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Petrographic study of the Pb- Zn Ore from Gwana in the Upper Benue Trough.

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Abstract

The Pb-Zn (lead-zinc) sulphide mineralization within the Benue Trough extends from the Lower Benue to the Upper Benue Trough, indicating a widespread metallogenic belt. Representative ore samples from this region were examined using Scanning Electron Microscopy (SEM) to investigate their mineralogical and petrographic characteristics. Petrographic analysis reveals that the mineralization is predominantly composed of Galena (PbS) and Quartz (SiO₂), with minor occurrences of Chalcopyrite (CuFeS₂), Magnetite (Fe₃O₄), and trace aluminosilicate minerals. During later stages, under near-surface and oxidizing conditions, significant replacement processes occurred. Galena was partially replaced by Anglesite (PbSO₄), while associated copper-bearing minerals underwent alteration. The movement of copper-rich solutions through the deposit led to the formation of thin, persistent bands of Covellite (CuS), often found within or adjacent to Anglesite zones. These formed contemporaneously with the oxidation of Galena. Chalcopyrite was similarly affected by oxidation, transforming into Covellite, whereas Magnetite and Pyrite (FeS₂), where present, remained largely unaltered, suggesting their relative resistance to oxidative weathering. Backscattered SEM imaging identified two distinct types of Galena: altered and unaltered. Further petrographic analysis in polished sections revealed three main textural varieties of Galena: cubic, fibrous (or gneissic), and granular. These textures provide insights into the paragenesis and post-depositional alteration history of the Pb-Zn mineralization in the Benue Trough.

Keywords

Upper Benue Trough
Pb-Zn Mineralization
Gwana
Scanning Electron Microscopy

1. INTRODUCTION

The Benue Trough is a 800km long, 50-150km wide intra-continental Basin, elongated in the north-east to the south-west direction and overlying the Precambrian Shield of the West Africa Mobile Belt (Benkhelil, 1989; Guiraud, 1990). The Benue Trough stretches from the Gulf of Guinea to the southern border of the Chad Basin.

The Pb-Zn Mineralization of the Benue Trough extends from the Lower Benue Trough to the Upper Benue Trough. Extensive work has been on the Pb-Zn Mineralization in the Lower and Middle Benue Trough.

Various researchers have interpreted the origin of the Pb-Zn deposits in the Benue Trough. Studies show that the source of the Pb-Zn mineralization corresponds to detrital feldspars, which were eroded from Precambrian Basement and re-concentrated with marine shales (Maurin and Lancelot, 1989). This is in accordance with the hypothesis, which was proposed by Grant (1971) that is the source of mineralization is Precambrian Alkali Feldspars within sediments). Maurin and Lancelot (1989) further ascribed the origin to role of hydrothermal solution derived from Mafic intrusions of volcanics, hence place the hydrothermal origin to be at low temperature of 140°C. These solutions were able to leach chlorides from the sediments and evaporate as well as Base

metal from clay and feldspars, which combines with Sulphur to form the Ore along permeable zones.

The Pb - Zn sulphide Mineralization in the Benue Trough extends from Lower Benue Trough to the Upper Benue Trough. But not much work has been done on the Pb-Zn Mineralization in the upper portion of the Benue when compared with the Lower and Middle portion of the Trough, especially around the Gwana area of Bauchi State. This paper discusses the petrographic characteristic of the Pb-Zn Mineralization in the area.

2. Location and Accessibility of the Study Area

The study area lies between latitudes 9°30'N to 9°40'N and longitudes 10° 44'E and 10°50'E Futuk sheet 172 SE within Alkaleri Local Government Area of Bauchi state. It lies in the extreme south of the Bauchi state south east of Alkaleri town. Futuk is accessible from Alkaleri by a tarred feeder road. From Futuk the road leading to Gwana is a complex route of untarred roads, footpaths and cattle routes that is usually inaccessible during the raining season due to lack of bridges across the major streams. Hence work is better done during the dry seasons. The location map of the study area is presented in figure 1.

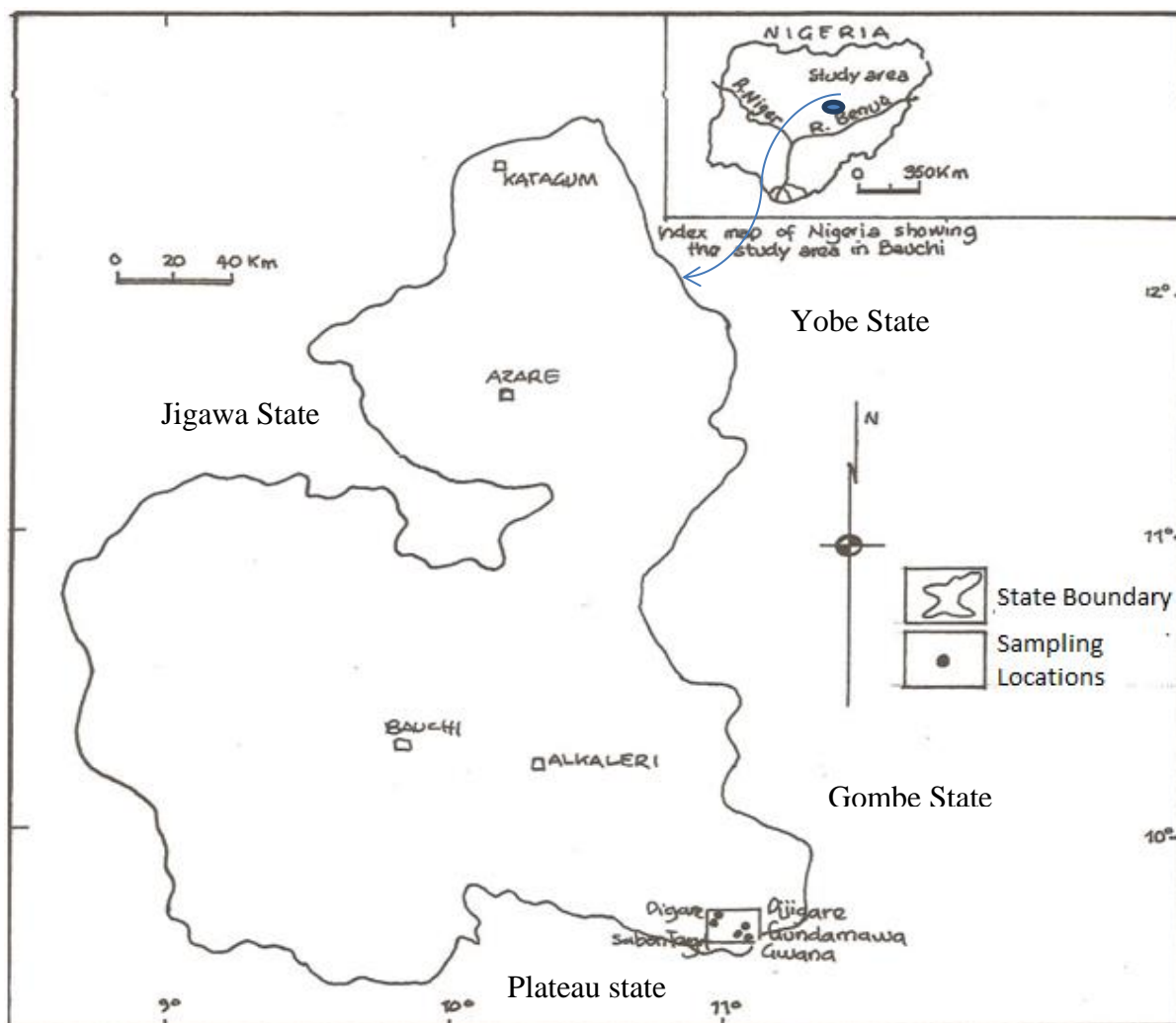


Figure 1: Location Map of the Study area; Gwana in Alkaleri LGA of Bauchi State. (Adopted from Bauchi State Land and Survey (2000))

3. Geology of the Study Area

The study shows that the Yolde Formation and the Bima sandstone predominates the study area. This relationship is exposed as a result of the general upliftment of the area due to the fold and/or volcanic activities. The Pb -Zn are veins are hosted by the Yolde Formation within the Upper Benue Trough, this is a transitional bed between the Marine shales and continental sandstone. The general trend of the veins is NW - SE with little bifurcation. It has the characteristic Lithology of thin alterations of shallow-water Shale and Sandstone with occasional nodular Limestone that contain Ammonites and other Fossils. Towards the Zambuk Ridge the beds become thinner

and more Granaceous as a "passage bed" which represents a Transition from dominantly Continental Deposits of the underlying Bima Sandstone to the overlying Deposits of the Pindiga Formation (and its lateral Facies equivalents). The Lithology of the Formation is of variable sequences of Sandstone and Shale, the base of the Formation being defined by the first appearance of the Marine Shale while the top is defined by the disappearance of Sandstones. Figure 2 shows the geological map of the study area.

Bima Sandstone

The Bima Sandstone observed in the field is coarse to medium grained, looking poorly sorted, having a creamy white colour, with some strands and dots of red in some parts as a result of ferroginisation,

the exposures are low to medium. The sandstone appears silicified

Yolde Formation

The Yolde Formation observed in the field is a medium to fine grained sandstone intercalated

with mudstones, clays and shales. The exposure is very low, and the sandstone is whitish, appearing to be moderately sorted to poorly sorted. It is also silicified and clay appears to be the cementing agents.

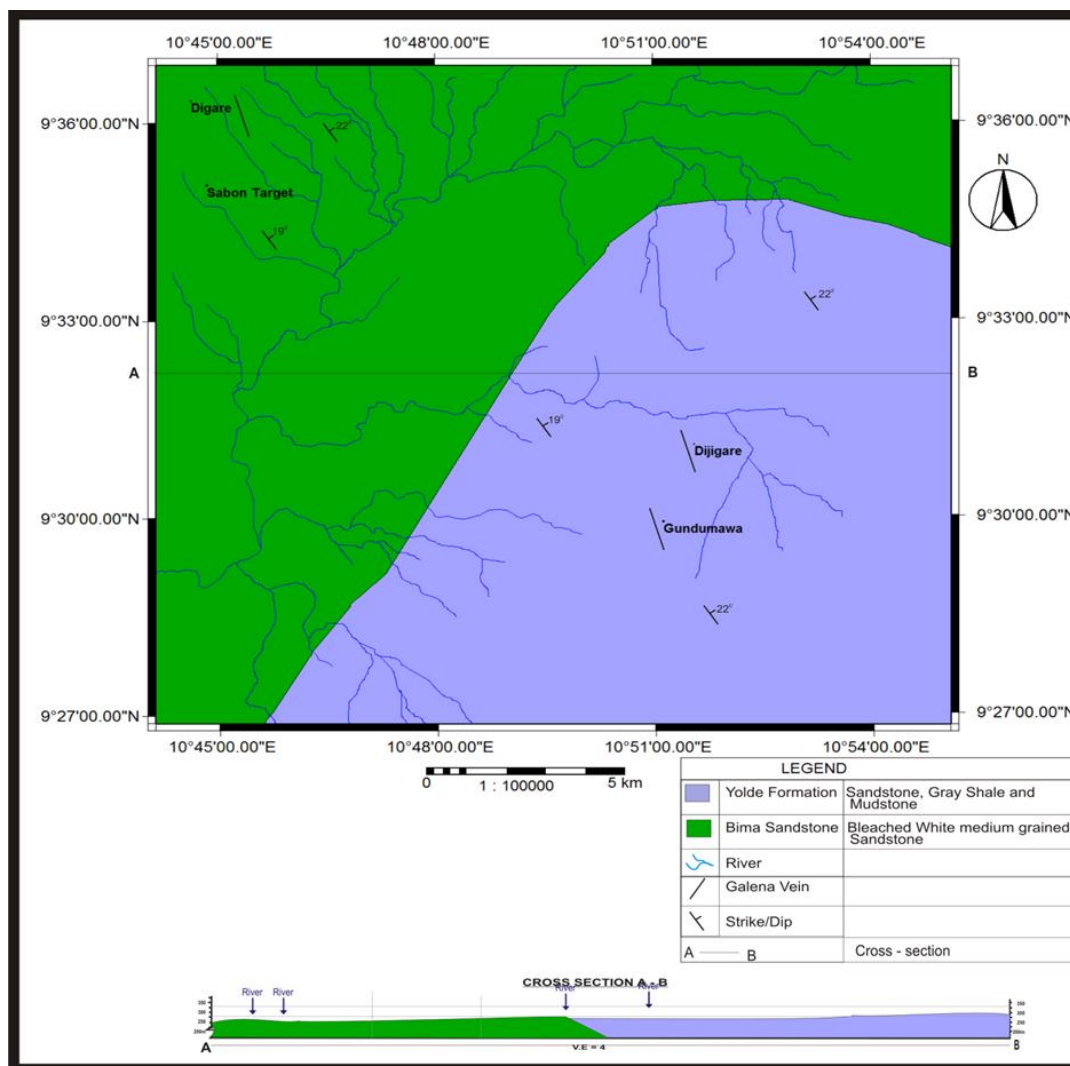


Figure 2: Geological map of the study area Gwana Futuk sheet 3 showing A - B Cross Section

4. Field Methods

Geological mapping of the area was undertaken and active mine sites were sampled. The field work involved tracing the veins and taking readings of their strike direction using a compass. The length, width and depth of the veins were taken using a measuring tape. The relationship of the

mineralization and the host rock was also observed. Representative samples of the Ores were collected from each of the mines. Fresh rock samples were collected at the different nine locations. Detailed survey was done along the major channel of River Payi, which bifurcates into a "Y"-shaped channel. GPS was used to locate the actual locations and elevations. Ore textures were also studied under reflected light.

5. Petrographic Study

Selected representative ore samples were investigated using the scanning electron microscope (SEM). The Scanning electron microscope (SEM) produces images by detecting various signals emitted from a sample in response to an accelerated electron beam. The sample is scanned in a raster pattern across the surface. Secondary electron and backscattered electron images are routinely collected for SEM analysis. Digitally assigning grey scale values to reflect signal intensity produces SEM images. Variations are measured by each raster location by the various signal detectors. Low intensity values appear dark (black), while the high intensity values appear white.

Backscatter electrons are high energy electrons that result from multiple elastic collisions of the incident primary beam electron with the nucleus of the atoms within the sample. These electrons then exit the surface, where a backscatter electron detector measures them. The measured backscatter intensity is proportional to the mean atomic number of the atoms in the volume sampled by the electron beam. Backscatter electron image provides a measure of atomic number contrast reflecting a variation in elemental composition, providing the basis for mineral identification.

All secondary electron and backscattered electron SEM images are inherently greyscale images reflecting intensity variations of a single signal type. The ability to visualize and possibly interpret the greyscale backscatter images are low due to the contrast difference is limited. This makes it difficult for the human eye to distinguish between the shades of grey, thus making mineral identification difficult. Pseudocolor (false color) are created by assigning specific colors to each grey scale value using a color lookup table, the difference in color reflects difference in SEM signal intensity instead of the actual color of the sample. Hence the term Pseudocolor or false color is used. This was used in the SEM plates to aid in mineral identification in the study.

Selected representation of samples were investigated using the scanning electron microscope

(SEM) in GEUS' and Core laboratories (UK) Ltd Aberdeen, UK where Spot analyses were made and a number of back scatter images taken. SEM analyses were also undertaken in the Putra University Malaysia.

Sample preparation involved cleaning the polished sections of all dust and impurity that could interfere with the electric beams, because SEM relies on electric fields to create an image. The cleaned polished sections were then coated with gold and carbon to improve their conductivity. False colors were added to the backscatter images obtained from SEM to delineate the grain boundaries.

6. Petrographic (SEM) Result of Ore Samples Studies

The petrographic results are presented as SEM and Backscatter images and showing the

various identified minerals in each, these are presented in plates I to XIII.

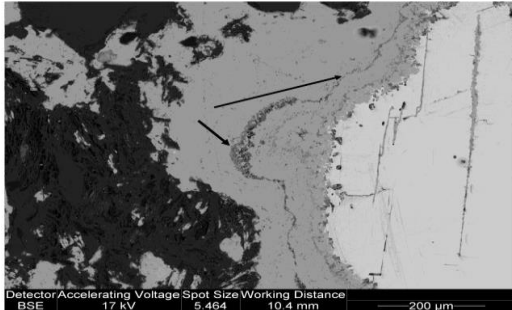


Plate I: Backscatter image in SEM of sample 1.

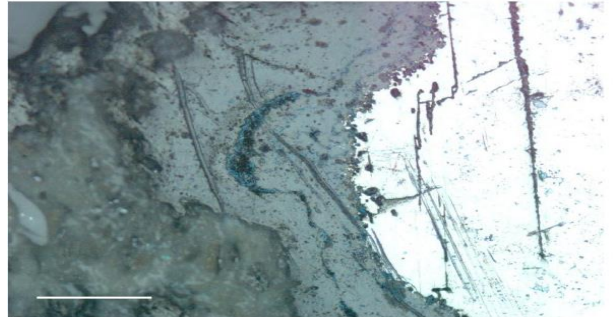


Plate II: Photomicrograph showing Covelite banding in Anglesite parallel to the Galena contact

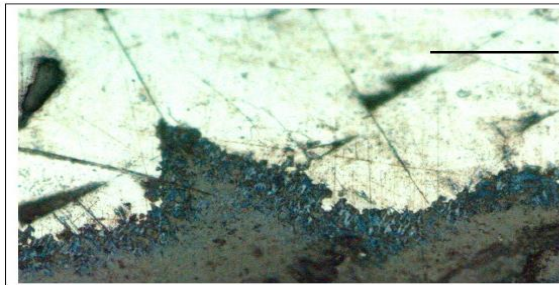


Plate III: Photomicrograph showing Covelite band at the contact between Anglesite and Galena as shown by the triangular pits

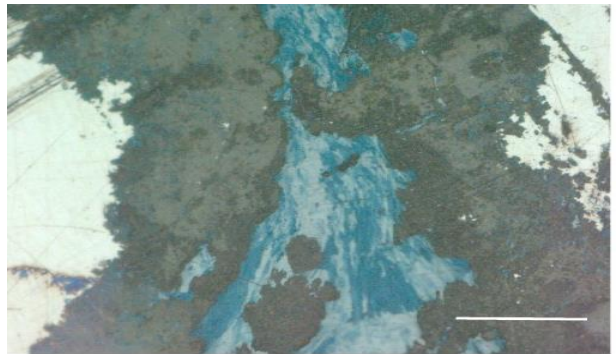


Plate V: Photomicrograph showing coarse grained Covelite in Anglesite (Covelite occurs as thin bands in Anglesite where the bands are parallel to the contact of the Galena).

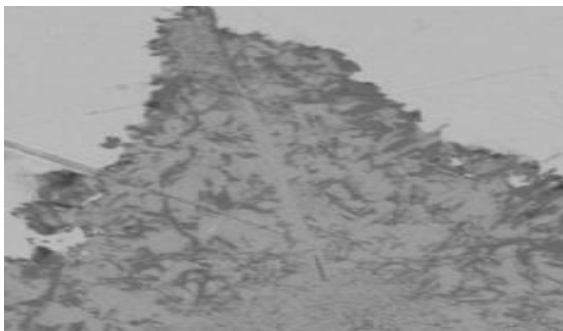


Plate IV: Backscatter image showing Covelite Rim with crystals of anglesite growing from Galena outwards from photomicrograph on plate III.

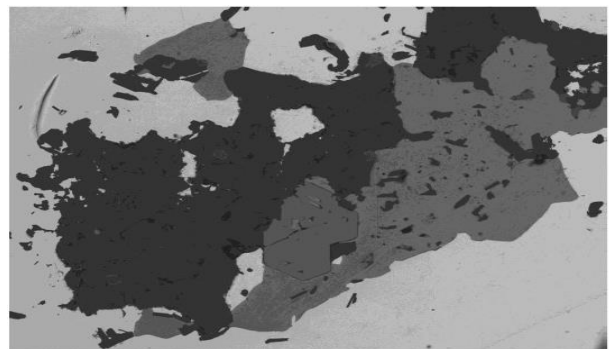


Plate VI: Backscatter image showing Chalcopyrite at the border between Quartz and Galena. Subhedral grain of magnetite partly enclosed in chalcopyrite

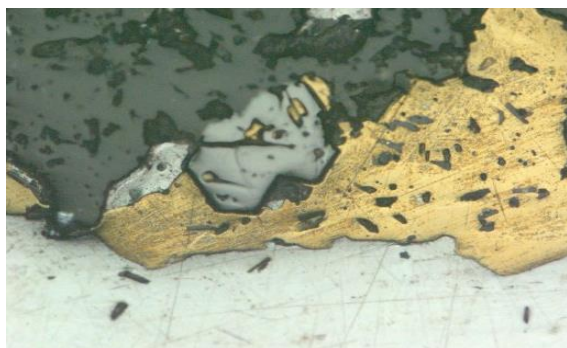


Plate VII: Photomicrograph showing Chalcopyrite occurring as anhedral grains locally altered to Covellite

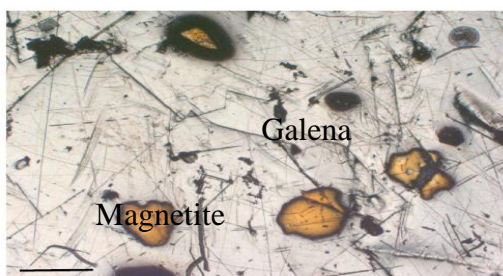


Plate VIII: Photomicrograph showing Galena and Chalcopyrite in the sample.

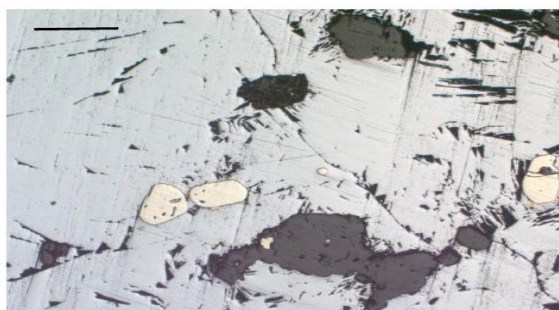


Plate IX: Photomicrograph showing the texture of Chalcopyrite Galena and Magnetite. The Galena shows characteristic triangular pits.

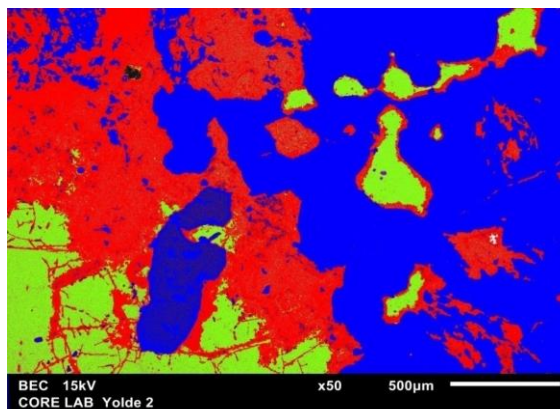


Plate X: Pseudo (false) Colour added to Backscatter image of Sample Yolde 2 to show the 3 different types of Minerals

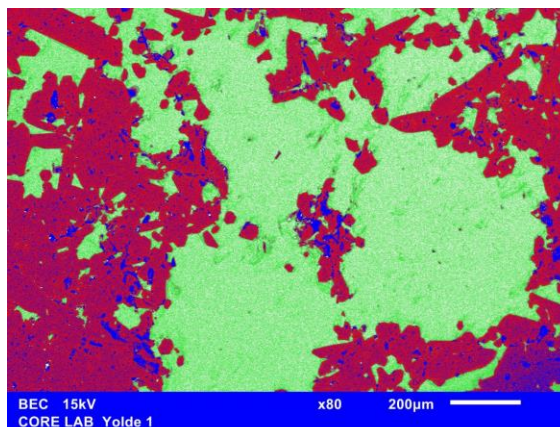


Plate XI: Pseudo (false) colour added to backscatter image of sample Yolde 2 to show the different types of minerals

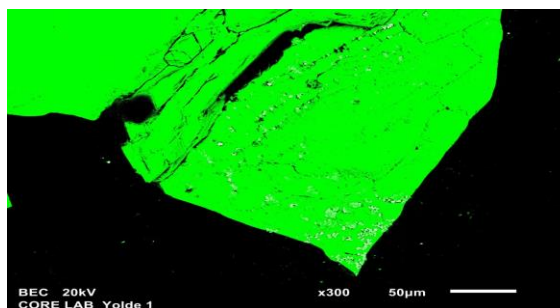


Plate XII: Psuedo (false) color added to the backscatter image of sample Yolde 1 showing the grain boundaries

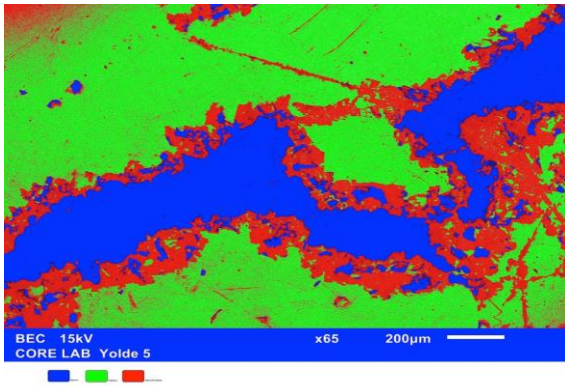


Plate XIII: False color added to backscatter image of sample Yolde 5 to show grain boundaries

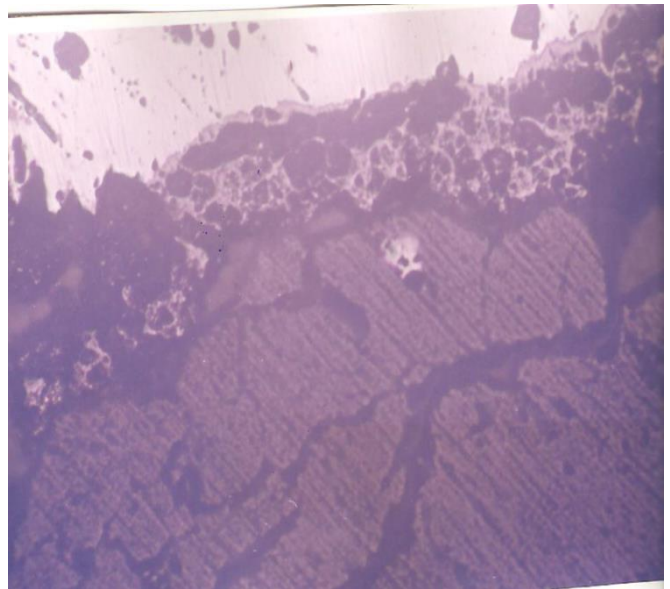


Plate XIV: Showing Sphalerite disease. This an alteration in the morphology of the Sphalerite crystals attributed to deformation. This is explained more in the discussion.

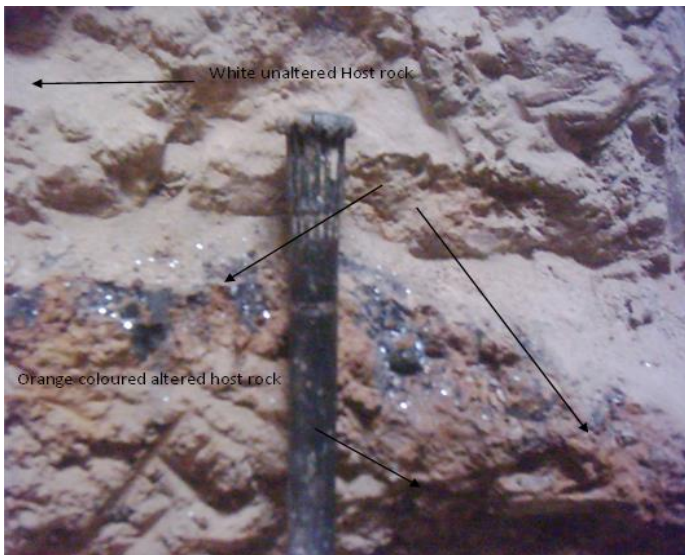


Plate XV: Lead vein in bleached white Yolde Sandstone host rock. Note the host rock below the vein is altered to a laterite or orange colour. This is wall rock alteration due to hydrothermal action.

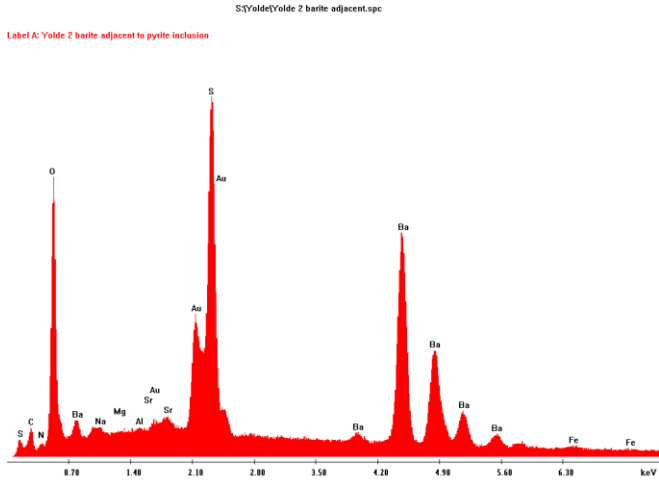


Figure 3: Concentration peaks in the sample Yolde 2 at the barite boundary adjacent to pyrite inclusion.

Figure 5: Galena grain adjacent to barite (Bright Phase)

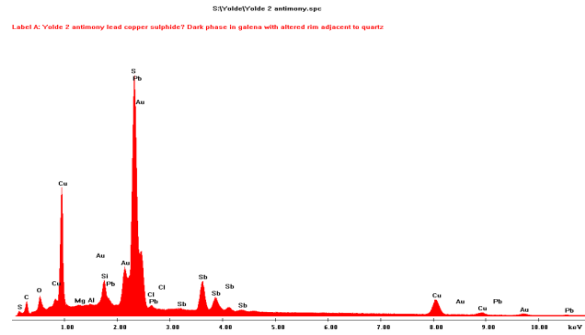


Figure 6: Dark phase in Galena with altered rim adjacent to quartz.

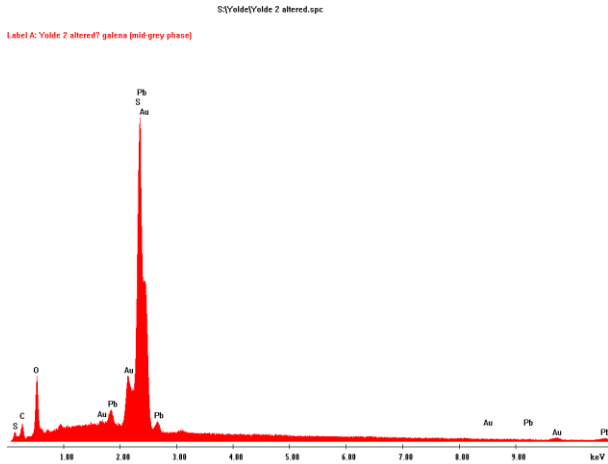


Figure 4: Peaks showing altered Galena phase represented by the two peak

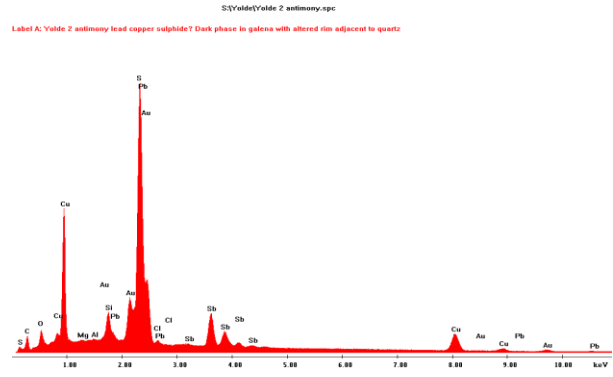


Figure 7: Pyrite inclusion in sample

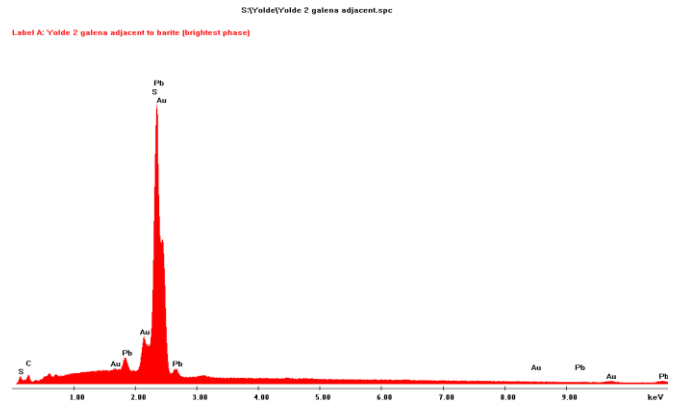
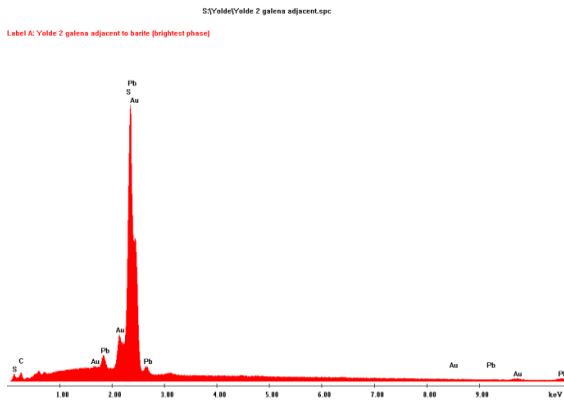


Figure 8: Altered Galena Mid-Grey phase

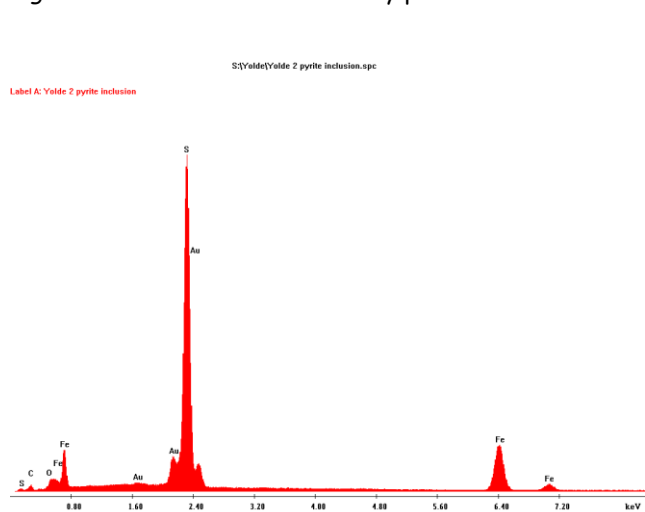


Figure 9: Galena Adjacent to Barite (bright phase)

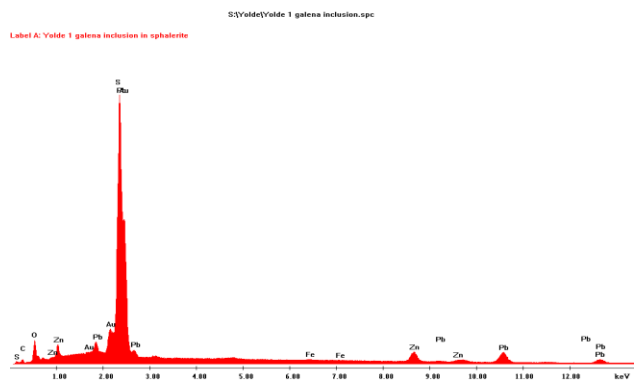


Figure 10: Galena inclusion in Sphalerite

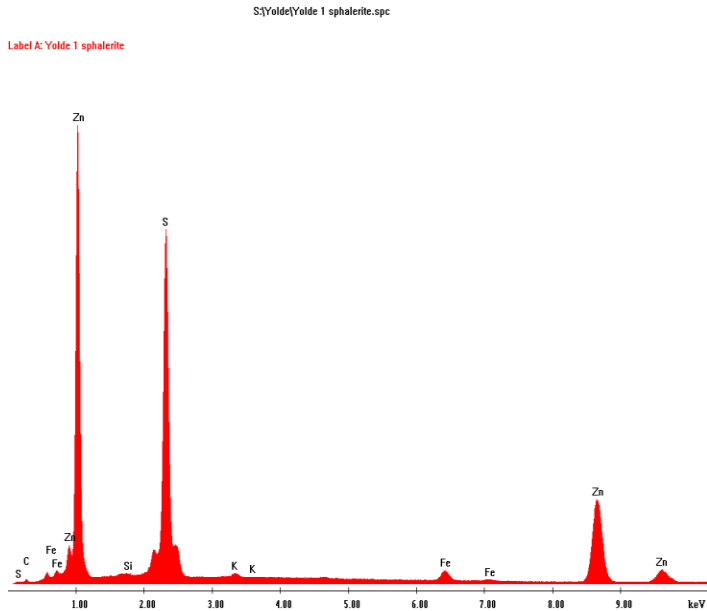


Figure 11: Sphalerite in sample yolde 1

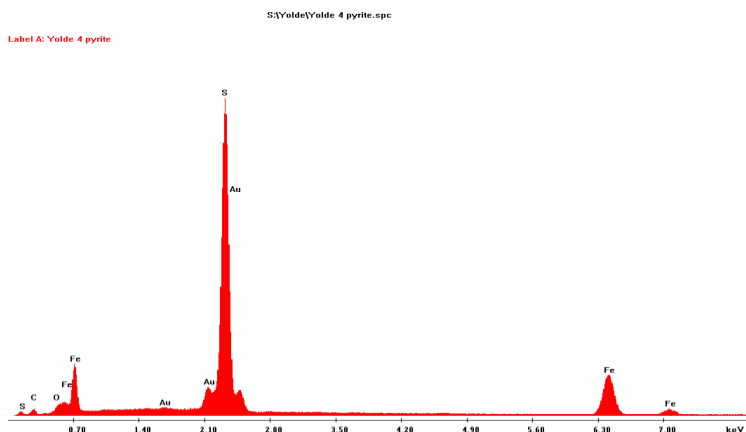


Figure 12: Pyrite in Yolde 4 sample

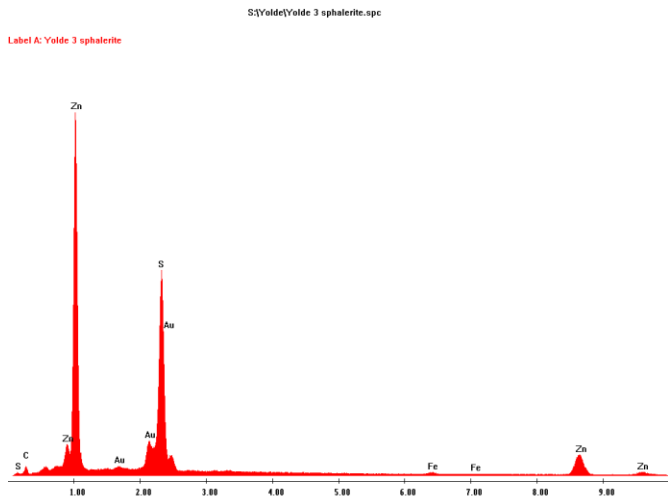


Figure 13: Sphalerite in Yolde 3 sample

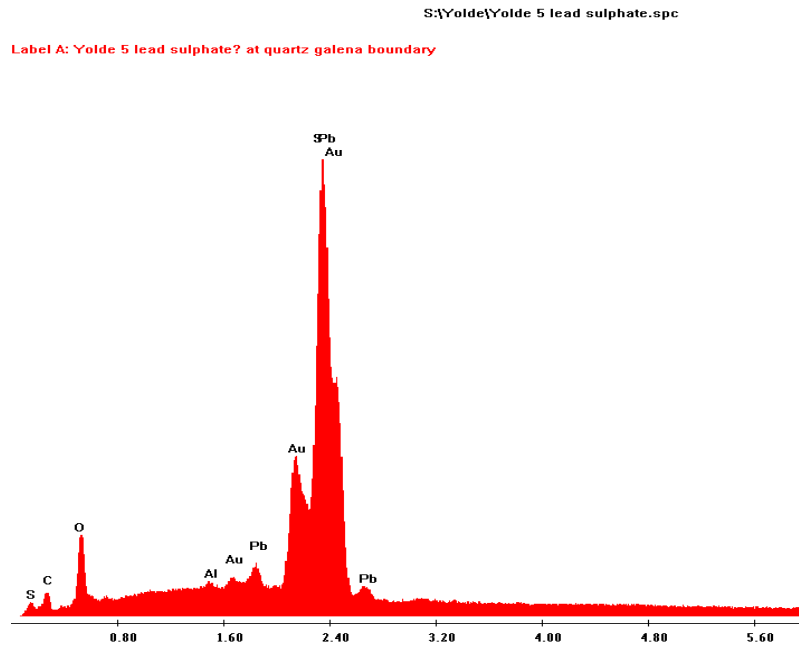


Figure 15: Lead sample at Quartz Galena boundary in sample Yolde 5

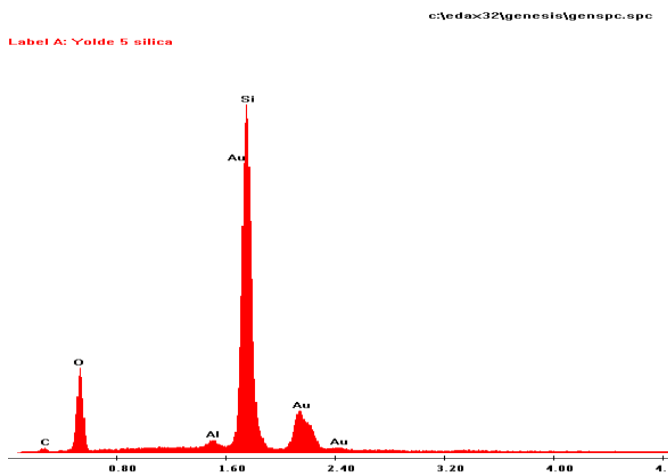


Figure 14: Silica in sample Yolde 5

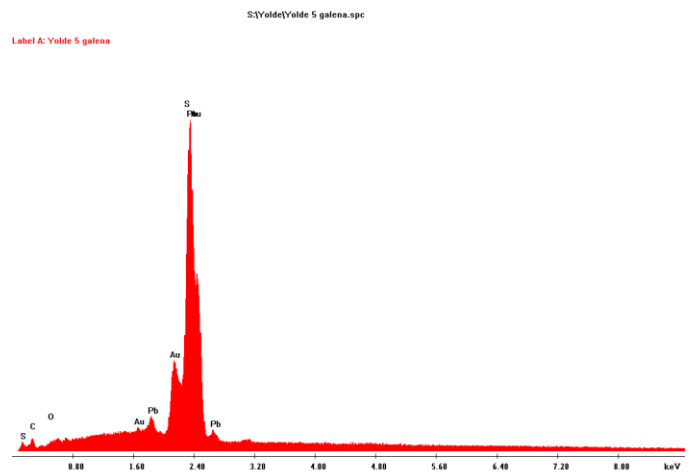


Figure 16: Galena in Yolde 5 sample

7. Discussion:

Plate I shows textural relationship between Galena, Anglesite and Covelite. Galena being is replaced by

Anglesite with a thin band of Covelite. Anglesite is seen in fractures replacing Galena

- i. Galena is the most dominant mineral in the sample
- ii. No exsolution were found in the Galena
- iii. Silver was not detected in the analysis

Anglesite is observed to be a replacement product of Galena formed in the oxidation zone in a near surface environment. Plate I.

Covelite occurs as thin bands in Anglesite where the bands are parallel to the contact of the Galena. The Covelite bands are found in the Anglesite as seen in plates II and III.

Quartz was found in the sample. It is a major constituent in most polished sections.

In Plate VIII it is observed that: Black circles around the chalcopyrite inclusions prevented the determination of boarder relationship.

- a) The black circles can be attributed to the height differences between the chalcopyrite and Galena
- b) The chalcopyrite looks dark inside of yellow is because of the carbon coating on the sample.

8. The Textural Relationships

The textural relationship in the samples studied is indicating the following series of events:

- i. Galena and Quartz with minor amounts of Chalcopyrite, Magnetite and a few Alumina silicates crystallized. At a later stage under near surface conditions fairly extensive replacement under oxidizing conditions took place. Galena was replaced by Anglesite at the same time as Copper minerals were altered and copper rich solutions circulated through the deposit giving rise to thin

but persistent bands of covelite often in anglesite formed contemporaneously with the oxidation of the Galena. Oxidation also affected the sparse grains of chalcopyrite forming covelite whereas magnetite and pyrite were left unaltered.

- ii. From the sample observed from the Backscatter SEM images the Galena in the samples is of two types, these are the altered and unaltered Galena type. This could be seen in plates IX - XVII.
- iii. The Gwana lead-zinc mineralization is worked for lead-zinc (Galena and Sphalerite) while Siderite is the main gangue mineral followed by Quartz. The other minerals are Chalcopyrite, Quartz, Pyrite, Mercasite, Cerrusite, Angleside and Sericite. Plates V - VII.
- iv. Mineralization is structurally controlled, being localized largely in fault zones, numerous honeycombed gossan blanket the vein. The gossan is composed of limonite and Silica with some Hematite. This is the result of alteration of the Siderite gangue and some Sphalerite.
- v. The Pb-Zn mineralization in the study area is a result of fracture filling. Incompletely filled vugs are small and narrow. They occur mainly where the proportion of quartz and or Siderite gangue is high. Most of the vugs are lined with well-formed quartz crystals mounted on relatively less developed crystals of Sphalerite some Galena and Siderite. This situation indicates slow rates of crystallization as is expected in the later phases of vug filling.

This would indicate deposition by metasomatic replacement. Evidence of deposition by vug filling is summarized

- a. Incompletely filled vugs and cavities are in mineralized zones
- b. Comb structures in which quartz crystals, well-formed project towards the Centre of the vugs are common evidence of crustification.

It is evident that both replacement and fissures filling influenced the process of deposition of minerals at various stages, as the early formed siderite was deposited in the fissure, some replaced lost rocks, the temperature-pressure conditions being favorable for each reaction. The fact the breccia in Shales is restricted to Siderite masses points to the validity of this reasoning.

- i. The association of organic matter with Zn-Pb deposits is common worldwide from the works of Powell and Macqueen, 1984; Leventhal, 1990; Kesler et al. 1994, among others. It was established that under certain conditions, this organic matter can be directly involved in the reduction of aqueous sulfate, leading subsequently to base metal sulfide deposition. Organic matter-mediated sulfate reduction can occur either by bacterial activity Bacterial Sulfate Reduction, process or by a biological reaction process referred to as thermochemical sulphate reduction. In contrast to biological sulfate reduction process, thermochemical sulphate reduction process is known to be an extremely slow process, although, under favorable circumstances it can be fast enough to generate H₂S during ore formation in MVT deposits (Thomas and Anderson, 2008).
- ii. In the studied samples, the mineralization is hosted In the Turonian Yolde Formation of the Yola Arm, Upper Benue Through as indicated, Regardless of the Host rock lithology Which consists of alternating beds of sands, shales and some carbonates, the ore phases are generally disseminated and massive only locally. The host rocks are

usually silicified, with the ore phases occurring mainly in the matrix. The paragenesis, deduced from the observations of hand samples and SEM work, consists of Sphalerite as the main ore mineral, together with Galena, pyrite, and minor traces of, chalcopyrite, lead, copper and antimony. Other coexisting phases include quartz and barite.

The paragenetic sequence can be subdivided into three stages:

- a) Pre-ore stage;
 - b) Ore stage; and
 - c) Post-ore stage(s)
- iii. The pre-ore stage corresponds to the beginning of the host rock silicification, characterized by the precipitation of quartz, together with minor crystal -sized pyrites. During the ore stage, quartz, sphalerite, Galena and minor traces of lead copper, antimony chalcopyrite and pyrite precipitated. These phases replaced the host rock and at the end of the stage also precipitated in veinlets. Alterations can be clearly seen around edges of Galena (plate X).
 - iv. Elemental analysis of the altered and unaltered parts of the Galena reveals the presences of oxygen within the altered region, which is absent in the unaltered region. This suggests that hydrothermal fluid was the major agent of alteration. Barite and quartz precipitated at the end of the ore stage plate X, both in veins and replacing the host rock. During the post-ore stage, barite continued to precipitate in veinlets and fill available fractures. Late quartz partially or completely replaced the host rock.
 - v. This case study of Zn-Pb occurrence in marine sandstone has provided evidence of a close link between organic matter oxidation

and ore formation. Considering the depths of formation, it can be inferred that the ore formed from brines compatible with thermochemical sulphate reduction process with organic matter as the reducing agents. The Yolde Formation has been identified as a matured source rock that can provide the necessary organic nutrients for thermochemical sulphate reduction to occur.

9. Paragenesis

The Paragenetic sequence of the Gwana Lead-Zinc mineralization is observed in the basis of the following observation

- i. The mutual relationship among the minerals in association as observed in both polished section in hand specimen and under microscope.
- ii. The SEM analysis and chemical analysis conducted
- iii. The position of the minerals in relation to the unfilled vugs wherever they are associated. The members in immediate contact with the unfilled vugs are the last to be deposited while the member bordering the shale host rock is earliest to be deposited.

It should be noted that in most cases only 2 and 3 minerals are found in association in one specimen, however the relatively association sequence have been identified as:

| | |
|------|------------------|
| LAST | 7- Marcasite |
| | 6- Quartz |
| | 5- Chalcopryrite |
| | 4- Calcite |
| | 3- Galena |
| | 2- Sphalerite |

EARLIEST

1- Siderite

Evidence shows that there was a continuous deposition of Quartz throughout the period of mineralization. From all the observed samples (plates X - XII), the largest amount was deposited at the last stages. This could be observed by the large well-formed crystals projecting into many vugs.

Some of the minerals have not found association with other sequences because they are not found in association with other minerals such as Calcite was found alone in vein or crest of minor folds. The above sequence agrees closely with Farringtons (1952) suggested sequence. He placed Calcite below Galena, Chalcopryrite and Marcasite between Chalcopryrite and Quartz.

10. Description of Minerals Observed

12.1 Siderite

It is massive, beige in color when fresh on exposure to the atmosphere it becomes tarnished to dark brown color. In addition to being found in the main vein, Siderite also occurs in minor fractures and veinlet some such veins cut through the host rocks at right angles when some cut across it at very low angles. In places the veins have been faulted and displaced.

The crystal faces are poorly formed indicating deposition at high temperatures. A large face two inches in length was recorded. Better formed tabular crystals are observed occasionally projecting into the vugs. Such crystals have two faces about two millimeters.

12.2 Sphalerite

It is generally opaque and dark brown in color. It is often found in intimate association with Galena. The crystals are large and tabular. Because of the large size of the crystals, no intergranular relationship was observable in polished section.

In polished etched section, however, Sphalerite displays primary growth twinning. The twin runs right through the crystal, the edges remaining parallel. Primary twins are syn depositional features. Some

samples in addition to primary twinning show 20 deformation twinning. The secondary deformation twins have the characteristic wedge shape. They are not well developed and are seen running transversely between two parallel primary twins

Deformation of the Sphalerite was slight enough to cause secondary twinning but not intense enough to distort or erase the primary growth twins, sphalerite disease was observed in plate XXI, this phenomenon can be attributed to an alteration in the morphology of the sphalerite crystals.

12.3 Quartz

It is dense, well-formed and milky white. It is often found showing comb structures as the crystals project into the unfilled vug. It displays characteristics prismatic form with the free end terminated by a pyramid with six faces.

12.4 Calcite

Calcite is found mainly as short narrow veins traversing the Shale. It was not seen in association with the other minerals. Deposition is fissure filling and Calcite fibers are seen running across the veins in which they occur. The result from calcareous extracted from the rock and deposited on the vein opening. The arrangement of these Calcite fibers is spectacular.

Calcite is also observed at the crest of minor folds in calcareous argillite. During folding, two folded beds create some space at the crest. Calcareous materials migrate from the shale and are deposited in this space.

12.5 Chalcopyrite

It occurs as minor mineral usually in association with Siderite and Galena. It has a golden yellowish color. In polishing section it is structureless. When etched, no twinning is observed. No lattice bending either. The Chalcopyrite does not appear to have undergone any deformation.

12.6 Galena

It is Lead-grey in color. There are three types of Galena are recognized on the basis of texture and forms. They are the cubic Galena, Steel Galena and Granular Galena.

- i. **Cubic Galena:** This is a highly perfect crystal form, which has not been deformed. It is found away from fault zones. The cubic Galena is the most abundant, the economically important form and the form used by the local population as cosmetic.
- ii. **Gneissic Galena:** Also known as fibrous Galena or steel Galena. These names are derived from the texture in hand specimen. It has a fibrous or gneissic texture, which is an evidence of deformation by shear strain. It is found near fault zones where movement has taken place. Under high magnification electron microscope the sample displays elongated cubic form with stratification.
- iii. **Granular Galena:** this is seen as a tiny granule in hand specimen, found along fault zones where shear stress due to faulting caused the cubic Galena to be altered.

12.6.1 Microtexture in Galena

i. Cubical Galena

In polished section, it shows parallel arrangement of triangular piths. When etched, the piths become more pronounced (plate XX). No lattice bending is observed and there was no discernible intergranular relationship. This form has not been altered (deformed) because it is not located near fault zones. A single cubic Galena has an average crystal face ranging from mm to 1.5cm, it is the most dominate form of Galena.

ii. Gneissic Galena (Altered Galena)

In hand specimen it has a gneissic or fibrous texture. In polished section it appears structureless but when etched it displays a well-developed granoblastic polygonal texture. The grains are well formed polygons with straight grain boundaries and triple junction

points. The grains have an average diameter of 0.03mm. This granoblastic polygonal texture is a previously deformed Galena is quite striking. It represents the attainment of textural equilibrium. After being deformed the Galena was subjected to suitable temperature so that it was annealed.

iii. Deformation and Annealing Of Galena

Transitional gliding occurs when one portion of a crystal slides over another without loss of cohesion. It is a process of indefinite magnitude, which takes place such that the corresponding crystal elements in each portion are similarly oriented before and after movement. Galena, subjected to shear stress due to faulting would be deformed. The annealing history of Gwana gneissic Galena is formed due to an external heat source from the hot mineralized fluids, at high temperature is altered, the Galena crystal relieves its high internal energy by recrystallization and grain growth followed giving rise to equidimensional polygonal grains. The grains are in a state of minimum internal energy and textural equilibrium has been attained. Etching brings out this cryptic structural relationship among the grains- the grain boundaries. Also from the SEM and Eddax results two forms of Galena were also identified in the samples plates X.

Figure 72 shows the representative textural changes in the course of development of granular and texture in Galena. The following represents the various stages of Galena evolution as represented in figure 73.

1. Cubical Galena undeformed
2. Deformation causes cubical Galena to become elongated attaining gneissic texture.
3. Recrystallization begins. Tiny crystals are formed attaining the gneissic texture
4. Recrystallization advances, grain growth steps in. The grains now begin to camouflage the gneissic texture.
5. More advanced stage of grain growth. The texture is now granular with nearly all traces of gneissic appearance erased.

6. Coarsest granular texture. Perfect equigranular grains, well formed grain boundaries and triple joint junctions.

Every stage above has a certain level of body energy.

The gneissic stage has the highest level of body energy. The falls of crystallization and grain growth begin to take place in stages 3, 4, 5 and 6 has the highest body energy level. Workers believe that the coarse granular Galena has even lower body energy than the original undeformed cubical Galena.

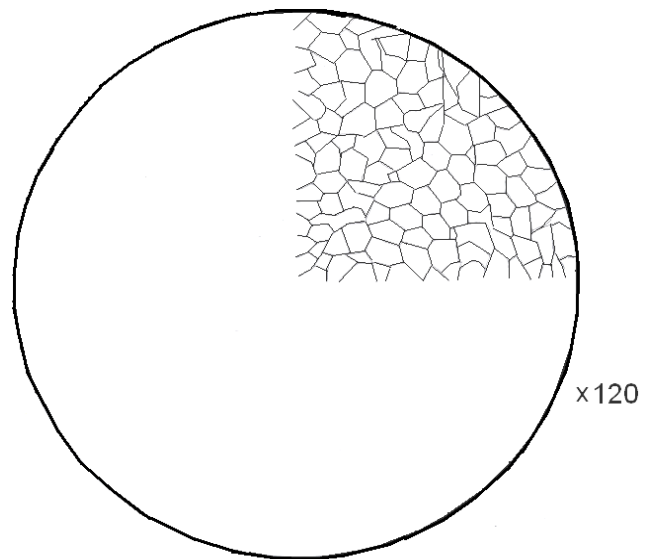


Figure 17: Diagram showing granoblastic polygonal texture in polished etched Galena (average grain: 0.038)

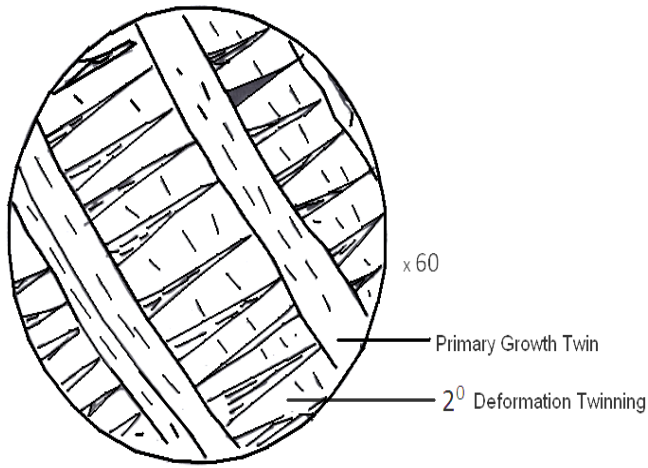


Figure 18: Crystal of Galena showing the two types of twinning growth

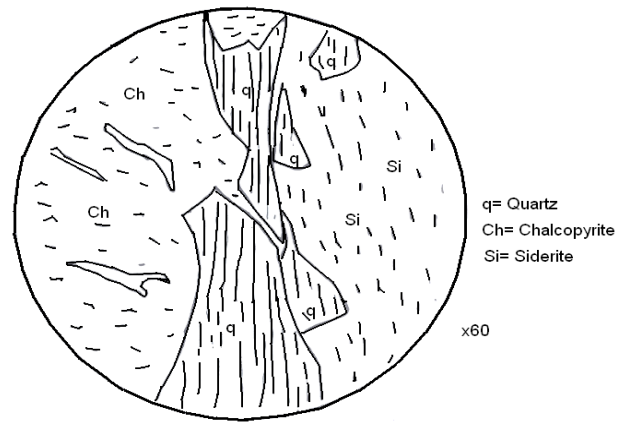


Figure 20: Stringer of chalcopyrite cutting through euhedral quartz crystals.

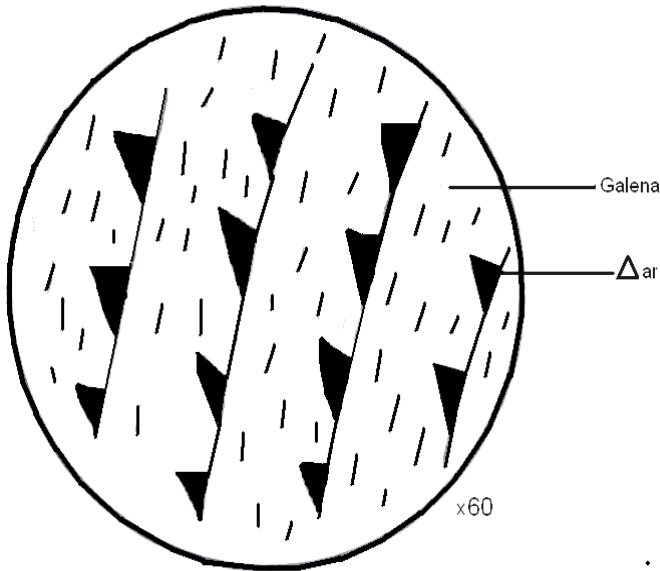


Figure 19: Diagrammatic representation showing triangular pits in Galena crystal as observed when the ore is etched. The Δ_{ar} pits are due to perfect cleavage along the 100 axis

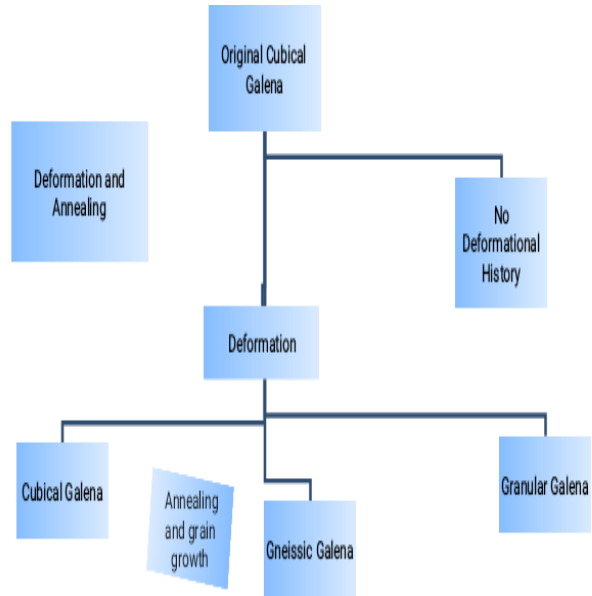


Figure 21: Schematic Relationship of the Three Galena Generations

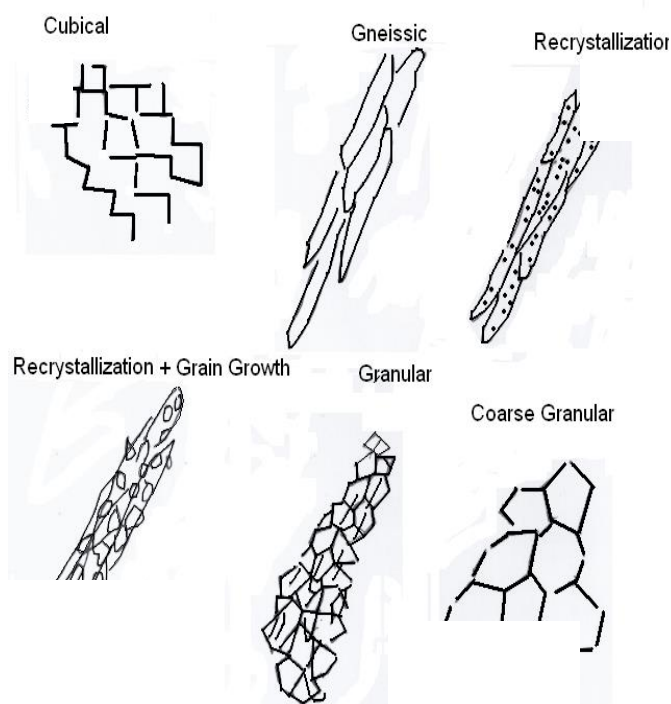


Figure 22: Textural Changes in Galena from Cubical to Granular

11. Oxidation and Vein Weathering

The lead - Zinc mineralization in Gwana is appreciably oxidized above the water table. Evidence of weathering and oxidation is found in the gossan zone. Weathered remains of the main vein are highly silicified. Most of the minerals have been altered to varying degrees.

Chalcopyrite is altered to Azurite (blue) and Malachite (green). Galena is coated with Cerussite and Anglesite. Alteration of Galena can be noticed from the back scattered image SEM. Siderite is altered to limonite and Hematite. These show reddish brown color in the dump. Marcasite is oxidized to various iron oxides. There is no evidence of supergene enrichment, Such as a blanket of primary minerals.

The Lead-Zinc deposit in the study area is an epigenetic ore deposit. This is certain on account of the fact that the minerals are deposited in veins and fracture zones in the shale Yolde Formation in the study area.

The genesis of the ore at the present stage and scope of this work can only be speculative. On the basis of field observation of the structure, petrography (SEM analysis) and taking into account previous work and literature re mineralization, it is proposed that hydrothermal origin. Deposition was in depth. The presence of pyroclastic ne one to suggest magnetic fluid did play a part in the mineralization. The intrusion is on a very small scale and cannot be effective in mineralizing the field.

Pyrite is turned from Sulphur, iron and organic matter. At lower temperatures $< 80^{\circ}\text{C}$, they are formed from bacterial reduction of Sulphur. At temperatures $> 80^{\circ}\text{C}$ Pyrite are formed by thermochemical Sulphate reduction based on the analysis of the samples altered. Pyrites were identified while the extent of alteration is by hydrothermal fluid x analysis shows the presence of oxy d Galena. This also suggest h e environment that supports thermic e reduction process.

12. Results:

Three textural groups of Galena are recognized in the sample during petrographical investigations in polished sections.

- i. These are cubic, fibrous or gneissic and granular Galena. In polished section cubic Galena shows parallel arrangement of triangular piths.
- ii. Gneissic Galena also known as fibrous is structure less when observed under polished section. When well-developed granoblastic polygonal texture is well displayed. The grains have well-formed polygon with straight sub- grain boundaries. Stanton (1972) interprets this texture as representing the attainment of textural equilibrium of the ore.

- iii. Granular Galenas are masses of tiny granules that is derived from cubical Galena through deformation and annealing or from the gneissic Galena through annealing and grain growth. Based on the results of petrographic analysis the dominant framework elements of the studied samples is quartz though with presence of several feldspars (orthoclase and plagioclase) and dominantly sedimentary rock fragments and a few igneous rock fragments as the source material which is an indication of the provenance for the studied samples from the study area.
 - iv. The hydrothermal fluids filled the fissures created by the tectonic deformation of the Benue Trough. The rock hosting the mineralization is the shales of the Yolde Formation, based on the field observations and petrographic study. From the sample observed from the Backscatter SEM images the Galena in the samples is of two types, these are the original Galena and the altered type.
3. From the SEM analysis it could be observed that the alteration in the morphology of the Sphalerite crystals can be attributed to deformation. This texture is sometimes referred to as Sphalerite disease. Blebs of chalcopyrite have been widely recognized in Sphalerite from Sulphide deposit, they have widely been attributed to exsolution, but whereas in fact they may be probably originate from replacement, there are 3 widely used descriptive textures used these are, Watermelon, Dusting and Bimodal. These characterize the Sphalerite disease. These are clearly the result of replacement of

original Fe bearing Sphalerite by an aggregate of chalcopyrite and low Fe Sphalerite as an integral part of the mineralization process.

13. Conclusion

Sphalerite is probably the most useful guide to the process of ore deposition, because it is common in a wide variety of deposit types, it is transparent except when it has very high Fe content, this characteristic allows for three dimensional textural studies it provides a wide range of colors that provide visual indication of growth morphologies, it is also a good host of fluid inclusion it is relatively refractive so its initial conditions are preserved and it has calibrated phase relationship which provides useful chemical parameters that help reconstruct the chemical environment of mineralization. The fine chalcopyrite intergrowth so densely that it is opaque in even the thinnest section, the opaque zone passes into the freshly color banded Sphalerite. This is not exsolution. The term chalcopyrite disease was attributed to the first response of Jim Craig when he said, "that's not a texture; that's a disease" scientist ever adopted this texture as Sphalerite disease.

Plate XIV Shows Sphalerite disease, this is an alteration in the morphology of the Sphalerite crystals which is attributed to deformation.

4. Elemental analysis of the altered and unaltered parts of the Galena reveals the presence of oxygen within the altered region, which is absent in the unaltered region. This suggests that hydrothermal fluid was the major agent of alteration. Barite and quartz precipitated at the end of the ore stage, both in veins and replacing the host rock. During the post-ore stage, barite continued to precipitate in veinlets and fill available fractures. Late quartz partially or completely replaced the host rock.
5. The Gwana Pb - Zn mineralization occurs in the marine sandstone of the Turonian Yolde Formation this provides evidence of a close

link between organic matter oxidation and ore formation. Also Considering the depths of formation, it can be inferred that the ore formed from brines compatible with thermochemical sulphate reduction (TSR) process with organic matter as the reducing agents. The Yolde Formation has been identified as a matured source rock that can provide the necessary organic nutrients for thermochemical sulphate reduction (TSR) to occur.

6. The host rocks are usually silicified, with the ore phases occurring mainly in the matrix. The paragenesis, deduced from the observations of hand samples and SEM work, consists of Sphalerite as the main ore mineral, together with Galena, pyrite, and minor traces of, chalcopyrite, lead, copper and antimony. Other coexisting phases

include quartz and barite. The paragenetic sequence can be subdivided into three stages:

- i. Pre-ore stage;
- ii. Ore stage; and
- iii. Post-ore stage(s)

7. The pre-ore stage corresponds to the beginning of the host rock silicification, characterized by the precipitation of quartz, together with minor crystal -sized pyrites. During the ore stage, quartz, sphalerite, Galena and minor traces of lead copper, antimony chalcopyrite and pyrite precipitated. These phases replaced the host rock and at the end of the stage also precipitated in veinlets. Alterations can be clearly seen around edges of Galena.

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