THE GEOLOGY AND GEOCHEMISTRY OF BARXTE MINERALISATION IN THE AZARA AREA, MIDDLE BENUE TROUGH, NIGERIA.

BY

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A thesis submitted to the postgraduate School, Ahmadu Bcllo University, in partial fulfillment of the requirements for the degree of M.Sc. Geology (Mineral Exploration)

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DECLARATION

I certify that this thesis is based on the results of research carried out by me, that it is my own composition and that it has not been submitted in any form for another degree or diploma at any other university or institution. Information derived from the published and unpublished work of others has been acknowledged in the text

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Signature of Candidate

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ABSTRACT

The rocks of the Azara area are made up of sandstones, shales and shaly mudstones, and limestones of the Awe formation, and sandstones of the Keana formation. Dacite, a volcanic rock, also occurs in the study area.

Mineralisation in the Azara area is in the form of brine springs and baryte deposits. Both are lithologically and structurally controlled.

All the brine springs are located on the same alignment on an anticlinal axis of a ENE-WSW fold that transcends the study area. Analytical results of the elements in the brine springs shows that they are marine in origin and are solutions of halite derived from an evaporite. The evaporites are associated with the transitional Awe formation of Cenomanian age but the brine springs seen on the surface are structurally related to the fractures that developed as a result of tension caused by the compressive stresses of the Santonian folding episode in the Benue Trough.

The barytes occur as fracture filling veins mostly in the sandstones of the Keana Formation at the nose and flanks of the ENE-WSW fold. The barytes are bydrothermal in origin. Within each vein system different generations of barytes with sharp contacts occur. Analytical results and trends of the elements

In the barytes show that the barium in the hydrothermal solutions was remobilised as a result of leaching, from mineralised basement rocks beneath the Cretaceous sedimentary cover. The presence of Cu suggests a temperature of 150 - 250°C. The Initial heat was supplied from volcanism in the study area. The barytes are probably Campano-maastritchian in age.

The evaporites and barytes in the Azara area are not genetically related. Though the brine springs and the Pb-Zn mineralisation in the Benue trough are spatially related, investigation shows that they are not genetically related.

Trace element studies only indicate that the baryte mineralisation represents the last stages of the hydrothermal activity that gave rise to the Pb-Zn veins in the Benue trough.

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Cm	Centimeters
Co.	Company
ENE	East-Northeast
G.S.N	Geological Survey of Nigeria
Kms	Kilometers
M	Meters
NE	Northeast
NIVR	National Institute of Vertrinary Research
NMC	Nigerian Mining Corporation
NNE	North-northeast
NNW	North-northwest
NW	Northwest
MM	Milimeter
Pub	Publication
SE	Southeast
WSW	West-Southwest

CHAPTER ONE

INTRODUCTION

1.1 Location and Extent of Project Area

The project area, centred around Azara village in Awe Local Government Area of Plateau state, is located on sheet 232 (Akiri) Nigeria (fig 1.1). This area is part of the middle Benue trough.

A total area of 495 km^2 situated between longitudes 9^{o} 06' E and 9^{o} 24' E and lattitudes 8^{o} 17' 25" N and 8^{o} 26' N was mapped on the scale of 1:25,000 with particular attention on the eastern half of the area where the barytes veins occur.

Azara is 68kms and 100kms from Obi and Lafia respectively.

1.2 Previous Work

The Benue trough has often been described as an elongate partly fault bounded depression occupied by up to 6000 meters of marine and fluvio-deltaic sediments that have been compressionally folded in a non orogenic shield environment (Wright 1975, 1981). These sediments, mainly Cretaceous in age, were intruded into by volcanic rocks of various types. The Benue trough (aulacogen) is the failed arm of a tripple junction RRR that led to the opening of the atlantic sea (Olade, 1975).

Mineralization within the Benue trough has been a subject of great interest since about the middle of this century. Lead-zinc-flourite veins, coal, salt, diatomite, clay, limestones and baryte deposits are known to occur within the Benue valley. Occurrences of other minerals such as trona, lignite, spring water, glass sand, iron ore, laterite, gravel and stone have been reported (Ford, 1981). See fig 1.2.

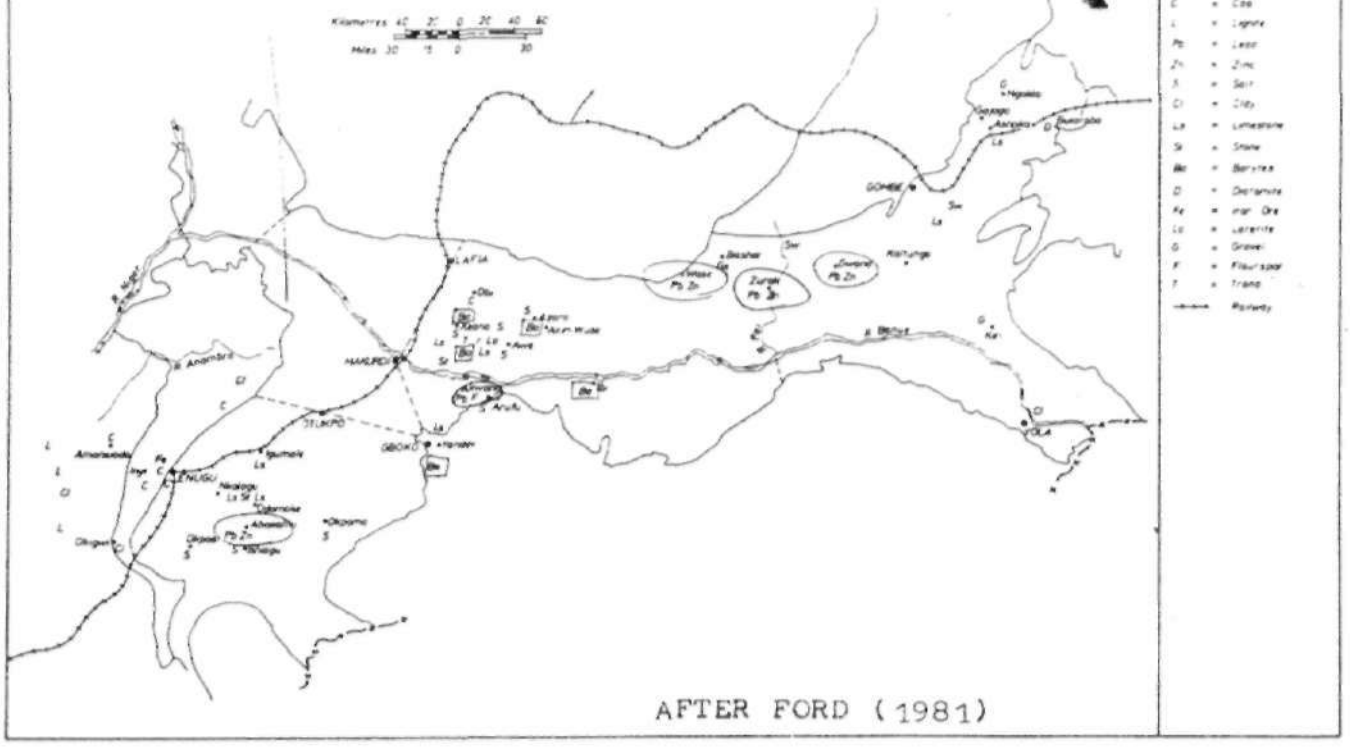
Tate (1959) reported the occurrence of barytes at Aloshi, Keana, Akiri, Shata, Ibi and Ubande in the Cretaceous rocks especially sandstones, and in the basement rocks. Bogue (1952) discussed the galena-baryte occurrences near Gabu, Ogoja Province.

FIG 1:1 LOCATION MAP OF PROJECT AREA



Fig. 1:2 *Economic Mineral Occurrences in the Benue Trough*

Scale 1 : 5,500,000



Note the trend of Pb-Zn and the concentration of Ba within the Trough

important economic mineral deposit (e.g Offodile et al, 1977; Offodile, 1980) along side uranium in the recent times by the Nigerian Mining Corporation (NMC) and the Nigerian Uranium Mining Corporation (Numco) respectively. Otherwise the baryte deposits continued to be mentioned in the literature only in passing when discussing the conomic minerals of the Benue Trough.

The local inhabitants of the study area are aware of the importance of the brines as sources of table salt: for this purpose they have for long been mining them for their local needs. Barytes, on the other hand, have not been mined locally by the inhabitants.

Barytes are the principal source of barium compounds and are used in drilling muds, as a pigment or extender in paints and as a filter in paper and ruber manufacture (Kerr, 1977). Baryte is often referred to as "heavy spar" because of its weight. It's 'quality' decreases with decreasing specific gravity and increasing silica. Tate (1959) recorded a tentative reserve of about 40,800 tons of barytes within the middle Benue valley; evaluation was

to 18 meters in depth. However recent studies by the NMC indicate a reserve of about 130,000 tonnes of barytes to a depth of only 10 meters within [illegible] 14 veins. Only five of these baryte veins have been classified economical to mine, at the present, by the NMC.

1.3 Aims and Scope of Prevent Work

The geology and geochemistry of the mineralisation around Azara area is investigated. The aims, and scope of this work are:

(a) To delineate the various lithological units of the study area.

(b) To study the structural features of this area and their relationships with the directional trends of the baryte veins.

(c) To study the physical and chemical variations across and along the baryte veins noting cases of wall rock alteration, if any, and the various generations of baryte.

(d) To make macroscopic and microscopic discriptions and distinguish the different varieties of baryte from each other, and 'time' the events of mineralisation.

(e) To study the brine springs of the study area and discuss the salt industry, highlighting the problems and prospects of salt mining.

(f) To study the chemical elements in the brine springs and compare them with the trace elements in the baryte veins.

(g) From the geological, structural and chemical studies undertake a synthesis of the possible genesis of mineralisation in the study area and discuss the relationship of the baryte deposits to the brine springs and the pb - zn mineralisation in the Benue Trough.

1.4. Geography

The area is fairly elevated. It is about 100 - 200 meters above sea level. Apart from a few ridges running nearly east - west (e.g the Kwara kwasa ridge) the area is generally undulating especially in the eastern part. Most of the baryte veins however occur with distinct topographical features (see Plate I).

River Ankwe, running southeastwards in the northern part, meanders southwards forming a substantial amount of old and recent alluvium along its banks. All the minor streams drain into this river. The drainage is dominated by a trellis pattern of flow though a few are dendritic.

The area is part of the middle belt of Nigeria and has a fairly thick savanna. Rainfall is heavy with an average of 150 - 180 cm per annum. The main rainy



Plate I. Perculiar topographic expression of the baryte composite vein. Locality: vein 17

period is between the months of May and September after which the ground vegetation begin to dry out culminating in bush burning in the months of December and January.

1.5 Accessibility

The area is fairly accessible. A major road, tarred up to Gwantu, passes from Lafia via Obi and Kanje to Awe. This is connected to Azara through a minor road passing through Ribi to Kanje. The lack of culverts on some of the streams on the minor road, and the lack of a bridge across river Ankwe posed some difficulties as canoes have to be used to cross the latter between the months of May and November. The minor paths are also not easily accessible during the rainy season due to the thick savannah. Accessibility is better during the dry season when the grasses are burnt and the streams are dried.

1.6 Mapping and Sampling Method

The traverse method was used for the lithological mapping in the study area. Traverses were taken with the aid of a geological compass and foot paths across the area. Rock samples were taken and described from outcrops along the traverses.

Samples from the baryte veins were taken at the starting and end points of the veins, in places where colour and texture variation are observed along the veins, and at the junction between the veinlets.

Samples from the brine springs were carefully preserved in rubber bottles.

17. Duration of Present Work

The literature review on the mineralisation in the Azara area was carried out in September, 1984. Field work started immediately in October, 1984 and lasted to April 1985. The field camp was at Azara. Laboratory work started from mid April to early June 1985.

CHAPTER TWO

GEOLOGY

2.1 Introduction

The part of the Benue trough under study consists of argillaceous, arenaceous and fossiliferous carbonate rocks and volcanic rocks. The macroscopic and microscopic descriptions of these rocks, the photogeologic interpretation and the structures of the study area are discussed in this chapter.

2.2 Lithology

Shales and shaly mudstones, limestones, sandstones and a dacitic volcanic rock are the main rock type of the study area.

2.2.1 Shales and Shaly Mudstones

The shales are dark green in colour and are strongly bedded. They outcrop beneath the limestones north of Ribi and on the stream one kilometer south of Jangwa on the Ribi-Jangwa road. These beds strikes 80° ENE and dip 40° N.

Shaly mudstones occupy a substantial part of the study area especially on the eastern half where there are observable geological contacts between this rock and the sandstones of the Keana Formation. This rock is greenish brown in colour, fine grained uniformly

textured and strongly bedded. Quartz constitutes about 60%, glauconite 20%, plagioclase 10% and mica 10% of the mineral composition. Opaque minerals are present in trace quantities. Outcrops of the shaly mudstone at the bank of the eastern stream on the outskirt of Azara show dips of 30^{O} and 25^{O} S.

These rocks are part of the Awe formation alternating with sandstones and siltstones in a type locality along Lafia-Awe road (Offodile 1984).

2.2.2 Limestones

These are generally greenish in colour, hard, massive and fossiliferous in texture. These fossiliferous limestones occur 700m north of Ribi on the Ribi-Jangwa road, one kilometer ENE of Sambegh village, and 300 meters north of Kurungu village: each extending laterally for not less than one kilometer. These outcrops are however thin varying between 40 to 100m across. The outcrop north of Ribi dip steeply to the north at 42°; an angle conformable to the dip of the shales underneath. The fossils in the limestones are identified as oysters. Differences on the basis of colour exists especially on the Ribi outcrop. The lower layer is darker in colour and with oyster shells (plate II) while the upper beds are lighter in colour and have some siltstone intercalations within

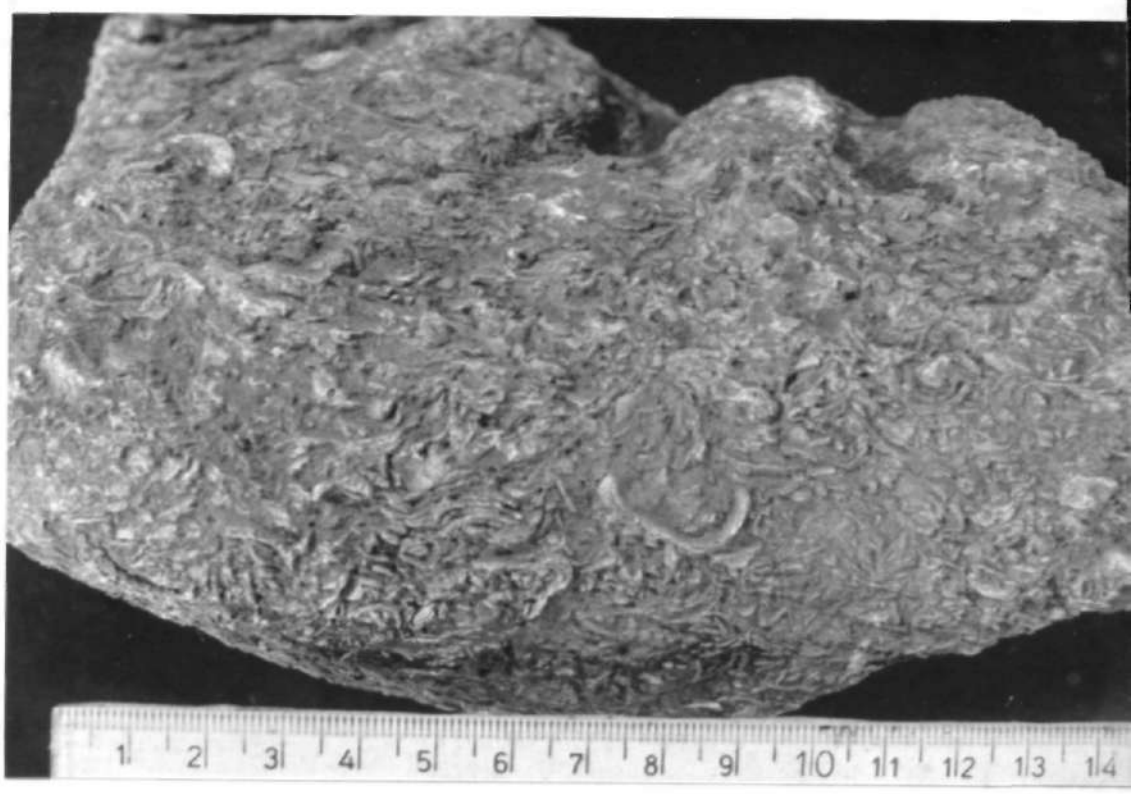


Plate II. Photograph of shells of oystess preserved in the limestone beds. Locality: 300m north of Ribi on the Ribi-Jangwa road.



Plate III: Photograph of cast of oysters preserved in silts stone intercalation in the limestone beds. Locality: 300m north of Ribi on the Ribi-Jangwa road.

which casts of lamellibranchs are preserved (plate III). These limestones are overlain by sandstones and underlain by shales.

The fossiliferous limestones are shallow marine beds of upper Cenomanian age belonging to the transitional Awe Formation (Wozny,, personal communication).

2.2.3 Sandstones

The sandstones in this study area belong to the Awe and Keana formations (Offodile, 1977).

The sandstones of the Awe formation are feldspathic (about 65% of the rock) and coarse grained. The sandstone beds alternate with thin beds of conglomerates, siltstone and shales (Phoenix and Kizer, 1966) indicating that the deposition was under alternating oxidising and reducing conditions. The Awe formation was therefore deposited in a transitional environment and consists of fluvio-deltaic and shallow marine sediments. It occupies the western half of the study area.

The sandstones of Keana Formation outcrop on the southern, eastern and northern parts of the study area. These sandstones consists of poorly sorted feldspathic, medium to coarse grained, grity, partly arkosic, pebbly sandstones. The pebbles are made up

of quartz and feldspar and are subangular to subrounded in shape. The pebbles are about 3-5mm in size. The rock is friable and light in colour (plate IV). Under the microscope quartz is present in the general fabrics and as grits and pebbles constituting about 25% of the mineral composition. while K - feldspars constitute 45%, plagioclase 15%, mica 8% and opaque minerals 4-6% of the mineral composition of the rock. The groundmass is mainly made up of fine grained quartz and some clay minerals acting as cement.

In most of the outcrops especially around Gidan soja and two kilometers NE of Azara the sandstone beds show current and cross bedding as alternating fine and medium grain sizes, and colour changes. The Keana sandstones dip between 25% and 43% north, east or south depending on their locality (plate v). Joints in the sandstones are mostly in the N-S directions. A few joints in the E-W directions have been recorded.

2.2.4 Dacite

These are extrusive volcanic rocks. They occur 300 meters east of vein 17 and in the stream extension of a fault north of new Wuse. They are grey-blue in colour, hard, fine but phorphyritic and siliceous in texture. There are vesicles filled with latter



Plate IV. Friable, light coloured sandstone of the Keana formation. JR is sample No. locality: the quarry site



Plate V. Photograph showing sandstone beds dipping to the south. Note the current bedding in this outcrop. Locality: 2kms NE of Azara. Note the E-W joint across the outcrop.

of quartz (plate vi). Feldspar crystals varying in size from 4 - 6 mm are present as phenocrysts. Quartz occurs both in the groundmass and as phenocrysts constituting about 25% by volume of the mineral composition. Other minerals and their percentages are orthoclase 15%, plagioclase 45%, mica (mainly muscovite) 10%, and opaque minerals 3%. The plagioclase crystals are cloudy and have undergone sericitisation (ie altered). See plate VII and VIII.

2.3 Photo geologic Interpretation of Study Area

The area of study is covered by areal photo No.s 4/138 to 4/148 and 4/088 to 4/097. The photoplates were collected and studied using the stereoscope at the G.S.N. Headquarters, Kaduna.

The drainage is generally trellis with a few dendritic patterns. River Ankwe, the main river of the area, flows from the northern part and meanders southwards. All the minor streams in the study area drain into river Ankwe.

The study area has only a few topographically raised features leaving most parts flat and undulating. There are watersheds on the north-western part and about six kilometers south of Azara trending NE and ENE respectively in a direction common to most fractures. The baryte veins outcrop with good relief but while these have steep slope and are discontinuous



Plate VI. Photograph of a sample of dacite locality: 300m east of vein 17. Sample No RS 16.

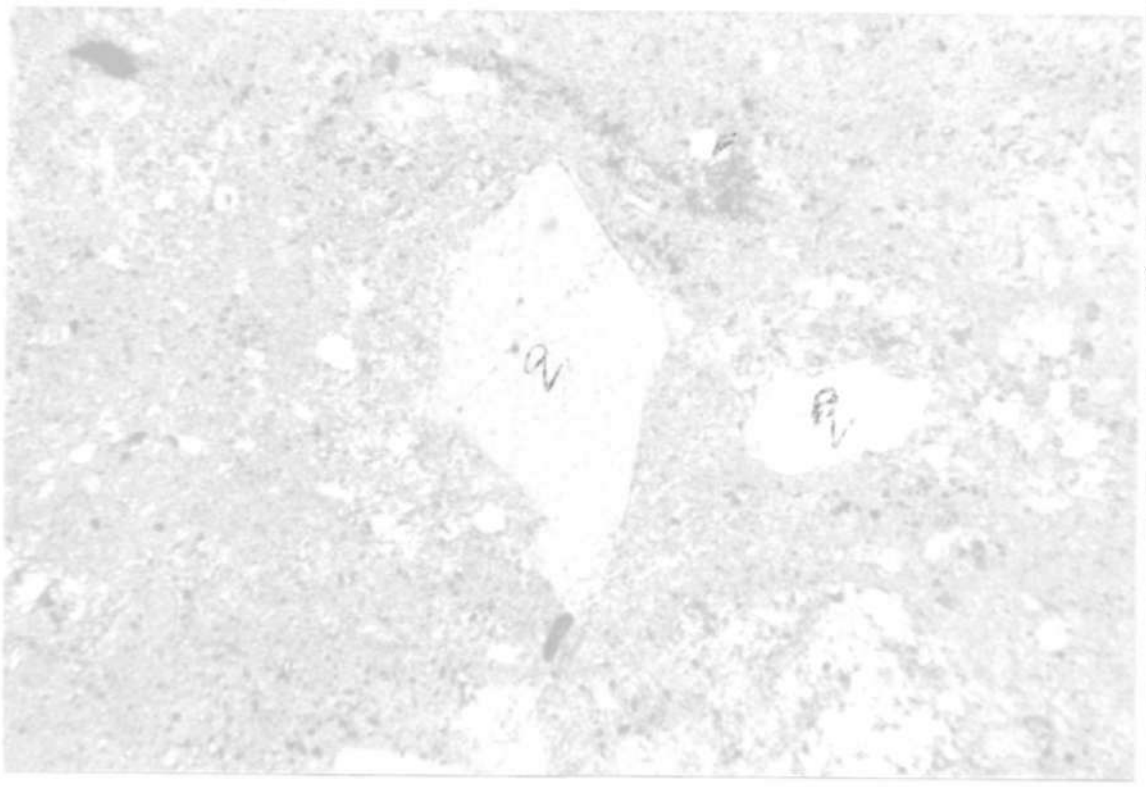


Plate VII. Photomicrograph of dacite showing the fine grained groundmass and some phenocrysts of quartz and feldspars. (X10) slide RS 16.

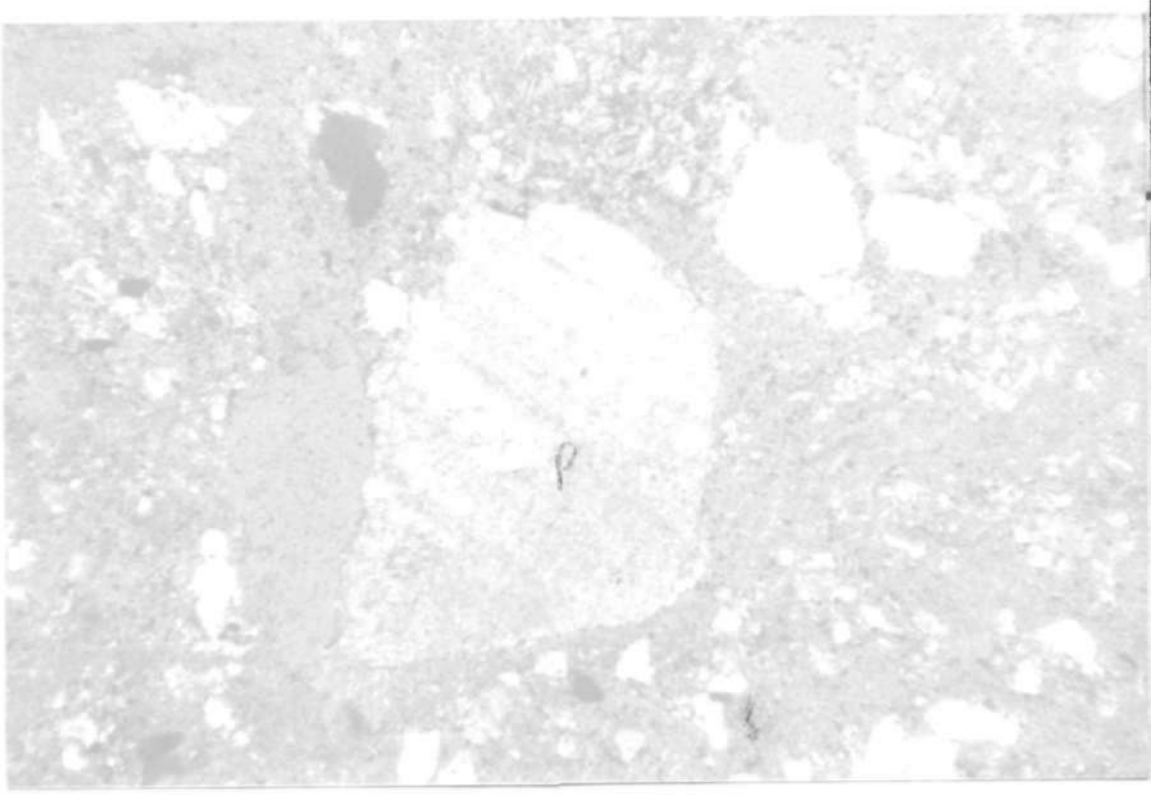


Plate VIII. Photomicrograph of dacite. Note the altered plagioclase in this sample. slide RS 16.

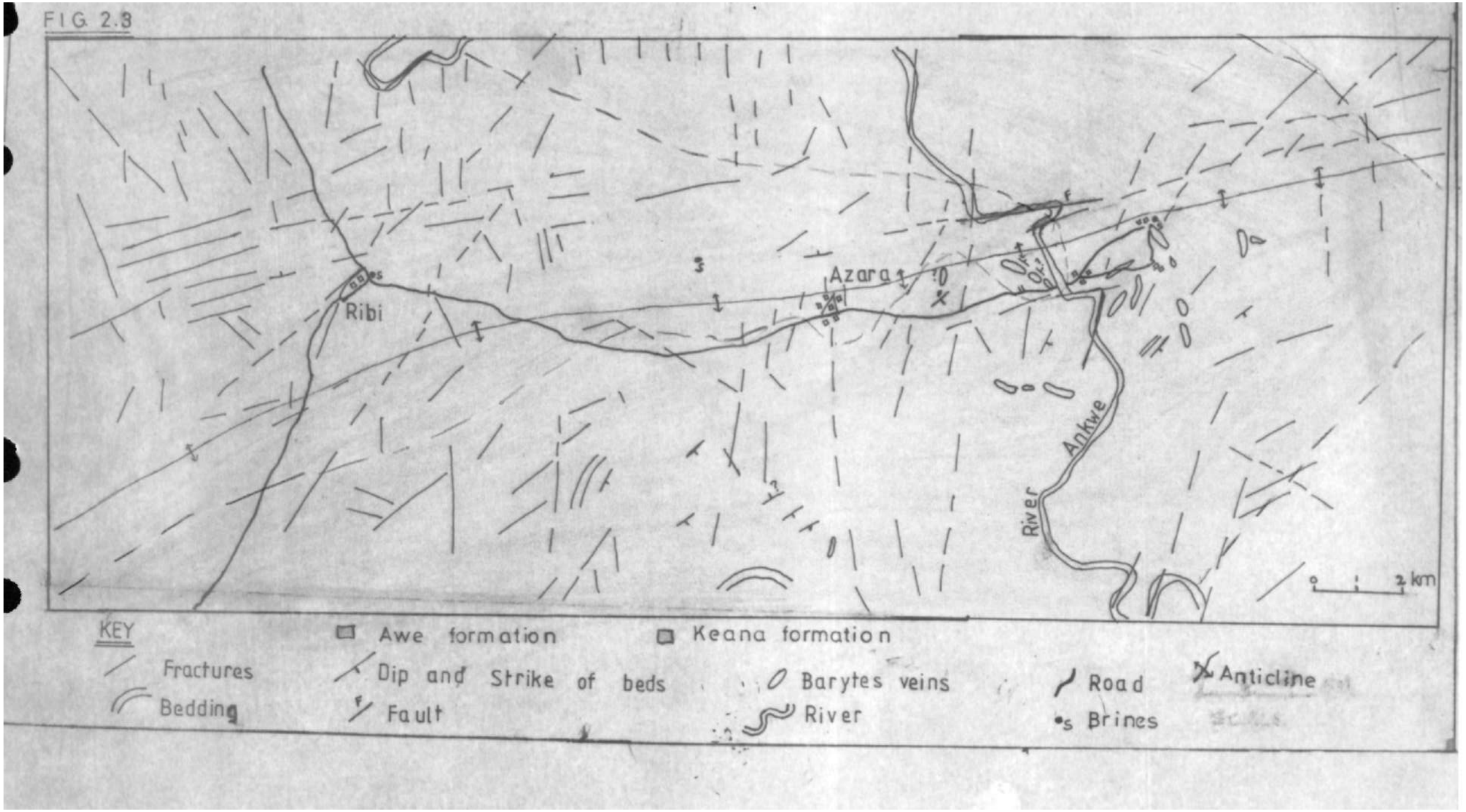
over some meters, the watersheds have a relatively gentle slope and are continuous for some kilometers. The baryte veins are concentrated at the eastern half whereas the watersheds are more pronounced in the western half.

The regional picture of the structures of this area is found on the western half where most of the fractures trend ENE-WSW. There are also some N-S, NNE-SSW, NW-SE and E-W fractures most of which are seen on the surface as running streams. The only observable fault is seen on river Ankwe at about 1½ kms north of new Wuse. This strike slip fault has controlled the direction of flow of the river in this part of the study area. It's lateral extension is seen as minor streams on either side of the river.

The directions of the angle of dip of the beds within the study area suggests a fold trending ENE whose axis passes near Ribi and Azara, and whose nose is at New Wuse. Bedding is especially common in the eastern and southern parts of the study area (fig 2.2).

The lithologies and their boundaries were drawn on the basis of tonal differences, reflection of the texture of rocks, concentration of fractures. These were groundchecked on the scale of 1:50,000 (see fig 2.1).

FIG. 2.3


Ribi
Azara
River Ankwe
0 1 2 km
KEY
Awe formation
Keana formation
Fractures
Dip and Strike of beds
Barytes veins
Road
Anticline
Bedding
Fault
River
Brines

2.4 Structures

From earlier descriptions, it is evident that the geological structures of the study area are joints, faults, beddings and folds of the beds.

The measured joint values on the ground show mainly NW-SE trends. Most of these joints are parallel joints especially on the shaly mudstone outcrops, a feature also seen on aerial photographs. The measured joints are: $325^{o}/90$, $330^{o}/89$, $328^{o}/90^{o}$, $0/90^{o}$, $155^{o}/80^{o}$, $150^{o}/90^{o}$, $170^{o}/90^{o}$, $0^{o}/90^{o}$, $155^{o}/90^{o}$, $320^{o}/90^{o}$, $323^{o}/90^{o}$, $88^{o}/90^{o}$, $320^{o}/90^{o}$. Most of the joints are vertical. Nearly all the minor joints are filled with iron oxide.

The fault that cuts across river Arkwe 1½ north of new Wuse is the only observable fault in the area. The eastern stream extension is filled with a dacitic volcanic rock.

Most of the rocks are strongly bedded and dip in a direction that suggest a fold. The dip values vary from 20^{o} to 43^{o} but in some locations values as low as 10^{o} S, 5^{o} S and as high as 60^{o} N were recorded (see figs 2.1). The fold is fairly steep. The rocks of the Keana formation occupies the limb while those of the Awe formation tend to occupy the crest of this fold.

The fold is related to a compressive stress while the fractures might have developed as a result of tension due to the compressive stress.

CHAPTER THREE

MINERALISATION

3.1 Introduction

Barytes and salt occurring as fracture filling veins and brine springs respectively are the main economic deposits of the study area. The mode of occurrence of the barytes and their macroscopic and microscopic descriptions, the brine fields, the salt industry and the rate of recovery of salt from the brines are discussed in this chapter.

3.2 The Barytes

Barytes occur in the undulating plains of the study area filled by Upper Cretaceous sediments represented mainly by cross-bedded sandstones, and shaly mudstones.

Tate (1959) recognized three main groups of areas within the middle Benue Trough known for baryte mineralisation. These include those:

i) occurring in Cretaceous sandstones and having much siliceous gangue at Aloshi, Igbor and Keana.

ii) occurring in Cretaceous sandstones and are almost pure or with little gangue. These include those at Akiri, Chiata and Ibi.

iii) occurring in basement rocks. These occur in weathered and gneissic rocks at Gbande. They appear disintegrated and contaminated.

The area of study is within the second group.

3.2.1 Mode of occurrence

The barytes of the study area occur as fracture filling veins concentrating at the 'nose' of an ENE trending fold. These fractures formed as a result of the release of tension, , strikes in different directions. Most of the veins strike 328°, 315°, 293°, 263° and 0° directions. Some of the veins, like the associated fractures (fig 2.2), are of several hundreds of meters in length (see fig 2.1).

Topographically, the veins have a perculiar outcropping pattern having steep slopes almost always with silicification and ferrugenisation at the roof portion. The level of outcroping of the veins is a function of the amount of silica in them. Where, on the roof portion, silicification is minimal the veins occur as low lying outcrops (eg vein 18) whereas veins with much silicification stand out clearly as high relief structures (e.g vein 17)

Individually, some of the veins have a stockwork plan of veinlets within a single vein as shown in fig 3.1.

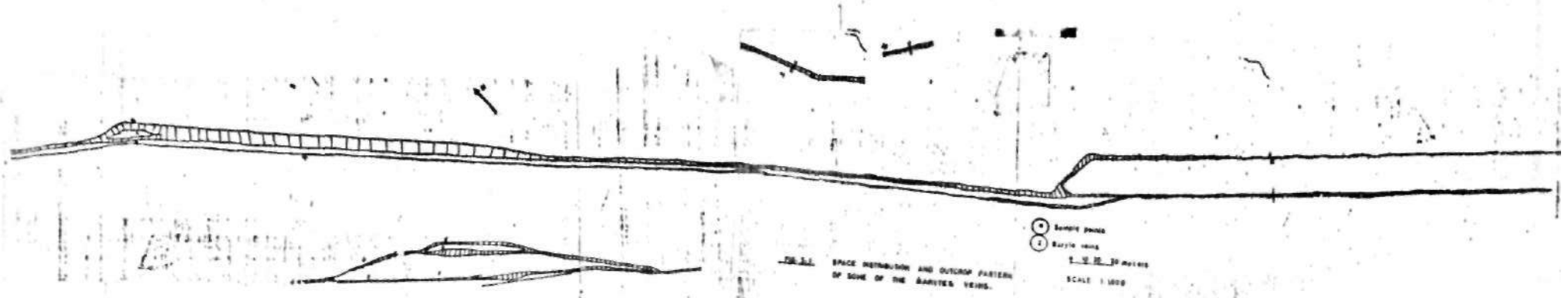


FIG 3.1 SPACE DISTRIBUTION AND OUTCROP PATTERN OF SOME OF THE BARUTEN VEINS.

Ref?

A drilling programme carried out by the NMC on five of the veins show that the veins are shallow; the deepest reaching 120 meter. An inclination of 45^{o} was recorded for most of the veins. This value corresponds with some angle of dip recorded for some sandstone outcrops in some parts of the study area.

3.2.2 Varieties of Baryte

Four varieties or generations of baryte are identified based on colour variations, size of crystals, presence or absence of silica, presence or absence of voids, and the existence of a marked boundary between these generations on one hand and between the veins and the host rock on the other hand. The contact between the generations are sharp and are filled with iron oxide minerals.

There is a strong ferruginized band that bounds the veins. The iron oxide minerals are dark brown in colour and massive in texture having some granular vesicles at their edges. The contact between the ferruginized band and the barytes is also sharp and tectonic in nature. The amount of iron oxide involved at contact between the various generations decreases from the vein - host rock contact inwards towards the center of the veins. Ferruginisation therefore acted as the first phase of the mineralisation and also as a "ground preparation" for the incoming barytes. The ferruginised band is layered (see plate ix).

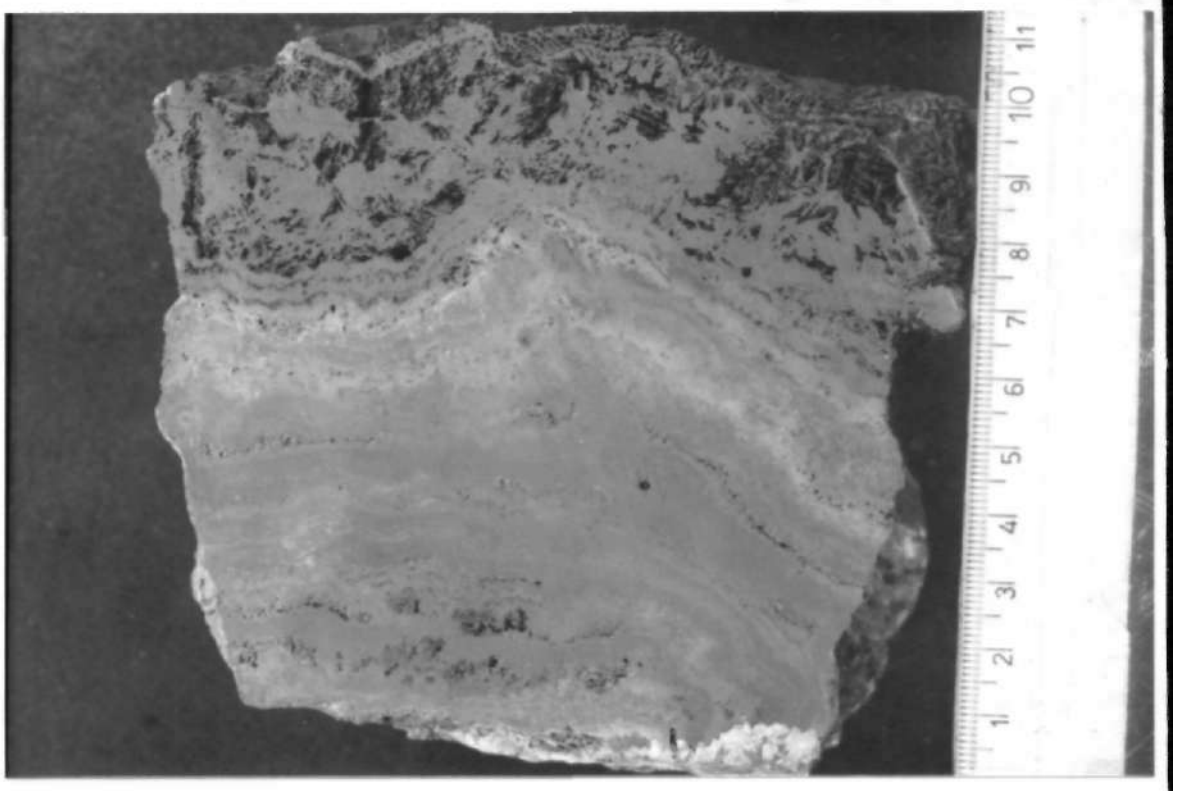


Plate IX. Photograph of a surface across the ferrugenised band. Note the nature of banding and the discordant and sharp contact of this ferrugenous band with some baryte crystals (b). Locality: vein 2

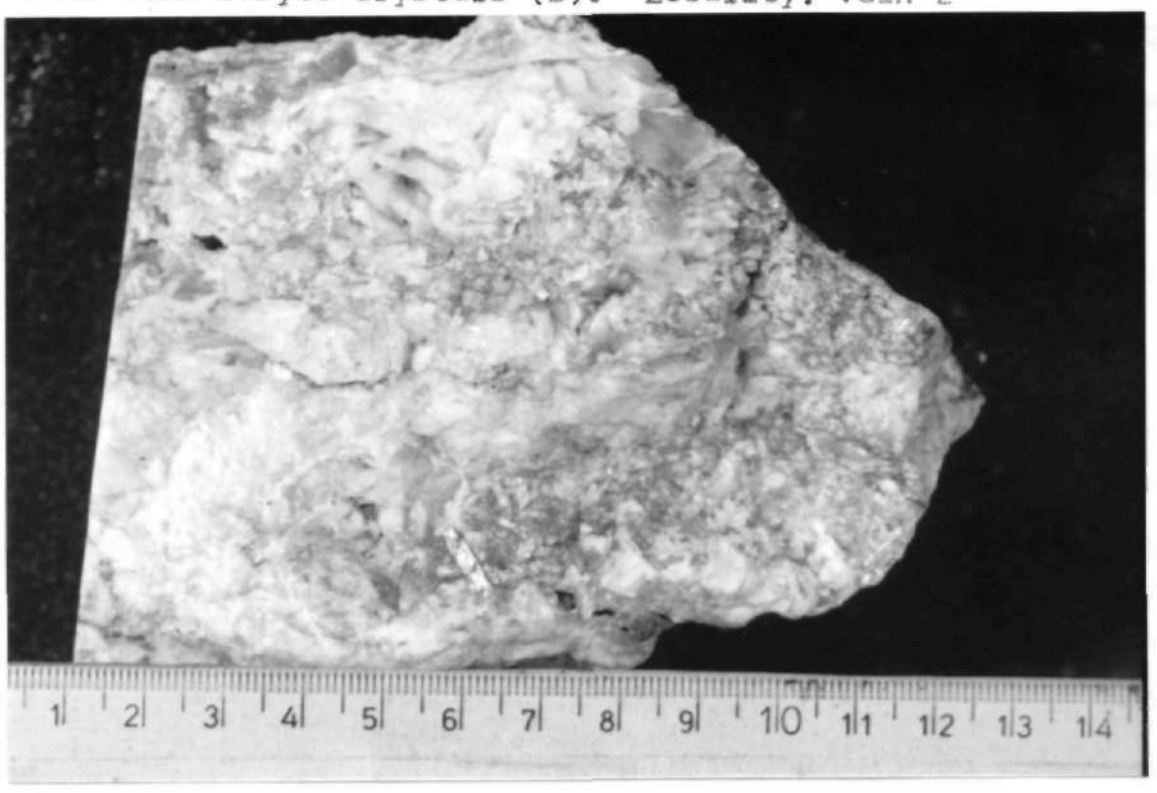


Plate X. Photograph of a sample of the pinkish variety. Note the crystal sizes and the texture of this sample. Locality: vein 4. Sample No. 4f.

The generations of baryte are discussed below.

3.2.2.1 The Pinkish Variety (A)

This is the first generation of baryte that intruded the fractures after the ferruginisation.

Macroscopically, they are pinkish in colour and massive in texture (without voids). Individual crystals are stalactitic in nature. The crystals are not very well developed and vary in length from 2mm to 6mm (see plate x). Field observations show that all the E-W, WNW-ESE and NW-SE trending veins have this variety bordering the ferruginised band. The N-S trending veins do not have this variety.

Microscopically, two types of the pinkish variety are distinguished:

The first type (a_1) is coarse grained with euhedral crystals of 0.5 mm to 3 mm in size. The crystals are polysynthetically twinned (plate xi, xii and fig 3.2). The percentage of quartz and ore (opaque) minerals are high having 10% and 15% by volume respectively. The quartz crystals are rounded and occur at grain boundaries as well as in the baryte crystals.

The second type (a_2) has coarse grained subhedral crystals of 2 to 8 mm in size. The crystals have cleavage in two directions (perpendicular to each other) but only the one along the longer axis parallel

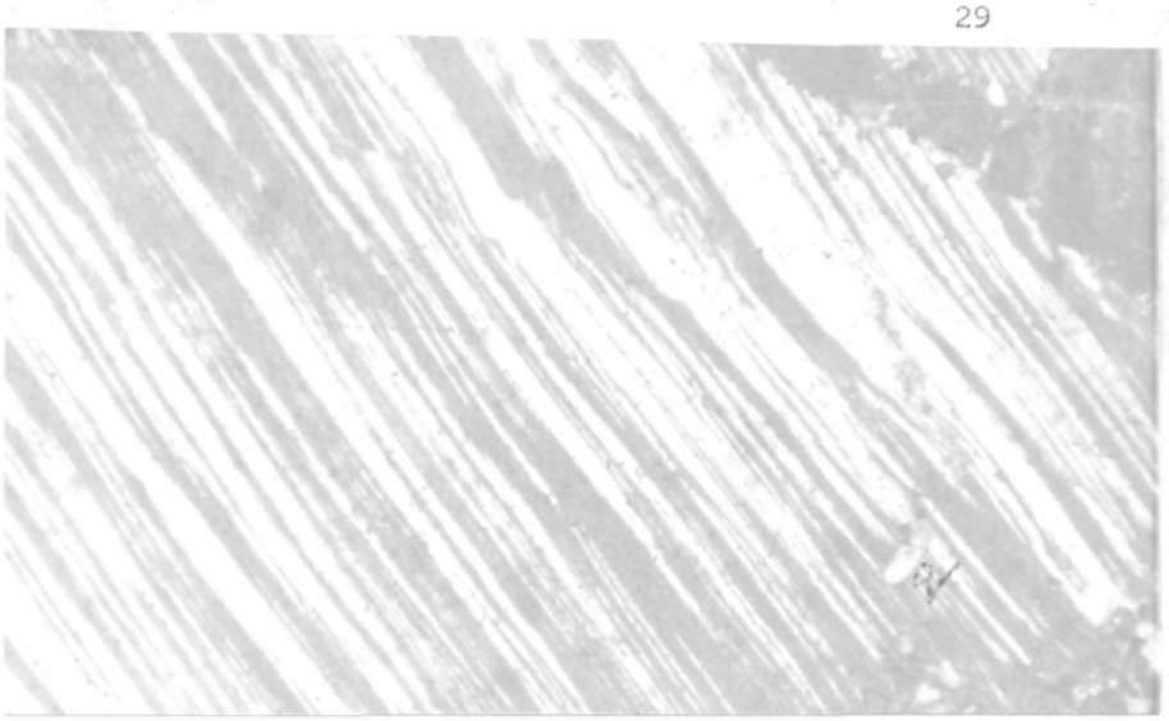


Plate XI: Photomicrograph of part of a crystal of the a_1 type of the pinkish variety under cross polarised light. (X10) Sample (and slide) No. 1b. Locality: vein 17 Note the polysynthetic twinning. q = quartz.



Plate XII: Photomicrograph of a part of slide 1b showing the relationship between the a_1 type of baryte crystals (b) and quartz crystals (q) at the grain boundary under cross polarised light (X10). Note the very fine size of the quartz crystals compared to those of barytes. Locality: vein 17.

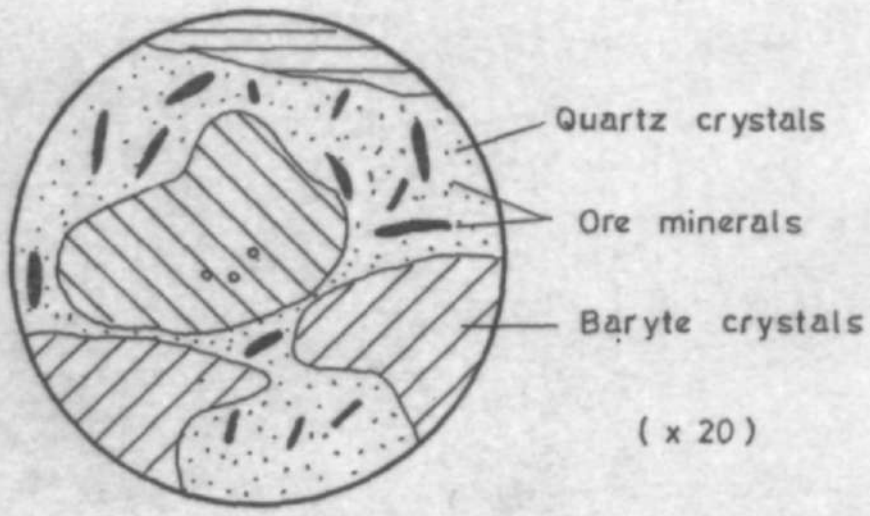


FIG. 3.2 Sketch of the polysynthetically twinned crystals of baryte of the Pinkish variety and the quartz and Ore minerals in sample 1b under the microscope.

to the plane of the crystal is prominent. Where the cleavage planes intersect, simple rectangular blocks are seen. 2V, the angle of extinction parallel to the longer axis, is 82^{o}: hence the angle between the optic axes is 41^{o}. Quartz and ore minerals are 8% and 3-4% by volume respectively. The quartz crystals are very fine grained and occur mainly at the baryte crystal boundaries suggesting that the former are younger in age (fig 3.3).

The a_1 and a_2 types occur at the boundary between the ferrugenous band and the barytes of the E.W and NW-SE striking veins. The boundary between the a_1 and a_2 types is, however, not distinct; suggesting that they are probably of the same age.

3.2.2.2 The Whitish or Colourless Variety (B)

Macroscopically, baryte crystals of the whitish generation are clear, transparent or colourless and are well developed. They vary in size from 2 to 4cm in length and 0.5 to 3cm in width. A perculiar feature of this generation is the presence of voids (plate xiii) and in some cases the deposition of iron oxide mineral and silica at the grain boundaries. Field observations show that while all the veins striking N-S are solely made up of this variety, the whitish generation was only a second generation in the NW-SE

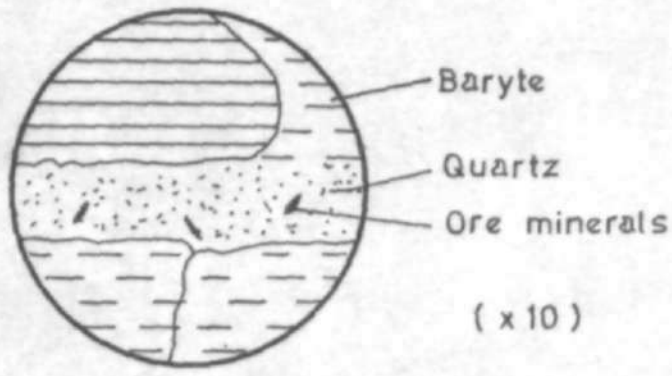


FIG. 3·3 Sketch of part of slide 1 g showing the relationship between the a_z baryte crystals and quartz under the microscope. Note the cleavage planes and the proportion of quartz and Ore minerals in the sample. locality vein 17.



Plate XIII: Photograph of the whitish variety of barytes. Note the presence of voids, the perfect crystals and the iron oxide infillings. Locality: vein 2.

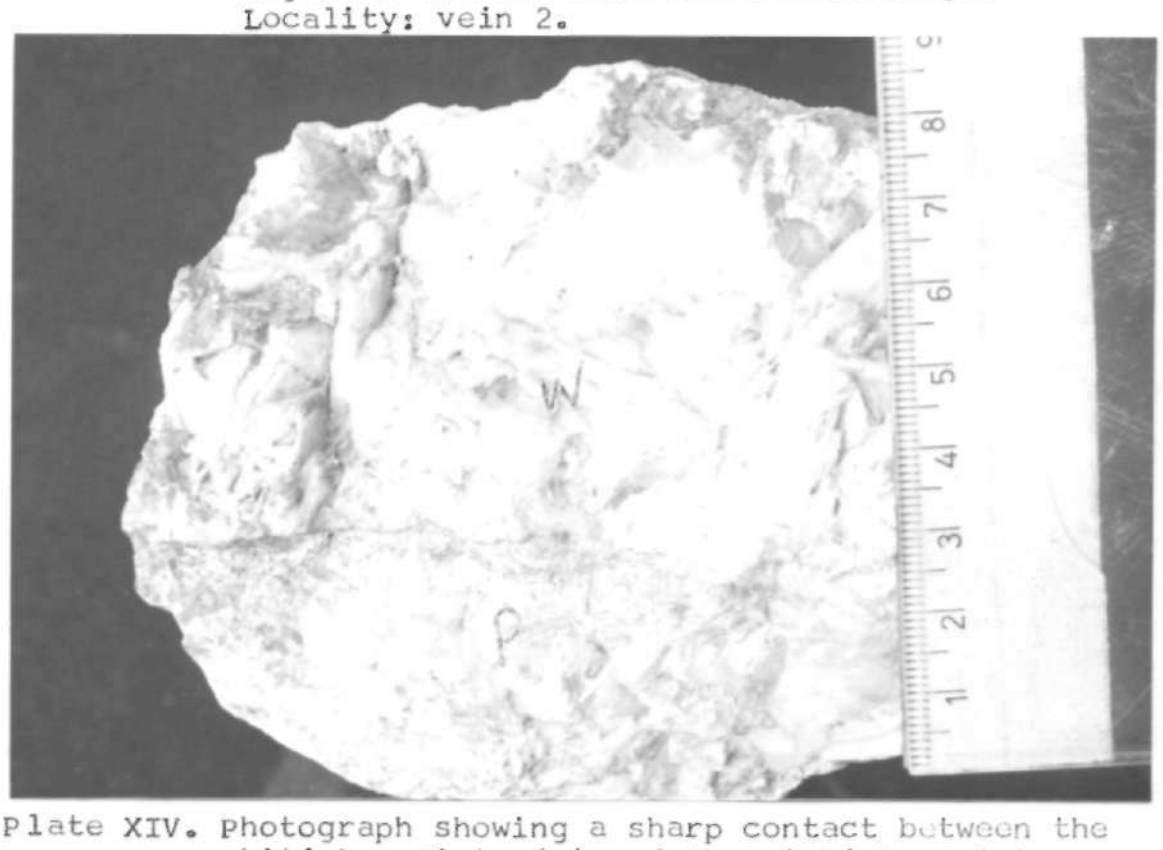


Plate XIV. Photograph showing a sharp contact between the whitish variety (w) and the pinkish variety

trending veins and the last generation in the E-W trending veins. There is a marked contact between the whitish and the pinkish generation of the E-W and NW-SE striking veins (see plate xiv).

Microscopically, two types of the whitish variety are also distinguished using the percentage of ore minerals and the trend of the veins:

Type b_1: This type of the whitish variety of baryte in the study area is coarse grained but uniformly textured. The crystals show cleavage planes in two directions almost at right angles (87° to 90°) to each other (see plate xv and fig 3.4). The type b_1, common only in the E-W, NW-SE striking veins, do not contain quartz or ore minerals. On these veins the type b_1 makes distinct geological contact with the pinkish variety.

Type b_2: The baryte crystals of the type b_2 are also coarse grained and uniformly textured and cleavage planes in two direction almost at right angles to each other like those of the type b_1. Ore minerals are however present forming about 15 - 20% by volume in the type b_2 (plate xvi). There is no quartz. The type b_2 is found only on the N-S striking veins where it forms a distinct geological contact with the ferruginous band bordering the vein.

Angle 2V for both types is 87°; hence the angle between the optic axes is 43° 30'.

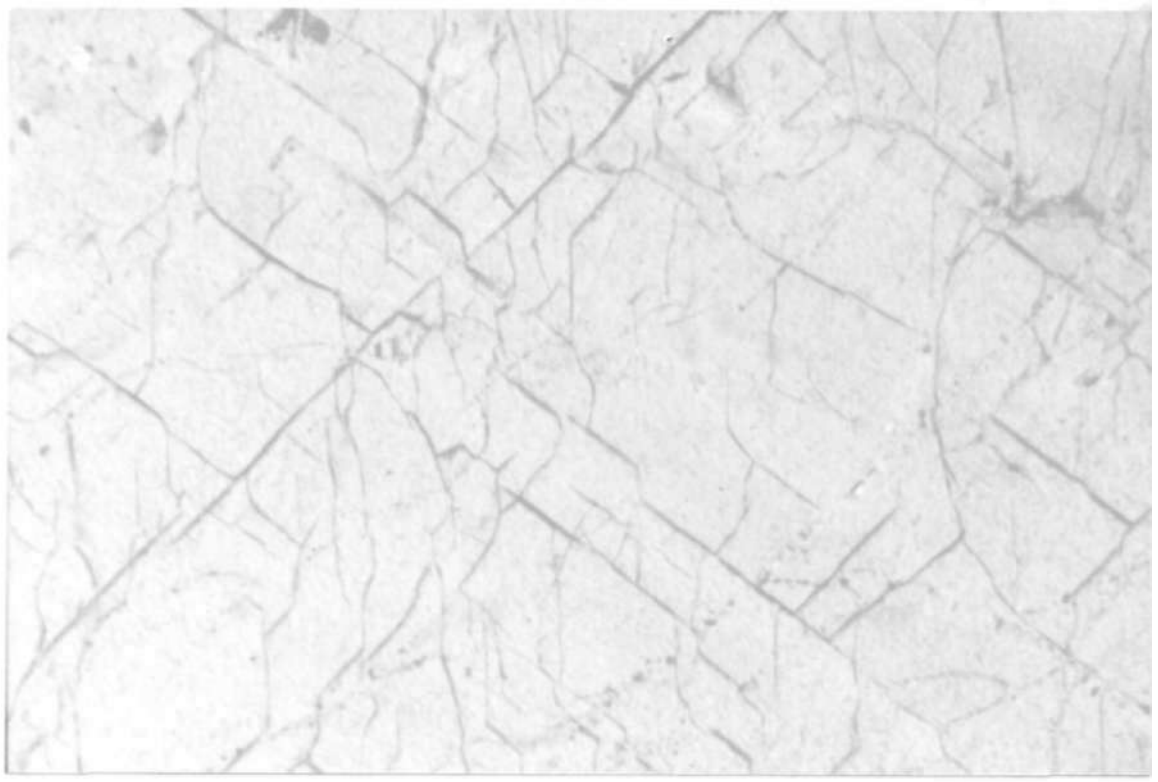


Plate XV. Photomicrograph of part of a baryte crystal of the whitish variety under crossed polarised light (X10). Note the cleavage planes in two directions and the lack of quartz crystals and ore minerals in the sample. Slike 2A. Locality vein 18.

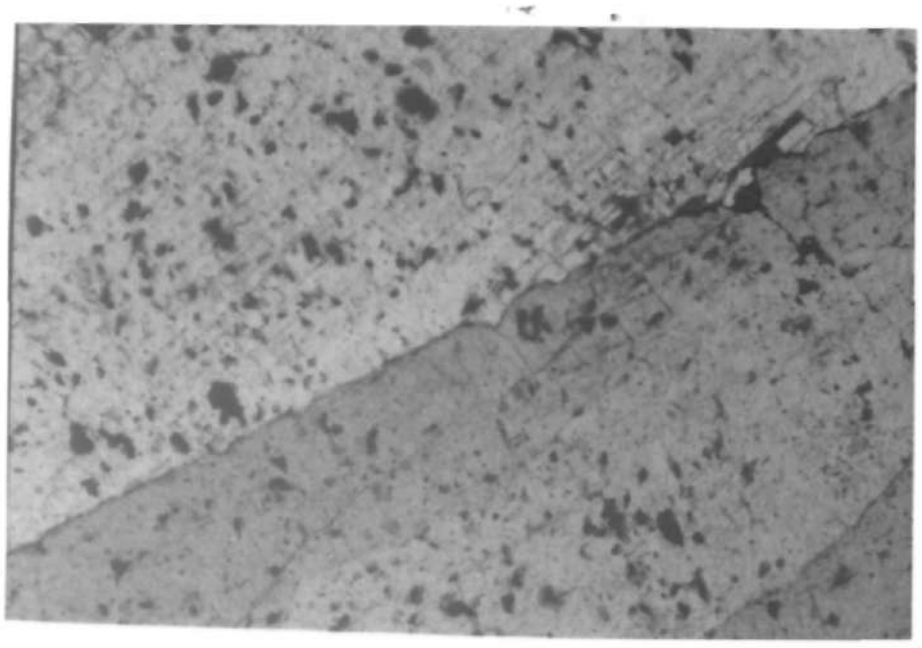
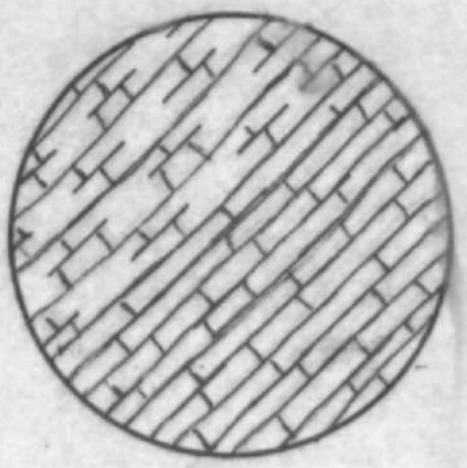


Plate XVI. Photomicrograph of part of slide 10 showing the sharp contact between two baryte crystals (b) of the whitish variety typical of the N-S striking veins under crossed polarised light (X10). The black dots are ore minerals in the baryte crystals. Locality: vein No 8.



(x 10)

FIG. 3.4 Sketch of part of a crystal of the whitish generation as seen under the petrological microscope Note the cleavage planes

[slide 2 A] Locality; vein 18.

3.2.2.3 The Smoky Variety (C)

This generation occurs as lenses in the core of vein 18 striking 328° (NW). The individual crystals are very well developed varying from 2 to 3.5 cm in width and 3 to 5 cm in length. These crystals grow individually, displaying the orthorhumbic crystal habit of baryte (plate xvii) and are free of quartz are iron oxide minerals. A sharp contact exists between crystals of this generation and those of the whitish generation (see plate xviii).

Microscopically, the crystals are glassy and fibrous in texture. There are neither twinning nor cleavage planes on the crystals (see plate xix).

3.2.24 The Cu-rich (Greenish) Variety (C_1)

This generation occupies a core position of some veinlets in veins 17 and 2 (plate xx) striking in the NW directions. On these veins, this variety extends for more than 6-10 cm in length but only about one meter wide. This cu-rich generation is bounded on either side by the whitish and pinkish generations (see plate xxi).

They are greenish in colour, massive in texture and fine grained. The greenish colour is secondary and may be due to the oxidation of small grains of pyrite (identified using handlens, x20) in this generation.



Plate XVII. Photograph of the smoky variety of baryte. Note the texture and growth of the crystals. Locality: vein 18.

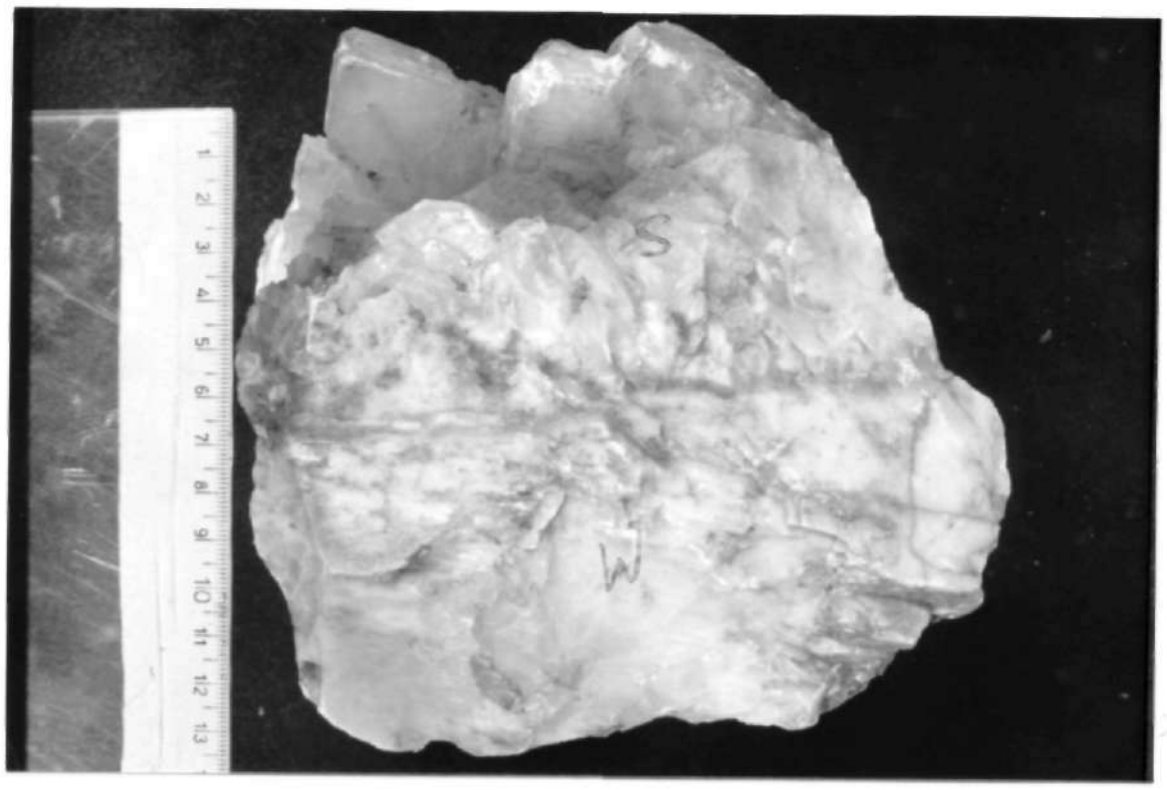


Plate XVIII. Photograph showing the contact between the whitish variety (W) and the smoky variety (S). Locality: vein 18.

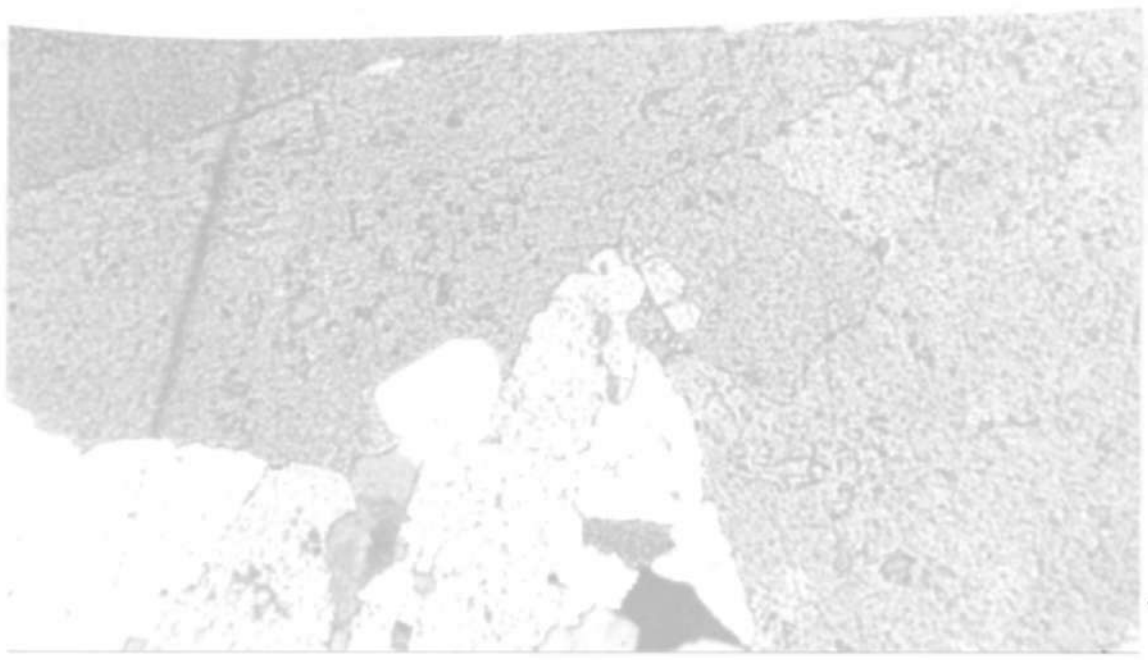


Plate XIX. Photomicrograph of part of slide 5 under under crossed polarised light showing the glassy textures of the smoky variety (X10). The light coloured crystals are fibrous crystals in this generation. Locality: vein 18.



Plate XX. Photograph of part of a veinlet in vein 17 showing the position of the cu-rich variety.

Microscopically, the crystals are subhedral in shape and typically have a plumose pattern of cleavage crystals with irregular boundaries (see plate xxii and fig 3.5). Quartz and ore mineral content is high having 30% and 10% aboundance by volume respectively. The quartz crystals are small and rounded like those of a_2.

Compared with the pinkish varieties, the quartz content in the cu-rich variety has doubled while the ore mineral content has decreased by one-third. This suggests that there was more silicification and less ferrugenisation at the close of events relating to the mineralisation of barytes in the study area than at the beginning.

The cu-rich generation is probably syngenetic with the smoky generation since both occupy the core portions of some of the veins e.g. vein 17 and 18.

3.2.2.5 Remarks

In general, there are three main generations, A, B, and C of barytes in the baryte veins of the study area. The first generation 'A' is common to both the E-W and NW-SE sticking veins. The second generation 'B' is common to all the vein systems and it is the only component of the N-S striking veins. The third generation C and c_2 (probably syngenetic)

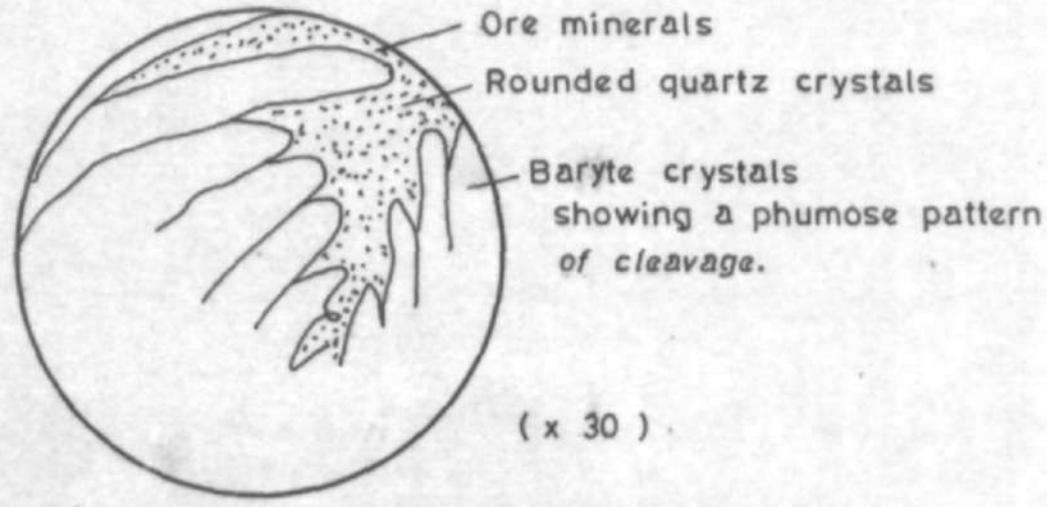


FIG. 3·6 Sketch showing part of slide 3
Note the size of quartz and
Ore minerals and the baryte
crystal boundaries.
Locality: vein 17.

occur only in the NW-SE striking veins. Fig 3.6 summarises these trends.

The generations described above probably represent different tectonic cycles associated with baryte mineralisation in the study area. Figs 3.7 and 3.8 are schematic representation of these generations in vein 17 and 18 respectively.

Silicification appear to have taken place in three stages involving increasing amount of silica. These are those associated with

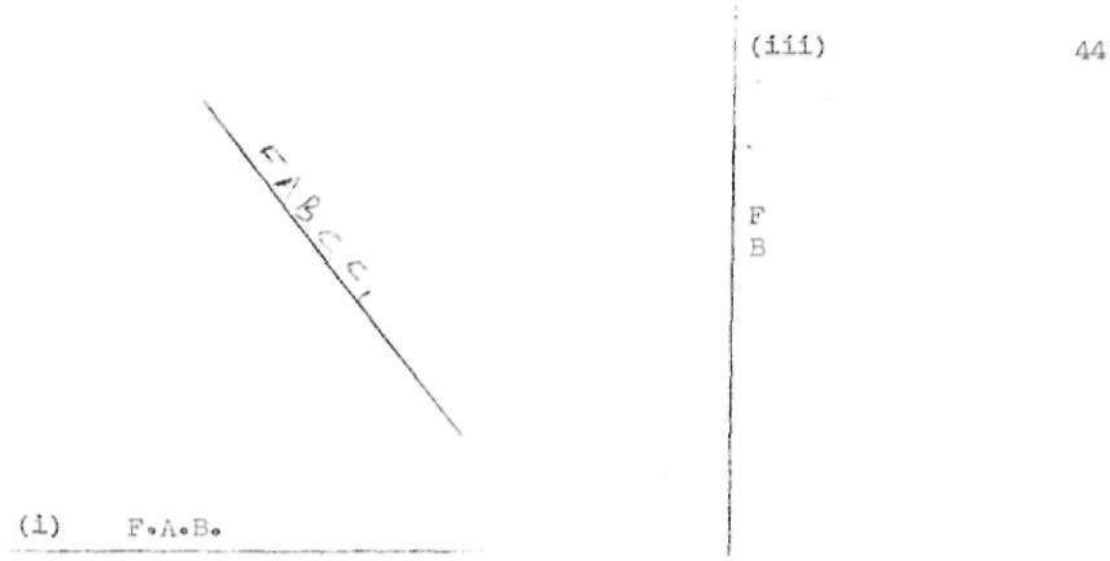
i) the iron oxide fluids that formed the ferruginized bands.

ii) the pinkish and cu-rich varieties at the beginning and the end of events relating to the formation of baryte veins.

iii) the roof portion.

The first and third phase silicification 'I and III) are common to all the vein systems. The second phase silicification is only associated with E-W and NW-SE striking veins. The third phase results in the formation of enhedral crystals of quartz in some voids and on the barytes veins (see plate xxiii).

Ferrugenisation, on the other hand, show a decreasing order of involvement in two stages: firstly in the ferrugenised band that borders the barytes veins,



		Direction			
(i)	=	E - W	F	=	Ferrugenous band
(ii)	=	NW - SE	A	=	Pinkish variety
(iii)	=	N - S	B	=	Whitish "
			C	=	Smoky "
			C_1	=	Cu-rich "

Note: B is common to all the vein directions

A occur only in the E-W and NW-SE veins

C, C_1 occur only in NW-SE veins

Fig 3.6 Major directional trends of the baryte veins and the associated generation in the study area.

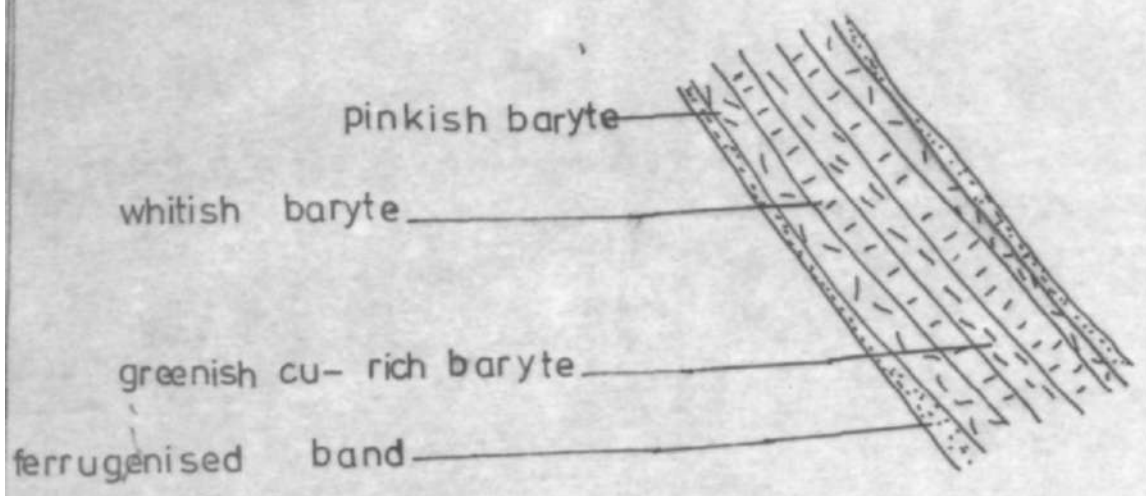


FIG:3.8 SHOWING THE VARIETIES OF BARYTE ACROSS A VIENLET IN VIEN 17 (sketch)

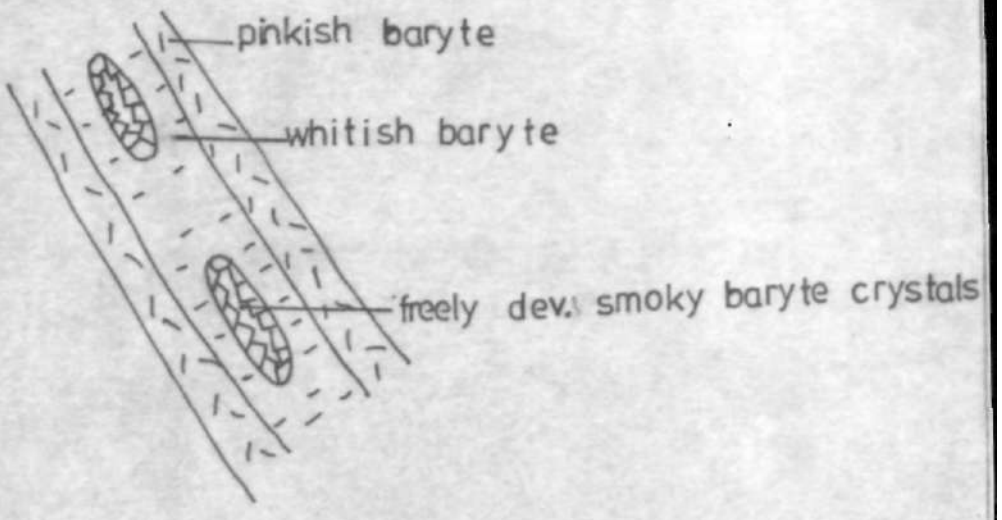


FIG:3.9 SHOWING THE VARIETIES OF BARYTE ACROSS VIEN 18 (sketch)



Plate XXIII. Photograph of a surface of sample 1m, vein 17, showing late stage enhedral crystals of quartz.

and secondly as ore minerals that accompany the barytes of the pinkish variety, b_2 type of the whitish variety, and the cu-rich varieties.

The nature of the ferrugenised band shown in plate ix indicate an involvement of volcanic heat. The volcanicity probably affected mainly the initial stages of the baryte mineralisation and perhaps accounts for the decreasing amount of ore minerals in the last stages of the barytes mineralisation.

A summary of the mega and microscopic studies are in appendix I.

3.2.3 Specific Gravity Measurements

Dry density measurements of some samples of the generations of barytes, dacite and limestones of the study area were carried out. The average values of specific gravity for the barytes are anomalous with 4.12 g/cm^3 over those of dacite (2.57 glems) and limestone (2.68 $g/cm)^3$ (table 3.1).This anomalous peak indicates that gravimetric survey could be used in prospecting for barytes in the study area (see fig 3.2).

Among the varieties of baryte in the study area, the smoky and cu-rich varieties have the highest S.G of 4.15 g/cm^3 and 4.17 respectively while the pinkish has the least S.G of 4.04 g/cm^3. The whitish variety also have high S.G of 4.13 g/cm^3. The S.G. values therefore increases towards the center of the baryte veins.

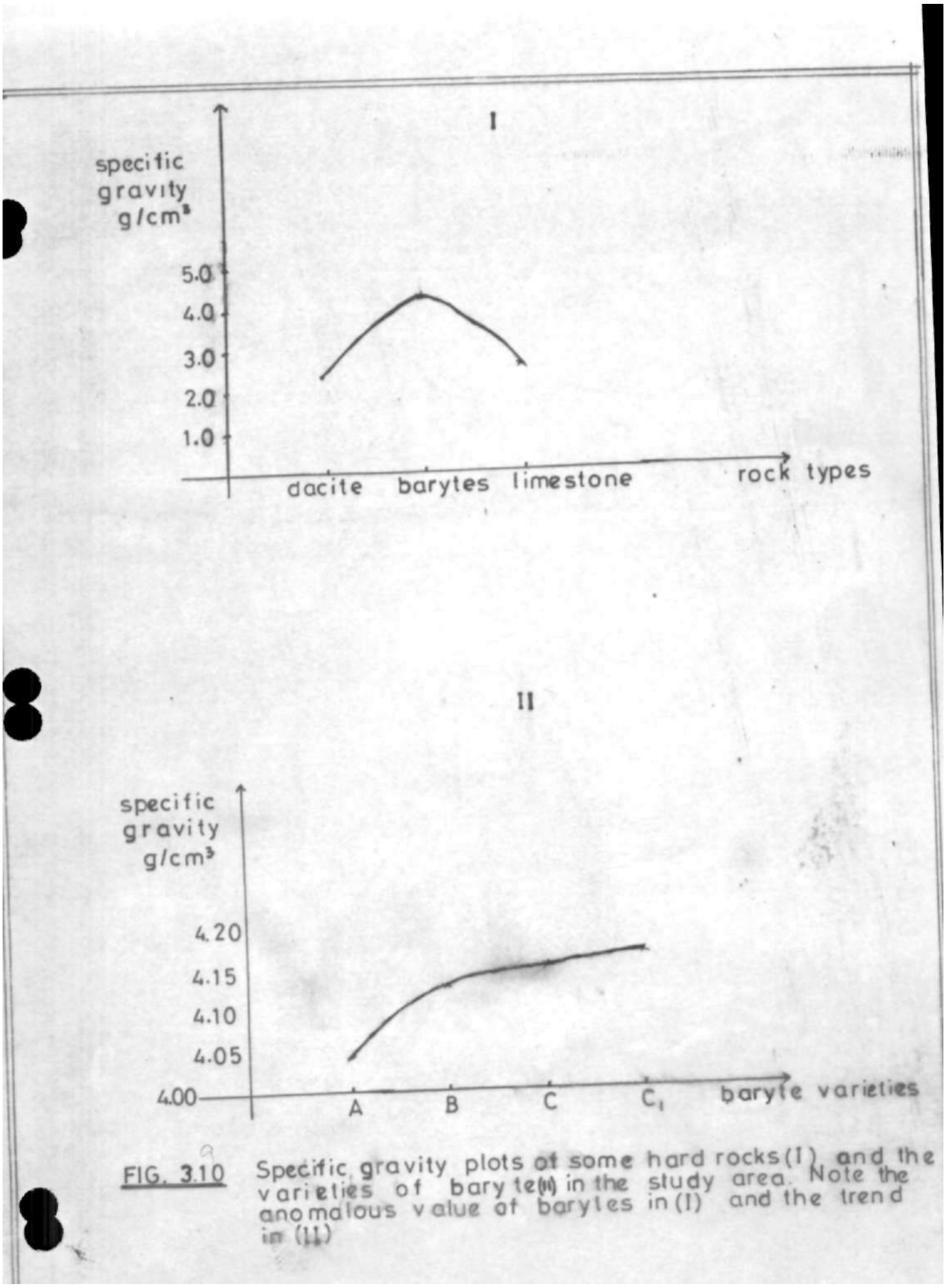


FIG. 3.10 Specific gravity plots of some hard rocks (I) and the varieties of baryte (II) in the study area. Note the anomalous value of barytes in (I) and the trend in (II)

Since the value of baryte increases with increasing specific gravity, the 'B' and 'C' generations are of more economic significance than those of 'A'.

Table 3.1: SPECIFIC GRAVITY VALUES OF BARYTES, DACITE AND LIMESTONES IN THE STUDY AREA.

ROCK TYPE	NO OF SAMPLES	SPECIFIC GRAVITY (AVERAGE) 91 cm^3
Barytes	9	4.12
Pinkish Variety	2	4.04
Whitish Variety	3	4.13
Smoky Variety	2	4.15
Cu-rich Variety	2	4.17
Dacite	2	2.57
Limestone	2	2.68

3.5 The Brine Fields

For the purpose of this discussion the brine fields hereunder refer to the brines at Awe, Ribi and Azara, and the salt spring at Akiri, These occurrences shall be collectively referred to as 'brine springs'.

The brine springs in Lafia area, situated between the Lower and the Upper Benue consisting of dark coloured shales and sandstones, and arkosic sandstones, respectively, occur within Upper

Cretaceous sediments (Phoenic and Kizer, 1966). The study area is the southern part of the Lafia area.

The brine springs of the study area occur within the Awe and Keana Formations. While the Azara and Ribi brines issue from shaly mudstones and sandstones of the transitional Awe Formation, the Akiri brine spring issue from the continental Keana Formation. These brine springs structurally issue from the crest of an anticlinal fold running ENE near Ribi and Azara terminating at Akiri, and have nearly the same alignment with the E-W strike slip fault across River Ankwe (fig 2.2). The folding, fracturing and environment have probably jointly controlled the locations of these brine springs. The brines at Ribi and Azara dry up in the heart of the dry season but mining can be continued by excavation. The Akiri brines do not dry but remain throughout the year.

Three wells in the study area, all located at Azara, are salty. Depth to water table increases from 55 meters at the end of the rainy season to about 70 meters at the end of the dry season.

3.3.1 The Salt Industry

The local procedure for salt mining from the brine springs of the study area follow a similar

pattern. The soils around a particular occurrence are salty and have a property of retaining the residue from the brine springs. Three steps are involved in the local mining of salt viz:

i) salt water is collected from the brines and poured on the soil. This is left to dry for about 3-6 days after which the soil and the residue on it are collected into a pot with a bottom outlet covered by a filtering cloth.

ii) The salt water is again collected and carefully poured into the pot. This takes the solutes into solution, passes through the filtering cloth and drops as a concentrated solution into a waiting bowl. This yellow coloured locally concentrated solution is called "Digo".

iii) The digo is boiled off, usually in the house, leaving a whitish residue that is usually kept on the ground for the water to completely dry out. This residue, the table salt, is ready for consumption.

The soil involved in the process can still be used three or four times after which it looses its properties and later discarded. In the case of Akiri, the salt spring (Plate xxiv) is collected for step (i) through a drainage channel locally constructed by the miners (plate xxv) while the water for step (ii)



Plate XXIV. Photograph of the brine springs at Akiri. Note the drainage channel.



Plate XXV. Photograph of part of the Akiri salt mining site.

is collected from the surrounding ponds. In all the fields, mining is exclusively reserved for women and their daughters headed by a senior member called "magajiya". The drainage system used at Akiri is also common at the Awe brine field which was visited and sampled, along with the rest, for chemical analysis.

The problems of the salt industry include the lack of necessary tools for mining, the effect of rain on the brines and the surrounding soils (plate xxvi), and the lack of patronage from the government and their agencies. Government could assist miners by buying their end product for refining, giving out loans to some individuals and or increase exploration on these occurrences with a view of going into full scale mining and be employers to the local miners.

A full scale survey into the brine springs in the Benue trough is recommended. The anticlinaria within the Benue trough are known to be genetically related to brine springs (Offodile, 1980). These could be studied in more detail. Discoveries would reduce importation of salt and earn foreign reserve for Nigeria.

3.3.2 Solutes Recovery Rate

In order to better evaluate the quality and quantity of the table salt recoverable from a given



Plate XXVI. Photograph of the Ribi salt mining site. Note the preventive measures taken against rain.

quantity of the salt water, the evaporation method was used [illegible].

10 ml of each salt water sample was taken into 20 ml beakers. This was weighed and kept in the sandbath at the temperature of 100°C until the water completely evaporated leaving a residue. The residue and the beaker was weighed in each case, and the weight of the solute substrated from that of the solution and expressed as a percentage. The result shows that the Azara brines has the highest rate of 3.46%, followed by those at Awe (1.89%), Akiri (1.61%) and Ribi (1.24%) (see table 3.2). The Azara brines is therefore the most concentrated while the Ribi brines is the least concentrated of the brine springs in terms of the quantity of table salt recoverable from them. The 'digo' of the brines also follow a similar pattern though the Ribi filterate appear more concentrated than the Akiri filterates.

The colour of the residue varies from white through yellow to grey due to impurities. The grains also vary from fine through medium to coarse[illegible].

TABLE 3.2: RECOVERY RATE TESTS OF SAMPLES FROM THE BRINE FIELDS OF THE STUDY AREA

Sample No	Locality	Lithology	WT of 10ml of Solution	WT of Residue	Percentage of Residue in Solution	Colour of Residue	Size of Crystals
1	Awe	Sandstones of the Awe formation	10.58	0.20	1.89	White	Large
2*	Ribi	-do-	10.50	0.13	1.24	White & yellow	Fine
3*	-"-	Awe formation	11.29	1.43	12.67	White + yellow	Fine
4	Azara	Shaly mudstone of the Awe formation	10.70	0.37	3.46	White	Large
5*	-"-	-"-	12.44	4.60	36.98	White	Fine
8	Akiri	Keana sandstone	10.55	0.14	1.33	White + grey	Fine
9*	-"-	-"-	11.12	0.94	8.45	White + grey	Fine
10	-"-	-"-	10.55	0.17	1.61	White + grey	Fine

*Are samples from the locally concentrated salt water: the 'digo'.

CHAPTER FOUR

GEOCHEMISTRY

4.1 INTRODUCTION

The major and trace element contents of the brine springs and barytes were determined through laboratory analysis. The distribution and association of such elements in these economic deposits are discussed in this chapter.

4.2 Analytical Methods

Chemical analysis for the elements in the brine spring samples was carried out using the Atomic Absorption Spectrometer (AAS) and flame photometer. Analysis for Ca, Mg, Fe, Pb, Zn was done using the PERKIN ELMER (SP 400) AAS of the Department of Geology, A.B.U., Zaria, and later cross checked with a PYE-UNICARM (SP 1900) AAS at the Biochemistry Division, N.I.V.R. Vom. Na and K abundance in the brine springs were analysed for using the flame spectrometer of the same institute, at Vom. The samples were diluted to a factor of 1,000 for the major elements and 100 for trace elements. The readings were taken gainst some standards whose graph was drawn by plotting absorbance against concentration (see appendix 1).

Analysis far Ba, Ca, Ti, Pb, Cu and Fe contents in ten baryte samples was done by the Research and Metallurgical Centre, Nigerian Steel Council, Jos. The results were interpreted using the graph method by plotting the percentage value against the various generations of baryte. The behaviour of these elements as shown in figs 4.1 to 4.7 are discussed.

Titration method was used to determine the amount of chloride (cl^-) present by volume in the brine springs. The titration was done using $Hg(No_3)_2$ solution prepared to a 0.0141N as a reagent. 10 ml of the salt water samples were each diluted 10 times. 10 ml of the solution was taken into a 50 ml beaker and diphenyl carbonzone indicator added. This was stirred until the colour became yellow. The $Hg(No3)_2$ in a burrete was titrated into this solution until the colour changed from yellow to purple. The volume of $Hg(Nc_3)_2$ used is a function of the amount of chlorine in the sample. This volume was converted to mg/l using the following procedure:

1ml of $Hg(No_3)_2$ = 50 mg/l of chloride

∴ the amount of chloride present = X m x 50 Xdf

where X = volume of $Hg(No_3)_2$ used

df = dilution factor (in this case 10)

The values of the chemical analysis of the brines springs are given in table 4.1 while those of the baryte samples are given in table 4.2.

4.3 The Distribution of Elements in the Brine Spring

The results of the chemical analysis of the Na, K, Ca, Mg and Cl in the brine springs are discussed in this subsection. Tests for Pb, Cu, Zn and Fe in the brines were negative.

4.3.1 Sodium

The value of sodium in the brine springs vary between 0.4 and 1.39 percent at Akiri and Azara brines respectively. The Awe and Ribi brines have 1.25 and 0.65 percent sodium. These values correspond with results of similar analysis on brine samples from Afikpo and Okigwe areas of the Lower Benue (Uzuakpunwa, 1981).

Values of sodium in the 'digo' are very high and show a concentration of 10.7, 12.9, and 8.6 percent at Ribi, Azara and Akiri brines respectively.

The high content of sodium (> 1%) in some of the brines indicates a contact with salt bed or a solution from it.

Sodium content in the stream and well water samples are comparatively low having 0.1 and 0.5 percent by volume. This shows that sodium is one of the least

components of the natural waters except for salt water or brines. The higher values of sodium in the streams could have been released during weathering of plagioclase in the sandstones of the study area.

4.3.2 Potassium

The value of potassium like that of sodium is highest in the Azara brines and lowest in the Akiri brine spring being 0.058 and 0.02 percent respectively. The potassium values, are moderate in the Awe and Ribi brines with 0.04 percent. The values of potassium in the 'digo' follow the same trend as those of the brines; 2.8, 2.48 and 0.72 percent in samples from Azara, Ribi and Akiri concentrates respectively. This indicates a concentration rate of between 1.6 and 2.7 percent of potassium in the 'digo'. The value of potassium in the brine field of the study area are similar to that obtained in brine samples from Abakaliki area (Uzuakpunwa, 1981).

The ratio of sodium to potassium is very high in favour of sodium in all the localities. This variation could be due to differences in the source and ionic charge/radii between the two elements, and the relative immobility of potassium.

The values of potassium in the stream and well water samples are comparatively low (0.02 and 0.01 percent respectively). These values are, however,

TABLE 4.1: CHEMICAL ANALYSIS OF THE BRINE-SPRINGS, STREAM AND WELL WATER SAMPLES FROM THE STUDY AREA.

Sample No.	Locality	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-
SS 1	AWE (brines)	1.25	0.04	0.027	0.077	0.77
SS 2	RIBI (brines)	0.65	0.04	0.029	0.010	0.55
SS 3	RIBI (Digo)	6.18	2.48	1.81	0.39	7.73
SS4	AZARA (brines)	1.39	0.058	0.091	0.017	1.35
SS 5	AZARA (Digo)	10.80	2.80	0.74	0.17	28.18
SS 6	AZARA (stream)	0.1	0.02	0.025	0.003	0.16
SS 7	AZARA (well water)	0.05	0.01	0.026	0.003	0.098
SS 8	AKIRI (salt pond)	0.28	0.023	0.016	0.003	0.47
SS 9	AKIRI (Digo)	4.66	0.72	0.021	0.006	3.76
SS 10	AKIRI (brine)	0.4	0.02	0.026	0.003	0.54
Average of the brine springs only		0.92	0.0395	0.043	0.009	0.803

Note: 1% = 10,000 ppm

individually high enough to suggest a different source for the waters of the study area.

4.3.3 Calcium

Calcium is a trace element in all the samples of the brines. The value of calcium in the brine, stream and well water samples vary between 0.016 to 0.091 percent. The calcium values are also highest in the Azara brines and lowest in the Akiri brine spring: a trend also maintained in the 'digo' samples. The concentration rate of the digo is considerably high. The calcium value in the brines of the study area is similar to the brine samples from Afikpo area (Uzuakpunwa, 1981).

Compared with the values of magnessium (table 4.1) there are between three and eight times calcium to one magnessium. This ratio indicates that the brines are fresh water in origin (Davies and Dewiest, 1966).

The value of calcium in stream and well water samples show that they have the same degree of hardness. Hardness is usually considered as a sum effect of calcium and magnesium.

4.3.4 Magnessium

Like calcium, magnessium is a trace element in the brines, the values vary from 0.003 and 0.017 percent in the Akiri and Azara brines respectively.

The 'digo' values are high showing high concentration rates. The trends show that the geochemistry of magnessium is quite similar to that of calcium. The Mg values are similar to the values at Afikpo area (Uzuakpunwa, 1958).

Magnessium is generally found in lesser concentrations in natural waters than calcium despite the higher solubility of most of its compounds. The 30 ppm value for the stream and well water and Akiri brine spring sample is typical for concentrations of magnessium in natural waters. Values above 40 ppm from samples of the other brines indicate a subsurface source. In addition, there is one magnessium to three or eight calcium and this suggest a marine origin for the brines in the study area..

4.3.5 Chloride

The chloride content in the brine springs vary between 0.54 and 1.35 percent. Like the other elements, the Azara and Akiri brines have the highest and lowest chloride values respectively. The Ribi and Awe brines have moderate values of 0.55 and 0.77 percent of chloride. These values are similar to those from the Okigwe and Abakaliki areas. (Uzuakpunwa, 1981).

Values of chloride in the stream and well waters are very low; they average 0.16 and 0.098 percent respectively. The 'digo' from the brine

fields have very high chloride value of 7.73, 28.18 and 3.78 percent at Ribi, Azara and Akiri respectively. This shows a similar trend with the natural brines, and a concentration rate of between 4.8 to 14 percent.

The results show that though chloride is a minor constitutent of the earth's crust, it is a major dissolved constituent of the natural water. The very high value of chloride (> 1%) in the Azara brines at the centre of the study area indicates that the brine springs are of marine origin.

Most chlorides in groundwater come from five sources namely.

i) ancient sea entrapped in sediment

ii) solution of halite and related minerals in evaporite beds.

iii) concentration by evaporation of chloride contributed by rain or snow.

iv) solution from dry fall out from the atmosphere particularly in Arid regions.

v) locally from volcanic water in hot spring systems (Davis and Dewiest 1966).

The high chloride values suggest that these brines were solutions of halite and related minerals in an evaporite deposit. Volcanicity in the study area (NW of New Wuse) could have possibly acted as a source of volcanic water and heat to the Akiri springs.

4.3.6 Remarks

The low concentrations of the elements (Na, K, Ca, Mg and Cl^-) in the Akiri brine sprirgs and the higher concentrations in the Azara and Ribi brines probably have lithologic control. The brines at Ribi and Azara issue from the Awe Formation while the brine springs at Akiri are within the Keana Formation.

4.4 The Distribution of Elements in the Baryte

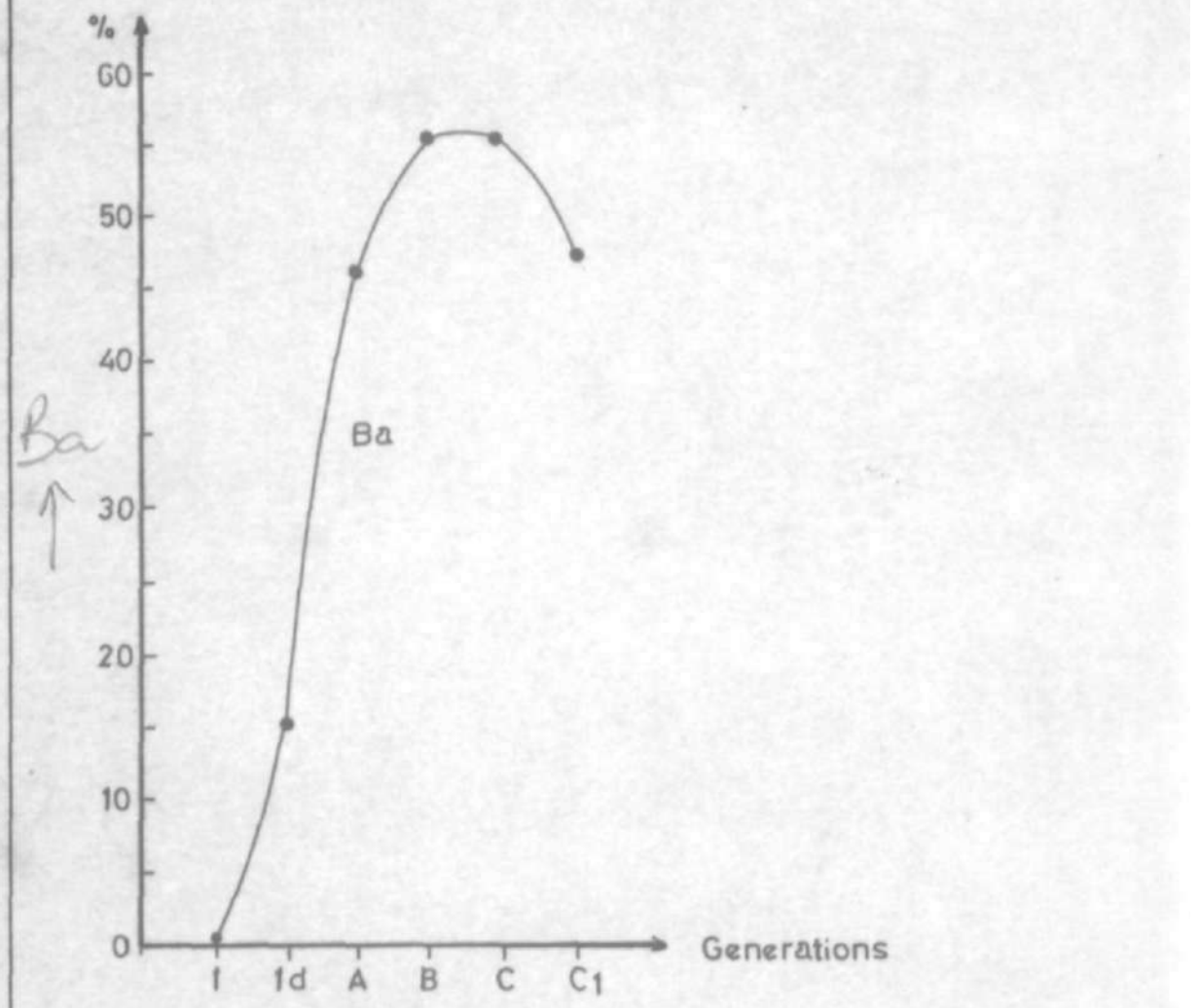
Results of the Analysis of Ba, Ca, Ti, Cu, Pb and Fe in ten baryte samples from different veins are discussed in this section.

4.4.1 Barium

The trend of barium from the ferruginous band across the various baryte generations is shown in fig 4.1. There is an exponential increase in the amount of barium from 0.78 percent at the ferruginous band through 15.20 percent at the contact between the ferruginous band and the baryte veins proper to 55 percent in some of the generations of barytes in the study area.

Within the baryte generations, the pinkish has the lowest barium content of 46.29%. The whitish and the smoky generations have the highest values of 56.58 and 54.82 percent respectively. The greenish cu-rich variety has a moderate value of 46.96 percent barium.

FIG. 4·1 The distribution of Ba in the baryte generations.



A = The pinkish variety.
B = The whitish variety [Average of sample 4, 8 and 10b].
C = The smoky variety.
C_1 = The greenish Cu rich variety.
1d = Host rock-vein contact sample.
1 = The ferrugenous band.

This result shows that there is an initial increase in the amount of barium towards the younger generations except for the cu-rich generation in veins 2 and 17, where the barium content dropped sharply. It also shows that the N-S striking veins having only the whitish generation, individually have more barium content than the NW-SE and E-W striking veins with two or more baryte generations.

4.4.2 Calcium

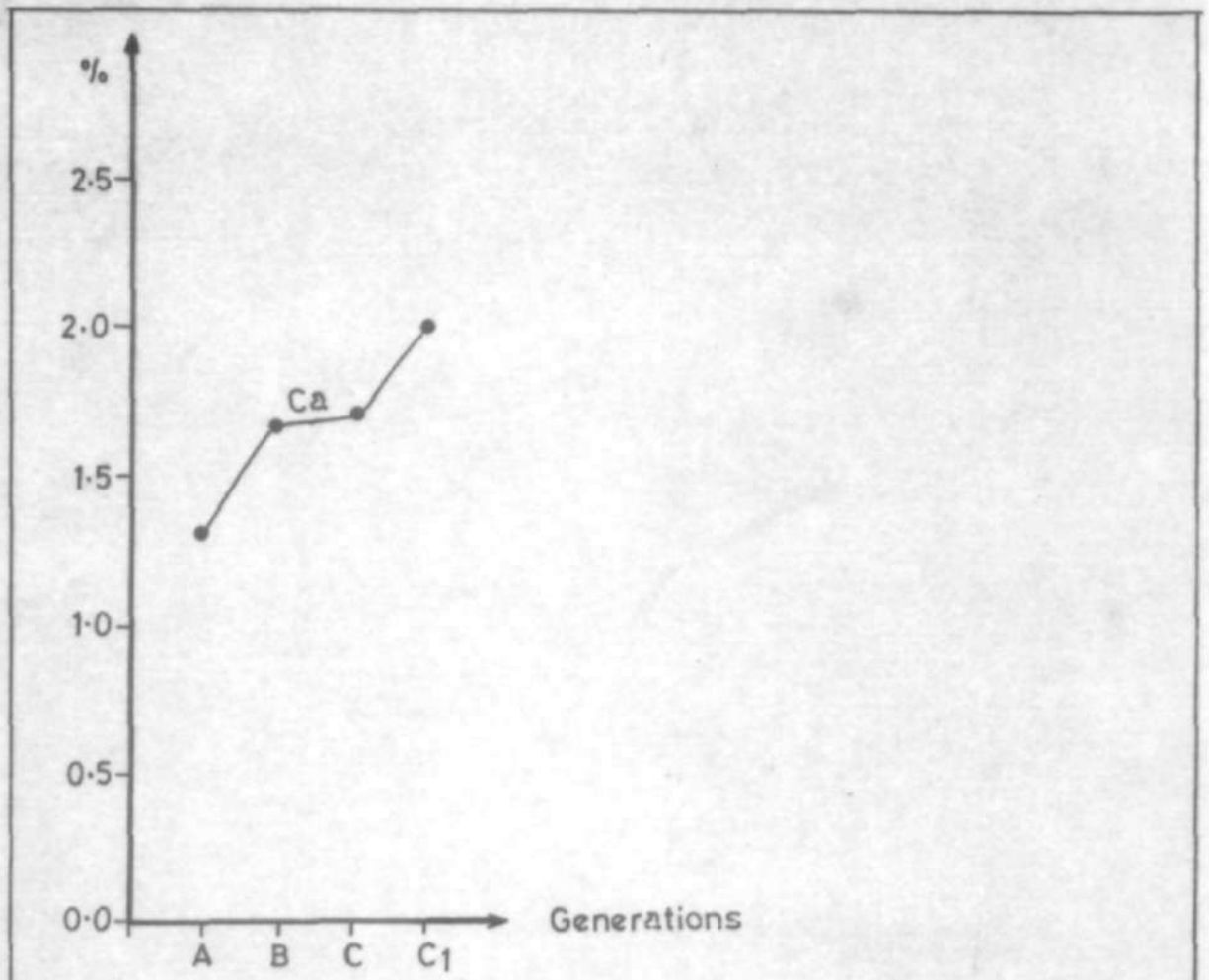
The value of calcium is highest at the vein-host rock contact with 5.21% and lowest at the ferruginous band with less than 0.01%. Within the generations, calcium values are highest in the whitish generations and lowest in the pinkish generation. The cu-rich variety has a fairly high calcium value of 2.0%. These trends are plotted in fig 4.2.

Calcium content steadily increased across the veins from the oldest to the youngest generations at the center.

Ca is isostructural with Ba though it has a smaller ionic radius. The ratio of Ca to Ba is small indicating that the replacement was also small.

Unlike Ca in the brines, there appears to be no lithological control in the distribution of this element in veins from different localities.

FIG. 4.2 The distribution of Co, in the baryte generations.



A = The pinkish variety
B = The whitish variety (Average of sample 4, 8 and 10 b)
C = The smoky variety.
C_1 = The greenish Cu rich variety.

4.4.3 Titanium

Titanium is a trace element in the baryte samples. Titanium values are high at the vein/host rock contact and in the ferrugenous band; havit an average 0.45 % and 0.30 percent respectively. Of the baryte generations, the pinkish variety has the highest value of 0.13 percent titanium. This value decreased through 0.08 and 0.04 percent titanium in the whitish, smoky and cu-rich varieties of the NW-SE veins. The values from the whitish generation of the N-S striking veins are slightly higher (average of 0.15% titanium) over those in the NW-SE striking veins.

A trend shown in fig 4.3 indicate that the amount of titanium decreases with the younger generations until the smoky and the cu-rich (C and C_1) generations where a constant is maintained. This trend of decreasing titanium content towards the younger generations indicate that the barytes were remobilised or reworked from barium-rich rocks since Ti is a refractive and immobile element.

There is an inverse relationship between titanium an Ca in the baryte generations. The Ti: Ca ratio however follows a similar trend as those of Ti: decreasing from the pinkish through the whitish to the smoky and cu-rich generations.

The titanium could be present as an oxide of barium e.g Ba Ti_4O_9.

4.4.4 Copper

The value of cu is high in the ferruginous band with 0.03%. Within the veins, the value of Cu is highest in the youngest generation of barytes in vein 17 .. with 0.04%. Cu content in the other genrations are 0.01, 0.003 and 0.001 percent in the pinkish, some whitish, and smoky varieties. The values of Cu in table 4.2 show that there is a decrease in Cu content from the ferruginised band to the whitish generation of the N-S striking veins (e.g. Vein8), and in some the NW-SE striking veins (e.g. vein 18). In vein 17 striking NW-SE however, the third generation of barytes had an enrichment of Cu.

The trend of Cu in the barytes, fig 4.4, could be due to changes in the Eh/Ph conditions during the deposition of the various generations of baryte in the fractures of the study area.

4.4.5 Lead

The amount of Pb in the barytes is high in the pinkish and the cu-rich generation having 0.006 and 0.004 percent respectively. From the pinkish variety, Pb value decreases sharply to an insignificant value in the whitish and smoky varieties, but increased again in the cu-rich variety.

The trend of Pb in the barytes (fig 4.5) follows a similar pattern to that of Cu. This indicates that

TABLE 4.2: CHEMICAL ANALYSIS OF SOME BARYTE SAMPLES (RESULTS WERE OBTAINED FROM THE METALLURGICAL AND RESEARCH UNIT OF THE NIGERIAN STEEL COUNCIL, JOS)

Sample No.	Locality	Variety	Ba %	Ca %	Ti %	Cu %	Pb %	Fe %	Remarks
1	Vein 2	Ferruginous band	0.78	0.01	0.30	0.03	0.003	57.67	
2	Vein 17	Pinkish	46.29	1.30	0.13	0.01	0.006	0.04	Ti-rich High Ti/Ca
3	-do-	Cu-rich (greenish)	46.96	2.00	0.04	0.04	0.004	0.56	Cu-rich
4	Vein 4	Whitish	54.27	2.20	0.08	0.003	0.001	1.12	Ca-rich
5	Vein 18	Smoky	54.82	1.70	0.04	0.001	0.001	0.04	
8	Vein 8	Whitish	55.06	1.60	0.09	0.003	0.001	1.40	
1d	Vein 17	Host rock-vein contact	15.20	5.21	0.62	0.003	0.001	13.16	Ti-rich
1h	-do-	Host rock-vein contact	15.99	1.60	0.27	0.002	0.001	0.56	Ti-rich
1k	-do-	Whitish-Pinkish contact	50.61	2.41	0.18	0.01	0.001	1.68	
10b	Vein 10	Whitish	56.58	1.20	0.27	0.01	0.003	0.84	

FIG. 4.4 The distribution of Cu in the baryte generations.

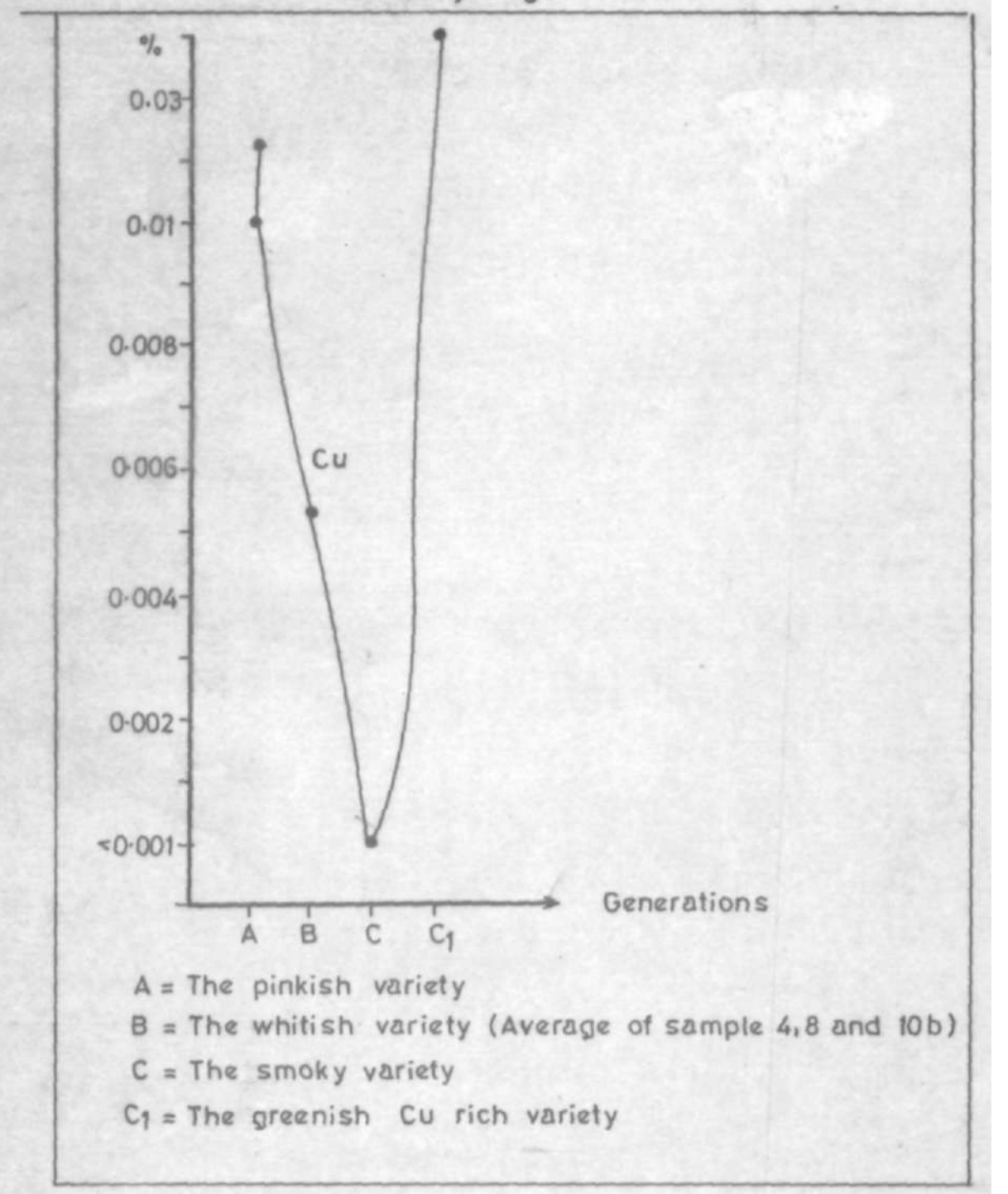
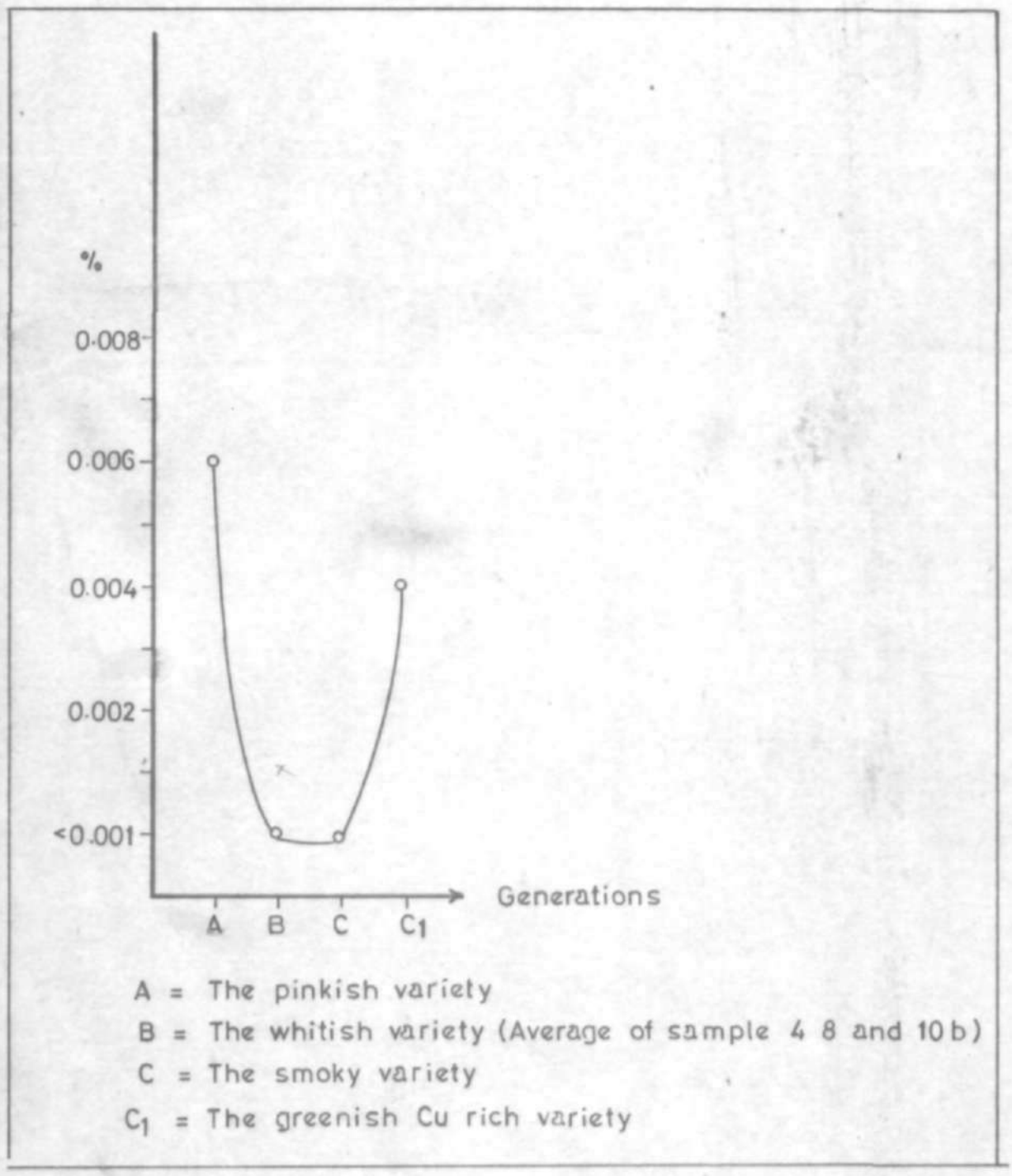


FIG. 4.5 The distribution of Pb in the baryte generations.



these elements have strong affinity for one another. The trend of Pb in the barytes could be attributed to changes in the Eh/Ph conditions.

The Pb in the barytes could be present either as a sulfide (Pbs) or as a sulfate anglesite ($Pbso_4$) which is isostructural with $BaSo_4$ or both (Ruchelt, 1978).

4.4.6 Iron

The amount of Fe in the baryte veins is highest at the ferruginous band having 57.67%. This decreased sharply through 13.16% at the band-vein contact to as low as 0.56% in the cu-rich variety.

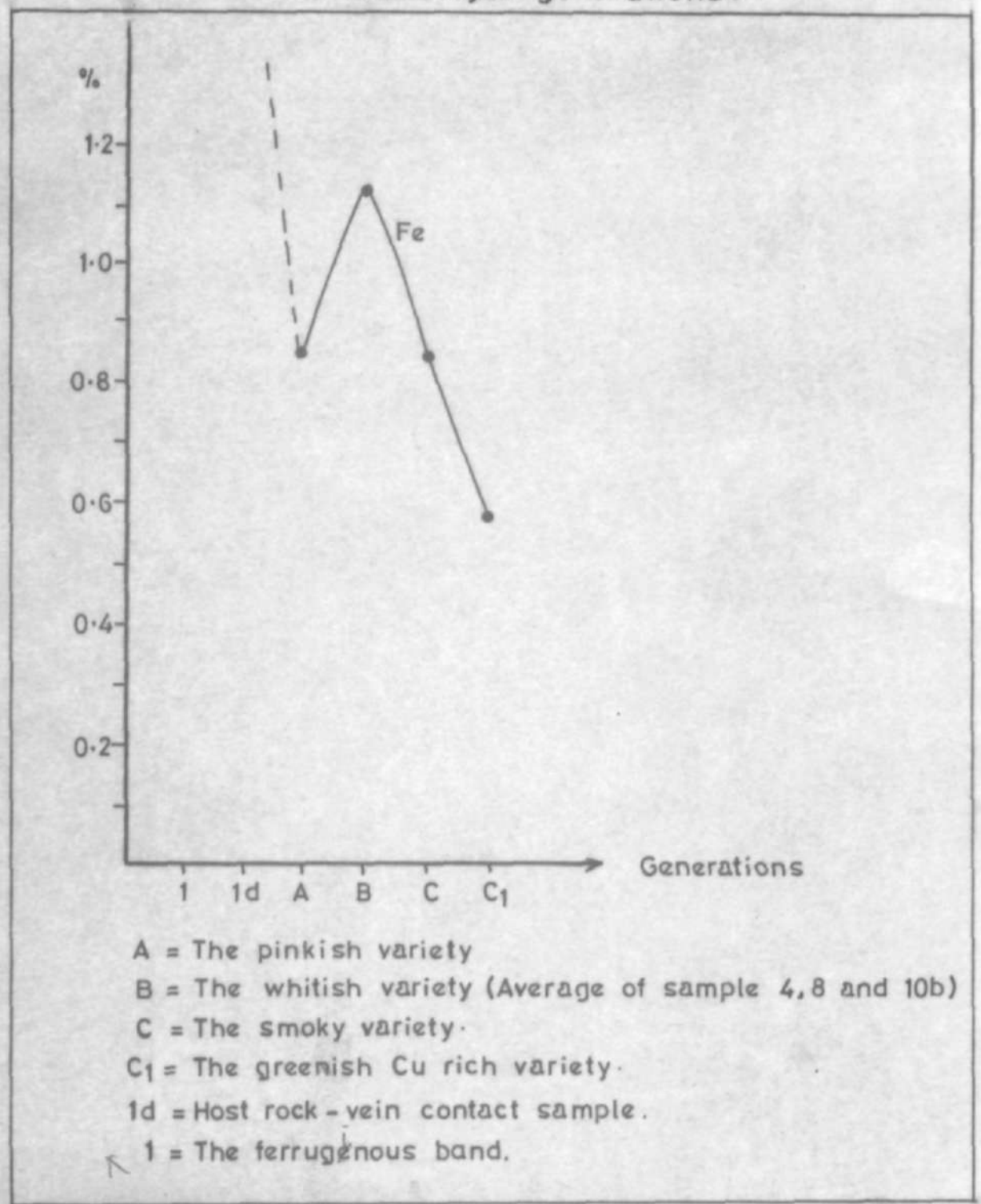
Within the veins the pinkish and smoky varieties have low values of 0.84% Fe. The whitish variety witnessed a little increase in the Fe content to 1.12%. This apparent increase is however insignificant considering the 57.67% Fe in the ferruginous band. The trend of Fe in the barytes (fig 4.6) corresponds with those of the microscopic descriptions in chapter 3.

The trend of Fe in the baryte veins show an inverse relationship to those of Cu and Pb.

4.4.7 Silica

For the purpose of comparison the estimated proportion of quartz in the slides of the samples

FIG·4·6 The distribution of Fe in the baryte generations.



A = The pinkish variety
B = The whitish variety (Average of sample 4, 8 and 10b)
C = The smoky variety.
C_1 = The greenish Cu rich variety.
1d = Host rock - vein contact sample.
1 = The ferrugenous band.

from some of the baryte veins in the study area are used here. The trend of silica is shown in fig 4.7.

Within the veins the amount of silica is highest in the pinkish variety. Silica is absent in the whitish and smoky varieties but present in the cu-rich variety. This shows that barytes in the N-S veins are completely devoid of silica while those in the E-W and NW-SE are rich in silica.

The silica trend corresponds with those of Cu and Pb, and could be due to changes in the Ph conditions of the hydrothermal fluids during deposition.

4.4.8 Remarks

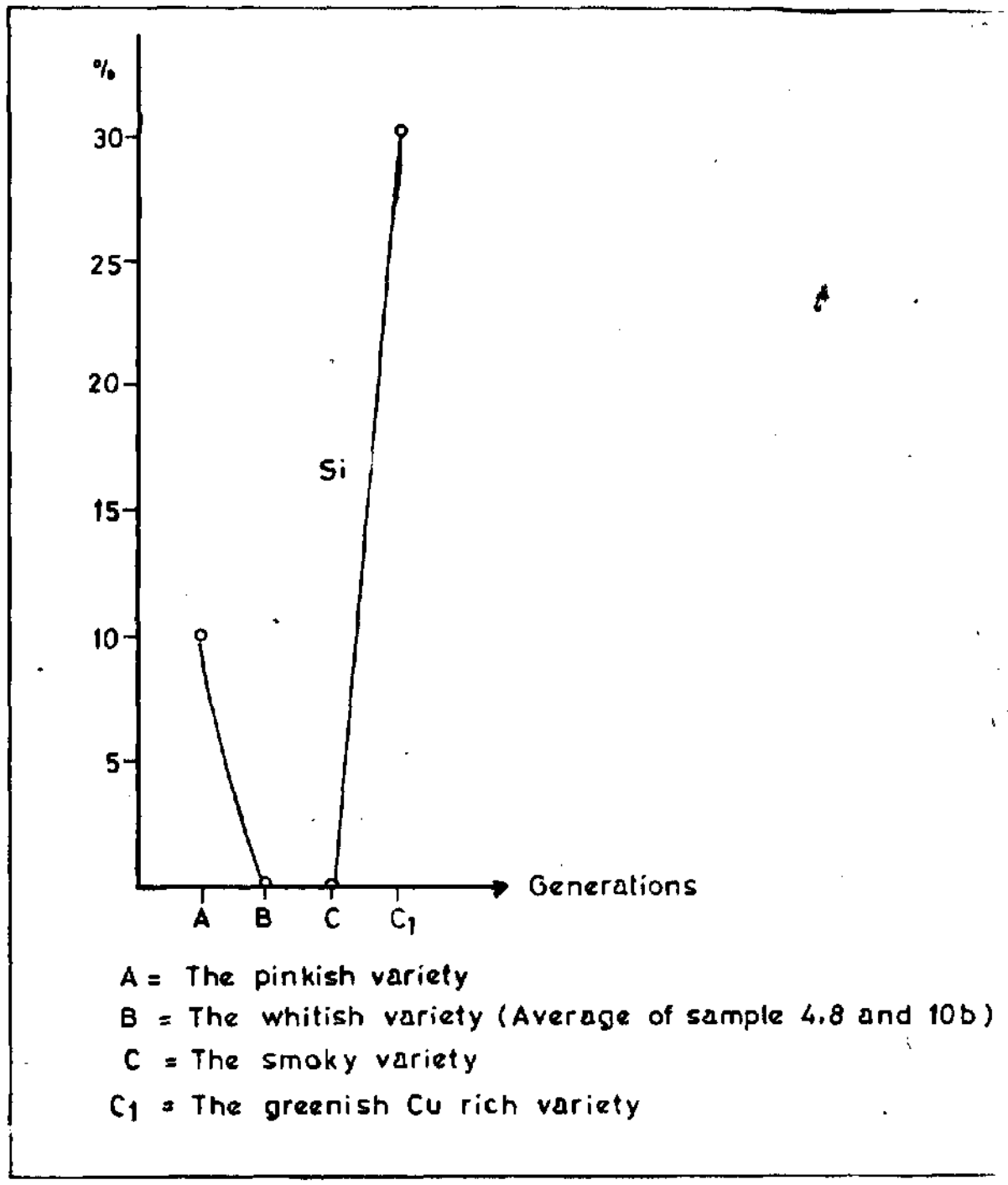
The NW-SE trending veins had increased supply of trace elements like Cu and Pb, and silica than E-W and N-S trending veins. This increase is mainly associated with the third generation cu-rich variety.

A constant is observed in the amount of Ba, Ca, Pb and Sio_2 between the whitish and smoky generations. This shows that the conditions relating to the enrichment of these elements in the whitish and smoky generation remain essentially constant during this 'period' of the mineralisation.

The fact that elements like Pb, Cu, and Fe present in the barytes are absent in the brine springs suggests that they are probably not genetically related.

The presence of sulfides in the pinkish and cu-rich varieties could be indications of lower Eh.

FIG. 4.7 The distribution of Si in the baryte generations.



A = The pinkish variety
B = The whitish variety (Average of sample 4.8 and 10b)
C = The smoky variety
C_1 = The greenish Cu rich variety

CHAPTER FIVE

ORIGIN OF MINERATION IN THE STUDY AREA

5.1 Introduction

From the geological, structural and geochemical investigations of the mineralisation in the study area, a synthesis of the possible genesis of the brines and barytes are deduced and discussed in this chapter. Also discussed is the association of these deposits with each other and with the Pb-Zn mineralisation within the Benue trough.

5.2 Origin of the Brines

The brines in the Benue trough are lithologically associated with the transitional Awe formation and its equivalents of cenomanian age in the lower, middle and upper Benue (cf Offodile 1984).

In the Benue Trough, the brines occur in a relatively narrow belt stretching from Abakaliki in Anambra state northeastwards to Zurak in Gongola state, and are associated with sedimentary and igneous rocks of cretaceous age. This belt encloses isolated salt ponds (Uzuakpunwa, 1981) or sub-basins (Offodile, 1984). The most important seepages are found in the Abakaliki, Keana and Lamurde anticlinoria where the brine springs issue from the flanks of the anticlinoria.

The brines in the study area are part of this belt. They issue from shaly mudstones, shales and sandstones of the Awe formation. The nature of the rocks of the Awe formation suggests an interplay of marine and continental environments suitable for the formation of saliferous beds.

The possible origins of salt water could be marine (derived from sea water), or continental (related to inland waters e.g. lakes.)

The results of the chemical analysis of brine samples from the study area show that the brine springs are generally rich in Na, K and Cl^-. The high Ca: mg ratio point to the fact that the brine springs are marine in origin. Uzuakpunwa (1981) has similarly described the brines at Afikpo Okigwe, and Abakaliki areas of the lower Benue.

During the middle Albian, early Turonian and campano-maastrichtiain times, the Benue trough witnessed three episodes of marine transgressions with their corresponding regressions in the cenomanian, Turonian - senonian and paleocene times. These episodes were controlled by tectonic and or eustatic factors and the evaporitic conditions appear to have developed, during the regressive phases when parts of the sea were cut off (Offodile, 1976).

The evaporites of the study area were probably formed during the Cenonanian regressive phase. The evaporites are lithologically controlled in terms of their association with the Awe formation but the brine springs on the surface are structurally associated with the fractures that developed after the Santonian folding episode resulting in the formation of the ENE-WSE anticlinal axis across the study area.

Laboratory analysis for Pb, Zn and Fe in the brine spring samples are negative. In addition to confirming the marine origin for the evaporites, the result also showsthat the evaporites are not related to Pb-Zn mineralisation in terms of origin in the Benue trough (cf. Uzuakpunwa 1981) as previously thought by some early researchers on the subject (McConnel, 1949; Simpson 1954). The Pb-Zn mineralisation in the Benue trough occurs as fracture filling epigenetic veins. They are also Cretaceous in age and have the same linear trend, structurally across the Benue trough, with those of the evaporites (see Cratchley and Jones, 1965; Nwachuku, 1972).

5.3 Origin of the Barytes

There are three possible modes of baryte formation viz:

a) probably magmatic - hydrothermal which originally does not contain any significant amount of barium but obtained this element by leaching suitable rocks (Engelhardt, 1936).

b) In sedimentary environment due to the dissolution of baryte from sediments by bacterial sulfate reduction in suitable diagenetic environments (Puchelt, 1967).

c) Certain metamorphic reactions may give off barium when structures which had incorporated high barium concentrations become unstable as a result of temperature and or pressure changes (Puchelt, 1978).

Synder (1970) discussed the occurrence of baryte in residual deposits overlying carbonate host rocks. Other examples includes the baryte occurrence in residual deposits on the banks of the white Volta, some 64 kms WNW of Temale in the northern region of Ghana (Afenya, 1982) probably derived from the gneisses and migmatites of the basement of Ghana. Barytes are also known to be associated with hot saline solutions elsewhere in the world (Deer et al, 1978).

The possible areas of occurrence of baryte in the Benue trough include:

i) Occurrence in the basement inliers e.g. the Gbande veins (Ford, 1981). This could be due to the mobilisation of barium in feldspars which probably became unstable as a result of metamorphism or the effects of Pan African orogeny. This could be concentrated in some fractures with the aid of hydrothermal fluids in the last stages of the orogeny.

ii) In the Cretaceous sediments due to weathering and leaching of source rocks in the Benue Trough.

iii) In fractures as hydrothermal epigenetic veins.

The barytes of the study area occur as fracture filling veins and are epigenetic hydrothermal in nature. They are structurally associated with fractures that developed as tension cracks as a result of the compressive stress that gave rise to the ENE-WSW fold in this area. The barytes veins in the study area are, therefore, probably Campano-Maastrichtian in age since the folding took place in the early to middle Senonian times (Carter et al, 1963).

Barium is deposited by fluids with a high oxidation potential where sulfur is present as sulfate. Suitable conditions of this kind occur

close to the earth's surface or in the subsurface areas where sulfate solution can mix or react with reduced barium containing waters. In solution, barium migrates to the region of sulfate stability and thus it is often bound to a narrow zone close to the earth's surface. This probably accounts for the shallow depths of the barytes veins revealed by geophysical investigations by the N.M.C. The source of the barium and, indeed, the hydrothermal solution is probably deep seated like those of the Pb-Zn veins (Olade, 1976), but in this case the conditions necessary for the formation of the sulfate are near surface or on the surface.

The trend of Ba and Ti in the generation of barytes increases and decreases respectively towards the center. This trend suggests that the barium was remobilised from a barium rich rock, probably from the mineralised basement rocks beneath and sedimentary cover of the Benue trough. The presence of Cu in some of the generations of baryte is an index of high temperatures of 150 to 250°C of the hydrothermal solution. There are little or no wall-rock alterations on the baryte veins.

The nature of the contact between the various generations of baryte are tectonic in origin and shows that the fractures opened for more than once. The initial opening was filled by the iron oxide

material. The second opening affected only the E-W and NW-SE fractures depositing the pinkish variety. The third opening affected the E-W, NW-SE and N-S striking veins depositing the whitish variety. The fourth opening affected only the NW-SE veins. There is therefore some metallogenetic epoch involved in the baryte mineralisation.

The presence of volcanic rocks near the baryte veins and the nature of ferruginisation that bounds the veins suggest a local heat source. The ferruginised bands are volcanic in origin and are the first phase of baryte mineralisation in the fractures. Volcanism therefore played a role in the initial stages of the baryte mineralisation (cf. Reyment, 1965).

In addition, the barytes are mainly associated with the Keana sandstones, unlike the Pb-Zn veins that occur in a variety of widely separated rocks (Olade, 1976). The limited areal extent of occurrence of the barytes and the lithological association with the Keana sandstones shows that the processes of formation of this ore are localised rather than regional as is the case with the Pb-Zn mineralisation.

CHAPTER SIX

SUMMARY AND CONCLUSIONS

This study is concentrated between Azara and Akiri villages. The area of study is made up of Cretaceous sediments of arenaceous, argillaceous and calcareous rocks, and an intermediate volcanic rock, dacite. The study area is largely covered by rocks of the Awe Formation consisting of sandstones alternating with shales, limestones and siltstones, and the Keana Formation consisting entirely of sandstones.

The regional study of structures within the study area shows that the fractures trend mainly in the E-W, NW-SE, NE-SW and N-S directions. The N-W fractures predorminate around Ribi area while the NE-SW and the N-S fractures predorminate around Azara and Akiri areas. These directional trends of the fractures reflect the subsurface geology of the study area. A sinistrial strike slip fault striking nearly E-W cutsacross river Ankwe 1½ kms north of new Wuse. Similar transcurrent faults have been reported elsewhere in the Benue trough (Benkhelil, 1982). Minor joints in the direction of the major fractures and bedding is also a common feature in the rocks. The dorminance of northwards trending fractures is indicative of basement control.

Mineralisation within the study area is both lithologically and structurally controlled. Lithologically, the brine springs issue from the evaporite beds in the Awe formation while the baryte veins mostly occur in the Keana Formation.

Structurally, both the brine springs and the barytes veins are associated with a ENE-SWSW trending fold across the study area but while the brine springs are associated with the anticlinal axis, the baryte veins occur along the flanks of the anticline. In addition the location of the three brine springs in the study area suggests a single structure, a fracture, intersecting the salt rich bed in the subsurface along the direction of the occurrence of the brines. In other words, the deposition of the evaporites are lithologically controlled while the solution that issues out of them is associated with the compressive stress that formed the fold, and the tensional cracks that result from them.

The occurrence of barytes in the study area fracture controlled. Detailed study of the barytes veins shows four stages of baryte mineralisation within the fractures all of which are tectonically controlled. The first stage involved the formation of a ferruginised band that borders all the veins. The second stage involving the deposition of the pinkish variety

affected only the E-W and NW-SE striking veins. The third stage affecting the E-W, NW-SE and N-S striking veins involved the deposition of the whitish variety. This third stage was the only baryte phase in the N-S striking veins. The fourth and the last stage was the deposition of the smoky and cu-rich varieties in the NW-SE striking veins. These stages of baryte mineralisation are distinguished macroscopically and microscropically on the basis of differences in colour, texture, amount of quartz and ore (opaque) mineral content, optical properties such as cleavage planes and twins, and the geological contacts between them. The smoky and whitish varieties have well developed crystals devoid of silica while the pinkish and cu-rich varieties are massive and are silica rich. The amount of silica in the veins is reflected in the morphological expressions of the veins since quartz is more resistant to weathering than baryte.

Analytical values for Na, K, and Cl^- show that the brine springs in the middle Benue and infact, in the entire length of the Benue Trough are indicative of an entrappment of saline water during one of the regressive phases of the episodes in the Benue Trough. The evaporite deposit could be in the form of a bed or a salt dome depending on the structural disturbance of the former. The ratio of Ca: mg in the brine springs also support a marine origin for

ther. The absence of trace elements like Cu, Pb, and Fe in the brine springs does not only confirm the marine origin but also shows that the brines are not genetically related to the barytes in the middle Benue or the Pb-Zn mineralisation in the entire Benue trough, though in the case of the latter, they are both spatially distributed along the length of the trough. The only likely relationship is that the halite solutions used fractures as passage ways.

On the other hand, analytical results of Ba and Ti in the baryte samples show that the barium is proably derived from the basement rock complexes beneath the sedimentary cover of the Benue Trough. Ba and Ti contents increase or decrease respectively towards the center of the veins. Barium could have possibly been leached from the basement deep below the sediment cover by the hot solutions initiated by the volcanism in the study area but because the conditions necessary for the formation of sulfate are surface or near surface, the solutions moved via fractures towards the surface and consolidated to form shallow veins. The nature of ferruginisation that bounds the veins support this claim of the involvement of volcanic heat in the formation of the baryte veins. The presence of Cu and Pb in some generations of the

barytes indicate changing Eh/Ph conditions, and a temperature of formation of about 150 - 250°C.

The presence of Cu and Pb in trace quantities in the barytes compared to reports of known lead - zinc - baryte veins (in the U.S.A., for example), cannot be used satisfactorily to deduce their relationship. It only indicates that the baryte mineralisation, probably, represented the last stages of hydrothermal activity that gave rise to the Pb-Zn veins in the Benue Trough.

There is a need to carry out fluid inclusion studies in the barytes to reveal the exact temperature of formation, the source and depth of the barium in the hydrothermal fluids. Ore (opaque) mineral study might also be useful in this regard.

It is the belief of the author that there are more veins concealed in fractures below the surface cover. These could be revealed by soil geochemistry and or gravimetric and seismic geophysical surveys to outline the veins and indicate their depth. This has been carried out in the midcontinent, United States, where there are residual cover on baryte veins in host carbonate rocks (Synder, 1970).

The varieties of baryte could be blend together for use in the oil industries as drilling mud. The whitish and smoky generations are however most suitable for use in the papper and rubber manufacturing industries. For this purpose, it is suggested that the Nigerian Mining Corporation should concentrate on the N-S striking veins since these are entirely the whitish variety devoid of quartz and have higher specific gravity. This could minimise the cost of 'jigging' and therefore increase profit.

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APPENDIX

I_1 MICROSCOPIC DESCRIPTION OF SOME SLIDES REPRESENTING THE VARIETIES OF THE BARYTES IN THE STUDY AREA

Generation	Slide	Variety	Colour in thin section	Crystallinity	Texture	Cleavage or Twinning	Percentage of Quartz	Percentage of ore minerals	Relationship Between Quartz and the Baryte Crystals	Remarks
A a_1	1b (vein 17)	Pinkish	Colourless	euhedral	Coarse grained	Polysynthetically twinned	10	15	Quartz occurs mainly at grain boundaries. Some crystals of quartz also occur on the baryte crystals. Both are seemingly syngenetic.	Baryte crystl fractured.
a_2	1g (vein 17)	Pinkish	Colourless	eubhedral	coarse grained	cleavage in two directions but only one is prominent	6	2-3	Quartz occurs only at grain boundaries	-
b_1	2 A (vein 18)	whitish	colourless	eubhedral	coarse grained	cleavage is three directions but only tow are prominent	NIL	NIL	NIL	Baryte crystals are of big size
B b_2	1c (vein 17)	whitish	colourless	euhedral	coarse grained	-"-	NIL	15-20%	NIL	-"-
C	5 (vein 18)	Smoky	Colourless	glassy and fibrous	Very Coarse grained	NIL	NIL	NIL	NIL	-
C_1	3 (vein 17)	cu-rich	Colourless	subhedral	coarse grained	Plumose pattern of cleavage	30	10	quartz crystals are both [illegible]	

APENDIX II

STANDARD ABSORPTION PLOTS FOR Na AND K ON FLAME PHOTOMETER

