokpa model section indicates a top saturated clay unit with a resistivity value of 19.1Ωm , this is followed by a compacted sandy clay unit with a resistivity value of 1330.5Ωm basement with a resistivity value of 3899Ωm . The barites in the area possibly intruded the granitic materials which extends to 11.5m in Gabu, 1500m in Osina and 152m in Alifokpa (table 2.0).

TABLE 2: BARITE EVALUATION FROM RESISTIVITY STUDY AT OSINA, GABU AND ALIFOKPA COMMUNITIES

COMMUNITY/ VES SITE	LAYER NUMBER	RESISTIVITIES Ωm	DEPT RANGE (M)	THICKNESS (m)	THICKNESS OF PROSPECT AREA (m)	LATERAL EXTENT (m)	AREA EXTENT (m)
Gabu	0 1 2 3 4	 36.3 380 3998 1544	 0.0-4.6 46-14.7 147-31.8 31.8-∝	 4.6 14.7 17.1	17.1	65	1105
Osina	0 1 2 3	 2188 210 595.8	 0.0-4.8 48-10.4 10.4-71.1	 4.8 10.4 60.7	5.6	25	1500
Alifokpa	0 1 2	 19.1 244	 0.0-10.21 10.4-33.0	 10.4 22.6	12.2	4	152
					TOTAL	$2757M^2$	

TABLE 3: ESTIMATION BARITE RESERVES OF THE MAIN VEIN IN STUDY AREA

LOCATIONS	WIDTH (W) 1	TRACEABLE LENGTH (M) 2	APPARENT DEPTH (M) 3	OVER DURDEN (M) 4	REAL DEPTH (M) 5	VOLUME(M^3) 1X2X5 6	BARITE RESERVE IN (TONS) 6 X SG 7
ALIFOKPA (AL) V	2.00	4	28.65	0.55	38	304	1,368
OSINA(OS) V1	4.20	25	45.6	1.60	5.6	6,373.5	28,680.75
V2	3.52	970	14.12	0.95	5.6	19,120.6	84,130.8
V3	2.95	850	39.50	1.00	5.6	14,042	61,784.8
V4	2.00	790	36.80	1.20	5.6	8,848	38,931.2
V5	2.60	1002	38.30	1.10	5.6	14,589.12	64,192.12
GABU (GA) V1	3.12	65	42.10	1.30	17.1	3,467.88	15,605.46
V2	2.80	965	40.00	1.80	10.1	27,290.2	122,805.9
V3	3.15	785	36.50	1.20	10.1	24,974.8	112,386.49
OMOJI (OM) V1							
V2	2.20	850	34.40	2.00	32.40	60588	261740
	1.95	760	26.60	1.70	24.90	36902	159416
OKPOMA (OKP) V1	2.15	900	35.20	1.15	34.05	65887	283313
V2	1.85	865	33.00	2.00	31.00	49608	213313
EKUKUNELA (EK) V1	2.2	1000	36.50	0.80	35.70	78540	328297
V2	1.6	950	34.50	0.40	34.10	51832	216658
ATAKPA (AT) V1	1.98	820	26.50	0.70	25.80	41889	183892
V2	2.10	680	19.80	0.50	19.30	27560	120990
V3	1.86	790	24.70	1.10	23.60	34678	152236
NKARASI (NK) V1	2.88	940	18.50	0.90	17.60	47647	197257
V2	1.58	850	23.40	1.20	22.20	29815	123432
EDONDON (ED) V1	1.98	790	38.00	1.00	37.00	57875	229187
V2	2.05	682	36.50	0.60	35.90	50192	198760
OKOKORI (KO) V	2.20	900	21.80	0.80	21.00	41580	175468
D	DOME	OF	RADIUS		40.60		1183461
OKUMURETET (ET) V	2.60	680	27.55	0.60	26.95	47648	198214
IYAMITETE (IY) V	1.60	740	33.55	0.32	33.23	39344	161312
AGOI IBAMI NORTH (AN)							
V1	1.85	880	30.00	1.20	28.80	46886	206300
V2	1.78	728	30.50	0.50	30.00	38875	171051
V3	2.20	770	35.00	1.10	33.90	57427	252677
V4	2.10	650	36.50	0.60	35.90	49004	215615
AGOI F. R.(AE) V1	3.32	815	42.00	1.20	40.80	110397	486849
V2	2.60	700	25.85	0.40	25.45	46319	204267
V3	1.90	820	39.50	2.00	37.50	58425	257654
AGOI EKPO (AE) V1	2.2	780	28.80	0.56	28.24	48460	204501
V2	1.20	800	39.50	1.20	38.30	36768	155161
ITU AGOI (IT) V1	2.00	965	31.60	0.70	31.10	60023	265302
UGBEM (UG) V1	2.90	640	28.00	0.45	27.55	51133	214758
V2	1.70	960	30.50	0.64	29.86	48732	204672
AKPET 1 (AK) V1	1.80	850	38.75	1.10	37.65	57605	252308
V2	2.80	790	32.00	1.20	30.80	65542	287076
V3	1.25	620	24.00	0.70	23.30	15058	79092
OKURIKE (OK) V1	1.80	850	38.75	1.10	2.8	2898	10723
V2	2.80	760	32.00	1.20	30.7	38682	143123
V3	1.25	620	24.00	0.70	25.54	27307	101037
IBOGO (IB) V1	1.80	800	40.00	2.00	38.00	54720	236738
V2	1.60	962	34.50	1.60	32.90	50640	219270
V3	2.2	860	37.50	1.50	36.00	68112	294925
NSAKWAN (NS) V1	2.4	790	36.50	1.40	35.10	66550	284598
V2	1.8	650	29.80	1.30	28.50	33345	143050
NDE (ND) V1	1.95	780	22.0	0.80	21.20	32245	136977
V2	1.4	660	12.5	0.60	11.90	10996	47391
					TOTAL		9,793,732.5 MILLION TONS

4. Evaluation of Barite Mineralization

Just few weeks after the completion of geological mapping of the study area, local and illegal miners were found to have spread almost all over the entire area. This really hindered the smooth running of the geophysical survey. However, geophysical survey was carried out in the areas with minimal mining activities such as Osina and Gabu and Alifokpa. In areas where intensive mining activities had commenced, the tonnage mined and that still left were both estimated for total computation of barite deposit in the area.

. The detailed computation of the barite reserves was done in considering the following:

BT = Width Traceable length * Real depth * Specific gravity

Where BT = Barite in tones

Width = measured width of barite veins in the field

Traceable length = lateral extent of barites estimated from HRP or field outcrops.

Read depth = depth estimates to the barite deposit within the host rock, this is acquired from results of VES apparent depth – overburden depths or from locally mined outcrops.

Specific gravity = Specific gravity of different barite samples measurement in the laboratory in the different sites, from previous studies they range form 4.2 – 4.7

The above computation Indicated that Barite reserves within the Oban Massif is greater that occurring within the Mamfe embayment and the parts of the lower Benue trough. The reserves within Oban Massif include Agoi villages has a total reserve of 1,981,177.00 metric tons, 1, 786, 876 metric tons there reserves are greater than those found in parts of the lower Benue trough which include Okpoma (Ojoja) 496, 626 metric tons, Gabu 250, 799.85 metric tons and Osina 277,719.67 metric tons. Also, the Mamfe Ekukunela village 544,955.00 metric tons Nkarasi 320, 689 metric tons (Fig 13).

The total amounts of barite deposit in Cross River State is estimated to be about 9,66,306 tonnes (nine million sixty six thousand Three hundred and six metric tons).

5. Conclusion

Mining activities for concealed barite deposits has been ongoing in different parts of Cross River State on small scale local mining in hand dug trenches/pits this research is a pioneer work in trying to estimate the total reserve for the state. The research employed geoelectrical surveys (VES and HRP), geological field mapping, and some laboratory measured parameters in evaluating the total barite deposits in Cross River State in excess of 9 million metric tones the highest in Nigeria. Its our hope that the high specific granites (14.3-4.7) which is higher than the oil companies standard of 4.2 and the large volume in excess of 9 million tons will attract investor in the oil exploration industries to exploit the large reserves of barite deposits in Cross River State, Nigeria.

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