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GEOLOGY AND MINERALISATION IN THE ALBIAN SEDIMENTS OF THE BENUE TROUGH, NIGERIA

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ABSTRACT: *The epigenetic lead-zinc-barite fluorite deposits of the Benue Trough are localized in N-S trending fractures developed within the lower Cretaceous Albian shales, limestone and arkosic sandstones. The mineralogy of the sulfide deposits consists mainly of sphalerite and galena, with minor chalcopyrite and marcasite, with quartz and siderite being the dominant gangue minerals. The ores of the Abakaliki-Isiagu deposits consist of massive sphalerite, galena, chalcopyrite, marcasite, siderite, calcite and quartz in descending abundance. Fluorite, quartz and minor galena disseminations are the mineral assemblages of the Arufu-Akwana-Azara mineral district. Sulfide minerals, such as sphalerite, galena and chalcopyrite are dominant in the Zurak-Wase deposits. The study revealed three stages of mineral deposition namely: the pre-sulfide stage, the sulfide stage and the post-sulfide stage.*

KEYWORDS: Mineralisation, Paragenesis, Brecciation, Lower Benue, Trough

INTRODUCTION

The Benue Trough is an intra-cratonic rift trending southwest-northeast from about latitude 6^0N near the Gulf of Guinea to about latitude 10^0N south of the Chad basin. It is enclosed within longitudes $8^0$and 11^0E. It is a linear trough with a strike length of more than 700km and a width that reaches a maximum of 160km in the southwest but tapers to a mere 50km in the northeast. The trough is bounded to the northwest by Bauchi Basement Complex and the anorogenic granites of the Jos Plateau. To the southeast, the trough is terminated by the Precambrian gneisses, migmatites and granites of the Calabar urban massifs while the southwest extension of the trough was quickly aborted by the younger sediments of the Niger delta. To the northeast, the trough is terminated by the Biu volcanics and the underlying basement rocks (Fig 1).

The Benue trough is a known metallogenic province (Ford 1981) with the following mineral districts namely;

(i) The Abakaliki- Isiagu lower Benue mineral district

(ii) The Arufu-Akwana – Azara middle Benue mineral district

(iii) The Zurak-Wase Upper Benue mineral district.

The Abakaliki- Isiagu Mineral occurrence.

The Abakaliki- Isiagu district consists of Isiagu deposit, the Enyigba lead-zinc deposit, the Ameri deposits, the Ameka deposit and the Akpatakpa lead-zinc deposit all belonging to the lower Benue Group (Fig. 1)

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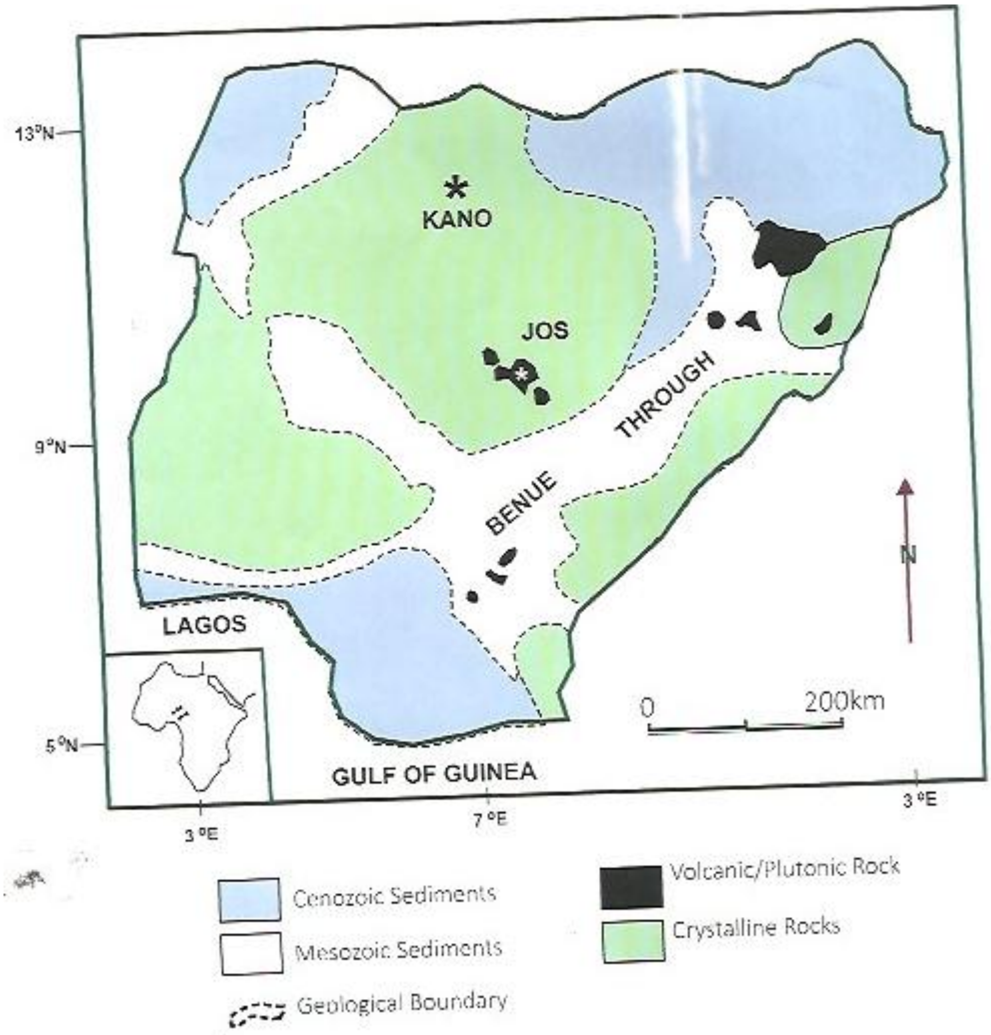

Fig 1: Generalized Geology of Nigeria showing location of the Benue Trough (Modified after Reyment 1965).

The Arufu-Akwana- Azara mineralization consists of fluorite veins at Arufu and Akwana and barite veins at Azara respectively. The Zurak-Wase lies in the upper Benue between latitude $9^0 5^1$N and $9^0 20^1$N and longitudes $9^0 59^1$E and $10^0 39^1$E and about 200km away from Jos through Bashir.

The Isiagu lead-zinc deposits was investigated using the Electrical resistivity and self-potential methods by Isife et. al., (2000). They found out that shallow water table was about 20m from the surface and that this depth approximately corresponded with the depth of the ore-body. Electrical measurements also showed that structural elements that controlled mineralization in Isiagu area are joints and fractures. This present work is aimed at determining the mineralogy and paragenesis of the mineral deposits.

Orajaka (1965) studied the lead-zinc deposits at Enyigba, Ameri and Ameka and observed the abundant development of gangue and ore minerals in partially filled vugs and cavities. On the basis of the observed features, he suggested cavity-filling processes of deposition from a telemagmatic source.

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MATERIALS AND METHOD

Field studies and sample collection

Geological mapping was carried out in the mineral belts of Zurak-Wase, Arufu- Akwana and Azara as well as Isiagu- Abakaliki areas. Five hundred (500) samples of ore, gangue and host rocks all together were collected from old mine dumps and from open pits dug by mining companies.

In the Zurak-Wase belt, sphalerite and galena ore minerals were sampled. Quartz and sandstone were collected as gangue and host rocks respectively. At Arufu-Akwana and Azara areas; galena, fluorite, barite, siderite, quartz, silicified limestone and sandstone were collected. In Isiagu-Abakaliki mineral belts, sphalerite and galena were sampled while siderite, pyrite and quartz were sampled as gangue minerals. Host rocks of carbonaceous shales with bands of lateritised sandstone were also collected.

Mineralogical Analysis

The samples collected were appropriately sorted out. Mineralogical studies of thin sections of the silicates, carbonate gangue minerals and host rocks were done at the laboratories of the Centre de Recherches Petrographiques et Geochmiques, (CRPG-CNRS), Nancy, France.

Local Geology

The lithologic successions in the lower Benue consists of about 2000m thick Nkporo shale deposited as an alternating shale and mudstone sequence which locally may become anomalous with bands of intercalating sandy shales and sandstone. The Mamu formation is a fine-grained well-sorted sandstone interbedded with organic-rich shales, mudstones and coal seams. It attains a maximum thickness of about 400m. The Ajali formation which conformably overlies the Mamu formation is composed of friable coarse poorly sorted feruginised sandstone which may become weathered to red laterite earth in places. Occasional bands of mudstone and shales have been mapped within this formation. The Nsukka formation is an alternating sequence of fine-grained sandstones, dark shales interbedded with numerous horizons of coal seams (Fig. 2.)

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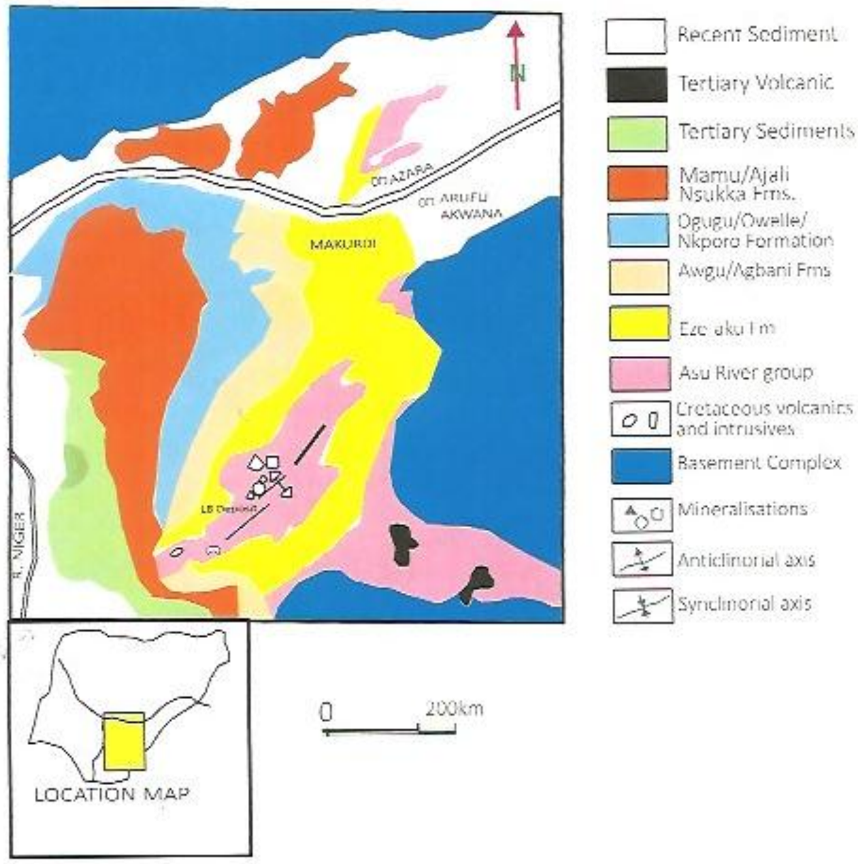

Fig. 2: Detailed Geology of the lower and middle Benue valley (Modified after Olade 1976)

In the middle Benue, the Lafia Formation consists of coarse to fine-grained sandstone with occasional bands of mudstone and coal. It is the youngest cretaceous sedimentary rock in the middle Beune and considered to be the time equivalents of the Mamu, Ajali and Nsukka Formations in the lower Benue (Reyment, 1965, Offodile and Reyment, 1976)

In the upper Benue, the Gombe Formation, consists of sandstone, siltstone and subordinate shale with occasional coal seams. The estimated thickness is about 300m and it is believed to be a lateral lateral equivalent of Lafia formation.

Tectonic Deformation

The structural features of the Benue Trough are represented mostly by folds produced during the Cenomanian (Nwachukwu 1972) and Santonian (Orajaka 1965, Olade, 1975) tectonic deformations. In the lower Benue an intense compressive folding produced the major Abakaliki anticlinorium and minor anticlines and synclines (Burke et. al., 1974). The major folds exhibit axially elongated domes parallel to NE-SW axis of the trough. Most of the minor folds are disposed to in an en-echelon pattern along the NW – SE direction with a low angle pitch to the SW. A notable representative of the anticlinal structures in the middle Benue is the Keana anticlinorium which is flanked to the North by the asymmetrical Giza synclinorium. Generally the anticline structures are broad and fan-shaped with a plunge to the south (Carter et. al., 1963) and they extend along strike for more than100km from the south of Makurdi to Zurak. In the

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upper Benue, the Lamurde and Jawara anticlines are the two prominent structural elements (Ojo, 1982). The Lamurde anticlinorium is a broad asymmetrical anticlinorium striking in a NE- direction. It is flanked to the north by the Dadiya syclinorium (Gratchley and Jones, 1965).

Fracture development in the cretaceous sedimentary rocks is more related to individual rock types and is controlled by their competence. The highest densities of fractures are found in the Bima sandstone while shaley marine sequences are less fractured major and minor fault trends are inferred from the interpretation of aerial photographs. Several concentrations of intrusive sills and dykes, bosses and stocks occur as lamprophyres, feldspathoidal syenite, leucodiorites, microdiorites gabbro and microgabbro and are essentially posterior to the lead-zinc mineralisations (Okezie, 1976).

The Abakaliki- Isiagu Deposits

These deposits are located in the lower Benue valley consisting of Enyigba, Ameri, Ameka (Fig. 3.) Isiagu (Fig. 4) and Akpatakpa (Fig. 5) the deposits are hosted by black carbonaceous shales while at Isiagu the shales are intercalated by siltstone- bands. In all the localities the sediments dip gently at about 30^0.

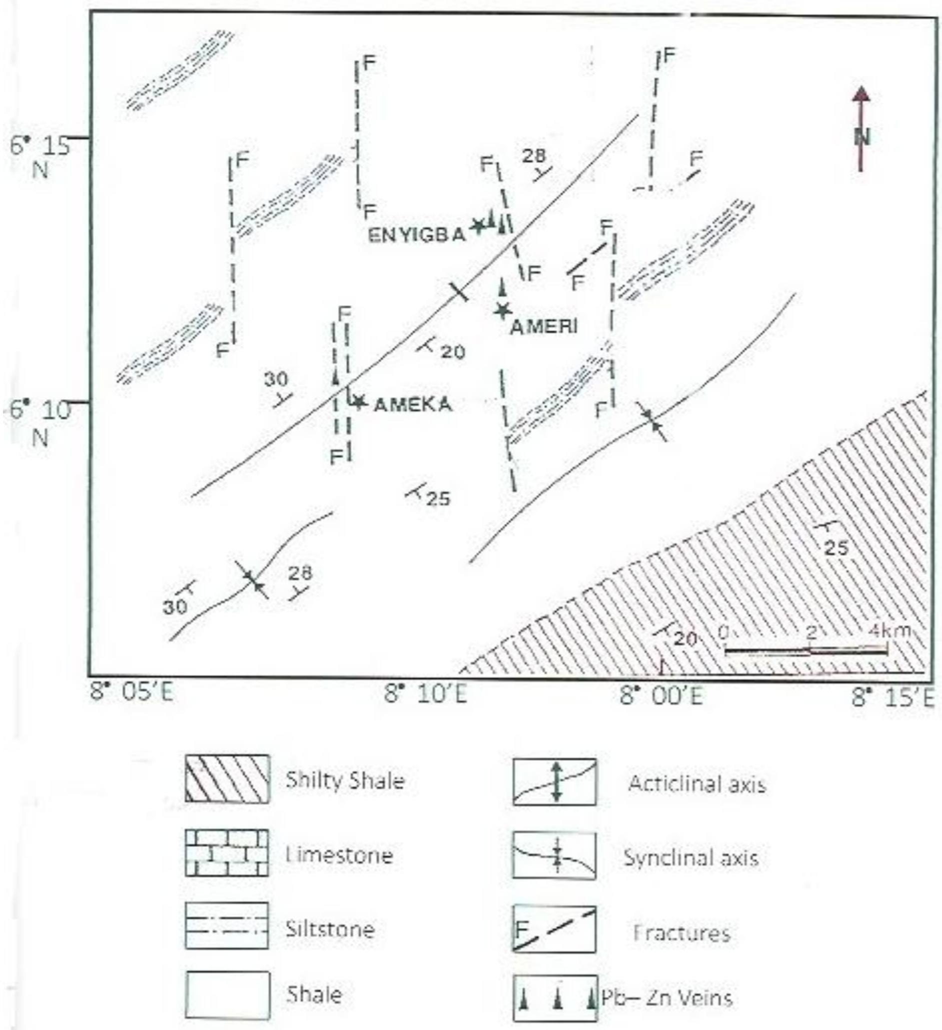

Fig. 3: Geology and lead-zinc veins at Ameka, Ameri and Enyigba (Minerals District Lower Benue)

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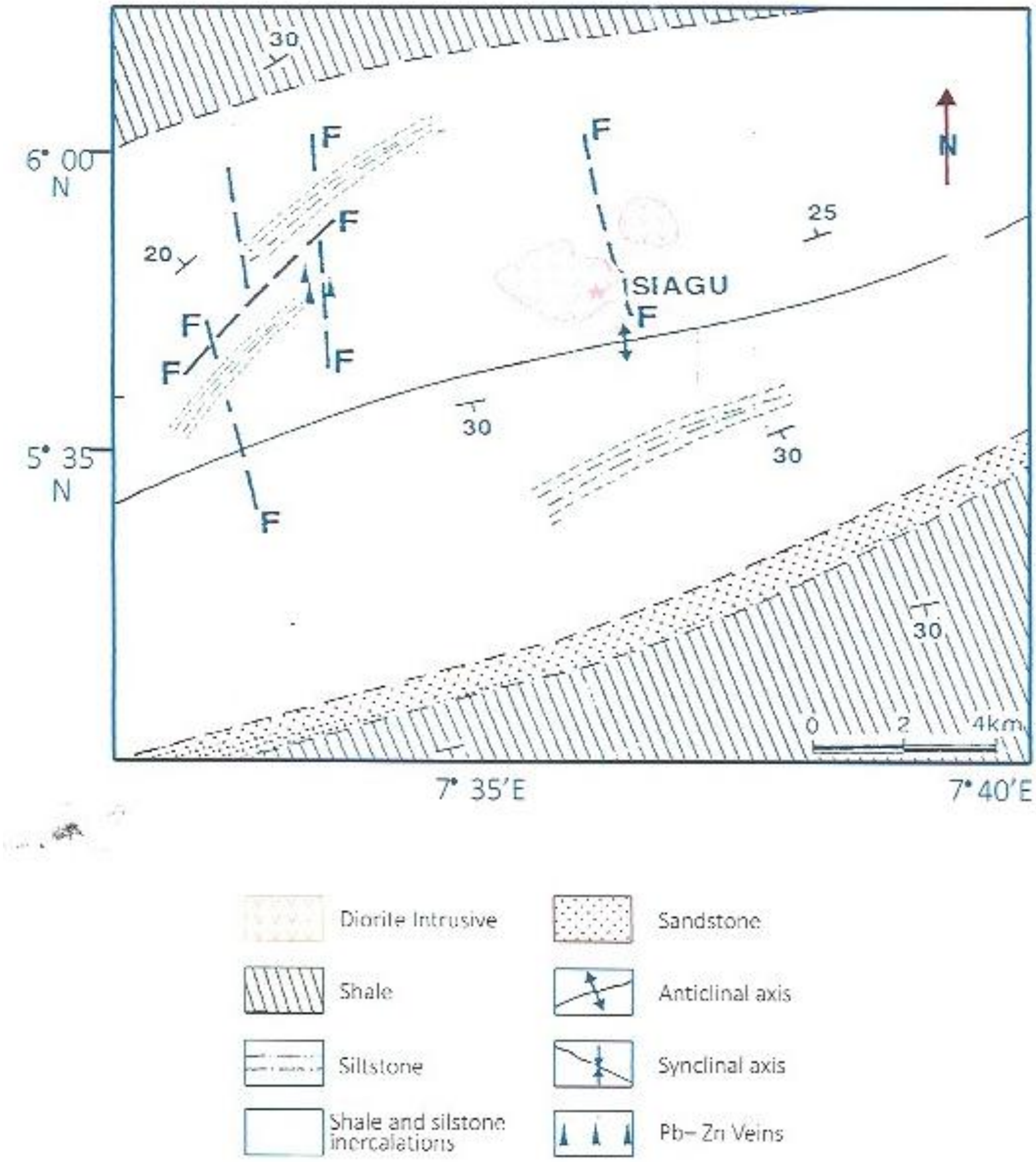

Fig. 4: Geology and lead-zinc veins at Isiagu (Modified after Olade 1976)

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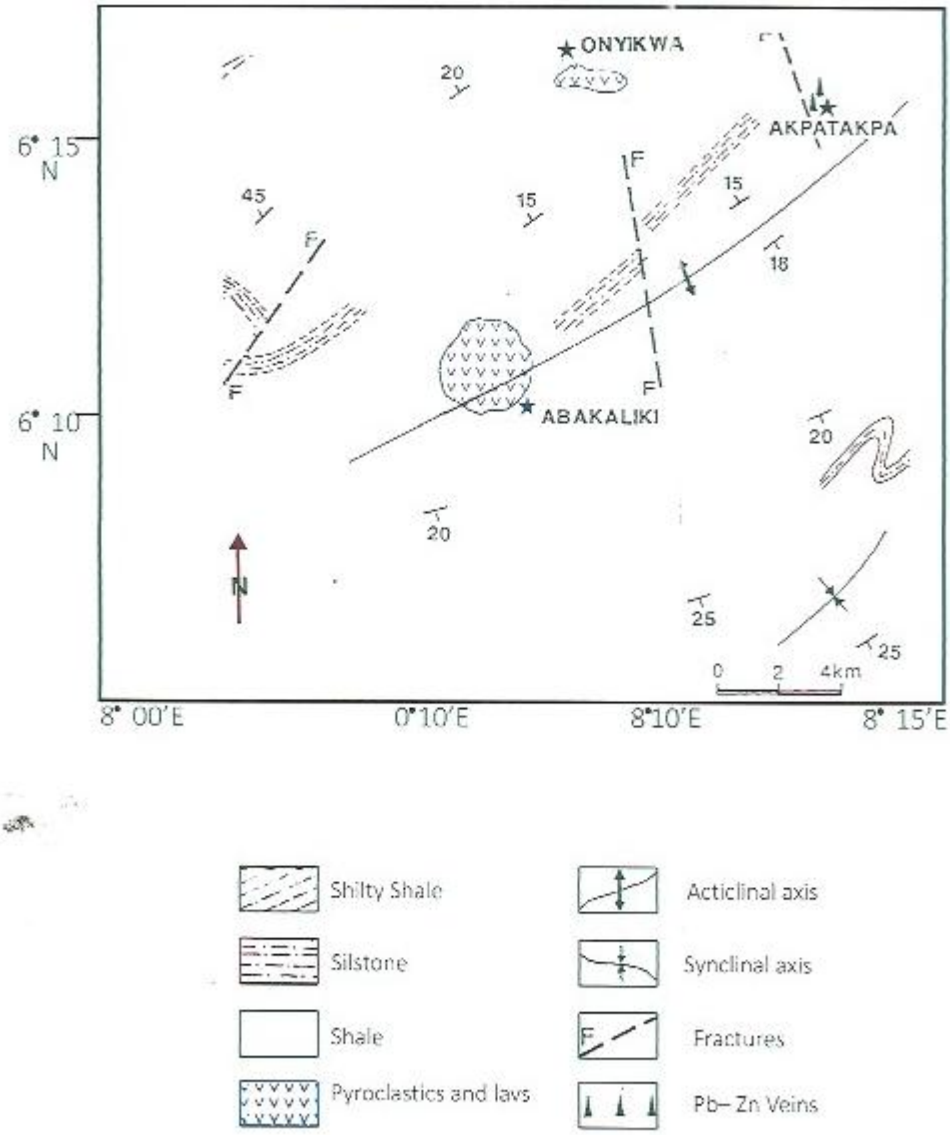

Fig. 5: Geology and lead-zinc veins at Akpatakpa (Modified after Olade 1976)

The sediments are folded predominantly along east-west directions with anticlinal axes trending NE-SW directions. Joints, fissures and faults occur en-chelon and strike N-S with vertical dipsranging from 70 -80^{0}W. The thickness of the fracture zones is quite variable from deposit to deposit. For example at Enyigba it is about 15m wide while at Ameri it is less than 3m. The ore bodies occur as irregular or lenticular veins within a pattern of N-S and NE-SW sheeted fractures with dips ranging from 65-80^{0}W. in thickness, the ore bodies varies from 0.2-1.5m over an average strike length of about 500m and whenever they occur as pinches and swells, they vary between 30-150m depth. Within each ore body, numerous ovoid inter-connecting vugs occur which range from 3-30cm in width and sometimes extending for about 1-2m along the strike. These inter-connecting vugs are believed to serve as open channels for circulating waters from various sources. At Isiagu 0.5cm -12cm stringers of oxidized siderite enclose discrete pods or boudinages of galena to form an exclusive pattern of varieties within the siltone bands. It is common to see breccias of the host rock plastered on to the ore

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suggesting that there was continuous tectonic brecciation of the country rock which provided the room for the open space filling mineralisations. Among the commonly observed open space structures are "tooth structures" of sphalerite and quartz hanging down from the cavity walls into the open central spaces.

Encrustations of later minerals generally mask or mantle earlier paragenetic minerals. Colloform banding is a typical feature of post-sulfide stage quartz. The ore of the Abakaliki-Isiagu deposits consist of massive sphalerite, galena, chalcopyrite, marcasite, siderite, calcite and quartz. At Isiagu, Ameri, Ameka and Akpatakpa, sphalerite forms the bulk of the ore which occurs as separate basal lodes to the overlaying galena lodes. At Enyigba, galena is however dominant.

Galena ranks second to sphalerite in relative abundance. It occurs as lead-gray crystalline cubic or octahedral forms. The well crystallized cubic form is generally striated and sheared while the octahedral form lacks any observable deformation. Nwachukwu (1972) has suggested that the cubic form was probably deposited prior to or contemporaneous with the deformation of the host rocks in the Cenomanian times. When the galena is oxidized, secondary anglesite may occupy some of these pits or sometimes the galena may be rimed by bluish-green covellite. Some galena cubes have been observed perching on later marcasite, suggesting that galena might have been produced from the dissolution of an earlier phase.

Chalcopyrite occurs as disseminated golden-yellow subhedral crystals. On exposure to weather, it is readily oxidized to malachite and azurite. Marcasite is locally abundant at Ameka and it occurs as light greenish – yellow crystal with spherulithic structure. Siderite is an abundant gangue mineral in this ore deposits and it precedes the deposition of the sulfides and other gangue minerals. It occurs as massive crystalline aggregate with light brownish or buff colour. On oxidation it changes to hematite which occurs as veinlets in the foot walls.

Quartz occurs as crystalline milky-white crystals lining either the inner walls of vugs or as cross-cutting veins and veinlets. Occasionally, it may occur as coating an earlier deposited minerals particularly sphalerite.

The Arufu – Akwana – Azara Mineral District.

The Arufu-Akwana deposits comprised of Arufu and Akwana fluorite with minor galena disseminations and the Azara barite deposits. The host rocks to the Arufu- Akwana fluorites are impure limestones which are highly silicified when mineralized and locally fossiliferous - when not silicified or mineralized. The carbonates are highly deformed resulting in cross and longitudinal joints trending NW-SE and E-W respectively (Fig. 6).

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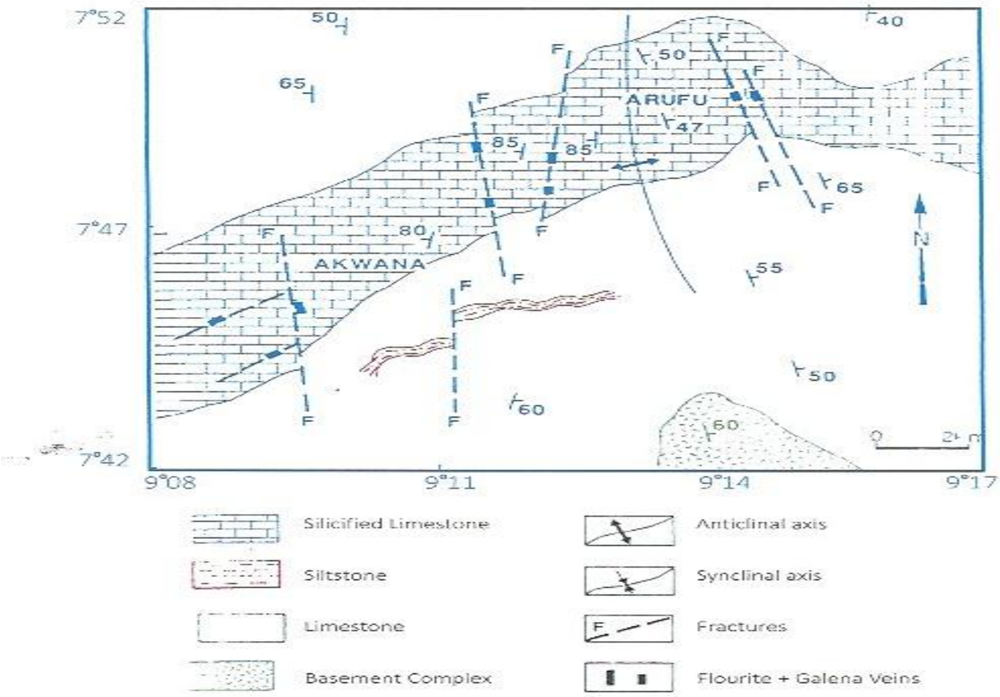

Fig6: Fluorite with Galena veins at Arufu/ Akwana

At least two episodes of brecciation are observed to have taken place in this mineral district (Plate 1).

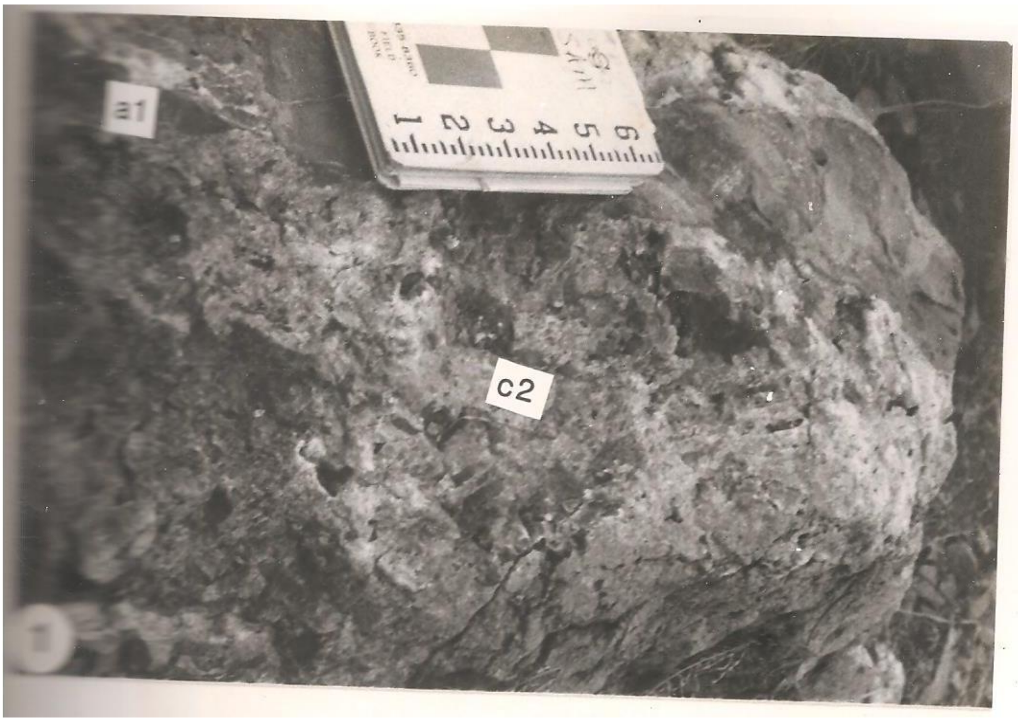

Plate 1: Episodes of brecciation

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The first episode commenced with the brecciation of the carbonates into angular fragments ranging from 5mm to 3cm in size. This episode was followed by the brecciation of silicified carbonate rocks into finer angular breccias plastered on the fluorities by a siliceous cement. It is observed that not all the limestones are mineralized but all mineralized carbonates have been intensely brecciated and silicified. In one locality at Arufu a darkish viscous bitumen was observed at the vein/ host rock contact. The fluorite veins are narrow, erratic and discontinuous and generally confined to sheeted fractures. On the average, they are about 20-30cm wide extending for about 5-10cm along the strike. The trend of the veins are E-W and NE-SW within steeply dipping silicified limestones.

The mineral assemblages are fluorite, quartz and minor galena disseminations. Fluorite is the most abundant mineral and can be classified into four main types on the basis of their diagnostic colours, the purple fluorite which occurs as coarse crystalline aggregates is the most widespread. They are euhedral to subhedral in shape and usually in contact with the host rock. They are also coarsely textured with an average crystal size of about 3mm. Very commonly they may be associated with the white variety or they may be mantled by a "blanket" of late quartz when not occurring as interstitial and fracture-filling minerals. The other varieties of fluorite are the white and green types both of which are of restricted occurrence. In some localities, crude colour banding /grading from gray fluorite to purple is sometimes displayed parallel; to the strike of the veins. The differences in the colour could be due to variations in trace elements or rare-earth-element (REE) compositions of the mineralizing solutions.

Quartz is very widespread and occurs either as a component of the groundmass of the silicified carbonates or as coarse crystalline aggregates as interstitial. It is also mapped as fracture fillings, as encrustations on fluorite or as a late phase crystalline "mantle". Galena occurs as perfect cubes about2mm in size within most of the fluorites. It is more widely disseminated within the gray fluorite. The galena is more susceptible to secondary processes such as leaching which often leaves behind cubic cast of the galena after it has been leached out following its oxidation.

The Azara-Barite Deposits.

The host rock to the barite veins ranges from coarseto fine-grained sandstone, mudstone, siltstone and arkosic sandstone belonging to the Asu River Group and the arenaceous sequences of the Awe formation. At the sites of barite mineralization, the rocks are highly brecciated with fragments varying from 2mm to 5cm in size. Brecciation of the country rock which was initiated before the commencement of mineralization also continued during the deposition of the barite resulting in not less than two to three episodes of brecciation (Plate 2).

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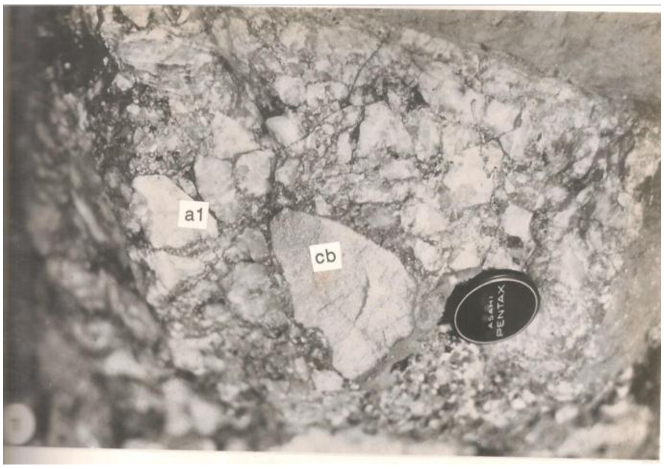

Plate 2 Episodes of brecciation.

The first episode started with the brecciation of the host rocks into angular fragments ranging from 2-5mm in size. Another episode was initiated after the deposition of siderite breccias of barite ranging from 2cm – 5cm produced during a subsequent episode of brecciation were cemented by ferruginous cement to form an agglomerate of breccias.

The barite occurs as veins and stringers ranging from about 15cm to 30cm in width and extending over an average strike length of 2km. These veins are controlled by a system of tensional fractures set in an en-echelon pattern along N-S, E-W and NE-SW directions. The veins in which quartz forms a major numerical component usually occur as low rising steeply dipping hills while veins in which there is little or no quartz are commonly found in the low lying areas. The major minerals are barite and quartz while pyrite and galena may occur as disseminations. Siderite is the main gangue mineral and it may be oxidized in places to dark brownish hematite. Barite is a gangue mineral quarried in the middle Benue valley. It occurs in three textural forms: a translucent massive form, a colourless form usually associated with medium-grained colourless quartz which occur as interstitial wedges between two barite laminations. The branded grey dark brownish form ranges from 1 to 3cm in size and siderite and hematite acts as the cement for the alternating bands of grey and brown. In places, the siderite cement may be thick enough to form a distinct band of its own, alternating with grey and brown barite bands. Siderite occurs as light brownish elongated crystals when un-oxidized but turns to dark brownish-red when altered to hematite.

The Zurak-Wase Deposits

The Zurak-Wase deposits occur in medium-grained arkosic sandstones intercalated by thin characteristic cross-beddings. In places they are limonitic as a result of iron impregnation derived probably from the dissolution of siderite. All the sediments have been gently folded to a monoclonal structure. Dips are generally low, ranging from 5-15^{0}E although the dips may become steeper near the zones of mineralization (Fig 7).

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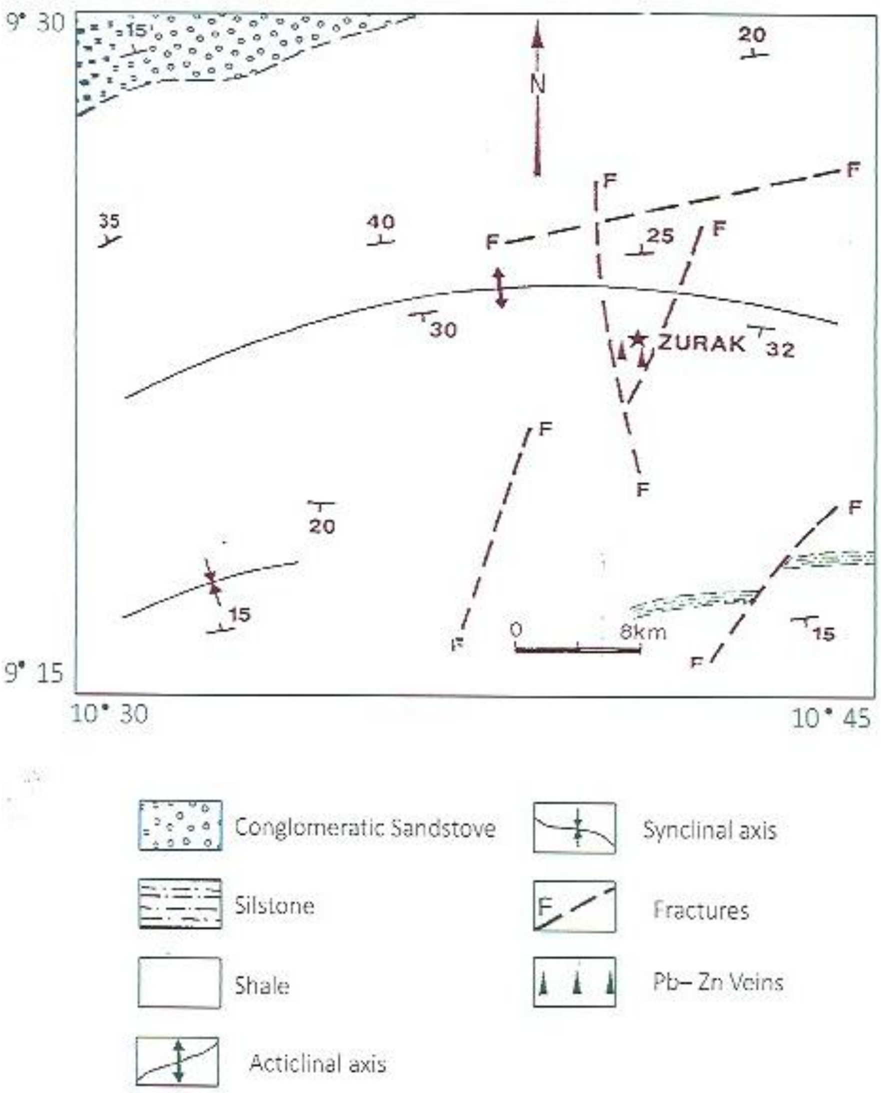

Fig. 7: Geology and lead-zinc veins at Zurak (Mineral District Upper Benue) (Modified after Farrington 1952)

The lead zinc ores occur as well defined veins in faults and fracture zone striking N-S with steep vertical dips to the east. A close examination of the old workings revealed that the strike length of the veins varies from a few meters with thickness ranging from a few centimeters to two meters. The sulfide minerals are sphalerite, galena and chalcopyrite. Quartz is the common gangue mineral. Sphalerite occurs in two forms, a massive reddish-brown aggregate and a dark brownish-black variety which is coarse in texture. The reddish-brown type is fine to medium-grained with granular galena dispersed within the mass. Galena ranks next to sphalerite in relative abundance. It occurs also in two forms. One form occurs as perfect cubes while the other occurs as inter-granular crystals within the sphalerite. Quartz occurs as cross-cutting veins and veinlets. It occurs also as encrustations over earlier minerals particularly sphalerite or line the inner walls of vugs. The cross cutting quartz usually exhibits two or three successive layers comprising a milky well crystallized crystal surrounding a core of fibrous colourless layer.

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Mineral Paragenesis

There are three stages of mineral deposition namely, the pre-sulfide stage, the sulfide stage and the post-sulfide stage (Table 1).

Table 1: Paragnetic sequence in the Benue valley.

	Pre-Sulfide Stage	Sulfide Stage	Post-Sulfide Stage
Breciation	Dissolution		
Siderite	---------		
Quartz	Silicification		
Sphalerite			
Quartz		------------	
Galena			------------
Pyrite		------------	
Chalcopyrite		------------	
Barite		------------	
Fluorite			------------
Calcite			------------
Marcasite			------------

During the pre-sulfide stage, there was extensive tectonic brecciation of the country rocks and dissolution of the wall rocks resultingin the development of pervasive vugs and cavities. This episode was succeeded by the deposition of siderite at Isiagu, Ameri, Enyigba and Ameka. At Arufu, Akwana and Zurak, quartz was deposited primarily by silicification of the wall rocks. The sulfide stages started with the deposition of sphalerite followed by galena which together constituted the principal sulfide ores. Pyrite and chalcopyrite were deposited as complements to the base-metal sulfide minerals. The third stage is the post sulfide stage which marks the waning stage of the hydrothermal activities. During this stage late stage-gangue minerals were deposited as barite, fluorite, quartz, calcite and marcasite.

CONCLUSION

In the lower Benue mineral district, at least five lead-zinc occurrences are localized within carbonaceous black shales which are about 3000m thick (Nwachukwu 1976). In the middle Benue, lead-zinc mineralization is insignificant while fluorite and barite are found in shallow silicate carbonate rocks and siltstone-sandstone sequences respectively.

In the upper Benue, the sulfides are hosted by arkosic sandstone. Although these deposits occur in different arkosic units and despite their distal nature they however share some common characteristics with the lower Benue. For example, all the mineralization are discordant, fault-controlled veins. They are deposited as open-space fillings. The fractures occur as steeply inclined tensional fracture systems usually transposed at right angles to anticlinal structures. Wall rock hydrothermal alteration is insignificant except for some silicification and kaolinisation at Arufu-Akwana and Ameka respectively.The mineralogy in all the localities are similar although at Zurak two episodes of sphalerite deposition contrast with the single phase in the lower Benue valley.

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