THE GEOLOGY, GEOCHEMISTRY AND MINERALIZATION

OF THE

ARUFU-AKWANA-UGBA AREA, MIDDLE BENUE TROUGH

BY

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of the requirements of the degree of:

Doctor of Philosophy (Ph.D)

Department of Geology

Faculty of Science

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(copy right statement)

DECLARATION

I certify that the following thesis is based on the results of research carried out by me, that it is my own composition, and that it has not previously been presented for a higher degree.

D.U. Chuku

CERTIFICATION

This dissertation entitled "The Geology, Geochemistry and Mineralization of the Arufu-Akwana-Ugba Area, Middle Benue Trough, by Daniel Ukaegbu Chuku meets the regulations governing the award of the degree of Doctor of Philosophy (Ph.D) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

DEDICATED TO MY FAMILY AND

TO THE SEARCH FOR THE

LIGHT OF KNOWLEDGE

ACKNOWLEDGEMENTS

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All the GSN numbers are used for easy reference in GSN records and for use in retrieving old records which will normally be stored. Otherwise all the tables, figures and plates so numbered are my original production except when otherwise stated.

ABSTRACT

Geological mapping of the Arufu-Akwana-Ugba area of the Middle Benue Trough indicates that it consists of Cretaceous sediments deposited in a series of depressions formed by the defferential subsidence of the Pan-African basement confined by the trough. Some of these sediments are continental in origin and may have fluvio-deltaic members while the majority are marine

Inside the trough isolated differentially faulted blocks outcrop at the present erosion level as horst-like inliers, sometimes in the form of ridges which are separated by narrow local basins filled with sedimentary series upto 3,000 metres thick. Both the inliers and the sediments are elongated along the NE-SW direction of the main axis of the trough.

Among the sediments the oldest is the Pre-Asu River Sediments which are Pre-Aptian in age, and intruded by Aptian rhyolitic sills, while unconformably resting on the Basement Complex. The succeeding Asu River Croup consists of two formations, namely, the Middle-Upper Albian coral - and mollusc-bearing shallow marine Uomba Formation consisting of limestones, shales and siltstones, and Late Albian to Early Cenomanian Awe Formation which marks the beginning of the regressive phase of the Albian sea, with transition beds of shales and sandstones. It is overlain by the continental sands of the Keana Formation, followed by the marine strata of the Eze-Aku Formation.

Structural analysis indicates that the Cretaceous sedimentary formations were subsequently folded, with fold axis parallel to the NE trending boundaries of the trough and apparently affected by later

folding at right angles to the trough thus imparting a characteristic regional sinuosity of the fold axes similar to that found in the Lafia-Awe area by previous workers. The dominant NE trend coincides with the disposition of the Benue rift structure.

The north-easterly trending fractures and faults are exploited by most of the galena-fluorite mineralization which occured in the area investigated. The fractures and faults are localized along the edges of the trough. The significance of the deeply penetrating Cretaceous marginal and axial basic intrusive rocks in relation to the galena mineralization and their possible relationship to the medial gravity anomaly and rift structure of the Middle Benue Trough, is explained.

The economic potential of the area is studied with particular reference to the stratigraphic and structural controls of the mineralization. About 2,000 stream sediment samples were collected and analyzed mostly for Pb, Zn, and PH. The conclusions drawn from the interpretation of the geochemical data show that reconnaissance stream sediment survey proves a useful tool in exploring for blind ore mineralization in the Middle Benue Trough and that detailed investigation on suitable areas should concentrate on the marine Albian limestone-black shale-siltstone-fine sandstone Asu River Group proximal to major fault zones. Criteria for distinguishing the three episodes and types of galena mineralization can be best defined according to crystal morphology as follows:

(c) Crystalline galena (Early Cenomanian) (b) Massive galena (latest Albian) (a) Galena specks and fibrous stringers (Late Albian).

Prospects for tapping the brine resources, limestones, and stone aggregates are shown to be high.

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ABBREVIATIONS

A.b.s.l.	Above Sea Level
GSN	Geological Survey of Nigeria
Shell Bp	Sheel Bp Petroleum Development Company of Nigeria Limited
B.P.	British Petroleum
N.M.G.S.	Nigeria Mining and Geosciences Society
LANDSAT	Land Satellite
SLAR	Side-looking air-borbe radar
Amer.	America
Bull.	Bulletin
Soc.	Society
Geol.	Geological
Mem.	Memoir
Ann.	Annual
A.G.I.D.	Association of Geoscientists for Internation Development
USGS.	United States Geological Survey.

CHAPTER 1

INTRODUCTION

1.1 Location and Access

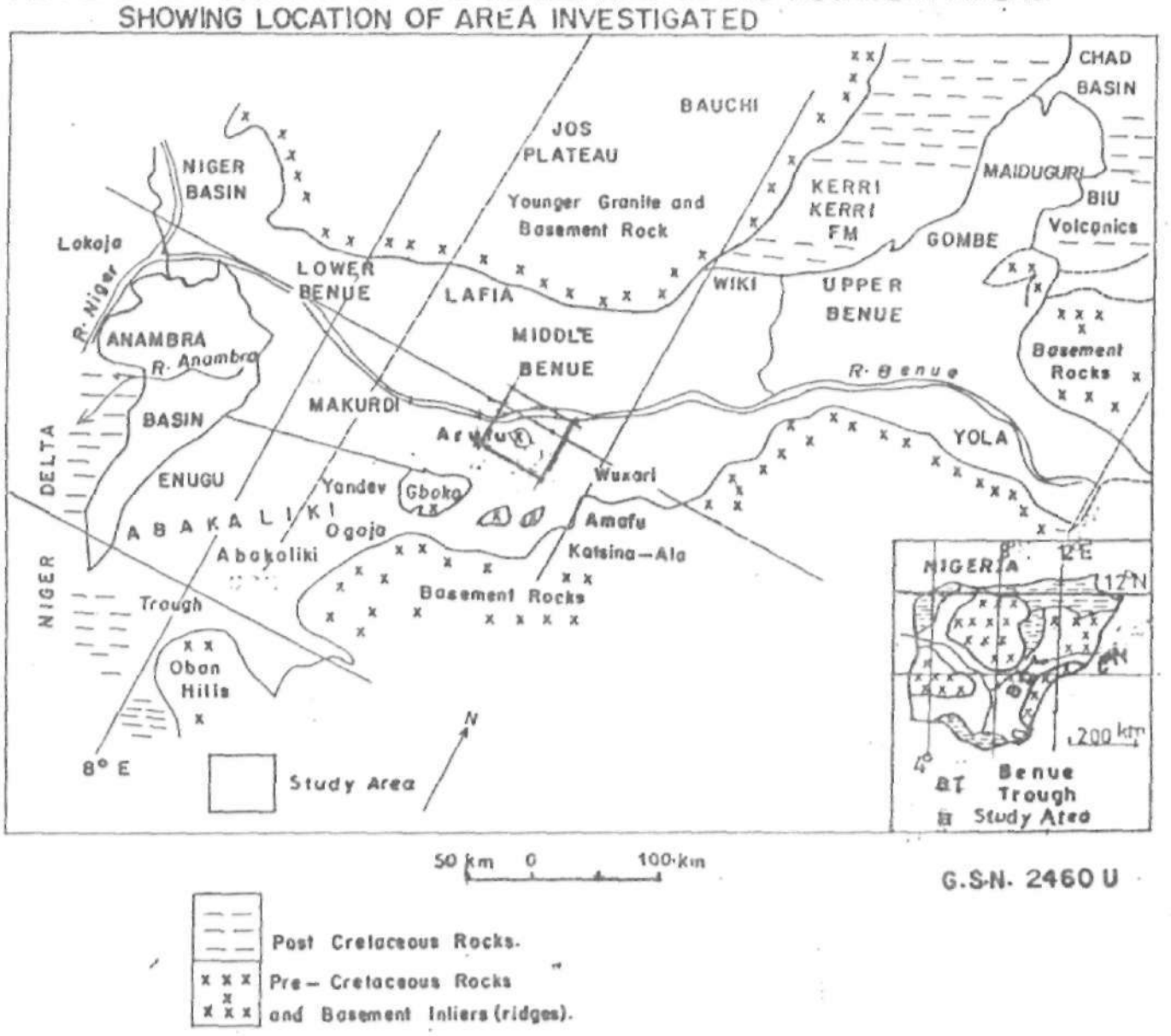
The project areas is the 1:100,000 Sheet 252 (Akwana) of the Geological Survey of Nigeria (GSN). This quarter degree sheet lies between latitudes $7^0 30'$ and 8^0N and longitudes 9^0 and $9^0 30'$E, with an overall land area of 2,970 square kilometres (Fig.1.2). This includes the western part of the Wukari Local government Area of Gongola State, the northern part of Katsina-Ala Local Government Area of Benue St ate, and the Awe Local Govenment Area of Plateau State. The area is situated in the Middle Benue Valley.

Access within the project area is shown in Fig.1.3. A major tarred road from Kwatan Sule via Makurdi to Wukari on the River Katsina-Ala traverses the northern section of the area. An all season motorable laterite road joins Arufu in the north to Ugba in the southern boundary of the sheet on to Yandev. Seasonal motorable roads links Abeda with Amuta and Afia, and Kente with Afia. There are many foot paths linking the sparsely populated and dispersed settlements. These help to reduce the problem of accessibility to outcrops.

1.2 Previous Work

Farrington (1952) outlined a stratigraphical sequence for the Middle Benue Valley. Over a decade later Cratchley and Jones (1965) carried out a geophysical gravity survey of the Benue Valley and attempted a stratigraphical correlation of the Lower, Middle and Upper Benue Valley, and also presented a geological

FIG 1.2 BROAD DIVISIONS OF THE BENUE TROUGH AND ADJACENT AREAS SHOWING LOCATION OF AREA INVESTIGATED



G.S.N. 2460 U

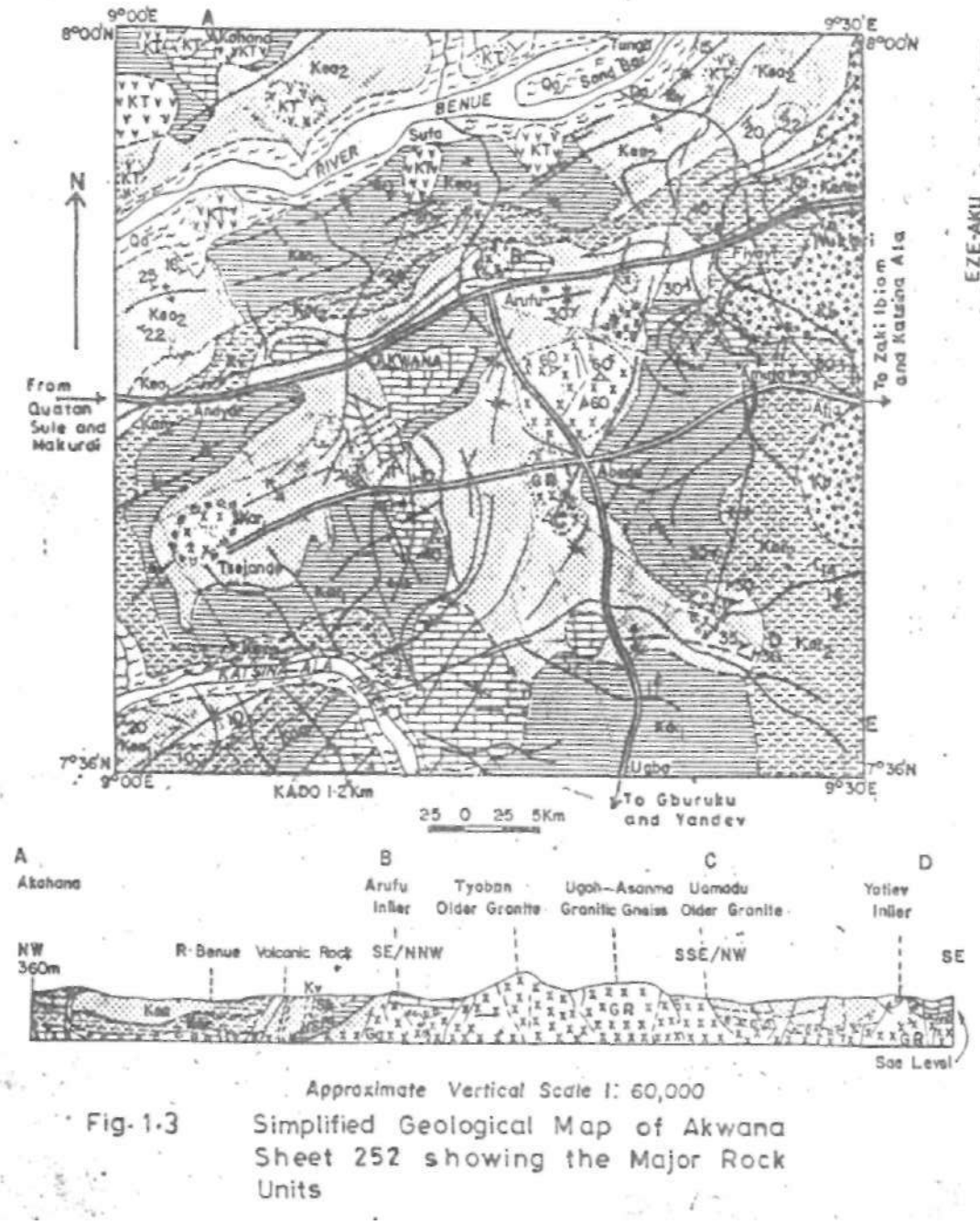




Fig. 1·3 Simplified Geological Map of Akwana Sheet 252 showing the Major Rock Units

outline of the area. More recently Offodile (1976) mapped the 1:100,000 Sheet 231 (Lafia) and carried out a reconnaissance survey of part of the adjoining Sheet 232 (Akiri).

Research interest has continued in the Middle Benue Valley either in the form of further geophysical data acquisition (e.g. Artsybashev and Kogbe 1974, Ajakaiye 1980, Adighije 1981, and Ajayi and Ajakaiye 1981) or in the search for theoretical models (e.g. Burke et al. 1970, 1973, Wright 1976, Olade 1976, 1979).

Lead-zinc mineralization around Arufu and Akwana had attracted some geological activities since the turn of the century. The native Jukuns worked on the deposits in pre-colonial days and marketed the galena as cosmetics. Between 1903 and 1925 various mining companies worked on the galena deposit. McConnel (1949) and Bogue (1952) examined the deposits and reported on the general geology of the Arufu-Akwana area.

1.3 Present Work

The present programme involved the mapping of the quarter degree sheet 252 (Akwana) (Fig.1.1 back pocket). The mapping method adopted was the compass traverse method where all the possible areas were traversed along road, foot paths, rivers and streams using topographic base maps. The topographic base map of the 1:100,000 sheet 252 (Akwana) was useful as the villages, settlements and some land marks and "bench marks" are easily located on the map, though some settlements which were on the map have ceased to exist.

Aerial photographic coverage of the project area at the contact scale of 1:40,000, was also used during the geological mapping.

In addition to preparing the much needed geological map and studying the economic mineral resources of the area of study, the present work was also intended to light the structural and stratigraphic control of mineralization; and try to resolve some of the outstanding problems of the origin and evolution of the Benue Trough and relationship to mineralization, including the prospects for exploration. These include:

(i) Working out the stratigraphy and structural history of the study area and correlating them with adjacent areas in the Middle Benue, the Upper and Lower Benue. This necessitated the mapping of the Arufu fracture zone covering an area of 10 square kilometres on a scale of 1:5000 in order to bring out some details of stratigraphic and structural control of observed mineralization Fig.3.20 back pocket).

(ii) Ralating the geological history and episodes of lead-zinc mineralization to the events connected with the continental extention of mid-oceanic (equatorial) south Atlantic Fracture systems, the drifting of African and American continents, and the origin of the Benue Trough.

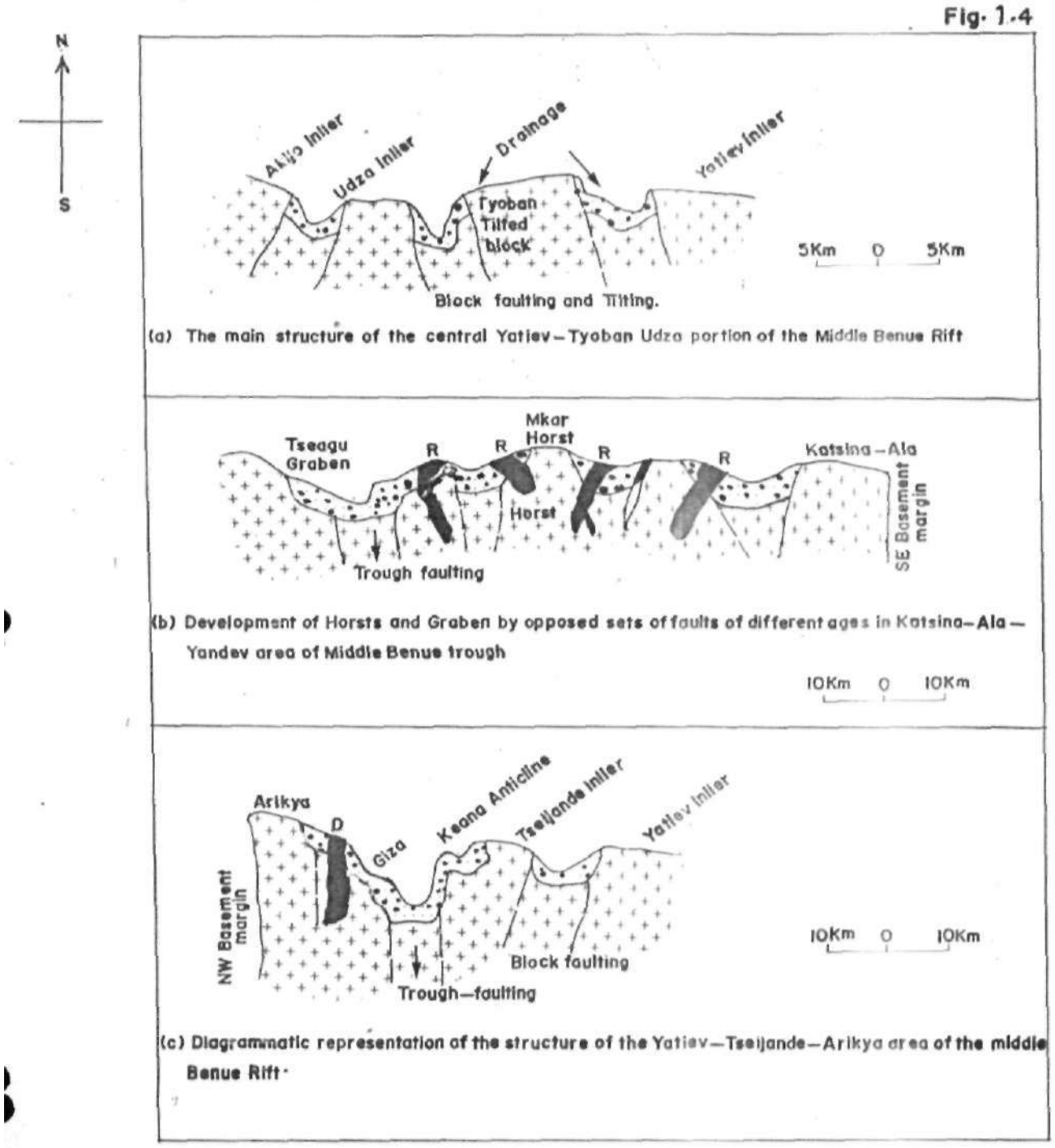
(iii) systematic study of the trough margins and marginal fracture systems of both the sedimentary rocks and the down-faulted or uplifted basement blocks, inliers, or ridges surrounding the area being investigated (Fig.1.5)

(iv) Resolving the question of lineaments, fractures and faults in the sediments which in places continue into the underlying crystalline Basement complex rocks.

(v) Use of other remote sensing devices like LANDSAT, SLAR (Figs.1.7A and B), the aeromagnetic interpretation

Diagrammatic Sections of Block and Trough Faulting in middle Benue Valley

Fig. 1.4



(a) The main structure of the central Yatiev–Tyoban Udza portion of the Middle Benue Rift

(b) Development of Horsts and Graben by opposed sets of faults of different ages in Katsina–Ala–Yandev area of Middle Benue trough

(c) Diagrammatic representation of the structure of the Yatiev–Tseljande–Arikya area of the middle Benue Rift.

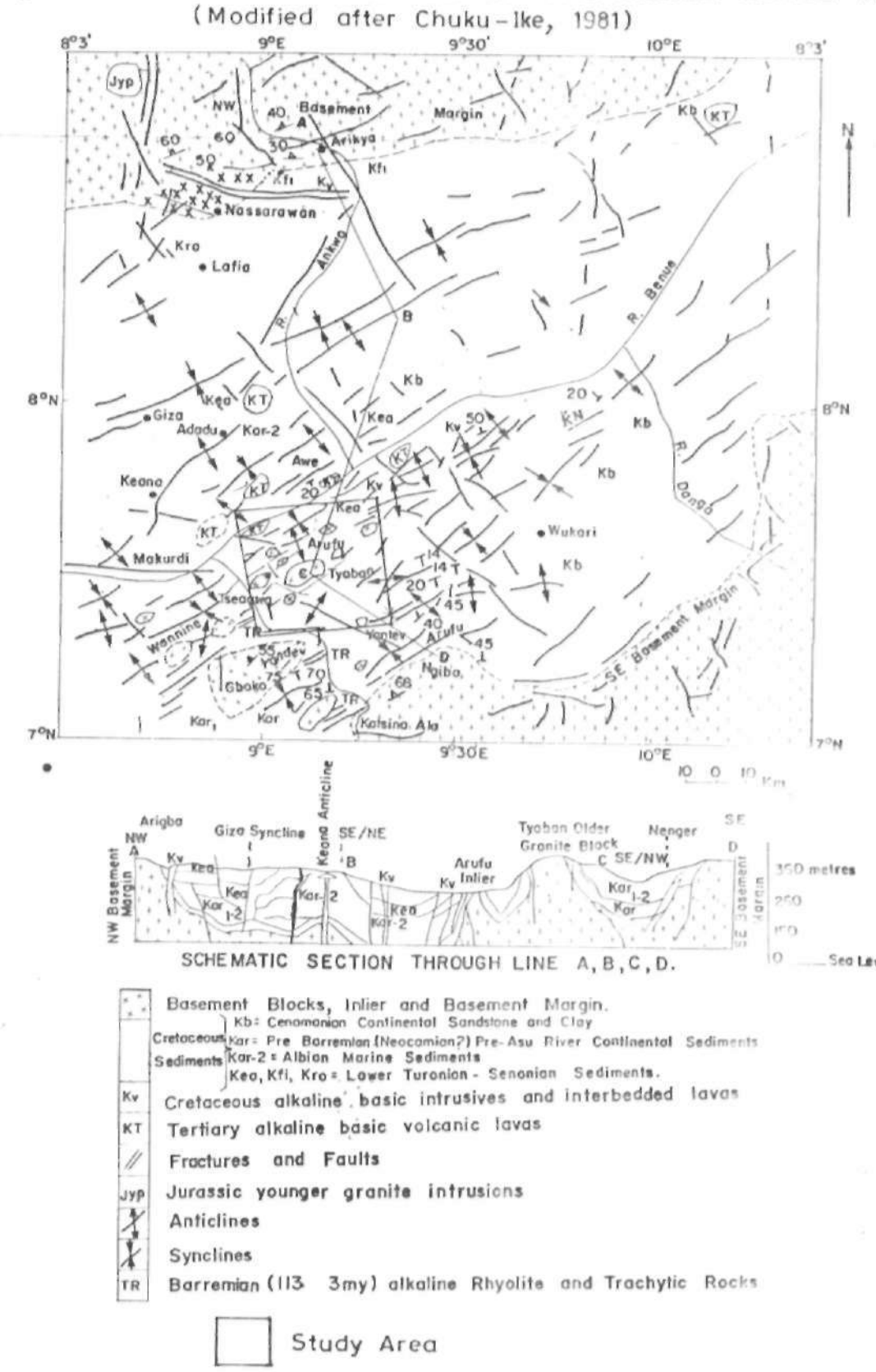
LEGEND

Cretaceous Sediments

U. Precambrian–Lower Palaeozoic Crystalline basement rocks

Cretaceous igneous intrusions including: Trachytic Rock and Alkaline Rhyolite (R), Dolerite (D)

Figure 1.5 STRUCTURAL MAP OF THE MIDDLE BENUE TROUGH.
(Modified after Chuku-Ike, 1981)



anomaly map of the project area, used to infer among other things, the probable direction of tilt of the basement blocks during rift-faulting (Figs 1.6 and 1.7c), and also to get insight into the basement disposition in relation to subsequent cover of Cretaceous sediments (Fig.1.4).

(vi) Showing how far the application of geochemical data agrees with other geological tools in indicating the stratigraphic and structural control of mineralization in the region.

(vii) Usefulness of chemistry in interpreting the environment of deposition of the sedimentary rocks in the evolution of the Benue Trough within the study area.

In this programme geochemical stream sediment sampling went on concurrently with normal geological field mapping. Reconnaissance trips were also made to adjoining quadrangles of sheets 232 (Akiri), 233 (Ibi), 253 (Wukari) and 272 (Katsina-Ala).

1.4 Relief

The Arufu-Akwana-Ugba area is part of an undulating rolling lowland stretching from the Yandev-Katsina-Ala-Amafu area (part of the SE margin of the Middle Benue Trough) to the steep scarp of Jos Plateau to the NW. In the mapped area, this generally rolling undulating terrian (the lowest point being 77 metres above sea level, beside the Benue River) is interspersed with several uplifted basement blocks or ridges aligned parallel to the axial trend of the Middle Benue Trough.

The rolling undulating topograph is disrupted by the presence of steep sided Older Granite range of hills in the central Tyoban - Abeda area, which reach a peak of about 371 metres above sea level around Tsekwen, characterized by gorges, faults, and shear zones.

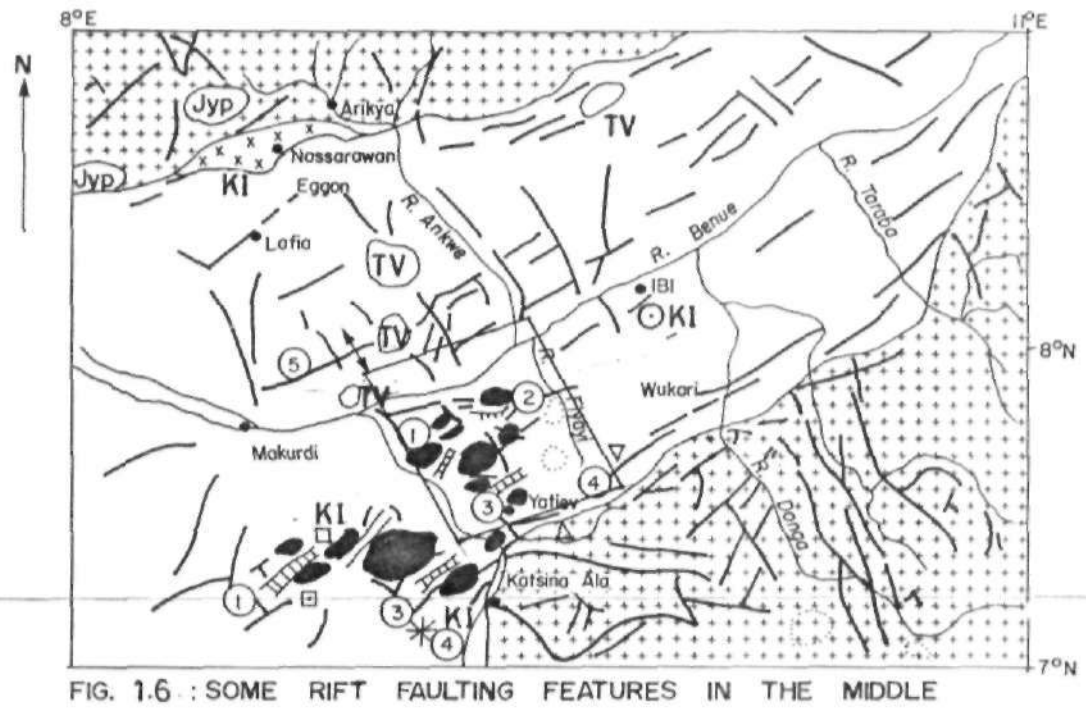


FIG. 1.6 : SOME RIFT FAULTING FEATURES IN THE MIDDLE BENUE TROUGH AND SAMPLE LOCALITIES OF THE RELATED EXTRUSIVE ROCKS, ETC, REFERRED TO IN THE TEXT.

km 50 0 50 km

Sunken areas

Raised Crystalline Basement Block

TV Tertiary Volcanic Centres

KI Cretaceous Igneous Centres

Jyp Mesozoic (Jurassic) Younger Granite Intrusion (From aerial photographs)

Fractures and Faults

Faults and Throws

Probable Cretaceous Fault Scarp Ridges

Circular Features From aerial photographs

Cretaceous Sediments

PreCambrian Lower Palaeozoic Crystalline Basement Rock

Study Area

(1) Tseagu Graben

(2) Yandev Graben

(3) Tseagodo Graben

(4) Katsina Ala-Amafu Graben

(5) Keana Anticline

□ DC 321 G, 380-382

⊡ DC 261 A-E, 205

✳ DC 306 A

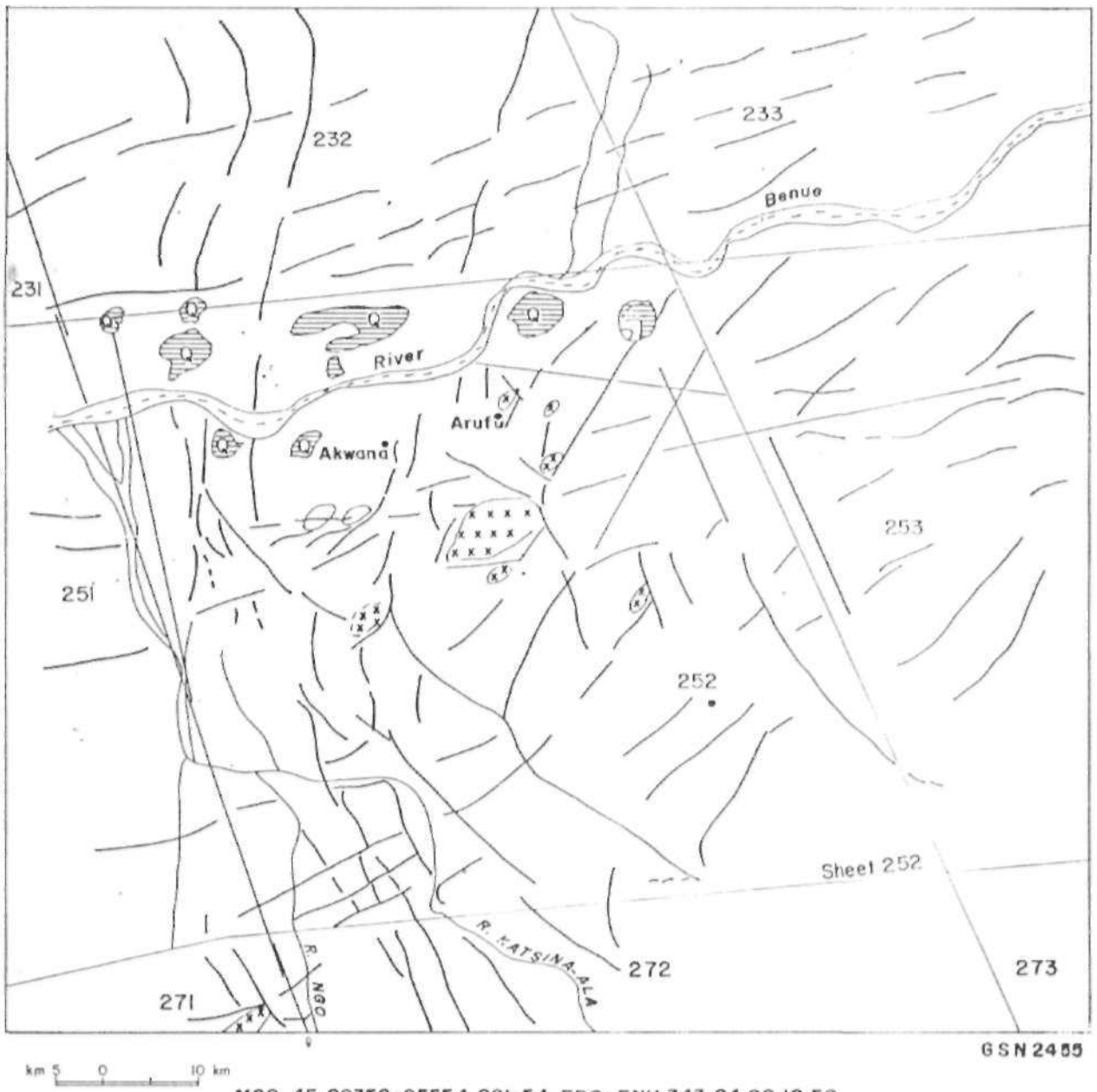
△ DC 376

▽ DC 227, 293 & 294

⊙ DC 307

: GSN. 431 F.

STRUCTURAL INTERPRETATION OF MSS LANDSTAT IMAGERY
OF AKWANA STANDARD SHEET 252 AND ADJACENT AREAS FIG. 1.7A



MSS 45,20352-05554,201-54, EDG-ENH-343,24,80,12-50
9TH. JAN. 1976.

L E G E N D

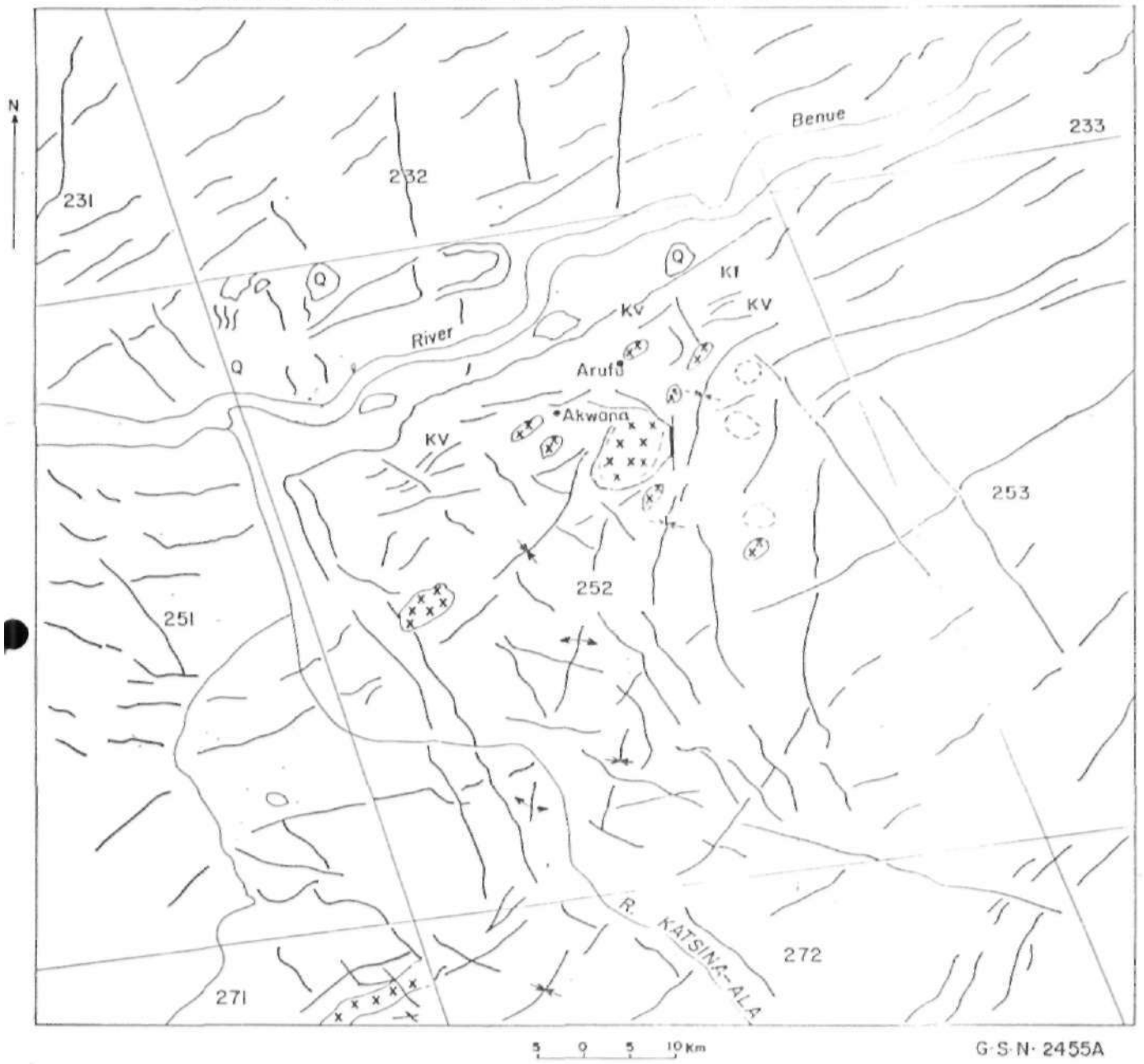
Q TERT.-REC. VOLCANICS

CRETACEOUS FORMATION

PRECAMRIAN CRYSTALLINE BASEMENT ROCKS

252 Akwana Sheet 252

STRUCTURAL INTERPRETATION OF RADAR SLAR MOSAIC N&S LOOK OF AKWANA STANDARD SHEET 252 AND ADJACENT AREAS, MIDDLE BENUE TROUGH FIG. 1.7 B



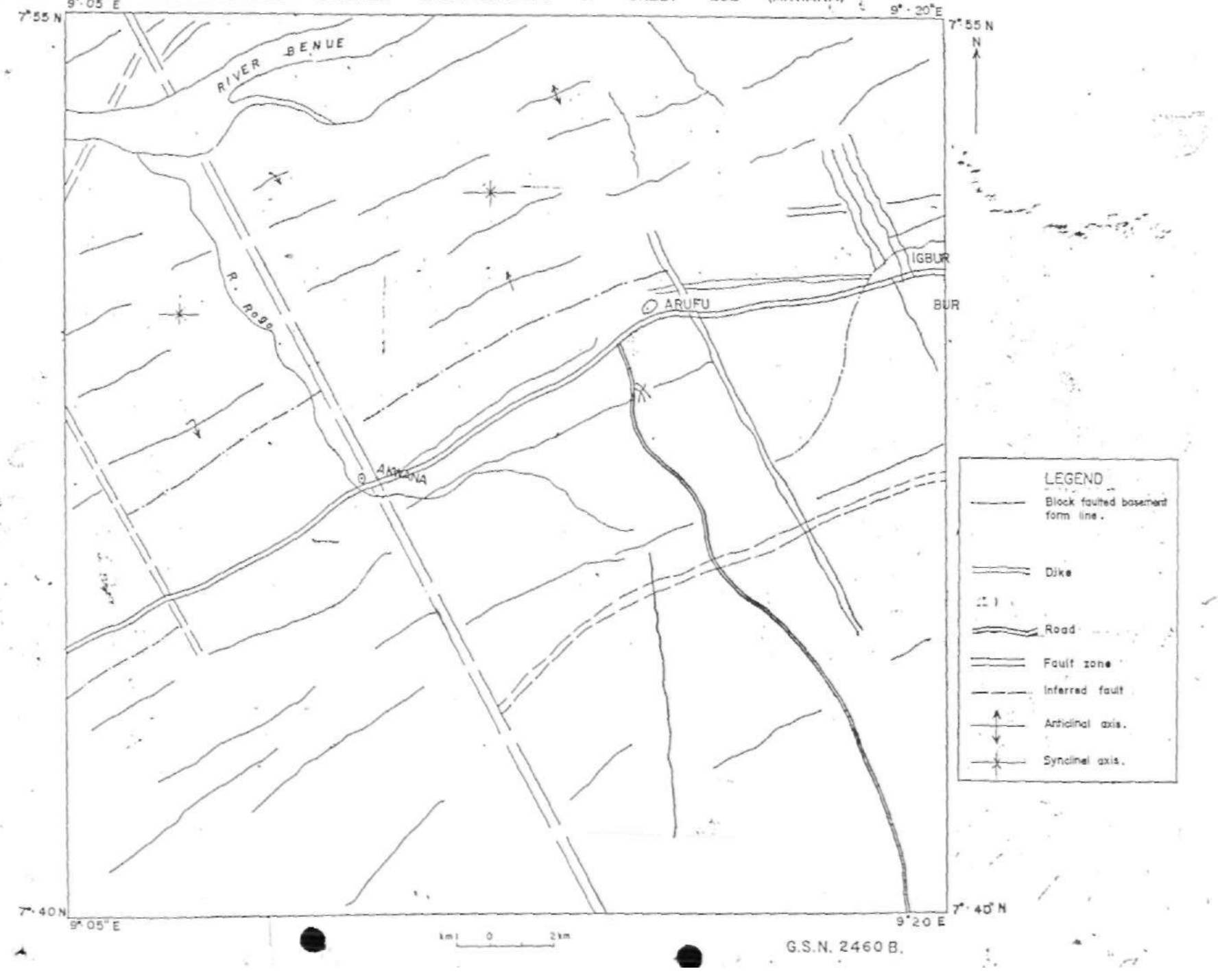
G.S.N. 2455A

RADAR MOSAIC N&S LOOK NG 32 : 15 N-5

LEGEND

- Q — TERT-REC. VOLCANICS
- CRETACEOUS FORMATIONS
- PRECAMBRIAN BASEMENT CRYSTALLINE ROCKS
- CIRCULAR FEATURE
- KI — DYKES AND SILLS
- KV — CRETACEOUS IGNEOUS INTRUSIVES AND LAVAS
- 252 — Akwana Sheet 252

FIG. 1.7C STRUCTURAL INTERPRETATION OF ARUFU-AKWANA AREA BASED ON G. S. N. AEROMAGNETIC ANOMALY INTERPRETATION OF SHEET 252 (AKWANA)



G.S.N. 2460 B.

From these hills the relief drops but not uniformly, towards the northern flattish-rolling plains and flat-topped hills with crests at the 152-183m level. But in the south, southeast and southwest (towards the Katsina-Ala river), the relief consists mainly of lateritized pediment surface, with gentle gradients.

1.5 Drainage

The River Benue is the main river into which the others flow. It forms a long braided system, draining the NW parts of the mapped area. It rises in the Adamawa highlands to the northeast and appears to be structure-controlled in this region, apparently near and parallel to the axis of the Middle River Benue syncline (Fig.1.8). Other drainage characteristics in the Tunga-Sufa - Annybe area include bodies of sand bars encircled by anastoming channel ponds, wide flood plains and more than one generation of alluvial deposits which suggest river channel wandering.

The second main river and the most important tributary of the Benue is the River Katsina-Ala which dominates the southwestern area with its characteristic straight stretches and high angle to rectangular fault - controlled bend in the Tsekur area (Figs 1.1 and 1.3). It is non-turbulent and slow.

Various orders of streams form tributaries to River Benue and River Katsina-Ala. The feeder streams are under various degrees of structural control. Some of the smaller tributaries flow parallel to the en echelon fracture zone ridges and meet the bigger streams at high angle to rectangular junctions, in the Arufu-Akwana area. The streams traversing the central hilly granite region (e.g. River Kyin) have a special north south trend which is, in fact, the trend of the major fault or shear zone in the area. The river flows roughly

parallel to the E.W or ENE-WSW trending anticlinal axis of the fold in the Cheorban - Gabo area.

In the low-relief area and plain (underlain by shale - carbonate - siltstone) to the north and southwest towards the Benue and Katsina-Ala rivers, the streams flow sluggishly in dendritic drainage.

Minor radial pattern of drainage was observed in the Buba - Uta hill (near Fiyayi village) which is underlain by brecciated, deformed Albian shales and siltstones of the Asu River Group. This was also observed in the Wankper - Aka hill near Amuta village and the Yatiev lormenger hills from which the Yatiev saline spring issues.

Radial pattern of drainage is observed to be characteristic of the so-called "circular features" of the Middle Benue Valley (Offodile 1976, Ford 1981).

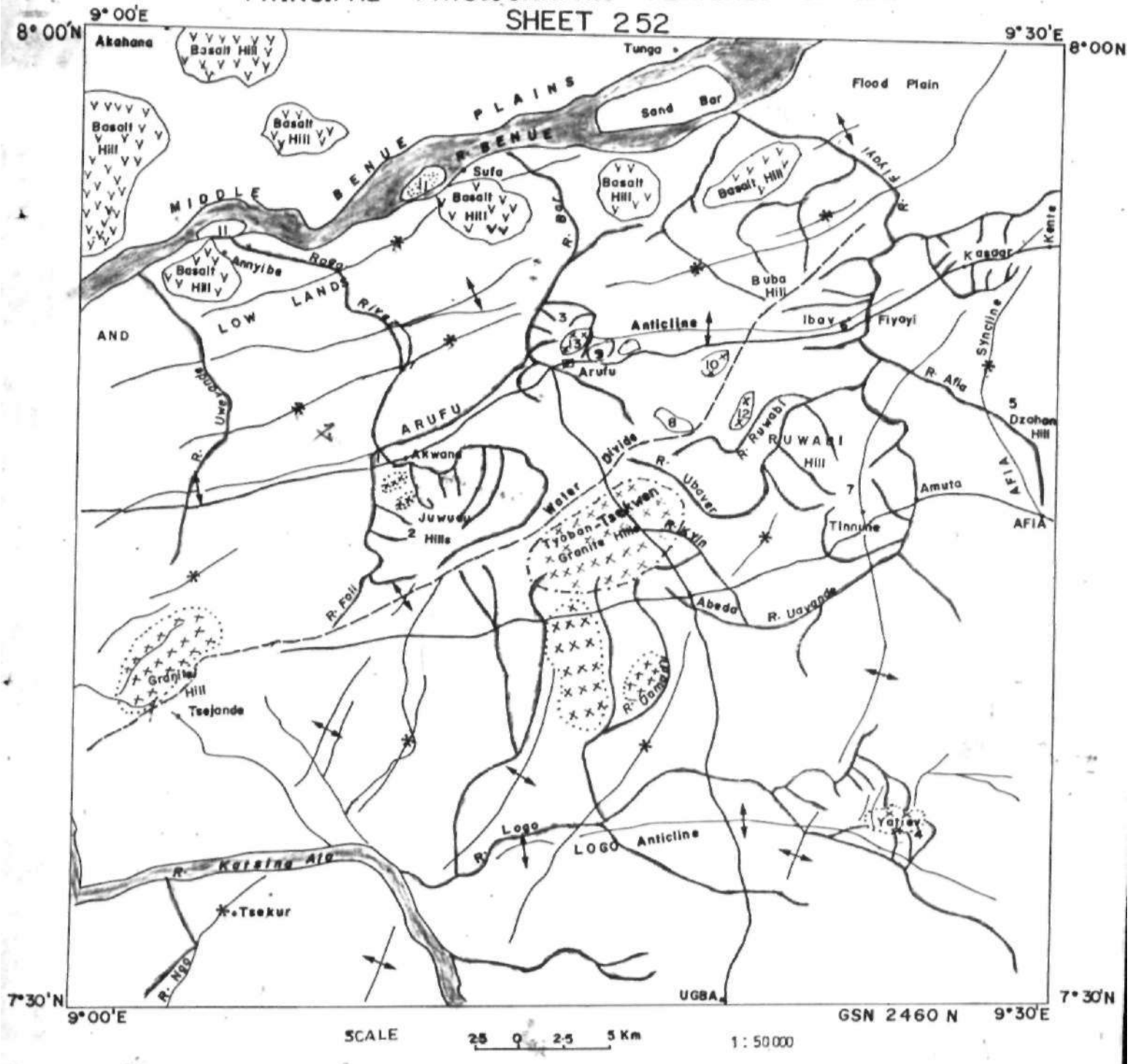
Generally, the mature streams in the study area flow in broad meandering valleys with gentle slopes but develop marshy ("Fadama") terrains in headwater areas. However, they flow in deeply incised valleys in areas where ridges occur.

1.6 Vegetation

The mapped area falls within the Guinea Savannah type of vegetation or open savannah woodland usually referred to as the savannah. Bush-stunted trees and shrubs are interspersed with medium sized trees (with canopy height of 2-3m) near water courses; but generally the vegetation is characterised by tall grasses and thorns with few scattered short trees, or patches of woodland consisting of both fire tolerant and fire tender trees. The common trees in the forested slopes in the Kente-Ikwe region underlain by shaly sandstones Sandstones, include the African oil bean trees, oil palm trees, while the common stunted trees are Vitek species and Cassia sp.

FIG. 1:8

PRINCIPAL PHYSIOGRAPHIC FEATURES OF AKWANA SHEET 252



P. T.O. for Key

Key to Fig. 1.8

1. Akwana Saline Pond.
2. Juwudu Hill Saline springs
3. Arufu saline springs.
4. Yatiev saline springs.
5. Dzahan saline spring.
6. Ibav non-saliferous spring and circular feature
7. Aka-Wankper non-saliferous spring and circular feature
8. Tseagua scarp ridge
9. Arufu shelly limestone scarp ridge
10. Igbur gneiss inlier
11. Sand bar along River Benue
12. Ruwabi Older Granite ridge
13. Arufu Granitic gneiss inlier

= With Local Salt Industry

= Anticlinal Fold axis

= Synclinal fold axis.

The dominant grasses are the tall elephant grass near stream channels, flood plains and headstream "Fadamas" and species of African Devil beans. The African Devil bean stems with delicate irritating, offensive hairs on the long beans, are abundant. The undergrowth in the river valleys include thorns and ropes. Palm trees (both rafia and oil palm trees) are also found in the flood plain of Rafin Gishiri to the west of Arufu.

The limestone-shale terrain around Arufu and Akwana and along the lower section of River Logo (north of Ugba), is dominated by thicker vegetation with thick undergrowth, while the hilly basement terrain is covered by stunted accasia trees, date palms and short grass.

CHAPTER 2

BASEMNET GEOLOGY

2.1 General Geology

The essential geological features of the region consist of down-faulted blocks of Pre-Cambrian crystalline basement, represented by biotite granite gneiss, migmatitic gneiss and the Older Granite, on which unconformably rest sedimentary and volcanic rocks ranging in age from Lower Cretaceous to Tertiary. The evolution of rocks of the Basement Complex is as proposed by various authors as compared with the study area in Table 2.3.

The oldest rocks in the region are remnants of an ancient sedimentary series probably of Middle Pre-Cambrian age. Sedimentation, igneous activity and regional metamorphism were followed by other orogenic cycles which transformed them into granitic gneisses and metasediments as in the Arufu, Igbur, Yatiev and Tseagodo areas. Other cycles include the Pan African Orogeny during which the diverse and widely scattered K-feldspar rich Older Granites were emplaced in the Tyoban-Tsekwen-Abeda and Tsejande areas and the metasediments largely transformed into migmatitic gneiss

As in the other parts of Nigeria, there is apparently no authentic records of sedimentation in the long interval between the Middle. Pre-Cambrian and Late Mesozoic times. Black and C[illegible] (1970) believe that this absence and/or scarcity of Pa[illegible]ic formations in Nigeria (and the adjacent Camer[illegible]d) may suggest that most of Nigeria and Cameroon [illegible]emergent landmass in Palaeozoic and Early Mesozoic ti[illegible]ted to accumulate in Nigeria in fossil evidence (Falconer 1911) . indicates that marine sed[illegible]

TABLE 2.3 PROPOSED EVOLUTION MODEL OF ROCKS IN THE BASEMENT COMPLEX OF 1:100,000 SHEET 262 (AKWANA) MIDDLE BENUE VALLEY, 1:250,000 SHEETS 25,26 and 47 UPPER BENUE VALLEY AND 1:100,000 SHEET 114 (GWOZA) UPPER BENUE VALLEY (NE CORNER) IN NIGERIA

EVENTS	1:100,000 SHEET 262 (AKWANA) MIDDLE BENUE VALLEY	1:250,000 SHEETS 25,26 and 47 UPPER BENUE VALLEY	1:100,000 SHEET 114 (GWOZA) U. BENUE VALLEY	TECTONICS	CROGENIC EPISODE IN NIGERIA	EVENTS OF NIGERIA IN GENERAL TIME	AREA
	SEDIMENTARIES	(ROCK)	DYKES.			M. Y.	
Uplift, high level magmatic activity, faulting, fracturing.	Quartzo-felspathic or granitic-pegmatite, quartz veins or dykes in the Tyecan quarry, Tsekwen, Tsejande and Yatiev areas.	Felsic Dykes Bonga Hills Volcanics Jamboram Hills Porphyry Kwaba Hill granites. Bukashaka Group	Liga Hill acid porphyry granite dyke, Disc Hill felsite dyke Gavva fault and associated shear trends; 521 m.y.	Crustal Tensional rebound in E-W direction	PAN AFRICAN 600 +/- 150 million Years	540 ± 40	Mid Cambrain
Granite intrusion Pegmatite and Aplite, development of Older Granite.	Coarse Porphyritic in Tsejanse and Tseagudo areas. Equigranular Granites Tyecan-Tsekwen Hill area, Divers Ruwati and Yamadu areas.	Porphyritic Pegmatite Granite with muscovite age of 574m.y. (Ajakaiye 1980) Equigranular Granite	Swarm of aplites in Liga Hill area and other places the fine medium coarse and very coarse Porphyritic Older Granite.	Late Orogenic Deformation producing predominantly N-S trending fractures.		500 - 650 500 - 650	Cambrian to Precambrian
Orogenesis, Deformation, Metamorphism Granitization Migmatisation and and reactivation of existing rocks. Diverse series of Potassic rocks OLDER GRANITE CYCLE	General Metamorphism in the area with subsequent migmatisation; Granodioritic rocks; N-S tectonic trend in most of the Older granites.	Anatectic migmatite with Biotite age of 646m.y. (Ajakaiye, 1980) Fine-grained Granite Quartz-Diorites and related rocks Basic and intermediate plutonic rocks. Syntectonic Granites	General metamorphism in the area with subsequent migmatitic and other associated rocks.	Syntectonic Deformation period of E-W stress		650 - 850	Pan African- Upper Proterozoic
Sedimentary deposition and igneous activity						800 - 1000	Katangan
Charnockitic intrusions					1000m.y.		
Granite formation and crustal reworking	Down faulted-uplifted. Biotite Granitic Gneiss inliers in Arufu, Igbir with NE - trend	Quartz--feldspathic Gneisses. Quartzites calcsilicates	Gneissic granites and Quartz-Diorites	Main period of deformation, isoclinal folding and shearing	2000 +/- 250m.y.	1900 +/- 250	Eburnean
Ancient Gneiss-Schist complex, cycles probably associated with intrusive cycles-Banded Gneiss-migmatite Gneiss Complex Crystalline Basement	Metasediments-muscovite-Biotite Gneiss in Tseagodo area, Quartzo-Feldspathic in Yatiev area. (Crystalline Basement)	Hornblende Biotite Gneisses Variably migmatised.	Older migmatites and metasediments as at Wija and Kparawa Biotite- Hornblende Gneiss and granitic Gneiss			2800 +/- 200 and over	LIBERIAN
	This Report	Carter et al. (1963)	Okeke (1980)	King & De Swardt (1949)	Rahaman (1976)	Modified after (1976)	McCurry

the Benue Basin (including the area mapped) in the Lower Cretaceous.

The Pre-Cambrian - Lower Palaeozoic Basement Complex surface on which the first sedimentary unit, namely, the Pre-Asu River sediments, was laid comprised the crustal rocks which once lay deep in the interior of the earth, but which, after considerable erosion, were exposed before the Lower Cretaceous beds were laid down.

The evolutionary history of the study was dominated by repetitive transgressive-regressive sedimentary cycles interspersed with several cycles of igneous activity and episodes of tectonic upheavals.

In the study area approximately 3,000 metres of sedimentary and igneous rocks were preserved within the depression. The present investigation indicates that about four cycles of igneous activity span the Lower Cretaceous to Tertiary history of the Middle Benue depression.

2.2 The geology of the Crystalline Basement

2.2.1 General Features

The crystalline basement of the Arufu-Akwana-Abeda area consists of metasediments, granitic gneiss, migmatitic gneiss and the Older Granite series. These form inliers and ridges aligned parallel to the axial trend of Middle Benue Trough. The basement rocks form about seven percent of the area mapped (Fig.1.1 back pocket).

The Older Granite Series is the dominant basement rock unit by areal extent and topography. Characterised by N-S trending fractures it outcrops extensively in the Tyoban-Abeda area while it forms NE-SW ridges and saddle structures in Tsekwen crestal area.

Other outcrops of the Older Granites occur about 250 metres south of Igbur village, four kilometres south of Abeda (along the banks of River Uamodu), and in the Tsejande area towards the SW. extreme of the study area. Similar basement inliers and ridges including granitic and migmatic gneisses are found in the NW and NE quadrangles of the adjoining Katsina-Ala Sheet 272 along the Yandev Katsina Ala tarred road. Generally these NE-SW trending basement inliers or ridges are aligned sub-parallel to one another and separated by local sedimentary basins, thus presenting ridge and Valley landscape.

2.2.2 The Granitic Gneiss

Field Geology

The granitic gneisses in the area mapped are generally dark grey foliated quartzo-feldspathic rocks of granodioritic composition. Alternating quartzo-feldspathic material (the feldspar is usually of pinkish colour) and biotite flakes define the foliation or banding in the Arufu and Igbur inliers (DC. 175, 198,199). In the Yatiev inlier the foliation is less distinct (DC.217). More commonly the quartzo-feldspathic material forms impersistent streaks a few millimetres thick which are invariably aligned parallel to the foliation as defined by the mica. Where the granite (felsic) material takes the form of indefinite impregnations a more uniform granite gneiss is produced.

Outcrops of the granite gneiss occur in the study area as relatively small subparallel horstlike blocks, inliers and ridge areas that are elongated along the NE-SW direction of the main axis of the Middle Benue Trough. They range in surface area from over 5km^2 (the Ugoh-Asanma Granitic Gneiss) to less than one square kilometre (the Igbur and Yatiev inliers). The Arufu inlier covers

an area of about 1.2 square kilometres. It forms a steep-sided ridge with a NE-SW trend.

On either flank of these ridge and horst-like structures are isolated and deep, fault-bounded basins containing Pre-Albian continental sediments, followed by Middle to Upper Albian marine sediments. The foliation in the northern portion of the Arufu inlier has a dip ranging from 45° to 50° NW, whereas the foliation in the southern portion has a dip of 50° . The basement appears to have a faulted contact with the Cretaceous sediments, marked by a NE-SW trending silicified zone, and intruded by a NE trending dolerite dyke.

The Igbur basement inlier consists of a weakly foliated medium grained dark grey granite gneiss (DC.198). Prominent biotite flakes and some amphibole crystals define the foliation dipping 65° SE with a strike of 20°. Near its contact with the overlying silicified Lower Cretaceous sediments, the gneiss outcrop assumes a strongly contorted, sheared appearance, with the texture grading from medium to fine (DC. 199).

The Yatiev Granite gneiss inlier (Fig. 1.1) occurs close to the compound of Tsedoguno about 14km NE of Ugba village, and about 200m south of an outcrop of a quartzo-feldspathic muscovite gneiss (DC.217). The Yatiev Granite Gneiss is a fine-medium grained micaceous rock, mostly light coloured but punctuated with black patches due to the concecentration of biotite (DC.216). The subparallel aligned muscovite and biotite flakes, and some quartzo-feldspathic material define the foliation, dipping 50° SE or NW. A prominent pegmatitic vein about 14 centimetres wide fills a vertical fracture which traverses the outcrop in the direction of 165°.

Petrography

In hand specimen the granitic gneisses and granite gneiss in the area investigated are generally poorly foliated mostly medium-fine grained leucocratic rocks. The latter differs from the former in that the granitic (felsic) material takes the form of indefinite impregnations,. leading to a more uniform gneiss being produced in the granite gneiss. These two varieties frequently exist together in the outcrops and because of their intimate association it is often not possible to show them as separate units in geological maps.

In thin section these quartzo-feldspathic rocks of granodioritic composition (Table 2.6B) consist mainly of equant mineral grains of strained quartz and co-existing plagioclase and mica (mostly biotite). The feldspars are both microcline and plagioclase, the plagioclase being mainly oligoclase or andesine. In addition there are late microcline and quartz, which replace the earlier minerals. The specimen DC. 175 (Table 2.6B) from the Arufu inlier, shows potash feldspar in the form of late pink coloured microcline porphyroblasts which are oriented subparallel to biotite flakes. These together define the foliation.

The mineralogical difference between the original and metasematic portions of rock affected by migmatisation is accounted for principally by the presence of microcline in the latter (DC. 317, 32). In the Ugoh-Asanma Granitic Gneiss ridge the microcline porphyroblasts become numerous and large, attaining 2 x 1.5 centimetres in size (DC.317). The groundmass of the rock is fine-grained. In the rocks unaffected by this migmatisation the bands and leucocratic segregations are composed essentially of oligoclase and quartz (DC.198).

TABLE 2.6A CHEMISTRY OF MAJOR AND TRACE ELEMENTS OF BASEMENT COMPLEX ROCKS

Major elements in oxide weight percent

nd = not detected. T = Trace

Minor elements in parts per million (PPM)

Rock Unit																
Sample No.	DC 305	DC218	DC216	DC198	DC199	DC320	DC317	DC325A	DC234	DC235	DC235B	DC323	DC324	DC326	DC327	175	418
Rock Type serial No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SiO_2	58.52	60.22	61.48	62.1	60.03	62.09	64.45	61.53	65.59	60.04	64.45	69.91	70.14	70.10	70.53	70.12	70.6
Al_2O_3	14.01	15.06	14.61	14.52	15.83	15.57	16.53	14.61	12.78	14.68	12.20	13.15	14.48	14.48	13.6	14.5	12.75
Fe_2O_5	3.20	3.02	2.24	2.5	1.5	1.39	0.79	2.07	1.7	2.44	2.83	0.7	0.97	1.47	11.08	1.5	1.7
FeO	3.20	10.20	11.06	10.31	5.03	10.01	3.0	9.90	10.06	10.03	12.44	3.02	2.00	2.0	2.0	2.7	5.0
MgO	3.4	0.79	0.77	0.71	1.44	0.57	1.23	0.79	0.3	0.99	0.1	1.0	0.75	0.76	0.79	0.7	0.37
CaO	3.63	2.40	2.08	1.14	1.96	1.02	2.76	1.38	1.56	1.91	0.97	1.8	1.13	1.14	1.38	0.15	1.55
Na_2O	4.71	3.58	3.84	3.28	4.93	2.96	4.43	3.27	3.25	3.20	3.11	2.94	3.28	3.28	3.27	3.29	3.3
K_2O	3.02	4.3	3.92	5.46	3.09	5.23	3.98	4.86	4.63	5.05	4.7	5.63	5.46	5.46	4.87	5.48	4.51
TiO_2	1.82	0.41	0.09	0.29	0.33	0.19	0.62	0.38	0.14	0.44	0.07	0.59	0.29	0.28	0.38	0.29	0.15
MnO	0.17	0.20	0.08	0.07	0.99	0.11	0.16	0.12	0.11	0.10	0.1	0.11	0.88	0.07	0.12	0.07	0.11
P_2O	0.67	0.15	0.01	0.6	0.7	0.45	0.27	0.09	0.05	0.12	0.03	0.16	0.6	0.07	0.09	0.6	0.05
TOTAL	98.14	99.13	100.18	99.9	98.9	99.58	98.22	99.01	100.11	99.0	98.99	98.97	99.08	99.1	99.02	99.4	100.12
Cu	20.1	67.7	50.5	20.2	50.6	9.2	10.1	7.7	nd	nd	20.2	7.7	7.1	nd	nd	35.6	nd
Pb	120.4	160.1	150.5	100.1	150.9	120.1	110.9	152.5	72.3	70.4	160.1	150.7	152.7	148.9	150.1	150.	73
Zn	80.0	136.8	140.4	49.6	67.9	20.2	29.2	60.9	40.3	30.4	70.9	60.1	59.3	30.1	31.2	50	40
Ag	15	20.1	16.6	10.3	nd	nd	nd	15.0	nd	nd	16.2	16.1	17.1	nd	nd	8	nd
Ni	29.0	106.1	102.6	3.6	6.7	6.4	6.4	8.1	10.2	6.7	50.7	54.3	53.2	10	10.2	4	12
Co	120.6	109.9	76.2	41.4	30.4	39.4	34.9	42.6	40.9	32.1	40.9	40.2	39.4	39.9	40.1	42	40
Mn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cr	101.7	76.1	10.9	56.6	60.2	70.7	67.6	56.7	100.9	99.2	67.4	59.2	61.3	8.1	10.2	57	56.8
Li	40.0	567.9	400.4	30.3	-	100.1	120.2	129.2	130.5	140.5	130.4	134.3	139.9	90	97	29	130
Ba	200	225.1	122.2	10.7	-	321.3	296.9	130.4	30.4	29.5	120.9	137.7	140.7	nd	nd	11	139
Sr.	102	62.7	-	-	227.99	125.5	132.1	230.0	-	-	-	-	-	-	-	-	-
Zr	72.7	102	135.0	215.6	152.8	136.6	139.9	201.2	10.11	201.9	200.1	42.9	43,91	182.1	179.3	217	229
Rb	102.4	100.1	175.1	294.1	119.8	250.2	230.3	176.1	119.8	120.2	180.9	260.1	200.7	294.3	284.4	290	178

TABLE 2.6B: MODEL ANALYSES OF BASEMENT ROCK

Minerals in Percentage estimated from thin Sections

Sample No.	DC305	DC218	DC216	DC198	DC199	DC320	DC317	DC325A	DC234	DC235	DC325B	DC323	DC 175	DC 324	DC 326	DC 327	DC37
Serial No.	1	2	3	4	5	6	7	8	9	10	11	12	16	13	14	15	18
Other Plagioclase	-	4.2	-	-	-	27.4	1.0	-	-	-	-	0.9	-	2.9	1.9	-	-
Oligoclase	25	20.7	33.1	26.0	28.9	28.4	12.7	15	19	15	6.0	10	26.0	16.5	12.1	9.9	29.
Albite	-	-	4.9	-	-	3.0	5.0	-	-	-	4.9	-	-	-	5.9	2.1	-
Andesine	10	15.1	-	5.0	5.0	14.0	6.0	6	10	12	5.2	5	56.0	2	-	-	-
Microcline	-	5.2	10.0	12.8	12	2.0	6.0	8	9	9	9.0	12	13.79	6.7	16.0	25	-
Orthoclase	-	-	-	2.0	5	-	-	14	19	16	23	8	2.0	20	5.9	20	20.
Myrmekite	-	-	1.1	2.2	5	1.6	1.0	7	0.1	0.2	.07	0.70	2.21	-	2.0	1	0.
Quartz	24	40.0	26.3	33.7	33.5	27.0	24.0	36.0	20.8	26.0	28.8	30.1	35.18	30	35	29	3
Biotite	12	2.5	10.0	12	10.8	24.0	27.0	15.0	13	110.9	11.0	18	11.94	15	19	10	11.
Muscovige	20	5.1	10.0	1.1	1.2	3.0	10.0	2.1	1.2	6.0	6.0	12	1.16	3	-	-	-
Lepidolite	3	2.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Hornblende	-	-	-	-	-	1.0	1.0	-	3	2.9	1.1	-	-	2	-	-	6.
Anthophyllite	-	-	-	1.5	1.5	-	-	-	-	-	-	-	-	-	-	-	
Actinolite	-	-	-	2.0	2.0	-	-	-	-	-	-	-	-	-	-	-	
Other Amphibales	-	7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Diopsidic Augite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Other Pyroxenes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Calcite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.
Epidote	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Sphene	0.9	2.2	-	0.1	0.5	0.01	0.8	0.3	0.5	0.8	0.9	1.3	0.1	2	0.5	0.6	0.
Chlorite	3	-	-	-	-	0.09	0.05	-	-	-	0.1	-	-	-	-	-	
Zircon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Staurolite	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	
Hematite	1.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Magnetite	-	-	1.7	9.1	1.2	2.0	1.0	0.36	-	1.1	1.0	1.0	1.2	1.1	1.6	1.0	1.1
Other Iron Ores	0.5	3.5	0.9	-	-	-	-	0.2	-	-	-	-	-	-	-	-	
Garnet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Apatite spinel	-	-	1.0	1.2	1.3	0.02	0.01	0.2	-	1.4	-	-	1.4	-	-	-	
TOTAL	99.6	99.5	99.9	99.9	100.1	99.12	99.56	99.1	99.7	99.9	97.1	99.4	99.95	99.6	99.3	98.7	99

KEY TO TABLES 2.6A, B.

(see Figure 5.56 for Sample localities)

1. (DC305) Muscovite-Biotite gneiss. From road cutting at KM12 along Yandev-Katsina Ala tarred road.
2. (DC218) Quartzo-felspathic micaceous gneiss collected from locality 64D near Tseduno compound, about 200m north of the Yatiev Granitic Gneiss Inlier.
3. (DC216) Granitic gneiss collected from the Yatiev inlier Locality 64C
4. (DC198) Med-coarse grained Biotite granitic gneiss from the Igbur inlier (Locality 39) about 1/4km SW of Igbur village.
5. (DC199) Sheared fine grained Biotite granitic gneiss from some locality as DC198 above.
6. (DC320) Medium grained gneissose Biotite Granite. From Ugoh compound (Locality 86A) about 5.8km west of Abeda along untarred road to Tsenyamkume.
7. (DC317) Porphyroblastic Biotite gneissose Granite from near Asanma Compound 4.4km west of Abeda along untarred road to Tsenyanmkume.
8. (DC325) Equigranular medium grained Biotite Granite from the River Ruwabi Granite about 2km NE of Tseaguda (Locality No. 183)

9. & 10 (DC234 and DC235 respectively)
Medium grained equigranular (Granodioritic) Biotite granite, from the Tyoban Quarry in the Tyoban - Tsekwen Hill Older granite terrain.

11. (DC325B) Pegmatitic Biotite Granite from the same locality 183 as No.8.

KEY TO TABLES 2.6A,B (Cont'd)

12&13 (DC323 & 324, respectively) Locality 179

(DC323) Medium grained Equigranular Biotite Granite

(DC324) Coarse porphyritic Biotite Older Granite. The two specimens were collected from near the compound of Tseiho in the NE margin of the Tyoban-Tsekwen Hill Granite. The coarse porphyritic variety appears to gradually merge with the medium grained equigranular variety.

14 & 15 (DC326 & 327)

Coarse-Porphyritic Biotite Granite from the Tsejande Hill (Locality 90) Older Coarse Porphyritic Granite body.

16. (DC175) Med-coarse Biotite-Granite Gneiss from Arufu Gneiss inlier, 2km NNE of Arufu.

17. (DC418 (Loc. 290)

Medium-Coarse Equigranular Biotite Older Granite from the Akijo Older Granite inlier on the left bank of S-N flowing R. Fofi on the slopes of the Juwudu Hills about 4km SW of Akwana and 1 km north of Akijo compound.

18. (DC376) Coarse-grained Hornblende-Biotite Granite, collected from an outcrop of the Pan African Older Granite (around Ngibo Village) which forms the SE. Margin of the Middle Benue Trough at KM. 16 along Katsina-Ala-Wukari tarred road.

Table 2.6B shows that the average mafic content of the granitic gneisses analysed in the study area is 16,8% by volume while the range is between 10% and 27%. The mafic mineral is predominantly biotite. Biotite occurs as fine and medium-grained crystals usually aggregated into lenticular bodies and parallel flakes. It is pleochroic from pale yellow to medium brown. Inclusions are commonly zircon and apatite in pleochroic haloes.

Minor amounts of green hornblende (1%) are often associated with biotite in the melanocratic bands and lenses and segregation of the lightly migmatised gneiss in the Asanma - Ugoh area. The hornblende in most cases tends partly to enclose the biotite, which implies a later period of crystallisation.

2.2.3 Field Geology and Petrography of the Metasediments

Generally, this group comprises all those rocks seen in the field which present both sedimentary and metamorphic structures such as relict sedimentary layering together with foliation, respectively.

The metasediments encountered in the area investigated include quartzo - feldspathic gneiss and muscovite - biotite gneiss. Mineral assemblages correspond to those of amphibolite facies (Fyfe et al. 1958). Feldspathization of the metasediments is reflected by the presence of late microcline. Only small, isolated outcrops of the relics of the metasediments are found in the study area, the largest being elliptical in outline, exposures are thus rarely more than a few square metres in area. Metamorphism, granitization and potash metasomatism have variably transformed these rocks into micaceous gneisses and quartzo-feldspathic rocks (Carter et al. 1963, Oyawoye 1970, Umeji and Vauchette, 1984).

Descriptions of some of the characteristic metasediments are given below.

Muscovite-Biotite Gneisses:

These are foliated rocks in which parallel mica flakes together with minor amphibole define the foliation. Around Tseagodo on a road-cutting at Km 12 along the Yandev - Katsina - Ala tarred road, these rocks are well developed. They occur near the Older Granite outcrops. In other places they occur as large rafts or Xenoliths and pendants in the Older Granite Series. At the road cutting mentioned above these metasediments are unconformably overlain by the Pre-Asu River Sediments

The contact is marked by severe shearing faulting and folding of both the metasediments and adjacent rock types at the contact.

This muscovite - Biotite gneiss exposure in the Tseagodo area has a dip of foliation of 70 - 80° SE and a strike of foliation of 10° to 25°. In hand specimen it is a strongly foliation medium grained light to dark coloured, partially weathered rock (DC.305), in which subparallel aligned mica flakes and quartzo - feldspathic material define the foliation. In thin section it shows 30% of colourless to palegreen muscovite, about 7% of pale brown - yellow green pleochroic flakes of biotite, 3% of bluish green chlorite. It also consists of both potash feldspar are (orthoclase and microcline) and plagioclase. The major feldspars are oligoclase and andesine. Orthoclase is subsidiary. The feldspars are altered showing granular or thin flakes of sericite. Microcline is of late generation. Both quartz and microcline replace the earlier minerals. The plagioclase has been marginaly invaded by microcline with the development of myrmekite. More intense feldspathization results in the formation of

microcline porphyroblasts. Quartz is strained and is upto 24% according to modal calculation (Table 2.6B).

Quartzo - Feldspathic Gneiss.

Near Tseagoduno compound, about 200m north of the Yatiev Granitic gneiss inlier, there is a low lying outcrop of quartz felspathic micaceous gneiss (DC.318). It is a medium - fine grained, foliated, predominantly leucororatic rock. The light colour is imparted by the present of muscovite, chlorite and sericite. The light colour is punctuated by subparallel alignment of dark coloured minerals, mostly biotite and some hornblende. In some portions there are segregations of light coloured quartzo - feldspathic bands. Foliation is marked by the parallel alignment of the mica and quartzo - feldspathic material. The foliation dips 65° in ESE direction, and has a strike offset by 10%.

Petrographically, this gneiss (DC.218) has a similar mineralogy to that encountered in the Tseagodo area (DC.305). But the quartz is up to 40% while muscovite and biotite are 5.1% and 2.5%, respectively. The mineralogical differences between the original and metasomatic portions of rocks affected by pegmatitic migmatisation is accounted for principally by the presence of microcline in the latter. The specimen (DC.218) also consists of both late microcline porphyblasts and plagioclase. The major feldspars are also oligoclase and andesine. Both late microcline and late quartz replace earlier minerals. The feldspars are greatly altered showing granular or thin flakes of sericite. Quartz is strained. More intense feldspathization has resulted in the formation of microcline porphyroblasts.

Other minerals include brown sphene which is always wedge

shaped, and is found wedging itself into the mafic minerals or dark iron - ores.

2.2.4 The Older Granites

Field geology

In the study area, there are five elliptical bodies of the equiangular older granites, namely, the Tyoban-Tsekwen Granite, the Uamadu River Granite, the Ruwabi Hill Granite, the Udza and Akijo Granite bodies, out of which the first three are the most prominent (Fig.1.8). These will be described in order in which they have been named.

The Tyoban - Tsekwen Granite body forms an ENE trending large block with a horst-like structure, covering a surface area of about 20 square kilometres in the central part of the study area. It rises abruptly above the surrounding Lower Cretaceous terrain, and reaches a peak of 352 metres above sea level around the compound of Tsekwen (Fig. 1.8).

The Uamadu River Equigranular Granite which forms a NE-SW trending elliptical body with area of about 1.5km2 is located about 2km SW of Abeda village. It is separated by a narrow zone of silicification from the Ugoh-Asanma Granitic gneiss inlier.

The Ruwabi Hill Granite is a pear-shaped equigranular granite ridge with a NNE-SSW trend located about 2km north-east of northern flank of the Tyoban-Tsekwen Hill Granite. It has an area of about 2 square kilometres.

The strike of foliation of the Equigranular Older Granite is in general north-south to NNE-SSW with a dip of 70-80°. On the slopes and crest of the steep, rugged hills around Mchia village along

the Ugba - Anyiin untarred road, the granite contains relict of metasediments and zones of pegmatite veins. In this area the foliation has a dip of 70° NW and is similarly expressed by parallel alignment of biotite flakes, elongate quartz and alkali feldspars. These have been drown out into rod-like aggregates which on weathered surfaces produce a fibrous or "Woody" structure.

In the Tseiho, Atongo, Tseaguda areas, the northern and north-eastern marginal facies of Tyoban-Tsekwen Hill Equigranular Granite, gives way to coarse-grained and coarse-porphyritic varieties (DC.323 and 324) and assumes a dark grey colour owing to the increasing content of biotite. The phenocrysts are twinned alkali feldspars ranging in size from 5 centimetres x 3 centimetres to 7 centimetres x 3 centimetres which, together with oriented, elongate quartz crystals, define the foliation, dipping 50 - 55° SE. Around Atongo village this dark-grey porphyritic type (DC.322 and 391) merges with the medium grained equigranular, micaceous, cream-coloured portion (DC.324) with no visible boundary between the two textural types.

The porphyritic phase of the Older Granite forms a NNE-SSW trending ridge near Tsejande village, about 23km southwest of Arufu. This basement inlier covers an area of about 3.5 square kilometres, and stands at an elevation of about 200 metres above the surrounding undulating plain underlain by Lower Cretaceous sediments (Fig. 1.1, back pocket). The Older Granite body consists of medium-coarse grained porphyritic biotite granite. It is weakly foliated (DC,326, 327). The foliation is marked by the preferred alignment of biotite flakes and pink microcline phenocrysts, and has a dip of 45° SE orNW, with a strike of 60°. Two cross-cutting pegmatite veins, one trending 90° and the other N-S, traverse the granite body (DC.412).

The most striking characteristic is the porphyritic texture formed by phenocrysts of perthitic microcline varying in length from 5 to 7 centimetres set in a medium - or coarse grained matrix.

Petrography

The mineralogy of the Equigranular Granites is virtually identical with that of the coarse-porphyritic granites and is described in one section. The main mineralogical constituents are outlined in Table 2.6B.

The Tyoban-Tsekwen Hill Granite, the Ruwabi Hill Granite and the River Uamadu Granite, which comprise the Equigranular granites, have a simple mineralogy.

In thin section, the following minerals occur in the equigranular granite-biotite, muscovite, hornblende, microcline, plagioclase, and quartz. Accessory minerals include sphene, orthite, epidote, clinozoisite, apatite, zircon, fluorite and iron ores. Alteration products include chlorite, muscovite, and iron ore minerals. They vary from leucocratic (DC. 234,235) to melonocratic rocks (DC. 325). The groundmass consists of quartz and microcline and albitic feldspars.

Biotite occurs as tabular plates arranged in small sheaf-like clusters, or as linear aggregates. It is strongly pleochroic from straw yellow or pale brown to dark brown. Occassionally it is pale green in colour. The biotite plates are always ragged and often skeletal as a result of corrosion by later minerals, they are embayed by plagioclase, microcline and quartz and these minerals commonly enciose shreds of biotite. The biotite plates are sometimes bent and twisted. Alteration of biotite to chlorite, muscovite and iron ore is common and tends to take place along the cleavages. As a result of alteration, biotite becomes woody in appearance and chlorite pseudomrphs after biotite

are sometimes present. Biotite is often intergrown with muscovite and hornblende. Pleochroic halos are seen in some crystals. Iron ore, sphene and orthite are enclosed by biotite or are often intimately associated with it.

Primary muscovite is confined to the biotite-muscovite variety of the equigranular-granites (DC.234,235). It occurs as thin tabular, colourless plates which are grouped in clusters or in linear aggregates. In one section, two generations of muscovite, the latter sharply cutting the other, were noted (DC. 235). The secondary muscovite plates are occasionally twisted and bent.

Hornblende is found in the more dark coloured biotite equigranular granites from the River Uamadu granite body (DC.325). It does not occur in the muscovite equigranular granites. In the dark brown biotite granite(DC.325) it was found badly sieved by quartz. It forms strongly pleochroic, pale green to deep green, ragged, prismatic crystals. These are often largely corroded and sometimes only a few, shred-like remnants of the mineral remain. Hornblende encloses iron ore and sphene and is replaced by plagioclase, microcline and quartz. It forms intergrowths with biotite, which appears to grow at the expense of hornblende. In specimens where hornblende is found it is present in minor amounts (DC.234,235,235B).

Microcline occurs at least in two generations in most of the equigranular granites. Early microcline is occasionally seen as semi-digested plates in the plagioclase, late microcline forms plates with ragged, sutured margins which embay the plagioclase and earlier mineral. It is often well twinned showing excellent gridiron twinning with spindle-shaped twin lamellae. In contrast to the

the plagioclase which is usually highly altered, the microcline is invariably fresh and clear. Microperthite is present in over 30% of the microcline. The perthitic albite constitutes a minor fraction of the microcline. The perthites are of the vein-perthite type in which albite appears as subparallel, irregular, thin, thread-like bands.

Microcline disrupts all the earlier minerals including biotite, muscovite, plagioclase and quartz. Patches or blebs of these minerals and sometimes entire euhedral plagioclase crystals are completely enclosed by microcline and occasionally give rise to sieve textures. A thin albite selvage is sometimes developed where plagioclase is replaced by microcline. Microcline plates are occasionally invaded by late quartz.

Plagioclase is invariably oligoclase in composition (An_{20}); albitic oligoclase is present in some specimens. Plagioclase tends to form euhedral crystals in which polysynthetic twinning is well developed. The crystals may be twisted or bent. It is earlier in formation than the bulk of the microcline and encloses blebs of early quartz, shreds of biotite, early microcline and zircon.

Plagioclase is invariablly more or less altered to sericite. Sericitisation commences from the core of the plagioclase, the margins of the crystal after remaining relatively fresh. It is probable that this selective alteration reflects a more calcic core, although zoning of the plagioclase is rarely apparent. Myrmekite and myrmekitic quartz blebs frequently occur in plagioclase. Other textural features include graphic and micrographic intergrowths of quartz and feldspars.

Quartz occurs in vein-like patches and as large plates whose

margins are irregular and often intricately frilled. It almost always shows strained (undulose) extinction. Parallel streams of minute dusty inclusions are sometimes found within the crystals. Two generations can be observed in most sections. Early quartz is represented by blebs enclosed in microcline or plagioclase; late quartz smoothly embays plagioclase and in some specimens is seen to truncate the late microcline. The myrmekitic quartz lies in the plagioclase and usually occurs close to a plagioclase - microcline crystal boundary. Its formation appears to be related to the replacement of plagioclase by microcline. The plagioclase undergoes a series of change as myrmekitization proceeds. Initially, a few quartz vermicules appear in well-twinned, fresh plagioclase. As myrmekitization becomes more intense the plagioclase is not almost completely enclosed by microcline.

Accessory minerals found in both equigranular and coarse-porphyritic granites include wedge-shaped and granular sphene. It is usually pale brown, sometimes faintly pleochroic and may show polysynthetic twinning. Sphene is intimately associated with biotite and iron-ore minerals and often occurs as rims of the latter. Skeletal crystals of sphene, corroded and truncated by late microcline, may be present.

Subhedral and anhedral crystals of orthite are found in many of the equigranular granites. The orthite is faintly pleochroic from pale brown to honey brown and is usually much altered. It may show simple twinning and zoning and sometimes surrounded by expansion cracks. Epidote is found in small amounts in a number of the granites. It commonly consists of granular aggregates though occasionally euhedrah crystals are present. It appears as an

alteration product of the plagioclase in some rocks. Clinozoisite is sometimes associated with epidote.

Iron ores, apatite, and zircon are present in most sections. Zircon is always invariably present accompanying the micas as halos and found in the ground as colourless grains with high relief.

General alterations of the feldspars are very common. These show clouds of alteration and some show flakes of alteration products - sericite and white mica - which are particularly well developed in altered plagioclase; chlorite forms at the expense of biotite. Calcite may be present as interstitial plates and late veinlets which cut off all the earlier minerals.

The mineralogical composition of many of the coarse porphyritic granites is of the granodiorite range (DC.322). Granodiorite is occasionally present as a marginal facies. Biotite and, of lesser importance, hornblende comprises the ferromagnesian minerals (Table 2.6B); the coarse porphyritic granites are poor in minor felsic bodies such as pegmatite, splite and quartz veins. Pegmatite takes the form of irregular, quartz - feldspar bodies, a few metres in length and a few centimetres wide in the Tyoban granite quarry. Occasionally pegmatite with subordinate magnetite forms concentrations along the granite contacts in the Tsejande area. Muscovite (which is present in many metasomatic granites) does not occur in the coarse porphyritic granite of the area mapped; the coarse porphyritic granites are rich in accessory minerals with iron ore minerals, sphene, orthite, and apatite often prominent.

The phenocrysts in coarse porphyritic granites are invariably microcline with strong to weak perthitic intergrowth. Inclusions of the

groundmass minerals are common. The outlines of the feldspars which appear in hand specimen to be nearly euhedral are irregular, characterised by tongues with the embayment of surrounding minerals. Myrmekitic fringes invariably borders plagioclase feldspars. As in the equigranular granites the plagioclase grains like the microcline phenocrysts and porphyroblasts, show the effects of strain, through wavy extinction, bent twin lamellae; and irregular zoning (DC.326,327).

Because of the large size of the microcline phenocrysts and porphyroblasts, modal compositions of granite are difficult to determine.

2.2.3 Pegmatitic, Quartzo-Feldspathic - Quartz Veins and Dykes

Pegmatitic and quartz-feldspathic veins and dykes composed of microcline and quartz occur in the basement rocks of the area mapped. They are frequently found associated with granitic gneiss, the slightly migmatised gneissose granites and the Older Granites. Pegmatites are however, conspicuously absent from the areas of metasediments (muscovite-biotite gneisses), except, perhaps, at the margins of these rock bodies. The pegmatites in the gneisses are both conformable and cross-cutting, but those associated with the Older Granite are invariably cross-cutting. They vary in size from veinlets only a few millimetres wide to 30 centimetres. Most of the pegmatite veins and dykes are the simple type with central quartz bounded by feldspar.

A semiconformable pegmatite vein about 30 centimetres wide, made up of quartz and feldspar crystals, traverses the Yatiev Granite gneiss. The vein trends in the direction of 175° while the strike of foliation of the host rock is 165°. The pinkish (microcline) crystals

measure 4 centimetres x 20 centimetres in size and have their long axes rotated perpendicular to the strike of the host rock, thus indicating an overprint of shearing in the rock. The contact between the pegmatite and the host rock is sharp.

The Tsejande Hill Coarse Porphyritic Older Granite (DC.412) is cut by two sets of pegmatite veins about 18 centimetres and 3.5 centimetres wide respectively, and also trend E-W trending vein truncates and offsets the N-S set for a distance of 3 to 10 centimetres laterally, and is thus younger. These pegmatites are composed of central quartz bounded by large pink feldspar specimen and are typically coarse. In the field and in hand specimen the pegmatite veins show sharp contacts with the host rocks but under the microscope appear to show transitional contacts.

Cross-cutting sets of pegmatite veins also occur in the Tyoban Equigranular Older Granite quarry about 8 kilometres south-west of Arufu village. In places pure quartz veins cut across the quarry faces. Feldspars are absent in these pure quartz aggregates that are intensely brecciated, and in places slickensided. This implies tensional and shearing phenomena respectively (Badgley 1975) in the rock.

In the Tseagodo area brecciated quartz veins lie conformably along the foliation plane of the host micaceous gneiss (DC.305) which make up the metasediments of the area.

The pegmatite veins associated with the Uamadu Older Granite Inlier are structureless and discordant with respect to the host rock.

2.3 Structural Features of the Basement

2.3.1 Foliation

In the present study the foliation is indicated in the rocks by the parallel alignment of mica and quartzo-feldspathic material on the outcrops. It is observed that the foliation defined also helps to delineate the pattern of small scale folding.

Over the Tseagodo, Yatiev and Igbur-Arufu areas, the strike fo foliation of the metasediments and the granitic gneisses is roughly in the NNE-SSW direction, whereas in the Tyoban-Tsekwen Hill, River Ruwabi, Abeda-Ugoh, River Uamadu and Tsejande Hill areas underlain by the Older Granite Series, the dominant foliation is N-S.

The Muscovite-Biotite Gneisses in the Tseagodo area have a dip of foliation of 70 - 80° NE or SW amd a strike of foliation of 42° to 135° (NE-SW to NW-SE). In the Yatiev area the metasediment consisting of a quartzo-feldspathic micaceous gneiss has a foliation marked by parallel alignment of mica and quartzo-feldspathic material dipping 65°E with a strike of 175°. The northern portion of the Arufu Granitic Gneiss has a dip of foliation of 45° - 50° NW whereas the southern portion dips 40 - 50° SE thus presenting a sort of anticlinal or horst-like structure.

The Igbur granite gneiss located about 10 kilometres east of Arufu, is weakly foliated. The foliation strikes 086° and dips 65° SE. Near its contact with the silicified (cherty) siltstone belonging to basal units of the Albian Asu River Group the granitic gneiss becomes strongly sheared with a textural gradation from coarse to medium to fine grain (DC.199) with schistose contorted appearance. The strike of foliation changes to 20° with a dip of 68° - 75° SE. In the Yatiev Granitic gneiss inlier, muscovite and biotite flakes, and some quartzo-feldspathic material with cream oligoclase and pink microcline, are elongated parallel and define the foliation

dipping 50° SW or NW and striking 120°.

In the granite gneiss in the Ugoh-Asanma area, about 4 kilometres west of Abeda, the foliation has a strike of 045° with a dip of 55°. Xenoliths and rafts of the metasediments are oriented parallel to the foliation. Around Asanma Compound the strike is 145°. .

Both the Equigranular and Coarse-porphyritic Older granites in the Tyoban-Tsekwen, River Uamadu, Udza-Akijo, Ruwabi Hill and Tsejande areas, have consistent N-S or NNE trending foliation with dips of 50° to 60° NW or SE.

2.3.2 Folding

Near its contact with the basal cretaceous sediments the Tseagodo muscovite - biotite gneiss is flexured into small (minor) isolinal folds. These minor folds have axes running in NW or N-S direction. The plunge is to the north and rarely exceeds 15° - 20°. Similar minor folds are found in the quartzo-feldspathic micaceous gneiss in the Yatiev area.

The Arufu and Igbur granitic inliers are folded with the anticlinal axes running in NNE-SSW direction. In the Asanma-Ugoh area, to the west of Abeda, observations in the slightly migmatised gneissose granite show the refolding of earlier E-W trending folds by later NNE-SSW trending minor folds.

The few dips of foliation recorded from the fairly large Tyoban-Tsekwen Hill equigranular granite and the Tsejande Hill coarse-porphyritic granite, indicate that these Older Granite bodies have been locally flexured into open symmetrical folds with NNE-S SW or N-S trending axes. These are thought to have imposed stresses that affected the rocks during the later part of the Pan African Orogeny.

2.4 Summary

The essential geological features of the study area consists of down-faulted blocks of Pre-Cambrian crystalline basement, represented by the remnants of an ancient metasedimentary series (muscovite biotite gneiss and quartzo-feldspathic gneiss), granitic gneiss and the Older Granite series (consisting of equigranular granites and coarse-porphyritic granite), on which unconformably rest sedimentary and volcanic rocks ranging in age from Lower Cretaceous to Tertiary.

The oldest rocks in the region are remnants of an ancient sedimentary series probably of Middle Pre-Cambrian age. sedimentation, igneous activity and regional metamorphism were followed by other orogenic cycles which transformed them into granitic gneisses and metasediments in the Arufu, Igbur, Yatiev and Tseagodo areas. Other cycles include the Pan African Orogeny (600 ± 150 m.y i.e. of Upper Pre-Cambrian to Lower Palaeozoic age) during which the diverse and widely scattered K-feldspar rich Older Granites were emplaced in the Tyoban-Tsekwen, Tsejande and Udza-Akijo areas.

The Basement Complex rocks form inliers and ridges aligned parallel to the axial trend of the Middle Benue Trough.

The basement rocks form about 7 percent of the area mapped. The Older Granite Series is the dominant rock unit by areal extent topography.

In the study area the strike of foliation of the metasediments and the granitic gneisses is roughly in the NNE-SSW direction, while the dominant foliation in the Older Granite Series is N-S.

Granitization and waves of potassic metasomatism (Oyewoye 1970) during the Pan-African Orogeny profoundly modified the earlier rocks. The close of the orogeny was marked by the intrusion of granitic dykes, pegmatite dykes and quartz veins into the older rocks. Thus there appears to be reasonable Pan-African orogenic imprint upon the basement granitic gneisses and metasediments of the study area.

Detailed chemical analyses (Table 2.6A) during the present study show that the outcrops of the granitic gneiss (DC.320) at the margin of the Ugoh-Asanma basement horst have a high content of silica (62% weight oxide), low iron content (1.39% expressed as $Fe_2^0{}_3$), low Ti0, (0.19% weight oxide), and also high potash (5.23% K_20) and side contents compared with sample DC 317 collected from the crestal area of the same structure.

Grant (1971a), Burke and Whiteman (1973), have noted that the close of the Pan-African Orogeny in Nigeria was generally marked by the intrusion of pegmatite dykes, sills and veins, including quartzo-feldspathic veins and pure quartz veins. Carter et al. (1963) envisaged three different stages of granitic magma injection into the host rocks of the Upper Benue Trough namely: (1) The Pre-Older granitic material period of emplacement probably during the Eburnean Orogeny (cf. McCurry 1976). (2) The injection of the syntectonic Older Granite Series. (3) The post-tectonic injection of quartz-pink microcline and grey feldspar pegmatitic veins and quartz veins (cf. Grant 1971a and b, Burke and Whiteman 1973).

The origin of the vein quartz so common in the Basement Complex of the study area is probably due to the migration of silica during the tectonism where shearing provided access to the migrating solution.

CHAPTER 3

CRETACEOUS SEDIMENTS

3.1 Introduction

The sedimentary geology of the region mapped is determined mainly by five sedimentary formations /units (Table 3.1). The first Albian transgression (responsible for the deposition of the Asu River Group of sediments) appears to have been preceded by the deposition of the Pre-Asu River Sediments consisting of unfossiliferous grits, sandstones and clays in the Yatiev, Tseaguda, Atongo, Atongo, Tsejande and Arufu areas, during rift-faulting as exemplified by the Tseagu Hill Alkaline Rhyolite of Aptian age 113 ± m.y.(Umeji and Vachette 1983). The Asu River Group of formations occupy the crest of a major anticlinal structure - the Arufu anticline - which is flanked on either side by the Keana Formation of Cenomanian age and the Eze-Aku Formation representing the Late Cenomanian to Early Turonian marine transgression.

3.2 The Pre-Asu River Sediments

Several workers have recognised the usually thin unfossiliferous or poorly fossiliferous continental sandstones and clays found at the base of the Cretaceous stratigraphic succession of the Benue Valley as well as the SE Nigerian sedimentary.

In the study area the Pre-Asu Sediments occur at the following localities:-

(1) About 2 kilometres NNE of Arufu village where they are highly lateritized and silicified (DC.288A, B,C.) and rest unconformably on the Pre-Cambrian granitic gneiss inlier (the Arufu Inlier) and are themselves overlain by shelly

TABLE 3.1 SUMMARY OF CRETACEOUS STRATIGRAPHIC SUCCESSION IN AKWANA SHEET 252 AREA AND ENVIRONS

	POST CRETACEOUS TERTARY		Cenozoic Volcanics 44 - 56 m.y.(Okeke 1980)	
CRETACEOUS	UPPER	Early Turonian	Akahana Shale - Limestone Unit	EZE-AKU FORMATION
		Late Cenomanian	Tsekur Sandstone-Shale Sequence Keana Formation	
		Early Cenomanian	Awe Formation Micaceous, tabular Sandstone-shale beds with inter-bedded volcanic lava and intruded by basic (Dolerite) rocks of age c. 100 m.y. Hurley (1968)	ASU RIVER GROUP GALENA-FLUORITE MINERALIZATION
	LOWER	Upper Albian Middle Albian	Uomba Formation (Arufu Limestone-shale-siltstone sequences)	
		Aptian Barremian	Unfossiliferrous continental coarse to conglomeratic sandstone and clays, in Yatiev, Tseagu, Tseagodo, areas with Rhyolite sill (113 ± 3m.y. at Tseagu.	PRE-ASU RIVER SEDIMENTS
		Lower Palaezoic to Upper Precambrian	Pan African Older Granite	
		Upper to Middle Pre-Cambrian	Biotite Gneiss and Granitic Gneiss	

Albian limestones.. The Albian limestones mark the first Albian marine invasion. The Pre-Asu River sandstone in this area is only about 50 metres thick.

2. In the Yatiev area (about 16 kilometres NE of Ugba village in the SE quarter of the sheet), the 85 metres thick Pre-Asu River Sandstone beds unconformably overlie the Precambrian muscovite-biotite gneiss (DC.216) and metasediments (DC.218), which constitute the Yatiev Inlier. The basal sandstone beds (DC.221) with associated saline spring are overlain by Albian fossiliferous marls, impure limestones and black shales.
3. The Tseaguda-Atongo area bordering the NE and SE flanks of the Tyoban-Tsekwen Older Granite Inlier.
4. In the Tsejande-Tongo area, where unfossiliferous, angular, feldspathic, poorly sorted, cross-bedded yellow-brown sandstone (DC.319B) directly overlies the basement Older Granite inlier (the Tsejande Older Porphyritic Granite).

In the study area the Pre-Asu River Sediments consist of strongly cross-bedded micaceous, non-calcareous thick bedded - massive felspathic (arkosic) sandstone (Table 3.2), poorly sorted silty dark grey, green, yellow siltstones, in places carbonaceous, pebble, gritty with subsidiary conglometrate. The beds show evidence of rapidly alternating vertical and lateral (cyclic) facies changes and a graded bedding feature probably marking seasonal changes in fluvial deposition.

The sandstones are of varied sizes (fine-medium to very coarse) angular, gritty and poorly sorted. The angular quartz pebbles (extrabasinal clasts?) are milky white to colourless and occasionally

smoky. Some laminated sandstones incorporate angular clay-stone pellets or fragments (intrabasinal clasts?). Some are finely colour banded (greenish, grey, white, yellow-brown, reddish, pinkish, purple).

Thin section study shows that the sandstones are generally made up of massive quartz. The quartz grains may be clear or slightly stippled with inclusions and are angular to subangular. The feldspars are mainly microcline and plagioclase and are present in small amounts. The sandstone matrix is chiefly siliceous, argiliaceous and sometimes carbonaceous. The angular quartz grains occur together with unaltered feldspars, and sometimes the crystals interlock with each other. The specimens (DC.227 and 294), contain 28% and 24% angular clastic grains of slightly altered orthoclase, and 10%, 7%, respectively of angular clastic plagioclase, mostly of albite composition. Angular fragments of granitic and gneissic rocks constitute 2% of each of the above two specimens. Places of mica (both biotite and muscovite) are also present.

Iron oxides (mostly hematite) occur as cement. Other accessory minerals include rutile and monazite.

In thin section, the claystones and siltstones (DC. 261, 321H, Table 3.3) consists of layered minerals in which muscovite is the most abundant. Quartz and feldspar make up the silt-minerals found within a sericite matrix.

Diagenetic and silicified zones are common in the sequence at Arufu and Yatiev where most of the quartz have been recrystallised and/or altered though their grains appear to have retained their original silt-size (DC,288A - D, 217, 222).

TABLE 3.2 LITHOLOGICAL UNITS FROM PENDA TO AMAFU IN SE MARGIN OF MIDDLE BENUE TROUGH (SEE FIG. 1.5)

Middle Albian Uomba Formation	Shale: Silty-sandy, olive grey-greenish, black, pyrite, poorly laminated. Marl - Impure Limestone: Grey, thick bedded with Albian inoceramids eg. Inoceramus Cripsi Mantell Siltstone-fine sandstone Greyish white, calcarecous Micaceous, thick bedded-Massive. Sandstone: Fine-medium-coarse grained and conglomeratic ferrugineous at base.
Pre-Asu River Sediments Pre-Aptian	Sandstone: Yellow-brown-red, cross redded, brown carboneous material. Sandstone: Arkosic-felspathic fine-med-coarse conglomeratic strongly cross bedded Claystone: Pink-purple, micaceous, silty. Sandstone: Clayey, fine-med-coarse, feldspathic angular purple coloured felspar fragments. Clayey Siltstone: Grey-green-purple, unbedded, thin, micaceous (DC. 227). Sandstone: Feldspathic, conglomeratic: Thick bedded-massive, cross bedded, arkosic.
Upper Pre-Cambrian to Lower Palaeozoic Basement Complex	Coarse - Porphyritic Biotite granite with vein quartz.

3.2.3 Depositional Conditions of the Pre-Asu River Sediments

There are geological, chemical and post depositional features which suggest depositional conditions of the Pre-Asu River sediments. For clarity these lines of evidence will be described in sequence. The presence of ubiquitous cross-bedding, angular quartz pebbles (extrabasinal clasts) associated with angular clay pellets (intrabasinal clasts - DC. 261B) and the presence of intraformational conglomerates - brecciatic sandstones and grus constitute the geological evidence that the Pre-Asu River sediments were in general deposited in high energy, fluvial - lacustrine environment. The ferruginisation observed is probably a syndepositional feature arising from the strong oxidising tendency that seems to have persisted in the continental high energy conditions that prevailed. These conditions may have persisted and iron-enrichment continued. The basal sandstones and clays might have been little exposed to this environment and they are therefore less affected by ferruginisation.

The variations and decreasing thickness of the type sections from SW and south through the central area, to the north and NE, may be partly due to the irregular relief of the crystalline floor in which the sediments accumulated and partly to the differing degrees of accommodation in the basin of deposition. Arkosic sediments were constantly forming along the margins of the basins. The colour of the sediments varies from brown and yellow to green and white. This shows oxidation and reduction phases in the sedimentary sequence.

The fossiliferous (Albian) limestone, marly and shaly beds that overlie the top of the sections at (i) Yatiev - River Logo type section

TABLE 3.3

CHEMISTRY AND MINERALOGY OF SILICEOUS SEDIMENTARY ROCKS

Note: Major Elements in pecentages; Minor Elements in parts Per million (PPM). - = Not detected. T = Trace, Minerals in percentages estimated from thin and polished sections;

Rock Unit Sample No. Serial No.	DC263B 1	DC288B 2	DC204 3	DC152 4	DC176 5	DC158 6	DC177B 7	DC264B 8	DC203 9	DC168 10	DC297 11	DC265B 12	DC265B 13	DC167 14	DC261D 15	DC321H 16
SiO_2	80.7	80.8	80.3	70.9	60.4	62.0	70.3	70.0	64.0	80.8	77.6	75.1	80.1	80.0	70.9	70.4
Al_2O_3	4.9	1.1	3.9	2.6	1009	6.6	7.4	10.4	9.1	10.2	1.6	1.1	2.7	2.5	3.2	11.32
Fe_2O_3	0.6	2.0	2.9	5.3	4.6	6.0	1.85	1.5	8.1	0.6	1.9	3.0	3.0	1.3	1.6	1.0
FeO	11.0	9.01	7.70	8.1	8.1	21.12	7.07	4.5	14.0	3.03	10.7	11.9	8.01	7.0	5.0	4.03
MgO	0.4	0.1	0.4	0.2	5.3	2.0	2.0	0.1	4.1	1.1	0.3	0.1	0.1	0.3	10.28	6.41
CaO	0.04	0.04	0.14	0.03	4.7	0.04	5.04	0.05	0.11	0.07	0. 5	2.04	0.04	0.03	0.54	0.08
Na_2O	0.05	0.05	0.04	0.05	1.6	0.05	0.05	0.04	1.20	0.18	0.05	0.05	0.05	0.05	0.02	0.10
K_2O	1.4	7.20	0.8	6.1	2.9	0.20	5.30	0.20	2.21	3.2	0.60	0.20	0.05	6.70	0.02	0.10
TiO_2	0.24	0.03	0.12	1.12	0.56	0.12	0.44	0.05	0.12	0.48	0.08	0.03	0.10	0.09	0.10	1.10
P_2O_5	0.10	0.03	0.27	0.07	0.09	0.09	0.19	0.06	0.06	0.09	0.61	0.03	0.03	0.01	0.66	0.52
S	0.30	0.4	2.5	5.8	0.77	1.7	0.04	13.0	1.2	0.22	6.4	10.40	16.90	2.10	8.9	2.3
TOTAL	99.73	99.75	100.07	100.17	99.93	99.92	99.68	99.90	100.19	99.97	99.89	99.95	100.08	100.06	100.02	100.08
Pb	150	120	210	250	155	346	300	3.500	350	350	6209	7600	1220	650	50	65
Zn	100	50	100	110	90	328	250	580	246	125	630	500	450	130	40	70
Ni	30	20	75	40	20	64.8	150	31.2	608	15	35	20	60	35	60	60
Mn	75	15	25	75	695	210	180	10	400	15	15	15	10	56	75	5
V	90	10	10	30	90	40	70	10	30	10	50	30	10	60	70	70
U	2	279	0.5	1.5	1.5	2	285.7	0.5	2	0.5	3	3	3	395	5	11
Li	5	2.5	10	305	25	20	20	2.5	10	15	5	3	4	2.5	3.5	3
Ba	200	50	100	60	700	200	800	150	100	200	200	150	50	110	190	260
Sr	5	3	15	2.5	415	40	513.5	2.5	5	5	3	3	2.4	3	30	20
Rb	65	10	35	35	150	15	145	10.0	10	128	16	10	3	25	2	3
B	Nd	-	50	15	85	-	-	-	5	-	-	-	10	-	5	10
Ga	5	-	3	1	-	-	-	-	4	-	20	-	1	-	12	13
Ag	2	10	4	1	2	2.6	2	38.4	3	2	13	9	13	3	3	5
Co	20	25	40	15	60	80	152	40	57	22	40	25	70	30	75	55
As	109	99	150	100	60	-	100	-	60	20	50	100	95	60	105	-
Quartz	80	71	70.0	71.6	60	40	60	69.8	60	65	75	79	77	85	60	57
K-feldspar	5	8	-	-	5	4	5	200	-	-	1	-	3	-	-	10
Plagioclase	-	2	-	-	5	-	2	1.0	-	5	1	-	1	1	7	1
Mica	14.7	4	10	7	15	2	3	3.0	2	22	5	4	3	6	25	23
Chlorite	T	10	10	2	15	10.9	20	-	10	2	-	-	-	1.2	2	2
Calcite	-	-	-	T	-	-	-	-	-	-	-	-	-	T	-	-
Pyrite	T	-	-	1	T	3	-	21	2	-	2	10	T	T	-	-
Magnetite	-	-	2	1	-	20	-	-	13	-	3	-	-	0.5	1.5	3
Hematite	T	5	7.8	8	-	20	T	2	1	10	2	5	2	2	3	2
Fourmaline	T	-	T	T	T	T	-	-	T	-	-	-	T	T	-	-
Zircon	T	-	T	-	-	-	-	-	-	-	-	-	-	-	-	-
Rutile	T	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Galena	-	-	-	-	-	-	-	2	-	*	3	8	T	T	-	-
Fluorite	-	-	-	2	-	-	-	4	-	-	-	5	T	-	-	-
Kaolinite	-	-	-	-	-	-	-	-	-	-	T	-	T	T	1	-
TOTAL	99.7	100	99.8	99.6	100	99.9	100	99.8	99.59	100	100	100	100	99.7	99.5	99

KEY TO TABLE 3.3 (SEE FIG. 5.56 FOR SAMPLE LOCALITIES

1. DC. 263: Siliceous cherty siltstone. From crest of N-S trending ridge, 400 metres north of Arufu Village. Locality 6.

2. DC.288B: Silicified brecciatic siltstone. From Basal Cretaceous Beds near contact with Basement Complex Granitic Gneiss (Arufu Gneiss Inlier) 0.2 kilometres NNE of Arufu village.

3. DC. 204: Pinkish and black disgenetically? Altared, recrystallized silicified (Cherty) siltstone from NW-SE trending ridge, about 2 kilometres NW of Anylin.

4. DC.152: Barren fractures silicified (cherty) feldspathized siltstone and medium-fine sandstone wellrock in N-S trending ridge contact with and/or truncated by E.W. trending ridge underlain by brecciated limestone mineralize with massive vein galena at 1.0 metre north of Arufu village.

5. DC.176: Veined Dolomitic Siltstone. Collected from N-S trending fracture zone ridge 1.7 kilometres north of Arufu village. Locality 6.

6. DC. 158: Mematite-Magnetite-quartz-chlorite siliceous (cherty) rock collected from one of the NNW-SSE or NE-SW trending on echelon fracture zone ridges, around, Towari (Ijoho) Compound, about 7 kilometres ENE of Arufu village. Locality 33.

7. DC.177B: Reconstituted quartz-chlorite-mica-siliceous rock, collected from a N-S trending ridge at a point 1.74 kilometres north of Arufu village. Locality 6.

8. DC.264B: Black quartz-pyrite silicified siltstone. From old mine trench dug along E-W trending fracture zone ridge underlain by silicified Albian limestone (and interbedded with siltstone) in places mineralized with Galena and Fluorite. Locality 2.

9. DC. 203: Quartz-magnetite-chlorite (silicified sandstone) rocks, from a NW-SE ttrending (en echelon fracture zone) ridge across the Arufu-Akwana tarred road, about 21/2 kilometres NW of Anyiin. Locality 11.

10. DC.168: Brecciated, recrystallized silicified siltstone from NW-SE trending ridge 0.5 kilimetre west of Arufu along tarred road to Akwana. Locality 8. NB. Wood material and fossil fragment in DC.169. Locality 8.

11. DC. 297: Veined and breccciated siliceous, ferrugineous siltstone, black dark brown massive, mineralized with disseminated galena, from an old miner trench dug along bed of a fracture-controlled tributary streams of River Gishiri about 11/4 kilometres NW of Arufu village. Locality 26.

12. DC. 267B: Black, massive silicified brecciated siltstone mineralized with fluorite and disseminated galena. From old mine Trench dug along E-W trending ridge, 200 metres north or Arufu village. Locality 2.

13. DC. 265D: Black silicified siltstone veined by quartz and pyrite. From same locality 2 as DC 265B above serial No.12.

14. DC. 167: Siliceous siltstone from a NW-SE trending ridge on right hand side of Arufu-Akwana tarred road, 2 kilometres NW Anyiin. Locality 8.

15. DC. 261D: Greenish grey clayey micaceous siltstone veined by quartz. From the basal bed of the Pre-Asu River Formation exposed at a road cutting at 12 kilometres along Yandev-Katsina Ala tarred road.

16. DC.321H Yellow-greenish micaceous kaolinized claystone of the Pre-Asu River Formation intruded by rhyolite sill exposed at a road cutting at Tseagu Hill, kilometre 77 along Makurdi - Yandev road, near boundary with the Precambrian Basement Complex Older Granite rocks.

(DC.214) and (ii) Arufu section DC.283, and 284) of the Pre-Asu River beds, are believed to represent the marginal deposits of an Albian marine invasion.

The measurements of cross-stratification azimuths yield 230° and 80° (southeasterly and easterly) indicating that the directions of transportation were SW-NE and E-W.

Davy et al (1978) have used the Boron-Gallium-Rubidium diagram (B-Ga-Rb) in their sedimentological and stratigraphical studies to relate depositional conditions. Using these diagrams (Fig.3.8) the micaceous samples (DC. 288A - B, DC. 260B, 227A and 261D) in Table 3.3 typical of the Pre-Asu River Sediments plot in the fresh water field.

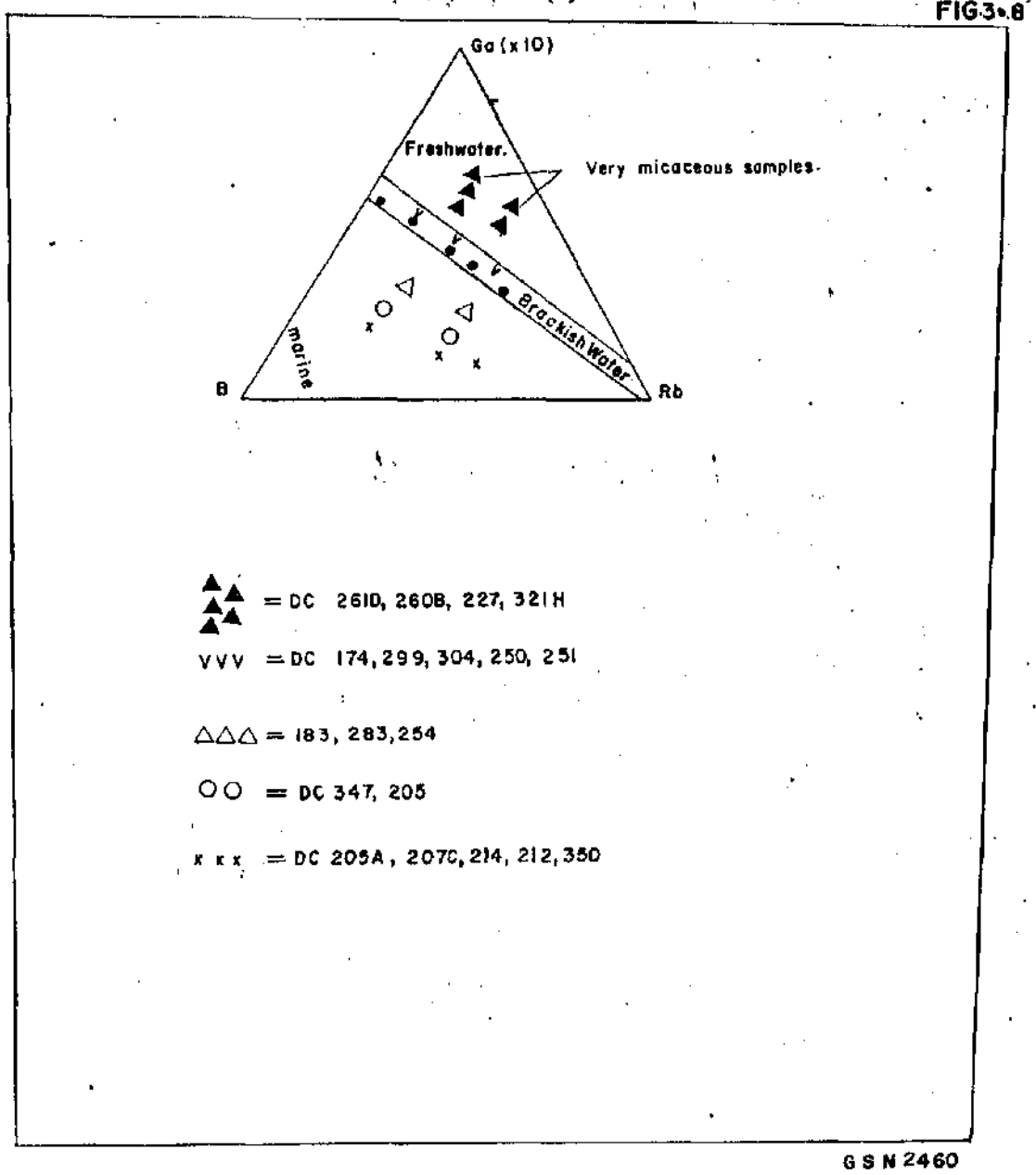
In the Yatiev-River Logo-Penda area or in the Nenger-Penda area (Table 3.2) the limestone-black shale-siltstone sequence (DC.212, 214; Fig. 3.8) plots as marine, as well as all of the silicified Albian limestones and siltstones that are mineralized with shiny speck and fibrous stringer galena (DC. 279, 350; Fig. 3.8) or the other types of galena. In the Yatiev-River Logo-Penda area or in the Nenger-Penda area, the Albian limestone-black shale-siltstone sequence overlies the Pre-Asu River Continental Sediments .

The B-Ga-Rb diagram is based on the geochemical behaviours of the three elements during sedimentation. Boron is enriched in argillaceous marine sediments, rubidium is enriched in sediments formed under brackish water conditions, while gallium proxies for argillaceous sediments formed under freshwater conditions (Rankama and Shama 1949).

Post depositional changes in the Pre-Asu River sediments at Arufu and Yatiev appear to be due to (a) Diagenesis on compaction

B–RB–GA DIAGRAM FOR SOME ROCKS FROM AKWANA STANDARD SHEET 252.

FIG 3.8



GSN 2460

and involved recrystallization of clays, microfaulting, and linear siliceous structures whose origin is attributed to diagenetic volume growth processes during diagenesis of the siliceous sediments (Steninitiz 1981) as previously described. (b) Silicification. (c) Tectonic deformation and facies changes, similar to that in the Lower Cretaceous continental sequence of the Upper Benue Valley which Allix and Popoff (1983) regard as corresponding to the "architectural change" in the basin due to the tectonic reactivation which seems to be directly connected with the evolution of the continental margin during the opening of the South Atlantic in the Gulf of Guinea region.

In the Tseagodo-Tseagu area post depositional changes includes partial resorption (pressure solution) of clasts by carbonaceous-siliceous ferruginesaous matrix, the development of authigenic tourmaline and the alteration on recrystallization of mica. In the zone of intense deformation at the Tseagodo Hill, incipient pink cleavage has developed and zones of pinkish white quartzo-feldspathic material have suffered marginal granulation. It is not clearly known whether the development of Kaolinitic zones on the siltstone-claystone beds at the Tseagu Hill section can be attributed to the alkaline rhyolite intrusion, or to near surface weathering (D C. 321H).

3.2.4 Palaeontology and Age

Apart from scanty dark-brown-dark green fossil (carbonaceous) wood of plant remains (DC. 221, 288B, 260B and 261C) found in the basal units between their contacts with the basement rocks at Arufu, Yatiev and Tseagodo areas, the Pre-Asu River sediments have not yielded any fossil material. Its age is therefore uncertain, and as the bottom and top of the formation appear to be cyclically dichronous,

the age may vary throughout the area.

However, since the sandstone-clay units in the Tseagu area are intruded by a rhyolite sill modelled by a K-Ar radiometric age of 113 ± 3 m.y i.e. Aptian (Umeji 1982, Pers. Comm.) there is some reason to believe that it ranges from Pre-Aptian to Barremian. The first marine deposits overlying the Pre-Asu River beds at Yatiev and Arufu areas contain Albian ammonites eg. Nysteroceras binum sowerby (DC. 284) and Elobiceras and bivalves (eg. Innoceramus Cripsi mantoll) respectively.

Falconer (1911) collected the Upper Albian ammonite Elobiceras newtoni apart from silicified limestones at Arufu, which underlie Cenomanian to Lower Turonian sediments and overlie the unfossiliferous Pre-Asu River Continental sediments. The implication is that the Albian marine transgression (invasion) therefore advanced at least as far as Arufu (Fig. 3.9).

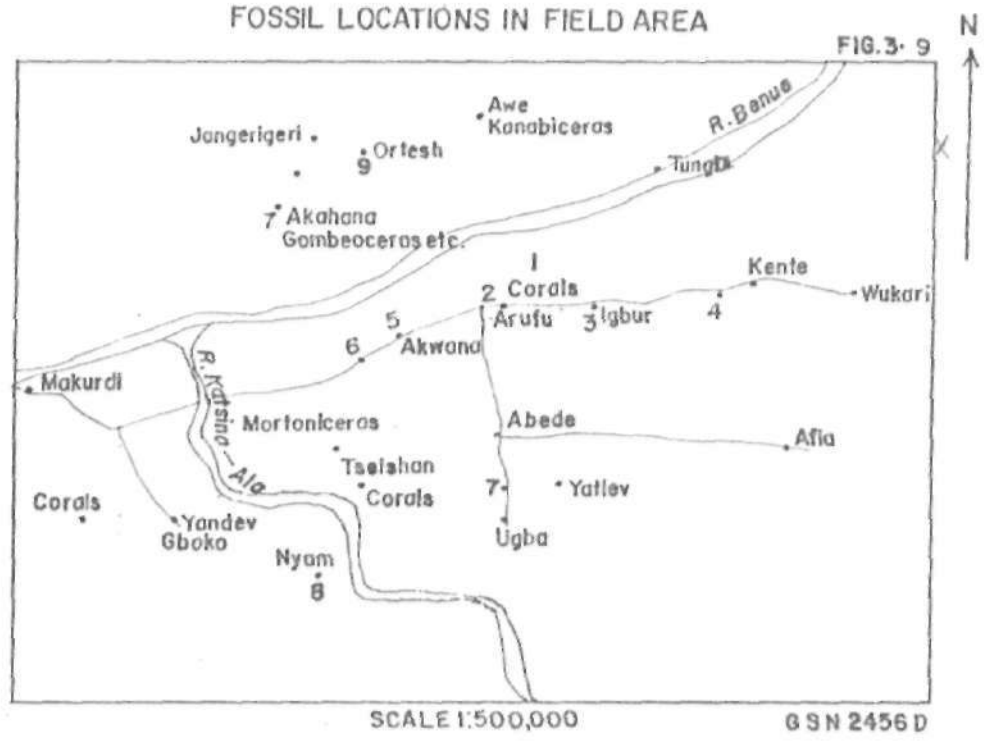
3.3 Asu River Group

3.3.1 Introduction

The Asu River Group (Shell B.P. Geologists 1960) is considered to be the oldest known Nigerian Marine sedimentary group, and had previously been variously described and named by other geologists working in different parts of southeastern Nigeriar. sedimentary basin and the Benue Trough (Bain 1924, Tattam 1944, Simpson 1955). Reyment (1965) examined the type section in the Abakiliki area and found that the sequence thought to be Albian in age, in fact contained (younger) Cenomanian beds.

In the Lafia-Keana-Awe area (Sheets 231 and 232) Offodile (1976) described the Middle Albian fossiliferous olive-green to grey-dark

FOSSIL LOCATIONS IN FIELD AREA



LEGEND on Fossil Assemblage

1(a) Ammonite : Hystoroceras binam Sowerby, Albian (DC 284)
(b) Pelecypod: Inoceramus Forbes L. Cretaceous (DC 283 Q)
(c) Pelecypod : Pholodomya Vignesi Larted U. Albian (DC283W)
2—Ammonite : Elobiceras newtoni Spath, Albian (DC170 B)
3(a) Ammonite : Mortoniceras (Durnovarites) Ishiagnense Reyment Albian
(b) Pelecypod: Neithea tricostata (Coqnand) U. Albian (DC207)
(c) Gastropod. Cinulia (Ringinella) Lachryma L. Cretaceous (DC 207 C)
4—Pelecypod: Pecten quinquecostato Sow Cenomonian (DC253C)
5—Pelecypod: Actinoceramus Sulcatus, Park L. Cret. (DC155)
6—Pelecypod: Pholadomya papyracea Meck & Heyden U. Cretaceous (DC 285)
7—Pelecypod: Inoceramus Cripsi, Mantell M—U. Cret. (DC 214)
8—Ammonite : Elobiceras newtoni Spath Albian (DC 347) In the Finegraind Nyam Limestone·
9—Ammonite Kanabiceras Septemseriatum (Cragin) Late Cenomanian

shales, siltstones, mudstones and subordinate clays , which constitute the Uomba Formation (Reyment 1965), belonging to the beds of the Asu River Group, while the Awe Formation represents the upper sequence of the Asu River Group. In the present area of study the above mentioned two formations of the Asu River Group are also recognized (Tables 3.4 and 3.5).

3.3.2 Uomba Formation

Reyment (1965) first described the type locality of the Uomba Formation at the Uomba River draining parts of former Lafia and Tiv Divisions in the northeastern part of former Benue Province. He described the sediments as consisting of sandstones, shales and sandy shales containing characteristic Albian oxytropidoceratid and diploceratid ammonites.

In the study area the Arufu Limestone-shale (Reyment 1965) correlates with the Uomba Formation. It consists of rocks of Albian age, consisting of Middle Albian shallow marine thick-bedded or shelly limestones with interbedded poorly laminated micaceous, olive-green to black shale, and siltstone-sandstone, mudstone, marked by ammonites, corals, pelecypods, gastropods and micro-fossils (e.g. Ostracodes and foraminifera). In the Arufu-Akwana area (Table 3.4) the outcrops are seen to occupy the Arufu anticline (Fig.1.1 back folder).

About 2.5 kilometres N.E. of Arufu the shelly limestone member grades upwards from boundstone through packstone to grainstone and and directly overlies clayey, medium-grained sandstone which is the topmost bed of the Pre-Asu River sediments. The latter in turn, rests unconformably on the Basement Complex Arufu granitic gneiss inlier. In the Tseishan-Tsejande area these carbonate rocks directly

overlie thick bedded calcarous and micaceous siltstone-sandstone (DC. 319A).

The Uomba Formation in the study area can be divided into eight lithofacies units or beds (Table 3.4). In the lowermost Bed 1 exposed about 2.5 kilometres north east of Arufu the limestone is highly deformed, siliceous shelly, in part oolitic, and contains a large number of articulated and flattened molluscan fossil assemblage, especially ostream pelecypods (DC.283A to Z) with a few Albian Cephalopods notably Hysteroceras binum sowerby (DC.284). and Tobiceras newtoni spath (DC.170; Falconer 1911). The shelly limestone units have been referred to as authochthonous "oyster bank" limestone (Bogue 1952). The interstices between the fossils are filled with linemuds.

The oysterbank limestone (DC.83,283) also contains some Early Cretaceous solitary. Scleractinian depressed corals identified as Stephanosmilia perla de formentel. The limestone specimen DC 183 from the lower beds has 79.9% equivalent $CaCo_3$ and 4.4% equivalent $MgCo_3$ mostly dolomite whereas the grainstone tyre (DC 287) which occurs towards the top of the formation has 85.81% equivalent $CaCo_3$ and 4.37% $MgCo_3$ (see Table 3.7 Appendix A). It also contains micro and macro faunal assemblages.

Using the classification of Dunham (1962) the lower unit limestone appears to start with a sandy lime boundstone (DC.183, 283) and grades upwards into a shallow water partly oolitic lime packstone-grainstone (DC.287). Numerous voids appear to have existed in the oysterbank lime boundstone and packstone - grainstone. But subsequent filling of these voids by calcite (probably during diagenesis) has resulted in a relatively low porosity.

TABLE 3.4

STRATIGRAPHICAL SUCCESSION IN ARUFU-AKWANA AREA
(SEE FIG. 3.21)

AGE	GROUP	FM	UNIT	DESCRIPTION OF LITHOLOGY
Late Albian Early Cen.		Awe Formation		Sandstone: fine grained, tabular and well bedded, interbedded with siltstone Shale: Flagy finely laminated, grey, silty, interbedded with fissile siltstone containg Late Albian - Early Cenomanian pelecypod. Pholadomya Papyracea
ALBIAN	ASU RIVER GROUP	UOMBA FORMATION	Bed 8	Shale: Sandy, poorly laminated, buff, micaeous, grey-green, ferrugineous towards top. Limestone: Fine, pale grey, calcilutic, interbedded with greenish black shale with pyritic nodules.
			Bed 7	Limestone: Sandy, silicified, brecciated mineralized with crystal galena Shale: interbedded with silicified siltstone and poorly bedded fine sandstone.
			Bed 6	Limestone: Calcilutitic interbedded with grey-green-black pyritic shale. Limestone: Fine, grey with Lower Cretaceous incerasid fossile.
			Bed 4	Limestone: Silicified, brecciated (DC.155A-C) selectively mineralized with massive galena and fluorite. Mudstone: Grey-black, pyritic, containing Albian pelecypod Actinoceran Sulcatud park.
			Bed 3	Siltstone: with slump structure, silicified, greyish colour.
			Bed 2	Siltstone: calcareous, yellow-grey, mineralized with galena. Limestone: Sandy, with fragments. Limestone: Shelly, cysterbank, coral-bearing, containg Albian ammonite.
Pre-Aptian		Pre-Asu River Sediments		Sandstone: Fine-medium-coarse, conglomeratic, ark.
UNCONFORMITY				
Pre-Cambrian	Basement Complex			Granite Gneiss of Arufu Inlier

TABLE 3.5 CORRELATION OF STRATIGRAPHIC SEQUENCE WITH PARTS OF THE BENUE TROUGH

AGE M.Y.	STATE	M I D D L E B E N U E T R O U G H			UPPER BENUE BASIN Dadya-Kumanha Nogbe (1981)
		Makurdi Sheet 251	Lafia Sheet 231	Akwana Sheet 252	
	Palaeogene and Younger	Nogbe etal. (1978)	Offodile(1976)	D.U. CHUKU(This Work).	
				BASALTIC VOLCANICS	Lanoja Sandstone
60	Maastritchtian -Campanian		Lafia Formation Lafia		Kumanha Shales
80	-Santonian- Coniacian	Awgu Formation	Volcanics Awgu Formation		SEKULE FORMATION
90	Early Turonian to Late Cenomian	Hiatus Shale Limestone Sandstone Makurdi FM. HIATUS	Hiatus Sze-Aku Formation	Sze-Aku Formation	JESSU FM. DUKUL FM.
100	Early Cenom. Upper Albian Middle Albian		Keana Formation HIATUS Awe Formation Asu River Formation	Keana Formation Awe Formation Uomba Formation	YOLDE FM. Bima Sandstone
110	APTIAN				
	BARREMIAN			Pre-Asu River Sediments	
120	NEOCOMIAN				
PRE-CAMBRIAN	B A S E M E N T C O M P L E X				

The filling of voids of calcite during disgenesis is regarded as an internal sedimentation of first generation in a submarine environment, probably in a littoral environment. Along the road to Anyiin, the middle and top beds appear to be cyclical equivalents of earlier units. For example Bed consists of mudstone -siltstone about 60 metres thick while Bed 4 consist of greyish green-black shale in places pyritic, poorly bedded about 120 metres thick. There are diagenetic imprints and slump structures (DC 168, 174,200-204).

About 6 kilometres west of Arufu and the Akwana-Juwudu Hill area, the upper Beds 5,6,7 and 8 of the Uomba Formation occur and appear to be cyclical equivalents of the middle Beds 2,3 and 4 and are marked by the Albian pelecypod, Actinoceramus sulcatus park (DC 155), contained is fine sandstone-siltstone. Bed 5 consist of an estimated 100 metres thick siliceous fine-medium grained sandy limestone similar to Bed 2. In the limestone- calcareous siltstone middle Beds 2,3 and 4 in Tseishan, Atongo and Igbur areas, contain the Upper Albian ammonite Mortoniceras cf. inflatum.

In the contact zone between the Uomba Formation and the overlying Awe Formation about two kilometres crest of Akwana, the topmost bed of the Uomba Formation, becomes more ferrugineous and more finely laminated mudcrack or dessication features (DC 300A) and ripple marks (DC.299) occur on the rocks.

3.3.3. Awe Formation

Exposures of the Awe Formation are found between Fiyayi village and a point 4 kilometres east of the village along the tarred road to Wukari. The Formation has an estimated thickness of about 450 metres in this locality. Here the sediments occur as exposures along the beds and banks of the Fiyayi River and its

tributaries for about 4 kilometres south of Fiyayi and extending northwards to Usende-Imortena area where the middle part of the formation becomes increasingly arenaceous and finely laminated. Between Jegate and Tseagosu compounds the formation is represented by between 300 and 360 metres of alternating sandy sandstones, siltstones - sandstone and shale with cross bedding, parallel bedding and ripple mark features. Good exposure are also seen in road cuttings at Ibav, Jeka and Kasar compounds between kilometre 40 and 44 along the tarred road (see samples DC.192 - 194, 243, 314 - 316, 358A - C).

At a road cutting at kilometre 441/2 around Ibav compound, the basal beds of this upper formation of the Asu River Group, rest on Uomba Formation (the Lower Sequence of the Asu River Group)

In the Kasaar-Fiyayi-Igbur area, the Awe Formation is composed of fine-medium-coarse grained well-bedded tabular calcareous sandstone which overlies finely laminated sandy grey yellowish brown micaceous shale. The sandstones become finer grained, cross-bedded and micaceous towards the base (DC.195, 356) with variable finely lamined fissile, flaggy sandy-silty shales. The shale component decreases progressively from bottom to top. The sequence appears to be cyclically arranged in a rapidly alternating succession. About 2 kilometres west of Akwana parts of the sequence are transitional, with mixed brackish to marginal horizons, well-sorted, subrounded (pebbly) fluviatile to deltoic silicified wood material (DC.302), desication or mud-crack features (DC.300A), carbonaceous partings and cellianassid (Vertical) and horizontal worm burrows (plate 3.4A, C,D) and ripple marks (DC.299). These may indicate a high energy, littoral or estuarine near-shore or tidal flat environment of deposition

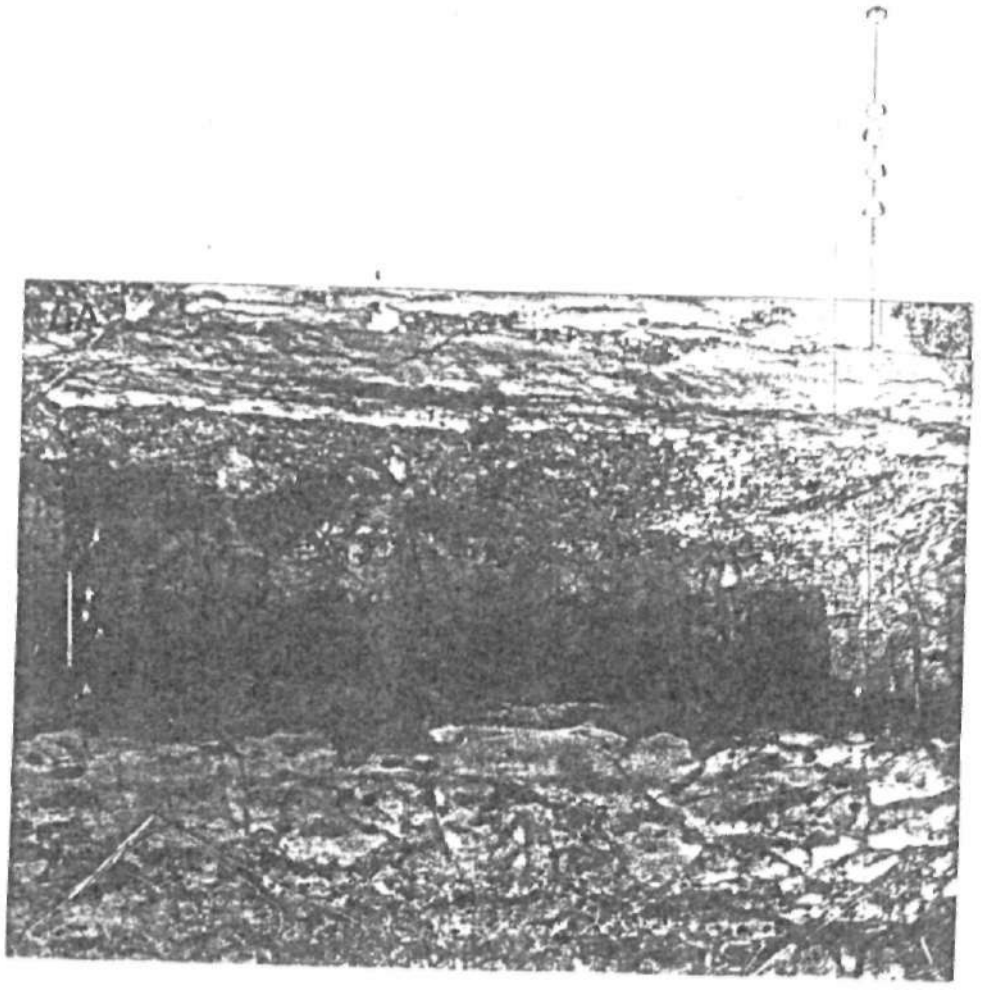
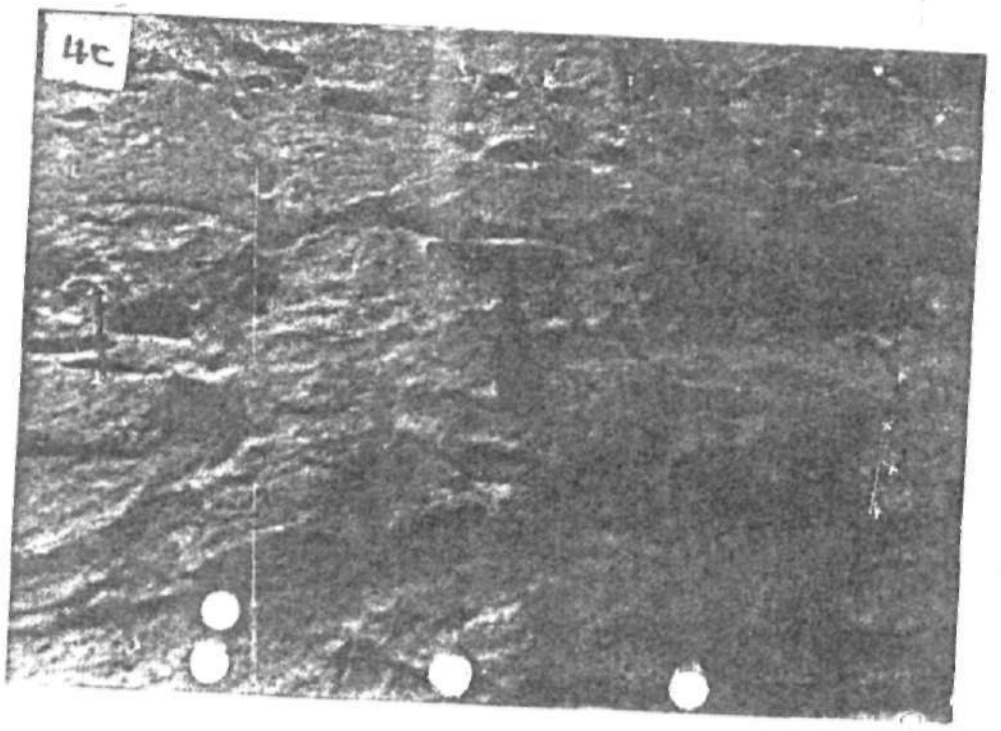


Plate 3.4A

Alternating Shales (SH) and Sandstones (SS) of the Fiyayi Shale - Sandstone Formation (Upper Sewuence of the Asu Piver Group).

Locality: Km 42½ road cutting of Jeka compound along Wukari - Arufu tarred road. Note the vertical CALLIANASSID burrows (about 3 cm in diametre) and horizontal worm burrows. ½ Natinal size.



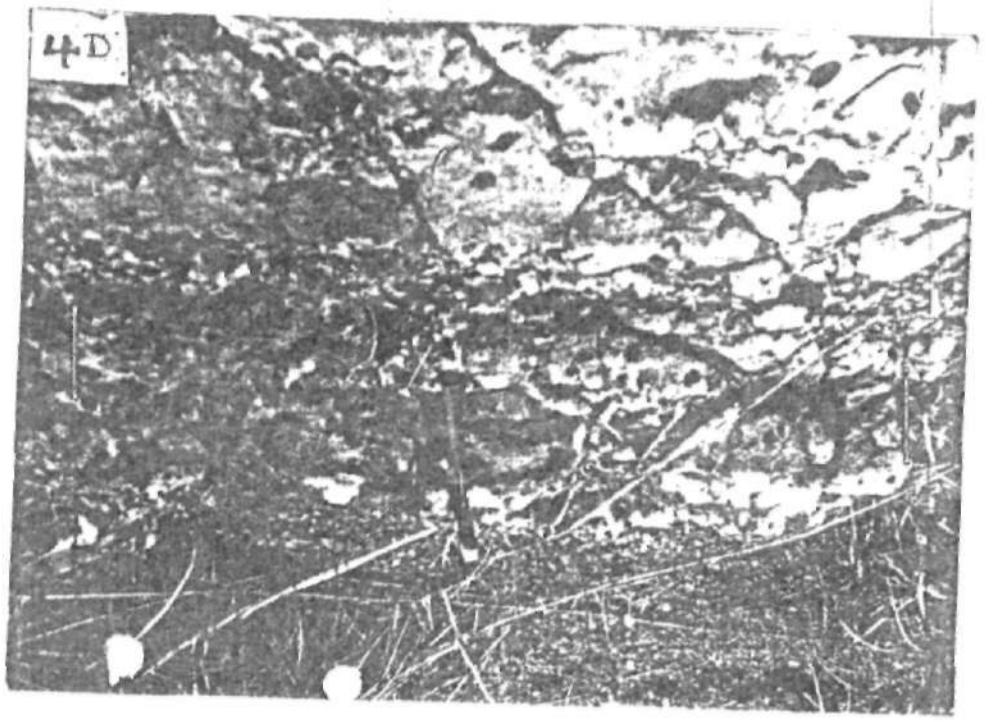


Plate 3.4C and D

Close up view of both the 3 cm - diameter vertical Callianassid burrows and horizontal worm tracks associated with 3.4A.

in which water level fluctuated rapidly.

The generalized sequence in the above area is as shown below, youngest beds at the top.

15. Sandstone: Fine-medium, tabular, well-bedded. micaceous, grey-yellow-white dipping 45° - 50° SW, separated from overlying Ibi sandstone by iron-stained surface pebbly horizon, nodular iron concretions and worm burrows.

14. Sandstone Fine grained, micaceous, finely laminated, flaggy cross-bedded, with horizontal worm tracks and callianassid burrows interbedded with whitish kaolinized clay, nodular iron concretions.

13. Sandstone: Medium-coarse, yellowish-white micaceous massive, subhorizontal at base overlain by greenish white 1 metre kaolinitic clay dipping 40°-50° SW with worm tracks and nodular structure-iron concretions.

12. Shale: Finely laminated silty, micaceous, weathered to greenish clays.

11. Shale-Mudstone-Clay: Sandy, thick unbedded with yellow-greenish sandy siltstone-sandstone (DC.243, 368B) in the middle thin medium-coarse, dark brown-pinkish sandstone at top with ferrugineous mottling (DC.368A), angular quartz pebbles and pinkish feldspar (extra-clasts) fragments, angular dark green clay

pellets (intrabasinal clasts) spheroidal weathering surface.

10. Sandstone: Fine grained, compact, well-laminated, greyish (DC.244, 193).

9. Shale-clay: greyish green and dark, silty, micaceous.

8. Sandstone: clayey (DC.192).

7. Sandstone: very fine-medium, finely parallel bedded (DC.362), cross bedded, brownish grey-cream colour, compact, "baked" appearance.

6. Shale-sandstone: Alternating succession of 2 metres thick tabular sandstone-fine to medium well-bedded micaceous with worm tracks and callianassid burrows bed dipping 15° NE.

5. Shale-mudstone-clay: interbedded with medium-fine thick-bedded massive, whitish calcareous sandstone (DC.194), greyish green, shale-mudstone-clay.

4. Shale: Finely laminated, silty, weathered to greenish clay and clayey soil.

3. Sandstone: Calcareous, fine-medium, tabular, well-bedded (DC 196) and in places finely cross-bedded, micaceous, with worm tracks.

2. Sandstone: Tabular, calcareous, fine-medium-coarse with subrounded discrete grains of quartz (DC.195, 356,336), feldspar, and/or unidentified ostracodes, interbedded at base with sandy micaceous, weathered shale-clay-mudstone.

1. Sandy micaceous shale and mudstone interbedded with fine-medium compact, greyish, purplish sandstone (DC.357, 358, 361) with intricate anastomizing network of dark cracks or veins filled with siliceous and ferrugineous material.

The above basal bed of the Awe Formation occurs at a road cutting across Ibav village where it dips 34° NE in a pulverized zone characterized by the presence of boulders of yellowish white kaolinitic clay (DC.361). Then westward near the Kehinde settlement along the Fiyayi-Arufu road the sequence gradually overlies the top of the Uomba Formation consisting of poorly bedded olive grey micaceous sandy shales, mudstone and siltstone.

In the above section, eight finely laminated sandy shale beds are present, individual units varying in thickness from 4.5 metres to 41.50 metres. The total thickness of the shale component in this section is 259.8 metres, and it predominates in the lower part of the sequence, while the sandstones having a total thickness of less than 30 metres, increase towards the top. (Table 3.6). The shales are poorly exposed and weather to form cotton soil.

Calcareous siltstone-fine sandstone bands (DC.336) and mudstone are found within the shale and the shale beds alternate with these layers. At a road cut around the compound of Ibav about 300 metres west of Fiyayi village, a band of sandy micaceous mudstone-shale altered to whitish kaolinitic clay (DC.315) is found towards the base of the formation in highly fractured zone in which the east facing lower side dips 34° NE. The shales are rarely exposed. Fresh surfaces have only been found in spoil heaps of wells and in excavations along the newly constructed tarred

TABLE 3.6 LITHOSTRATIGRAPHICAL SUCCESSION IN KASAAR-FIYAYI-IGBUR AREA (SEE FIG. 1.1)

AGE	GROUP	FM.	UNIT	DESCRIPTION OF LITHOLOGY
MIDDLE - LATE ALBIAN	GROUP	AWE FORMATION		Sandstone: Fine-grained, micaceous, tabular, Silty, whitish, yellow-green, with worm tracks and callianisaid burrows. Shale: Finely laminated, sandy, greenish colour with brown mottling. Sandstone: Fine grained, cross-bedded, parallel bedded micaceous. Shale: Green, silty, micaceous with thin mudstone layers.
MIDDLE ALBIAN - LATE	RIVER[illegible]ASU	UOMBA FORMATION		Shale: Greyish yellow-brown, poorly-coarsely laminated. Limestone: Yellow-grey, sandy (DC. 375-377) with ferrugineous nodular concretions. Shale: Sandy, micaceous, yellow - brown. Mudston: Silicified, highly fractured, inter-bedded with grey shale, with Albian ammonites, gastropods and pelecypods Siltstone: Pale grey, silicified, - brecciated and mineralized with galena.
				UNCONFORMITY
PRE-CAMBRIAN	BASEMENT	COMPLEX		Granitic Gneiss of the Igbur Inlier

Wukari-Kwatan Sule road.

Elements of continental sedimentation and transitional horizon towards the top of the formation are shown in the above section described by the presence of angular quartz pebbles (extrabasinal clasts). These form bands within a sandy shale-mudstone-siltstone rock (DC,243, 368C). The underlying rapidly alternating shale-sandstone layers have both horizontal worm tracks and vertical callianassid burrows. These are exposed in road-cuttings between the compounds of Kasaar and Jeke at the type locality (Table 3.6). This is indicative of transitional tidal flat environment which interplays with fluviatile environment associated with the late Albian to Early Cenomanian regressing shallow sea in a tidal flat environment. The angular quartz pebbles have evidently undergone little abrasion and are characteristic of fluvialitel rapidly deposited sediments without reworking.

About 2 kilometres west of Akwana village and persiting westwards to Chikor village, sandy shales, fossiliferous finely bedded and tabular sandstone (DC.205) containing the Late Albain - Early Cenomanian pelecypod Pholadomya Papyracea predominate in the lower part of sequence at its contact with the underlying Uomba Formation (Table 3.6). This basal part of the formation has ripple marks with the stoss and pointing 240°, and also mud-crack-dessication features (DC.300A). These are also both horizontal worm tracks and vertical callianassid burrows (DC.290, 299, 300, 301-304).

At a road-cutting about 2 kilometres of Akwana, the Awe Formation is seen to overlie the Uomba Formation. Here there are no indications of a stratigraphic break except some evidence of periodic hard grounds probably caused by change of style of sedimentation

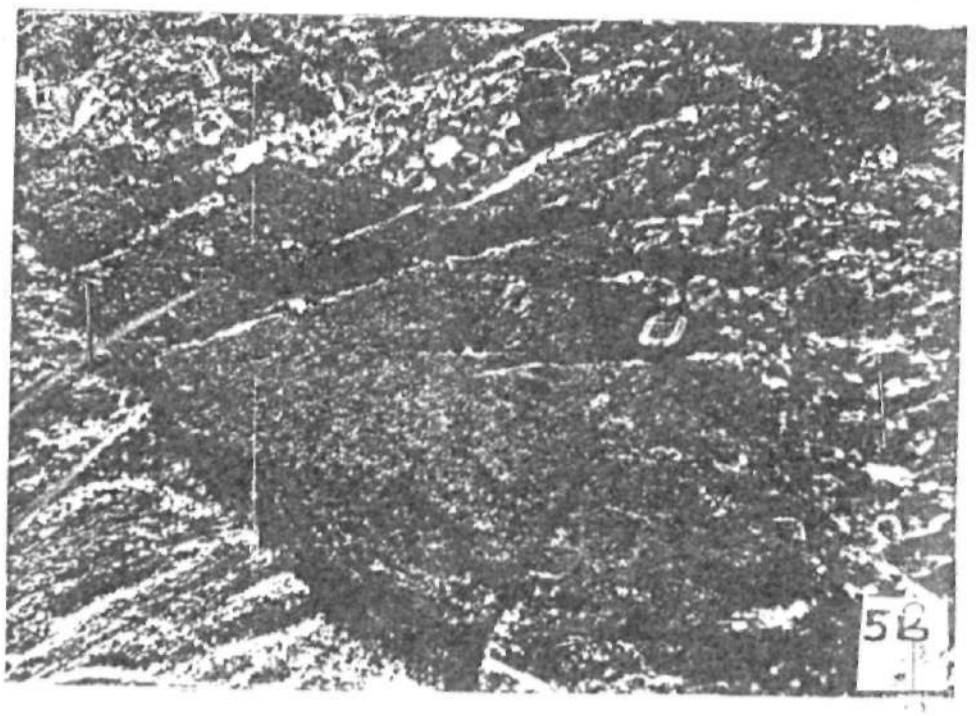


Plate 3.5B

Andyar Basaltic Lava Flow with bedded structure (dipping 25°NW) apparently interbedded with the Late Albian - Early Cenomanian Shale-Sandstone Piyayi Formation (Upper Sequence of the Asu River Group), in the axial area of the Arufu Anticline.

Locality: Km 88 along Wukari-Kwatan Sule road, near Andyar Village.

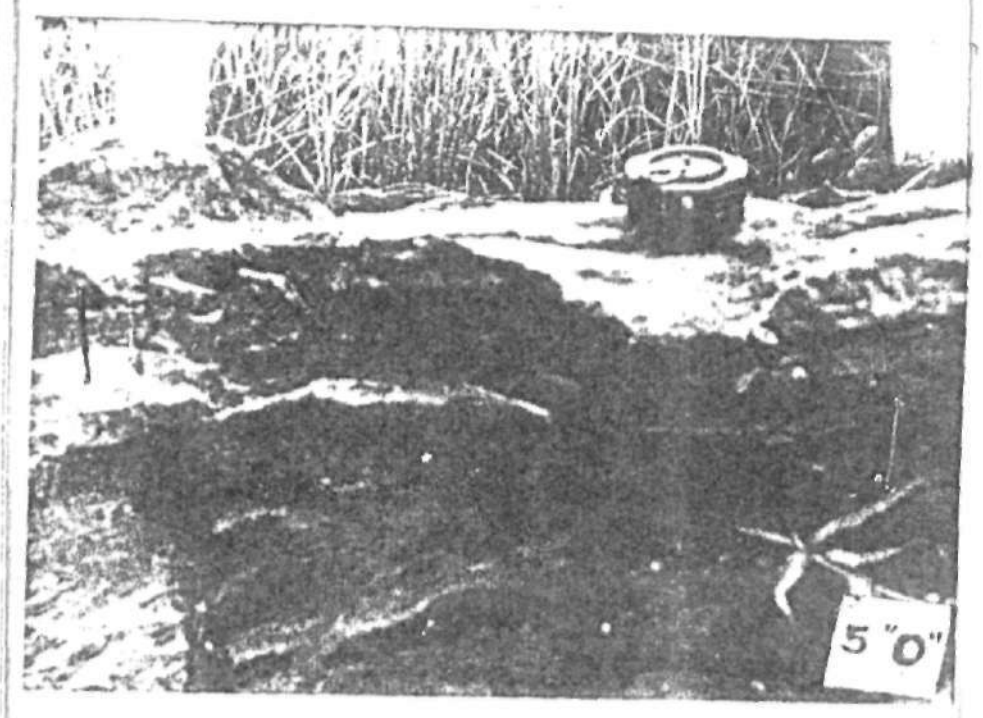


Plate 3.5 "O"

Exposure of Ibi Continental Sandstone (Cenomanian) interbedded? with basaltic lava in the axial region of the Ibi anticline.

Locality: 3 km south of Ibi Town along road cutting at km 35 along Wukari - Ibi road.

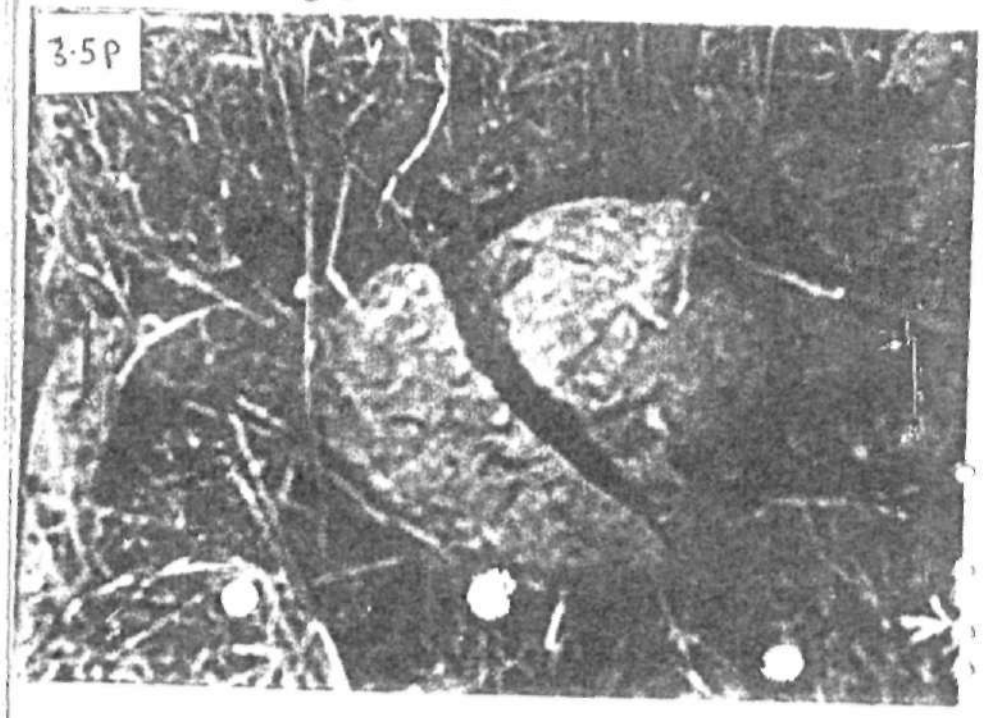


Plate 3.5P

Pillow-like structure in the Andyar Basaltic Lava (see Plate 3.5B) suggestive of emplacement under subaquaeous (submarine?) environment possibly contemporaneous with the deposition of the Fiyayi Formation.

The estimated thickness of the formation in the area is about 350 metres metres. The sandstones are typically cross-bedded, massive-thick bedded, feldspathic , arkosic and sometimes conglomeratic sandstone, with clays and silt-stone predominantly in the lower part.

At the type locality at the road-cutting, the lithological sequence recognized it as follows (top to bottom).

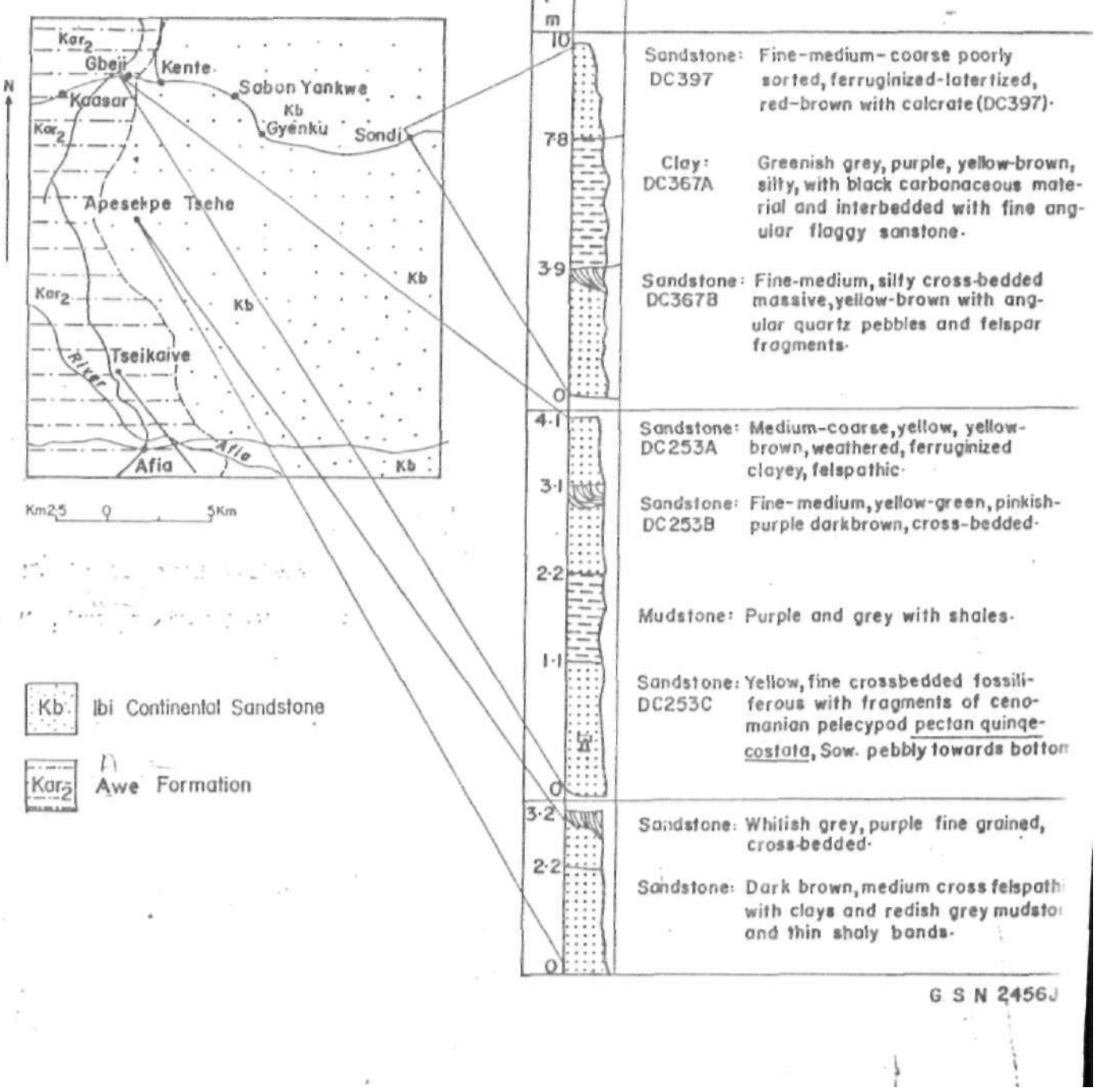
		Metres
Sandstone:	Ferrugineous, cross bedded arkosic, fine-medium with Manganese concretions (top)	1.1
Clay:	Silty greenish grey	2.2
Siltstone:	Siltstone with calcrete nodules	1.0
Sandstone:	Fine-medium grained, angular poorly sorted, cross bedded associated with volcanics	3.6
Sandstone:	Thin band of calcareous sandstone	0.2
Siltstone:	Green, silty with sandstone and calcrete nodules	8.1
		16.3

Base not seen

A typical section of the formation starts from Kayey village and persists discontinuously northward through Ibi town to the south of bank of River Benue, on both limbs of an anticlinal fold with the axis running NE-SW through the southern outskirts of Ibi town. The section is discontinuously exposed mostly along the Wukari - Ibi tarred road, running through the crest and centre of the anticlinal structure.

This section exposed is thought to represent the middle to upper units of the formation. The lower unit of the formation recorded from well cuttings at Gbeji, Kente and Sondi (Fig. 3.10) several

Fig. 3.10 IBI CONTINENTAL SANDSTONE SECTIONS



In the area under study, the formation consists of two units, namely:

1. Tsekur sandstone-clay shale sequence (Late Cenomanian).
2. Akahana Shale - Limestone - (Latest Cenomanian-Early *Turonian*).

3.5.1 Tsekur Sandstone-Clay-shale sequence

In the study area the unit consists of rapidly alternating sequence of sandstones, grey-green shales and clays as shown in the following general section (youngest beds at top):

10. Sandstone: Fine-medium, clayey, micaceous, multi-coloured (purple) yellow, brown, white, pink brown) ferrugineous.
9. Sandstone: Very fine grained, micaceous , clayey, with interface crest ripple marks and lunate ripple marks with stoss and trending 60° - 50° indicating a disturbance of current flow.
8. Shale-clay: Sandy, grey.
7. Sandstone: Cross-bedded, clayey, fine, grey, pale-brown with friable shaly intercalations, cross-beds dip 9° - 15° SW or NE.
6. Shale-Clay: weathered, micaceous, sandy, dipping 20° NW with yellow-brown ferrugineous siliceous nodules or concretions.
5. Sandstone: Fine, buff, micaceous, bedded, tabular, with anastomizing fractures, with linguoid ripple marks crest trending 45°, indicative of unitary flow or fluviatile environment.
4. Shale-clay: Grey green, silty, gently dipping 5° NW

interbedded with thin bands of fine grained thin bedded sandstone.

3. Sandstone: Fine-medium, micaceous, thick bedded, yellow-green with angular to subrounded quartz pebbles (extrabasinal clasts) and angular greensish clay pellets (intrabasinal clasts).

2. Sandstone: Feldspathic with pink-purple angular K-feldspar fragments and ferrugineous-siliceous cement (DC 251B).

1. Shale: Sandy, finely laminated, micaceous, with thin bands of fine sandstone-siltstone-clay, and callianassid burrows and worm tracks (DC 251A).

The general lithological section described above in the Tsekur-Lukor-Tseunum areas (straddled by a SW-NE trending synclinal structure) continues westwards and SW into Nwannune area in the SE quadrangle of the adjoining Makurdi Sheet (251). Here the sequence attains an estimated thickness of about 1,100 metres.

At a road cutting near Tseihom compound (at kilometre 88 along Wukari-Tsekyo (Kwatan Sule) tarred road, the base of the Tsekur Sandstone sequence is marked by light brown, yellow, purple, whitish micaceous fine grained clayey, loosely compacted and weathered sandstone (DC 258A). This is interbedded with sandy clayey, red-brown, yellow-white, fine-medium, sandstone (DC 258E) with both horizontal worm track and vertical (callianassid) burrows.

On the western limbs of a synclinal structure around Hamza (10 kilometres SW of Tsekur) the upper units consist of brown, fine grained micaceous sandstones with very little clay or shale. North of

Hamza along the north bank of River Ngo, the base of the sequence is marked by a bed of flaggy sandstone about 3 metres thick, interbedded with a thin layer of grey-green finely laminated sandy shale, weathered to light grey-yellow clay and soil and sandy argiliaceous rubble.

3.5.2 Akahana Shale-Limestone-Sandstone Unit

In the Sufa-Moyin-Akahana area the unit consists of hard grey, bluish black poorly bedded shales and siltstones. In places there are facies changes to sandstone, limestone or sandy shales, which are described below.

Shale Member

Four beds of the shale member are exposed on the southern slopes of a flat-topped hill about 4 kilometres south of Kwatan Sufa (on the south bank of River Benue, about 9.5 kilometres NNW of Arufu village). The exposures consist of hard, bluish to grey black compact, poorly laminated sandy-silty shale (DC 230). The strike of the beds is 10° while the dip is 35° - 40° WNW. The total estimated thickness of the section is 66 metres. The suboutcrop area is about 4 kilometres x 1.5 kilometres, but most of the shale surface is capped by dark compact fine grained (Tertiary?) basalt flow (DC 231) leaving only small baked remnants of the shale. The shale primary bedding is cut by high angle to vertical north easterly and northwesterly joints (the latter set is younger than the former). The shale weathers to form cotton soil, a brownish black clayey soil with high (sticky) shrinkage capacity, which is the typical weathering product of the shales throughout the outcrop areas.

Along the stream draining the NE and SW outskirts of Keffin Moyin village and the broad valley of the N-S flowing River Asuka

(about 16 kilometres SW of Tunga), the formation has an estimated thickness of 200-300 metres composed of poorly thick-bedded hard grey-black silty shale (DC 365 and 322B, respectively). The shale has whitish grey or light grey siltstone intercalations, and is interbedded with occasional thin bands of micaceous clayey poorly bedded-marine sandstone. The beds generally dip 10° - 22° SSE. The lower part of the section consists of grey black shale with occasional nodules and nodular beds of yellow sandy mudstone. The middle part of the section shows small scale folding.

At Ortesh, about 15 kilometres SW of Awe, the shales occur as calcareous intercalation and marly horizons at the base (DC 330A) with fossiliferous limestone in the middle, and calcareous sandstone (DC 331B) at the top. A similar lithological relationship exists in the Akahana area (DC 322A, 322B and 329; Table 3.9).

Limestone Member

Around the village of Akahana about 10 kilometres SW of Jangerigeri an extensive limestone sequence (DC 322) with marly horizons at the basal part, occurs, with proflific assemblage of ammonites reported by Offodile (1976). The limestone exposures persist discontinuously to Jangerigeri and Ortesh, some 6 kilometres east of Jangerigeri village. The basal beds of the limestone can be best studied around the compound of Ortesh, where the shelly facies is composed almost entirely of Oyster beds (DC 333A), with some marly horizons. The dark grey shelly limestone beds dip gently 5° - 10° WSW, with a strike of 170° (roughly N-S). The limestone bed is in the middle and is underlain by the marly horizons, but overlain by dark thick bedded-poorly bedded medium grained calcareous sandstone (DC 333B), westwards, along the bush tracks the shelly limestone has

TABLE 3.9: LITHOLOGICAL SUCCESSION IN AKAHAN-TSEIHOM-TSEJANDE AREA (SEE FIG. 1.1)

Age			DISCRIPTION OF LITHOLOGY	
Late Cenomanian - Lower Turonian	Eze-Aku Formation	Tsekur Sandstone Akahana Shale Limestone Unit	Sandstone:	Fine-medium whitish grey, Calcareous.
			Limestone:	Shelly, silty, containing fragments of Lower Turonian fossil.
			Shale:	Dark grey, silty, fossiliferous with assemblage of earliest Turonian amonites.
			Sandstone:	Fine-medium grained micaceous, thick-bedded.
			Shale:	Dark grey compact, poorly laminated.
			Sandstone:	Fine-medium, micaceous poorly bedded, well sorted
			Sandstone:	Fine-medium, micaceous clyayey, red, brown, yellow white, cross-bedded, iron stained towards base.
Pre- Middle Albian to Late Albian to Early Cen.	Asu River Group	Awe Formation	Shale:	Grey-greenish, flaggy, fissile, Silty, containing Late Albian-Early Cenomanian pelecypod - Pholadeya caryracea
			Shale-Sandstone:	grey, finely laminated shale, fine tabular sandstone cross - bedded bedded, carbonaceous
		Uomba Formation	Shale:	Poorly-coarsely bedded, sandy, with interbedded mudstone, olive grey-grained band, Micaceous
			Limestone:	grey with nodules, and silty horizons.
			Sandstone:	angular, feldspathic poorly sorted, cross bedded, yellow brown
			UNCONFORMITY	
Upper Cambrian - Lower Palaeozoic Basement Complex	Pan-African Older Granite		Coarse porphyritic granite (DC 326, 327) from the Tsejande Granite inlier	

interbedding of dark-grey-black fine crystalline, thick-bedded limestone (DC 330=. Towards Jangerigeri the basal part of the limestone becomes marly, and clayey (shelly). The more shelly facies of the limestone are usually composed of Lower Turonian Oysters, mainly Exogyra Olisiponeisis. Offodile (1976) has reported the occurrence of a Latest Cenomanian ammonite Kanabiceras septemseratum form a marly horizon in the same vicinity.

Sandstone Member

Fully marine, poorly bedded, mostly calcareous sandstone (DC 322B, 322A), usually forms the upper parts of the shales and limestone around Akahana and Ortesh. Carbonate materials occur as thin intercalations within the sandy laminae.

In the basal marginal areas, where the unit interfingers in areas of transitional environment, with other formations, e.g. to the north of Ortesh and Jangerigeri, around Agbenke, Baki, Imoterna-Lan-Damsa area (NE quadrange), the sandstone is fine grained, thinly laminated shaly and carbonaceous. The lamination in the marginal sandstone (DC 259) at Agbenke (at kilometres 91, Wukari-Tsekyo tarred road), is subhorizontal to gently dipping (dip 10° - 25° NW). In the Imoterna-Lan-Damsa area, there are small scale wave and current ripple marks and post-deformational structures. In this zone, the sandstone is interbedded with shales and mudstone and clays, with pebbly, ferruginized horizons.

The sandstone bands in the silty shale to the NE of Keffin Moyin, thickens southwards towards the slopes of the flat-topped hills, to the NE of Tunga. There it forms a poorly thick-bedded sequence consisting of fine-medium grained massive, brownish yellow micaceous sandstone (DC 331A). A partial section exposes in the slopes of the

hills at least, 27 metres of the sandstone (DC 331A) underlain by sandy shales. The beds dip 30° SSE, and are capped by a thin brownish yellow ferrugineous sandstone horizons. The sequence continues south-eastward across the north bank of the River Benue to the south bank, towards Akpetyo, and thus giving rise to the Akahana Shale-limestone. The shelly limestone (DC 322B) was probably formed in littorial shelf areas near the shore, while, further away from the continent, predominantly argillaceous material (mostly greenish black mudstone and shales) were deposited, including siltstones, sandstones and clays under slightly reducing anaerobic environment.

Evidence for near shore environemt is provided in thin sections by small-scale graded bedding and ripple marks, and also the presence of recrystallized mud pellets, The shelly limestone bodies in the Akahana - Ortesh area are considred to be autochthonous and accumulated under shelf-littoral condition and/or open marine shelf. The presence of ripple marks indicates that the deposition of the sandstone-shale sequences took place in the vicinity of wave base or under traction current, or under a wave base.

3.6 Evidence of Palaeocological Conditions from Forminiferal Microfauna

In the earlier part of this chapter reference has been made to the presence of shaly beds towards the top of the Barremian Pre-Asu River Continental Sandstone Formation in various parts of the study area - e.g. in the Tseagu - Yandev area which are believed to represent the marginal deposits of an Albian marine invasion (cf. Carter et al. 1963). In the recent investigation carried out by Petters (1983) he has shown that regional foraminiferal distribution

patterns corroborate lithologic and microfaunal evidence in support of the predominance of marsh and shallow brackish and anoxic epeiric environments of deposition for the Benue Trough.

Petters (Optcit) identified some foraminiferal assemblages around Yandev (Tseagu-Tseagodo area) in the Albian Shales at the top of Pre-Asu River Basal Continental Grits and Sandstone, which are suggestive of brackish lagoons and estuaries. These assemblages comprise mostly arenaceous taxa such as Ammobaculites, Miliammina, Reophax, Ammotium and Ammocliscus. When plotted on the triangular diagram (Murray 1973), these foraminiferal assemblages were shown to fall in the Molocene estuarine and lagoonal fields. The above arenaceous assemblages are tolerant of low salinities in modern upper estuarines and lagoons (Murray 1973). These suggest, by analogy, that the Albain assemblages in this part of the Middle Benue Rift-like Trough, could have inhabited similar environment. Alternatively, Petters (1983) believes that, with the influx of freshwater into the Benue Trough during the initial Albian transgression, the seaway itself, could have resembled a large brackish lagoon.

Initialingress of the sea into the Benue Trough occured in the Middle Albian (Reyment 1965, Offodile 1976). But despite this most of the green Albian shales exposed in the Fiyayi - Arufu - Akwana area (in the Wukari Local Government Area, Gongola State) of the Middle Benue Trough which were apparently deposited by the initial transgression, are unfossiliferous. These probably represent marsh deposits along the margin and distal parts of the Albian brackish epeiric sea (cf. Petters 1983).

The Late Cenomanian to Early Turonian was a period of widespread marine transgression in the Middle Benue Trough like

most parts of the world (Offodile 1976). Petters (1983) has shown that available foraminiferal evidence points to widespread marine transgression in the Middle Benue Trough like most parts of the world (Offodile 1976). Petters (Opcit) has also shown that available foraminiferal evidence points to widespread anoxia in the shallow sea that flooded the southern and middle parts of the Benue Trough while marsh conditions prevailed in the NE parts of the basin with intermittent inundation by open sea. The organic rich (0.5 to 7.4% total carbon, Petters and Ekweozor 1982 A & B), dark grey and black laminated shale of the Nkalagu Formation (lateral equivalent of the Lower Turonian Eze-Aku Formation contain, in the main, exclusively dwarfed low-diversity benthic microfauna, which suggest deposition in an oxygen depleted basin (Petters 1983 A&B).

Petters (1979) has also noted that in the Upper Benue Valley the Pindinga Formation (correlatable with the Lower Turonian Akahana Shale-Limestone Unit of the Eze-Aku Formation of the study area within the Middle Benue Trough, contains mostly simple - chambered arenaceous species of Ammoastuta and Ammobaculites which suggest the prevalence of extensive marsh conditions. He cites the predominance of smectite or montmorrilonite (Hydrous silicate of Ca, Na, Al, Mg and Fe) in these shales as evidence in support of marine marsh and humid palaeo-environments.

In the Middle Benue Trough the occurrence of coal seams (Offodile 1976) at the top of the Eze-Aku Formation, suggests the existence of coal swamps during this phase of maximum flooding in the Middle Benue Trough (Petters 1983).

The above discussions have shown that microfaunal criteria, among other techniques, can be used to interprete palaeo-environments

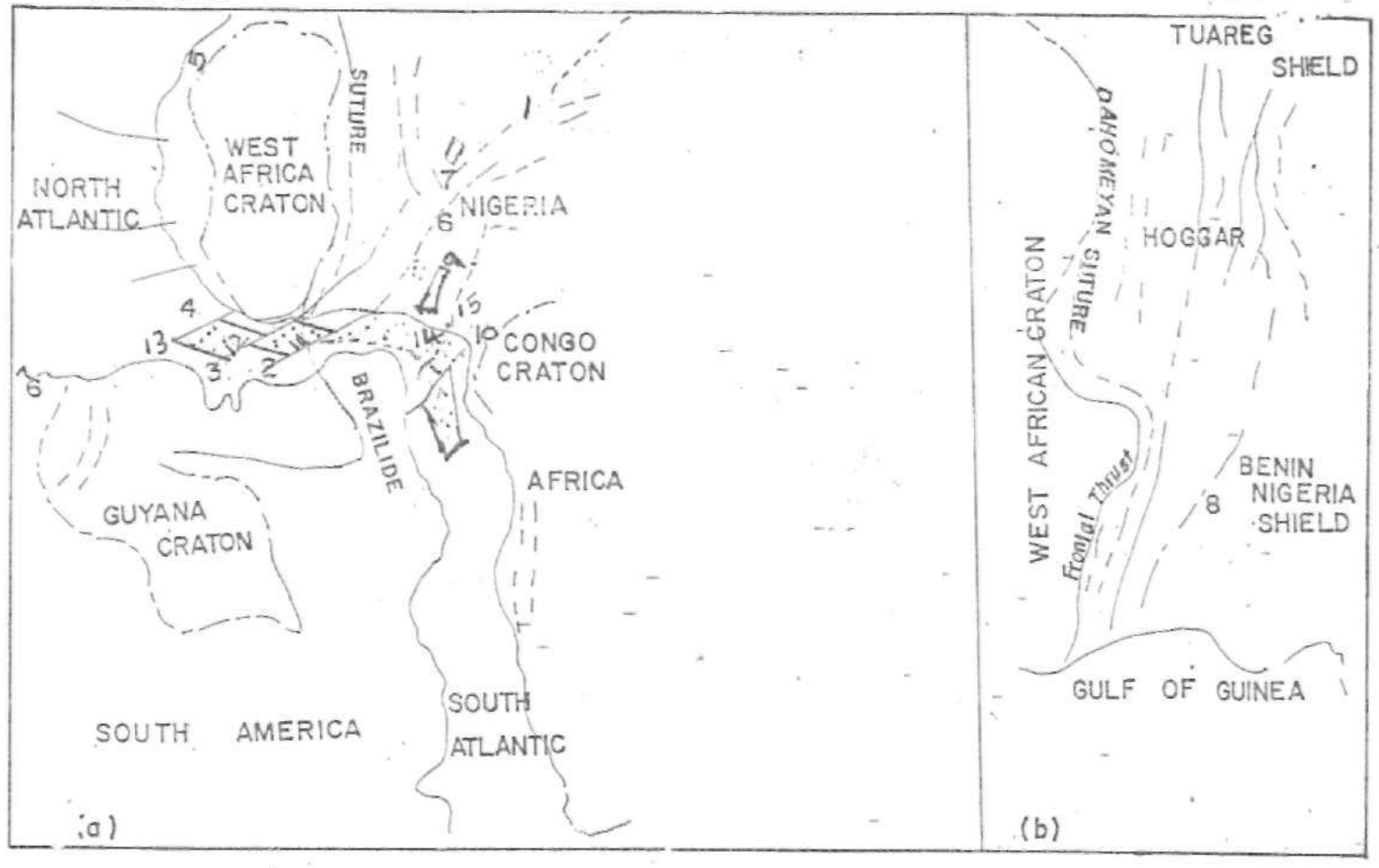
in the Benue Trough. Humid palaeoclimate, global eustacy, and local diastrophism were among the determinants of sedimentation in the Benue Trough (Petters 1978) A & B). Fluvial cyclothems and cross-bedding occur in the basal sandstones of the Asu River Group and in the Pre-Asu River Sediments of the study area, within the Middle Benue Trough. Ostracodes and foraminifera (Petters 1979, 1983B) suggest restricted and anoxic epeiric sea and marsh enviroments. Foraminiferal palaeoenvironmental indicators such as the predominance of patterns of arenaceous benthic foraminifera when applied basinwide allow the delineation of marshy, brackish epeiric and anoxic environment. These environments favoured the widespread preservation of organic carbon (Petters and Ekweozor 1982 A, B) in the study area.

3.7 Discussion:

The foregoing considerations indicate that the sedimentary history of the study area (within the Middle Benue Trough) is dominated by repetitive cycles wholly or partly linked with global sea level changes, the growth of the Mid-Atlantic Ridge (cf. Murat 1970) and the onshore extension of one of the mid-oceanic fractures zones into west Africa (Fig. 3.11) during the early stages of the separation of South America from Africa. The Cretaceous sediments were deposited in a series of depressions formed by the differential subsidence of the Pan African granitic basement within the area. Some of these sediments are of continental origin and may have fluvio-deltaic members while the majority are marine.

There are geological, chemical and post-depositional features which suggest depositional conditions of the six Cretaceous Formations encountered in the Arufu - Akwana - Ugba area (in the

FIG. 3.11



Schematic Map of West African Coast showing Cratonic areas and mineralized fracture Zones (Modified after Burkeetal, 1970; Black, 1980)

(a) In relation to the Barazilian Coast

(b) Eastern margin of west African Craton

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(P.T.O FOR KEYS)

=== Rift structures

– – — Fracture zones (Transform faults)

KEY TO FIGURE 3.11

1. Niger - Nigeria Mesozoic Younger Granite Tin Belt.
2. South West African Tin Belt.
3. Brazilian Tin Belt.
4. Libarian Tin Belt.
5. Moroccan Tin Belt.
6. Rodona - Guyana Tin Belt.
7. Pan African Ophiolite Suite in Southern Morocco associated absestos, podiform chromite, and pt. - co-Ni Mineralization.
8. Pan African Peridotite - serpentinite association mineralized with asbestos, chromite, with nickel enrichment in Mallam Tanko -Ribah - Bado area of NW Nigeria Schist Belt.
9. Benue (aulacogen) valley with Pb-Zn mineralization.
10. Ascension fracture zone.
11. Chain fracture zone.
12. Ronache fracture zone with iron sulphate concentration, metalliferous sediments, metallic oxide and sulphide in the Mid Atlantic Ridge.
13. St. Paul's fracture zone.
14. Postulated Cretaceous Triple Junction - fragmented continental margin forming good habitat for petroleum accumulation in the Niger Delta area.
15. Charcot fracture zone.

Middle Benue Trough) investigated. For clarity these lines of evidence will be discussed in sequence. The presence of unbiquitous cross-bedding, angular quartz pebbles (extrabasinal clasts) associated with angular clay pellets (intrabasinal clasts - DC 261B) and the presence of intraformational conglomerates, brecciatic sandstone and grus constitute the geological evidence that the Pre-Asu River sediments were generally deposited in a high energy environment. The ferruginization observed is probably a syndepositional feature arising from the strong oxidizing tendency that seems to have persisted in the continental high energy conditions that prevailed. These conditions may have persisted and iron-enrichment continued. The basal sandstones and clays might have been little exposed to this environment and they are therefore less affected by ferruginization.

The variations and decreasing thickness of the type sections of the Pre-Asu River sediments from SW and south through the central area may be partly due to the irregular relief of the crystalline basement floor in which the sediments accumulated and partly to differing degrees of accommodation in the basin of deposition. Arkosic sediments were constantly forming along the margins of the local basins. The colour of the sediments varies from brown and yellow to green and white. This shows oxidation and reduction phases in the sedimentary sequence.

The nonmarine sandstones of the Pre-Asu River Sediments and the basal parts of the Uomba Formation (lower sequence of the Asu River Group) are overlain by limestones and shales in the Arufu-Akwana area. Geological evidence (such as the basal limestone-shale beds) suggests that the Uomba Formation was in general deposited in a low-energy quiet shallow marine shelf environment. It apparently

represents the first Middle Albian transgression into the Middle Benue. As the Middle Albian Marine transgression from the South Atlantic ocean quickly moved up the Benue Trough to Ugba, Arufu and Akwana areas interspersed with differentially subsided Pan-African granitic basement blocks, the shale component of the formation was deposited in the centre of the basin while on the stable to slowly subsiding shelves and platforms, equivalent shelly limestone (DC 183, 283) which formed oyster banks together with acleractinean solitary corals, and well sorted limestones with ammonites, gastropods and pelecypods, were deposited or accumulated together with subordinate calcareous siltstone. Marine brecciatic to conglomeratic materials were deposited along active fault scarps. Limemuds were probably deposited along with natural clays and muds during the shallowing of the Albian sea or as a result of inadequate subsidence (due to warping and differential uplift or parts of the sea floor) resulting in the formation of argiliaceous limestones and marl (DC 212, 214) on the Ugba - River Logo area.

It must be noted that the several parallel NE-SW trending basement blocks or ridges separated by relatively deep, narrow local sedimentary basins scattered in the central part of the study area (Fig. 1.5) may have created special restrictive varieties of the prevailing marine conditions in this part of the Albian sea, creating favourable environment for existence of acleractinean solitary corals (DC 289). The series of ridge areas, inliers may simply have represented areas of uplifted basement or basic intrusions at shallow depth.

The Uomba Formation (lower sequence of the Asu River Group) is characterized by limestone-shale deposition while the Awe

Formation (Upper part of the Asu River Group) is marked by shale-sandstone deposition. Elements of continental sedimentation and transitional horizon towards the top are shown by the presence of angular quartz pebbles (extrabasinal clasts). These form bands within a sandy shale-mudstone-siltstone rock (DC 243, 368C). The underlying rapidly alternating shale-sandstone layers have both horizontal worm tracks and vertical callianassid burrows. These are exposed in road-cuttings between the compounds of Kasaar and Jeke (Table 3.6) along Wukari - Fiyayi road. This is indicative of tidal flat environment which interplays with fluviatile environment associated with Late Albian to Early Cenomanian regressing shallow sea in a parallic environment. The angular quartz pebbles have evidently undergone little abrasion and are characteristic of fluviatile rapidly deposited sediments without reworking.

In the study area there was apparently a transition between the Early Cenomanian continental condition during which the Keana Formation was deposited and the Late Cenomanian marginal marine condition during which the Tsekur sandstone-shale (which forms the basal part of the Eze-Aku Group) was accumulated. This was achieved through a rapidly alternating sequence of thinly bedded micaceous sandstone and finely laminated grey -green shales and clays (DC 251A) probably under shallow marginal marine-deltaic and estuarine environment. On the other hand evidence for near shore shallow environment of deposition for the Akahana Shale-Limestone sequence is provided in thin section by small-scale graded bedding and ripple marks, and also the presence of recrystallized mud pellets. The shelly limestone member in the Akahana-Ortesh area is considered to be autochthonous and formed under shelf-littoral

condition and/or open marine shelf.

The transgressive movements responsible for the deposition of the Akahana Shale-Limestone sequence, as evidenced from Palaeontological data started during latest cenomanian times (cf. Offodile 1976). The formation was deposited in a shallow marine slightly reducing (as shown by the greenish black colour of the shale) coastal environment during a period of low input of terrigenous material due to low run-off from the land resulting from reduced erosional effect of the post-Albian uplift and the gradient of the palaeoslope. This environment could be ideal for marine life to develop near the coastland under normal salinity conditions. Occasionally near the shores marine and fluviatile conditions interplayed in transitional environment between the Tsekur Formation and the underlying Ibi Sandstone.

Davy et al. (1978) have used the Boron-Gallium-Rubidium (B-Ga-Rb) diagram in their sedimentological interpretations. Using these diagrams (Fig. 3.8) the micaceous samples DC 288A-B, 260B, 227A and 261D, typical of the Pre-Asu River Formation, plot in the fresh water field. In the Middle-Upper Albian Arufu Formation and the Albain Awe Formation (both of which constitute the Asu River Group in the study area), the mineralized limestone and the barren tabular siltstone-sandstone plot as marine and marginal marine-brackish water respectively (Figs. 3.12 and 3.13).

The Latest Cenomanian to Early Turonian Akahana Shale-Limestone samples (DC. 322, 329, 333A, 332A, 230, 259) plot as marine while the basal shale (DC 251A) and clayey siltstone (DC 258C) from the Late Cenomanian Tsekur Sandstone Shale Sequence plot in the

marginal marine - brackish water area (Fig. 3.14). The two very micaceous samples (DC 252B and 258A, Table 3.10, Nos. 13 and 14) plot in the fresh water field (Fig. 3.14). These two samples were collected from the upper beds of the Eze-Aku Formation

In the Cenomanian Keana Formation the basal clayey shaly sandy horizon recorded from the well at Gbeji (DC 253C, Fig. 3.16) plot in the brackish to fresh water marginal area (Fig. 3.14), while the upper micaceous beds at Sondi (DC 367A and B, Fig. 3.10) plot in fresh water field (Fig. 3.14).

In Bed 5 of the Uomba (Arufu Limestone - Shale) Formation, the carbonate - rich sediments and impure sand-clayey siliceous shelly limestone (DC 373 - 375) hosting disseminated galena mineralization in the Igbur - Ruwabi Hill area (Table 3.6) appear to have been formed in a brackish to fully marine environment (Fig.3.16). The diagram may not indicate open marine environment but rather hypersaline depositional conditions. The diagram for Beds 2 and 3 of the Arufu Limestone-Shale sequence is given in Fig. 3.15. In terms of origin of the siliceous limestone and siltstone and their mineralization the B-Ga-Rb diagram is less useful because of the undoubted redistribution of metal sulphide into the fault zones, caused by silicification.

The B-Ga-Rb diagram is based on the geochemical behaviours of the three elements during sedimentation. Boron is enriched in argiliaceous marine sediments, rubidium is enriched in sediments formed under brackish water conditions, while gallium proxies for argillaceous sediments formed under fresh water conditions (Rankama and Shahama 1949).

FIG 3.12 B-Rb-Ga diagram for rocks from Bedl shelly Limestone of Arufu Limestone Shale (see fig-17D) and rocks from Sura-Akahana Shale Limestone (see figs-17th and M).

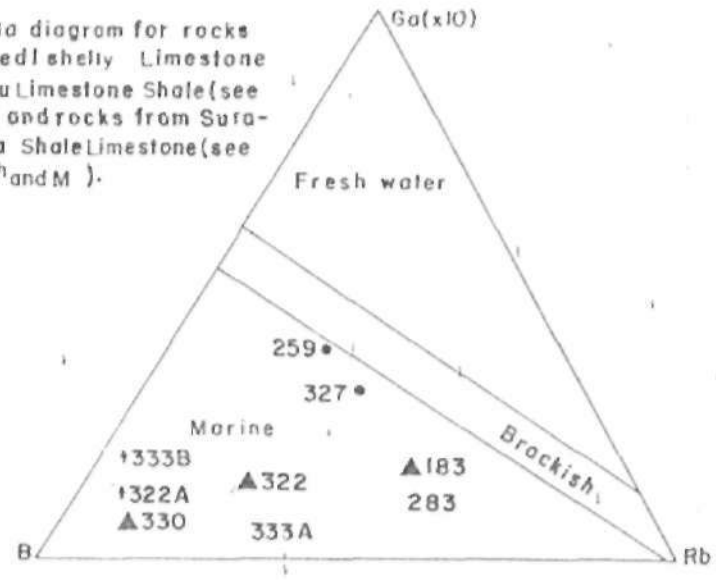
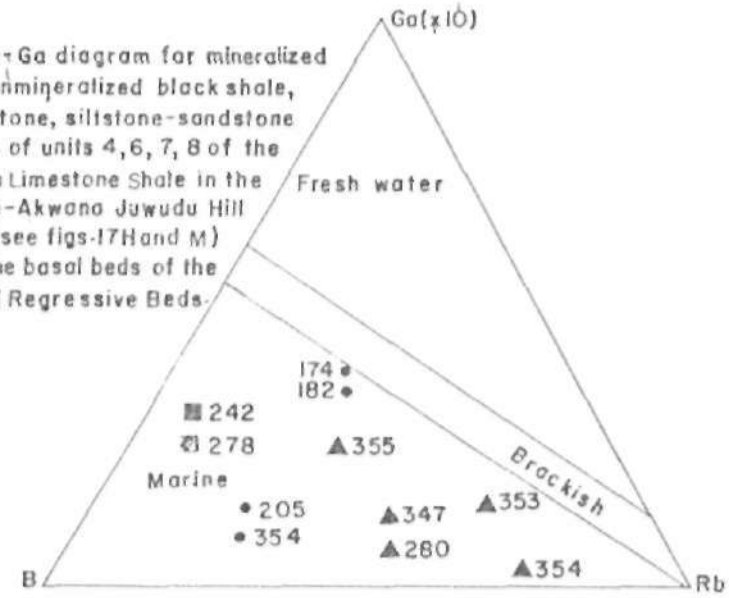


FIG 3.13 B-Rb-Ga diagram for mineralized and unmineralized black shale, limestone, siltstone-sandstone rocks of units 4, 6, 7, 8 of the Arufu Limestone Shale in the Gbale-Akwano Juwudu Hill area (see figs-17H and M) and the basal beds of the Fiyaji Regressive Beds.



K E Y

+ ..... Unmineralized calcareous sandstone
■ ..... Mineralized limestone
▲ ..... Unmineralized limestone
● ..... Unmineralized blackshale and sandstone
▲ ..... Mineralized sandstone and siltstone
DC240 Analyzed specimen number

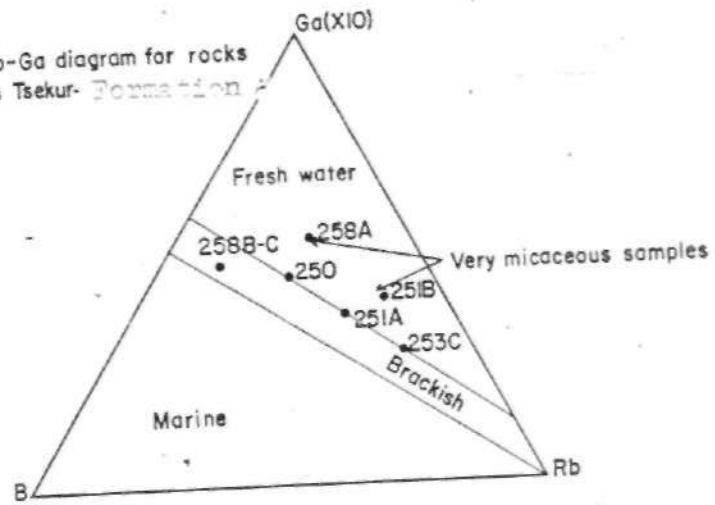


FIG. 3.14 B-Rb-Ga diagram for rocks from Tsekur- Formation

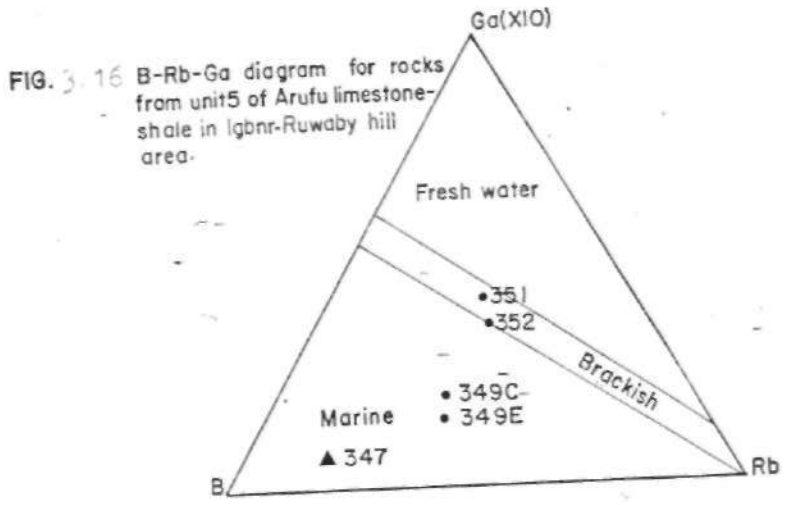


FIG. 3.16 B-Rb-Ga diagram for rocks from unit5 of Arufu limestone-shale in Igbnr-Ruwaby hill area.

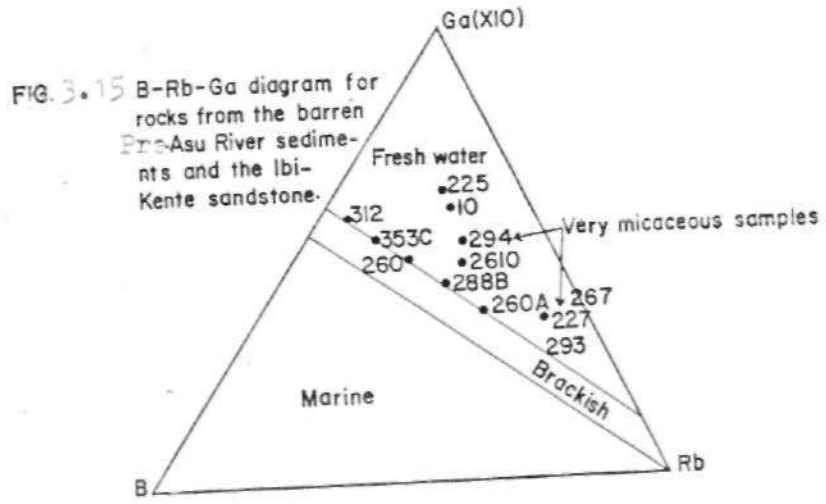


FIG. 3.15 B-Rb-Ga diagram for rocks from the barren Pre-Asu River sediments and the Ibi-Kente sandstone.

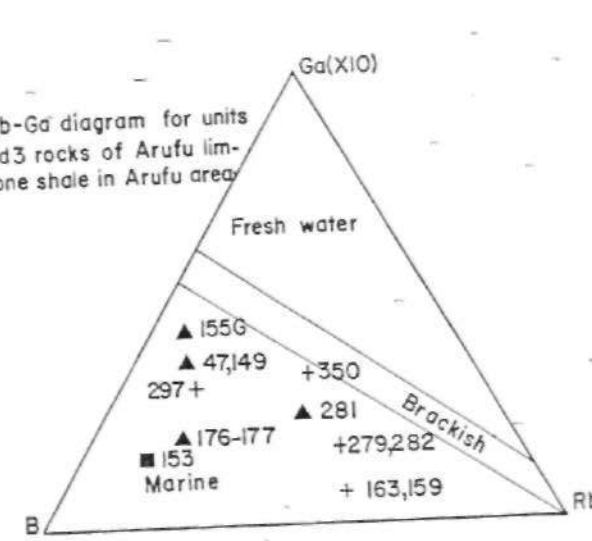


FIG 3.17 : B-Rb-Ga diagram for units 2and3 rocks of Arufu limestone shale in Arufu area

K E Y

■··· Barren sandstone siltstone

+··· Mineralized siliceous limestone and siltstone

▲··· Less-mineralized limestone and siltstone

• Unmineralized black shale/sandstone

K E Y

●····· Unmineralized black shale/sandstone/clay

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Post depositional changes in the Cretaceous formations of the study area include (a) Diagenesis on compaction and subsidence (b) silicification and dolomitization (c) Tectonic deformation and facies changes.

Post depositional changes in the Pre-Asu River sediments at Arufu-Yatiev are due to diagenesis on compaction and involved recrystallization of clays, microfaulting and linear siliceous structures whose origin is attributed to diagenetic volume growth processes during the diagenesis of the siliceous sediments (cf Steninitiz 1981). In the Tseagodo-Tseagu area, and around Atongo-Tseaguda area (Fig. 1.1 back pocket) post depositional changes include partial resorption (pressure solution) of clasts by carbonaceous-siliceous-ferrugineous matrix, the development of authigenic tourmaline and the alteration on recrystallization of mica. In the zone of intense deformation, incipient pink cleavage has developed and zones of pinkish white quartzo-feldspathic material have suffered marginal granulation.

The marine Albian shale-siltstone rocks and the limestone sequence, and the boundstone and packstone-grainstone in particular, of the study area, contain products of deep burial diagenesis, subsidence and contemporaneous erosion. These include, respectively (a) slup structures (DC 168, 200 - 204) (b) intraclasts of pelmicrite, and burrowed biomicrite (DC 183, 283) deposited in shelf-littoral and other sheltered environments (c) Ostrean pelecypod debris and degraded rhodoliths derived from Oyster-banks and (d) depressed scleractinian solitary corals (DC 289) derived from a physical break down of a coral colony in the Arufu and Tseishom areas. While inadequate subsidence during deposition of the lower limestone-shale

Beds 1 to 4 of the Uomba Formation in the study area might be a possible reason for such widespread penecontemporaneous erosion giving rise to periodic hard grounds, the role played by storms in generating much eroded debris cannot be ruled out.

The association of the Lower Cretaceous scleractinian solitary corals - Stephanosmilia per lata de formentel (DC 283, 283C, H.289, 291) with the "Oyster Bank" shelly Limestone is apparently enigmatic, and can be related to the special environment created by the narrow sedimentary depression (graben structure) separating the two NE trending uplifted basement inliers - the Arufu Inlier to the West and the Igbur Inlier to the east. These solitary corals are capable of swimming freely or floating in deep sea or shallow marine water, and have a considerable temperature and depth tolerance (Milliman 1974, Johnson 1961). Under normal circumstances this coral assemblage could be interpreted as indicating the proximity of cold currents as discussed in this chapter.

Silicified zones are common in the Asu River Limestone-shale-siltstone sequence at Arufu and Yatiev where most of the quartz has been recrystallized and/or altered though their grains appear to have retained their original silt size (DC 288A-D, 222). Pressure solution indicates that this area experienced further subsidence and development of considerable overburden. The magnesium bearing waters responsible for the dolomitization after phreatic cementation might have had their origin from the basinal side due to compaction of shale to which the limestone changes facies in the down dip direction.

The slump structures are indicative of deposition on a yielding subsiding, irregular (basement) surface. Characteristically, the sediments of Beds 3 and 4 shales of the Arufu Formation are fine-

fine-grained, poorly laminated, thick-bedded or massive. Reyment (1965) has observed that fresh water and low-selinity shales are extremely finely bedded, whereas marine shales are coarsely bedded and poorly laminated owing to flocculation by the sea water of clay particles arriving from the water course. The apparent non-calcareous nature of most of the sediments of units 3 and 4 can be attributed to dolomitization, and silicification processes probably due to burial diagenesis on compaction and subsidence. The pitted vughy surfaces on the siltstone in Bed 3 and the interbedded limestone in Bed 4 shale of the Arufu Formation are probably due to pressure solution and may indicate that the local sedimentary basin in the Anyiin-Akwana area experienced further subsidence and development of considerable overburden.

In the Lower Cretaceous sequence of the area mapped (within the Middle Benue Valley) the lithological variations were apparently controlled by the lithology of basement structures active during sedimentation (cf. Wright 1981).

CHAPTER 4

STRUCTURAL GEOLOGY AND IGNEOUS ACTIVITY

4.1 Introduction

It is generally believed that the Benue Trough like the other West African basins, was initiated during the lower Cretaceous in response to the separation of the African Landmass from the South American continent, and the subsequent opening of the Atlantic Ocean. The sedimentary sequence in the coastal basins of West African and Brazil show remarkable similarity (Reyment and Tait 1972, Omotsola and Adegoke 1981, Maurin 1987).

Detailed structural studies during the present investigation indicate that the initial stage in the evolution of the study area (in the Middle Benue Trough) appears to have involved uplift, doming and rift-like faulting (normal) faulting parallel to the NE-SW trending boundaries of the trough), probably during Pre-Barremian or Aptian Early Albian times.

Available stratigraphic evidence also indicates that the subsidence of basement blocks (that is, rift-generated basement subsidence) underlying the Middle Benue Trough resulted in the initial deposition of a sequence of immature continental grits, clastics (feldspathic sandstones) and pebbly, gritty sands of the Pre-Asu sediments in the Lower Cretaceous (Barremian?) over the entire basin. This deposition which was initiated in fault-controlled depressions on the crystalline basement was accompanied by alkaline rhyolite extrusion modelled by a K-Ar radiometric age of 113 $\pm$ 3 m.y. i.e. Aptian (Umeji and Vachette 1983) in the Tseagu Hill area.
Over 350 metres of these continental sediments are still preserved in

the Tseagodo Graben. The Aptian age for the Tseagu Hill Rhyolite sill indicates that the age of the Pre-Asu Sediments is at least Pre-Aptian (Barremian to Neocomian?).

The thickness of the sedimentary sequences in different parts of the trough appears to have varied according to the prevailing structural situations. It is believed that the basaltic vents and flows so common in parts of the Upper Benue and Gongola rivers are represented, to the Middle and Lower Benue by doleritic dykes, sills and smaller intrusions where the sediments are thicker.

McConnel (1949) and Farrington (1952) believe that the emergence of basalts volcanism in the Benue Depression has been dominant, hence the scarcity of craters and agglomerates in the study area and other parts of the Middle Benue is evidence for the subordination of gaseous activity. Thus one can imagine that the basaltic rocks rose easily in OPEN FISSURES and fractures in the competent rocks of the Basement Complex but found difficulty in penetrating plastic sedimentary series in which fissures would not remain open. Hence, where the sediments were thick hypabyssal types of rocks resulted.

Contemporaneous with and/or following Albian and Lower Turonian marine transgressions in the study area, with the resultant deposition of the Asu River Group and Eze-Aku Formation respectively, the associated basement gneisses and granites as well as the sediments in the basin underwent uplift forming a series of horst-like and graben-like structures, the overlying sediments were apparently subsequently drape-folded. The structural pattern that emerged is evident from the plot of depth to the top of basement in

the boreholes drilled and road-cut lithological sections exposed in the Tseagu-Yandev area. The surface expression of the major regional fracture and fault trends are shown.

Considerable erosional activity accompanied the uplift and block faulting. The Pre-Asu River Continental Sediments were apparently extensively eroded from the horst-like basement inliers and ridge - areas.

Fracturing along the strike of the rift-like trough opened the way for the escape of magma from the underlying zone of partial melting in the mantle, the expansion of which gave rise to the original layers of basic igneous rocks in the sedimentary sequence in the Arufu-Ikwe-Buru area as dolerite dykes and sills under tensional regime.

In the first part of this chapter the study of the fracture (fault) analysis is undertaken with a view to reconstructing the distribution of the palaeostresses in the study area. In the last part of the chapter dealing with the nature of rift-faulting, the stress pattern is then compared with the geometry of tectonic structures related to similar continental rift systems in other parts of the world e.g. the East African Rift System. The geomorphic phenomenon of erosion surfaces and the associated alkaline igneous activity are added to form a model that most satisfies the observed field relation of rifting in this part of the Middle Benue Trough.

4.2 Structural Analysis and Interptretation

4.2.1 Method of Study

As has been stated in the introductory part of this work, the approach to resolving the apparently complex structural problems of the area mapped consisted mainly of detailed fracture analysis in order to delve into the systematic study of :

(a) the trough margins in the Ngibo-Amafu area to the southeast.

(b) the margins of the NE-SW trending basement inliers, blocks and ridges together with the local sedimentary basins on their flanks separating them, for comparison.

About 2000 field measurements were made of the attitudes, frequency and mineral infilling (galena, quartz fluorite, pyrite, saline waters, iron oxides, secondary encrustations, silicified rock or igneous material) of the fractures, joints (Table 4.14A,B,C, Appendix B). Another batch of special measurements were made of the fold axes and "Ss" beds, with the aim of constructing Rose Diagrams, Point Diagrams and Polar transformation (Reconstruction) Diagrams derived from Table 4.15 (Appendix B).

(c) Field investigation of fractures and lineaments in the underlying and surrounding crystalline basement rocks, which in places continue into the sedimentary rocks probably due to rejuvenation along old structural lines of weakness in the basement. This may indicate shallow basement surface beneath the sedimentary surface concerned.

(d) the significance of some parallel NW-SE transverse structures and NW-SE silicified en echelon fractures, lineaments or fault systems aligned parallel to the NE-SW trend of the Middle Benue Trough or transverse to it.

(e) Complementary Remote sensing and geophysical techniques of fractures analysis.

Remote Sensing Techniques

(i) Photogeology

Interpretation of the aerial photo coverage at the approximate contact scale of 1:40,000 of the Akwana

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standard sheet 252, was undertaken in order to study the major structural or geological trends in the region. Also major geomorphological features were highlighted.

(ii) SLAR RADAR

Mosaic Sheet No. 32 - 15 N and S of the Middle Benue Valley at the contact scale of 1:500,000.

(iii) LANDSAT

Multispectral LANDSAT imagery transparencies and Mosiac (No.20352 - 05554, 9th January 1976 at the approximate contact scale of (1;500,000) were studied to evaluate the applicability of these satellite imageries to the Benue Trough problem.

4.2.2. Folding and its possible relation to shearing movements and vertical adjustments

Figure 1.1 (back pocket) shows that the main fold trends of the Arufu-Akwana-Yatiev area are mostly NE-SW varying to ENE-WSW, roughly parallel to the boundaries of the Middle Benue Trough. The folds in the Late Cenomanian to Lower Turonian Eze-Aku Formation plunge at a low angle of 4° to 10° to the southwest, while those in the Lower Cretaceous Pre-Asu River Formation and the marine Asu River Group are doubly plunging at angles of 4° to 30° NE and SW or NW and S. The variablility in their strike reflects the sinusoidal feature of the main fold axes and is thought to be due to the effect of later folding in the Post-Lower Turonian or Santonian times, superimposed on the earlier Late Albian? - Early Cenomanian? deformation (cf. Offodile 1976) which affected the Lower Cretaceous formations.

Offodile (opt.cit) believes that the compressional forces responsible for these folds probably generated the shearing and faulting often found in the Keana Formation. The axial regions of many of the folds in the study area are marked by alkaline igneous activity, e.g. the axis of the Mbadim Anticline is marked by the Tseagu Hill alkaline extrusive ryholite sill modelled by the K-Ar age of 113 ± 3 m.y. i.e. Aptian (Umeji and Vachette 1983) emplaced into the Pre-Aptian. Pre-Asu River Basal Sandstone. The volcanic rock forms a dome-like structure. The Older Lower Cretaceous sedimentary formations are characteristically more intensely folded, and in the Asu River Group en echelon drag folds occur in the Arufu - Buru area. There is also the possibility of drape folding in Yatiev - Ugba area underlain by both the Pre-Asu River Sandstone and the marine Asu River Group. These features are thus thought to have resulted from both repeated compressive forces (Benkhelil 1982) and/or vertical adjustments during basin development (Wright 1981, Nwachuku 1985, Hoque and Nwajide 1985) that acted on the formations. With regard to the latter mechanism of folding in the trough it is thought that the accumulation of sediments in the basin probably led to the development of instability at the base of the faulted crustal blocks which culminated in large scale folding of the overlying sediments with fold axis parallel to the NE trending axis of the trough. The compressive view comes from Benkhelil (1982) who proposes a covergent strike-slip mechanism for folding of the trough with axes parallel to its NE trend.

Some observations that seem to favour the existence of a thrust? fault (cf. Offodile 1976) in the study area include the continuous shi shift to the north of the location of the axis of the Arufu and Buru Anticlines (Fig. 1.1. Back pocket). Ajayi and Ajakaiye (9181) have

made similar observations with respect to the Ciza syncline and the Keana Anticline.

But in Olade's model for the rift origin of the Middle Benue Trough (Olade 1975, 1976) the upwelling and cassation of mantle plume in the area culminated in the rifting of the trough and the subsequent folding of the sediments it contained with the fold axes parallel to the trough. His strongest support for this model was the apparent lack of thrust fault, that could explain why the sediments were thus folded.

Apart from the folding and fracturing (faulting) exhibited by the Cretaceous sandstone, shale and carbonate formations in the cores of the anticlinal structures the Cretaceous sedimentary beds of the area mapped generally possess a gentle regional dip of 8° - 12° to the NNE or NNW. On approaching the axes of the Arufu and Buru Anticlines and those of the complementary Kanji and Middle Benue synclines, respectively, the regional dip veers to the SE, or NW, especially in places where the folds are split into smaller parallel on echelon structures, as if the movement was relayed northwards. Also on approaching the axes of the anticlines and synclines the highest (youngest) Lower Turonian formations undergo marked changes in lithology in the Buru-Sufa area giving place to sandstones over the axes of the folds. The outcrops narrow considerably due in part, to steepening of dips and also because of marked thinning of the formations caused by faulting.

In the southeastern part of the study area, the Yatiev Anticline and its complementary Afia syncline, have gentle fold axes which run roughly in a NW-SE direction perpendicular to the trough axis.

The two folds are doubly plunging at low angles. At Afia, the gentle synclinal fold axis coincides with the course of the Afia River. The axis of the Yatiev anticline, in the Ibav-Fiyayi area, is marked by a "Circular Feature" which has a dome-like structure in the Wankper-Aka area. This dome-like structure is probably due to a blind igneous intrusive body (cf. Offodile 1976).

4.2.3 Joint and Fracture Analysis Interpretation in relation to major fault structures

Tables 4.14 A-C (Appendix B) make up the data obtained from the systematic field study of the joint and fracture patterns of the study area. The Rose, point, stereographic Diagrams are plotted from the above data.

Joints and fractures may generally be referred to predominant structural trend in a region. This predominant trend may be expressed by fold axes and faults, basin rims warps or uplifts in foreland (cratonic) areas (see Badgley 1975).

The Rose Diagram indicates that three main classes of joints are present both in the basement and sedimentary terrains of the study area as follows:

(a) S-(strike, longitudinal) joints which are roughly parallel to the foliation in the crystalline basement rocks or parallel to strike of sedimentary bedding planes and fold axes. The S-Joints in the study area generally have NNE-SSW or NE-SW trends.

(b) C-(Cross) Joints which are roughly perpendicular to the fold axes or strikes of bedding planes and foliation. In the study area these have steep (70° - 80°) to vertical dips and are usually located along the margin of the

crystalline basement. They are characterized by NNW-SSE or NW-SE trends. Near the basement margins they usually truncate or offset the earlier NE-SW sets amd continue in northerly to NW direction forming curved (arcuate?) structures.

(c) D-(Diagonal, tear, wrench, shear) Joints, which occur in the study area as paired sets (D_1, D_2) usually with N-S or N by E trends in the Cretaceous sedimentary terrain. In the Precambrian Basement Complex terrain the D-Joints and shear fractures sometimes assume NW-SE orientations. These three classes of joints have characteristically steep dips.

Generally the D-Joints and Fractures intersect fold axes or regional strikes of foliation in the basement rocks or sedimentary rocks at acute angles varying from 15° to 45°. They also intersect to form acute dihedral angles about the cross-joint trend and are also characterised by steep dips.

In the study area the S-Joints are recognized as set III joints while the C-joints are known as set II Joints and the D-Joints as set I Joints in the sedimentary terrain and also in the basement area.

In the basement area the D_1 - Joints trend N 10° - 13° E while the D_2 - Joints trend 30° - 45°. They intersect to form obtuse angles about the strike joints in the basement and sedimentary areas, and acute dihedral angles about the cross-joint trend. The dips in both the basement and sedimentary terrains range from 45° to 65°.

Within the silicified zone marking the northern margin of the Tyoban - Tsekwen basement granite block, the steep slopes of the

massif face the north bank of the NW-SE flowing Ubaver stream in the Tseaguda Changoji-Tseadzum area (Loc. 161, 181, 258, 259). Here the D_2 - fractures contain slickensided vein quartz (DC 388D). This marginal fracture may be suggestive of a horizontal compression as a force system responsible for the shearing probably leading to differential uplifting of the Older Granite body (Badgley 1975).

Structural Interpretation of Borehole Data

Another aspect of the fracture analysis and structural interpretation in relation to major fault structures is shown in Fig.4.22B, obtained from the plot of depth to the top of basement in six boreholes drilled in the Yandev - Gboko area (Fig. 4.22A) for limestone investigation (see Onuogu 1963). The logs of three of the boreholes are shown in Figs. 4.23 to 4.25. The main structures of the area drilled is the Mbadim Anticline (underlain by the Lower Cretaceous sequence). The axis of the fold in the Tseagu Hill area, is marked by an alkaline rhyolite volcanic extrusion, with a dome-like curved, structure.

The Tseagu Hill Rhyolite is emplaced as a sill into the Pre-Asu River Sediments.

It is important to note that some of the test boreholes were drilled vary near the margins of the granitic Basement Complex by the Benue Cement Company Limited (B.C.C. Ltd.), and had at the ending of 1981, penetrated about 200 metres into the Lower Cretaceous sediments without the basement being struck (B.C.C. Ltd. pers. comm. 1982). The great sediment thickness near the margin of the basement may be interpreted as being due to the fact that the borehole is located on the down throw side of a normal fault and may then confirm

the idea of step-faulting or graben structure in this part of the Middle Benue Trough.

Foliation in the Mbadim Basement Complex inlier strikes N-S while the regional dip of the overlying Lower Cretaceous sediments comprising the western limb of the Mbadim Anticline is 10° - 25° SE. Steeper dips in each case occur nearest to the contact with the Basement Complex. This is evidence of "crowding".

The structural patterns of the area that emerged is evident from a plot of depth to the top of the Basement Complex in the vertical boreholes drilled (Fig. 4.22B). This plot shows that (rift) generated basement subsidence during the Lower Cretaceous (Pre-Barremian or Neocomian?) resulted in the deposition of basal continental grits and sandstone (DC 260, 227, 293-4) - the Pre-Asu River sediments - in a series of rapidly subsiding fault-controlled depressions on the Basement Complex over the whole basin. This was followed by alkaline volcanic activity leading to the extrusion of rhyolite sills (DC 361, 321G, 381, 382 and 383, Fig. 4.22B) into the continental sediments during the Aptian as exemplified by the Tseagu Rhyolite sill, of 113 $\pm$ 3 m.y. radiometric age (Umeji 1981 pers. comm.).

This was followed in Middle Albian by the deposition of marine platform carbonates - the Yandev Limestone (Reyment, 1965). An early episode of deformation probably led to the folding of the Cretaceous rocks in the Cenomanian (Nwachuku, 1972, 1975), and may have originated due to reactivation of the basin along the basement faults.

Then during a major tectonic activity probably associated with vertical adjustment and folding of the Benue Trough during

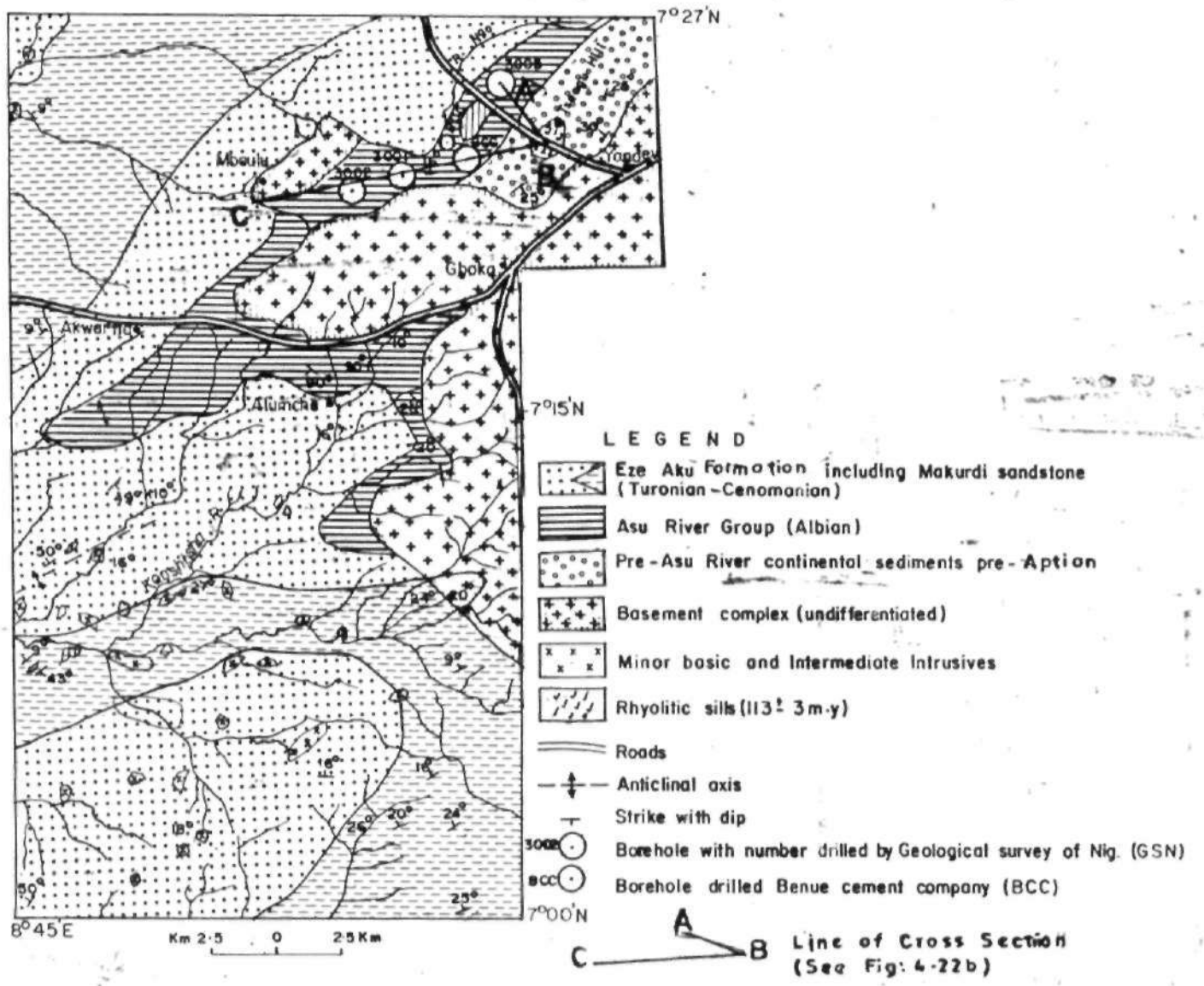


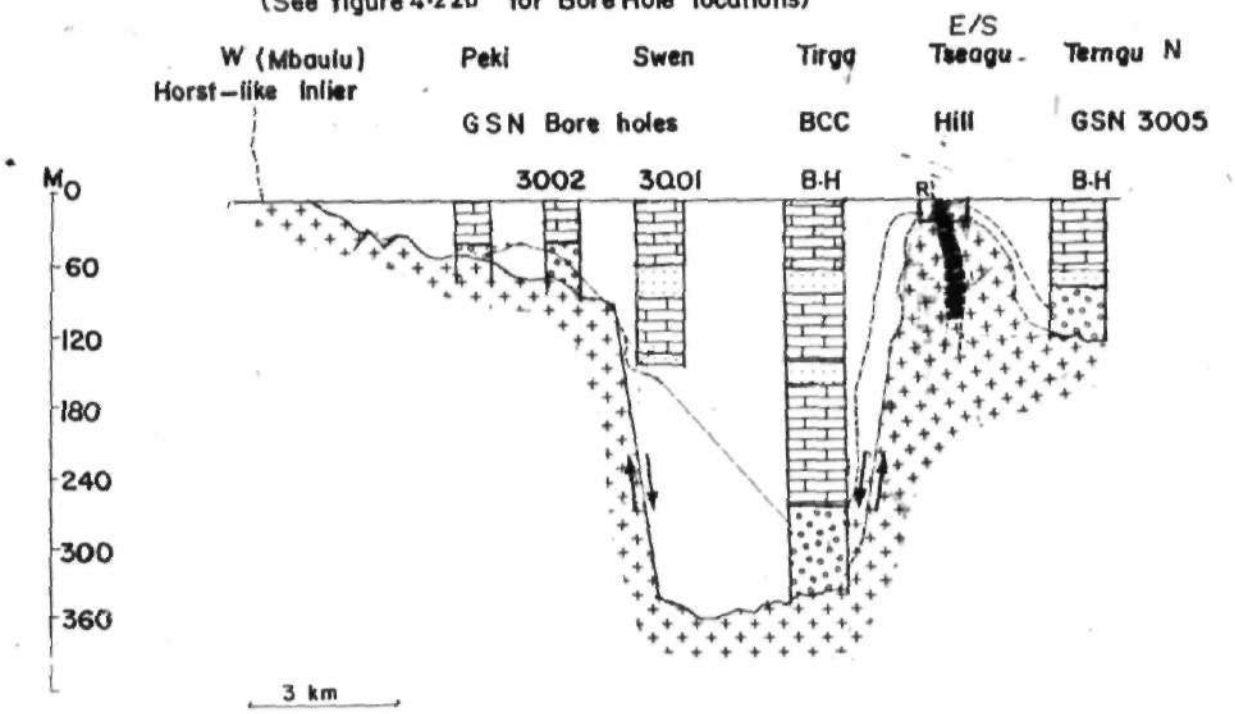
Fig. 4·22a Geological Map of Gboko/Yandev area (Modified after Onuogu 1963)

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COLUMNAR SECTION ACROSS NGO RIVER—TSEAGU HILL — MBAULU AREA. NOTE GRABEN-LIKE STRUCTURE.

FIG: 4-22 b

(See figure 4-22a for Bore Hole locations)



Gboko (Yandev) Limestone — Asu River Group: Albian Limestone with interbedded Shales and Sandstones

Pre—Asu River Continental Sediments: Pre— Aptian

Basement Granitic gneiss and the Pan African older granite: Pre-Cambrian - L. Palaeozoic

R Tseagu Hill Rhyolite : 113 ± 3my (Aptian)

GSN 2449 C

LITHOLOGIC LOG OF GSN BH 3005 AT TERNA, 16 KM S-W OF NYAM NEAR LEFT BANK OF RIVER NGO HEAD STREAM AREA. FIG. 4.24

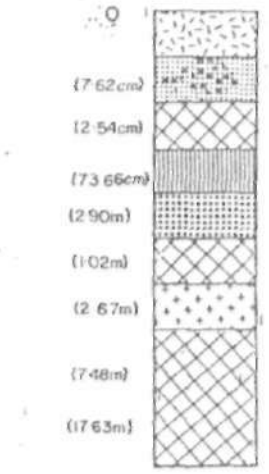
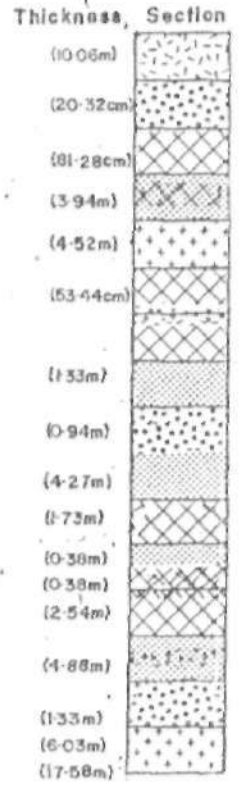


FIG. 4.23

GSN BH 3006 Near Gar Compound 2.25 km N-W Tseagu compound. (Tseagu Hill) or the right bank of lower valley of R. Gamgambe.



GSN 2456E

LITHOLOGICAL LOG OF GSN BH 3002 AT MTOM. FIG. 4.25

Thickness	Section	Description of Lithology	$MgCO_3$ %	$CaCO_3$ %
(4·27m)		Overburden: Clay, Silt		
(12·80m)		Sandstone: fine 10cm of basement at top		
(13·72m)		Shale - Siltstone		
		Sandstone fine calc·		
(16·4im)		Siltstone		
(18·70m)		Sandstone: fine calc·		
(19·8im)		Siltstone		
(22·86m)		Mudstone with 9cm sst at base		
(24·80m)		Siltstone·		
(24·69m)		Mudstone·		
(26·70m)		Sandstone; fine calc		
(28·35m)		Siltstone·		
(42·67m)		Mudstone·		
(45·72m)		Siltstone·		
(53·04m)		Mudstone·		
(54·38m)		Limestone; coral bearing, pyritic	1·51	80·4
(54·86m)		Limestone: med· grained	2·01	91·4
(57·9im)		Limestone: med· grained	1·38	87·1
(60·96m)		Limestone: impure with pyrite	1·38	72·65
(65·85m)		Limestone: med-fine grained	1·57	76·65
(67·78m)		Limestone: fine grained	0·75	82.9
(69m)		Siltstone·	0·33	9·4
(70·03m)		Limestone: impure silty	0·75	71·65
(72·90m)		Limestone: med· grained	1·17	80·65
(75·95m)		Limestone: med· grained	0·75	85·65
(79m)		Limestone: silty	0·96	69·15
(82·04m)		Limestone: med· grained with 17cm siltstone - at top·	0·75	76·15
(84·15m)		Limestone: silty	0·33	77·90
(84·76m)		Siltstone	0·33	13·90·
(85·09m)		Limestone: med. grained	1·57	84·15
(87·94m)		Limestone: with thin silty beds	0·75	68·25
(88·7im)		Limestone: silty with scleractinian corals	0·54	56·65
(89·08m)		Breccia-conglomerate sst with calc. matrix, grey, green, clay mudstone· cross-stratified felspathic-conglomerate sandstone		
(103·12m)		Granite and gneisses (Basement complex)·		

GSN 2456F

Cretaceous, the Basement Complex rocks, as well as the sediments in the area were tilted and block faulted leading to further development of a series of horsts and graben (Fig. 4.26).

Field experience in the present investigation indicates that the area is affected by at least, two systems of faults. Early axial faults with northeasterly trends are truncated or offset by transverse fractures with NNW orientation, as for example near the Mbadim inlier. Where the Lower Cretaceous sequence abuts on the western end of the Mbadim basement inlier, the throw may be of the order of over 250 metres.

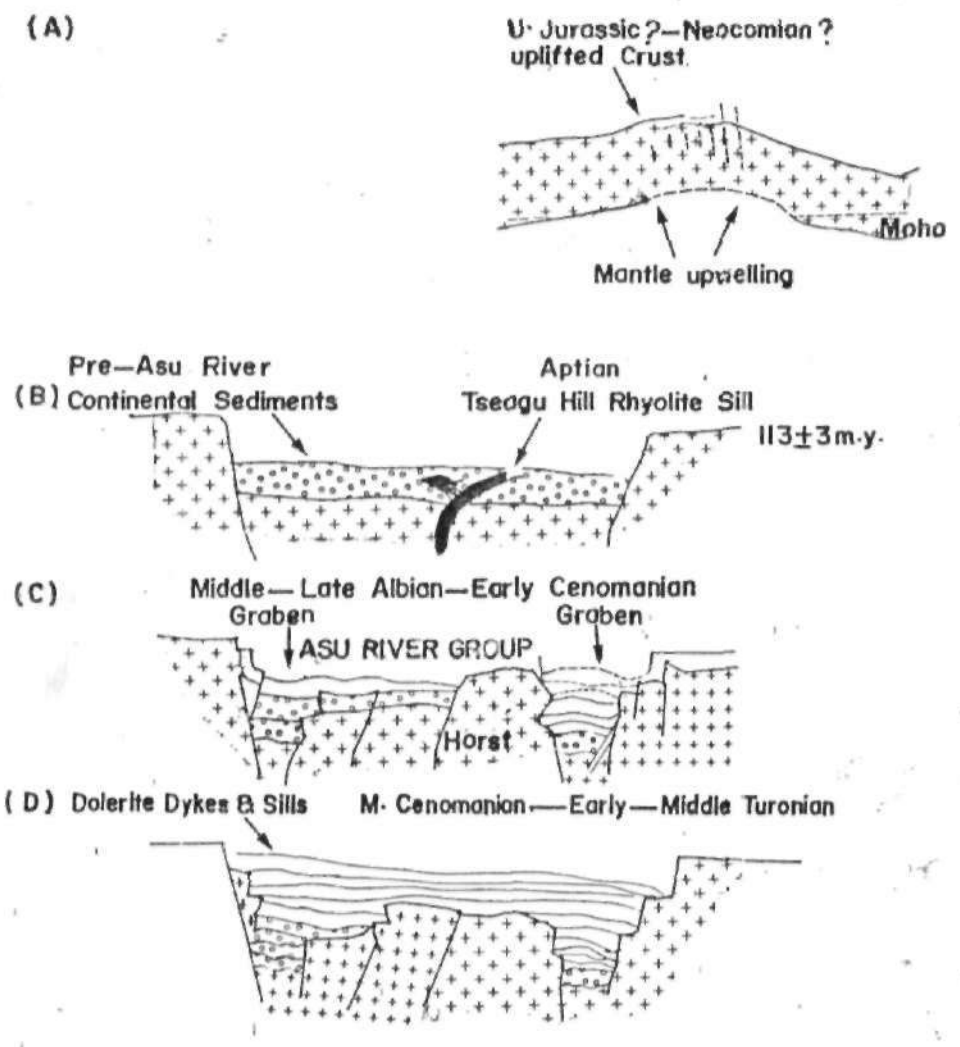
The graben structure in this part of the study area may indicate that isostatic loading by sediments filling an original graben structure might have resulted in an enhanced down warping of the flanking areas of the Middle Benue Trough, so that the resulting linear depression might be much wider than the original RIFT, and the marginal fault scarps have been overlapped and buried by sedimentary fill (cf. Beaumont and Sweeney 1978) accompanied by silicification and diagenesis during basin development.

Structural Analysis of Basement Inliers

Several types of faults occur at different scales in the basement of the study area. In the Tyoban inlier two main subparallel-fault zones (crushed zones) cross-cut the whole inlier in a NE-SW direction (Fig. 1.1 backfolder). The fault zones display both both ductile and brittle shear zones. The ductile zones contain fault rocks that consist of crudely mylonitic bands while the brittle ones are expressed as brecciated structures (cf. Maurin et al. 1986). The latter reworks the former in the same crushed zone.

TECTONIC MODEL FOR THE EVOLUTION OF TSEAGU UGBA ARUFU-AKWANA AREA (Middle Benue Basin)

FIG. 4.



G.S.N. 2449D

Near its contact with the overlying crushed and silicified Cretaceous rocks the Igbur inlier granitic gneiss assumes a contorted, sheared appearance parallel to the strike, which now assumes a N-S direction, implying a rotation through 20° in reverse sense of movement. The rock appears to have been converted to a mylonite. A decrease of grain size can be seen, as well as a progressive stretching of the feldspar porphyroblasts and quartz ribbons (DC 199). On the Sm foliation surface the stretching lineation of quartz ribons and feldspars is horizontal and the vertical foliation and horizontal stretching lineation characterize a ductile strike-slip fault. The sigmoidal-shape of the stretching characteristic of a ductile zone (Ramsay and Graham 1970) can be used as a criterion of sense of movement, which is dextral in this case.

Thin section analyses of the sheared (mylonitic)facies of the granitic gneiss from the Igbur Inlier were carried out in a plane normal to the foliation Sm and parallel to the stretching lineation. The following microscopic features were exhibited:

(i) Elongated bands of micaceous aggregates with chloritized biotite, chlorite, feldspar and rare muscovite define the foliation Sm.

(ii) Rare sigmoidal-shaped feldspar flakes show evidence of rotation in a ductile mossaic and brittle behaviour (Boullier 1980). This sometimes marks an obliquity of the foliation to the shear plane similar to the C-S surfaces described by Berthe et al. (1979).

(iii) Sm. moulding sigmoidal shaped flakes and ribbons.

(iv) The quartz exhibits evidence of plastic behaviour characteristic of mylonite (Bell and Etheridge (1973):

shape fabric, deformation bands and elongated crystalline ribbons. Some ribbons contain elongated quartz grains with undulose extinction (indicative of strain) while others contain statistically recrystallized polygonal quartz grains (White 1977).

(v) Retrogressive bands of brecciated material sometimes occur parallel to the pre-existing foliation and/or shear planes.

(vi) Small bands of brecciated material constitute shear plane C parallel to Sm.

In thin section the occurrence of chlorite and rare muscovite in the granitic gneiss associated with the destablisation of biotite indicates that the mylonitic (sheared) facies developed at a relatively low temperature (Maurin et al. 1986).

Within the NE-SW trending fault zones of the Tyoban Muscovite biotite Older Granite Inlier steeply dipping brecciated fault bands, a few metres wide are seen to rework the mylonite. They form several crushed zones striking N 45°E or N 50°E.

According to Sibson (1977) the brecciated shear zones represent cohesive fault rocks characterized by brittle fragmentation and decrepitation within shear zones. In the study area, on the hand specimen scale, the brecciated material occurs as microbreccia displaying angular fragments in a dark mossaic or matrix. In thin section angular fragments of cracked feldspar and quartz with undulose extinction occur within a fine-grained matrix which contains greenish brown micaceous aggregates and iron oxides. As brecciated rocks are random fabric rocks it is difficult to determine the nature and the direction of movement within the shear zone.

However, horizontal slickensided lineations were often observed on the vertical walls of the brecciated bands. Thus if movement criteria as defined by Petit et al. (1983) are applied in some of the cases studied, the movement may be sinistral. It could also mean that sinistral (shearing or transcurrent) movement was followed and/or reworked by brecciation, indicative of deformation under a tensional regime.

The fault breccia zones contain angular fragments, ranging from 1 to 10 centimetres in size, or either previously deformed (mylonitic material, granitic gneiss) or undeformed (isotropic granites etc.) rocks. The fault breccia zones rework the shear (mylonite) zones. They probably represent deeply penetrating vertical movement.

Microfault Analysis

In the field, substantial faults are marked by strips of closely spaced fractures, 1 to 3 metres wide displaying mainly coalescent subparallel planes. Most of the micro-fractures have steep to vertical dips. The fault planes frequently display linear features when preserved from weathering. The NW-SE flow direction of River Kyn appears to be controlled by a major NW-SE trending fault on the Tyoban Granite massif. The sense of fault movement was also determined by the observation of fault plane markings and features of synkinematic crystallization such as mineral lineation and segregation. The geometry of crushed zones, striated secondary planes and breaking features as proposed by Petit et al. (1983) were considered. A preliminary plot on an equal area projection of micro-faults are plotted separately. Fig. 4.28D gives the acute angle formed by the conjugate shears and yields a quite precise determination of the strain axis, Z. Point diagrams of faults on the

Precambrian Basement Complex granitic rocks in the Tyoban-Abeda in relation to foliation and folding, and also the stereographic diagrams of the regional joint system indicate that the joint system is related to faulting and uplifting of the same Precmabrian Basement Complex Complex rocks.

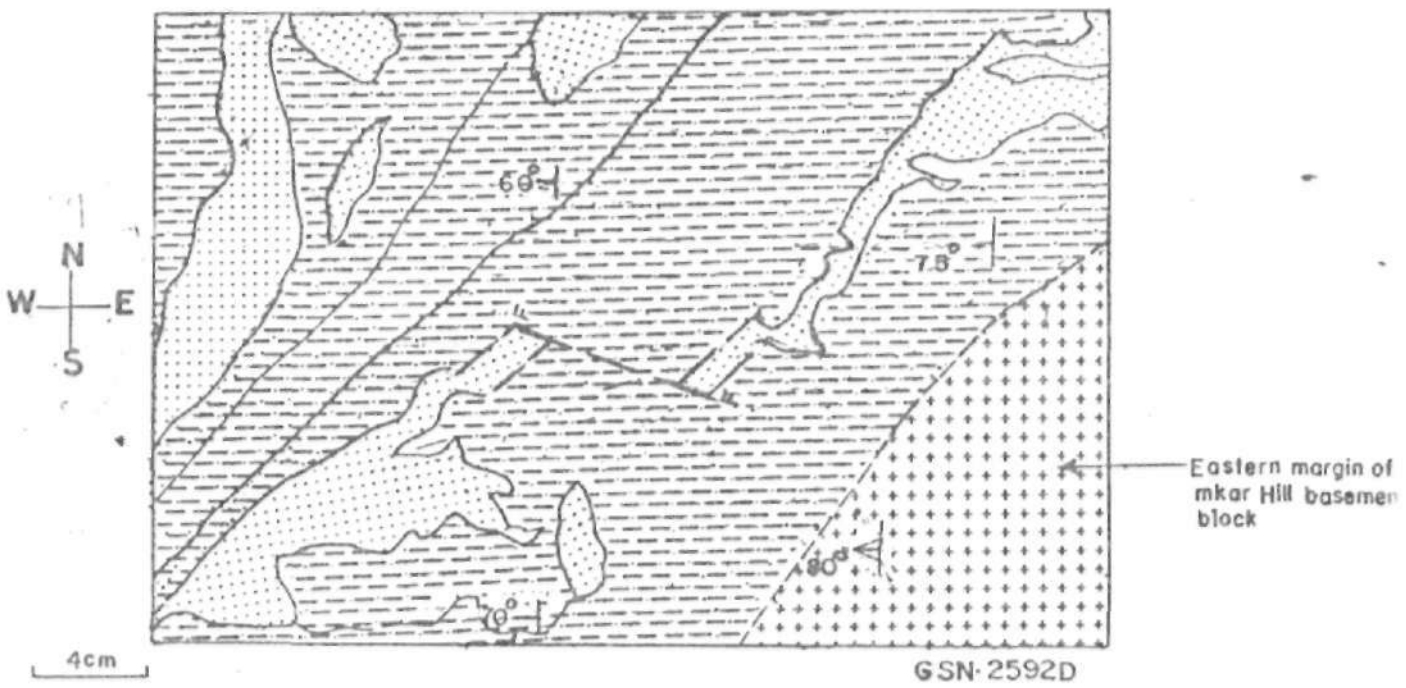
Fault Structures within the Cretaceous Sediments

Extension of the shear zones in the Tyoban Inlier within the sedimentary cover can be followed to the NE and SW for several kilometres. Near Tseaguda and Atongo the extension is marked by highly fractured and crushed silicified rocks. In the Igbur-Tseaguda area, the deformation is characterized by a system of crushed (sheared) and brecciated silicified (i) siltstone (belonging to the Asu River Group) (ii) feldspathic sandstone of the Pre-Asu River Sediments (Fig. 4.27; Plate 3.1).

Fold and Fault Structures within the Mineralized Cretaceous Sediments

The basement inliers of the study area are mostly surrounded by the Asu River Group sediments consisting of mineralized limestone-shale, fine grained sandstone-siltstone and in a few places by unmineralized continental arkosic conglomerates, feldspathic sandstones and clays of the Pre-Asu River Formation. These display fold and fault structures on differnet scales. the large scale structures are dominated by extension into the Cretaceous cover of the reactivated fault zones of the basement inliers, faulted contacts between the Cretaceous sediments and the basement and the various anticlinal structures.

The folding of the mineralized beds is not evenly distributed but expressed by isolated folds in whose cores are exposed many of



Arkosic – Feldspathic sandstones, conglomerates, clays and mudstone

Feldspathic sandstone

Granitic Basement complex rocks·

80° Dip and strike of foliation of Basement complex rocks

60° Dip and strike of beds of cretaceous sediments·

Fig.4-27 NW-SE Trending · · · fault (FF) on the eastern edge of the Tseagodo Graben(see Fig·1 ·6 for location) Underlain by the lower cretaceous .Pre-Asu River Basal continental arkosic sandstone, feldspathic sandstone and clays· The basal sandstone beds are down-thrown against the eastern margin of the mkar Hill Horst block Underlain by precambrian granitic basement rocks

Locality:- Km 12-13 along Yandev-Katsina Ala tarred road·
same feature shown in plate 3·1, ·

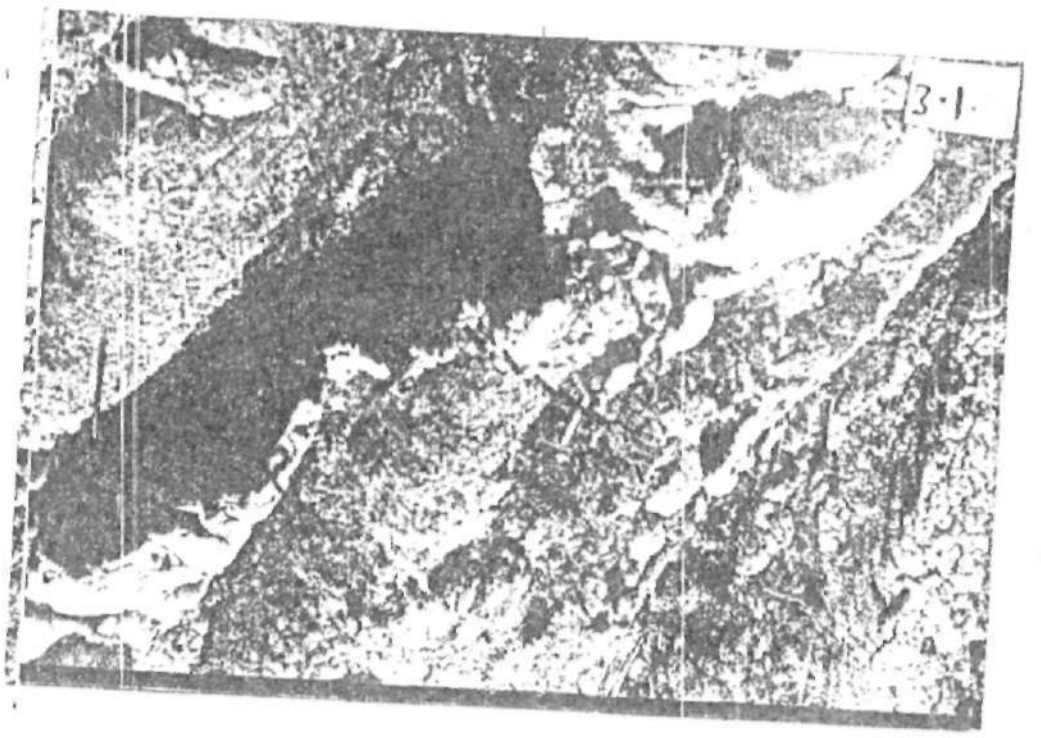


Plate 3.1: NW trending fault (FF) on the eastern margin of the Tucagodo depression underlain by the Lower Cretaceous Pre-Asu River continental sediments. The conformable veins and basal sandstone beds (X) are down thrown against the eastern margin of the Gboko (Mkar) Horst block underlain by Precambrian granitic basement rocks (CY). The steepening of the dip of the Cretaceous beds near their contact with the Basement Complex may indicate faulted contact with the latter along NE-SW direction (See Fig. 3.27 for proper compass orientation).

Locality: Road-cutting at Km 12 along the Yandev-Katsina Ala tarred road.

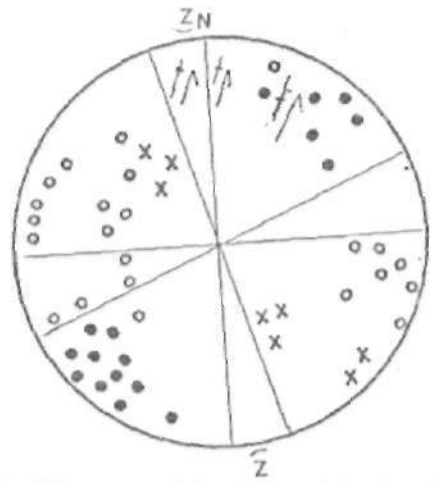


Fig. 4: 28D: Stereographic plot of faults for Tyoban (inlier) basement Terrain area lower Hemisphere.

EXPLANATION

X = Pole to normal (fault plane

O = D^1 Wrench fault (Dextral)

o = D^2 Wrench (Shear) fault (Sinistral)

⫽ = Trace of slickenside on fault plane

• = Dextral strike slip fault
o = Sinistral strike slip fault
N = Trace of slickenside on fault plane

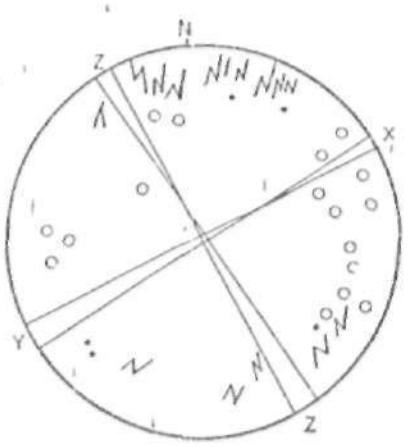


Fig. 4-28E— Stereographic plot of strike slip faults for Iqbur-Tseaguda area (Cretaceous Terrain) Lower Hemisphere (see fig. 1-1 for location)

o = Pole to fault plane
Y = Trace of slickenside on fault Place.

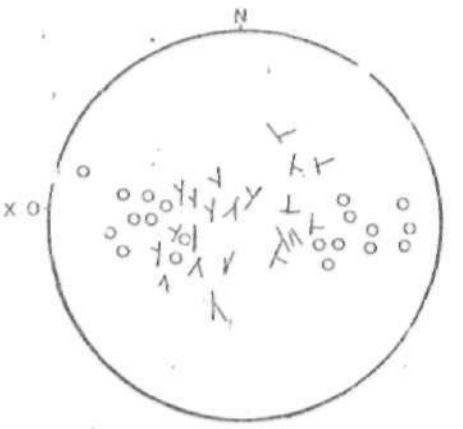


Fig. 4-28F Stereographic plot for normal faults for Arufu Udza area (Cretaceous Terrain) Lower Hemisphere (see fig. 1-1 for location)

the basement inliers e.g. around Arufu. They are strongly asymmetric and their steeply dipping limbs (mineralized in galena) are highly sheared and brecciated around the Igbur Valley (Figs.4.28A-B). The main galena belt of the Arufu-Akwana area is located on the southern limb of the Arufu anticline. The axial traces of the folds trend NE-SW to ENE-WSW. This alignment suggests control by deeply penetrating faults parallel to the basement (inlier) fault zones.

Along the extensions of the reactivated basement faults into the sedimentary cover, some minor folds seen around Igbur and Udza probably result from dragging (Fig. 1.1 back folder). In the Udza-Anza area the folding of (galena) mineralized sediments around the Udza and Tyoban Inliers is located along narrow strips and was apparently closely controlled by basement fault zones.

In the lower part of the Benue Trough the postulated extensions of the Chain and Charcot fracture zones (Benkhelil 1982) bound an important lead-zinc mineralized feature, the Abakaliki anticlinorium centre of active alkaline basic to intermediate igneous activity during Aptian times.

Fault Structures in Mineralized Cretaceous Sediments

Extension of the shear-zones in the Tyoban Inlier within the sedimentary cover can be followed to the NE and SW for several kilometres. Near Tseaguda and Atongo the extension is marked by highly fractured and crushed silicified rocks. In the Igbur-Tseaguda area, the deformation is characterized by a system of crushed (sheared) and brecciated silicified (i) siltstone belonging to the Asu River Group and mineralized in disseminated galena, (ii) unmineralized feldspathic sandstone of the Pre-Asu River Continental Sandstone Formation, separating lenses where the bedding is relatively well

preserved. The mineralized crushed zones form 50 - 100 metres wide elongate en echelon ridges. On a megascopic scale each crushed band is made up closely spaced fractures of various attitudes cutting each other and mineralized in galena. The primary sedimentary structures appear to have been obliterated. The individual fractures show as yellowish grey or whitish bands several millimetres to 1 centimetre wide locally thickened by lenses. In hand specimen the mineralized fractures have the following features:

(i) a central band consists of finely crushed quartz grains with random fabric. In thin section some angular quartz phenoclasts display undulose extinction, and are associated with deformed stringers of galena.

(ii) a sharp boundary between the central brecciated band and the country rock where the quartz grains and the granular specks of steel grey galena undergo a beginning of brittle fragmentation.

(iii) a sharp boundary between the central brecciated band and the country rock where the quartz grains and the granular specks of steel grey galena undergo a beginning of brittle fragmentation.

(iv) Lenses ranging from millimetre to several centimetres size develop along the fractures. The main galena belt of the Igbur valley is traversed by early faults with northeasterly trends that are truncated or offset by curved sets with northwesterly orientations near Igbur village where basal unit (Bed 3) of the Arufu Formation abuts against the basement.

At the northwestern end of the local (graben) basin between the Arufu and the Igbur basement inliers (considered to be a northern extension of the Yandev Graben, the NNE-SSW trending galena belt is apparently cut and offset by NE-SW fractures which are parallel and en echelon giving a "stepped" appearance. These fractures (faults) show minor normal displacements varying from 4 centimetres to over 15 metres. In the depression (graben basin) lying between the Tyoban and the Udza and Arufu inliers the (galena) mineralized, steeply dipping en echelon silicified and brecciated fault zones and lineaments, form prominent elongated ridges 50 to 100 metres wide aligned in a NE-SW direction. These may be normal faults.

At the northeastern end of the disseminated galena ore body within the Igbur local basin a NW trending set of fractures truncates and offsets the mineralized NE trending earlier set, with a somewhat normal displacement of 20 - 30 metres eastward against the Igbur basement Inlier.

Deep-seated marginal faults (which are mineralized in galena where they traverse Albian marine limestones and siltstones) are located along the edges of the graben structures i.e. they are marginal to the basement horst blocks. The most prominent of such faults is the Iyorja faults which runs in NE direction along the margins of the basement inliers in Abeda-Atongo area.

Among the mineralized vertical fracture planes, horizontal striations appear to have resulted from sinistral movement along NE-SW direction. North of Arufu and around Igbur and Udza villages. Slickensided striations occur along high angle to vertical faults. Away from the main shear zones the brittle deformation decreases in

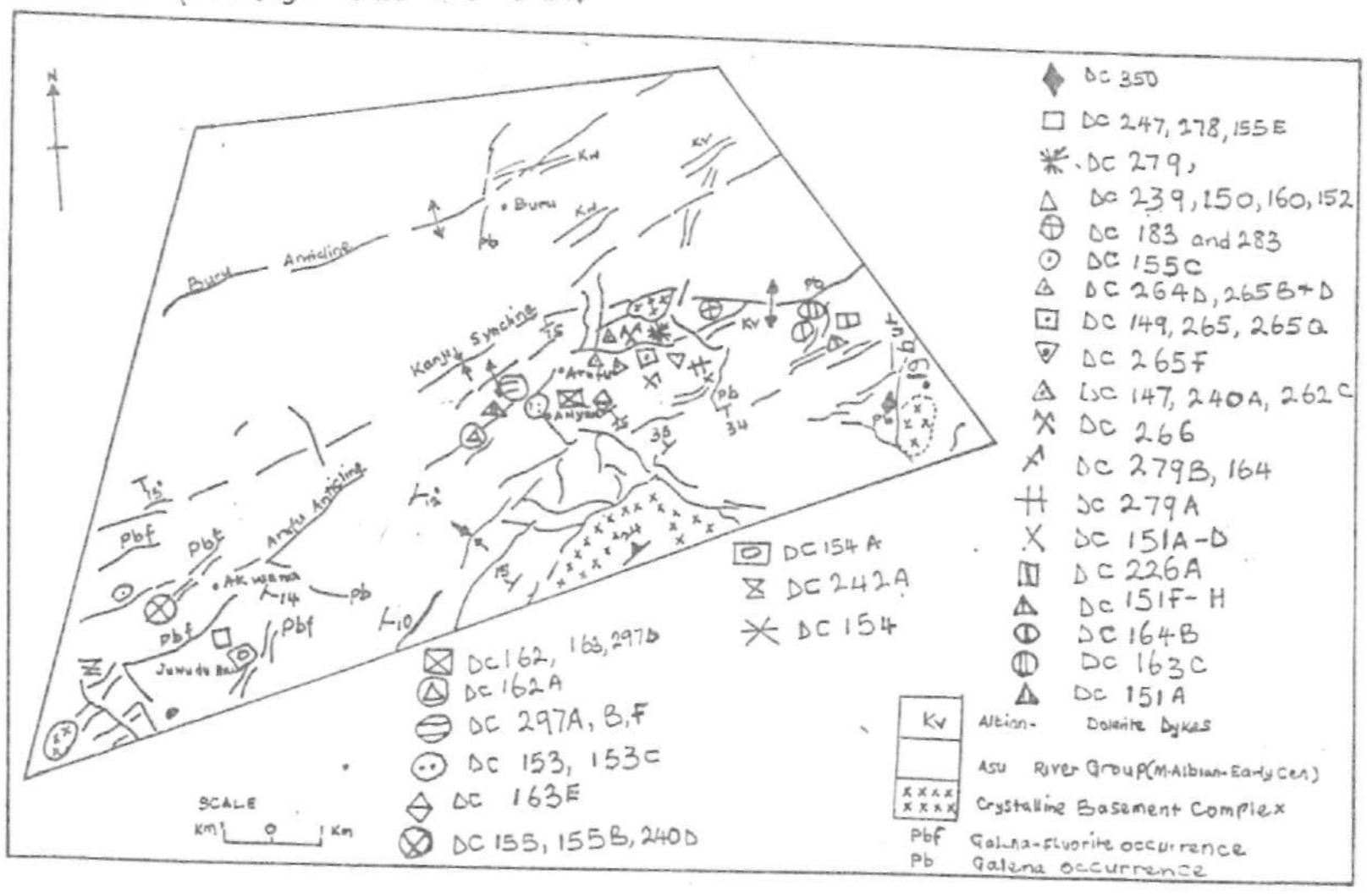
intensity. The faults form regular sets of conjugate fractures which may be strike-faults. The amount of displacement among mineralized minor faults to the SW of Akwana is limited varying from 4 to 10 centimetres. Around Arufu, Igbur, Tseaguda and Abeda-Anza area the deep-seated NE-SW trending crushed and silicified fault zones are cut and displaced towards the basement by NW-SE trending sets. The amount of down throw varies from 200 to over 300 metres (Chuku 1986).

The Arufu fault zone persists in a NE-SW to ENE-WSW direction for over ten kilometres. It is mineralized with the galena specks and stringers massive galena and crystal galena. This fault runs parallel to the southern limb of the Arufu anticline, and contains a Cretaceous dolerite dyke (Chuku 1986).

Structural Analysis of Mineralized fault planes

Determination of the main palaeostress axes on the basis of several families of mineralized slickensided (striated) fault planes was performed using stereographic projections. The obliquity of the striations to the Sn surface used as a criterion for sense of movement (Etchecoper 1977, Burg and Laurent 1978) indicates a dextral movement for the NNE or ENE shear zones. In this a plot an equal area projection of the mineralized slickensided (striated) planes is constructed separately and gives the acute angle formed by the conjugate shear. This yields a quite precise determination of the strain axis, Z. Rose fracture patterns of the Cretaceous sedimentary cover were also plotted and compared with those of the basement inliers. These palaeostress plots indicate that brittle deformation was involved in all cases. The stretching axis (X), horizontal all over the sedimentary area becomes vertical within the

FIG. 4.28A Pit and Surface Sample Localities of the Mineralized and Barren Limestone - Shale - Siltstone Units of the Asu River Group in the Akwana-Arufu - Igbur fracture Zone (see Figs 3·20 and 3·21)



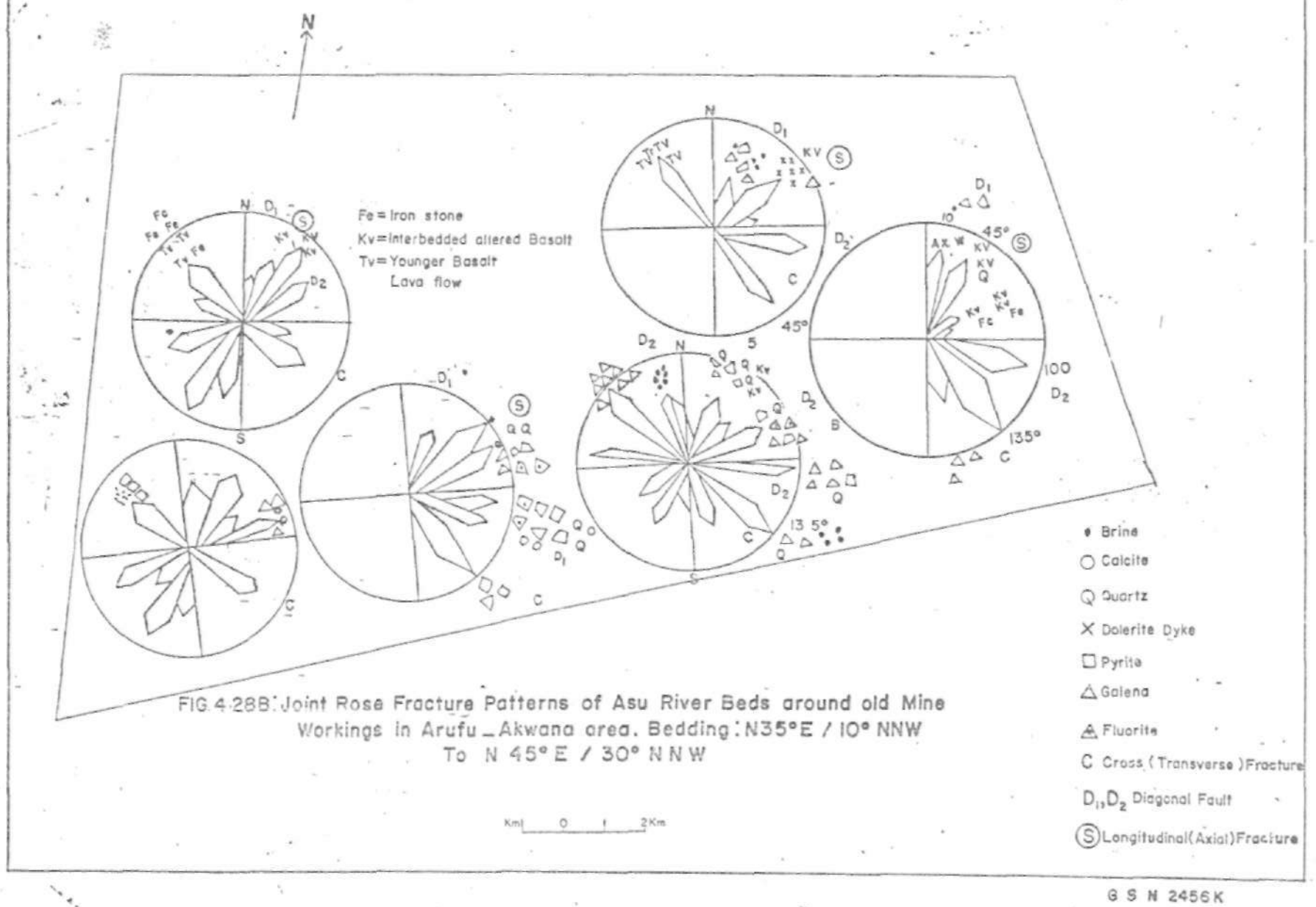


FIG 4.28B: Joint Rose Fracture Patterns of Asu River Beds around old Mine Workings in Arufu – Akwana area. Bedding: N35°E / 10° NNW To N 45° E / 30° NNW

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uplift and drape folding of the overlying sediments. Shears in the basement, as indicated by slickensides on the rocks (DC 388D), display considerable changes of strike near Tsekenghoba compound (to the south of the above basement margin).

Set III joints and fractures are generally curved in and in places concentric. They commonly constitute the NE-SW trending parallel en echelon fracture zones. These en echelon lineaments form preminent silicified scarp ridges, down-towards the basin (cf.Chuku-Ike 1981) in the Arufu, Igbur, Atongo-Tseaguda, Anyiin and Juwudu Hill areas. They may be normal faults parallel to the NE-SW trending boundaries of the basement inliers and also the Middle Benue Trough.

In the structural plots (Figs.4.28B) set III is classified as S-longitudinal, strike) lineament. Around the Yatiev saltpond these NE trending lineament sets display steep irregular surfaces.

Set I joints and fractures, are intermediate in character between II and III. They run parallel to N-S trending discretely placed transverse silicified structures. Their trend varies between 5° and 15°, thus forming acute (dihedral) angles between the strike of the bedding planes and fold limbs or axes, and may be due to tensional faulting (cf. Badgley 1975).

The set III S - (longitudinal, strike) joints form parallel steeply dipping to vertical silicified structures with northeasterly trends in the area mapped. Set III does not seem to have any radial relationship to the folds but is roughly parallel to the fold axes in the north and northwest mostly underlain by the Late Cenomanian-Lower Turonian Eze-Aku Formation. It is better developed near fold axes.

In the Afia, Yatiev, and Vakange and Logo River areas, where the fold axes trend almost N-S or E.W, set I Joints run parallel to the fold axes.

In the mineralized zones at Arufu, Akwana, Buru, Igbur, Nyosu Iyorshagher areas, set III fracture zones characterized by NE or NNE trends, host massive galena (DC 239) and disseminated galena (DC 275, 350) mineralization respectively, confined to silicified and brecciated marine Albian limestones and siltstones.

Saline springs issue from set I fractures or lineaments in the Juwudu Hill, Nwannan and Arufu areas, and from set II around Akwana (Fig. 4.28B, cf. 4.28C).

Set III lineaments are encountered in both the Lower Cretaceous to Cenomanian sedimentary rocks, but is absent in the Lower Turonian Formations of the Eze-Aku Formation.

In the deformed fracture zones to the west and south-west of Arufu and the Juwudu Hills, ENE trending set III fractures(faults) host coarsely crystalline (cubic) galena mineralization in Albian silicified limestone-siltstone sequences (DC 242, 278,297E).

In the Arufu-Anyiin area set I lineaments have nearly constant strike everywhere in the terrain in which they occur, regardless of the fold axes. The fractured surfaces are in places slickensided (DC 267), in others they are both slickensided and brecciated.

Field observations (Fig. 4.32) indicate that set I joints are truncated and offset by both the NE trending set III and NW trending set II, showing that the N 5°E or N 15°E trending set I is

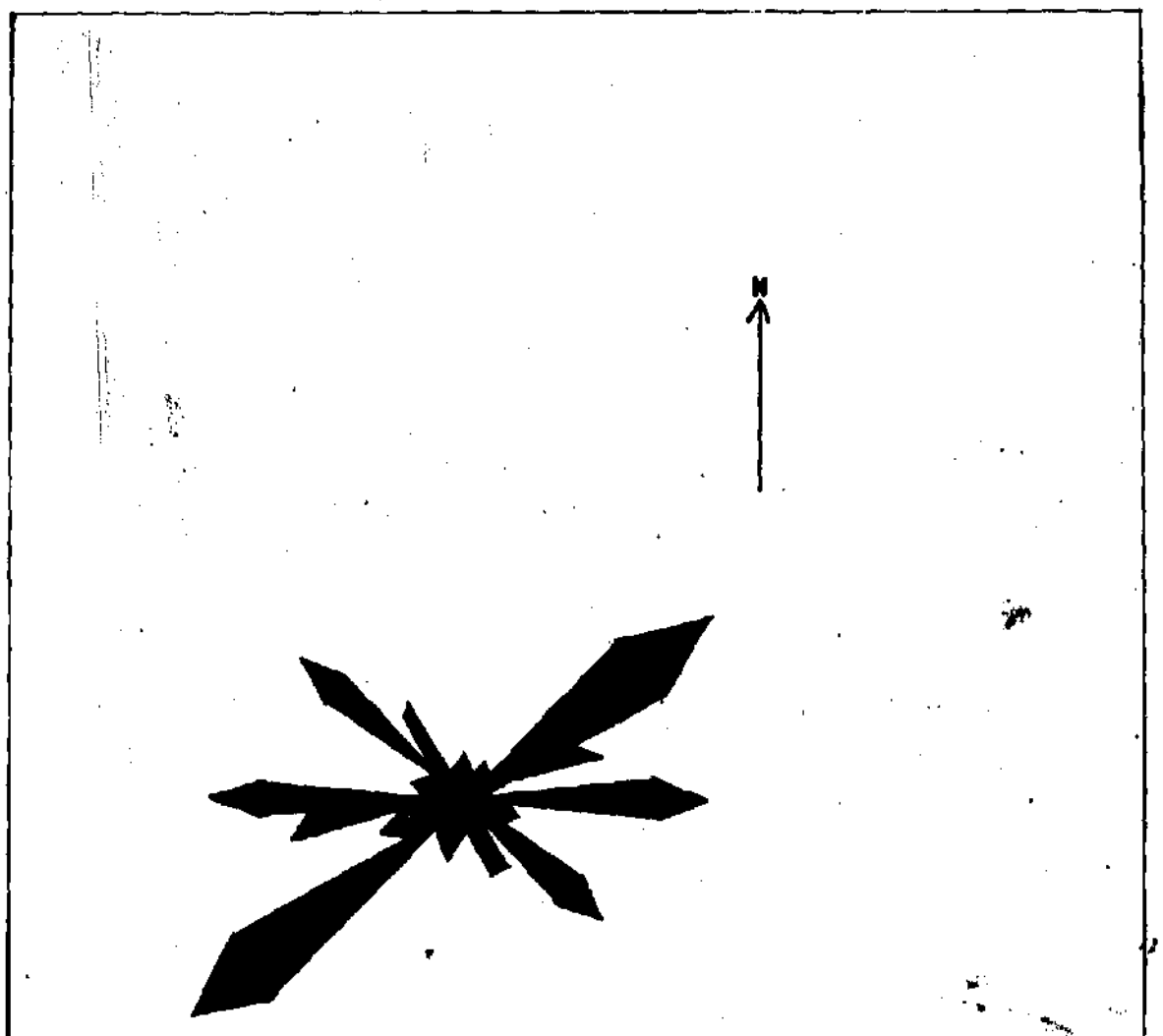
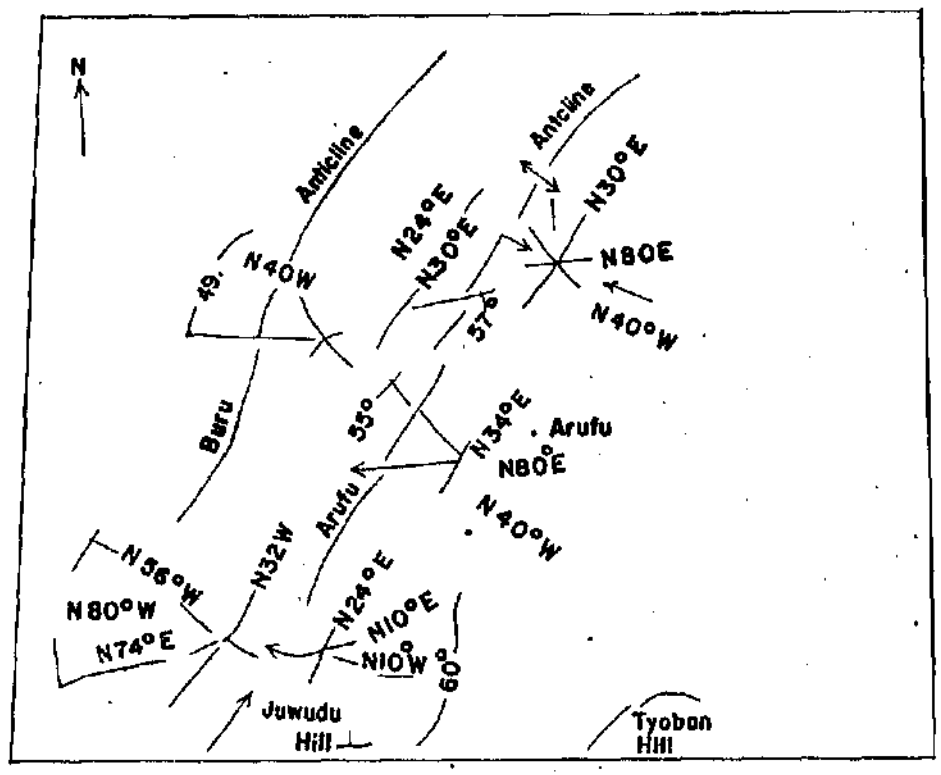


Fig. 4·28C : Rose Diagram of Fracture Patterns around Tseogu Hill Intrusive Alkaline Rhyolite Quarry. Based on 80 statistical measurements.

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SCALE : 1: 250,000

Fig.4-29: Fracture Patterns on Arufu Anticline and adjoining Structures after transformation of bedding back to horizontal each Joint rose represents about 14 Joint Stations. The opposing arrows accompanying the Rose Diagrams are probable orientation of lateral Stress direction.

is apparently the oldest set, while set III is truncated and displaced by set II showing that set II is the youngest. Fig. 4.28B shows the joint Rose (fracture Pattern) of Arufu-Akwana area. Fig. 4.29 shows the joint patterns of the Arufu Anticline (emphasizing the area shown in Fig. 4.28B). The diagram (Fig. 4.29) shows the joint patterns in this structures after the transformation of the bedding planes back to the horizontal by stereographic methods. This rotation was done because of the highly deformed nature of the folded region. The rotated joint pattern would more closely approach the idealized joint distribution expected on the anticlines. From this it is concluded that much of the jointing particularly, the longitudinal (S) variety, developed during the later stages of the folding (Figs 4.30 and 4.31). It is to be pointed out that much of the jointing is equally perpendicular to the original bedding or has high angle of intersection with the bedding regardless of the present attitude.

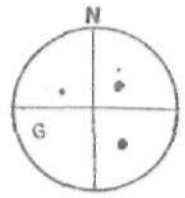
Basement Terrain

Fig. 4.30 is the map of the Tyoban-Tsekwen Older Granite Hill (and the adjoining, NE-SW trending basement inliers) with superimposed point Diagrams interpreted from contour diagrams (plotted from Table 4.14B, Appendix B).

Fig. 4.31 shows the stereographic diagrams of the regional joint pattern which is believed to be more related to the Cretaceous uplifting of the basement underlying the Middle Benue Trough than to directions of Precambrian folding. The attitudes of foliation in relation to possible Precambrian folding are shown in Fig. 4.30.

FIG 4·30

EXPLANATION



Joints confined to Pre-Cambrian Basement Terrain
Joint set common to both Pre-Cambrian and Cretaceous Terrains

Older Granite

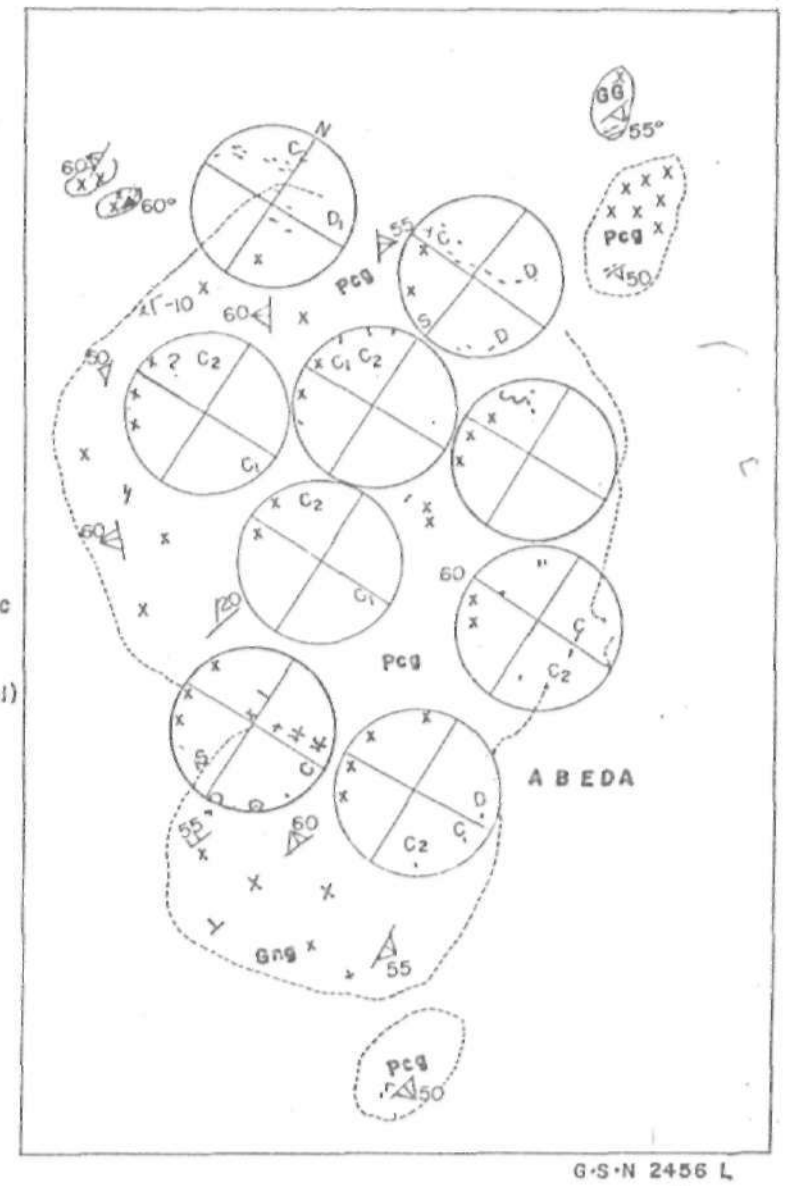
Gnassose Granite

Granitic Gneiss

60 Strike and Dip of Foliation

C_1, C_2 : Cross Joints
S : Longitudinal Joints
D : Diagonal Joints

Point diagrams of Joint sets on the Precambrian Basement Complex Granitic Rocks in the Tyoban—Abeda area..... Middle Benue Trough in relation to Foliation and folding (same area as Fig.4·31)



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1Km 0 Km

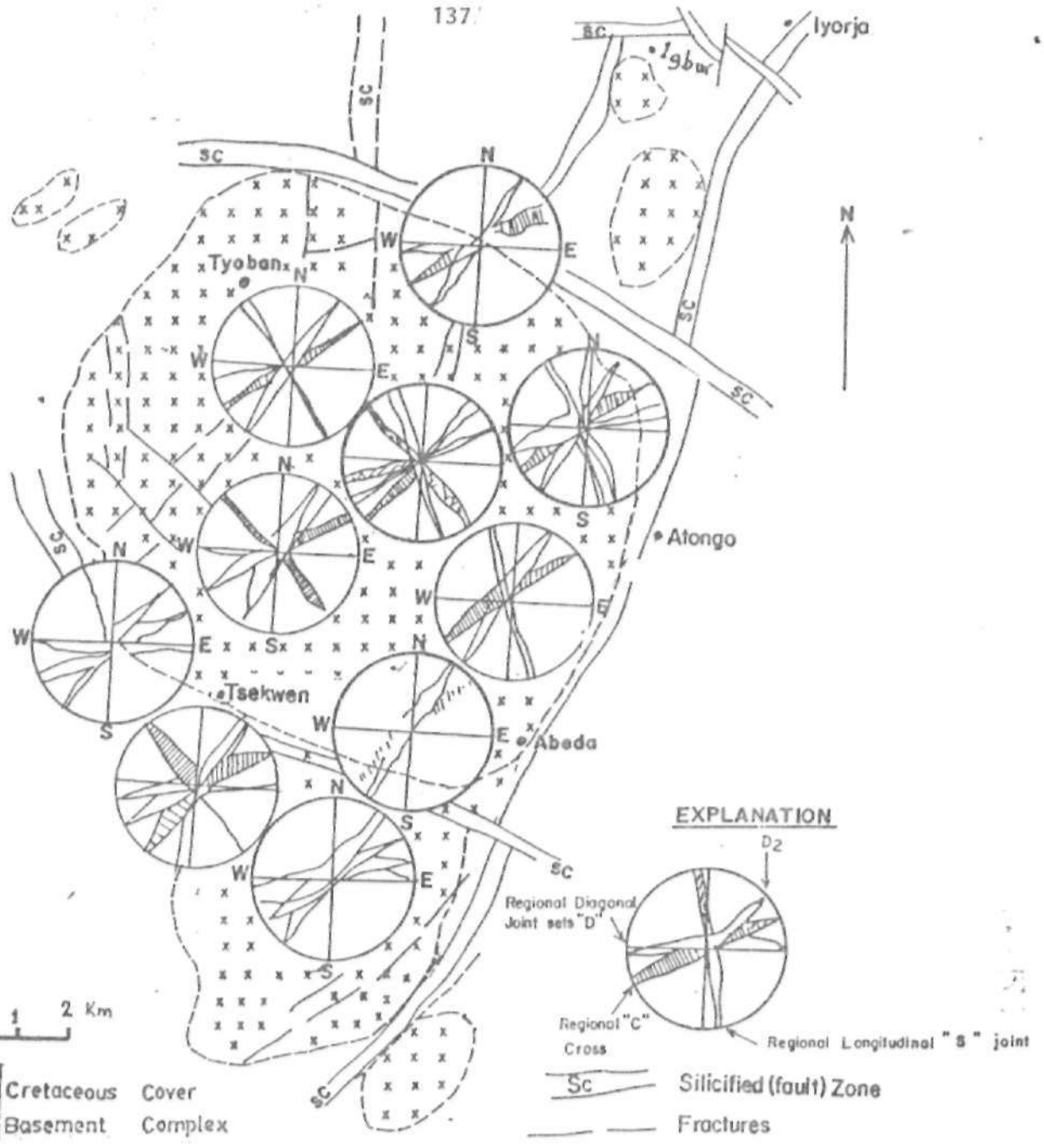


Fig. 4·31:- Stereographic diagrams of the Regional Joint system which is believed to be related to Faulting and uplifting of the Precambrian Basement Complex Granitic Rocks in Tyoban – Abeda area rather than to directions of Folding.

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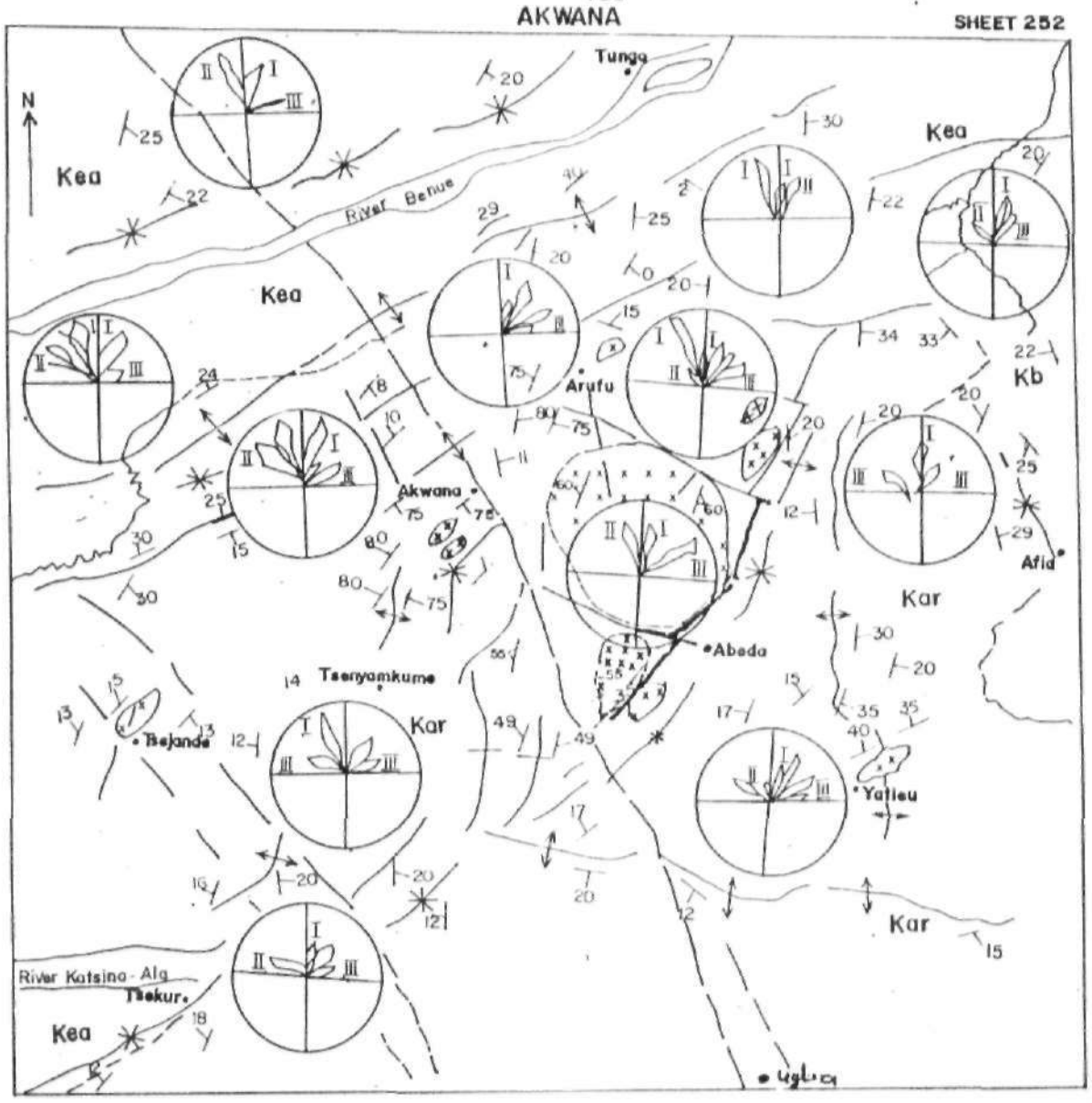


Fig 4·32:- Rose diagrams showing strikes of joint sets in Akwana standard sheet 252, M. Benue valley

4.2.5 Joints and Fractures of Tectonic Significance

Relationships between Joint Sets in Sedimentary and Basement Terrain

The NNE-SSW or NE-SW striking D-(diagonal), tear, Wrench, shear) joints in the Basement Complex terrain (Figs. 4.30 - 31) occur as S-joints in the Cretaceous sedimentary terrain (Figs. 4.28B, 4.32). The NNW-SSE or NW-SE trending sets in the basement terrain is similar in many respects to the C-joints in the sedimentary terrain. Set II Cross-joints in the Lower Cretaceous sediments (Fig. 4.32) may thus be rejuvenated C-(cross) fractures inherited from earlier deformations in the underlying basement.

The N10°E trending D-joints cut more obliquely (smaller intersection angle) across Precambrian foliation in the Older Granite bodies and granitic gneiss (Fig. 4.31, Table 4.14B). It is believed that the joint sets in this case were somewhat younger than the Pan African Orogeny (550 ± 250 m.y. ago) during which the crystalline basement rocks were foliated. In the Tseadzun-Atongo area (Pre-Cambrian Basement Complex Terrain), Iyorja-Tseagosu and Tseven-Akpetivo areas (sedimentary terrain) the NNE-SSW trending fracture zone which appears to continue from the Pre-Cambrian into the Cretaceous terrain respectively, hosts brecciated and felsite veins (DC 288D, 402A) in the basement terrain and are thought to be of Late Pan African age (Grant, 1971), but was rejuvenated during the Cretaceous. In the Lower Cretaceous terrain around Atongo, Abeda, Igbur and Iyorja villages, this NNE trending fault contains silicified, ferrugineous rocks (DC 388A, 405), or hosts the galena specks and fibrous strings type of mineralization (DC 350). In other places similar fractures contain dolerite dykes and sills of Late Albian to Cenomanian age and also alkaline basaltic lava flows of probable

Tertiary age. This may be a good example of continued propagation of fractures along old lines of structural weakness (cf. Olade, 1978, 1979).

The orientation measurements of fault planes and their slickensides are plotted on both the stereographic projection and Roase Diagrams. These show a distribution into two conjugate shears (D_1 and D_2). The acute angle formed by the two shears yields a quite precise determination of the strain axis, Z.

4.2.6 Discussion

Faults in the study area are not well exposed. But the indirect effects of faulting are evident. For example, faulting has resulted in marked steepening of dips and variation in strike directions at several points throughout the area especially in the silicified zones. In the majority of cases the determination of the fault plane alignment is not possible because of the marking effect by stream alluvium and the superficial cover on the valley sides. Eg. faults occuring on the River Katsina-Ala might have caused the abrupt right-angled bends on the section of the river draining the SW portion of the study area.

However, numerous multiple parallel sets of fractures and lineaments abound in the field and were studied in detail as has been previously described. Many of the fractures (minor faults) have offset and displaced the Cretaceous sedimentary beds for distances varying from five centimetres to over ten metres towards the margins of the basement inliers in the Udza-Akijo area (Fig.3.21 back-folder), and show step-faulting characteristics (Loc. 288). Some of these may, in fact, be related to major normal faults and

area of igneous intrusions (Fig. 4.33). In addition, satellite imagery study of the structure shows predominant multiple parallel sets of NE-SW trending lineaments and steep to vertically dipping fractures associated with N-S and NW-SE discretely placed silicified transverse structures. The silicified zones are now the topographic expressions of many of these lineament sets. Many of the silicified zones could be normal fault systems which may have been obliterated by post-faulting deposition of thick sediments in the basin (Table 4.14C, Appendix B).

Field observation also shows that some of the faulting around the basement ridges (inliers) would relate to local stress. The NE trending faults which are marginal to and also cut across the basement inliers are seen to continue into the Lower Cretaceous Sedimentary cover. These faults were probably reactivated (propagated) along old structural lines of weakness in the basement (cf. Olade 1978, Wright 1981, Maurin et al 1986). The Pan African Older Granite inlier in the Tyoban-Tsekwen area (Figs. 1.1 and 4.31) exhibits parallel fault zones trending N45°E which display a network of both sheared and brecciated crushed zones. The latter appear to have reworked the former. Similarly, the reactivated fault zones extend into the Cretaceous cover in the Antongo-Tseaguda-Igbur area where they are seen as thin silicified and sheared (crushed) zones and lenses on which are superimposed brecciated structures which appear to rework the former. The crushed (slickensided) zones are characterized by conjugate en echelon silicified fault zones and lineaments around Udza, Akwana, Arufu, and Igbur. These may be due to syn-depositional normal faulting (cf. Chuku-Ike 1981, Maurin et al. 1986).

The NE-SW fault zone are intersected and displaced by NW-SE faults. Intersection of the NE-SW conjugate fault zones by NW-SE trending wrench faults probably coincided with the first pelaeostress field giving rise to basins (Graben structures) and uplifted (horst) structures (the basement inliers) which initiated the Middle Benue Trough. The point diagrams (Figs. 4.34A-F) show that the folds are closely associated with faulting in the region.

The tensional faults are mostly situated along the margins of the crystalline basement and basement inliers. Shear faults (Suggestive of transcurrent movement) appear to be of minor importance in the sedimentary terrian. Some of the Albian silicified siltstones (DC 267) in the Arufu fracture zones also have slickensided surfaces and according to Badgley (1975) this is suggestive of shearing or transcurrent movement while the brecciation of competent rocks is suggestive of normal or tensional faulting. The slickensides on the siltstone (DC 267) located about 300 metres NW of Arufu, have a NNE trend. In the Rose diagrams these fractures are distinguished as D-(Diagonal, Wrench, Tear) sets of joints (Set 1 joints).

But NW-SE trending shears is the basement block in the Tyoban-Igbur-Tsekwen-Abeda area display considerable textural changes from (coarse to fine) and changes of strike, while the N-S shear causes the steepening of dip of foliation and diminution of texture from coarse through medium to fine (DC 198 and 199), and/or igneous activity (Fig. 4.33) in both Basement Complex and Sedimentary terrain.

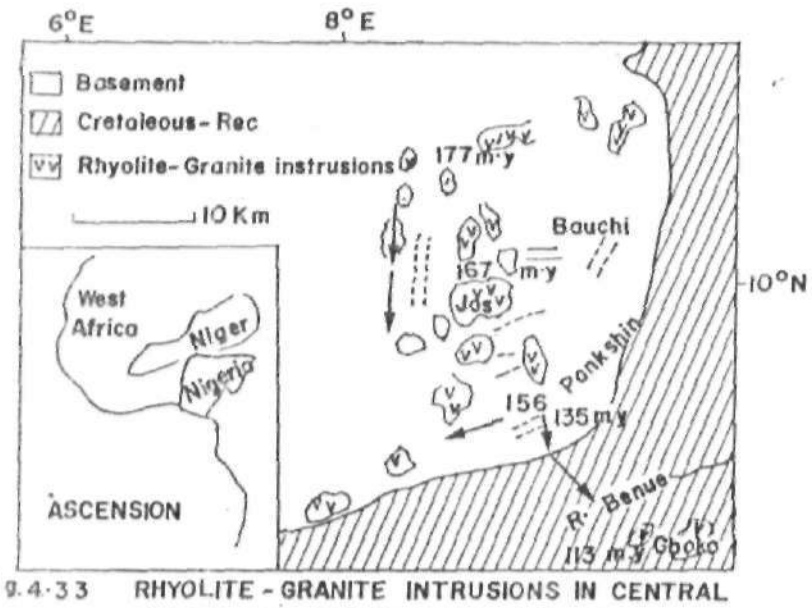
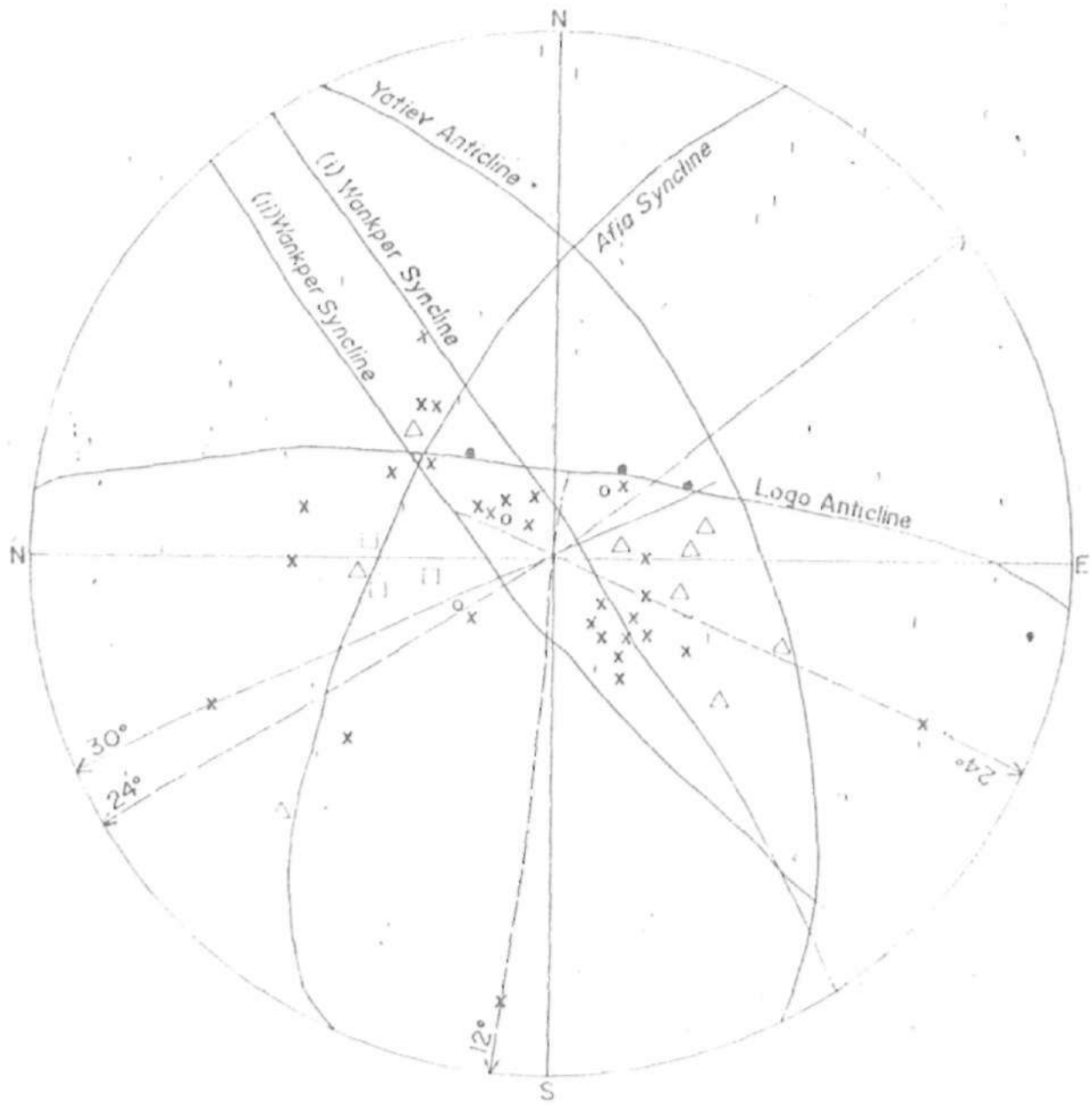


Fig.4·33 RHYOLITE - GRANITE INTRUSIONS IN CENTRAL NIGERIA AND MIDDLE BENUE VALLEY.

Arrow shows migration of succesive intrusives centres stippled lines show fracture and lineament trends

(Modified after Van Breeman and Bowden 1973, fig·1)

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N B. Measurement 61 Points on ss Plane.

FIG 4·34A: Point Diagram showing Axial Plunge of folds affecting mainly only Albian Asu River Group Beds and Neocomian?– Aptian? Pre–Asu River Continental ——Sediments around Ibom, Wankper, Yatiev, Afia Areas.

EXPLANATION

△ Afia Syncline. Plunge: L ⊼ 16°/ 24° SE (1[illegible]°).

Yatiev Anticline. Plunge: L ⊼ 154° / 30° SW ([illegible] 45°).

x Wankper Syncline. Plunge: (i) L ⊼ 138°/40° SW
(ii) L ⊼ 142°/2° NE (3[illegible]°)

Logo Anticline. Plunge: L ⊼ 96° /12° S (186°)

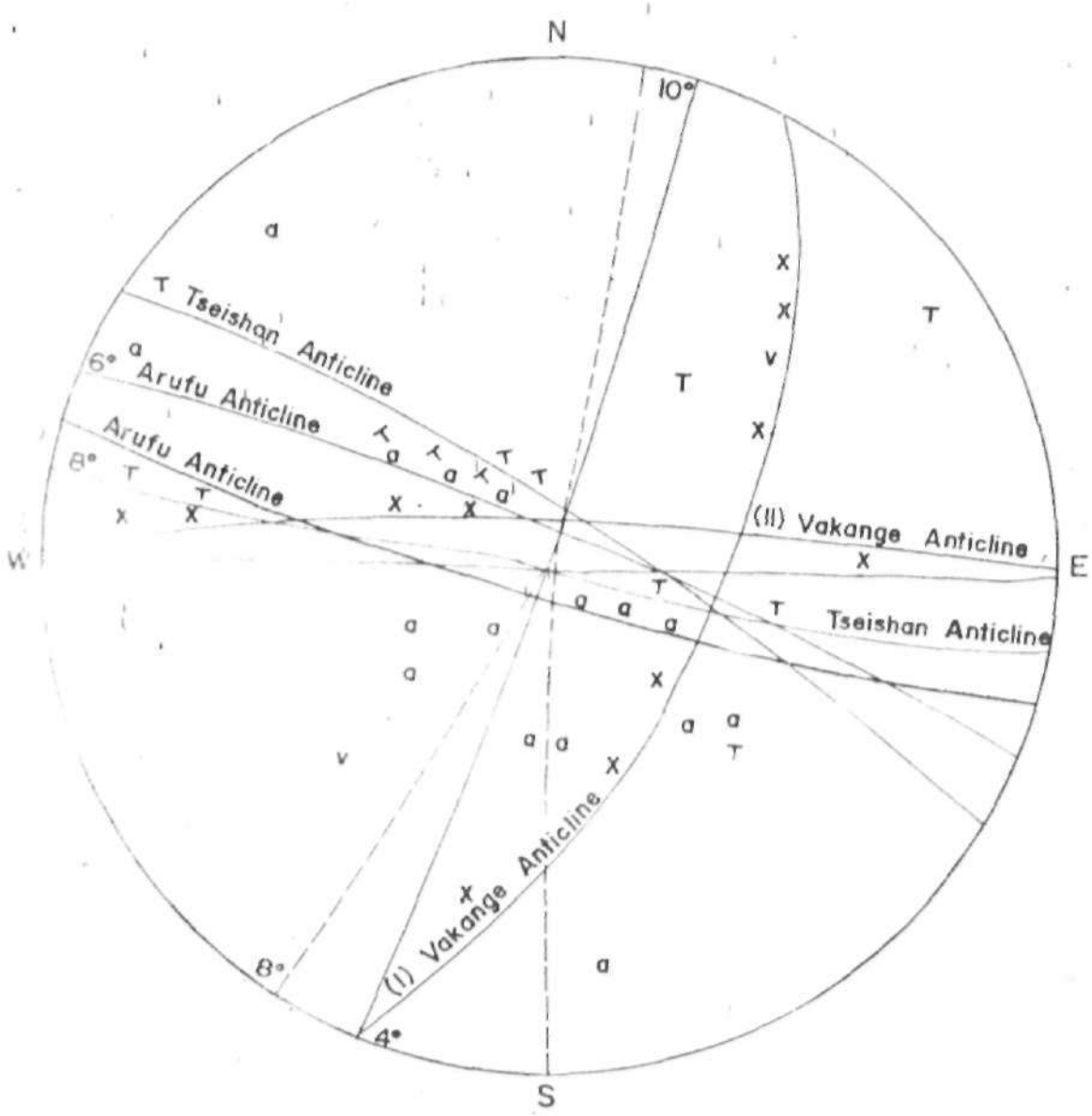


Fig. 4348 Axial plunge of folds confined to Asu river group beds, (M. Albian - early cenomanian) underlying Central - southern parts Akwana standard sheet 252. SS plane.

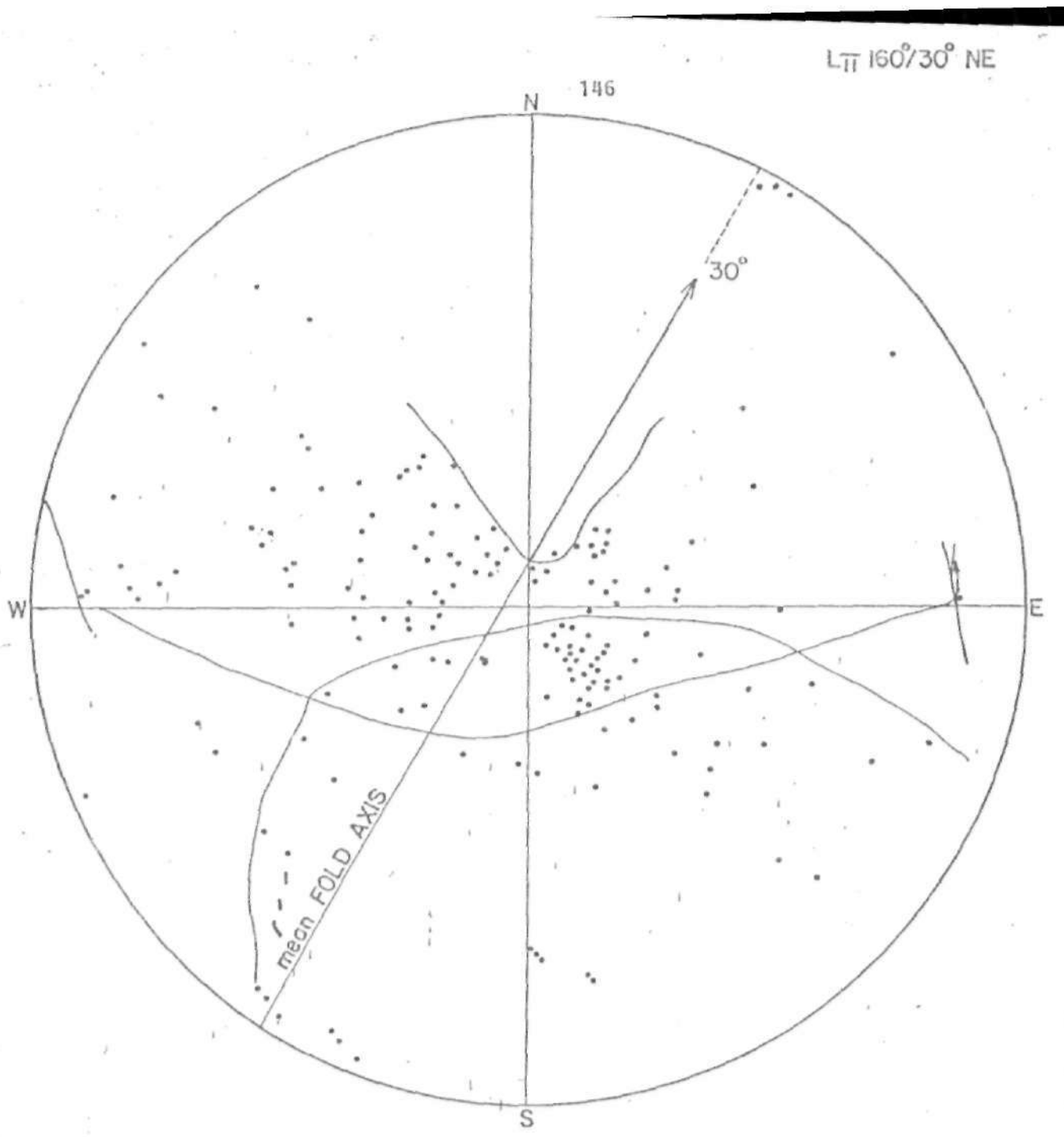
MEASUREMENT:- 89 Points, showing poles of SS planes.

EXPLANATION

X: Vakange Anticline: Doubly plunging
v. (i) Plunge. 17°/26° NW
v (ii) " 270°/6°s (180°)

a: Arufu Anticline: Doubly plunging.
a (i) L II 112°/4° SW
Plunge: L II 105°/6° NE (86°)

T: Tseishan Anticline. Doubly Plunging
T (i) Plunge: L II 103°/8° SW.
T (ii) " L II 102°/4° NE (10°)

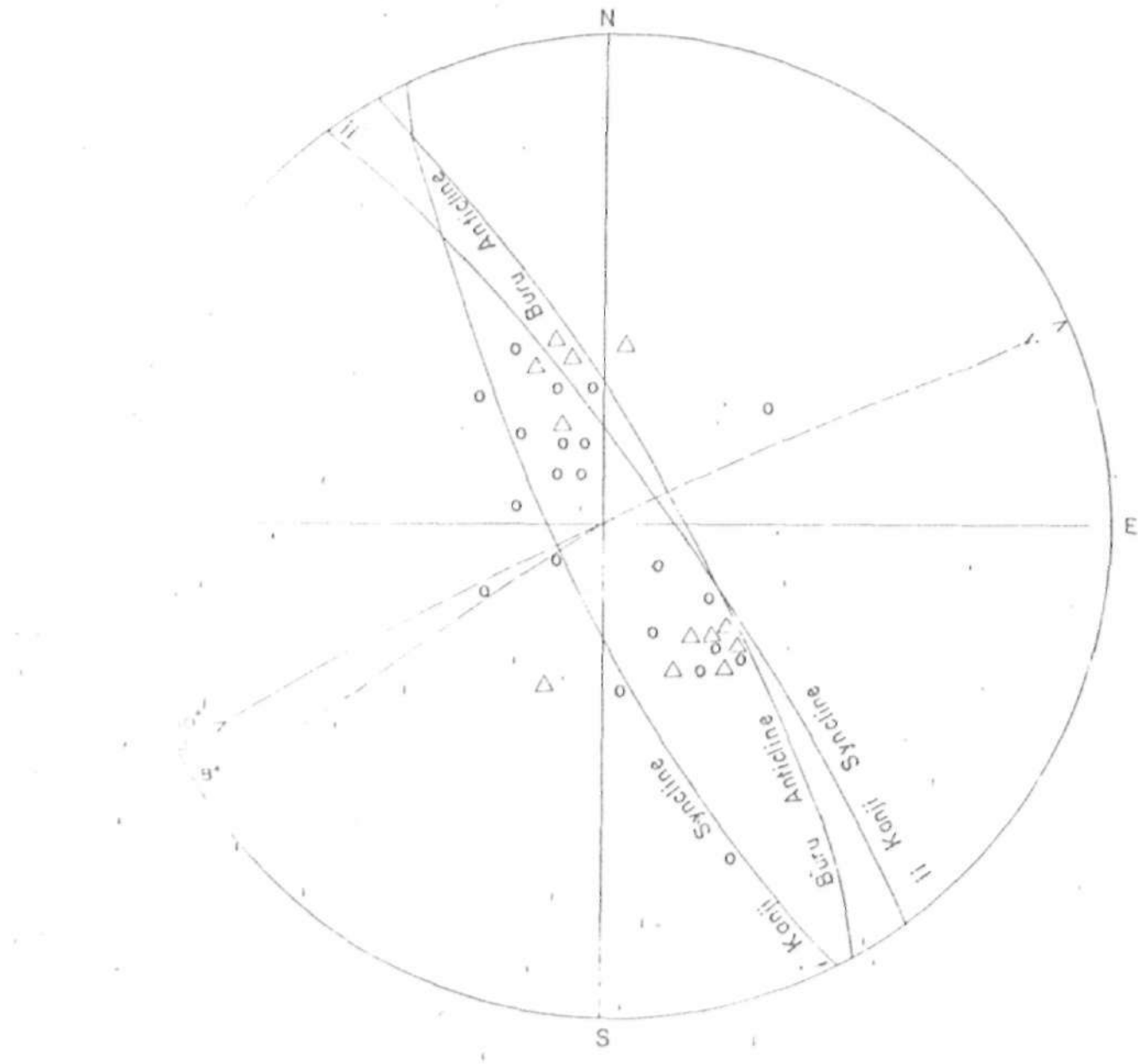


NB. Measurement 148 points on SS planes

FIG. 4·34C : Point diagram showing Poles of Folds affecting only lower Cretaceous (mostly Albian 'Asu River Group)- Cenomanian (Ibi Kente Sandstone) Beds in Tsejande., 'Akwana, Arufu, Fiyayi, Kente, Afia, Yaffev, Ibom areas·

Age of folding : Albian- Cenomanian ?

G·S·N 2455 D



Measurement From 49 Points on SS. Planes

Fig. 4-34D: Point Diagram Showing Axial Plunge of Folds affecting both older (Albian Asu River Group) beds and younger (Cenomanian Ibi sandstone and L. Turonian Eze-Aku Shale Group) beds in Kanji, Buru Bako, Akahano-Agbenke areas.

EXPLANATION

o ..... Kanji syncline: Doubly plunging
plunge (i) L π 155°/10° N-E
ii L π 142°/8° S-W(234°)

△ ..... Buru Anticline:
plunge L π 150°/10° S-W (240°)

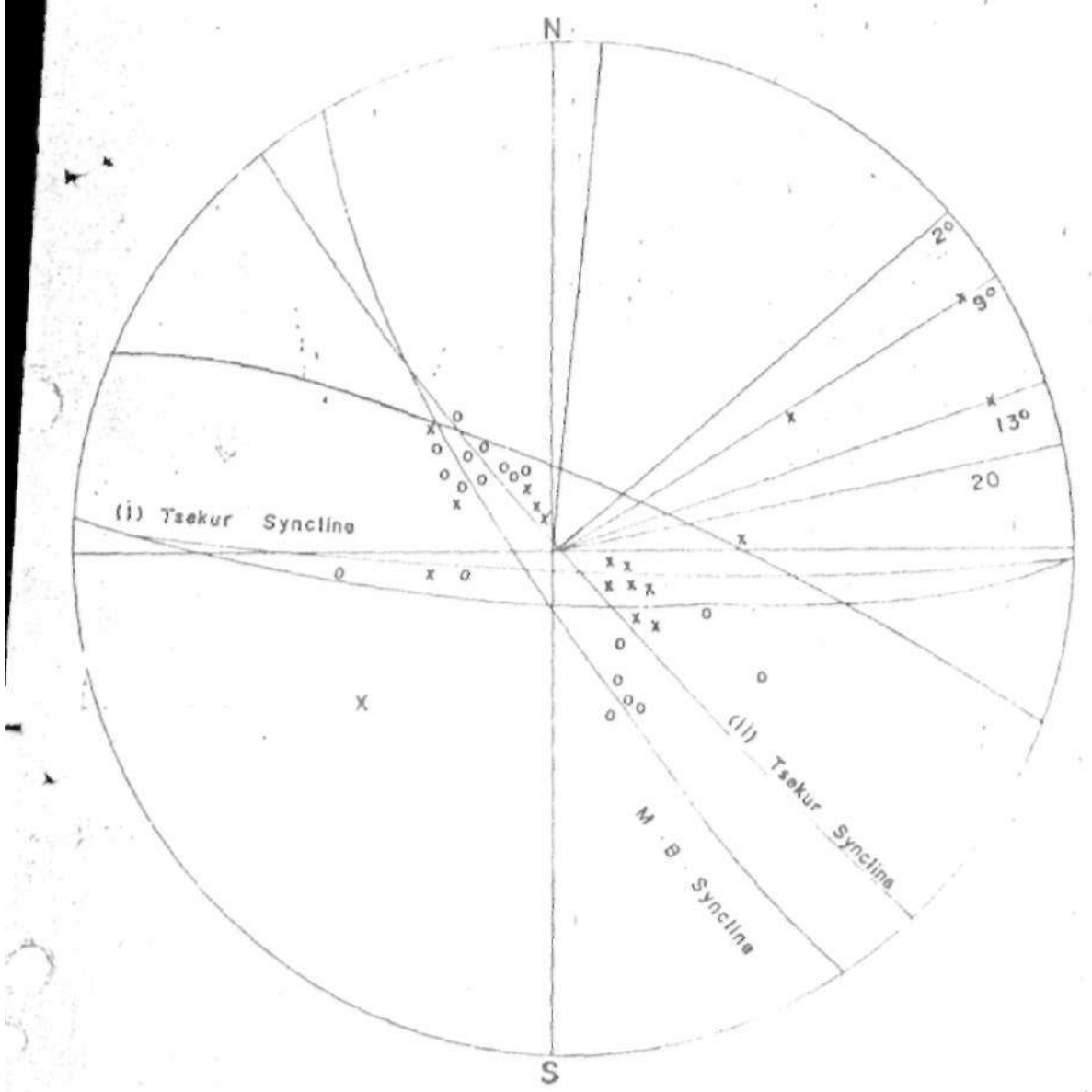


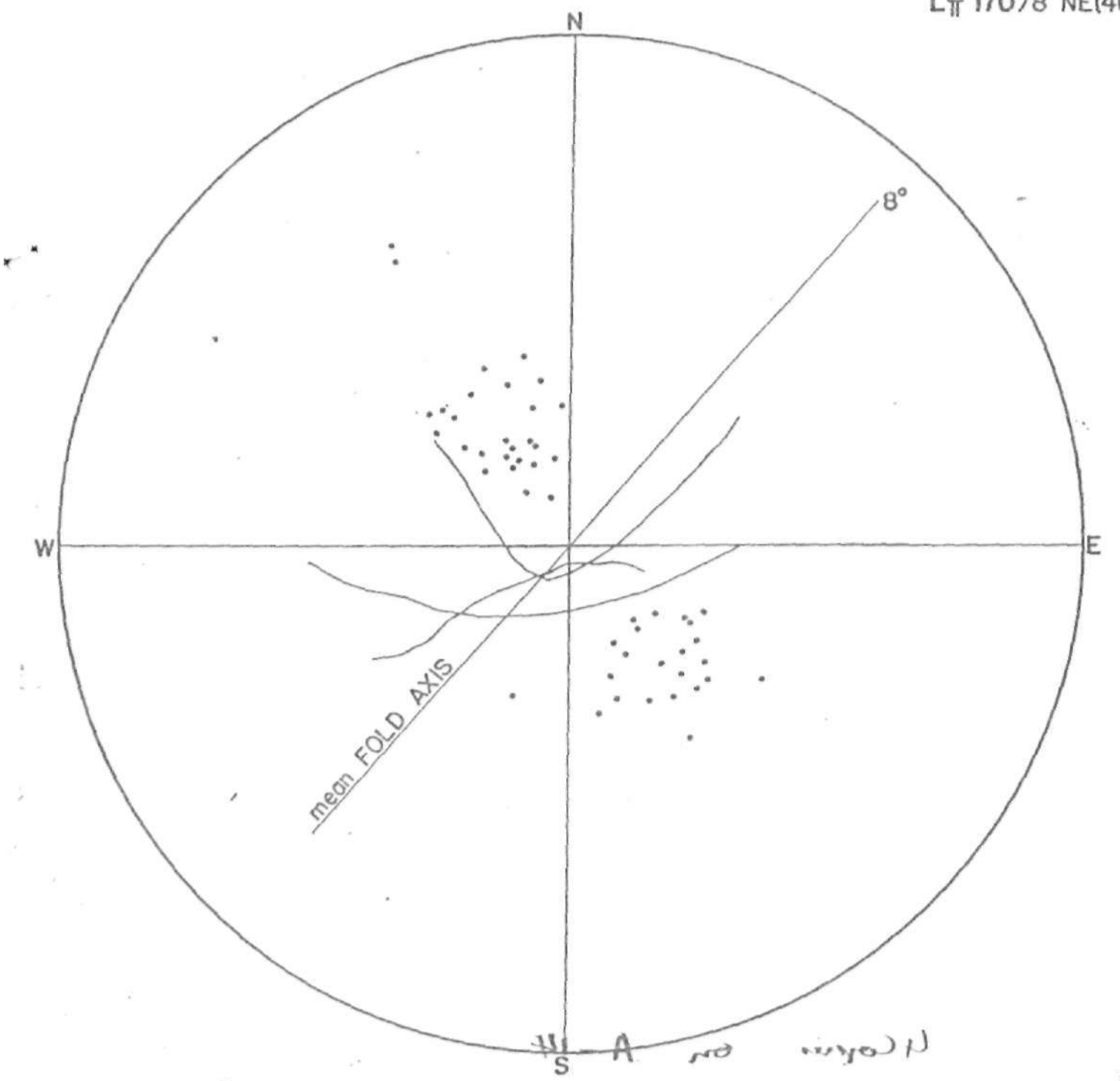
FIG.4.34 E AXIAL PLUNGE OF FOLDS

FORMATION : Akahana Shale Cenomanian–Limestone (Kea_2) Latest Cenomanian–L.Turonian EZE–AKU SHALE GROUP
Tsekur – Tsehora Sandstone – Clay– Shale Kea_2^1 Upper ? Cenomanian .
Ss Plane measurement:– 29 Points (only Dips Plotted)
Locality :– SW & NW — NE Quadrangle – Akwana Standard Sheet 252, Middle Benue Trough

EXPLANATION

X :– Tsekur Syncline
O :– M·Benue Syncline
Tsekur Syncline : L π 97°/4°N (S°)
Plunge (i) L π 97/4° N (5°)
(ii) L π 142/2° NE(51°)
M·B· Syncline L π 143°/9° E (60)

L_{II} 170°/8° NE(4



FIG· 4·34F : Poles of fold affecting both Albian, cenomanian and lower Turonian bed

Age of folding: Lower Turonian or Post Turonian prob. Senianlain

Measurement of Dips and Dip direction — 49 points locality NE-NW quadrangles Akwana sheet 252 (MB·Valley)

G·S·N 2455 E

In the area mapped the near meridonal (N-S) joint sets form the Oldest lineament pattern in both the basement and sedimentary terrains, the NE-SW trending fractures truncate or offset the N-S set. In turn the NW-SE set (the youngest) transects the NE-SW set and the fold axes almost at right angles.

In the Igbur-Arufu-Akwana area the NE-SW set usually occurs as curved parallel en echelon fracture zones each over 21 kilometres long as "down-towards-the basin" (cf. Chuku-Ike Optcit) topographic features underlain by Albian silicified brecciated limestone-shale-siltstone sequences. Where exposed, these parallel en echelon fracture zones are known to continue towards the SE basement margin of Middle Benue Trough in the Amafu-Tseagodo area. These are strong structural and topographic evidence of faulting associated with the SE trending boundary of the Middle Benue Trough. These could be marginal (boundary) fault systems which may have been obliterated by post faulting deposition of thick sediments in the basin with resultant silicification and diagenetic changes during basin development.

Cratchley and Jones (1965) inferred a normal fault along the basement - sediment boundary between Donga and Wukari, which is in the southeastern margin of the Middle Benue Trough. Chuku-Ike (1981) mentioned a major en echelon zone which has been confirmed by LANDSAT imagery as occuring along the basement-sediment boundary in the Donga-Amafu SE Middle Benue Trough Margin. These may be marginal (boundary normal) faults.

At certain localities the NE-SW fractures and lineaments appear as closely spaced parabolic irregular concentric fractures which characterize the circular features at Ibav village, Tseagodo Hill and Yatiev saltpond.

Work carried out on other areas of en echelon fracturing like the East African Rift system, shows that en echelon faulting is related to crustal extension and normal faulting (Yairi 1975). Probably the marginal en echelon Middle Benue fractures are related to the earlier (older) N-S (Near meridonal) fractures. On the other hand the curved, open NW-SE trending sets of fractures are usually perpendicular to the fold axes and the NE-SW trending set of fractures, and also truncate them. They were probably initially formed complementary to the NE-SW lineament but were rotated to this direction during the Upper Cretaceous folding and shearing (cf. Chuku-Ike 1981).

4.2.7 Concentric Fractures in Relation to Circular Features and Domed Areas

In a road-cutting near the compound of Ibav at kilometre 44 along the Wukari-Arufu tarred road, closely spaced parallel NE-SW trending concentric fractures are found on the folded fractured, deformed Albian sandy shale-siltstone sequence, on the SE limb of the Arufu Anticline, near its axial region. The exposed thickness of the Albian Asu River Group sediments is about 4 metres. The fracture planes are filled with soft greyish white kaolinitic clay (DC 315A) probably derived from the hydrothermal alteration of the shale (DC 315B).

The beds dip in differnet directions. The lower side of structure dips 34° NE while the higher more competent side underl underlain by siliceous micaceous fine grained sandstone, dips 25-30° SW. The "arched" or "domed" central portion dips 10°-15°N, Thus the zone appears to have a "domed" structure. Anastomising fractures trending NW, E-W and N-S, are found in addition to the

Ne-SW concentric set.

These fractures are filled with brown-black iron oxides and pinkish red siliceous material. Towards the base of the section a non-saline spring whose temperature (measured at the point of emanation) is 30° - 35°C, issue from the NW-SE trending fractures. The hilly area which marks the topographic expression of this feature, is characterized by a radial pattern of drainage.

A similar concentric circular feature is found in the Yatiev area associated with the Yatiev salt spring. The brine which constitutes the saltpond flows copiously from the highly fractured silicified, feldspathic sandstone (DC 222) marked by NE-SW trending closely spaced, irregular, parabolic, concentric fractures. The salt spring appears to flow from a transition zone between the underlying Pre-Asu River Basal Continental Grit and sandstone (DC 221), and the overlying marine Albian Asu River Group sediments.

The causes of concentric lineaments and fractures are poorly understood but it is believed that they probably reflect deep crustal failures. The alkaline rhyolite sill in the Tseagu Hill appears to have been emplaced in the Pre-Asu River Continental sediments through NNE-SSW to NE-SW trending concentric or curved fractures within the graben-like structure.

4.2.8 Ripple Marks, Graded Bedding, Current Bedding and Load-Cast Features

Symmetrical ripple marks were observed in a few locations of the study area within the fine grained shaly sandstone-siltstone units of both the Asu River Group and the Eze-Aku Formation (Fig.4.38).

Graded bedding structure is exposed on the Tseagodo Hill road-cutting at kilometre 12 along Yandev-Katsina-Ala tarred road while "varved" structure is present on the cross-bedded arkosic-feldspathic sandstone (DC 227), in the Amafu Sandstone Member of the Pre-Asu River Continental sediments, exposed between kilometres 22 and 30 along the Katsina-Ala - Wukari tarred road.

In the graded bedding feature, the textrual gradation in the cross bedded sandstone consists of coarser grains at the basal portion and finer grains towards the top.

This textural gradation is represented in vertical section of the cross-bedded strata. The origin of the textural gradation might have been due to variable supply and deposition of sediments by the shallow water currents at the time of deposition.

The "varved" structure exhibited on the arkosic feldspathic sandstone (DC 227) in the Amafu area may be due to seasonal change in the rate of sediment supply. There might have been some periodic floods when coarser materials were deposited and post flood stages with deposition of very fine sediments, suggestive of fluvial reworking.

Contemporaneously deformed bedding or "Loadcast" feature (usually occurring following deposition but before consolidation of sediment), were observed in the following two areas: (a) The Shausa-Imortena area (Loc. 95) 4 kilometres north of Gbeji (NE quadrangle), marking the contact zone between the basal sandstone of the Ibe Continental sandstone (Cenomanian) overlying shaly units of the Late Albian Awe Formation. There is bulbous structure on the deformed sandstone-shale (DC 384, Loc. 93). The rocks consist of medium, shaly, friable, tabular, light grey, poorly cemented

sandstones with pinkish feldspar grains still preserved making up the coarsest fraction of the rock. It looks like a quickly "dumped" material. The fine portion has asymmetrical ripple marks, (b) 1.5 kilometres south of Ugede compound about 30 kilometres southwest of Abeda, there are weathered outcrops of sediments marking the boundary between basal sandstone facies of the Fiyayi Formation and the underlying clayey siltstone-mudstone- shale Bed 4 of the Arufu Formation. There is a ripple-marked bulbous structure on the specimen (DC 422). The underlying shaly beds in each case are believed to have been in plastic condition at the time of deposition.

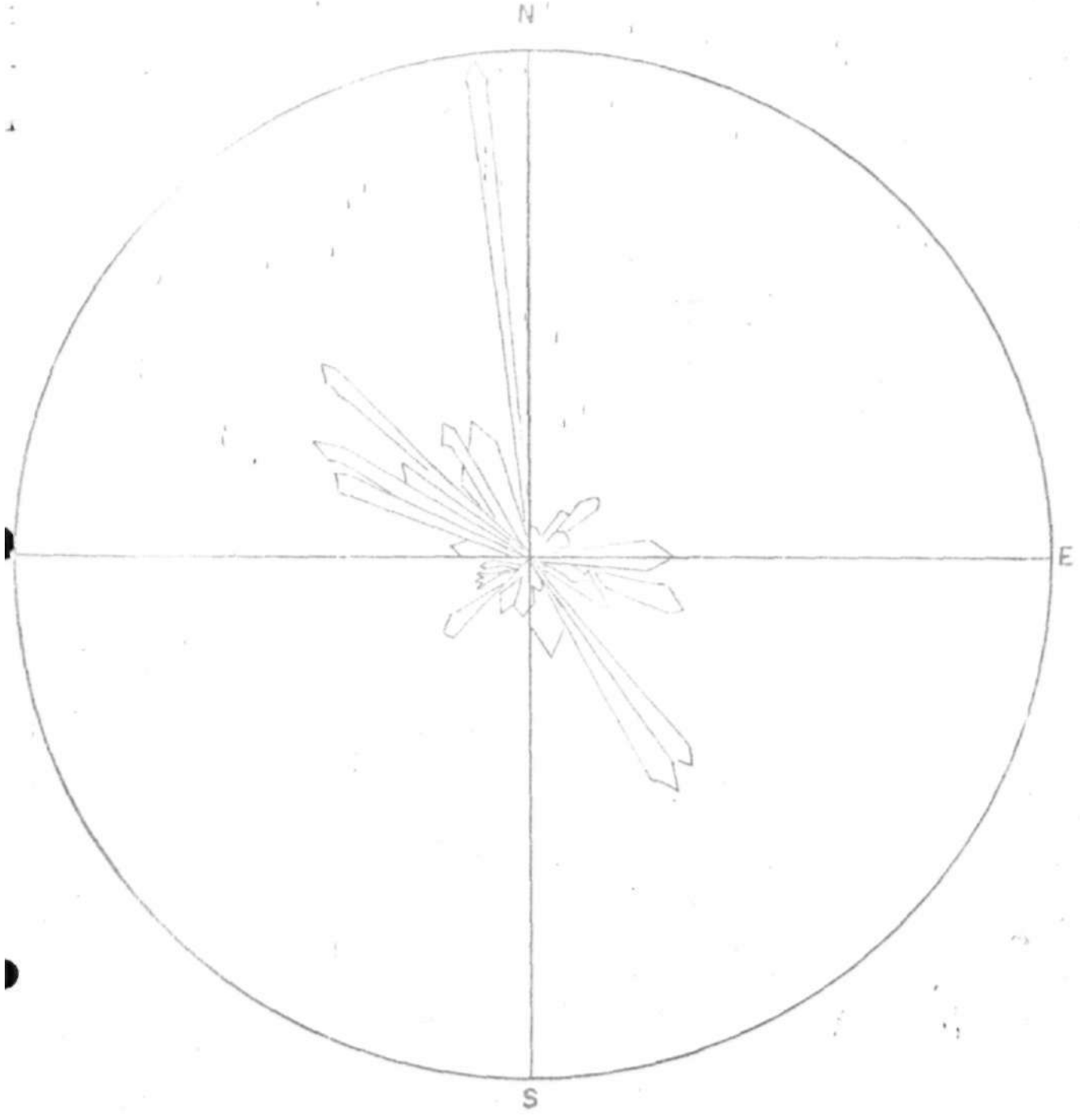
Interpretations of Rose Diagrams and Stereographic Structural Plots

Figs. 4.36A - B to 4.39A-B, are plotted to show the attitudes of cross-bedded strata. These diagrams show the stereographic poles of the current bedding azimuth and dip orientation azimuth of current bedding of the different lithostratigraphic units of the study area.

The Rose Diagram (Fig. 4.39B) shows the difference in the direction of the deposition current as follows;

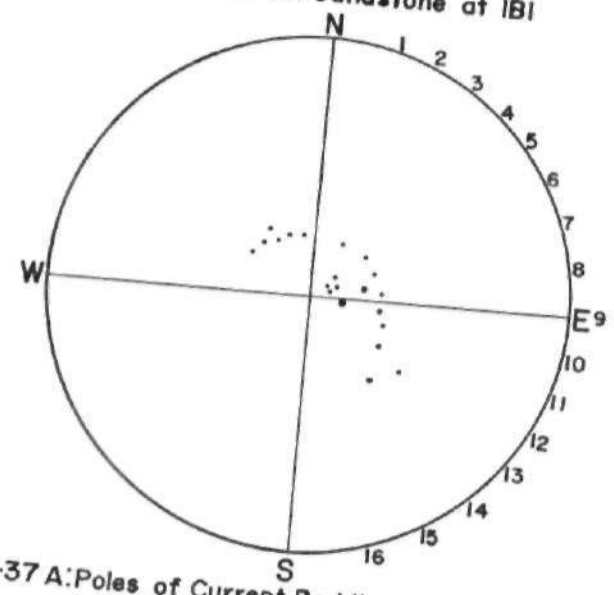
(a) The Amafu Sandstone member of the Pre-Asu River Basal Continental Grits and Sandstone Formation, appears to have been deposited by current flowing or coming from the northeast, while the Tseagodo Sandstone member of the same formation was probably deposited by current coming from southeast.

These two sandstone members underlie NE-SW trending graben-like or synclinal troughs separated by uplifted? Older Granite crystalline basement lying to the east of Tseagodo and Ngibo (Fig.1.5).



FIG· 435 : Dip Orientation. Azmuth of Cretaceaus Rocks in Akwaiia Sheet 252·

FIG. 4·36A : Sterographic Poles of Current Bedding of IBI Sandstone at IBI



FIG·4·36B : Current Bedding Orientation Azmuth IBI Sandstone at IBI

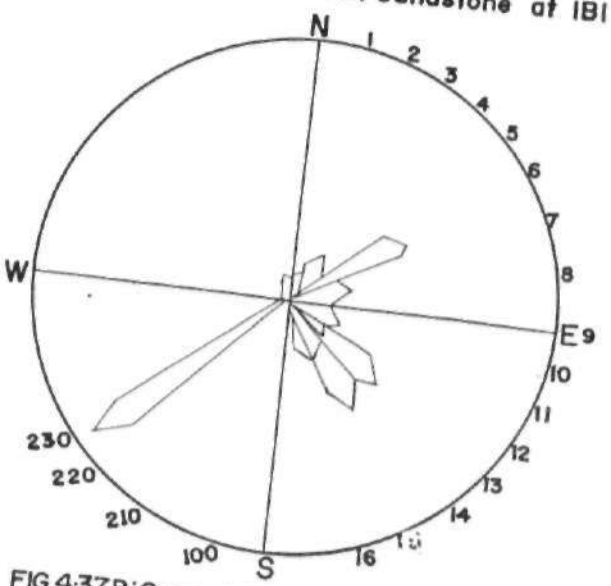


FIG. 4·37 A : Poles of Current Bedding of FIYAYI Formation in FIYAYI–AKWANA–AFIA area

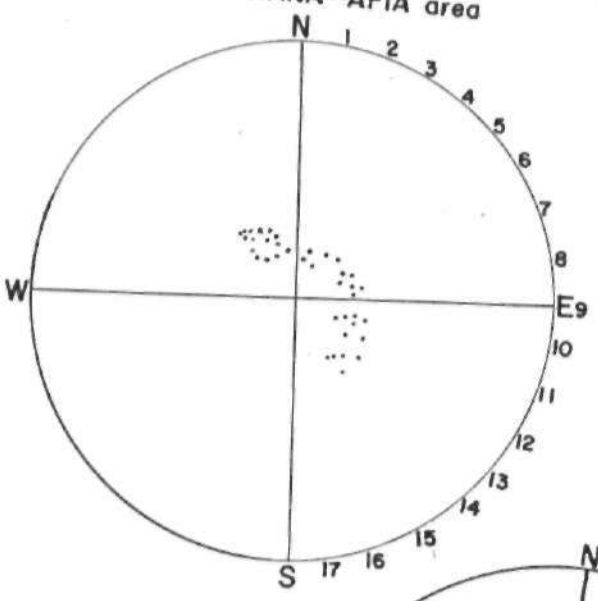
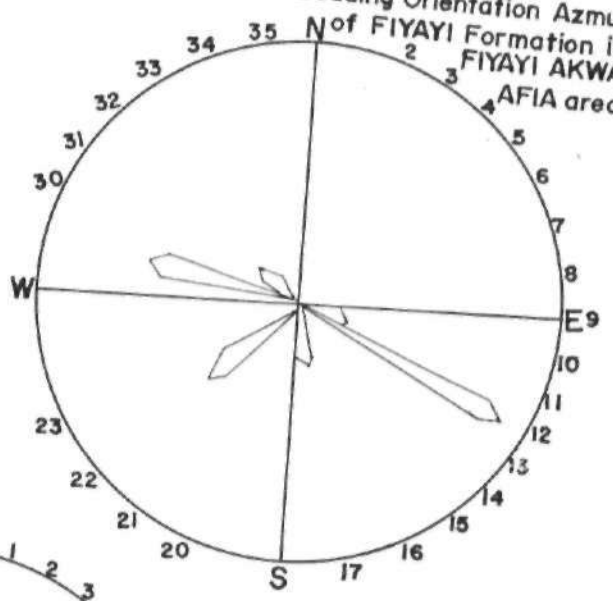


FIG. 4·37B : Current Bedding Orientation Azmuth of FIYAYI Formation in FIYAYI AKWANA AFIA area



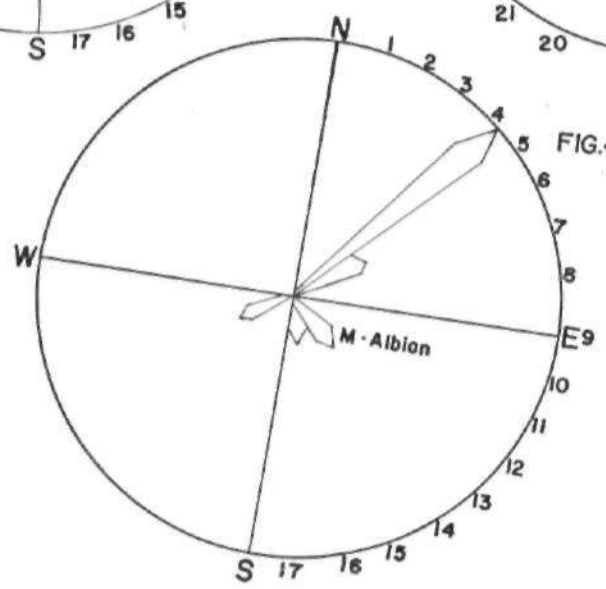


FIG. 4·38 Ripple mark Orientation Azmuth of M·ALBIAN Sediments of sheet 252

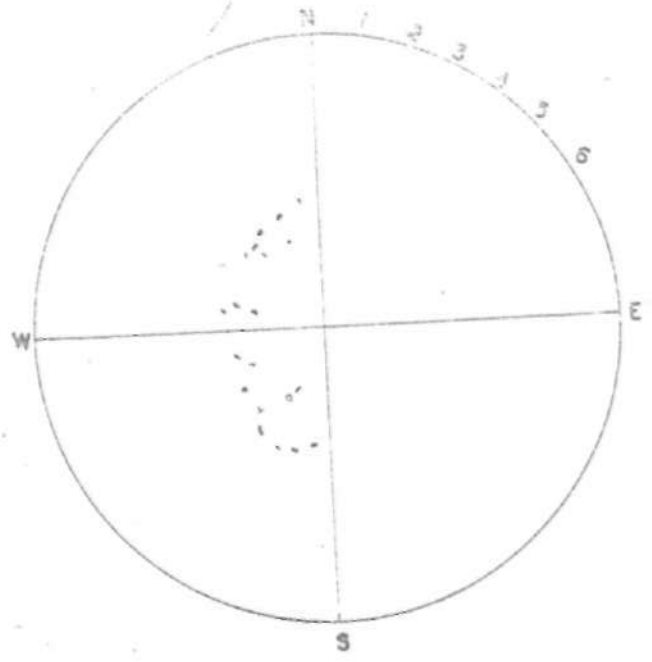


Fig 4·39A: Pole of current
Bedding of Pre-asu river basal
Continental sandstone
At Tseagodo and Amafu

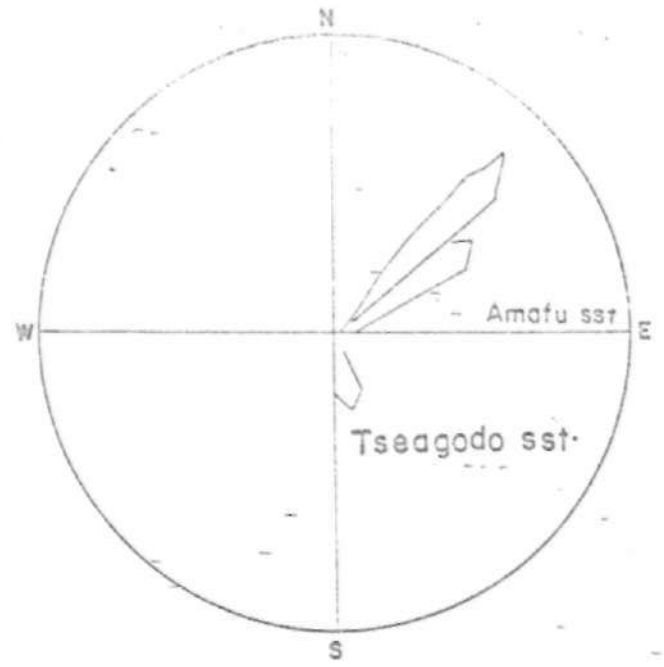


Fig 4·39B: Current bedding
Azmuth preasu river
Basal continental sandstone
At Tseagodo and Amafu

In the case of the Amafu Sandstone member, the general NE direction of the dips appears to coincide with the palaeoslope and may indicate that the direction of current is parallel or subparallel to the depositional basin, but the divergence of direction of the depositing current of the Tseagodo sandstones member almost at right angles to the slope may be due to pre-depositional structural control or barrier mentioned about - i.e. the uplifted crystalline basement block between Tseagodo and Ngibo (DC 376). Such an uplift may have been caused by the Lower Cretaceous rift-faulting. There may also be the possibility of DRAPE FOLDING of the overlying Pre-Asu River Continental sediments as supported by field evidence.

The roughly fan-shaped distribution patterns of dip directions (Fig. 4.36A, 4.39A and B) may suggest a kind of BRAIDED river channels or deltaic environment in which the continental sequence was deposited with the direction of transportation of sediments varying widely over short distances. Some structural barriers such as the uplifted or down-faulted basement ridges areas may have played some significant role in the determination of the site of deposition.

Figs. 4. 37A and B show the current bedding dip azimuth of the normal marine Middle-Upper Albian and Lower Turonian sediments of sheet 252. In both cases the direction of depositing currents appear to be NE-SW with divergences in direction in the environment of the Fiyayi Formation. This may be due to deposition of part of this formation in a deltaic, transitional environment (Fig. 4.37B).

The ripple marks are found in the fine grained sandstone-siltstone units of the formations. These structures are characteristic of deposition in the deeper part of the delta in a traction current environment (DC 299).

4.3 Igneous Activity

4.3.1. Introduction

The study area is in the Middle Benue Trough which falls within a narrow zone of mineralization, running from the southwest of the country to the northeast see Cratchley and Jones 1965). This narrow zone is within the centre of tectonic activities that took place in the Benue Valley. Thus the potential of the Benue Trough for sources of raw material of economic significance (plates 4.7A and B) may be related to its form, origin, and history as a rift-like structure which failed to develop into a full ocean basin and can be compared to similar geological and tectonic-structural environments in other parts of the world.

4.3.2 Cycles of Igneous Activity

Four generations of Lower Cretaceous to Tertiary or later igneous activities are recognized in the study area and its adjacent regions (in the Middle Benue Trough) as follows:

1. Aptian Rhyolitic alkaline volcanism.
2. Late Albian Intrusive cycle.
3. Third cycle intrusive and extrusive activities in Late Albian to Early Cenomanian times.
4. Fourth cycle extrusive volcanic activity in Late Cretaceous - Early Tertiary.

First Igneous Cycle

The earliest recorded igneous activity consists of the Tseagu Hill alkaline rhyolite sill, whose radiometric K-Ar age is modelled by 113 $\pm$ 3 m.y. i.e. Aptian (Umeji, 1981, Pers. Comm.). This Lower Cretaceous igneous extrusive activity appears to have been

associated with the intial rifting of the Benue Trough and the African continent and the latter's separation from South America at the Gulf of Guinea (Hurley 1968). The representative rocks include the NNE-SSW trending alkaline rhyolite sills and veins in the Tseagu Hill area (DC 321G, 380 - 382) emplaced into the Pre-Asu River basal continental sediments within the axial region of the anticline near Yandev.

Second Cycle Igneous Activity

The second episode of igneous activity probably occurred in Upper to Late Albian times when NNE-SSW trending hypabyssal, unmineralized dolerite dykes and sills (DC 185, 185A), were intruded into the Middle-Upper Albian Bed 1 shelly limestone member (DC 183, 283) of the Arufu Formation (Lower Sequence of the Asu River Group) and the Pre-Asu River Basal continental sandstone, around the Arufu Granite gneiss basement inlier. This intrusion is not encountered in the Upper mineralized units of the Arufu Formation.

Third Cycle Igneous Activity

The third episode of igneous activity apparently occurred in Late Albian and Cenomanian times as follows:

(a) Medium grained hypabyssal, partly altered ("calcareous") dolerite sills and dykes (DC, 178,188, 249), were emplaced into the Asu River Group of formations around Buru (DC 178) and the Ajimi-Ikwe area, about 6 kilometres NE of Arufu. The intrusion occupies NE-SW trending axial "S" - fractures which truncate and offset the earlier (second cycle) dolerite bodies (DC 187) occupying NNE-SSW trending fracture sets, near the confluence between Rivers Kutaji and Bar, about 4 kilometres NNE of Arufu. The altered medium grained dolerite bodies (DC 178)

occur in the proximity of disseminated galena mineralization around Buru Hill and a saline spring near Nwannan compound about 1 kilometre SE of the disseminated galena showings L 535A, Table 6.25A).

(b) Altered mildly alkaline basalt lava - the Andyar Basalt (DC 256A, B,C, 414A, B) with spilitic affinity (DC 256D) was extruded and interbedded with the Late Albian to Early Cenomanian Awe Formation. This Late Albian-Early Cenomanian Lava was later partially covered by Late Cretaceous to Early Tertiary alkaline basalt lavas (DC 257). The Andyar Basaltic Lava flow is confined within the Asu River Group.

(c) Altered mildly alkaline basaltic lavas (DC 224, 225, 309, 307) which were extruded and interbedded with the Cenomanian Keana Formation, about 3 kilometres south of Ibi town. It is exposed at a road-cutting along the Wukari-Ibi tarred road, and occupies a NE trending axial fracture zone in the crestal area of the Ibi anticline.

The Andyar interbedded basaltic lava has a semi-pillow (spilitic) structure which strongly suggests that it invaded the Late Albian-Early Cenomanian marine sediments when they were still wet.

Fourth Cycle Igneous Activity

This fourth and last cycle occurred in the post Lower Turonian or at the end of the Cretaceous but more likely early Tertiary (Okeke 1980) when strongly alkaline lavas poured out and penetrated all the Cretaceous geological formations. They occur mostly in NW

trending C-fracture zones and in a few NNE-SSW trending sets at Buru, Tseiyorde, Sufa (DC 231A-B), Annyibe (DC 340), on the south bank of the Benue, and in the Tunga-Akahana area on the north bank of River Benue, which flows in a NE-SW direction in the region. These lava flows constitute the main topographic highs around Buru (DC 181), Sufa (DC 231A-B), Annyibe (DC 340) and Akahana where they form flat topped and conical hills.

4.3.3 Relationship of Igneous Activity(?) to Geosynclinal Sedimentation

Farrington (1952, P. 591) believes that from the roughly medial arrangement of the associated Cretaceous intrusive, it is possible that the Benue Trough Cretaceous formations were deposited in a GEOSYNCLINE, while Cratchley and Jones (1965) believe that the origin and evolution of the Benue Trough involved a combination of rift valley and geosyncline. On the other hand, Tattam (1944) considers that the preservation of these sediments in probably due to Tertiary warping (downwarping).

In the first part of this chapter an attempt was made to adduce field evidence to prove that the Middle Benue Trough, as represented by the study area, has a rift-like structure. These include presence of parallel normal marginal faults along the boundaries of the trough.

The suggestion by Farrington (1952) that the Cretaceous formations of the trough were deposited in a geosyncline may be examined as follows. The first universal problem in the use of the term geosyncline is the difficulty of lack of general acceptable criteria for the recognition of the various stages of development of either modern geosyncline or ancient geosyncline (Petti john 1948, Aubouin 1965,

Reading 1978), either in the American view or in the European concept (Krynine 1941, Pettijohn 1957, Aubouin 1965, Reading 1978). Also plate tectonics has now largely superseded geosynclinal theory by suggesting that one of the most important controls on sedimentation and orogeny is the position of the sedimentary basin relative to a plate or continent/ocean boundary. In modern practice many elements of the geosynclinal theory are retained and are used to describe ancient orogenic belts. For the purpose of this work a geosyncline is defined according to De sitter (1947) and Reading (1978) as a deep narrow elongate trough with a thick sedimentary fill (usually folded in the case of an ancient geosyncline) in which the various stages of development resulted mainly from vertical movement, with subsidence followed by compression and uplift. These various stages include the Pre-orogenic or carbonate platform stage, the pre-flysch stage. the flysch stage (geosynclinal greyweck stage) and the molasses or post-geosynclinal arkose stage (Krynine 1941, Pettijohn 1957, Aubouin 1965, Reading 1978, Table 14.1). Geosynclinal evolution usually culminates in mountain building or orogeny.

In the study area early cyclical trough sedimentation took place in a series of subsiding, fault controlled (rift-generated) depressions on the uneven yielding basement Complex surface, culminating in the deposition of the Pre-Asu River Basal continental Grits and feldspathic sandstones and clays, in the Lower Cretaceous (Pre-Barremian, Neocominan?). In the Tseagu-Tseagodo area these immature clastics and arenites were later invaded by alkaline rhyolite lavas during the Aptian, 113 ± 3 m.y. (Fig.4.22B). In the Amafu area cyclical deposits of arkosic - feldspathic sandstones are also present in the Pre-Asu River Continental sediments.

This early continental sedimentation was followed by repetitive trabsgressive - regressive shallow marine deposition in the trough undergoing intermittent uplift and subsidence; spanning the Albian to Lower Turonian, accompanied by or simultaneous with several other cycles of alkaline basic axial igneous intrusive activity. The different lithologic sequences described in the marine Albian, Early Cenomanian and Lower Turonian times do not show to any appreciable extent the usual geosynclinal stage characteristics. Rather, the depositional regimes (Table 2. 3) are essentially those of foreland facies (Carbonate platform stage of Aubouin 1965).

An apparent geosynclinal facies of sedimentation appears to have been manifested only in the deeper parts of the Middle to Upper Albian sea. In Beds 3 and 4 of the Uomba Formation there are thick sequences of shales, siliceous (cherty) siltstones and subordinate calcilutite limestones. Some of the siliceous sediments (eg. DC 152, Table 3.8 serial No. 15 appendix B) appear to have sediments accompanied by basic igneous activity (intrusion of dolerite dykes and sills), It is however, to be noted that the siliceous,cherty layers in Beds 3 and 4 of the Arufu Formation may not be original primary features but may be due to silicification, diagenesis in deep burial and the rise of geotherms during basin development (Pettijohn, 1949, p.451).

The Middle Benue Trough as represented by the study area is seen as a failed intracontinental rift structure, i.e an aulacogen (Olade 1975), in which block faulting and differential subsidence were followed by regional subsidence, and continental (arenaceous and argillaceous) sedimentation with alkaline rhyolite volcanism, and then by Middle Albian marine carbonate sedimentation with Late Albian - Early Cenomanian basic magmatism (dolerite dyke intrusion

and basaltic extrusion). This carbonate platform facies developed is the intracontinental rift zones (graben) accompanined by the formation of epigenetic galena deposits of Lower Cretaceous which Reading (1978 p.466) considers to be similar in age to the lead mineralization in the Amazon fracture zone of Brazil (South America).

As regards the relationship to the South Atlantic fracture system, Olade (1975), Burke et al. (1977), Reading (1978) and Chorowics (1983) regard the Benue Trough as a Cretaceous NE-SW trending, long-lived deep, linear auxillary structural (rift) basin, extending outwards from the continental interior to Gulf of Guinea. But probably, as it was not in the main line of rupture of the NW-SE trending South Atlantic Rift System, it aborted or failed to open into true ocean basin (Chorowic 1983). These main NW-SE trending rift zones with which the failed Benue rift system was regionally linked formerly, subsequently continued to be active and became the South Atlantic Ocean (Burke, Dessauvagie and Whiteman 1970, Reading 1978; cf Maurin 1987).

Hoque and Nwajide (1985) propose a four stage tectono-sedimentological evolution model of the Benue Trough. In this model they recognize four stages in the tectono-sedimentological evolution of the Benue Trough as auloacogen.

1. Rifting Stage (Graben-like depression is formed by crustal extension followed by rifting) represented by coarse feldspathic sandstones and clays associated with intermittent alkaline magmatism (e.g. the Tseagu Hill Rhyolite (modelled by a K-Ar age of 113 $\pm$ 3 m, y. and the tranchytic rocks occur along Makurdi - Katsina-Ala road).

2. Trough Stage - represented by mudrocks, feldspathic sandstones, argillaceous limestones of the Asu River Group (which accumulated in a broad synclinal depression during the initial Albian transgressions) and alkalic to subalkalic volcanism (eg. the Ishiagu micro-diorites (the second cycle dolerite dykes and sills of the Arufu - Buru area).

3. Deformation Stage - represented by drape folds caused by accumulation of thick sediments in the trough leading to development of instability at the base of faulted crustal blocks which culminated in large scale folding of the overlying sediments with fold axes parallel to the trend of the trough. This was accompanied by large scale alkaline basaltic volcanism eg. the Andyar interbedded basalt lava; sills, dykes, tuff ring, tuff breccia pipes surge and flow deposits (eg. the Ababkaliki pyroclastics)

4. Platform Stage - represented by sandstones with some mudrocks. The post-Santonian sediments are largely undeformed but broadly upwarped with a few degrees of dip toward the cratonic margin of the trough. Westward migration of sites of deposition was controlled by boundary faults of the trough.

4.3.4 Field and Age Relations of the Various Igneous Bodies and the Host Cretaceous Sediments

First Cycle Igneous Bodies

Whole rock K-Ar retention ages of samples of the alkaline rhyolite sills in the Tseagu-Tseagodo area by Umeji and Vacbette (1983) give an age of 113 + 3 m.y. i.e. Aptian. As the veins and

and sills are emplaced in the Pre-Asu River Basal continental Grits and sandstone Formation with baking effects on these beds it is believed that the host Pre-Asu River sediments are Barremian (Neocomian?) or at least very early Barremian in age.

Both the host rock and the rhyolite sill are highly fractured (brecciated) and deformed by NE-SW trending vertical fractures which are truncated and offset by later NW-SE trending ones.

At kilometre 12 along Yandev - Katsina-Ala tarred road similar K-feldspar rich felsite veins (DC 241F, 383) are emplaced along the bedding planes of the Pre-Asu River sediments exposed at the road cutting. The basal Cretaceous sediments are in direct contact with the eastern flank of the whole basement block and have been subjected to intense tectonism including normal faulting. The basal Cretaceous sediments are folded into a synformal (synclinal) structure. The NE-SW trending felsite sills and veins and the host rocks are traversed by NE-SW trending parallel to subparallel sets of vertical earlier S-fractures (faults) that are transected and offset by NW-SE trending C-fractures.

Petrographic studies (Table 4.11B) and detailed chemical analyses (Table 4.11 and 4.11A) indicate that some of them are alkaline rhyolites (cf. Jacobson et al. 1977).

Second Cycle Igneous Bodies

The field relation of the dolerite intrusion belonging to the second cycle igneous activity can be studied on the SE flank of the horst-like Arufu basement inlier which is exposed in the core of the Arufu anticline where small dolerite dykes (DC 185A) are emplaced within the lateritized Pre-Asu River Continental feldspathic sandstone

unconformably overlying the Pre-Cambrian Basement Complex (Arufu granitic gneiss inlier). The fine-grained dolerite sill (DC 185) with a NNE-SSW trend is also intruded into basal, brecciated Bed 1 shelly limestone member of the Middle-Upper Albian Arufu Limestone-shale formation (Lower sequence of the Asu River Group), The Basement rock (DC 175), the Pre-Asu River sediments (DC288A,B,C) and the Bed 1 shelly limestone member of the Arufu Formation. are unmineralized. In all cases no baking effects or chilled margin were observed, probably due to the fact that the intrusions were emplaced along open (fissure) tensional fractures. This may also be due to the thinness of the dykes and veins.

In the case of the Pre-Asu River sediments (DC 288A-C) any trace of baking effect appears to have been obliterated by intense silicification and lateritization, where the intense deformation on the Middle-Upper Albian shelly limestone may have produced masking zones.

About 2 kilometres NNE of Arufu one of the NNE-SSW trending dolerite sills is offset and displaced vertically towards the basement by a NW-SE trending set of C-(Cross) vertically dipping fractures (Figs. 3.20 and 3.21 back pocket).

The lack of contact features could be a further demonstration that the emplacement occurred under a tensional regime (open fracture in-filling) - the presumed dominant mechanism in the evolution of the Benue Trough.

The second cycle dolerite bodies are confined to the unmineralized Pre-Asu River Continental sediments and the Bed 1 (Lower most unit) of the Middle to Upper Albian marine Uomba Formation. Therefore the age is at least Late Albian.

TABLE 4.11 CHEMICAL ANALYSES OF RHYOLITIC ROCKS

(SEE FIG. 1.6 FOR SAMPLE LOCALITIES)

SAMPLE NO. DC	380	321 G	261 A	321 C	381	382	261 B	261 F	383	UPPER BENUE ALKALINE RHYOLITE (OKEKE 1980) L 147	AVERAGE LATER ALKALINE RHYOLITE NIGERIA YOUNGER GRANITE PROVINCE	AVERAGE RHYOLITIZ LAVA (CAR MICHAEL et al, 1974)
SERIAL NO	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2 wt%	72.5	72.03	73.7	72.85	72.2	73.6	74.1	73.01	74.16	72.417	74.17	74.22
Al_2O_3	11.920	12.0	11.51	11.32	11.5	10.142	12.0	12.13	13.0	12.953	10.67	13.27
Fe_2O_3	1.01	1.0	1.1	1.0	1.1	1.1	1.00	1.1	1.12	1.02	1.77	0.88
FeO	2.36	2.49	2.6	2.58	2.74	2.48	2.10	3.54	3.64	2.662	3.18	0.92
MgO	0.60	0.70	0.50	0.14	0.37	0.606	0.40	0.03	0.18	0.611	0.23	0.28
CaO	0.297	0.66	0.209	0.42	0.40	0.223	0.19	0.117	0.28	0.187	0.38	1.59
MnO	0.270	0.21	0.065	0.32	0.46	0.36	0.10	0.102	0.35	-	0.34	0.05
Na_2O	3.650	5.06	4.838	4.83	5.64	0.349	2.53	2.49	2.66	2.650	4.11	4.24
K_2O	5.720	5.10	5.340	5.67	5.14	6.340	5.21	4.3	4.25	5.722	4.47	3.18
TiO_2	0.272	0.28	0.264	0.08	0.16	0.350	0.20	0.03	0.025	0.270	0.16	0.28
P_2O_5	0.08	0.41	0.035	0.04	0.02	0.005	1.10	0.30	0.30	0.085	0.02	0.05
S	0.822	0.01	0.53	0.01	0.11	0.83	0.01	0.11	0.12	-	0.01	-
Ignition Loss	-	-	-	0.50	0.85	-	-	-	-	-	0.66	0.50
Total wt %	98.914	99.95	99.094	99.76	99.8	99.688	99.54	99.9	99.97	98.094	100.19	99.99
Cu ppm	6	5.0	19	7	10	8	4	5	5	-	-	-
Pb	251	240.0	250	300	220	22	206	215	220	-	-	-
Zn	23	20	25	30	24	23	15	17	16	200.5	-	-
Ni	6	5	8	5	8	7	4	5	4	2.5	-	-
Co	7	6	9	6	10	9	5	5	7	-	-	-
V	3	2	5	2	2	2	3	3	4	-	-	-
U	2	2	4	3	3	4	5	5	5	-	-	-
Li	122	120	130	120	115	129	135	132	133	-	-	-
Rb	244	239	140	130	139	133	232	340	330	-	-	-
Sr	233	240	230	237	248	247	237	220	421	220.5	-	-
Zr	27	20	30	22	27	23	17	16	15	5.1	-	-
Ag	32	85	90	80	86	89	86	81	89	1208.1	-	-
Cr	-	-	-	-	-	-	-	-	-	-	-	-
F	5.1	5.0	4.5	4.0	5.5	5.6	5.0	5.1	5.8	5.9	-	-
Cl	500	609	600	50	300	319	600	3.01	313	-	600	-
	309	300	299	300	700	712	490	1100	1130	-	200	

KEY TO TABLE 4.11 (See Figure 1.6 for Sample Localities)

1,2 DC 380, DC 321G respectively. Brown alkaline rhyolite, Tseagu Hill Quarry about 5 kilometre west of Yandev, kilometre 77 along Makurdi - Yandev tarred road. They Rhyolite sill is emplaced into the Pre-Asu River Formation.

3. DC 261A. Brown alkaline rhyolite boulder collected from Tseagodo Hill underlain by the Pre-Asu River Basal Formation about 12 kilometres west of Yandev, at kilometre 12 along the Yandev. Katsina - Ala tarred road.

4. DC. 321C. Porphyritic facies of the Tseagu Hill Rhyolite, collected from the same locality as pit 321G above.

5-6 DC 381 - 382. Bluish grey alkaline rhyolite forming irregular NE-SE trending sills and veins in Lower Cretaceous sediments underlying the depression separating two horst - like basement block; the Mbadim Inlier to the west and western flank of the Mkar Hill - Gboko Block to the east, at kilometre 78 along Makurdi - Yandev tarred road.

7-9 DC 261B, 261F, 383: Alkaline Felspar - Quartz porphyry rocks. Forming NE - SW concordant veins in Pre - Asu River Formation kilometres 12 - 13 Tseagodo Hill road cutting, along Yandev-Katsina - Ala tarred road, on eastern flank or Mkar Hill - Gboko horstlike block.

10. Gwozo alkaline Rhyolite, Upper Benue Trend, after Okeke (1980, sample No. L147).

11. Average of 5 alkaline rhyolites, Younger Granite Province, after Jacobson et al. (1977).

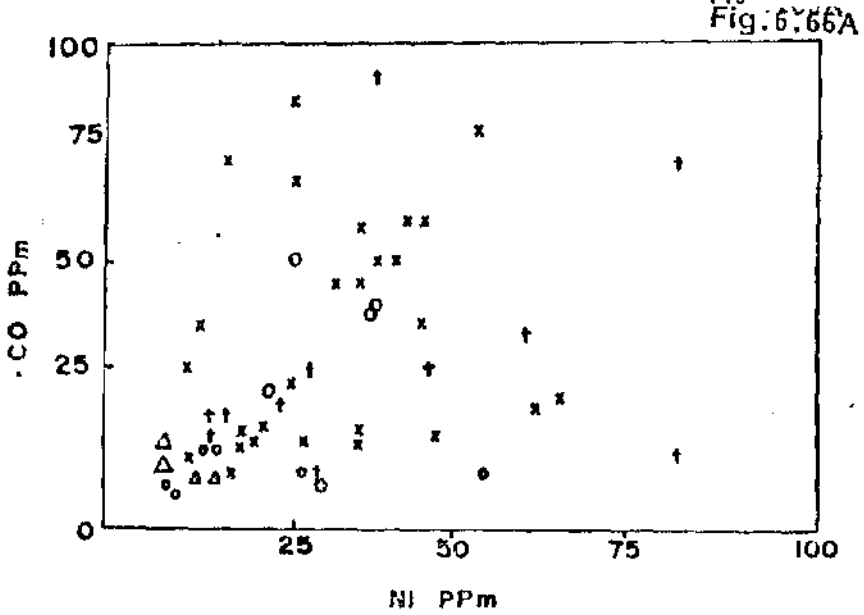
12. Average Rhyolite lava, after Carmichael et al.(1974, P, 554, Table 11 - 6 No. 5).

sediments were still wet. i.e. undergoing consolidation and diagenesis, then it will be easy to see the reason for the disparity in the abundance of the two elements Pb (Pb^{+2} = 1.20A electronegativity = 0.8) and Zn^{2+} = 0.74A) compared with K (K^{+2} = 1.33A electronegativity = 0.8). This shows that lead is diadochic with potassium. Figure 6.66E shows the relationship between lead and potassium in the sediments of the study area. Lead is thus admitted into the crystal lattice of potassium in potash feldspar minerals and K-feldspar-rich rocks (mostly granite) during crystallization and shows preferential enrichment in them (Mason et al. 1968) while zinc is admitted into crystal lattice of major elements like iron (Fe^{+2} = 0.74A) of ferromagnesian minerals (amphibole, pyroxenes) and pyroxene-rich (basement) rocks. Thus the scarcity of amphibole and pyroxene rich basement rocks and sediments in the study area may account for the scarcity of zinc sulphide (sphalerite) minerals while galena (Pbs) is abundant (cf. Hanor 1979).

Lead concentration in the alkalic igneous rocks and the K-feldspar rich granitic basement rocks of the study area shows positive correlation with the K_20 value which is consistent with the above geochemical characteristics of lead. Thus the leaching of base metal lead from the K-feldspar Albian marine clays, the invading early Cretaceous alkaline igneous bodies and the (crustal) K-feldspar rich granitic Basement Complex rocks of the study area were probably responsible, in some way, for the availability of metalliferous (Pb) solutions. In the Middle Benue Trough (mostly underlain by K-feldspar rich granitic crustal basement rocks), galena generally occurs in virtual exclusion of sphalerite (Bogue 1952). But galena and sphalerite deposits occur both in the Abakaliki-Ishiagu area of Lower Benue characterized by

RELATIONSHIP OF CO TO NICKEL IN THE MINERALISED MARINE BEDS OF THE FORMATIONS OF THE ASU RIVER GROUP (GP)

Fig. 6.66A



SYMBOLS:

Δ Kar_1 Bed 7 Silicified Limestone – Sandstone – Siltstone.

O Lower Beds of Awe Formation Ka_2.

† Other units of ASU River GP.

x Kar_2 Bed 3 Silicified Brecciated siltstone shale.

o Kar_2 Bed 2 Silicified (Jasperoid) Limestone interbedded with silicified siltstone-Pyritic Black Shale.

Δ Kar_1 Bed 5 Silicified (Jasperoid) Brecciated Limestone interbedded with siltstone - shale.

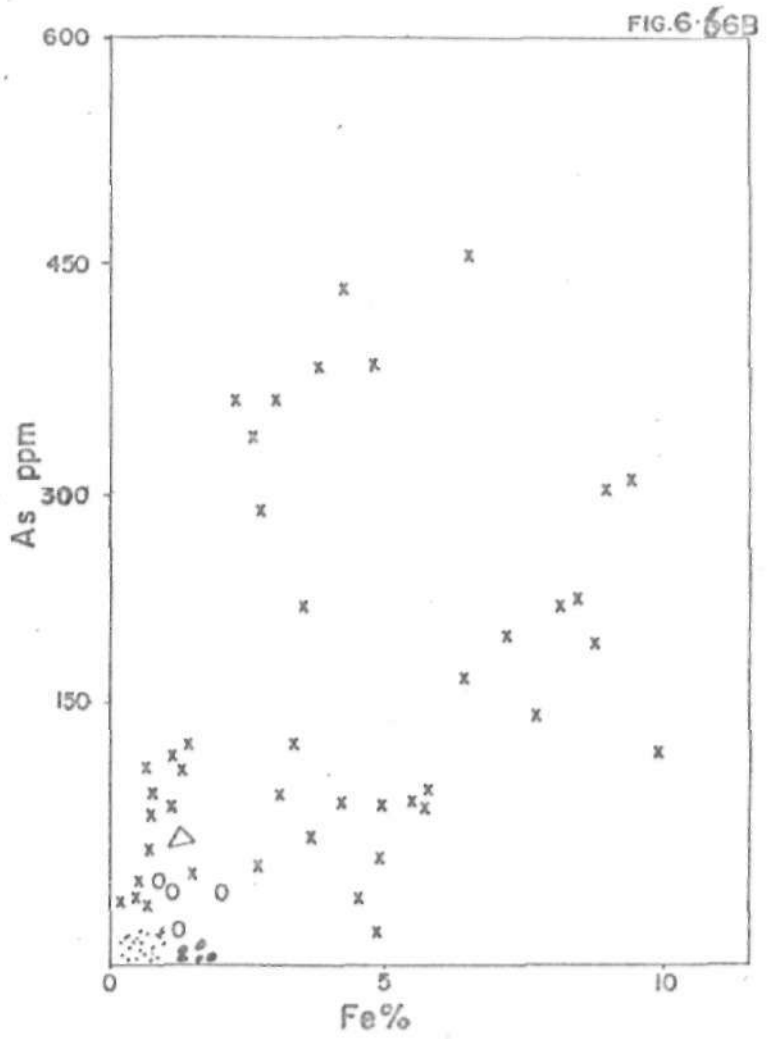
Kar_1 Uolnba Formation.

Kar_2 AWE Formation.

G.S.N.2460K

Relationship of Arsenic to iron symbols as in fig 6·56A

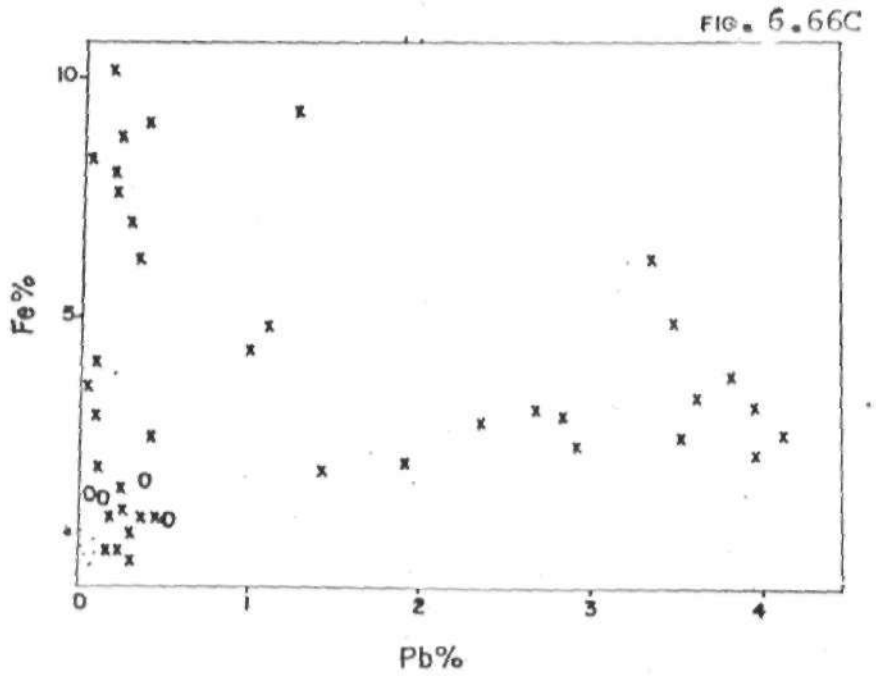
FIG.6·56B



G.S.N. 2460 L.

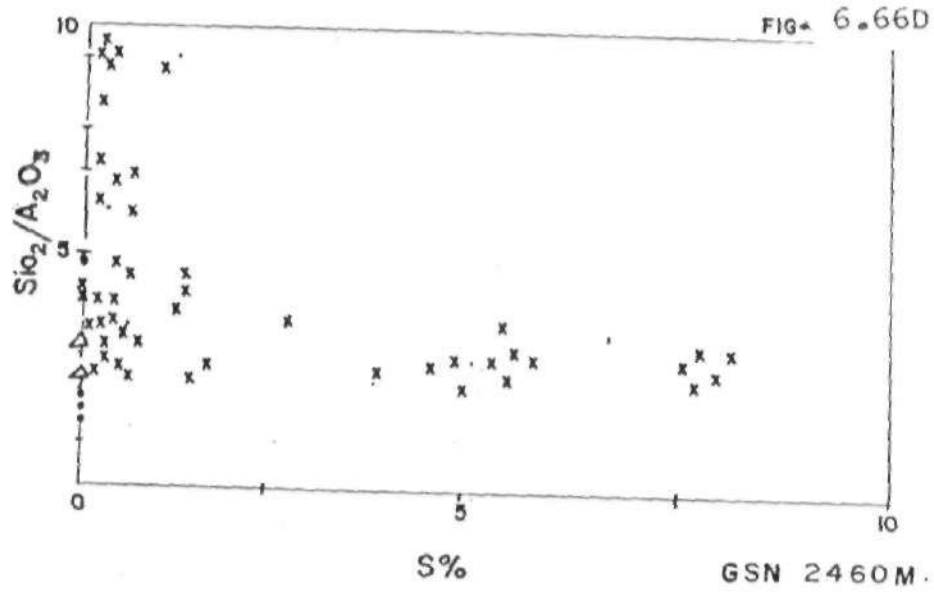
RELATIONSHIP OF IRON TO Pb SYMBOLS AS IN FIG. 6.66A

FIG. 6.66C



RELATIONSHIP OF SILICA/ALUMINA RATIO TO SULPHUR. SYMBOLS AS IN FIG. 6.66A

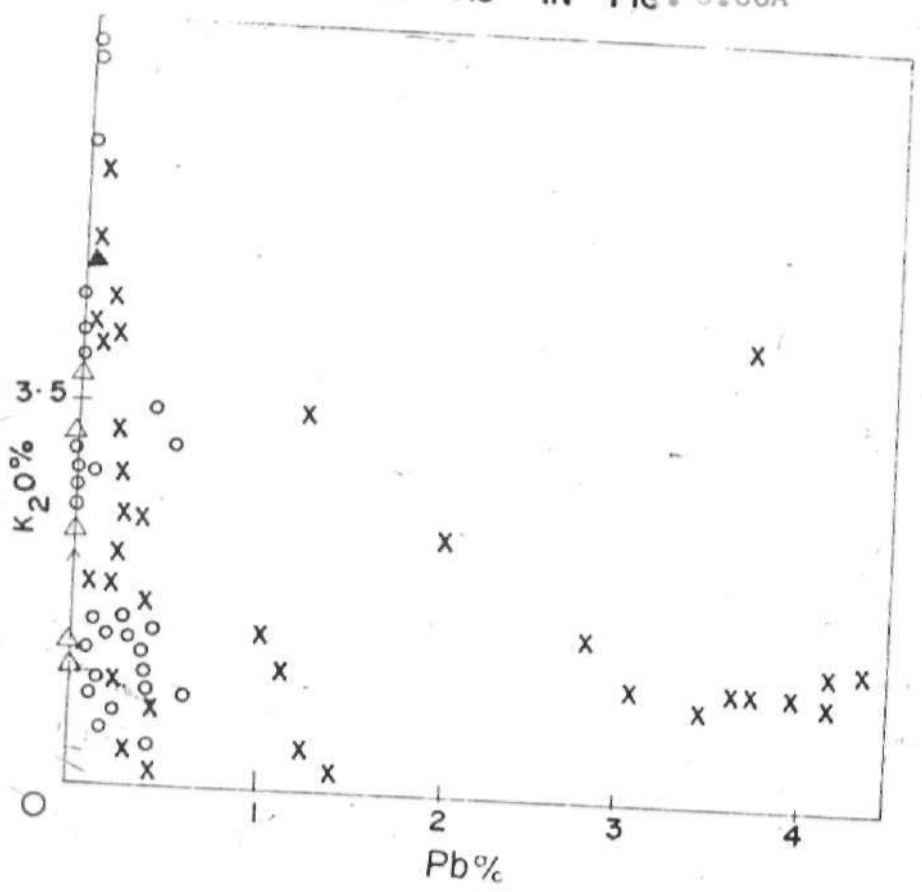
FIG. 6.66D



GSN 2460M.

FIG. 6.66E

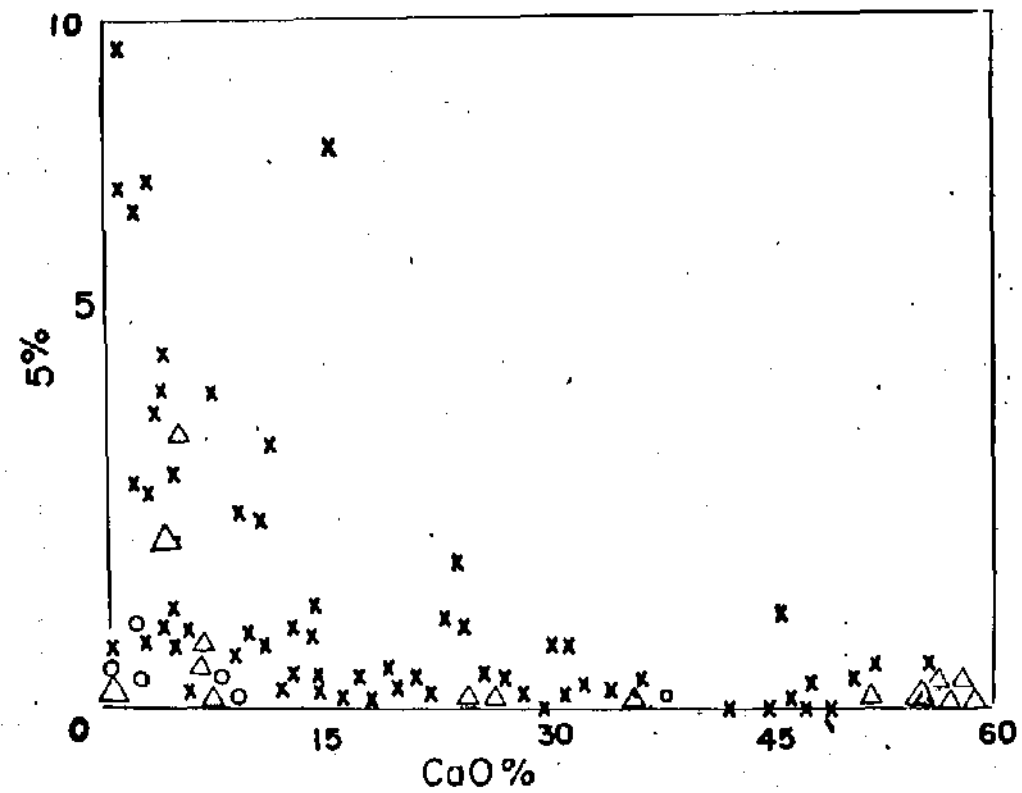
RELATIONSHIP OF POTASSIUM (as potash) TO LEAD. SYMBOLS AS IN FIG. 6.66A



GSN 2460P

FIG. 6.66F

RELATIONSHIP OF SULPHUR TO CARBONATES
(As CaO) SYMBOLS AS IN FIG. 6.66A



GSN 2460 Q

TABLE 4.17A CHEMISTRY OF SOME HYDROTHERMAL INTRUSIVES, VOLCANICS AND FELSPAR PORPHYRY VEINS.

Major Elements in Oxide weight per cent Minor Elements in parts per million (ppm)

SAMPLE NO.	DO178	181	306A	251	340	345	225	307	256B	256D	257	185	185A	188	190	249	277	3210		261B
SERIAL NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		19
SiO_2	49.45	54.5	54.9	46.35	44.55	47.1	44.4	44.5	16.1	47.15	46.96	52.2	50.0	46.3	48.1	49.0	49.52	72.05		74.9
Al_2O_3	12.0	14.34	18.8	13.6	13.9	13.4	13.56	13.4	13.57	13.12	14.36	12.0	15.51	11.45	14.41	11.95	11.95	12.0		12.0
Fe_2O_3	14.85	14.37	1.6	2.39	1.30	2.00	4.4	4.9	14.89	3.45	14.12	3.52	3.82	14.80	3.8	14.80	3.56	1.45		2.3
MgO	9.4	8.18	0.4	8.2	7.95	8.0	7.7	8.0	8.25	8.12	8.0	10.60	10.60	9.45	10.62	10.62	8.60	0.73		0.40
CaO	7.1	3.54	1.7	7.17	6.30	6.1	5.2	6.1	8.77	8.41	7.59	7.18	6.87	7.12	6.82	6.50	7.75	0.66		0.79
MnO	0.15	0.18	0.09	0.18	0.06	0.16	0.3	0.3	0.20	0.15	0.17	0.17	0.15	0.15	0.20	0.20	0.29	0.21		0.10
Na_2O	3.9	10.32	5.62	6.50	7.39	8.3	6.4	7.6	7.39	8.11	8.83	4.20	4.0	6.9	7.0	4.0	4.2	5.00		2.63
K_2O	0.9	2.85	5.22	4.99	2.90	2.5	1.7	1.8	1.84	1.41	0.60	0.60	1.37	0.9	1.36	1.4	1.60	5.1		5.21
TiO_2	1.5	2.40	0.44	3.87	3.20	2.50	3.7	3.2	3.11	2.10	2.57	2.20	0.84	1.5	0.82	0.82	2.20	0.28		0.20
P_2O_5	0.19	0.85	0.10	0.73	0.74	0.38	1.3	1.3	0.31	0.13	0.27	0.31	0.05	0.19	0.10	0.10	0.31	0.41		0.10
S	0.02	0.03	0.01	0.41	0.80	0.40	0.1	0.1	-	-	0.01	0.48	0.42	0.02	0.41	0.40	0.48	0.01		0.01
FeO (Fe_2O_3)	7.0	8.0	3.0	5.03	5.0	5.0	5.0	8.09	7.0	6.0	7.0	5.10	5.0	7.0	5.0	7.01	7.0	2.0		2.5
Ignition Loss	5.65	6.8	8.57	2.64	5.01	2.82	3.1	0.6	0.60	0.13	0.62	1.45	1.57	5.65	1.58	1.53	2.40	-		
TOTAL	100	99.95	100	99.98	100.02	99.96	99.9	99.89	100.12	99.80	100.10	100.01	100.23	100	100	100	99.76	99.95		99.94
Cu	50	40	5	45	42	54	55	54	59	60	42	55	50	56	58	50	56	5		4
Pb	60	135	240	170	117	89	54	80	23	7	17	43	75	45	81	83	87	240		206
Zn	30	60	90	61	60	59	70	79	82	51	58	74	71	71	70	79	125	20		15
Ni	80	119	5	120	121	120	90	95	130	125	120	81	85	83	86	90	65	3		4
Co	60	62	3	60	59	67	61	65	40	45	60	63	67	62	66	69	60	6		5
Mn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
V	170	126	5	120	124	130	315	180	160	170	123	169	170	173	172	175	150	2		3
U	2.1	2.0	10	2.0	2.1	5	12	2	3	5	2.3	3	4	3	5	10	2			
Li	40	20	100	15	19	25	40	40	50	55	20	44	48	47	50	68	15	120		135
Ba	102	309	570	400	300	200	190	195	164	126	90	24	26	100	28	27	82	635		534
Rb	30	140	350	357	141	116	92	89	92	76	70	25	76	31	70	80	89	240		237
Sr	200	130	50	140	135	139	210	206	210	220	130	211	210	29	211	220	215	20		17
Zr	90	125	300	120	117	130	115	100	157	161	120	125	100	212	105	110	100	65		86
Ag	5	2	10	5	3	2	6	6	5	3	3	7	6	4	5	5	2			
F	300	[illegible]	600						339	24[illegible]		305	300	304	309	300	582	609		600
Cl	70		44						80	9[illegible]		70	71	75	70	71	80	50		490
Cr	215	246	5	250	260	251	260	270	220	23[illegible]	266	220	230	230	222	240	220	5		5

TABLE C.11 MODAL ANALYSES OF SOME HYPABYSSAL INTRUSIVES, VOLCANICS AND FELSIC VEINS

MINERAL in Percentages (Estimated From Thin Section, Polished section and Mineral assays).

SAMPLE NUMBER	DC178	181	306A	231	340	345	225	307	256B	256E	157	185C	185A	188	190	249	277	321G	261B
SERIAL NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Quartz	15	1	5.5	1	2	1	2	2	1.5	2.5	1.1	1.6	1.6	15	1.3	1.4	20	16	34
Other Silica, glass		4.7	2.3	4	4		6.9	6.1			4.6								
Labradorite	12	20		28.63	27.80	28.6	15.4	18.80	18.00	18.79	18	34.9	34.85	12	34.9	34.6	20		
Oligoclase		2		1.15	1.20	1.48					2		2		1.15	2.10			
Andesine									8.0	4.0			2	-	1.02	2.07			
Albite	10	17.0	37.0	15.9	16	19.9	32	29.2	25.39	28.2	18.0	10	8.12	39.6	8.1	8.0	8	16	24
Orthoclase	2	4.2	20.80	11.12	11.02	11.0	0.9	0.40	1.40	3.19	8.32	2	1.3	2.4	1.25	1.35	2	38	30
Other plagioclase	6						0.6	17.1	13.72		-	10		5.3				0.8	2.6
Olivine	2	5.3	2.9	16.01	16	16.22	15	13	2.93	3.48	6	2	1.33	2.7	1.38	1.40			
Titanaugite	-	-	-	6.05	9.15	9.0	-	-		6.71	-	-	-	-	-	-	6		
Augite-aegarine	10	4.2	14	3.1		-	9.76	8.21	15.37	15.97	17.7	18.	15.02	10	15 02	15.0			
Hypersthene	3	-	0.5	0.01	1.1	1.25	3.27	1.5	11.92	4.87	-	2.5	2.82	3	2.8	2.8	3	0.5	
Pigeonite	1	-		2.0	2.40	2.0	2			2.0	-	1.5		1	-		5		
Other Pyroxenes	14	31.8	6.9 4	1.0	1	1.0	4				18	1	20	14	20.02	20.0			
Hornblende																	1		
amphibole in general		2									2						.2		
Magnetite	2	2	2.2	1	1	1	1.61	1.74	3.36	2.48	2	1.1	3.44	2	3.4	3.42	3	2.5	2.5
Ilmenite		2	2.4	3.65	3.60	3.7	6.06	1.0	6.08	1.07	2	3.0	5.74		6.93	6.95	6	0.7	2.6
Hematite												1.0							
Apatite	-	0.70	0.2	1.70	1.95	1.65	2.12	1.05	0.71	0.78	0.70	1.1	1.1				0.20	0.1	0.6
Sphene																	6		
Analcite			6.4						1.2	1.2									
Mica (Biotite)	5	1	1	2.37	2.4	1				0.5	1	3.0		5		2	2	0.2	2
Chlorite	12.5	3		1	1	1	1			0.5	3	25		25	5	5	17.0		2
Pyrite																			
Zircon																			
Calcite	5								2.1	2.1		1		3	-	-			
Nepheline				0.57	0.50	0.55						-	-	-					
Total	99.5	99.9	100	100.28	99.92	100.35	99.9	100.05	100.91	100.35	99.72	99.6	99.22	100.0	99.25	99.3	100.2	100	100

KEY TO TABLE 4.11 A AND B (SEE FIGURES) 5.56 AND 1.6
FOR SAMPLE LOCALITIES

1. DC. 178: Altered (albitized) medium grained unmineralized dolerite from a NE-SW trending dyke intruded into calcareous micaceous sandstone of the Late Albian Fiyayi Formation (Upper Sequence of Asu - River Group Kar_2) and truncates a NNE trending fracture zone underlain by fine sandstone-siltstone mineralized with disseminated galena. Buru Hill, 5 kilometres North of Arufu village.

2. DC.181: Alkaline Basalt (Tertiary) Lava from forming the flat topped Buru Hill 5 kilometres North of Arufu aligned in N-S direction. Associated with Nodular Vesicular Laterite (DC.180) capping the crest and slopes of the Buru Hill.

3. DC. 306A: Trachyte - Lava forming part of a NE trending ridge about 10 kilometres west of Katsina Ala - Town. Exposed at road - cutting between kilometres 26 and 27 along the Yandev - Katsina Ala Road.

4. DC.231: Fine hard, black alkaline olivine basalt lava flow forming flat topped hill on the south bank of the River Benue. Baked effect and chilled margin on the Lower Turonian Akahana Formation. Locality: 4 kilometres South of Kwatan Sufa.

5. DC.340: Dense black fine Basalt forming a flat topped Hill around Tseiyorde with NNE-SSW trend, NE Quadrangle of the Akwana Sheet 252.

KEY TO TABLES 4.11A AND B (CONT'D)

6. DC. 345: Fine Black compact alkaline lava (at Annybe on south bank of River Benue) along a N-S trending fracture zone transverse to NE trend of Middle Benue Valley.

7. DC.225: Non-Porphyritic brown-greenish altered alkaline olivine Basalt Lava associated with Ibi sandstone (Kb) at a road-cut 3 kilometres south of Ibi along the Wukari-Ibi tarred road.

8. DC. 307 Porphyritic facies of the alkaline olivine Basalt of DC. 225 (No.7) above DC.225 shows a sharp - boundary between the two types.

9. DC.256B: Altered, weathered, alkaline Basalt lava interbedded with Late Albian micaceous sandstone of the Fiyayi Shale-Sandstone Formation (Upper part of Asu River Group) near Andyar village, at kilometre 85 along Wukari-Kwartan Sule Ferry Road.

10. DC.256D: Altered Alkaline Basalt with semi-pillow structure associated with DC.256B (No. 9) above.

11. DC.257: Fine hard black compact post-Lower Turonian - Tertiary? Alkaline Basalt Lava flow across DC.256B (No.9) above with no observed chilled margin or contact.

12. DC.185: Altered greyish black fine-medium grained dolerite from a NNE - SSW trending dolerite dyke intruded into the shelly limestone unit of the Arufu limestone 2.2 kilometres NNE of Arufu Village.

13. DC.185A: Fine grained black compact dolerite from a NNE-SSE trending dolerite dyke intruded into the Pre-Asu River sediments near contact with basement granitic

KEY TO TABLES 4.11A AND B (CONT'D)

granitic gneiss (Arufu inlier) above 2.1 kilometres NE of Arufu.

14. DC.188: Fine-medium grained compact black dolerite from a NE-SW trending dyke intruded into the Fiyayi Formation about 4.5 kilometres NE or Arufu.

15. DC. 190 Fine-medium black dolerite from a NE-SW trending dyke across River Bar, intruded into Late Albian micaceous sandstone of the Fiyayi Formation about 2 kilometre NE of Buru Village.

16. DC.249: Black hard medium grained dolerite, from a NE-SW trending dyke around Ikwe village.

17. DC.277: Medium grained greyish greenish pyroxene-rich dolerite from a NE-SW trending dyke about 2 kilometres south of Tseagosu and 7 kilometres NE of Iyorja.

18. DC.261A and 321G: Alkaline Rhyolite from NNE-SSW trending Bill intruded into the Pre-Asu River Sediments at Tseagu Hill at kilometre 77 along the Makurdi - Yandev tarred road.

19. DC.261 & F: Feldspar-Quartz porphyry rock with pink K-feldspar phenocrysts from a faulted concordant vein in the Pre-Asu River sediments at Tseagodo Hill road - cutting at kilometre 12 along Yandev - Katsina-Ala tarred road.

Near the confluence between the S-W flowing river Bar and the SE-NW flowing river Kutaji, a NE-SW trending medium grained altered dolerite body (DC 188) truncates and displaces (vertically for 4 metres) one of the NNE-SSW trending dolerite bodies emplaced in a shelly fine calcareous sandstone belonging to the basal units of the Late Albian-Early Cenomanian Awe Formation (the Upper part of the Asu River Group).

The second cycle dolerite bodies (DC 185,185A, 187, Tables 4.11A and 4.11B) are not mineralized in galena or any other sulphides. Their widths range between 20 metres and 45 metres, with an average of about 25 metres.

Third Cycle Igneous Bodies

These consist of two groups;-

(a) The altered hypabyssal NE trending dolerite sills and slightly disconcordant (dkye) bodies (DC 178, 181, 188, Table 4.11B). They vary in width from 20 metres to 50 metres, with an average of 25 metres.

(b) i Basaltic (volcanic) lavas e.g. the Andyar Basalt - in places with spilitic effinity (DC 256D, 256A) interbedded with the folded sediments.

ii Basaltic lavas interbedded or associated with the Cenomanian Ibi Continental Sandstone (DC 224, 225, 307, 309). The lava is emplaced in a NNE trending zone about 100 metres wide estride the axis of the Ibi Anticline.

In hand specimen the subparallel concordant-semiconcordant dolerite bodies consist mostly of medium grained altered, calcite-bearing dolerites, In the Buru-Ajimi-Ikwe area these igneous bodies

are found in the axial (crestal) regions of anticlinal structures with NE-SW trending axes, showing that their emplacement is structurally controlled. For example, the dolerite sill (DC 178) outcrops on the southern slopes of the flat-topped Buru Hill (5 kilometres north of Arufu) which marks the crest of Buru anticline with a NE-SW trending axis. The host rock is a finely bedded calcareous, micaceous, cream coloured, fine-medium grained sandstone belonging to the basal beds of the Late Albian Awe Formation. This dolerite is unmineralized and traversed by ENE-WSW trending fracture zone which hosts disseminated galena mineralization (specimen L. 535 A).

There is no evidence of any marked structural deformation imported on the sediments by the intruding dolerite bodies. Neither was there any baked effect nor chilled margin.

On the western slopes of the Buru Hill about 1 kilometre SE of this location there is a NW-SE flowing saline spring near the compound of Nwannan. The spring issues from a set of parallel fractures.

In thin section some pigeonite and relict olivine are seen in the altered dolerite. These may suggest that the dolerite was originally THOLEITIC igneous body but later on albitized, and heavily altered (spilitized) by soda and carbonate - rich deuteric hydrothermal fluids consequent upon emplacement, into partly unconsolidated but still wet sediments; possibly some of the solutions responsible for the disseminated galena mineralization contained in the ENE-WSW trending sets of fractures were brines already in the wet marine sedimentary pile. The moving basic magma (responsible for the emplacement of the dolerite bodies along tensional axial fractures)

probably acted as subsidiary host source which accelerated and set the mineralizing waters or solutions into circulation along permeable zones which subsequently formed disseminated (galena) sulphide, deposited at favourable structural locations

According to Macdonald and Kapsura'a (1964) classification the dolerites are found at the edge of the alkaline series and may thus be said to be mildly alkaline.

The characteristic feature of the Third Cycle dolerite is the intense alteration by albitization and this process is shown by the higher albite content of the rocks (DC 178, 188, Table 4.11B) in which the albite contents are 10% and 9.6% resoectively. Relict (Skeletal) olivine is present (2.3. - 2.4%) - Hyperstherse constitute 3% by volume of each of the above specimens (DC 178 and 188). The specimen DC 178 was collected from a NE-SW unmineralized dolerite sill in the crestal area of the Buru Hill anticline. The dolerite intrusive is about 20 metres north of a NE-SW trending fracture which hosts disseminated steel grey granular galena mineralization (L. 635A), in Late Albian fine calcareous sandstone-siltstone-sandy shale sequence. Pigeonite makes up only 1% of each specimen.

Quartz is also rare, the commonest alteration products are chlorite, calcite, sericite and uralitized pyroxene in the intensely albitized portions (DC 178).

The presence of pigeonite and hypersthene in the medium grained axial dolerites may suggest that they were originally tholeiitic dolerites albitized and heavily altered (spilitized by soda and carbonante-rich deuteric hydrothermal fluids, consequent upon

emplacement into partially consolidated but still wet sediments, possibly still undergoing deformation.

In the case of the Buru Hill dolerite (DC 178) it seems likely that at least, some of the solutions responsible for both igneous rock alteratio alteration and the nearby disseminated galena mineralization were brines within the sedimentary pile. The Nwannan salt spring is about 1 kilometre SE of the Buru Hill dolerite.

No direct field evidence was found which related the nearby Buru Hill disseminated galena mineralization to the nearby unmineralized dolerite. Both of them are aligned parallel to the NE-SW trending axis of the Middle Benue Trough. Probably both the galena mineralization and dolerite intrusion are approximately contemporaneous, with the igneous body acting as a subsidiary heat source to the rising, circulating mineralizing fluids.

These field relationships tend to support the view that the source of the galena mineralization is from deep circulating hot solutions which leached metals from the sediments and the K-feldspar rich granitic basement rocks. Being hotter than the surrounding sediments the igneous bodies presumably acted as a subsidiary heat source for the rising circulating mineralizing fluids along permeable (open fissure) zones to form sulphide deposit. (GALENA) at favourable structural locations.

4.3.6 Interbedded Lavas

Extrusive igneous rocks in the form of lavas interbedded with the Cretaceous sedimentary rocks of the study area were difficult to document during the present investigation because of intense weathering. However, thin layers of highly weathered clayey

material that probably represent thin layers of lavas interbedded with units of the marine Fiyayi Shale-sandstone Formation (Late Albian to Early Cenomanian) were observed along the road cuttings between likometres 41 and 43 along the Wukari-Arufu tarred road. This layer is about 0.7 metres thick and consists of a volcanic rock material that has been altered to red-grey-greenish clay-silt, characterized by spheroidal weathering surfaces. These rocks contain altered olivine (iddingsite), cloudy plagioclase, and iron-oxide. Some secondary calcite and small amounts of kaolinite are present. Relict kaolinized plagioclase feldspar crystals can still be seen.

Andyar Basalt

At kilometre 85 road cutting on the eastern outskirts of Andyar village along Akwana-Kwatan Sule tarred road, a mildly alkaline basaltic lava covers an extensive area. The lava is interbedded with tabular sandstone belonging to the late Albian Awe Formation, in a NE-SW trending fracture measuring about 3 1 kilometres in the axial area of the western plunging end of the Arufu anticline. The basaltic lava (DC 256A-C) appears to have the same dip 20-25° NW on the northern flank of the fold but the dip direction changes to SE on the southern limb of the fold. Parts of the lava have a semi-pillow spilitic structure (DC 256D). The outcrop (DC 414A,B) extends southwards across the road to the western outskirts of the Compound of Tsebagi, where it assumes a highly fractured appearance. The estimated thickness of the lava is about 10 metres.

The Andyar Basalt occupies both banks of the SW-NE flowing River Uweyande. The host clayey sandstone is highly lateritized and ferruginized in this zone. Both the lava and the sedimentary rocks form a NE-SW trending ridge; towards the west bank of the

river the interbedded basaltic lava is truncated by a NW-SE trending compact black fine grained strongly alkaline basaltic lava flow (DC 257) which weathers to greenish brown clayey soil, lateritized. No chilled margin contact feature was observed perhaps because the "newer" basaltic lava was mostly seen in boulders.

The presence of semi-pillow like lava features (DC 256D); and the intense alteration features such as albitization and spilitization on the Andyar Basalt, are indicative of cooling and emplacement of basic magma in partly consolidated but still wet sediments of the Awe Formation, possibly still undergoing deformation. The volcanic lavas show either spheroidal weathering or have crumbled into irregular ashy grey masses which can be crumbled in the hand. Under the microscope the two specimens (DC 256B and 256D, Table 4.11B) show some subhedral phenocrysts of olivine, in places altered to red iddingsite. Calcite is present and is associated with analcite. The groundmass consists of altered olivine, cloudy plagioclase laths and granular magnetite. Nepheline or leucite is present in very small quantity or occurs as traces.

The Andyar Volcanic (basaltic) lava is unmineralized and no direct field evidence was found which related the galena mineralization at Akwana about 12 kilometres east of this Andyar igneous body to the Lower cretaceous-Cenomanian dolerite sills or dykes.

Ibi Volcanic (Basaltic) Lava

At a road cutting on a hill (overlooking the broad valley of the NE-SW flowing Rafin Soja) about 3 kilometres south of Ibi town, along the Wukari-Ibi tarred road, is exposed the type locality of the Cenomanian Keana Formation, which is situated in the crestal area of the Ibi anticline with a NE-SW trending axis. This sequence (DC224)

is interbedded with a highly weathered volcanic lava (DC 225,307), which is emplaced along the crestal area of the anticline. The volcanic rocks have been invariably so highly weathered that at most exposures it is very difficult to obtain suitable specimens for petrographic studies. The interbedded lava dips concordantly at 15° - 20° SE or NW on both limbs of the anticline. On the northern slopes of the hill facing the valley of Rafin Soja, parts of the lava flow have weathered to greyish green clays and no trace of the original constituents remains.

Parts of the flow are porphyritic (DC 307) while others are non-porphyritic (DC 225). The porphyritic facies is characterized by several poorly aligned slender milky white feldspar laths and large pink tabular feldspar fragments (megacrysts?). The non-porphyritic or sparsely porphyritic facies also carries scattered large glassy red to yellow clear feldspar megacrysts. Both porphyritic and non-porphyritic facies contain fairly abundant limenite (DC 225 and 307) and are vesicular.

Both types of basaltic lava are also composed of tables and laths of plagioclase set in a groundmass of plagioclase, glass, iron oxides, chlorite and amygdale fillings of quartz and calcite. Estimated modal composition is as follows (Table 4.11B):

Porphyritic type (DC 307): Plagioclase (65.4%), glassy material (6.1%). iron oxides (8.82%), ilmenite (7.08%), quartz 2%, calcite carbonate amygdale) 2%, chlorite 1%, olivine 13%, aegerine augite 8%, Hyperstheme 1.5%

Non-Porphyritic type: Plagioclase 54%, glass (6%), Iron Oxides (7.67%), ilmenite (6.06%), Quartz (2%) calcite (Carbonate amygdale) 2%, 2%, chlorite (1%), olivine 15%, aegerine augite 8%, hypersthene 3.3%.

The plagioclase consists of albite, and labradorite, and is commonly altered to sericite. Magnetite and ilmenite occur as patches and disseminations, whereas chlorite appears as replacement of earlier formed ferromagnesian minerals. Carbonate and quartz are mainly vesicular fillings. The texture of the lavas is intersetal to hyalophitic.

The Ibi volcanic lava is not known to be mineralized although the associated Cenomanian Keana Formation is mineralized with barite in the NE outskirts of Ibi.

4.3.7 Chemical Analysis

Nineteen least altered samples of the different types of igneous rocks encountered in the study area during the present investigation were carefully selected from the sample collection obtained during the geological mapping. Out of this number three are acidic (salic) igneous rocks made up of intrusive alkaline rhyolite (DC 321G) and alkaline feldspar-quartz porphyry (felsite) vein rock DC 261B and F) and trachytic rock (DC 306A)

Two samples (DC 185 and 185A) belong to the second cycle fine-grained doleritic rocks, while the altered (albitized) dolerites are represented by four samples (DC 178, 188, 190 and 277). The interbedded alkaline basaltic (volcanic) lavas consist of four samples (DC 225, 307, 256B and 256D), while the remaining six samples (DC 231, 340, 345, 257, 181, 249) represent the Tertiary strongly alkaline basaltic lavas.

The samples were crushed and ground to minus 150-mesh and analysed by both atomic absorption spectrophotometry and wet chemical processes (gravimetric and volumetric analyses). Determinations were

made for SiO_2, Al_2O_3, TiO_2, Fe_2O_3, FeO, CaO, K_2O, Na_2O, MnO, P_2O_3, S and ignition loss (H_2O, CO_2 etc).

Since an important aspect of the present investigation includes among other things, the source, origin and mode of emplacement and stratigraphic - structural control of the galena mineralization, the trace element analysis included many of the base metals usually associated with lead (pb). These include Zn, Ag,Cu, Ba. The other trace elements like Zr, Cr, Li, Rb, Sr, Ni, Co, V, were determined mostly for petrogenetic considerations.

4.3.8 Geochemical Interpretation of Results

Major Elements

First Cycle Igneous Rocks

The SiO_2 values of the rhyolitic rocks are generally high, with a range of 72.03 to 74.16%. Compared with the Tseagu Hill rhyolite (DC 321G, etc) the Tseagodo feldspar-quartz porphyry rocks (DC 261B, F) are higher in silica but lower in alkalis. However, the silica and alkali contents of all the rhyolitic rocks fall within the compositional range of rhyolitic rocks (Carmichael et al. 1974). Compared with the average "Later intrusive alkaline rhyolite" composition of the Nigerian Younger Granite Province (Jacobson et al. 1977), these Tseagu-Tseagodo Hills rhyolites rhyolite series (cf. Macdonald and Kapsura 1964).

Second and Third Cycle Igneous Bodies

The Na_2O and K_2O contents of both the second cycle fine grained dolerite (DC 185, 185A) and third cycle medium-grained dolerite dykes and sills, indicate that they have an alkaline affinity. Compared with Manson's et al. (1968) average basalt composition

Table 4.16A) the Late Albian-Cenomanian third cycle basaltic lavas (DC 225, 256B, D, 307: table 4.16A), are enriched in TiO_2 MgO, P_2O and Na_2O and depleted in Al_2O_3, Fe_2O_3, CaO and K_2O. The relatively high Na_2O and low K_2O contents may reflect secondary alteration (spilitization and the development of sodic plagioclase (albitization). Variations in CaO,MgO may be due to variation in the amounts of carbonate amygdales, chlorite and interstitial glassy groundmass. The high TiO_2 content may reflect the abundance of ilmenite.

It is apparent from the mineralogical characteristics and major element composition of the Late Albian-Cenomanian third cycle hypabyssal albitized dolerite sills and dykes, and also the Late Albian-Cenomanian interbedded basaltic lavas that must have been subjected to pervasive secondary alteration involving:-

(a) subsequeous processes in wet partially consolidated sedimentary pile undergoing diagenesis or

(b) submarine weathering.

Fourth Cycle Igneous Rocks

The results of detailed chemical analysis of six samples of the post-Lower Turonian to Tertiary (fourth cycle) volcanic lavas are shown in Table 4.11A. The SiO_2 values of the five olivine basalts (DC 181, 231, 340, 345 and 257, Table 4.11A) are generally low with a range of 45.1 to 46.5%. This depletion may be attributed to pervasive carbonate replacement and alteration, including albitization. This range falls within the composition of basaltic rocks (Manson et al. 1968). According to the classification of Macdonald and Kapsura (1964) their silica and alkali compositions place them in the basic alkaline series.

The results of this analysis appear to indicate that these predominantly Cenozoic volcanics may be typical of the continental alkaline basalt association, although a minor degree of tholeiitic affinities are apparent in some samples due to the presence of pigeonite and aegerine augite. But even then the relatively high potash contents make the affinity unlikely. An interesting feature of these rocks shown by the chemical analyses is their high soda content which is relected in the occurrence of sodic pyroxene even where the dominant feldspar is potassic.

Minor Elements

The minor element concentrations show variations which somehow reflect similar variations in their coherent major elements. However, Zr which is relatively immobile during alteration processes (pearce and Cann 1971) is fairly uniform in concentration and comparable with values obtained for basalts (Table 4.16A). Rb and Ba show good positive correlation with K_2O which is consistent with their geochemical coherence during magmatic and secondary alteration processes. Li values are high compared to average basalts, but there is a positive correlation in the salic rocks (DC 321G, 261F and 306A). Compared to average basalts and the Abakaliki (Lower Benue Trough) basalts Upper Benue Basalts (Table 4.16A) the volcanic basaltic lavas of the study area are enriched in Cr and Ni which are consistent with their mafic character, and the relatively high TiO_2 and Fe_2O_3 values.

Pb concentrations in the igneous rocks show positive correlation with the K_2O value which is consistent with the geochemical characteristics of lead (Pb). Lead (Pb^2(ionic radius = 1.20A Electronegativity = 0.8) shows preferential enrichment in rocks rich

in K_2O or in potassium minerals like potash feldspars in which it replaces potassium (K^+, ionic radius $\pm$ 1.33A, electronegativity =0.8). Thus the salic rocks of the study area (DC 306A, 321G,261F), rich in potash (K_2O) and potash feldspar (orthoclase) have relatively higher Pb concentration than the more basic or basaltic rocks. The contents of lead and Zn in igneous rocks is shown in Table 4.16.

Zinc (Zn^{2+} ionic radius = 0.74A) is admitted into crystal lattice of the major element iron (Fe^{2+} ionic radius =0.74A) of the ferromagnesian rock forming minerals (amphibole, biotite and pyroxene).

Zn shows a corresponding increase with Pb especially in the potash-rich (K-feldspar rich) igneous rocks where Pb concentration is greater. Anywhere, a comparison of Table 4.11A to Table 4.16 indicates that both lead and zinc concentrations in all the Cretaceous Tertiary igneous rocks are only of background level, even in the Cenomanian dolerite sills (DC 178, 188, 190) in the proximity of the Late Albian - Early Cenomanian galena mineralization around Buru and Arufu. This supports the field observation that there is no direct evidence to relate the galena mineralization to the Lower Cretaceous to Cenomanian dolerite sills or dykes.

Cu and U appear unrelated to any minerals or igneous rocks because of their flat and low distribution, although there is apparent low Cu concentration in the acidic (salic) igneous rocks (DC 306A, 321G, 261F).

4.4 Summary

The association of the Albian to Cenomanian sediments with the potash-rich underlying Aptian rhyolite sill (DC 321G) and felsite veins and sills (DC 261F) emplaced into the Pre-Asu River Continental sediments, and with the Cenomanian interbedded volcanic basaltic

TABLE 4.16 Lead and Zinc Contents in some Igneous Rocks

Rock	Pb	Zn
Gabbros, dolerite, basalt and related	PPM	PPM
rocks average	5	90
Basic igneous rock average	9	
Granite rocks, average	30	
Quartz Diorite, Diorite		120
Granites of Southern Lapland, average	9-27	
Acidic (Salic) igneous rocks average	19	
Grano- diorite, Quartz Syenite		200
Plagioclase Granite		150
Plagioclase - microcline Granite		30

Source: Rankama and Sahama 1949.



Plate 4.7A

Local Salt Industry. A woman engaged in salt refining process in the Akwana Salt pond.

Locality: 1.3km west of Akwana Village.

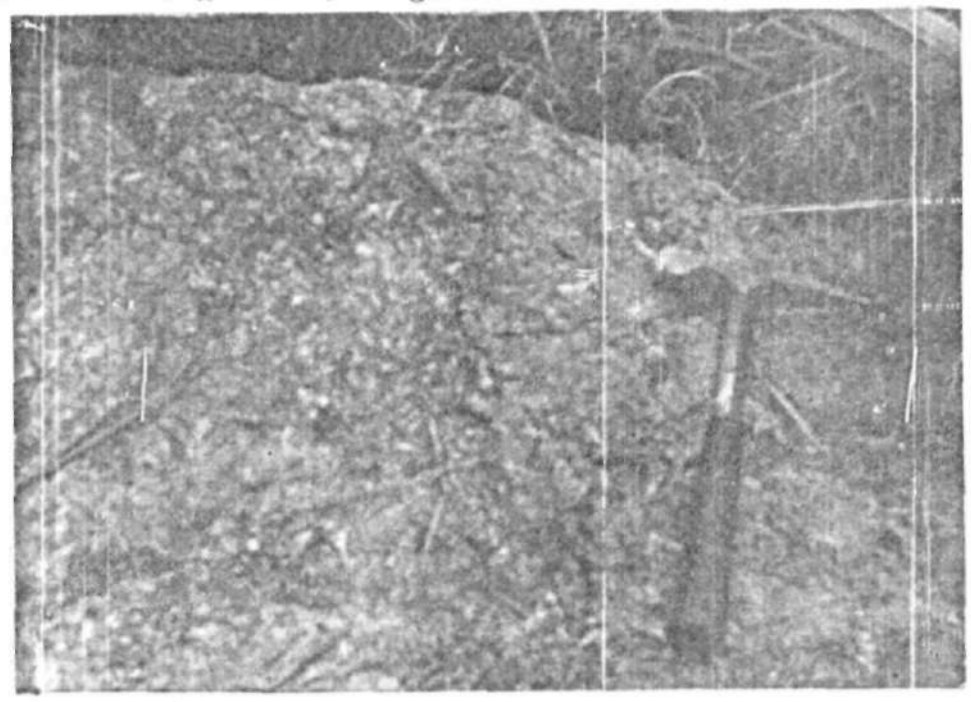


Plate 4.7B

Thick bedded to massive shelly ("Oyster bank") limestone in the basal bed (Bed 1) of the Middle-Upper Albian Limestone-Shale Arufu Formation.

Locality: 2 kilometres NNE of Arufu Village.

TABLE 4.16A: CHEMICAL COMPOSITION OF BASALTS

	1	2	3	4	5
SiO_2	48.60	45.37	49.3	47.2	51.2
TiO_2	3.15	1.87	2.0	2.4	1.4
Al_2O_3	15.90	16.58	16.0	13.8	15.9
Fe_2O_3	0.00	2.95	3.20	3.2	2.9
FeO	5.30	7.4	9.20	8.0	8.0
MnO	0.06	0.18	0.17	0.16	0.17
MgO	2.95	8.26	6.6	7.0	6.2
CaO	6.29	9.11	9.9	10.1	9.9
Na_2O	4.40	2.50	2.9	3.2	1.4
K_2O	1.89	1.93	1.0	1.4	0.7
P_2O_5	0.74	0.73	0.32	0.48	0.21
CO_2	8.10	Nil	--	---	---
H_2O	1.90	0.44	0.90	1.0	0.8
S	0.90	0.41	---	--	--
Total	100.18	100.12	100.09	99.94	99.94
M	ppm	---	---	--	---
Zr	157	--	--	135	106
Y	18	--	--	30	32
Rb	153	--	--	51	30
Ba	254	--	--	444	244
Li	28	--	--	10	8
Cs	2.4	--	--	--	--
Cr	219	--	--	187	162
Ni	130	--	--	101	85
Co	30	--	--	42	39
Cu	54	--	--	108	121
Zu	33	--	--	--	--

1. Abakaliki Alkaline Basaltic Lava (Olade, 1979)
2. Olivine Basalt, Biu Plateau (Carter et al 1963)
3. Average Basalt after Manson et al (1968)
4. and 5 Average Alkaline Basalt after Manson (1968)

lavas in the study area, may lead to the suggestion that magmatic activity manifesting as rhyolitic, felsic veins and sills and as interbedded volcanic basaltic lavas in the sedimentary sequence, was in some way, responsible for the availability of metalliferous (Pb) solutions. Under most circumstances these were dispersed, but ore deposits probably formed where they were channelled to the surface along deep-seated fractures (faults) and permeable zones and deposited at favourable sites, with the dolerite sills and dykes acting as subsidiary heat sources in their proximity or neighbourhood. Thus it appears that the galena mineralization in the study area was generated when a variety of parameters intersected field observations indicate that some of the magmatic activities occurred either before (DC 321G, 361), while some appear to be approximately contemporaneous with (DC 178, 188, 256B, &), and the rest (Tertiary alkaline olivine basaltic lavas) post-dated the galena mineralization.

Repeated and continuing Cretaceous to Tertiary or even later alkaline igneous activity in the study area (in Middle Benue Trough) and the Benue Trough as a whole has been attributed to reactivation of magmatism along pre-existing line of structural weakness in the crust (cf. Umeji 1985) in response to stresses affecting the African plate (Grant et al. 1972, Wright 1976a). Thus the stratigraphic position of the igneous rocks, relative to the sedimentary pile that host them, suggests that these rocks were emplaced during a reactivation rather than at the initial stage.

Alternatively, the association of axial NE trending dolerite sills and dykes (in the crestal area of the Buru Hill anticline) and the disseminated galena mineralization, may not necessarily have a genetic significance but may be due to the repeated movement of the same

fracture zone in the underlying crystalline basement rocks (cf. Akande et al 1988).

It is believed that the basaltic vents so common in the valleys of Gongola River and the Upper Benue, are represented in the Middle and southwest (Lower) Trough, where the Albian sedimentary cover is thick, by doleritic dykes and sills and small intrusions. The emergence of the basalts of the Benue valley has been quiet, and the scarcity of craters and agglomerates is witness to the subordination of gaseous activity (McConnell 1949, Carter et al. 1963).

It may be imagined therefore, that the basaltic rocks rose easily in open fractures in the competent rocks of the Basement Complex (under tensional regime?) but found difficulty in penetrating a plastic sedimentary series in which fissures would remain open, hence where sediments were thick Cretaceous hypabyssal (doleritic) types of rocks resulted (McConnell opt cit., Farrington, 1952, Wright, 1976a, 1976b 1981).

The presence of interbedded (?) spilitized basaltic volcanic lava with semi-pillow structure (DC 256D) and their close spatial and stratigraphic association with sandstone, shales of marine origin (Late Albian-Early Cenomanian Fiyayi Formation) in the Andyar area, suggest that the Andyar Volcanism involved volcanic eruption in a subaqueous (shallow marine?) environment.

More significant are some rocks described above with strongly alkaline affinities and probably undersaturated (DC 306A etc) including varieties containing TITANAUGITE. This may provide a considerable support that we may be dealing with a Cretaceous-Tertiary alkaline igneous province where the original character of the

rocks has sometimes been obscurred by post-magmatic modification (cf. Wright 1976a).

The presence of pigeonite and some hypersthene in some of the dolerites described may suggest that some of the axial dolerites were originally tholeiitic dolerites, albitized by deuteric-hydothermal fluids, consequent upon emplacement into partly consolidated but still wet sediments, possibly undergoing deformation.

Being hotter than the surrounding Albian sediments the igneous bodies presumably acted as subsidiary heat sources for the circulating mineralizing fluids rising through permeable (open fissure) zones in the wet sedimentary pile still undergoing consolidation and diagenesis, to form metal (galena) sulphides at suitable structural locations.

The commonly altered condition of the dolerite intrusives especially in the Buru-Kutaji Valley area (DC 178, 188;) could be partly attributed to the passage of hydrothermal solutions through them, although we cannot exclude the possibility that some of the alteration may be due to soda metasomatism resulting from intrusion into wet sediments (cf. Farrington 1952).

The occurrence of Cretaceous-Tertiary alkaline rhyolitic-basaltic-doleritic magmatic bodies along the axial NE-SW and transverse NW-SE trending fractures may indicate that these are deep-seated open fractures or crustal failures through which the magmas rose under a TENSIONAL REGIME. The NW-SE trending fractures are perpendicular to the fold axes. They probably initially formed complementary to the NE trending sets but assumed the NW-SE direction during a latter tectonic episode.

These deep-rooted predominantly Lower Cretaceous basic

(dolerite-alkaline basalt) and acidic (alkaline rhyolite) igneous rocks, which are indications of deeply penetrating fractures, localized near the axis and along or beyond the NE-SW trending margins of the trough, suggest that the Middle Benue Trough originated as a rift valley. In the case of the Tertiary basaltic volcanism in the study area, the magma was probably generated by pressure release in arched zones. Magmatism in the Benue Trough from the Tertiary to the Recent times suggests that the rift zones have constantly been reactivated.

Finally, the field and structural evidence of (i) Several periods of folding in the Lower Cretaceous-Cenomanian times and also in the Santonian (cf. Nwachuku 1972, Olade 1975), (ii) the several stages of faulting, rift-faulting and graben generation and (iii) the various cycles of igneous activity in the Aptian, Late Albian to Cenomanian, in the study area, indicate that the sequence of events in the tectonic evolution of the Cretaceous Benue Trough may have been repeated in a cyclic manner with intercyclic structural deformations (cf.Offoegbu 1984). The geochemistry of the rocks is consistent with magmatism in a continental rift tectonic setting.

4.5 The Nature of Rift Faulting

4.5.1 Introduction

The different types of faulting and the associated igneous activity as well as several geomorphological features, can be related to the nature of rift faulting in the Middle Benue Trough. Reconnaissance geological traverses during the present investigation covered most parts of the northwestern basement margin, the central region, and the southeastern basement margin of the Middle Benue Trough.

The Benue Trough is now generally regarded as an intracontinental rift valley (Olade 1975, Wright 1976, Ajayi and

Ajakaiye 1981; Benkhelil 1982, Ofoegbu 1984) or as an intracratonic graben basin (Hoque and Nwajide 1985), though there are several unresolved questions such as the apparent lack of normal faults parallel to its NE-SW trending boundaries. In the present investigation this problem is addressed especially in the Middle Benue area.

During rifting, uplift and tension cause fracturing followed by differential vertical movements. The movements among the faulted blocks continued during and after the deposition of sediments and resulted in both faulting and folding of strata. This may thus explain folding along longitudinal axes in the Benue Trough (cf.Wright 1981, Nwachuku 1985).

The origin and structural evolution of the Benue Trough attributed to the opening of the South Atlantic as an on-shore extension of the equatorial fracture zones along the northwestern and southeastern basement margins of the Trough (Benkhelil 1982) were probably related to the pre-existing structures of the underlying and/or flanking Basement Complex rocks. In the study area the underlying Basement Complex rocks consist of Pre-Cambrian metasediments (Biotite gneiss and quartzo-feldspathic muscovite gneiss), granitic gneiss and the Pan African Older Granite Series. In Chapter 2 of this work it has been stated that the major structural trends in the basement are N-S, NE-SW, ENE-WSW. Along the NW basement margin of the Middle Benue Trough an E-W trending mylonite zone passes through the southern outskirts of Nassarawa-Eggon.

The concept of the intracontinental rift origin of the Benue Trough led to its classification as an aulacogen (Olade 1975). Early

hypotheses include the belief that the application of the Y-shaped tripple junction rift model (RRR) to the separation of the South American and African continents in the Early Cretaceous times, best explains the final configuration of the Benue Trough (Burke et al.1970). Benkhelil (1982) suggests that the Benue Trough may have been initiated by the extension of the equatorial fracture zones onto the continent during the early stages of the separation of South America and Africa. He believes that a transcurrent movement along deep-seated faults (probably initiated due to old lines of weakness within the mobile belt) of the basement is responsible for the structure of the trough.

4.5.2 Salient Features of the Middle Benue Rift Structure

In general block-faulting involves the tilting of the land surface about a central axis of tilt and without large vertical adjustments (James 1956). Thus the average height of the land surfaces remains about the same or only rises gradually in a given direction. All faults observed bounding blocks of this nature in the Middle Benue Trough are believed to be NORMAL FAULTS as earlier discussed.

In the central rifted (arched, tilted) zone straddling the Arufu-Tyoban-Yandev area of the Middle Benue Trough the major tilting is towards the west and southwest. This is shown by the pattern of drainage. However, it appears that an earlier set of block-faults has caused tilting of the land surface to the northeast. Where the older and younger opposed sets interplay, graben and horst are developed, namely, the Depression between Tyoban-Tsekwen basement Older Granite horst block and the Tsejande Older Granite basement ridge-inlier, and the Igbur basin between the Arufu and Igbur Granitic Gneiss basement inliers. No trough-faulting

is found in the above rifted central zone, and it is probable that this central part of the Middle Benue Trough is due solely to block-faulting giving rise to depressed areas by the formation of graben or the downwarping of a series of tilted blocks.

The recent geophysical investigation undertaken by Ajayi et al. (1990) in the eastern part of the Lower Benue Trough, shows that deep magnetic anomalies detected in this region trend NE-SW and are thought to be possibly associated with basement ridges which centrally occur within and parallel to, the general trend of the Benue Trough. This conclusion may confirm the belief that these deeply located basement ridges could have created horst and graben structures as is the case in the Middle and Upper parts of the trough, except that the latter the basement ridges and inliers are exposed at the present erosion level (Figs. 4.42, 4.43, 4.44).

Difficulty in Recognizing Rift Features in the Middle Benue Trough

Unlike other modern continental rift valley systems in East Africa, Brazil etc. which are still active, and date principally from the Mid-pleistocene to Recent, the Middle Benue Trough and indeed the whole Benue Trough, is of Cretaceous age, and is regarded as an aulacogen (Olade 1975) or a senile rift structure originating at about the time of the opening of the Cretaceous South Atlantic Ocean, and forming an extension of that original fracture system but failing to open into a true ocean basin.

In addition to the rift-structure being very senile, the relationship of the different geological cycles are such obscurred by post rift-faulting deposition of sediments, silicification, deep tropical decomposition due to weathering processes etc., and the dense bush cover.

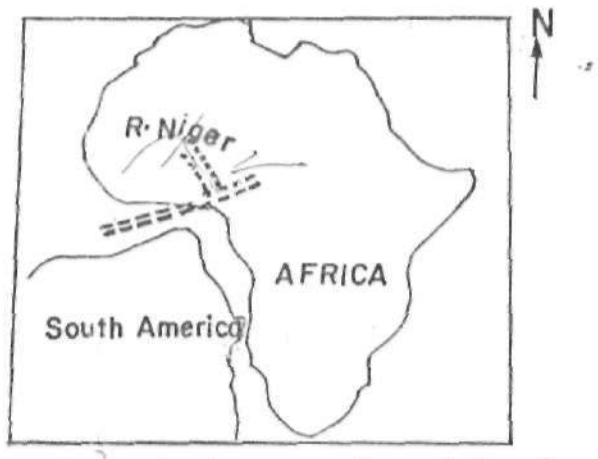


FIG.4.40 Early interpretation of the Benue and Niger Depressions as rifted Structures. From king (1950). See also Pugh and king (1952) Furon, (1963) Reyment (1965; P113)

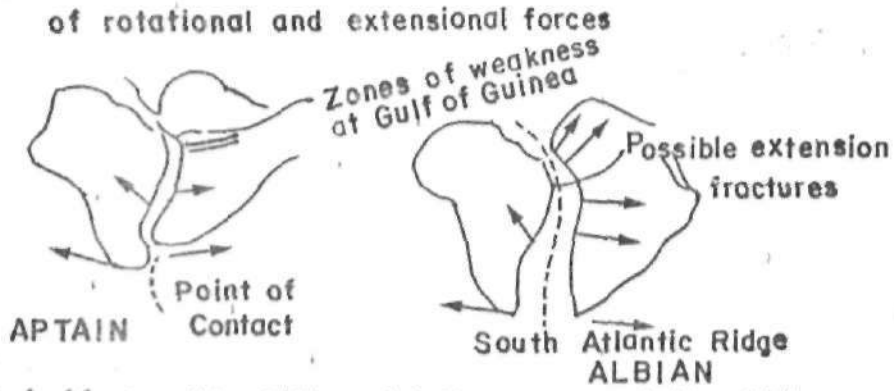


FIG. 4.41 Possible Differential Movements of the African and South American landmasses along Fracture widening from south to north. (From offodile 1976)

G.S.N. 23456A

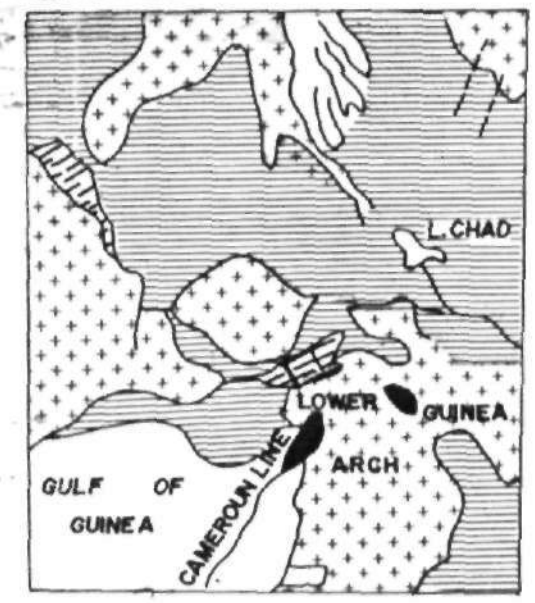


Fig. 4.42: The Rift Structure of Nigeria-Hoggar Zone.

Basement.

Sediments.

Rift Valley.

Young Volcanics.

After M.E. Offodile (1976).

Study Area

GSN 431A

FIG.4.43 SCHEMATIC SECTION THROUGH THE CRETACEOUS SEDIMENTARY/BASEMENT INLIER MARGIN IN THE TSEKUR-UGBA-YATIEV AREA.
Note the possible Drape-Folding.

Kea Eze-Aku Formation

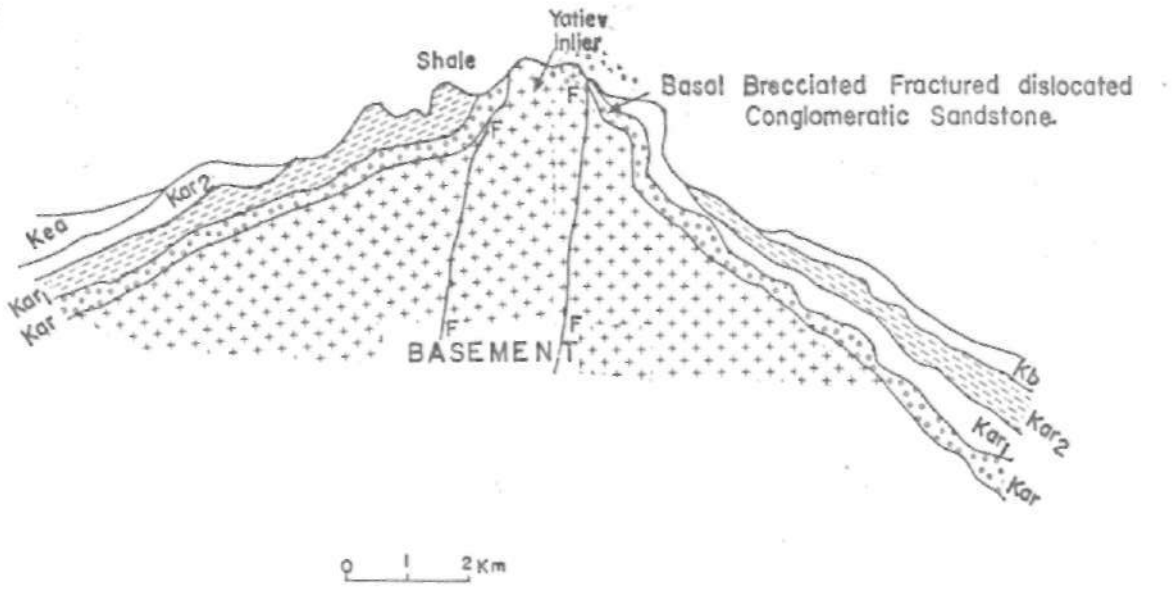
Kar2 Awe Formation } ASU RIVER GROUP
Kar1 Uomba Formation }

Kar Pre-Asu River Continental Sandstone

Granitic Gneiss of the Yatiev Basement Inlier

F—F Fault

Kb Ibi Continental Sandstone



G. S. N. 431.

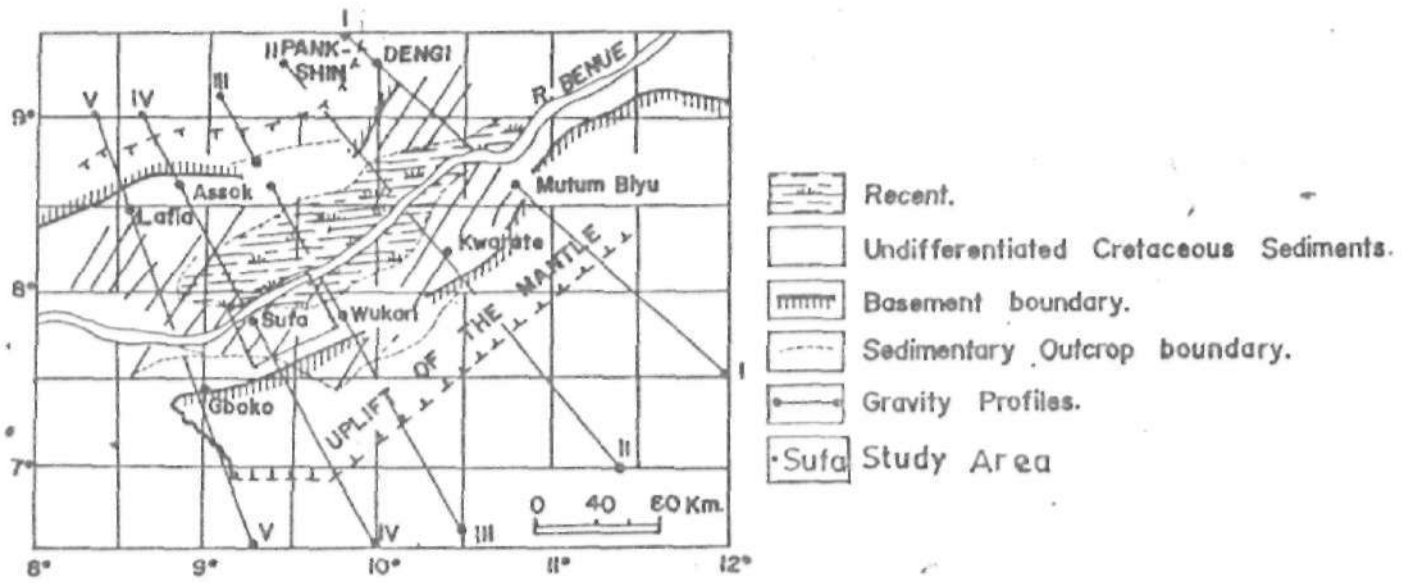


FIG. 4-44 : Geological sketch map of the Benue Trough showing locations of mantle uplift (From Artybashev and Kogbe 1974.)

GSN 2469

King (1950), using geomorphological evidence, conjecturally arrived at the rift theory for the origin of the Benue Trough (Figs. 4.40 and 4.41). The main argument advanced against the trough being a RIFTED BELT in the absence of marginal surface indications of the rift (Lee 1952), despite the fact that the trough is a belt of Cretaceous Sediments whose elevations hardly exceed 200-300 metres above sea level and which is also sandwiched between two highland margins of basement crystalline rocks of Upper Pre-Cambrian to Palaeozoic age (Oyewoye 1970) reaching maximum elevations of 500-1220 metres above sea level on the north western or northern margin (Jos-Mambilla Plateau), 500 - 1,829 metres on the eastern or SE margin (Obudu Plateau - Oban Massif, Adamawa Highlands).

Despite the above limitations, recent more detailed investigations have revealed that the Benue Trough has many features in common with other intra-continental rifts:

(i) It is long (560 - 800 kilometres) compared with its width (170 - 200 kilometres) in a South-easterly direction from the West African re-entrant at the Gulf of Guinea (Hoque and Nwajide 1985).

(ii) It cuts through uplifted crystalline basement cratonic rocks (Fig. 4.44).

(iii) It is characterized by normal-faulting parallel to the NE-SW trending boundaries at least, in the Middle Benue Trough axial trending faults and folds predominate over others

(iv) There are abundant signs of volcanicity.

(v) There are thermal springs along its central, axial zone, suggesting that the Benue Trough is marked by a geothermal high.

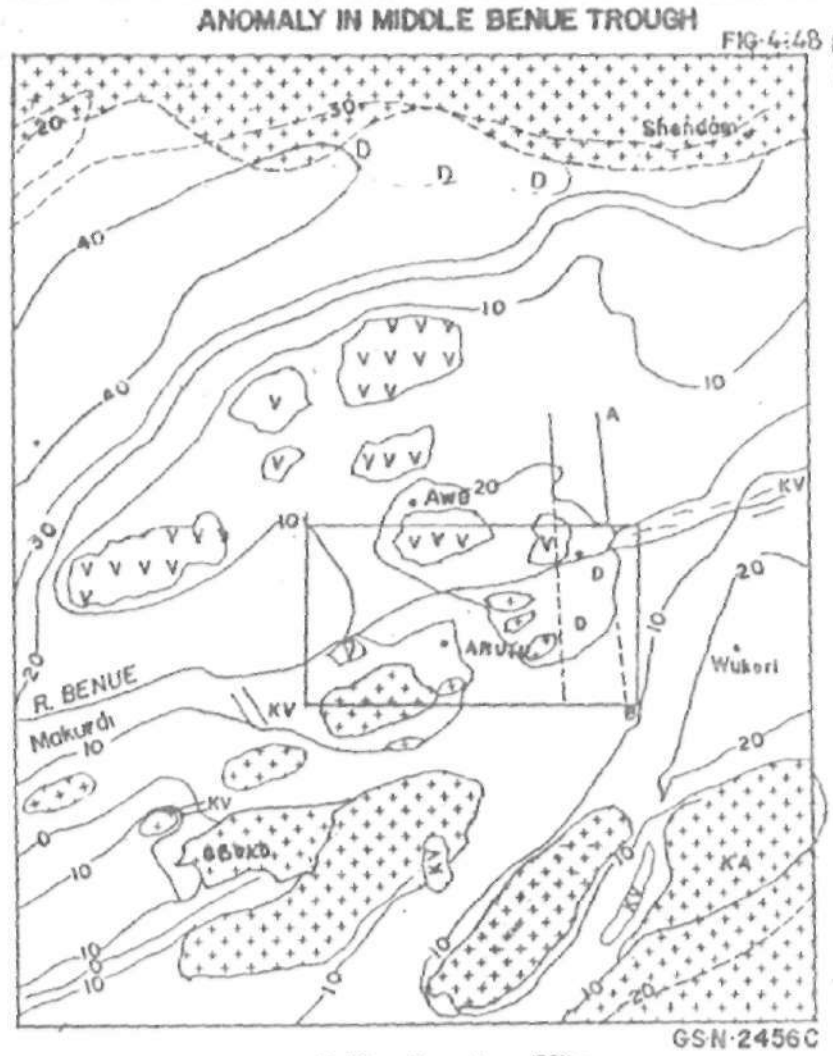
(vi) The existence of the axial positive anomaly has been shown to be dependent on how the rift-structure had developed as follows (Adighije 1981), in the Upper Benue there is a complete absence, the gravity pattern being similar to that of typical active continental rifts with thick fill of sediments as exemplifted by the Albert and Kavirando rifts(Figs.4.46 and 4.47), of East Africa (Burke and Whiteman 1973). With the development of the axial positive anomaly in the Middle Benue, the gravity pattern (Figs. 4.47, 4.48), resembles that of the Gregory rift (Burke and Whiteman 1973), which is believed to have originated by block-faulting (James 1956). In the Lower Benue (Abakaliki Trough) to the southwest, the gravity pattern shows some complexity that resembles that of the Red sea in that the positive axial anomaly in the Lower Benue is considerably smaller than that of the Red sea that is attributable to new oceanic crust (Ajayi and Ajakaiye 1981, Ofoegbu 1984).

(vii) Condie's statement (1983) that aulacogens and cratonic (rift) basins commonly contain arkosic-feldpathic sandstones; conglomerates and bimodal volcanics (basalt, phonolite or trachyte) may equally be applicable to the Cretaceous Sedimentary and Volcanic rock assemblages of the study area within the Middle Benue Trough (see specimens DC 227 or 293, 221, 256A -C and 306A)

In the 4-stage tectoni c sedimentological model proposed by Hoque and Nwajide (1985) for the evolution of the Benue Trough as an intracratonic basin (aulacogen) it is stated that the rifting stage was lithologically characterized by the accumulation of older (Aptian-Santonian) Sandstones

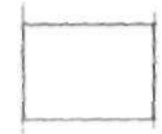
RELATIONS BETWEEN SURFACE GEOLOGY AND GRAVITY ANOMALY IN MIDDLE BENUE TROUGH

FIG·4:48



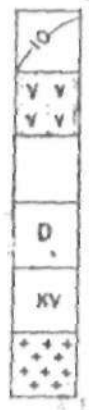


Axial Postive Anomaly attributed to a dense mass



Study Area

LEGEND



Isogal lines (Modified after Cratchley & Jones 1965; Adighije, 1981)

Tertiary? basaltic Lavas

Cretaceous Sediments

Cretaceous intermediate—basic Intrusives

Cretaceous basic Igneous bodies associated (interbedded with Cretaceous Sediments).

Basement Blocks, Inlier ridges and basement margin

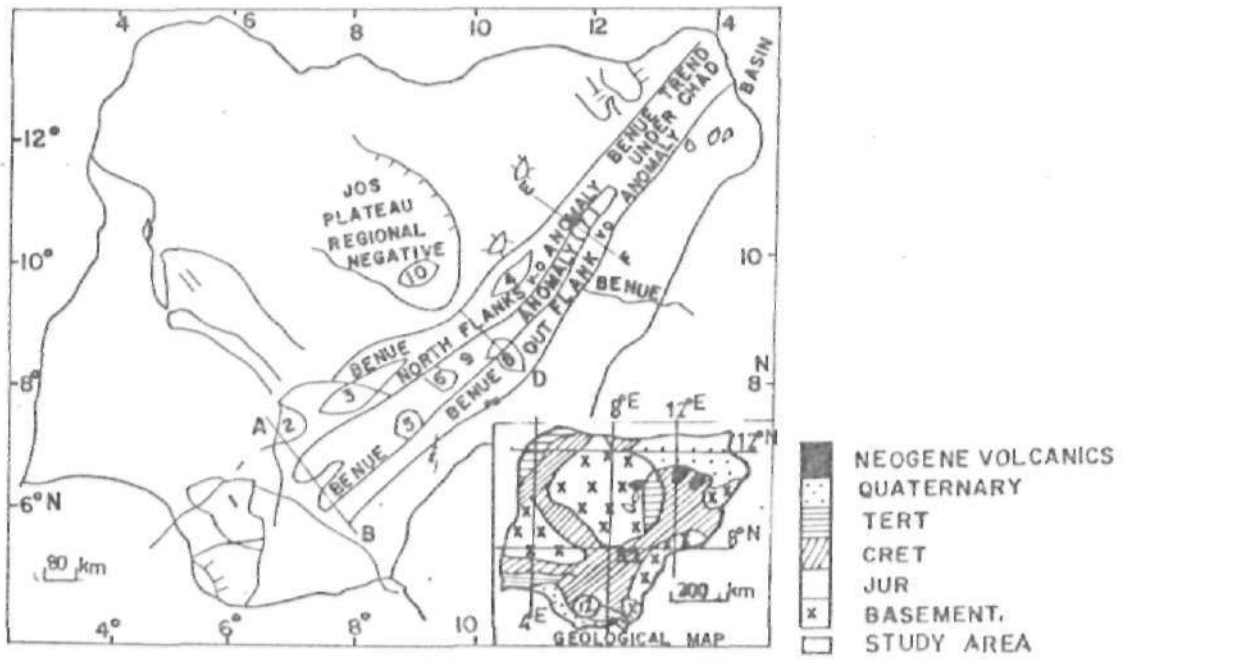


Fig. 4.46 :Generalized Bouguer Anomaly map of Benue Trough from (Ajakaye and Baslke 1972.)

1 = Delta minimum
2 = Idah Positive
3 = Amkpa Negative
4 = Wikki Negative
5 = Gboko positive
6 = Awe Positive
7 = Kaltungo Positive
8 = Jalingo Positive
9 = Geldam Trough
10 = Jos - Bukuru Granite negative
11 = Nupe Basin, with no gravity Data
12 = New occanic Crust·

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which are generally texturally immature, coarse and arkosic-feldspathic, as distinct from the Younger (post-Santonian) Sandstones which are texturally immature quartz arenites.

Geomorphological Indications of Uplift and Downwarp

The general uplift within the southeastern or eastern and northwestern margins of the Middle Benue Trough (Arttybashev and Kogbe 1974) was apparently intermittently active from Lower Cretaceous (Neocomian?) to Upper Cretaceous times, onwards to early Tertiary, and the complementary tilt or downward (subsidence) towards the southwest, probably determined the pattern of Cretaceous marine sedimentation.

The Logo-Katsina-Ala drainage system apparently contrived to maintain its course to the Benue against the rising arched (uplifted) some of the Tseagu-Yandev area, controlled by a system of intersecting earlier NE- and later NW - trending faults. Likewise, the predominantly S-N flowing River Uweyande and the Uavande - Fiyayi drainage system appear to mark the western and, eastern limits respectively, of the uplifted and tilted central zone of the Middle Benue Trough, with concomittant depressed areas on both sides. Because the axis of maximum upwarp (uprift) for both the Cretaceous and Tertiary differential movements lies in the central highland area and trends in a NE-SW direction the rivers run in NW and SE or southern directions from a divide that runs approximately in a NE-SW direction. However, differential subsidence can cause block-faulting, tilting etc. producing geomorphological features which can also be attributed to uplift.

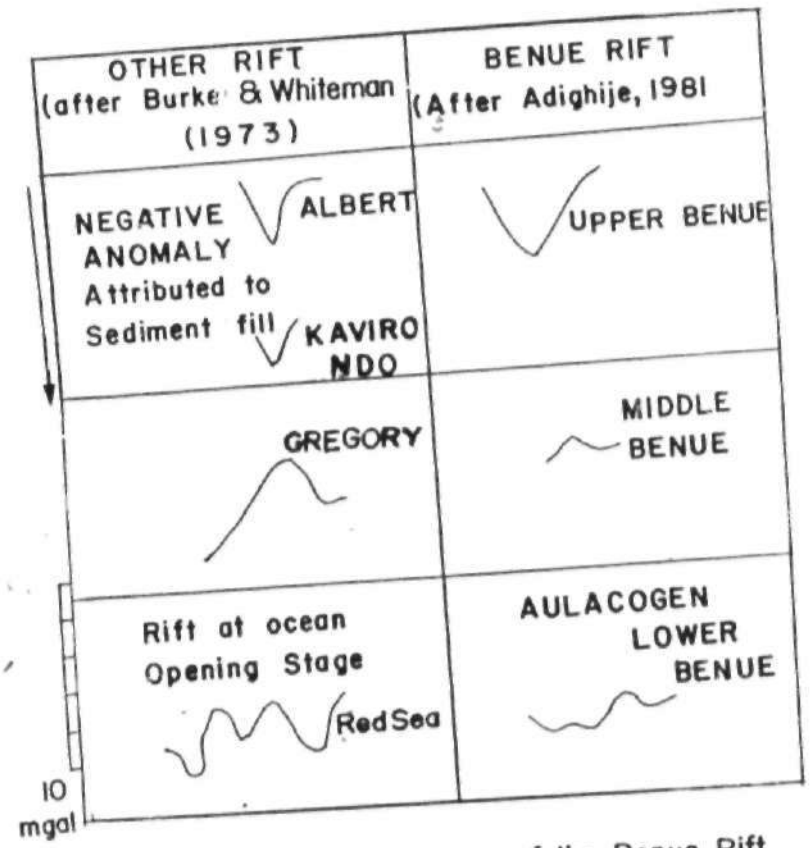


Fig. 447 The structure of the Benue Rift compared with other rifts in Africa

4.5.3 Zones of Rift-Faulting in the Middle Benue Trough

Recent geological mapping and structural interpretation of the Arufu-Wannune-Katsina Ala area of the Middle Benue Trough shows that the folded Cretaceous sediments were deposited in four belts of fault-controlled depressions (Graben) on a Pre-Cambrian Lower Palaeozoic basement. These sediments are flanked by and interspersed with parallel isolated down-faulted basement horst blocks, inliers and ridges. Interplay of opposed sets of block-faulting have led to the attendant development of graben-like structures. These features are elongated along the NE-SW trending boundaries of the Middle benue Trough.

Ajayi and Ajakaiye (1981) have also inferred the existence of two other parallel graben separated by an axial ridge or horst (the Keana anticline). Each of the graben is said to consist of a zone of subsidence between two parallel normal faults. Consequently, these two graben can be termed rifts following the definitions of Gregory (1896, 1921) and Mohr (1973). The authors believe that the width of the more obvious graben within the Giza syncline is about 40 kilometres which falls within the range of widths, 50 $\pm$ 15 kilometres as proposed by Holmes (1978) associated with rift valleys. The second graben (south of the Keana ridge) is also said to be a zone of subsidence between parallel faults of the axial regions of the Wannune syncline, the Makurdi Syncline and the Gbajimba Syncline, which form a synclinorum bounded by a fault in the north parallel to a normal fault.

Field observations and structural analysis during the present investigation show that four similar graben-like sedimentary local basins separated by northeast trending fault-bounded Basement Complex inliers and ridges, occur in the study area, namely: The Tseagu-, Yandev-, Tsegodo- and Katsina Ala/Amafu graben depressions.

However, the occurrence of these Basement complex ridges may not necessarily represent uplifted blocks but simply imply vertical differential movements. These blocks might have formed stable blocks, while the intervening areas subsided or were down-faulted.

4.5.5 Discussion

Rift and Volcanism

The association of localized deeply-rooted Cretaceous basic igneous (dolerite) intrusion with the regions of uplift, is an indication of deeply penetrating fractures. This may suggest that the evolution of the Cretaceous Middle Benue rift-structure involved mainly vertical crustal movement with little or no lateral separation (Olade 1978, 1979). It is to be noted however, that the association of volcanism with regions of uplift is not confined to rift zone, but also characterises, for example, the volcanic areas of Hoggar and Tibesti in the Sahara (cf. Kign 1950).

In the case of the Tertiary basaltic volcanism, magma is thought to have been generated locally by pressure release in arched zones. Heat generated locally by friction of rift-faulting might have led to volcanism at the surface in zones where compression was not excessive.

If local melting occurs at the base of the rift valley shear zones in the manner suggested, e.g. due to friction of rift-faulting, the occluded gases and the more liquid differentation products would have a chance of escaping. Escape would only be possible in these sectors in which compression was not great. In fact, it would be seen from the structural maps of other continental rift system (ref. King 1950) that rift volcanics occur in sectors from which uplifted blocks are

absent and consequently the compression comparatively slight. In the Middle Benue Rift Structure Cretaceous (Volcanic) igneous activity is only found at the cross-roads of ancient rejuvenated fault-patterns. Continuing Cretaceous to Tertiary alkaline igneous activity in the Benue Trough has been attributed to a reactivation of magmatism along the existing lines of structural weakness as a response to stresses affecting the African plate (Wright 1976B, Ofoegbu 1984).

The Cretaceous Middle Benue rift volcanics would therefore be due to friction and the consequent rising of the pressure-temperature conditions below the rift-floors. In this respect, Benkhelil (1987) suggests that the influence of the equatorial (Oceanic) fracture zones and crustal stretching were responsible for the igneous activity and wrench tectonics in the trough.

Rift Models

Many workers believe that the application of Y-triple junction rift model (RRR) to the break-up of the Afro-Brazilian plate, in Early Cretaceous times best explains the final configuration of the Benue Trough (Burke et al. 1970, Olade 1975, 1978, 1979, Wright 1981). It is envisaged that two arms of the RRR rift system each separated to form the South Atlantic Ocean, the Gulf of Guinea and the third, the failed arm, is represented by the Benue Trough (Chorowics 1983), The concept of the rift origin of the Benue Trough led to its classification as an aulacogen (Olade 1975) or an intracratonic graben basin (Hoque and Nwajide 1985).

Wright (1970) proposed a rift model in which the crust was either flat or buckled prior to rifting. Ajayi and Ajakaiye (1981) point out that the defect of this model is that a simple graben cannot explain

the abnormal width (170-200 metres) and other peculiarities of the trough (cf. Holmes 1978). Olade (1976) proposed another rift model for the trough based on the existence of a periodic "on and off" Cretaceous hot-spot beneath the present Niger Delta. In this model the upwelling and Cessation of mantle plumes in the area culminated in the rifting, and the subsequent folding of the sediments it contained with the fold axes parallel to the trough axis and its NE-SW trending boundaries. His strongest support for this model was the apparent lack of thrust faults in the trough, that could explain why the sediments were thus folded.

The cause and mechanism of folding in the trough is still poorly understood. However, Wright (1981) explains that compressional movements accompanying broad regional uplift of the "Guinea dome" (cf. Olade, 1975) may be responsible for the folding in the Benue Trough, although there is no obvious cause of the necessary compressional movements, to suggest that such compressional movements actually occurred. As such, Nwachuku (1985) suggests that folding in the trough should be seen as the result of differntial block faulting in the underlying basement leading to drape folding of the overlying Cretaceous sediments (see Fig.2 from Wright 1981). Similarly Hoque and Nwajide (1985) have suggested that the accumulation of thick sediments in the trough during its"Deformation Stage of evolution" (Table 4.17) may have led to development of instability at the base of faulted crustal blocks, which culminated in a large scale folding with fold axes parallel to the trend of the trough. A slightly different view comes from Benkhelil (1982) who proposes a convergent strike-slipping machanism for folding in the Benue Trough.

Field evidence during the present investigation indicates the following sequence of events in the evolution of at least, the Middle

Table 4.17 Stratigraphic Sequences in the Middle Benue Trough, Stages of Evolution and Associated Galena Mineralization.

AGE		Middle Benue Trough	Depositional Environment and Lithology	Stage of Evolution (modified after Hoque and Nwajide 1985)	Associated Galena Mineralization
TERTIARY	EOCENE	Basaltic Volcanics 56 m.y. (Cheze 1980)	Continental environments Erosional Processes	Platform stage Deformed and uplifted parts of the trough become positive elements to shed detritus	
	PALAEOCENE				
	MAASTRICHTIAN -CAMPANIAN	LAFIA FORMATION	Mostly continental (fluvial-lacustrine environment); clays, mudstone quartz arenites		
CRETACEOUS	SANTONIAN-CONIACIAN	AWGU FORMATION	Shallow marginal marine shale, coal limestone, feldspathic sandstone	Deformation Stages: Intense deformation and folding of sediments parallel to trough axis	
	Early Turonian	Eze - Aku Formation	Shallow marine carbonates blue black shales and Feldspathic sandstone and clays	Trough Stage: broad synclinal depressions and and widening of initial graben structures; mild folding Dolerite Dyke intrusion and extrusion of basaltic lavas; silicification, brecciation;	
	CENOMANIAN	Keana Formation	Continental environment feldspathic sandstone		
	Late ALBIAN M. ALB.	ASU RIVER GROUP Awe Formations Uomba Formation	Marine restricted (reduced) environment, Black shales, siltstone, coral bearing Limestone, feldspathic sandstone		Crystal Galena Massive Galena Speck and Fibrous Stringer Galena.
	Aptian	Pre-Asu River Continental Sediments	Lacustrine and freshwate environment, Arkosic and feldspathic sandstone clays	Initial Rifting and Graben generation stage, Alkaline magmatism e.g. Tseagu Hill Rhyolite of 113±3 m.y. age	
	Barremian				
CAMBRIAN - PRECAMB.		BASEMENT COMPLEX			

following sequence of events in the evolution of at least, the Middle Benue Trough:-

(a) Mantle upwelling leading to uplift, doming and thinning of the crust.

(b) Block and rift-faulting and graben generation.

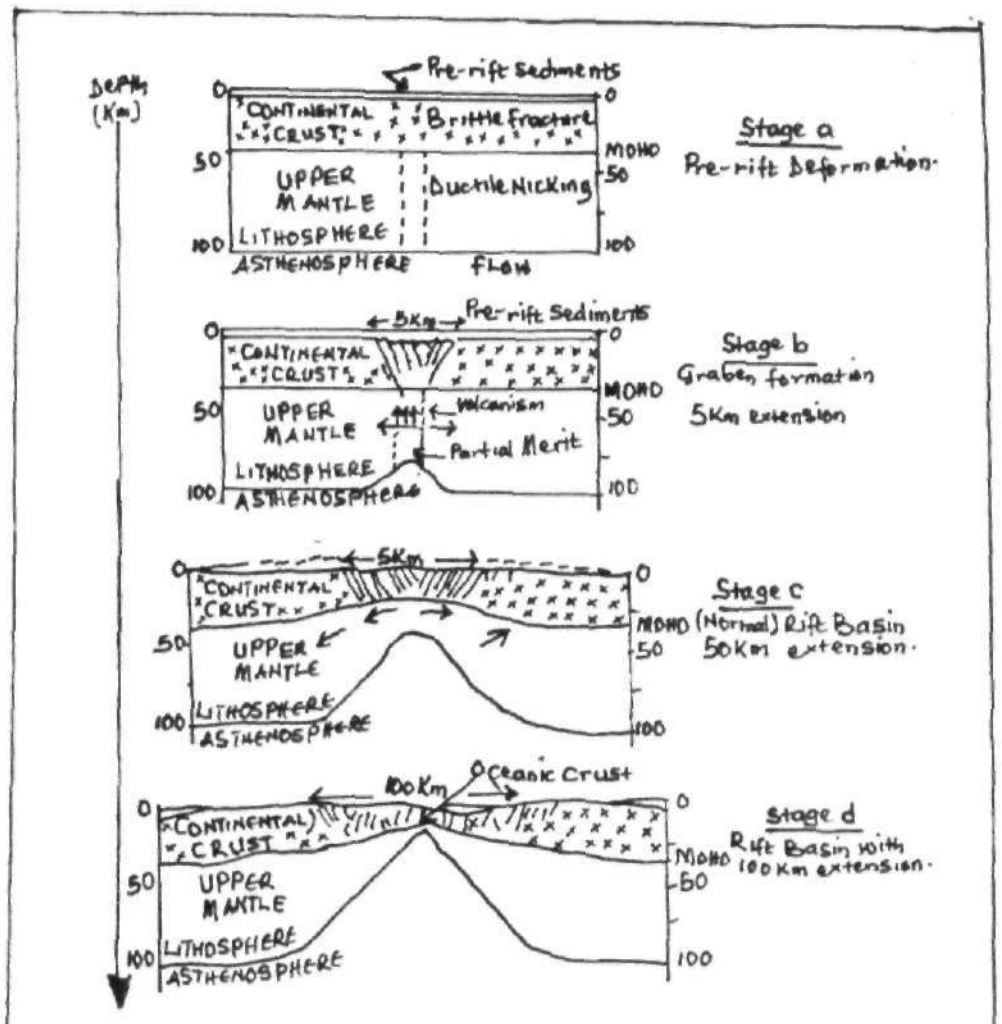
(c) Emplacement of alkaline volcanic rocks (alkaline rhyolitic and trachytic rocks) of Aptian age, in the Pre-Asu River continental sediments, followed by intrusion of dolerite dykes into the Albian marine Asu River Group which had been already block-faulted and rifted.

It is thought that this sequence of events may have been repeated in cyclic manner in the Lower Cretaceous with intercyclic structural deformations as evidenced by the various cycles of igneous activity and periods of faulting in the study area. It has also been in this work that the various cycles of dolerite dyke intrusion possibly re-used old structural lines of weakness and rift-faults in the underlying basement blocks.

In view of further relevant information derived from the present work, such as the existence of four additional parallel graben (subsided belts bounded by parallel normal faults and separated by parallel basement horst blocks with NE-SW orientation) in the Arufu-Wannune-Katsina Ala (SE basement margin) area of the Middle Benue trough, it is believed that the origin and peculiarities of the rift-structure of the Middle Benue cannot be explained by assuming a single rift (cf. Ajayi and Ajakaiye, 1981). The rifting which led to the formation of more than four parallel rifts (graben) infilled by folded Cretaceous sediments and separated by parallel basement blocks can be explained using the model of rift basin formation proposed

by Salveson (1978) and applied in the investigation of the rift structure of the Middle Benue Trough by Ajayi and Ajakaiye (1981). In this model the assumptions are that the crystalline crust underlying the Middle Benue did not necessarily buckle before deformation and that the deformation involved the whole lithosphere and extends into the asthenosphere. When tension was applied the underlying crystalline brittle basement crust deformed by shearing or block-faulting while the upper mantle necked visco-elastically (see stage a, Fig. 4.49; cf. Ajayi and Ajakaiye, 1981). The result was said to be the formation of an initial graben, about 5 kilometres wide, due to extension (see stage b, Fig. 4.49). If the tension continued to exist, the crust would thin through further faulting, extension would continue and further necking of the crust would allow the asthenosphere to rise (see stage c Fig. 6 from Ajayi and Ajakaiye, 1981). The rising of the Upper Mantle material would lead to extrusion and intrusion of alkaline (volcanic) igneous material into the block-faulted zones observed at Arufu, Tseagu and the hill about 10 kilometres southwest of Katsina Ala. As the tension persisted the crust thinned and stretched further, continued extension and would allow the asthenosphere rise high. The surface extension (of the graben) may now increase upto 50 kilometres which is within the range $50^{\pm}$ 15 kilometres normally associated with rifts (Holmes, 1978). Further extension allows the asthenosphere to reach the base of the thinned continental crust and oceanic crust is consequently emplaced along the axis of the rift (see stage d, Fig.4.49) as in the Red sea.

If the above stage c, Fig. 4.49 of Salveson hypothesis is correct in the appraisal of the graben structure in the Middle Benue Trough it may account for the progressively varying widths of the individual graben within the Middle Benue rift-structure.



NOTE: Horizontal direction not to Scale

fig. 4.49 (after Salveson, 1978)
Salveson's Model of rift basin formation

Based on this model Ajayi and Ajakaiye believe that the rifting stage attained by the Middle Benue (or the whole Benue) Trough before the tension ceased, may be considered to be intermediate between the present stages of rifting attained by the Afar Depression and the Red Sea. Hence according to them it is very likely that the tension existed long enough for the Benue Trough to attain its present shape which is similar to the Red Sea but not long enough for the oceanic crust to outcrop as found in the Red Sea.

Benkhelil (1982), Benkhelil and Robineau (1983), attributed the origin of the Benue Trough to the on--shore extension of equatorial fracture zones along the northwestern and southeastern margins of the trough along which a ministral shear occurred and was transmitted to their continental extensions.

During the present investigation no field evidence was found to indicate that transcurrent faulting was the major mechanism in the evolution of, at least, the Middle Benue Trough. However, the results of the structural analysis of the Lower Cretaceous fault structures of the study area have shown that the NNE-SSW deepseated conjugate slickensided (sheared) fault zones are reworked by silicified brecciated structures which had been superimposed on them probably in Late Albian-Cenomanian times. The implication of this is that probably the opening of the trough was initiated by shearing movement or faulting on which was subsequently superimposed a brecciating regime in Late Albian-Cenomanian times. The acid volcanic rocks (rhyolites and trachytes) and the dolerite dykes and the interbedded basalts, are associated with block-faulting and uplift. They are located along the NE-SW or ENE-WSW trending axial, normal faults and are alkaline (Chuku 1983).

These localized, deep-rooted Cretaceous intrusions with alkaline affinity are indications of the existence of deeply penetrating fractures (Olade, 1978, Ajayi and Ajakaiye, 1981), and show that the volcanism was caused by distension phases (Popoof et al., 1981). These features located beyond the margins and axis of the trough suggest that at least. the Middle Benue Trough really originated as a rift valley (cf.Ajayi and Ajakaiye, optcit). They also indicate that the evolution of this Cretaceous rift structure involved mainly vertical crustal movement and little or no lateral separation (Olade 1978, 1979).

The presence of slickensided surfaces in the Marine Lower Cretaceous silicified siltstone in a few places (eg. around Arufu) may be indicative of some shearing movement on the Lower Cretaceous sediments probably as a result of transcurrent faulting in a N by E direction. While we should not exclude the possibility that transcurrent faulting may have played some role in the evolution of the Benue Trough (cf. Thorpe and Wright, 1979) it will be wrong to adduce that the same transcurrent faulting which led to the opening of the South Atlantic and Gulf of Guinea in the Lower Cretaceous, was the major tectonic control (Nagy et al. 1976). The Middle Benue rift structure in its plan has been determined partly by the regional stress field contemporaneous with rifting and concomittant plateau uplift (cf. Mohr 1983). In other words the geodynamics of the Middle Benue Trough is controlled by interplate tectonics (cf. Benkhelil 1987).

In the Middle Benue Trough as in the Afar Depression (Chenet and Letousey, 1983) the most important tectonic features are block-faulted and tilted away from the axis and tectonic activity predominates over volcanism.

The rift was probably opened and propagated from the shearing

lineaments mainly from the southern extremities, according to the stress field and the heterogeneities of the basement. But more importantly, the evolution was controlled by vertical tectonics and crustal thinning at the intersection of the main Wrench faults and of the initiated graben (cf. Masse, 1983).

The recent confirmation of a late Cretaceous rift structure in the Middle Niger Valley (trending in a NW-SE direction and linking up with the Lower Cretaceous Benue Rift Valley around Lokoja by Kogbe and Ajakaiye (1983) may lend support to the view that the Benue Trough was part of an RRR triple junction situated under the Niger Delta and north of the Takatu Rift in Guyana (see Fig. 5 from Burke et al. 1972) in which the arms developed at different times and presumably at different rates (Wright 1976). The southern arm was probably the first to become active in the Lower Cretaceous followed by the Benue arm in about Albian times. The northwestern arm (The Mid-Niger Rift) probably became active in terminal Cretaceous (Kogbe and Ajakaiye optcit.). However, these authors warned that it would not be prudent to relate the Mid-Niger Rift to the origin of the South Atlantic because it may be much younger than the Benue Rift as it does not contain deposits that are older than terminal Cretaceous. Instead they postulate that the origin of the Mid-Niger Rift may be related to some post-Cambrian tectonic episode like the widespread Santonian movements which affected a large part of Nigeria. The striking similarity between the trend of the Niger Rift and the NW-SE structural trend of the underlying crystalline basement rocks is cited. Therefore, reactivation of major fracture trends in the basement was considered to be the most suitable explanation (Fig. 4.50).

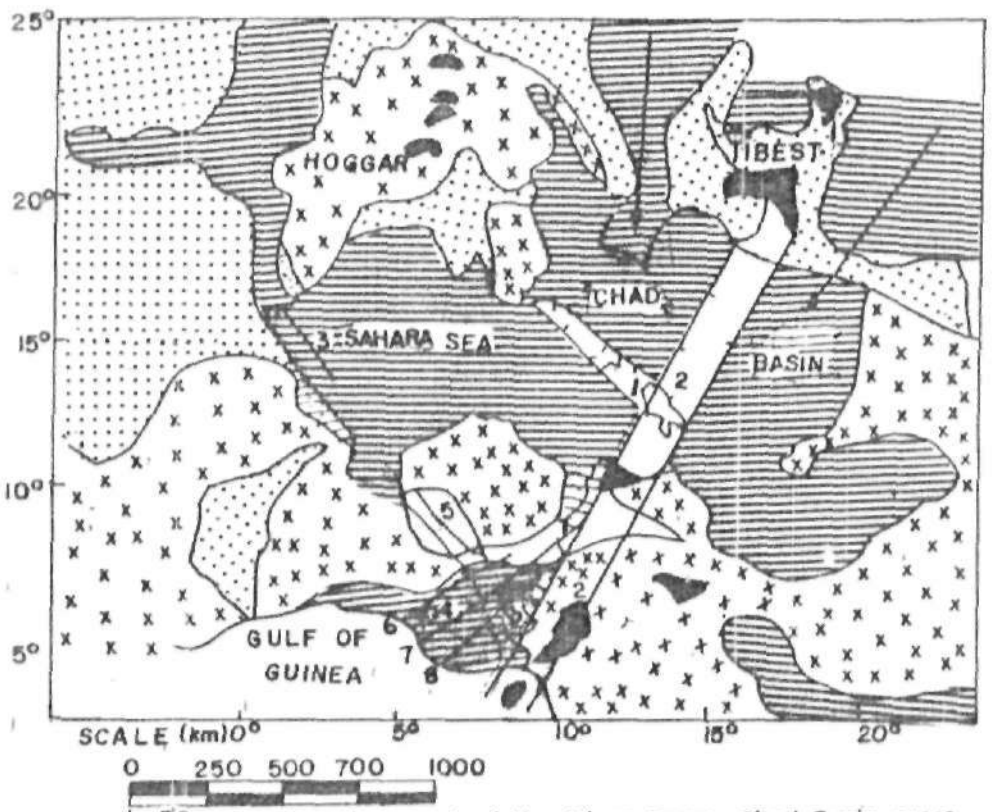


FIG. 4.50 Geological framework of the Niger, Benue, Chad Basin areas
(Modified after Matheis, 1976)

Basement Complex
Palaeozoic sediments
Upper cretaceous sea
Tertiary volcanics
Graben structure
1 Air - Chad Graben
2 Cameroom - Tibest Graben
3 *Graben of Goo*
4 Niger Fault.
5 Mid - Niger Rift; Kogbe & Ajakaiye (1985)
6,7,8 Romanche, chain, charcot, oceanic fracture zone, respectively
With on-shore extensions (Benkhelil, 1982a)
→ *Transgression at upper cretaceous sea*
B·T:- Benue Trough

CHAPTER 5

BRINE DEPOSITION AND GALENA MINERALIZATION

5.1 Introduction

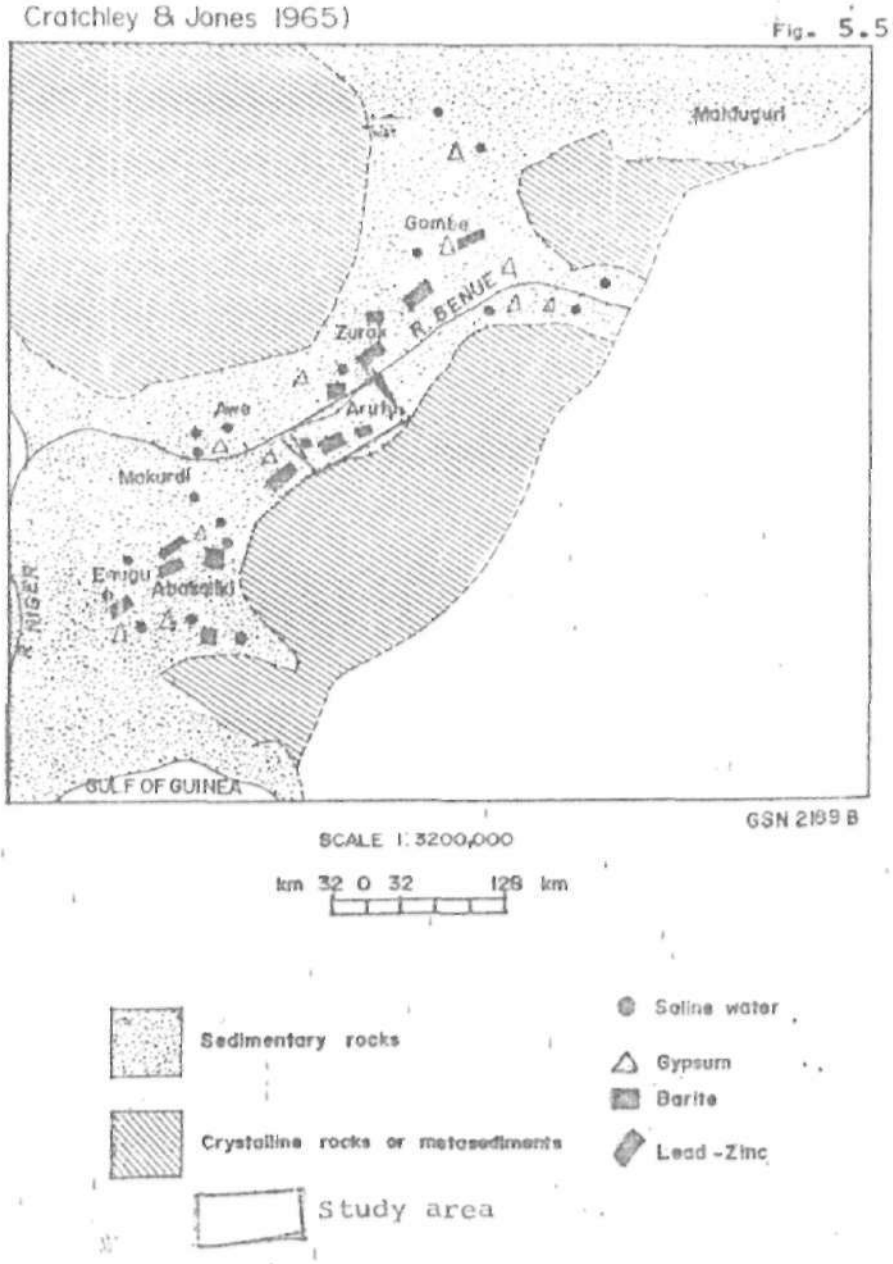
In the present investigation of the brine springs in this part of the Middle Benue Trough (Fig. 5. 51) effort was concentrated in searching for evidence (both in the field and laboratory) bearing on the origin of the saline water, principally whether or not it might be derived from rock salt, and the origin of the saline material itself. The lines of investigation included (i) the detailed geomorphological features of individual saline springs (ii) their geology and (iii) the relationship between the brines, the igneous intrusions, volcanic rocks, and the galena mineralization. Laboratory work included detailed chemical analyses for the component salts and the significant trace (minor) element concentration.

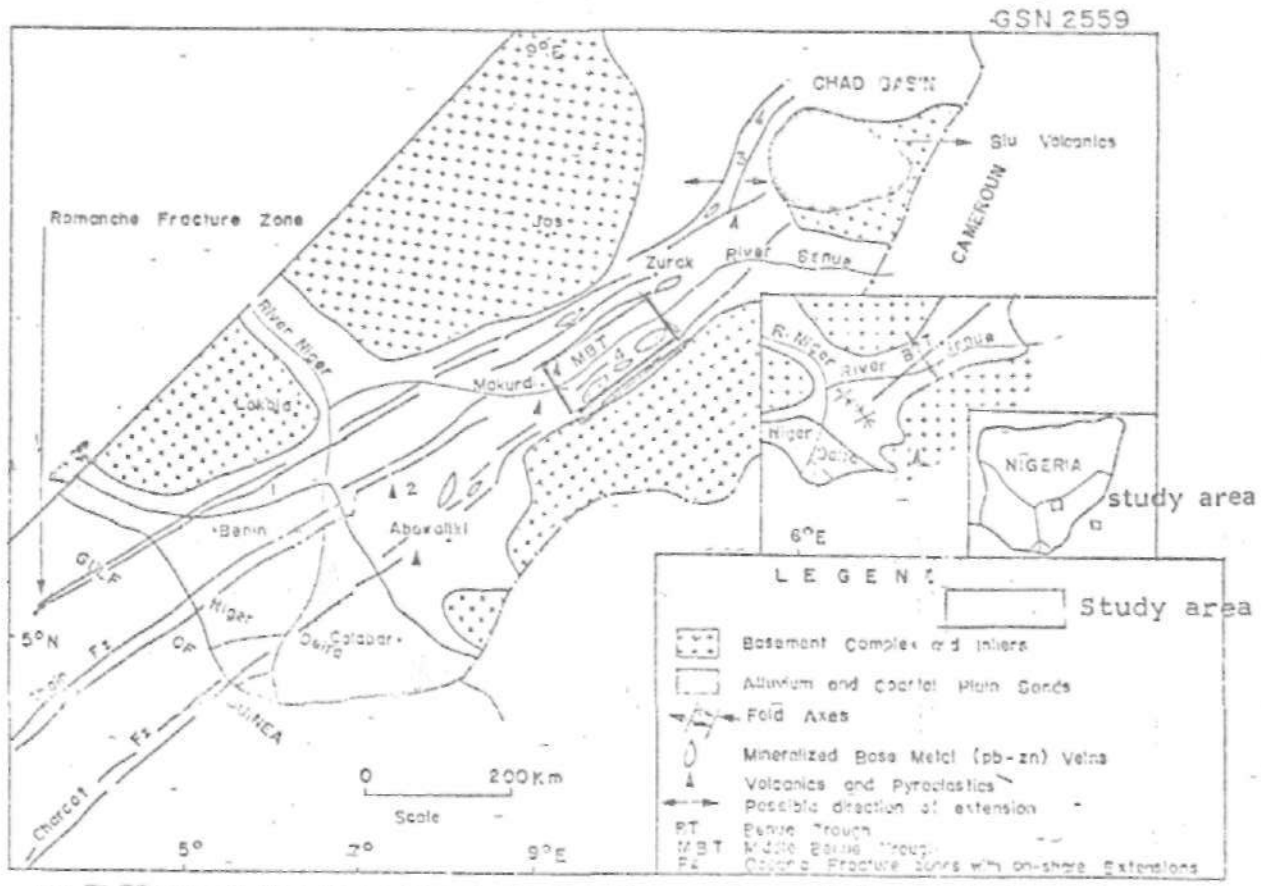
Generally most of the saline waters are the sodium chloride type, differing in salinity. Where the concentration of sodium and chloride ions are relatively high, calcium, magnesium and potassium sulphate and carbonate/bicarbonate are present in very much smaller quantities.

The springs are frequently associated with fractures, in the axial areas of the folded marine Albian rocks in which they are confined in the study area. In places such fractures are masked by superficial cover. In the northern part of the sheet there is a marked association between the saline springs and zones of galena mineralization (Arufu-Akwana-Buru area) but in the south (Yatiev- Afia area) the salt springs do not have any nearby indications of epigenetic mineralization. In a few places (eg. Yatiev) the salt water springs may appear as see pages and bedding planes of interbedded transitional

Distribution of saline water with associated gypsum, barite and lead-zinc mineralizations in the Benue trough (modified after Cratchley & Jones 1965)

Fig. 5.51





MBT Study Area.

Fig 5.52 Map of The Benue Trough Showing The Locations of Base Metal (pb-Zn) Deposits in Relation to The Extension of The Atlantic Fracture Zones (Transform Faults) The Chain And Charcot Fracture Zones After Maeda (1973) The Romanche Fracture Zone After Fail et al (1970) 1, Benin Flank; 2, Abakaliki Uplift; 3, Lower Gongola (Arm) Graben Structure Benkhelil (1932 a); 4, Arufu-Akwana Galena-Fluorite Deposits

sandstones and shales in between the Pre-Asu River Sediments and the Middle to Upper Albian marine Asu River Group. Mostly the waters are freeely flowing at the surface even on relatively elevated topography often giving rise to pools of salty water which form important local sources of salt. The temperatures at the point of emanation is turbid to warm varying between 30° and 35°C.

5.2 Brine Deposits

Eight brine springs occur scattered in different localities within the study area. The five saline springs in the Arufu-Akwana-Juwudu Hill area are localized to Upper Albian Asu River Shales and Siltstones, and issue from the flanks of anticlinal folds in a belt running from the northeast or northwest. At Yatiev, Nwannan and Dzahan, respectively the remaining three brine springs emanate from formations transitional between marine and non-marine environments. The Nwannan brine issues from the southern flank of the Buru anticline, in valleys and depressions that have cut into the underlying Awe Formation.

At Yatiev, the picture is much clearer, with the brine gushing out from fractures in the Albian (Asu River Group) siltstone-shale beds overlying the Pre-Aptian Pre-Asu River Continental Sediments. The gushing brine forms a pond. As in the adjoining Sheet 232 (Akiri) described by previous workers, the Yatiev brine appears to be under considerable pressure and has registered temperature of up to 40°C, and flanks the east side of the Yatiev anticline.

The fractured siltstone through which the Akwana-Juwudu Hill brine springs flow, is usually part of Bed 5 of the Uomba Formation (Table 5.17G).

TABLE 5.17D. CHEMICAL ANALYSIS OF SURFACE SALTS FROM EVAPORITIC PLAYA LAKES

Nos	1 %wt	2 %wt	3 %wt	4 %wt	5 %wt
NaCl	3.47			0.50	68.50
$MgCl_2$	-			trace	4.00
Na_2CO_3	20.00			0.69	5.20
Na_2SO_4	26.53			87.81	15.30
$CaCO_3$	30.80				
$CaSO_4$	2.00				
Insoluble	14.00	47.0	47.0	11.00	
H_2O, etc	3.20	30.73			
Acid soluble Ash	-		21.03		
CaO	-	0.832	0.321		
MgO	-	0.100	0.308		
K_2O	-	0.495	0.310		
Na_2O	-	38.24	10.486		
Oxides of Fe and Al	-	0.202	1.423		
P_2O_5	-	0.045	trace		
Cl_2	-	1.001	trace		
CO_2	-	35.00	10.71		
SO_3	-	0.189	2.420		
	100	106.382	100.348		

EXPLANATORY NOTES ON TABLE 5.17D

1. Specimen from Manga natron as given in the "Documents Scientifiques de la Mission Tilho. Vol.2, p.587.

2. Sample of "Red Kanwa" - Red "flour" potash or natron, from Yesufari in Geidam District (Bornu State). Analysis modified after McCulloch,? An inquiry into the Dietaries of the Hausa, etc. West Africa Meel. Jour. Vol.3,p.64.

3. Specimen of "White Kanwa" - White "Flour" potash or natron Gashwa District, Bornu State.
   Source: Same as for No. 2.

4. Specimen of salt from Zomba, a few kilometres north of the border from Lake Chad, west of Mainaim, Niger Republic.
   Source: Same as for No. 2.

5. Specimen of Common Salt from Playa Lake Salt encrustation in the Gaidam District, Bornu State.

TABLE 5.17F: Element Ratios in Typical Magmatic Waters. After White at al. (1963)

	Silic Volc. Granite/Rhyolite Idaho, USA	Gabbro/Basalt Ultramafic Water loo, Md. USA	Andesite/Diorite Syenite Idaho, USA.
Ca/Ma	0.9	0.8	6.7
Mg/Ca	0.2	0.4	0.04
K/Na	0.6	0.5	1.4
HCo_3/Cl	15.0	37.0	-
SO_4/Cl	1.9	9.2	-

TABLE 5. 17G: COMPARATIVE TABULATION OF THE SALT SPRINGS.

SPRING LOCALITY	LITHOLOGY	STRUCTURAL CONTROL	AGE OF ROCK	SALINITY	TRACE ELEMENT CONSTITUENTS
Arufu area	Folded, brecciated Silicified siltstone of the Uomba Formation.	NNE trending fault across axis of the Arufu Anticline.	Middle to Upper Albian	4.95 to 5.02	Pb, Zn, Sr, F
Akwana area	Folded, Silicified, brecciated Siltstone of the Uomba Formation	ENE trending closely spaced parallel Vertical fractures elongated along the axis of the Arufu Anticline.	Middle to Upper Albian	5.21 to 5.42	Pb, Zn, Sr, I, B
Juwudu Hill area	Folded, Silicified, Brecciated Siltstone, shale-limestone beds of the Uomba Formation	Flanking normal faults marking the edges of a graben-like depression	Middle to Upper Albian	5.39	Pb, Zn, Sr, F, I, B.
Yatiev area	Folded, fractured Silicified Siltstone-Shale beds of the Uomba Formation	Intersecting NE and NW trending faults in the axial region of the Yatiev anticline.	Middle to Upper Albian	6.10	B, Sr, I.
Nwannah area	Folded, tabular sandstone beds of the Awe Formation	NW trending closely spaced parallel fractures astride the Buru Anticlinel axis trending to the NE	Late Albian to Early Cenomanian.	3.3	Pb, B, Sr.
Dzahan area	Folded Sandstone beds of Awe Formation	Closely spaced parallel fractures with NW trend.	Late Albian to Early Cenomanian.	1.8	B, Sr.

5.3 Chemical Characteristics of the Saline Waters (Brines)

Table 5.17A shows the reseults of chemical analyses conducted on nine samples collected from the brine springs which occur in the study area. Out of the nine samples two were taken from hand jug wells at Arufu and Akwana. Water from all the wells at Akwana, has a strong saline taste (DC 427) suggesting that the Albian shale-siltstone-sandstone sequence that underlies the village is associated with aquifers impregnated with brine solutions.

All the brines analysed are generally rich in sodium (Na) and potassium (K) chlorides. Traces of lead (Pb) were found in the brine spring occurrences at Akwana, Juwudu Hill, Arufu and Buru where the springs are near the zone of galena mineralization. But at Dzahan and Yatiev where the brine springs are not associated with galena mineralization, traces of lead were not detected.

Results of the chemical analyses also show that the brines in the six springs sampled, are also rich in magnesium and potassium chlorides in addition to the main sodium chloride content. These are strongly indicative of a possible marine origin. Most evaporites or brines of continental origin are devoid of double salts of K and Kg-chlorides and sulphates (Table 5.17E). These commonly occur as sylvite, cdrnellite, kainite, bischofite, in marine evaporites, while on the other hand NE-rich minerals as natron, gaylussite, thermatrite and lazulite occur in continental evaporites.

Tests for $C0_3$, Br, Zn, Pb and As were mostly negative in the above samples. The very minor presence of 1-2.5 ppm lead in the samples from Arufu, Akwana and Buru - Nwannan area, may be regarded as back ground values, or due to contamination of the brine during flow across showings of galena mineralization.

TABLE 5.17A: CHEMICAL ANALYSES OF SALINE WATER SAMPLES

SERIAL NO.	1	2	3	4	5	6	7	8	9	
Sample No. DC	423	424	425	348 426	427	428	429	430	431	Sea Water Ocean
Depth (m)	0	20	0	0	20	0	0	0		
PH at 25°C	9.5	7.5	9.5	9.0	7.0	9.0	7.5	9.0	8.5	
Temp	35	30	35	35	30	36	35	33	35	
Density at 25°C gm/cc	1.5	1.5	1.51	1.4	1.4	1.35	1.3	1.3	1.2	
Sodium Na_{wt}	2.10	2.01	2.02	2.4	2.52	7.49	2.49	2.1	1.76	
Sodium as Nacl %	4.95	5.02	4.98	5.21	5.42	5.39	6.10	3.3	1.8	2.72
Potassium K %	0.074	0.06	0.067	0.075	0.061	0.069	0.070	0.050	0.030	
Potassium as Kcl %	1.09	1.04	0.03	1.04	1.04	1.01	1.01	1.03	1.072	0.08
Total chloride %	2.54	2.59	2.59	2.51	2.33	2.16	2.10	2.3	2.2	
Total Dissolved solids %	4.77	4.74	4.75	4.47	4.56	2.61	5.65	3.58	2.61	2.5
Mg ppm	430	430	425	503	360	400	400	370	360	
Ca	800	785	809	891	896	910	915	901	700	
Pb	2.5	2.6	2.5	2.1	1	302.4	.4	1		
Zn	1	1	0.9	9.7	0.5	0.28				
B					8.8	1				
Sr	1	1	0.8	1	1	1	1	1	1	
F	1.5	1.6	1.8	2	1	12	-			
So_4	74.6	67.7	70.2	67.1	67.3	66.5	5.66	64.9	63.6	
I					0.8	1	0.1			
Cl	20000	31000	31105	38200	33150	36000	37006	8050	3006	
Mg/Ca Ratio	5.238	5.058	5.312	5.527	5.217	5.128	5.0	5.21	5.14	5.23
Na + K/Cl Ratio	0.886	0.878	0.90	0.829	0.853	0.878	0.862	0.875	0.710	0.87
K/Na Ratio	0.35	0.039	0.033	0.031	0.024	0.0266	0.020	0.0238	0.017	0.021
Ca/Na Ratio	0.038	0.039	0.04	0.037	0.034	0.04	0.0399	0.042	0.039	0.04
HCo_3	100	110	105	120	111	116	171	30	12	
HCo_3/Cl	0.005	0.0035	0.0033	0.004	0.0033	0.0032	0.0032	0.0037	0.0039	0.004
So_4/Cl	0.0037	0.0023	0.0023	0.002	0.002	0.0018	0.0015	0.008	0.0211	0.10

KEY TO TABLE 5.17A (See Fig. 5.56 for Sample Localitites)

All samples were collected between February and March, 1982.

1. DC.423: Surface saline water from Arufu Saline spring 2 kilometres north of Arufu issuing from Middle-Upper Albian silicified, fractured, brecciated siltstone of the Arufu Formation.

2. DC 424: Saline water from a hand-dug well 200 metres NE of Chief(s house, Arufu village.

3. DC.425: Saline water from Rafin Gishiri Stream 2 kilometres north of Arufu.

4. DC.426: Brine from Akwana salt pond, 1.25 kilometres west of Akwana Village near Galena - Fluorite Veins.

5. DC.427 Salt water from a well near the Chief's house, Akwana, underlain by the Arufu Formation.

6. DC.428 Brine from Juwudu Hill saline spring. About 2.5 kilometres SW of Akwana near galena - fluorite veins within the Arufu Formation.

7. DC. 429: Saline water from Yatiev salt pond about 25 kilometres NE of Ugba.

8. DC. 430 Saline water from Nwannan saline spring, 1 kilometre south of Buru Dissminated Galena showings within the Fiyayi Formation.

9. DC 431: Weakly saline water: from Dzahan saliferous spring, 3 kilometres North of Afia underlain by the Fiyayi Formation.

In Buru-Nwannan area it is observed that the brine spring issues from NW- trending fractures which truncate the NNE - trending fractures hosting disseminated galena mineralization.

Thus, apart from confirming the marine origin for these brines, the tests also show that the brines are genetically unrelated to the episode of galena mineralization.

It is also to be noted that the "domed?" circular features found in areas of barytes and salt spring occurrences in the adjoining Keana-Awe area of the Middle Benue Trough believed to be indicative of diapric structures, also occurs in the study area. But they are not restricted to areas of base metal mineralization and salt spring occurrence (see Ford 1981, and Fig. 28 from Offodile 1976).

Element Ratios

White et al. (1963), Hem (1970) have shown that the characterization of brines by means of ratios or range of ratios of one ion to another, is a useful tool for tracing the migration of brines or their origin. Offodile (1976) has used such parameters as Mg/Ca, Na + K/Cl, K/Na, $S0_4$/Cl, $Nc0_3$/Cl and Ca/Na ratios, to indicate that the brine springs in the Keana-Awe area (adjoining the study area to the north), are mostly of marine origin. These parameters were also found useful in the present investigation.

These ratios are shown in Table 5.17A. Offodile (Optcit) found that the Na + K/Cl ratios are critical and gave values very close to those of seawater, ranging from 0.6 to 0.69 as compared with 0.87 for seawater. The Na + K/Cl ratios in the samples collected from the project area (Akwana Sheet 252) gave values ranging from 0.710 to 0.886 as compared with 0.87 for seawater. This may further

TABLE 5.17E: ANALYSIS OF BRIME SAMPLES FROM THE MOI IGBO BOREHOLE AND MOI IGBO SALT POND, BENUE STATE

Sample No.	1	2	3	4	5	6	7	8	9
Depth(m)	30.48	33.48	37.56	42.672	47.244	51.816	59.436	75.96	*D
	%wt	%wt	%wt	%wt	%wt	%wt	%wt	%wt	%wt
Chlorides	0.083	0.083	0.078	0.08	0.079	0.0871	0.080	0.0824	
Bicarbonates	0.076	0.076	0.075	0.079	0.076	0.077	0.078	0.079	
Carbonates				Faint trace	Faint trace	Faint trace	Faint trace	Faint trace	
NaCl									0.46
Total Solids	0.138	0.138	0.131	0.131	0.13101	0.139	0.134	0.13403	0.49

NB. 1. The Chloride and bicarbonate radicals are expressed as the corresponding sodium salts.

2. The results indicate that there is a slight change in the saline content of the water in the borehole between 30.48 and 60.96 below the surface.

3. *Surface Brine Sample from Igbo Salt Pond. PH = 8 brine very slightly alkaline. NaCl is the dominant saline constituent. Sodium bicarbonate in small proportion Li,Sr,Ca,Mg, K, Br, SO_4, NO_3 , I present as traces

Source: GSN Lab. Report Appendix A (1946)

support the view that the brines in the Akwana-Arufu area are pos possibly marine in origin, thus supporting the views of Tattam (1942) The slightly lower HCO_3/Cl and the generally low SO_4/Cl ratios may be due to diagnesis in the sedimentary pile. Sulphates are very easily broken down by bacteria under anaerobic conditions obtaining in such a geological environment.

5.4 Origin of the Brine

5.4.1. Introduction

In general, sedimentary deposits of salt accumulate under quite complicated conditions seeeming to require among other things an arid climate and the repeated influx of new seawater into large coastal basins not continuously flushed by the sea nor fed by streams and rivers of large magnitude. Coastal lagoons and estuaries are not particularly favourable loci for the accumulation of salts unless the processes of replenishmnet by flooding and subsequent evaporation and precipitation of the salt also continue over long periods of geologic time and condition of isostatic equilibrium.

Models

The rifting in the south Atlantic during the Early Cretaceous was associated with marine transgressions. This influx of seawater into the West African Coastal basins, during the Aptian-Albian and the ensuing geological and palaeoclimatological conditions, probably gave rise to the deposition of salt evaporites as in Cuanza, Gabonese and Sergipe-Alagoas basins starting from the south in that order (Brink 1974). This similarity may suggest by analogy, the possibility of saline basins in parts of southern Nigeria sedimentary basin, including the Benue Trough.

If the above model is applied to the Benue Trough, it should be understood that in this type of structural features the rate of overall uplift and down-faulting of the central trough is not constant through either time or space. There is the general pattern of opening and subsidence initiated from the southwest and propagating towards the north and east leading to deposition of upto 5 kilometres mainly marine sequence in the Lower Benue grading to a thinner c. 2 kilometres sequence with terrestrial deposits predominating in the Upper Benue, Superimposed on this is the effect of differential uplift giving rise through transgression and regresssion to interdigitating of marine and continental sedimentation, and the combined effects of both vertical differential movements and varying rates of erosion (from the uplifted flanks) and consequently of deposition (within the trough) which could cause impounding of large masses of fresh or salt water within the trough.

If salt water of either marine or juvenile origin flowed into such an area continuously or intermittently, there was the possibility that it might be lost by evaporation, leading to the formation of evaporite beds. Such a hypthesis would connote an arid climate in the Cretaceous times. This appears at odds with the lush vegetation required to produce the Upper Cretaceous coal deposits, although a migration of this portion of the earth's crust from an arid climatic zone to a wet one is conceivable (Van Breeman and Bowden 1973).

Falconner (1911) first suggested the occurrence of the Benue brines within a transitional environment, between the Upper part of the Muri (Bima) sandstones of Cenomanian age and the Turonian limestones. He further pointed out that the brines were under considerable pressure and associated with subordinate anticlinal axes along which they issue.

But he did not elaborate on the type of pressure, whether artesian or non-artesian. As a spring the pressure could connote 'artesian' depending on the structural di sposition of the spring.

During the present investigation the Yatiev Brine spring is seen gushing out from and along transitional shale-sandstone beds between the Mid-Albian to Upper Albian Asu River Group and Barremian (?) Pre-Asu River basal continental grits and sandstone. The flow rate is relatively high although there is no evidence to suggest that it was under artesian pressure. The Yatiev Brine spring is located in the axial area of the Yatiev Anticline.

Tattam (1942) dismissed the occurrence of beds of rock salt and stated that the brines were due to the possibility of salt impregnation of the pore space in the sands. He could not accept the presence of any artesian pressure and attributed the pressure to rock weight, which according to him slowly displaced the brine upwards. Uplift and folding may cause the salt to be pressed out of the shales into sandstones that may be associated with them, migration over considerable distances often taking place. Tattam's chief evidence against the case for existence of beds of rock salt, deposited contemporaneously with the sandstone and shales of the Benue Trough, is that these sediments are of types which are deposited in the sea or over the deltas of rivers. The great rock salt deposits of the world, excepting certain special types, were deposited in large inland lakes or sea under arid conditions. Briefly, Tattam (1942) suggests origin from seawater trapped as connate water in the pore space of marine muds which later changed to shales; intense folding and fracturing forced the salt out of the shales into sandstones associated with them.

McConnel (1949), Pargeter (1956) relate the brine of Arufu and Akwana to a late hydrothermal phase of local volcanic activity. But they did not elaborate. However, the geochemical parameters as derived from the present study do not compare favourably with typical magmatic waters, as given by White et al. (1963).

The brines in the above two areas (and in fact, in the Benue valley generally) show a relatively much lower Ca/Na, K/Na, SO_4/Cl and much higher Mg/Ca ratios. However, field studies indicate the presence of interbedded volcanic (basaltic) lavas (DC 266A-C, 414A-B) with apparent semi-pillow structure (DC 256D) associated with the topmost units of the late Albian marine Awe Formation around Andyar about 12 kilometres west of Akwana village.

A magmatic origin for the brines has often been suggested because of the tripartite association of brine, lead-zinc, and igneous activity in the field. But the present investigation has shown that this tripartite association may be associated with other factors than a common genetic origin for all of them.

Phoenix (1966) and Okezie (1966) thought that the salts were evaporitic in origin, though Okezie further suggested the possibility of existence of salt domes beneath the Cretaceous sediments. But the problems with the above suggestion are:-

(a) There is no known evaporitic sequence in the Benue valley from the examination to indicate that the beds of rock salt occur, but this argument is of no value as an evidence in a flat country of high rainfal in which such beds would be dissolved by surface water before erosion had a chance to expose them.

(b) The so-called circular features (Offodile 1976) which occur in the areas of brine occurrence (and are believed to indicate possible salt diapric structures) have been shown in the present research to be associated with uplifted "domed" zones of possible hidden intrusive igneous or "mud" bodies that are not yet exposed to erosion.

Farrington (1952) explained that the brine springs were due to the leaching of disseminated alkaline salts and did not think it to show any direct association with igneous rocks, though the brines are common in areas of mineralization.

Offodile (1976) maintains that the Na + K/Cl ratio is critical and gave values (in the case of the Keana-Awe brines) very close to that of sea water, ranging from 0.6 to 0.5 in all the analyses he carried out, as compared with 0.87 for sea water. In the Arufu-Akwana the samples analysed during the present investigation gave Na + K/Cl ratios ranging from 0.710 to 0.9. In both cases this suggests that the brines in the Keana-Awe area and the Arufu-Akwana area are possibly of marine origin.

The 9 detailed chemical analyses conducted on the saline waters from the Akwana-Arufu area show that brines have lower Ca/Na, K/Na, SO_4/Cl and higher Mg/Ca. than those of magmatic waters. Also they have low Ph (alkaline) ranging from 7.0 to 7.5. The samples also contain varying amounts of minor (trace) elements of Pb, Zn, B, Sr, F, C . These values range from 1 to 2.5 ppm in areas where the brine occurrences are near zones of galena mineralization, but are absent in areas where there are no nearby showings of galena mineralization.

It is believed that the amounts of the elements in the brine may be related more to the diagnesis, or membrane infiltration of sea or connate water, than to a metal bearing fluid of magmatic origin.

But this does not preclude the possibility of intimate contact between the brines and the magmatic waters. For example in the case of the Nwannan saline water, it flows from NW-SE trending fractures which truncate the NE-trending set that hosts the disseminated galena mineralization, showing that there might have been some contact between the brine and the galena mineralization.

It is agreed with White (1965) and Offodile (1976) that the relationship between the brines and the lead-zinc deposits in the Benue Trough cannot be explained by a straight forward simple mechanism. A more complex model, which probably involves the interaction between connate, or evaporitic brines, and magmatic waters, with the deposition of lead-zinc and barytes as suggested for the Mississippi Valley (White 1965, Sawkin 1968) appears feasible.

In the study area the brine occurrences appear to be confined to marine and transitional sedimentary units ranging in age from Lower Cretaceous to Early Cenomanian. No brine or saline water occurrence was encountered in the predominantly marine Lower Turonian Eze-Aku Formation. The prevailing geological conditions above observed in the field, point to the possible existence of connate waters of marine origin. But where the salt water springs appear as seepages along bedding planes and/or S - (strike, longitudinal) joint or fractures as is the case with the Yatiev Brine spring, one may think of the existence of evaporitic water of marine origin particularly where the flow is along interbedded transitional sandstones and shales as at Yatiev. The indication therefore is that the brines in the study area (in Middle

Benue Trough) are possibly connate waters associated with or without evaporites. These shale-siltstone-sandstones which generally host the brines are part of the Asu River Group of sediments deposited at an early transgressive phase of an Albian Sea within the Benue Trough. The subsidence (giving rise to the Trough) was followed by a period of non-deposition during which evaporite deposits probably started to form. There may be some indirect evidence (Ford 1981) from geomorphology, geophysics (negative gravity anomaly) and structural interpretations to suggest the existence of salt dome in the Middle Benue and further investigations are going on to check this hypothesis. There are also several other areas with possible salt domes in the Abakaliki Anticlinorium of the southern Benue Trough, some of which have been also the subject of gravimetric studies and drilling down to 400m (GSN 1979, pers. comm.). But this may not have been deep enough to encounter the inferred anomalous body.

Another problem is that the economic appraisal reports of the actual salinity at individual sites that have been made differ from author to author probably due to seasonal variations resulting from admixture of surface (meteroric) water. In the study area the salinity values range from 1.76% NaCl to 6.1% NaCl.

Phoenix (1966) proposes the possibility of evaporitic deposits analogous to sediments of Lower Cretaceous of Gabon and Congo and Angola (Belmonte et al. 1965). The oldest sediments of the study area - those of the Pre-Barremian (Neccomian?) to Aptian Pre-Asu River Continental Grits and sandstone, the Albian-Early Cenomanian Asu River Group and the Cenomanian Ibi (Bima type?) sandstone do not show evaporitic sequences.

Nothing may be said against the theory of connate seawater trapped in the sedimentary pile (Tattam 1942, Pargeter 1956), except that it should be considered with caution, especially as Olade (1976) has put up the other possibility which emphasized the role of tectonic processes, rather than igneous activity as the principal factor responsible for the localization of the lead-zinc mineralization in the Cretaceous sedimentary rocks of the Benue Trough. This process, he thought, actively involved the connate brines which appear to have been activated by geothermal heat or plume (cf. Van Breemen and Bowden 1973). This suggestion is more or less in line with the above theory of connate water.

Recent N and 0 isotopic studies conducted by Ogundipe (1988) on the subsurface brines in parts of Abakaliki district in the Lower Benue and in Wase-Zurak area of the Upper Benue, are reported to show a fairly large range of both SD and $S^{18}0$ values between - 13 to + 10‰ and - 4.4 to + 0.8‰ respectively. The salinities of these saline waters are also said to be highly variable from 0.1 to 14.3 g/1Cl. Ogundipe interpretes these SD values to represent fossil basinal brine. This interpretation is consistent with the view on the origin of the brine in the study area.

5.4.2 Saline Sedimnents

The occurrence of saliferous horizons has been reported in the Albian or Lower Turonian Marine Limestone-Shale-siltstone-sandstone sequences in parts of the Middle Benue Valley (Offodile 1976). This was considered to reinforce the possibility of salt evaporite beds and hydrocarbons in the region.

Table 5.17 i show the results of chemical analyses conducted on some samples collected from such an assumed

saliferous horizon in a calcareous sandstone transitional zone separating the lowermost part of the folded Lower Turonian Eze-Aku Shale beds from the Upper part of the folded Asu River Group Shales in the Agila area in the SE quadrangle of the Igumale standard sheet 288 (Middle Benue Trough). The first set of samples were collected at regular lateral intervals of 10 centimetres across the sandstone. The second set of samples were collected at 10 centimetres vertically down the bedding plane of the same sandstone body that was considered to be made up of saline sediments. In this horizon saline water is seen to be seeping copiously from NNE trending vertical parallel fractures along the bedding plane of the sandstone for some distance before changing the direction of flow into the NW-SE and finally discharging the saline water which forms the Agila Salt Pond.

The results of the analyses showed that the total salt (salt mass) and NaCl content of the salt mass decreased with decline in intensity of soaking of the sandstone by saline water moving through the rock both vertically downward or upward and laterally. Also the saline taste of the "soaked" sandstone decreased with increasing distance both laterally and vertically from the point of passage of the saline water. This shows that the saline content of the sandstone was probably not a primary feature but as a result of brine moving along fractures in the sedimentary rocks.

The brine which in many parts of the world's great oilfields collects in anticlines below the oil is regarded as being derived from seawater imprisoned in the poro space of marine muds which later change to shales. The oil is formed from dead marine organisms and is likewise deposited and imprisoned in these muds. Uplift and folding usually cause both salt and oil to be pressed out of the shales into

TABLE 5.17I (i): Lateral Variations in NaCl Contents of Marine Albian Asu River Fine Sandstone Soaked With Brine at AGILA (SE Qaudrangle) Igumale Standard Sheet 288

Lateral Distance From Discharge zone (cm	0	10	20	30	40)	
Sample No.GL	62970	62978	62977	62973	62980	Unsoaked Sample
Na %	24.4	18.6	10.1	16.5	17.4	2.4
K %	1.2	0.7	1.3	0.5	1.3	0.05
Cl %	13.5	8.7	9.5	9.3	10.3	0. 5
Ca %	3.5	3.2	2.5	1.5	3.0	1.5
Mg %	0.6	0.7	0.3	0.8	0.2	0.16
Fe %	2.5	0.5	0.7	2.5	1.0	2.5
$CaC0_3$ %	0.5	0.4	0.35	0.25	0.39	0.5
Salt Mass in the Sample %	0.90	0.79	0.46	0.20	0.18	ND
NACI in Salt Mass %	98.8	97.9	97.9	93.8	85.6	ND
$S0_4$-2	ND	ND	ND	ND	ND	ND

TABLE 5.17I (ii) Vertical Variations in NaCl Contents of Marine Albian Asu River Fine Sandstone "Soaked" with Brine at Agila, SE Quadrangel of Igumale Standard Sheet 288

Vertical Depth from Discharge Zone cm	0	10	20	30	40	Sample
Sample No. GL	62970	62975	62972	62974	62979	2.4
Na %	24.4	16.5	12.6	17.9	17.9	0.06
K %	1.2	1.5	0.7	0.5	1.0	0.5
Cl^- %	13.5	9.7	10.0	9.7	9.7	0
Ca %	3.5	0.1	2.7	0.1	3.0	
Mg %	0.6	0.6	0.3	0.4	0.1	
Fe %	2.5	1.5	3.0	2.3	6.5	
$CaC0_3$ %	0.50	0.001	0.3	0.001	0.45	
Salt Mass in Sample %	0.90	0.65	0.49	0.32	0.10	
Naclin Salt Mass %	98.8	97.9	97.9	95.8	83.6	
$S0_4$-2	ND	ND	ND	ND	ND	ND

ND = Not Detected.

sandstones that may be associated with them, migration over considerable distances often taking place. If suitable structures have developed as a result of folding, oil and brine may be trapped and form a reservoir in the sandstones. If folding and fracturing have been intense both may be dissipated, if not too intense, the oil may disappear but a good proportion of the brine may be preserved. This last case probably represents what has happened in the more disturbed Cretaceous rocks of the study area and other parts of the Benue Trough in general with which the brines are associated.

5.4.3 Brine in Relation to Galena Mineralization

As both large volumes of saline and non-saline connate and juvenile waters circulated through the sedimentary column they became warmed probably in areas of geothermal high. Some of them especially the warmed more mobile saline water (brine) flowed (circulated through the permeable open fracture) zones on the flanks or axial, crestal areas of the anticlinal folds and issued out as saline springs as occur today at Arufu, Akwana, Nwannan, Dzahan, Yatiev, or as non-saline springs as occur at Ibav, Kaasar, Wankpar, Amafu and Tseagodo.

Under favourable conditions these warm circulating chemically active and mobile saline water, probably collected at times minute quantities of base metals (lead etc) from the surrounding K-feldspar-rich clays in the sediments and the K-feldspar-rich granitic basement rocks. These were concentrated in subsequent deposition in restricted narrow environments (created by down-faulted basement blocks and inliers) as shiny speck and fibrous stringer galena (DC 279, 350; Table 3.8 Appendix A) controlled by temperature, pressure, Ph and Eh., in the Arufu, Akwana, Buru, Igbur and Nyosu area.

It should be noted that diagenetic processes within the wet sedimentary pile could have contributed in warming the mineralizing fluids before being further affected by a subsidiary heat source possibly emanating from approximately a contemporaneous intruding igneous body in the case of the Buru Hill "shiny speck and fibrous stringer galena occurrence (DC 178).

Field studies indicate that the galena mineralization apparently reflects environmental and temporal control. The Latest Cenomanian to Early Turonian Marine Eze-Aku Formation is known to be barren of galena mineralization in the study area, as well as the Cenomanian Continental Keana Formation. The underlying Pre-Asu River Continental Sediments are also unmineralized with galena. The mineralization is confined to the predominantly Middle to Upper Albian marine Asu River Group.

5.5 Galena-Fluorite Mineralization

5.5.1 Introduction

Chemical and mineralogical studies have been carried out on the brecciated, silicified, weakly mineralized limestone - black shale - siltstone sequences, from Beds 2,3,5 and 7 of the Upper to Middle Albian marine Arufu Formation at Arufu, Akwana, Igbur, Nyosu - Iyorshagher area and the Juwudu Hills. Similar studies have been conducted on the basal units of the predominantly Late Albian marine Awe Formation around the Buru Hill with showings of shiny speck and fibrous stringer galena mineralization.

The sulphide mineralization is mainly galena with traces of pyrite. No zinc mineral is present either as primary or secondary. The galena mineralization is stratigraphically controlled by being confined to marine Albian rocks and also structurally by being

contained in closely spaced parallel steeply dipping to vertical fracture zones (suggestive of brittle deformation) in this part of the intracontinental Benue rough.

The galena mineralization was preceded by the brecciation, silicification, dolomitization (of the limestone and other calcareous rocks) and fluorite deposition in the limestone terrain at Arufu, Akwana and the Juwudu Hill. The deformation (brecciation, etc.) of the limestone-shale-siltstone and sandstone sequences created open (tensional?) fissures favourable for the emplacement of the fluorite and galena minerals.

All the galena mineralization is located in the crestal area of anticlinal structures along the edges of graben structures and along ENE or NE trending en echelon lineaments, and fault zones, and is essentially epigenetic and at shallow depth)Figs. 5.60 and 5.61 Appendix B). These mineralized NE trending fault zones can be matched with the continental extensions of three equatorial oceanic fracture zones:- the Romanche, Chain and Charcot fracture zones (Benkhelil 1982). The criteria for distinguishing the three episodes and types of galena mineralization in the study area can best be defined by crystal morphology as follows (Table 5.17N):

(c) Crystal galena (Late Albian to Early Cenomanian)

(b) Massive galena (Late Albian, specimen DC 239)

(a) Galena specks and fibrous stringers (Early to Late Albian specimens DC 279, 350).

The galena specks and fibrous stringers consist of shiny granular specks and fibrous stringers of steel grey crystals contained in the limestone deformed by closely spaced NNE trending vertical

fractures. These vertical fractures are in turn out and offset by northeasterly trending fracture zones containing massive galena. The northeasterly fracture zones are, in places, offset by ENE or E-W trending fault zones characterized by the presence of crystalline galena mineralization. The crystalline galena usually consists of coarsely crystalline (cubic to cubo-octahedral) undeformed galena.

Figure 5.56 is an index map showing the locations of galena-fluorite occurrences in the study area, in relation to limestone, brines, and some other indurstial minerals and aggregates. Figures 3.20 and 3.21 (backfolder) show that there were several galena pits, shafts and old mine excavations (cf. McConnell 1949, Bogue 1952) sited at Arufu Akwana by the early miners with a total of over 80 meters penetrated. Figs 5.55A-C show the generalized paragenetic diagrams of the three morphological types of galena and the fluorite encountered in the district.

During the present field work the veins were seen, in places, in the sides of only a few pits as most of the workings are caved or partially filled with debris. Some of the deeper shafts around Arufu contain water. The veins in which the mineralization occurs are confined generally to fracture zones, in places, silicified, brecciated, sheared or slickensided.

5.5.2 The Galena Specks and Fibrous Stringers

As is shown in Table 5.17N the occurrences of galena specks and fibrous stringers at the various localities, generally consist of small granular and irregular grains (specks) disseminated or dispersed within the Albian marine siltstones, shales and limestones.

The inaccessibility of the area and forested terrain have for a

TABLE 5. 17M Morphological Types of Galena in the Mineralized Marine Albian Silicified Limestone-Siltstone Sequences.

Morphological Types	Grain Size	Arufu	Akwana	Igbur	Buru Hill	Kyon	Iyorshagher	Associated Silicified Structures
1. Galena Specks and fibreus stringers	/0.2mm							NNE - SSW to NE-SW enechelon fracture zones in narrow Local
(a) Finely Granular Steel grey Galena.				DC- 350				
(b) Irregular Grains and Knots	1mm-10mm	DC.279						Sedimentary basins.
2.Massive Galena		DC.239	DC.240D 240D					ENE-WSW Trending Veins, which truncate or offset the NNE- SSW or NE - SW sets.
(a) Lenticular-Podlike Patchy Type.		DC.265 B, 152	DC. 155B 349					
(b) Fibrous Stringers Granular-galena in Drusy Cavities and Vugs.	/0.2mm - 5mm	DC.149 262						
3. Crystal Galena	1mm-10mm		242.					NW-SE or E-W trending fracture zones (in brecciated silicified limestone and Siltstone). Curved Parabolic ENE trending fractures truncate which sets in 1 and 2
(a) Cubic Type		DC.297 E, F	278					
(b) Fibrous galena found Scattered in parts of the Cubic or Cubo-Octahedral galena.								

	Early	Late
Jasperoid (domilitization and silicification)		———
Crystalline quartz		———
PYRITE DC. 279		
Disseminated FIBROUS		———
GALENA DC. 279 DC. 265F		———
Leaching of Galena		———
Cerussite DC. 279		———

Figure 5.55A Generalized Paragenetic Diagram of the shiny speck and speck and Fibreus Stringer galena mineralization at NE Arufu, Buru, and Nyosu, Iyorshagher (S. Abeda).

Jasperoid (Silicification and Dolomitization)		———
Fluorite ———	DC. 265	———
Crystalline Quartz ———	DC. 265F	———
Pyrite ———	DC. 265F	———
Galena ———	DC. 265B	———
FRACTURING		XX
Drusy Vughy Quartz ———	DC. 246D	
Leaching of galena		———
Cerussite ———	DC. 278, 279	———
Calcite and granular quartz	DC. 149	

Figure 5.55B Generalized Paragenetic diagram of Massive Galena/Fluorite Deposits in the EW trending fracture zones of Arufu and Akwana.

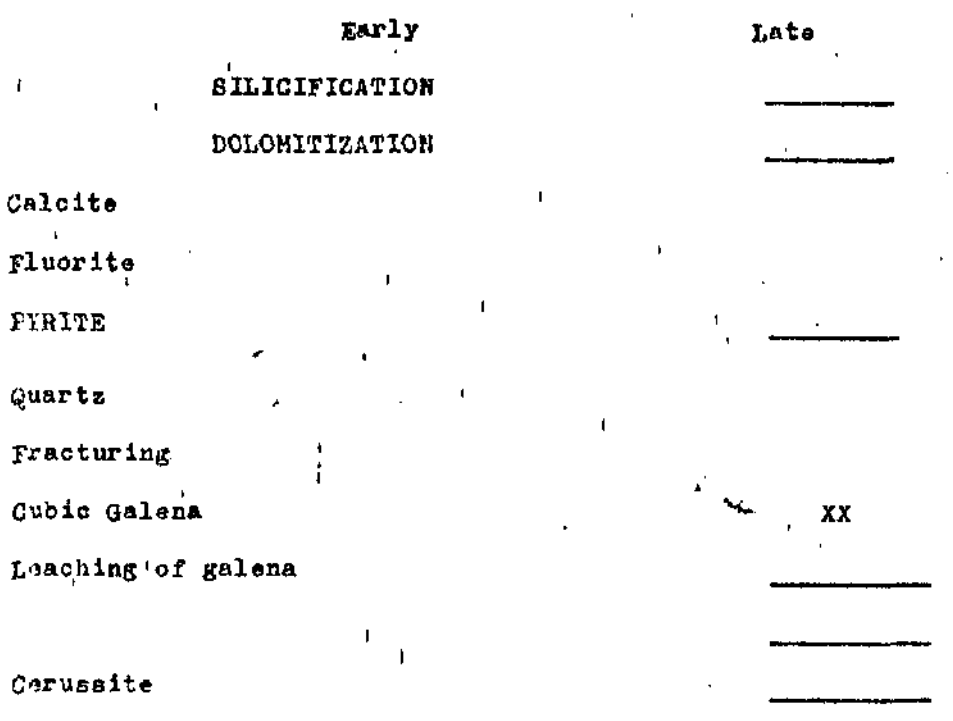


Figure 5.55C: Generalized Paragenetic diagram of Crystal

Galena Mineralization of SW Arufu and Juwudu

Hills (SW Akwana).

Fig: 5.56 LOCATION OF GALENA AND FLUORITE DEPOSITS IN RELATION TO SALT SPRINGS, DOLERITE DYKES, VOLCANIC ROCKS, LIMESTONE DEPOSITS, AND BASEMENT COMPLEX ROCKS



LEGEND

DC 10	Sample with numbers
pb.f	Disseminated Galena
v.pb.f	Vein Galena and fluorite
c.pb.f	Crystal Galena with fluorite
Δ	Pyrite
v.pb	Vein Galena

cpb	Fault Zone Galena
Tv	Tertiary Basaltic Lava Flow
kv	Late Albian – Early Ceno Interbedded Basaltic Flow
K1	Dolerite Dykes And Sills
S	Saline Spring
LS	Limestone
	Cretaceous Sedimentary Rocks
	Basement Complex Rock
	Direction of Flow of Salt Spring

long time militated against the systematic, more detailed exploration of these occurrences. However, with the present impetus of mineral exploration in the region it is hoped that when fully investigated one may be dealing with a relatively large reserve (with a land area of about 100 square kilometres) but low grade (max. tenor = 3% Pb) ore field.

Three of the speck and fibrous stringer galena deposits located in the SW and NE outskirts of Arufu occur within the Albian limestone (DC 163, 163D, 279) interbedded with sandy black shales (DC 148) and clayey siltstone - fine sandstone (DC 163E). The strike of the mineralized beds varies from 15° to 23° east. The mineralized zones occur sporadically and discontinuously in the gently undulating limestone-shale-siltstone terrain starting from a point about 400 metres NNE of Arufu. There are a few exposures in the sides of the trenches eg. (DC 279 at pit A2, DC 153, 163D; Table 3.8, Appendix A) and indications are that the speck and fibrous stringer galena mineralization is widely scattered throughout the study area. Since no systematic underground development has been carried out it will be premature to suggest that there is not enough galena mineral (owing to the sporadic and discontinuous distribution or mode of emplacement) to warrant large scale open pit operation. It is not known whether or not that the better grade ore will be encountered at depth. But results from the logging of the mineralized pits A2, A5-8 (see Figs. 3.20, and Table 3.8, Appendix A; Figs. 5.60 and 5.61 Appendix D) appear to be encouraging.

The fracture zones have a sheeted appearance and the individual NNE-SSW trending fractures are only a few centimetres wide. The maximum width of the zones of disseminated galena

TABLE 5.17N: *Occurrences of Galena Specks and Fibrous Stringers*

Locality	Mode of Occurrence in the Host Marine Albian Rocks
1. Arufu Area (a) 0.5 to 2 Kilometres NNE of Arufu	In Bed 2 Limestone and siltstones of the Uomba Formation
(b) Mai Tunku 5 kilometres NE of Arufu (c) Anyiin Ridge-River Duhu Area	In silicified Fine Sandstone-siltstone of the Uomba Formation.
2. Igbur River Valley	In silicified Bed 3 siltstone of the *Uomba Formation*, at the eastern margin of the Igbur Basin
3. Ruwabi Hill *Blind Ore Zone*	Middle – Upper Albian Limestone-siltstone shale sequence. Ore zone demarcated by Cxpb geochemical stream sediment Anomalous dispersion pattern.
4. Buru Hill	Fine sandstone siltstone sandy shales of late Albian Awe Formation.
5. Nyosu-Iyorshagher Area.	Albian siltstone-shale on both Limbs of the Yatiev Anticline

mineralization in the above area was about 1.6 metres and ten to twelve individual lenses are present in this distance.

The mineralized fracture zones have vertical to steep dips (70° - 80°) to the SE or NW in the Arufu area. If the dip is uniform in depth the maximum thickness of the limestone would not be less than 100 metres if no fault intervenes. The strike length of the mineralized zone does not exceed 150 metres.

Ore Mineralogy and Petrology

The sulphide minerals consist of primary galena and pyrite as an accessory. The galena is mainly finely granular to subhedral. The steel grey galena shiny specks are thin semi-conformable bands and disseminated crystals (DC 350) or small irregular stringers dispersed within the Albian silicified, fossiliferous and brecciated siltstones (DC 307B, C). Away from the silicified, brecciated mineralized zone, calcareous siltstones interbedded with black-shales are observed to the south of Igbur village (DC 207A). Coarse-grained patches of galena specks and stringers are less common and may be found in the same outcrop containing the finely granular steel grey variety (DC 350).

Galena is the main sulphide mineral in order to abundance (tenor = 2.4% Pb). Pyrite constitutes only 0.6% weight in the sample (DC 350). The enclosing siltstone is essentially composed of quartz (55% wt.), chalcedonic opal (4%), K-feldspar (1.6%) and chlorite (10%, see DC 350; Table 3.8 Appendix A) by modal calculation.

The beds are mainly shaly and silty towards the base (and calcareous in places not affected by silicification and dolomitization). The western sheared margin of the Igbur basement inlier is only

five metres from the limits of the mineralization in the basal marine Cretaceous sequences. The secondary minerals include crussite whose origin can be attributed to fact that the siltstone-fine sandstone sequence was pervious to underground water movements.

Higher up in the stratigraphic sequence the inter ore beds consist of dominantly calcareous to dolomitic (siltstone) arenites.

Ore Structure

The structure of the Igbur Valley ore body resembles that of the sister deposits in the SW and NE of Arufu. The main galena belt of the Igbur Valley is traversed by early faults with northeasterly trends that are truncated or offset by curved sets of fractures with northwesterly orientations near Igbur village where the basal Cretaceous sequence (Bed 3 of the Arufu Formation) abuts against the basement (Fig. 5.62). The galena is located on the southern limb of the Arufu anticline with an ENE trending axis, near its crestal area. These faults have minor vertical displacements ranging from a few centimetres to 15 metres.

In the Igbur area the ore structure consists of highly crushed (sheared and brecciated) and silicified siltstone mineralized with galena specks and fibrous stringers (Fig. 3.63, Plate 5.8) belonging to the Middle Albian Arufu Formation (Lower sequence of the Asu River (Group). These ore strata form part of the NNE trending fracture zone which are believed to be an extension of the shear zones in the Tyoban-Tsekwen Pan African Older Granite basement inlier into the Cretaceous sedimentary cover. The mineralized crushed zones form 50 - 100 metres wide elongate en echelon ridges. On a megascopic scale each crushed band is made up of closely spaced fractures of

various attitudes cutting each other and mineralized with galena. The individual fractures show as yellowish grey or whitish bands several millimeters to 1 centimetre wide locally thickened by lenses (Fig. 5.63; Plate 5.8). In hand specimen the mineralized fractures have the following features:

(i) a central band consists of finely crushed quartz grains with random fabric. In thin section some angular quartz phenoclasts display undulose extinction and are associated with deformed stringers and shining specks of steel grey granular galena.

(ii) a sharp boundary between the sheared brecciated band and the country rock where the quartz grains and the granular specks of steel grey galena undergo a beginning of brittle fragmentation. Indeed, brecciation appears to have followed and reworked the shearing regime.

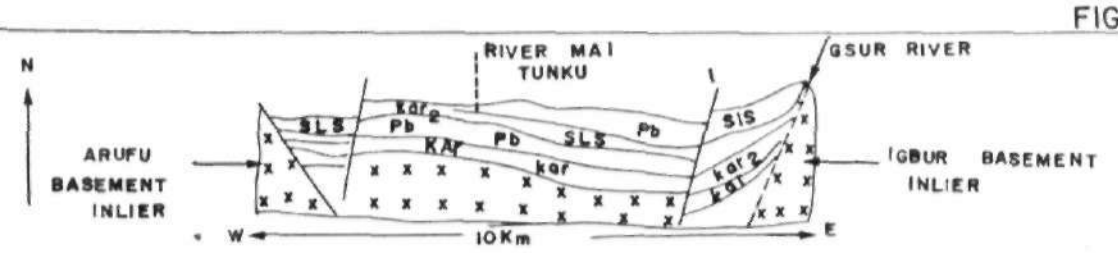
(iii) lenses ranging from millimetres to several centimetres develop along the fracture (Fig.5.63). The main galena belt of the Igbur area is traversed by early faults of northeasterly trends that are truncated and offset by curved sets with northwesterly trends near Igbur village where the basal unit of the Uomba Formation abuts against the Igbur Basement Inlier (Fig.5.62).

5.5.3 Massive Galena - Fluorite Deposits

Introduction

The zones in which the massive, patchy galena mineralization occurs are generally confined to silicified zones in the marine Albian limestone-black shale-siltstone sequences. The general trend of the mineralized (fault) zones is NE-SW to ENE-WSW at Arufu and Akwana.

FIG·5·62.



Diagrammatic East-West Section through the eastern portion of the basin of deposition of the lower cretaceous sediments in relation to emplacement of the lead deposits silicified limestone (SLS) and silicified silstone (SIS) members of the middle upper Albian Arufu formation (Lower sequence of the Asu River Group kar_2) are mineralized with lead pb deposits. All units THIN as they approach the fault bounded Arufu and Igbur Basement Inliers kar = Pre-Asu River Basal continetal sandstone.

GSN 2455F



PLATE 5.8

Conjugate crushed lenses (below and above the hammer) affecting the silicified mineralized (galena) siltstone units of the Arufu Formation, about 225 metres SW of Igbur Village near Km 54 along Wukari-Arufu road. Note the fracture cleavage (CL) within the Lenses. Same Locality as the diagrammatic sketch Figure 5.63 shown on the next page.

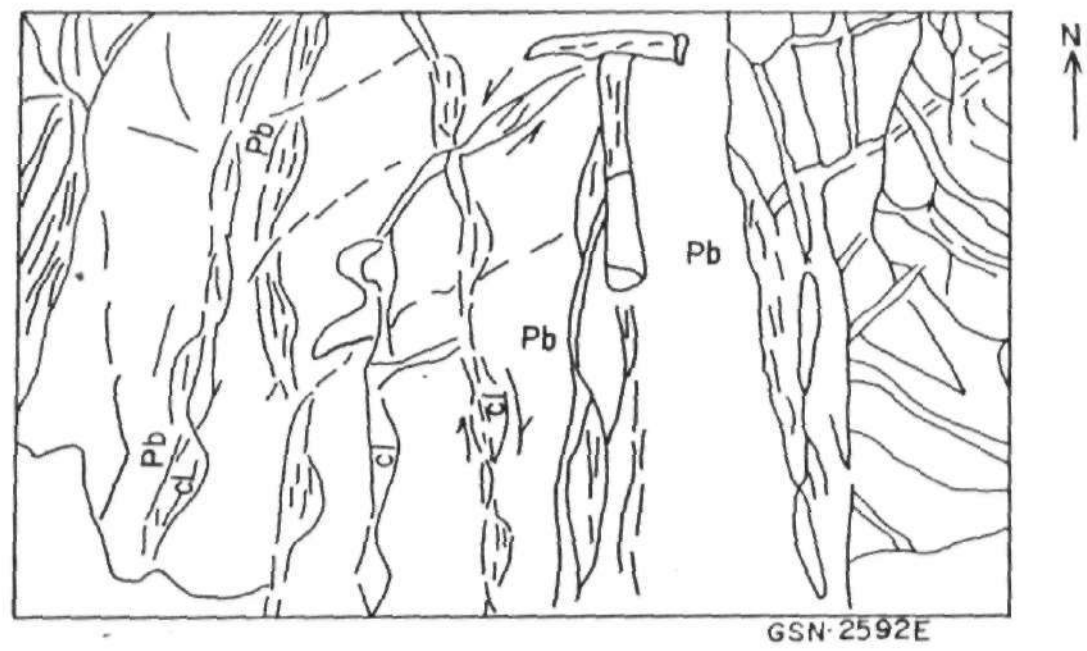


Fig. 5.63 . NNE Trending conjugate crushed fault zone affecting sandstone – siltstone units Arufu formation (Lower – sequence of Asu River group) about 22 metres SW of Igbur village near Km 54 along Wukari – Arufu tarred : The shearing affects both the cretaceous sediments and the western edge of the Igbur basement inlier

Pb - Galena mineralization
Note the fracture cleavage (cl) within the lenses

4 cm

These massive galena deposits are associated with subhedral brownish, purple-pinkish fluorite occurrences, with a gangue of crystalline and crusty (cavity filling) quartz. The dip of the veins is variable but usually steep, not less than 45° north or south (on both limbs of the Arufu (Anticline) and 80° to vertical, in places.

At both Arufu and Akwana the individual veins are generally narrow, discontinuous, patchy or lenticular, varying in width from eight to thirty centimetres. Judging from the lengths of the trenches and shafts the length of individual veins appear to vary from only a few metres to not more than eight metres. The maximum width of the zone of continuous mineralization seen in the deepest shaft (10 metres deep) to the north of Arufu, was 1.5 metres and eleven individual veins were observed in this distance (Bogue 1952).

There are six old massive galena-fluorite mine workings at Arufu with a total length of about 1000 metres and a total footage of 40-45 metres along the ridge.

The dip of the veins at shaft A16 about 200 metres north of Arufu village varies from vertical to steep (70° - 80°) to the south on the southern limb of the Arufu Anticline. The mineralization is confined to fractures in silicified, brecciated limestone, in places interbedded with siltstone and black-shale (DC 148). If the limestone continues at the same dip as exposed, the thickness of the mineralized zone may be estimated at between 20 and 30 metres if no fault intervenes.

The floor (run) of shaft A16 is nearly level, and a 2-3 metres thick laterite roof (overburden) apparently maintains a certain constant height on the mineralized silicified Bed 2 limestone in the

Arufu area. The descriptions of the occurrences are as tabulated in Table 5.17 M

5.5.4 Ore Mineralogy

The mineralogy of the three massive galena-fluorite deposits around Akwana village, is largely similar to that of the veins in the Arufu area. The minerals recognized area:-

1. Jasperoid (DC 155B) - Earliest.
2. Fluorite; coasrsely crystalline (cubic) dark brown-purple variety (DC 423).
3. Quartz (including anhedral type) that lines veinlets and fills drusy cavities, cracks and vugs (DC 349D) in siliceous limestone.
4. Massive galena (DC 240D) and patchy form, contained in siliceous limestone and fluorite (DC 155B, 349C).

The specimens (DC 155B and 423) collected from the Tsumada workings show that jasperoid is the earliest result of intense silicification, followed laterally by purple fluorite (DC 323) and quartz. These are then followed by anhedral whitish grey fluorite and quartz which fill veinlets and line drusy crustified cavities and vugs towards the centre of the ore body or workings. It is believed that the crystalline quartz and the crustified form are contemporaneous with the purple fluorite and the stringers respectively. This part of the workings consists of a wide zone of impregnation in which widths of 6 and 6.3 metres parallel to the E-W veins were recorded (McConnell 1949) reaching a maximum length of 273.6 metres. The walls of the lode were reported to be made up of much black fine siliceous limestone and McConnell (optcit) found in several places a stock work of veinlets of massive, fibrous (patchy) galena and fluorite penetrating the limestone.

TABLE 5.17H: Massive Galena Deposits in Akwana Area.

Name of Deposit and Locality	Mode of Occurrence in Host Marine Albian Rocks
1. Tsumada Workings	In E-W trending Fracture zone underlain by silicified, brecciated limestone - siltstone-Black Shale
2. River Fofi Deposit 4km SSW of Akwana, and about 1/2 km NE of Akijo NE trending Older Granite Inlier. Deposit located on west Bank of River Fofi.	Contained in E-W trending subparallel narrow veins consisting of a zone of impregnations in silicified Limestone
3. River Rogo Deposit, on the east bank of River Rogo about 2 kilometres east of Akwana Village	Subparallel Stringers of massive galena and pink fluorite in silicified limestone interbedded with shale and siltstone.

5.5.5 Ore Resources

The strike length of the E-W trending massive galena-fluorite workings about 200 metres north of Arufu village, is about 91.44 metres, with a width of probable mineralized (ore) zone varying from 10 to 20 metres. The extent in the depth of the deposit will be controlled by the thickness of the mineralized Bed 2 siliceous, brecciated limestone member of the Arufu Formation. Although the unmineralized Basement Complex rocks crop out only 105 metres north of the above workings it has been shown that the limestone has been down-faulted with a throw of not less than 100 metres, and the chances that the ore bodies would continue to a depth of at least 100 metres may be considered good. The massive galena-crystalline fluorite mineralized fracture zones are discontinuous, erratic and narrow, varying from less than 10 centimetres to two metres.

5.6 Genesis of Galena Specks and Fibrous Stringers, and the Massive Type

5.6.1 Facts Related to the Genesis

Certain facts bearing on the question of the ore genesis of the galena specks and fibrous stringers and massive types are highlighted and summarized as follows:

1. The NNE - trending fine grained axial dolerite intrusives (DC 185, 185A, 187) belonging to the second cycle of igneous activity, are unmineralized with the sulphides (galena and pyrite).
2. The NE - trending medium grained albitized dolerite intrusives belonging to the third cycle of igneous activity in the study area, appear to be penecontemporaneous with the NE-trending vertical

fracture zones (in the Arufu-Buru-Mai Tunku area) which are mineralized with disseminated galena (DC 260A, 279, 350; Table 3.8 Appendix (a)). Yet these albitized dolerites (DC 178, 188) are barren of an sulphide (galena) mineralization.

3. The extensive albitization of the medium grained dolerites in the Buru Hill area (DC 178) suggests that magmatic emanations were active during and/or after emplacement, that is during consolidation and burial diagenesis of the Albian Marine sedimentary pile.

4. Galena specks and Fibrous Stringers and massive galena mineralization together with the basic dolerite intrusions favour anticlinal structures at Arufu and Buru Hill (Fig. 3.21 back pocket).

5. Galena mineralization did not reach as high in the Cretaceous stratigraphic sequence as the post-Lower Turonian to Tertiary (basaltic) basic alkaline volcanics. Continuing Cretaceous to Tertiary alkaline igneous activity in the study area (within the Middle Benue Trough) may be attributed to reactivation of magmatism along the existing lines of structural weakness in the the sialic crust in response to stresses affecting the African Plate (Olade 1979, Wright 1975, Grant 1972).

6. Extrusion of lava during sedimentation in the Albian sea of the study area left layers of basic igneous rocks in the sedimentary sequence, which were reinforced by later intrusions (cf. the Andyar interbedded basaltic lavas). The fracturing along the line of the RIFT

probably opened the way for the escape of magma from the underlying zone of partial melting in the mantle, the expansion of which gave rise to the original uplift.

The circulation of juvenile water, or at least warm saline groundwater, probably continued and possibly leached some of the first formed galena specks to impregnate other Albian formations elsewhere in the sedimentary sequence giving rise to the massive galena lodes and deposits (characteristically of high grade but low reserve) at Arufu and Akwana where suitable carbonate (limestone) rocks were present.

Partially, similar processes appear to have operated in the formation of the MISSISSIPPI VALLEY Type of galena deposits of the U.S.A.

7. Probably a series of axial fractures within the RIFT-LIKE MIDDLE BENUE TROUGH contributed base metals to (marine) sediments at the time of deposition and sooner or after - that is, during consolidation and diagenesis in the Late Albian times. This probably led to the formation of the various deposits of comparatively low grade disseminated galena in the marine Albian host rocks-siliceous limestones, siltstone, fine sandstones and shales.

5.6.2 Discussion

The galena specks and fibrous stringers and massive galena mineralization were confined only to Albian marine (Asu River Group) rocks, which may reflect temporal control.

As has been pointed out in chapter 4, the probable genetic relationship between the dolerite intrusives and the galena mineralization may only be of an indirect nature with the igneous bodies

acting as subsidiary heat sources to the circulating mineralizing solutions along permeable (open fissure) zones in the marine Cretaceous sedimentary column leaching base metals from:-

i. the feldspar rich clays in the surrounding sediments.

ii. the underlying K-feldspar rich granitic basement and;

iii. the igneous bodies themselves to form galena and other sulphides which were subsequently emplaced at favourable beds.

The E-W trending Tsumada massive galena and fluorite workings occur in a series of small fractures in fine brecciated silicified limestone (DC 155B), indicative of formation under tensional regime (cf. Badgley 1975, Wright 1981).

Similarly the River Fofi workings (Ashanti Consolidated Mines Ltd. 1926) are contained in E-W trending subparallel veins consisting of a 10 metres wide zone of impregnations in bedding plane fractures mineralized in veinlets of galena and purple crystalline fluorite. The fluorite in places fills veinlets and lines cavities. In both the River Fofi and the Tsumada deposits the black fine grained jasperoid (made up of cryptocrystalline silica) occurs as a result of intense silicification of the limestone and grades laterally from limestone host rock towards the centre of the ore body, as galena-fluorite rock. Patches and pods of galena are found both in the siliceous limestone and the fluorite.

The shiny speck and fibrous stringer galena deposits of the study area can be partially compared with disseminated galena deposits of SE Missouri District of the Mississippi valley (Behre, Hey and McKnight, 1950). The massive Galena-Fluorite occurrences at Arufu and Akwana also bear some resemblance to the Kentucky-Illinois

Fluorite Deposits (Behre et al. optcit).

Tattam (1930) considers that the best analogue to the galena deposits of the study area is the Rhenish Schiefgbirge. Here and in other similar fields the mineralization is usually regarded as being of low temperature hydrothermal origin. The question of whether the mineralizing solution is of:

(a) Magmatic

(b) non-magmatic and/or

(c) indirect magmatic origin, is locally resolved depending on the particular relationship between the igneous bodies and the galena mineralization.

In the study area (c) is considered to be operative. The reported association of the massive galena (DC 239) with native silver (McConnell 1949, Bogue 1952) and purple crystalline fluorite, at Arufu, may indicate formation at a medium temperature (a little over 200°C) probably related to lime-skarn formation (Smirnov 1976), involving late hydrothermal skarn processes (Fig. 5.59 Appendix D), characteristic of a limestone country (Burt and Rose 1979).

The last phase of the vein mineralization, which included late calcite, late granular quartz, was probably deposited at a somewhat lower temperature.

Lack of canalization of the ore solutions and the consequent irregular and branching nature of the ore bodies is taken by Grant (1906) as one of the main characteristics of the upper zones of deposition (formation at shallow depth). This feature is marked in the Arufu-Akwana massive galena deposits. The wide penetration of the limestone at Arufu (DC 265B) and Akwana (DC 155B) by mineralizing solutions is seen. Little veinlets of quartz and fluorite

containing galena are commonly seen and locally form aggregates.

The concentric zoning of Ag and fluorite with decreasing values from a centre within the ore body, e.g. at pit A15 about 200 metres north of Arufu possibly indicates a metal supply from a deeper seated source along early diagenetic fissure zones. Clearly, that the galena mineralization cannot be directly related to basalt-rhyolite layers indicates volcanic activities during the Aptian, Albian and Cenomanian times in the study area. So it is possible that metal-bearing solutions of igneous origin may have participated in forming the lead ores of the Arufu-Akwana area.

The best evidence to date, though not conclusive indicates that the ores were deposited by hydrothermal solutions with temperatures probably not exceeding 100°C (Nwachuku 1975, Olade and Morton 1980). One of the convincing reasons for accepting this interpretation is that the deposition of the ores was contemporaneous with the late stages of the regional deformation of the region a relationship usually found in districts where ores are hydrothermal. Also the paragenetic sequence and zoning are characteristic of ores recognized by all as hydrothermal in origin.

5.7 Crystal Galena Mineralization

5.7.1 Mode of Occurrences

Occurrences of the above type of galena mineralization are found in the most intensely deformed, silicified and brecciated zones of the Arufu-Akwana area as follows:-

1. The Rafin Gishiri Valley Deposit about 1.5 kilometres NW of Arufu village, consisting of coarsely crystalline (cubic to Cubo-octahedral) undeformed galena (see DC 153A, 162A, 297A, B, E, F; Pits A22 - A25).

2. Around Akwana

(a) Juwudu Hill deposit, about 24 metres SE of Akwana village consisting of (i) the undeformed cubic type and (ii) fibrous galena found scattered in parts of the cubic or cubo-octahedral galena associated with greyish white or green brownish massive fluorite (see DC 154A, BD; 155G, 242, 278). (b) Udza Deposit, about 5 kilometres SW of Akwana.

The trend of the mineralized fracture in the Rafin Gishiri Deposit is approximately NNW to NW, forming a series of curved, irregular - concentric sets. The total width of the mineralized zone is about 100 metres, while the width of the individual fractures varies from two to six metres or more.

The Juwudu Hill Deposit straddles the interfluvial area between the Rogo and Fofi Rivers about 2 kilometres SW of Akwana village. These two rivers encircle and dissect the Juwudu range of hills. The deposit consists of a series of workings over a distance of 348 metres. Most of the pits are now partially filled with debris but several of them are 7 metres in depth and 16 metres wide. The galena-fluorite mineralization is in a series of closely spaced parallel vertical to steeply dipping faults (fractures). The strike of the fractures varies from N65° to 080°. The dip is 65° to 75° to the SE.

The Udza Deposit is located about 5 kilometres NW of Akwana village, on the northern outskirts of Udza Compound. Two prominent shafts are seen, now partially covered with debris and overgrown with vegetation. One of the shafts (Pit A37), which is not caved, is about 6 metres deep and about 2.5 metres wide and 10 metres long. The shaft is about 200 metres northeast of the NE-SW trending Udza

Older Granite basement inlier (DC 416) whose eastern edge is outlined by the left bank of Fofi River. The specimen (DC 242) was collected. It consists of coarsely crystalline cubic galena and grey massive fluorite in siliceous limestone.

5.7.2 Ore Structure

Like the other two types of galena encountered in the study area the crystalline type is characterized by being open-fissure filling type mineralization in fault zones. The mineralized faults also form part of the fractured or sheeted zone. Generally, individual zones exhibit a single pattern of closely spaced jointed, broken ground in which one or more better developed fractures occur. The stronger fractures (on more competent rocks) are generally straight, although curved concentric sets may exist as in the Rafin Gishiri Deposit at Arufu. At this deposit the deformed brecciated planes along which the undeformed galena crystals formed may swell to appreciable greater width. Along the brecciated zones materials containing angular fragments of tectonized inclusions of the wall rocks are seen (DC 152, 297F, E).

The culmination of the intensely deformed zones in the three occurrences studied appears to consist of a series of divergent fractures. Some of the fractures are also minor faults along which repeated small scale movements have taken place more or less vertically, horizontal movement is not pronounced. Brecciation has occurred at places along most of these faults, especially those underlain by the more competent silicified Albian sequences.

Morphologically the crystal undeformed galena outcrops are characterized by being coarsely crystalline (cubic) and usually has

perfect cleavage trace (DC 242, 278). Some fibrous variety may be found in parts of the coarsely crystalline cubic galena, traversing the former, suggesting formation at a later time. Some may occupy cracks in the earlier crystalline type (DC 297A, B, C, F). At the Rafin Gishiri Deposit the crystal galena mineralization is contained in NW-SE mineralized sets, and is believed to be the latest to be emplaced.

In Juwudu Hill Deposit the ore is concentrated along vertical to steeply dipping, closely spaced, parallel, fault zones on both limbs of the fault-bounded depression (basin). But the basin is so narrow that the two limbs are close together, and patches of lean ore occurs in the central area, connecting the two limbs. The controlling fractures are apparently vertical faults. Displacements of 4 centimetres to one metre were recorded towards the north-eastern flank of the Udza basement inlier. The controlling NE-SW trending synclinal axis straddling between the Udza workings and the Udza basement inlier is crossed by minor NW-SE trending flexures, thus making the axis of the structure rise and fall and so become sinuous and asymmetrical.

Coarsely crystalline undeformed galena is associated with a gangue of grey white massive fluorite, and both crystalline quartz (DC 242, 278) and crustified type lining up cavities.

5.7.3 Ore Resources

Most of the ore-bodies in the crystal galena deposits appear to conform to the constant NW-SE and ENE-WSW or E-W trends. Probably the more important economically of these two is the ENE trend, although the tendency to irregular, curved and arcuate outline of the ore-bodies may appear to invalidate this assertion.

In the case of the Udza Deposit, the narrow sporadic nature of the mineralized fracture zones and the usual low grade of the ore (tenor - 2.4% lead) exposed may make it unlikely that this deposit would be of economic interest.

Chemical analysis and polished section studies of the specimens (DC 242, 278) collected from the two metre depth level of pit A37 show that lead content is 2.2% Pb while galena (Pbs) is 2.9% wt. The crystal galena deposits may be regarded as being of low grade but of large reserve.

5.7.5 Ore Genesis of the Crystal Galena

In the study area the more accessible crystal galena bearing ores have been so opened up, exhausted and abandoned that the present workings consist of debris filled or water filled old trenches, shafts and mine dumps. So no authentic systematic order of crystallization or paragenesis, can be established without applying much of the indirect geochemical exploration technique.

So, with the help of lithogeochemical sampling, geochemical stream sediment and profile residual soil techniques the following prelimary conclusions were arrived at during the present investigation regarded the paragenesis (Sequential order of mineral formation):

1. In addition to leaching the carbonate rocks, the mineralizing solutions in the early stages, appear to have silicified and dolomitized the pre-existing Cretaceous sediments. The silicification was earlier. Rocks normally calcareous within and bordering the ore deposits are locally completely altered to silicified (Cherty) siltstones and sandstones in predominantly arenaceous terrain while they were altered to fine grained silicified rocks in a

in a limestone country with the concomittant formation of FLUORITE as a result of lime-skarn late hydrothermal processes (Smirnov 1976, Burt and Rose 1979).

Late Albian igneous (dolerite) intrusive activity (DC 185, 185A, 187) and Early Cenomanian (basaltic) volcanic activity (DC 256A, B, C) in the Arufu and Andyar areas respectively, probably acted as subsidiary heat source to the circulating mineralization solution along (open fissure) permeable zones in the sedimentary sequence perhaps, still wet, i.e. undergoing burial diagenesis and consolidation.

2. The fluorite was probably partly replaced by calcite in the fault zones (Currier 1944) which in turn was probably partly replaced by the sulphide merals eg. pyrite which appears to be the earlies of the suphides shown in the specimen (DC 242) cf. Bastin 1939).

3. The quartz, probably in part, contemporaneous with the fluorite continued to deposit until somewhat later stage. There was probably a late generation of calcite which formed on top of the fluorite.

4. Quartz was followed by galena.

From this paragenetic order it is evident that the order of crystallization follows roughly the same sequence as the horizontal zoning of specimens DC 242, 278 collected from different depth levels at pit A34 in the Juwudu Hill Deposit and DC 155E from pit (A33, and also DC 154A from pit A35). These two pits are separated from each other by a horizontal distance of over 100 metres. The similarity of the results of their chemical analyses and polished section studies, is quite striking.

The sources of the ore element fluorine in the fluorite deposits which were formed earlier than the cubic galena, was probably partly magmatic (derived from the partially cooled igneous bodies (DC 185, 185A, 256A, B, C,) which the circulating mineralizing solutions encountered as they moved along permeable (open fissure) zones within the sedimentary sequence. These probably partly leached some fluorine from the underlying K-feldspar rich granitic basement inliers (DC 175, 418).

The source of the crystal galena mineralization is considered to be the adjacent galena specks and fibrous stringers or the massive galena which contains all the base metals of the crystal galena type, though in a greatly reduced quantity.

Probably as the Upper Cretaceous sedimentation continued in this part of the Middle Benue Trough, culminating in different phases of tectonic activity which deformed the earlier galena and dilated the earlier structures, it resulted in the annealing and crystallization of the coarse cubic galena.

5.8. Association of Fluorite Deposits with Rift? Zones of the Study Area

From the discussion on the nature of rift-faulting in chapter 4, it is evident that the Arufu-Akwana Fluorite district occurs in the northward extension of the Tseagu Graben within the central rift zone of the study area. Van Alstine (1976) has called attention to the common association of major fluorspar districts and continental rift systems and lineaments of the world, eg.

(1) In the 6,400 kilometres long East African Rift System where, fluorite deposits are found in Kenya, Tanzania, Malawi, and Mozambique. In these areas, like the Arufu-Akwana district,

the rifts are associated with fluorspar deposits, and alkaline igneous rocks.

(2) In the 800 kilometres long Rio Grande Graben (U.S.A.), which is part of a major continental rift zone of tensional faulting that extends southward into Mexico and northward into New Mexico, Golorado, Wyoming etc. More than 45 fluospar districts are cited along the Rio Grande Graben. The rift zones consist of bounding and en echelon normal faults and cross faults that create salients and reentrants across the graben and a series of discontinuous topographic and fault-bounded sedimentary basins, similarly associated with alkaline rhyolitic and basaltic lavas. The associated Kentucky-Illinois fluorite district is cited as being accompanied by commercial quantities of lead, zinc and barite.

The Arufu-Akwana fluorite deposits are accompanied by a commercial quantity of lead. He then suggests that this typical association can be regarded as a regional guide in search for new fluorspar deposits.

Figures 3.20 and 3.21 (back pocket) show the spatial relations between the fluorspar deposits of the northern extension of the Tseagu Graben. These limestone-hosted fluorspar deposits at Arufu and Akwana are chiefly along normal faults, en achelon or marginal to the graben structure.

Fluorite deposition in the dtudy area seems to be genetically related to the Cretaceous rifting, which probably provided access for the volatile fluorine from depth probably due to (cf. Van Alstine 1976):

(a) Volatile emanations from a crystallizing alkaline basaltic

magma et. the Late Albian-Early Cenomanian Andyar Basalt around Andyar village (DC 256B).

(b) Remelting of late fluorite-rich alkaline fractions of the underlying Upper Albian fine grained alkaline dolerite intrusive in the Arufu area (DC 185A).

(c) Fluorspatite and other fluorine-bearing minerals derived from the K-feldspar-rich Arufu basement granitic gneiss inlier of the Udza and Akijo Pan African Older Granite basement ridges.

Regardless of the original source of the fluorine, it is believed that it probably leaked from the Lower crust or mantle along the deep-seated rift structure or lineaments in the Arufu-Akwana area.

In the silicified, brecciated limestone terrain at Arufu, Akwana and around the Juwudu Hill the formation of fluorite was probably as a result of lime-skarn late hydrothermal (150°C - 250°C temperature range) processes (cf. Smirnov 1976, Burt and Rose 1979; see also Fig.5.59 Appendix D).

In the Arufu-Akwana-Juwudu Hill area the fluorspar deposits are accompanied by a commercial quantity of galena.

The deep-seated faults provided channels for the circulation of fluorine and the mineralized juvenile connate or groundwater probably during the deposition of the massive greyish-whitish or greenish brown fluorite in the Juwudu Hill area. The associated igneous activity (manifesting in the Arufu area as a probable source of fluorine) possibly acted as subsidiary heat (energy) source to drive the mineralizing solutions along the channels during the deposition of the pinkish brown subcrystalline fluorite. The block faulting probably also

interrupted the flow of fluids and formed the local basins and mineral traps in the study area. The NE trending axial and marginal fault zones which contain the fluorite -massive galena deposits appear to be part of the major conjugate fracture systems which correspond to the on-shore extensions of the equatorial oceanic fracture zones which may have initiated the opening of the Benue Trough in Cretaceous times (Ajakaiye et al. 1986).

Recent data on the fluid inclusion microthemometry and the associated trace element concentration patterns from the fluorite deposits at Arufu and Akwana (Akande and Zentilli 1988) are also consistent with the derivation of the greyish white fluorite forming solution from a highly saline brine which intersected with the gneissic basement or arkosic sediments derived from the basement. These authors state that the very high initial $^{87}Sr/^{88}Sr$ ratios averaging 0.71497, measured in the calcite associated with the fluorite, is comparable with these reported for basement gneisses.

The above data on the fluorite mineralization of the study area and also the data presented in this work on the origin of the lead (which was probably leached from the underlying K-feldspar-rich Pre-Cambrian granite basement), may further illustrate the possible metallogenic relationships and significance of the Pre-Cambrian (to Lower Palaeozoic) Basement Complex to the evolution of the Younger mineral belts in the Nigerian sedimentary basins, especially, the Benue Trough (cf. Akande and Zentilli 1988).

5.9 Summary

The distinct stratigraphic control of the epigenetic galena mineralization, its association with brecciated and faulted silicified limestone and siltstone-sandstone ore structures will be of great value

for further exploration in this part of the Middle Benue Trough. Detailed investigations for galena in suitable areas should therefore concentrate on the brecciated marine Albian (Asu River Group) limestone-shale-siltstone-fine sandstone sequences proximal to silicified major fault zones. The brittle deformation is characterized by development of closely spaced high angle to vertical subparallel fractures, which provided favourable ground for ore deposition. The galena mineralization is episodic and confined to marine sedimentary rocks of Albian age, thus reflecting temporal control.

The association of the major fluorspar deposits (in the Arufu-Akwana limestone terrain) along normal faults en echelon or marginal to the graben structure (rift zone) and lineaments may be regarded as a regional guide in the search for the deposits in the Albian limestone terrain of the Benue Rift structure. The fluorspar may be accompanied by commercial quantities of galena, sphalerite, barite, uranium and rare earth minerals.

The nature of the contacts between the three varieties of galena and the two types of fluorite veins in the study area suggests in each case, that the fractures opened more than once in the process of mineralization (cf. J.I. and Ike, 1988).

Silicification was early and widespread in the Lower Cretaceous sedimentary and igneous rocks (both extrusive and intrusive) or the study area. It resulted in increased Si (Table 3.8 Appendix A) and Fe contents and decreased Ca, Mg, Ti and Al contents in the altered sedimentary rocks. The silicified rock zones are interpreted to be the result of water-rock interaction related to the circulation of warmed connate (Juvenile) water through originally highly permeable open

fissures in the wet sedimentary column and some of the igneous (extrusive and intrusive) rock zones. Silicification eventually zealed the upper part of the aquifer forming impermeable cap-rocks at the tops of the beds which make up the Lower Cretaceous formations, e.g. Beds 2,3,5, and 7 of the Middle-Upper Albian Uomba Formation. In the above subsequently mineralized units of the Uomba Formation the impermeable barriers are considered to have acted as cap-rocks to the (lead) mineralizing solutions.

The silicification of the limestone-shale-siltstone-fine sandstone sequences (Asu River Group) proximal to major fault zones and graben structures (rift zones) of the study area, is believed to be the product of extensive Lower Cretaceous alteration in the Middle Benue Trough that presents a good exploration target for galena deposits in the region.

The reported association of the massive galena with native silver and purple crystalline fluorite at Arufu (McConnell 1949, Bogue 1952) suggests that the ore fluids might have attained medium temperatures approximating a little over 200°C or higher at the period of formation, and is reminiscent of the Rhenish Schiefgbirge (Tattam 1930, Farrington 1952). Such higher temperature is expected when ore forming fluids get hotter at deeper parts of the basin. The mineralogy and texture of the galena lodes in the study area are comparable to these of the Abakaliki-Ishiagu Lead-Zinc district of the Lower Benue Trough and partially to those of the giant Navan Lead-Zinc ore body in Central Ireland, and appear to be related to base metal generation in continental rift environments (cf. Akande et al. 1988; Dim et al. 1990).

The concentration of Pb - mineralization in the vicinity of Igbur Buru, Arufu-Akwana areas with its apparent control by major structural fractures such as lineaments, faults and palaeo highs supports the hypothesis that the mineralizing fluids flowed up through these major zones of crustal failures and precipitated as galena (lead sulphide) in chemically and structurally suitable beds.

The similarity of the Pb - mineralogy as well as minor element trends in both the Uomba and Awe Formations suggests a common mineralizing event for both stratigraphic units, although mineralization may have occurred over a long period of time and possibly was intermittent.

Epigenetic features such as spatially associated ductile shear zones in the Igbur area which acted as fluid channel ways and well developed vein sets in these galena deposits indicate that the apparent conformable or stratiform nature of the deposits (in places) is due to (i) selective replacement of pre-existing bedding in a zone around the fluid channel-way or (ii) movement of the mineralizing fluids along permeable bedded plane fractures.

The frequent tripartite association of galena mineralization, dolerite intrusion and brine deposition may be associated with other factors than a common genetic origin for all of them.

CHAPTER 6

GEOCHEMISTRY OF MINERALIZATION

6.1 Introduction

In the previous chapters data obtained from different geochemical techniques have been employed in making interpretations and analogies regarding the mineralization in the study area in relation to stratigraphy, structure and igneous activity. This chapter attempts to highlight these aspects of the geochemical studies.

The following geochemical methods have been employed:-

(a) Whole rock geochemistry, involving the collection of mineralized and barren rock samples along lateral and vertical profiles or traverses in the existing old old mine workings and/or newly dug pits or trenches, and subsequently subjecting them to detailed chemical analyses with the aim of probing their major and trace element geochemistry.

(b) Geochemical drainage sediment survey, consisting of (i) A Geochemical Orientation study concerned mostly with determing the relative merits of sampling water, alluvial sediment, and soil from seepage areas, and (ii) A geochemical reconnaissance stream sediment survey.

6.2 Whole Rock Geochemistry

6.2.1 Sampling and Analysis

Field observation indicates that the base metal sulphide (galena) mineralization in the study area is confined to closely spaced subparallel narrow fractures and veins in marine Albian limestone-

shale-siltstone-sandstone sequence. These numerous fractures and veins trending in various directions, constitute the fault zones, varying in width from less than 10 metres to 100 metres. The galena mineralization is selective, erratic and discontinuous, so the sampling traverses were arranged along rectangular grids across the lateral extension of the mineralized zones.

On the basis of magascopic examination rock samples were designated as mineralized or barren. In order to investigate and establish the optinum lateral sampling intervals and also the variation in metal contents of the rock (Lateral zoning) samples were collected at uniform intervals over the barren less deformed rocks but in the case of the mineralized rocks, the lateral spacing was closer over and near the mineralization and wider farther away (Figs. 3.20 and 3.21, back pocket).

To investigate any possibility of vertical zoning the mineralized rock samples were collected from various mine workings (Table 3.8, Appendix A). The samples were collected at regular lateral intervals normal to the strike of the mineralized fractures. An effort was made to collect unweathered samples.

One gramme of each of the crushed specimens (sieved to minus 100 mesh) was weighed out for hot Aqua Regia Digestion (HX) for analysis by gravimetric and volumetric (wet chemical) methods, or by instrumental Atomic Absorption Spectrophotometry (ASS).

Instrumental Precision

In both cold (CX) and Hot Aqua Regia (HX) extractions, ten per cent of all samples were analysed in duplicate and precision estimated (Fig. 6.64). Results indicated Precision better than $\pm$ 20 at the 95%

confidence level (Howard and Thompson 1976).

6.2.2 Result

Major elements were determined in weight oxide per cent as Al_2O_3, CaO, Fe_2O_3, FeO, MgO, MnO, P_2O_5, SiO_2, SO_3 or SO_4, Na_2O, K_2O, TiO_2, respectively. Minor or trace elements - Pb, Zn, Cu, Ag, Ni, V, U, Li, Ba, Sr, Rb, B, Ga, As, Zr, etc. were determined in parts per million (ppm). Table 3.8 (appendix A) shows the results of detailed chemical analyses conducted on 49 mineralized specimens and 11 barren samples.

Rock forming minerals and sulphides (galena) and other ore minerals were determined by modal analysis in percentages from thin and polished sections respectively.

Contents of SiO_2, CaO, MgO, Pb, Zn, Fe, As and S in the samples from three pits in Arufu-Akwana area are plotted in figures 6.65A-C, and some important inter-element relationships are shown in Figures 6.66A-C.

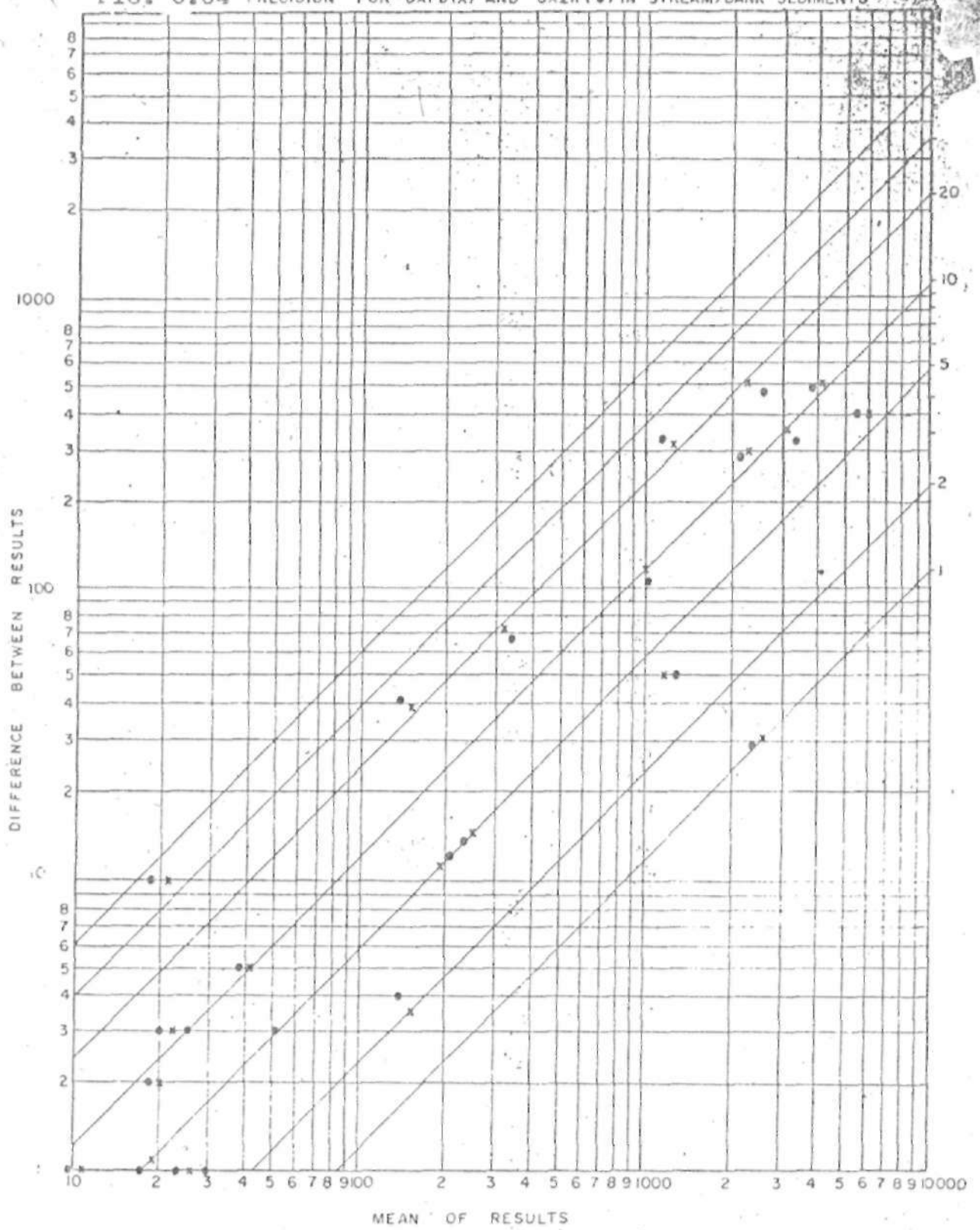
6.2.3 Major Elements

The whole-rock chemistry of the mineralized sequences in the Arufu-Akwana-Juwudu Hill silicified fracture zone (Fig. 3.21 back pocket) varies slightly from that of the Buru Hill-Igbur-Nyosu area. Though there is a scatter of values (with overlap between the sites) the mean values for almost all the constituents are appreciably different. The differences are highlighted in Table 3.8 (Appendix A).

Silica and Alumina

Shales from all the formations underlying the deformed and less deformed silicified terrain and the intensely silicified, brecciated fault

FIG. 6.64 PRECISION FOR CXPb(X) AND CXZn(●) IN STREAM/BANK SEDIMENTS



GSM 2460T

zones appear to have SiO_2/Al_2O_3 ratios within the range of 6 to 6.4, indicating that the relative proportions of quartz to clays plus feldspar are similar throughout (cf. Lambert and Scott 1973).

Calcium, Magnesium and Iron in Carbonates

High iron contents in the silicified brecciated, dolomitized carbonate rocks are reflected by brownish to yellowish, reddish surface coatings of iron oxide - hydroxide in weathered outcrops (DC 265B, 155B). The fine-grained sizes of some of these altered rocks, the rare occurrence of calcite residuals and the variable iron content between adjacent fragments in the beds, are suggestive of early diagenetic dolomitization.

Manganese

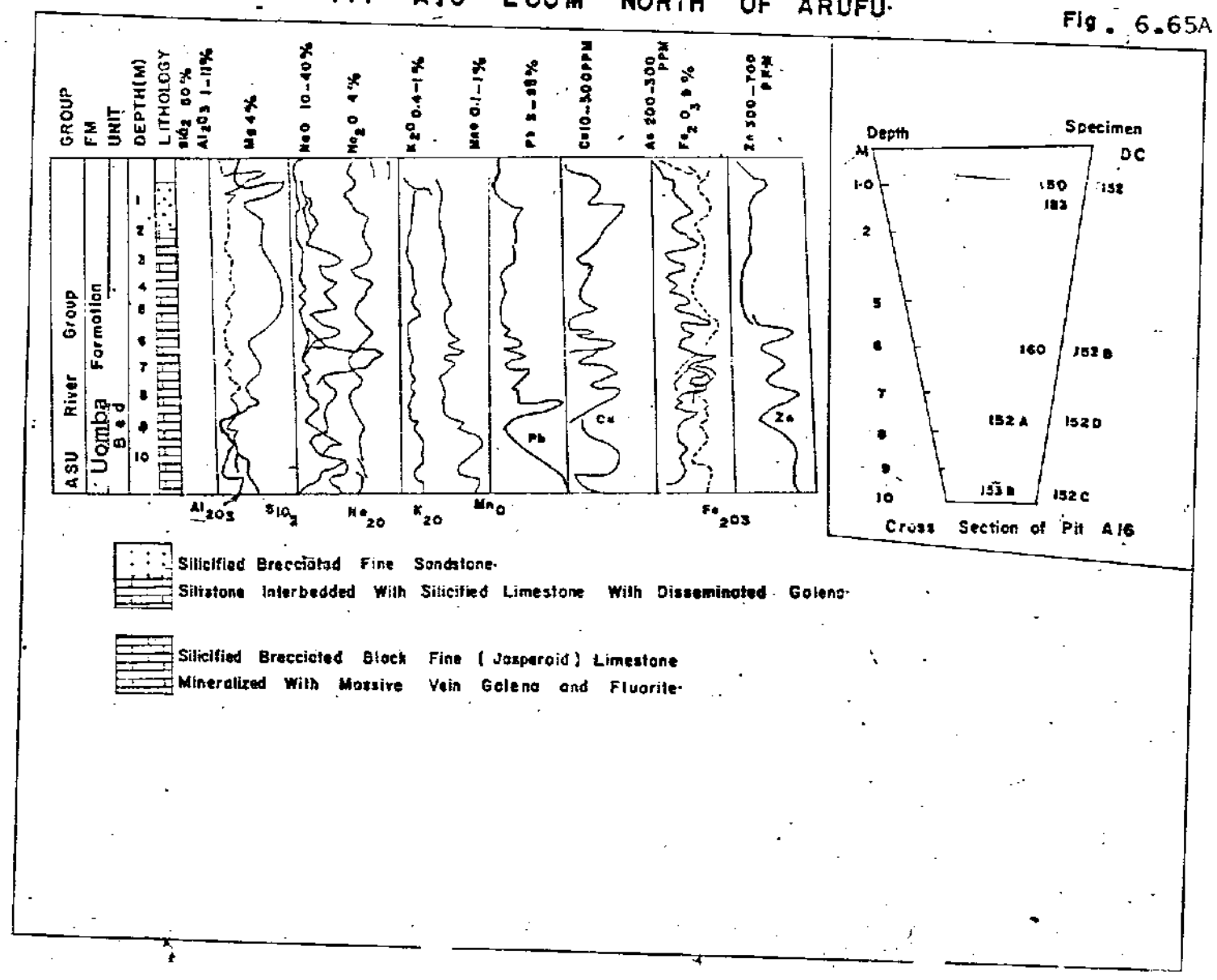
Mn is highest (up to 1.13%) immediately below the mineralized portion (Bed 2) of the Albian marine Arufu Limestone-Shale Formation (Lower Sequence of the Asu River Group), where it is concentrated in the shaly and dolomitic beds of the limestone member of the Uomba Formation, about 2.2 kilometres NNE of Arufu village.

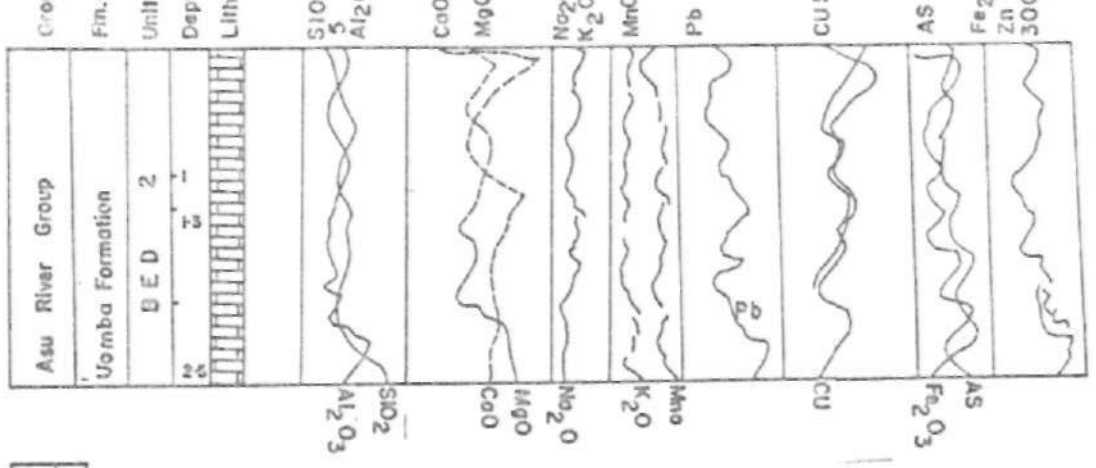
Potassium

The black-green-grey shales throughout the mineralized zone is marked by relatively high K contents (up to 6% K_2O) which parallel their Al contents (up 16.46% Al_2O in the sample DC 254. The K_2O contents throughout the galena deposits of the study area is remarkably constant around a mean value of 1.7% (Table 3.8 Appendix A). The potash content of the feldspathic shaly sandstone sample DC 243 is about 5.16% K_2O while that of the silicified, dolomitized sediments are on the average 1.3%, with a range of 0.4 to 3% (Fig. 6.65C).

VARIATIONS OF ELEMENT ABUNDANCES IN MAIN OLD MINE PIT A16 200M NORTH OF ARUFU.

Fig. 6.65A





Siliceous Limestone mineralized with dissimated Galena.

Fig.6.65B Variations of Element abundances in old mine pit A2-A4: The Disseminated Galena Deposit about 500m NE of Arufu.

G.S.N. 2460W.

The specimen DC 152 is a medium-fine grained dark grey massive, highly brecciated wall-rock sandstone (interbedded with siliceous, brecciated limestone belonging to the mineralized Bed 2 limestones of the Uomba Formation) in the ENE trending massive galena-fluorite deposit at pit A16, 200 metres north of Arufu village. The wall-rock surface is characterized by the present of angular pink K-feldspar fragments (0.4 - 1 milimetre in diametre).

Sodium

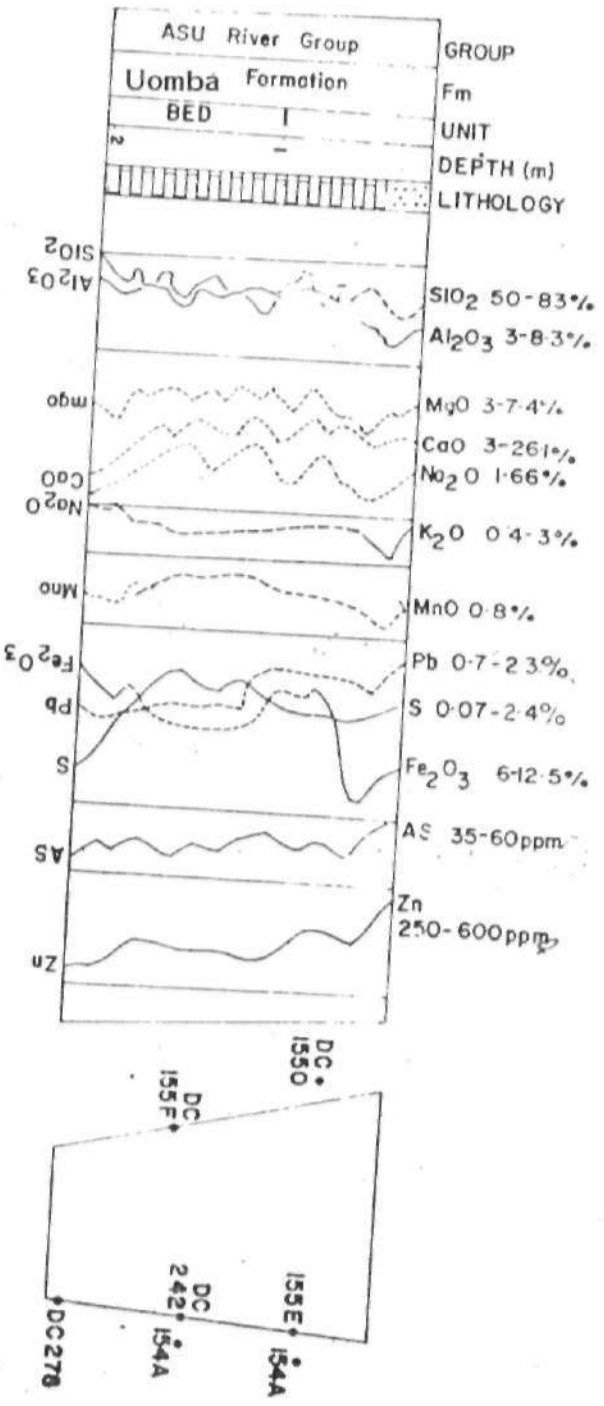
Na (as Na_2O) is relatively very low throughout the unaltered marine Albian sediments ranging from 0.05% (DC 300) to 0.41% (DC 254) in the shales and 0.20% in dolomite-rich siliceous sandy limestone (DC 183). It is high in the altered Albian shales, (up to 4.84%). The values are moderate in slightly silicified limestone (1.7% Na_2O). However, the Na_2O contents are very low in the intensely or completely silicified limestones, rarely exceeding 0.2%.

6.2.4 Interpretation

1. The relatively high Na_2O and low K_2O contents in some samples may reflect secondary alteration during weathering and/or diagenesis. Variations in CaO and MgO are attributable to the obvious variations in the amounts of carbonate. The loss of CaO in the intensely silicified, deformed limestone terrain around the Juwudu Hill, Arufu and Akwana, can be accounted for by the presence of carbonate veins along the fracture or fault zones.

2. The major elements - Mn (as MnO), K (as K_2O) and Na (as Na_2O), Ti (as TiO_2) do not appear to show any significant association with carbonate deposition.

3. The relationship between Ca and Mg in carbonate-rich



Silicified, Fractured Fine Sandstone - Siltstone interbedded with Silicified Limestone.

Silicified Breccioite Sandy Clayey dolomitized Limestone with Crystalline (cubic) Galena and massive Fluorite.

FIG.6.65C VARIATIONS IN ELEMENT ABUNDANCES IN PIT A33-A35 AT JUWUDU HILL FAULTZONE COARSELY CRYSTALLINE GALENA-MASSIVE FLUORITE DEPOSIT, 3Km. SW OF AKWANA.

G.S.N. 2460X

sediments indicates that dolomitization was more intense among the shelly limestone deposited along subsiding oysterbank (DC 283D) to coral bank (DC 289, 292, 283B, 283P) shoreline and probably preceded by silicification. In some of the specimens the silicification was so intense that the limestone has apparently been transformed into JASPEROID-like rocks (DC 264D, 265B, 155B, 149). Limestones close to and/or within the shiny speck and fibrous stringer galena or massive galena-fluorite ore bodies, have variable but high iron contents. There is a progressive decrease in Fe content with increasing distance from the deposit. High iron contents in the limestones is caused by brownish to reddish surface coatings of iron-oxide hydroxide (limonite) on weathered outcrops.

4. The variable lead concentration in the three limestone units (Beds 2, 5, 7) of the Uomba Formation suggests that the metalliferous solutions were not uniformly present over all the subsiding area and it is likely that metal contents were highest in local basins nearest the points of influx of the solutions. On this basis the ore solutions which could have ascended the NNE-SSW parallel fracture zones or faults appear to have been active during sedimentation and they delineate the edges of the local Cretaceous basin. It has been shown in the previous chapters that the NE-SW striking faults of the horst-like basement inliers and blocks as well as the rejuvenated N-S trending Pre-Albian? Faults in the Basement Complex terrain appear to have played significant roles in the concentration of base metals in the study area.

Similarly, the contemporaneous-penecontemporaneous intrusion of doleritic and volcanic bodies into the Arufu Limestone probably aided the accumulation of metalliferous solutions. Under most

circumstances these were dispersed. But the shiny speck and fibrous stringer galena, massive galena and fluorite formed where they were channelled to the surface along deep-seated faults or fractures and emplaced at suitable sites in the Arufu-Akwana area.

6.3 Elements associated with the Sulphide (Galena Mineralization

6.3.1 Introduction

Adams (1954) has shown that mineral veins could be formed by circulating waters that had derived their dissolved materials from the rocks through which they passed. Subsequent mass-balance calculations (e.g. Krauskopf 1967, Billings et al. 1969) have shown that leaching a small fraction of metals present in common rocks, including sediments, may provide sufficient material for generating ore deposits of the Mississippi Valley Type.

6.3.2 Possible Controls on the Distribution of Some Elements Characteristic of the Galena Deposits of the Study Area

1. Sulphur

The sulphide deposits of the project area occur mostly as galena (Pbs). Pieces of barite ($BaSO_4$) have been reported scattered on yam heaps about 300 metres north of Arufu (Bogue 1952).

In the area of study, generally, the carbonate-rich sediments in the Arufu-Akwana mineralized fractures zones contain more sulphide (galena) mineralization than equivalent marine Albian shales. Some parts of the ore grade samples (DC 148, 349E) interbedded with the silicified, dolomitized and brecciated mineralized carbonate (DC 349B-D) contain less than 5% of CaO. Thus the metal-sulphur-oxygen ratios in the various physicochemical environments of hydrothermal ore formation appear to be related in the composition of the precipitated

minerals forming natural paragenetic assemblages in the study area.

Discussion

In his consideration of Sulphur-Oxygen fugacity (Sulphur-Oxygen regime), Smirnov (1976) noted that while the Sulphur regime in hydrothermal ore formation changes in time, the oxygen regime also changes in space. Its concentration or partial pressure rises as the hydrothermal solution ascends. Barnes (1979) has also stated that the availability and oxidation state of sulphur are important in determining whether or not a sedimentary brine could be a potential source of ore-bearing solution. This relationship of the reaction between metal ions and chemically active sulphur or oxygen regime is considered to be of special importance in the formation of hydrothermal deposits (Smirnov 1976). Thus metals capable under normal conditions of yielding both Sulphur and Oxygen compounds like lead, zinc, iron and tim are mainly deposited as sulphides when oxygen contents of hydrothermal solutions saturated with hydrogen sulphide is low and as oxides when the concentration is high (Barnes 1979).

The sulphur was probably derived from bacterial reduction of seawater sulphate to hydrogen sulphide (H_2S) within the still wet, semiconsolidated Albian sedimentary sequence, undergoing diagenesis. The sulphur content might have been enhanced by:

(a) Volcanic exhalation as evidenced by the presence of interbedded lava flows in parts of the marine Albian sequence e.g. the Andyar volcanic lava.

(b) Volatile gaseous matter from the penecontemporaneous doleritic intrusions (DC 178) which the mineralizing solutions probably encountered as they circulated through the (open-fissure) permeable zones in the

Arufu_-Buru area (Fig. 3.21 back pocket).

Hanor (1979) has stated that dissolved sulphate content of subsurface brine is highly variable but usually lower than the 2700 ppm level found in sea water. The reduction of dissolved sulphate to sulphide (H_2S) was probably a dominant process in the early diagenesis of the organic-rich marine Albian sediments consisting of silicified, brecciated fine sandstone-siltstone with slump structure (DC 200-204E), and black-green (in places) pyritic shales interbedded with very fine limestone (DC 280= - deposited in the deeper part of the subsiding basin betweeen Arufu, Anyiin and Akwana (cf. Berner 1971).

Similarly, Hitchon (1968) has shown that H_2S - rich gases characterisitically occur in carbonate sequences, but may have been generated originally in organic-rich bsinal shales. The occurreence of reduced sulphur species as $S0_3$ = in the present-day subsurface fluids (saline springs) of the study area is instructive and important, as sulphur is necessary for the precipitation of galena and sphalerite.

Barnes and Czamanske (1967) noted that in sulphide-rich mildly alkaline brines, bisulphides become progressively important complexing agent for metals, a factor that could enhance both the extraction and transport of lead and zinc.

2. Lead and Zinc

The relatively barren basal sandy shelly Limestone Bed 1 of the Arufu Formation, contains Pb up to 599 ppm in DC 183 (about 2 kilometres NNE of Arufu) but only back-ground Zn (maximum value found was 90 ppm, see DC 183, 287C). This Bed 1 Limestone under underlies the mineralized Bed 2 limestone (DC 229 pit A, Table 3.8, Appendix A; DC 163 pit A5-A6, Fig.5.60, Appendix D) which contains

which contains the shiny speck and fibrous stringer galena deposit, the earliest phase of galena mineralization in the study area.

The plots show that there is a gradual increase of Pb towards the base of the galena deposits (i.e. near the base of Bed 2 Limestone Member of the Albian Arufu Formation), and similarly gradual changes in abundance of this element at the base and top of invididual ore-bodies. They also show that even though Zn is insignificant it also has parallel gradual increase of decrease with Pb. There are considerable variations in Zn/Pb ratios in the ore bodies. The ore beds contain variable anomalously high Pb contents. The specimens DC 163 and 279 contain 2.4% of this metal each.

A number of Pb anomalies occur in the hanging wall (roof) lateritized siltstone-shales for at least two metres above the shiny speck and fibrous stringer galena deposit (DC 163) in NNE trending vertical parallel fractures, about 3 kilometres NE of Arufu (Fig. 5.60, Appendix D). These have widely varying Pb/Zn ratios and the maximum value of Pb found was 1.75% while Zn has a maximum value of only 495 ppm.

In each of the pit samples taken laterally from the galena deposits around Arufu and Akwana Pb anomalies occur near the base of the mineralized Beds of the Uomba Formation.

The most promising ore bodies are found within the finer grained marine arenaceous or sandy carbonate rocks.

Figure 6.66C shows the relationship between lead (Pb) and Fe while Figure 6.66E shows the relationship between Pb and K. There appears to be some lead increase related to the calcareous carbonaceous tabular K-feldspar rich fine-grained shaly sandstones (DC 182) interbedded with flaggy, silty shales, belonging to the Lower Units of

the Late Albian marine Awe Formation (Upper sequence of Asu Group) in the Buru Hill area. These fine grained carbonaceous sandstones and shales host the Buru Hill shiny speck and fibrous stringer galena showings. Outside the ore deposit, there are significant, systematic increases in Pb in these carbonaceous fine grained K-feldspar rich shaly tabular sandstones interbedded with shale (DC 243, 302). In Fig. 6.66C the relatively high iron content of the Bed 3 silicified brecciated siltstone-fine sandstone member (DC 297E) of the Arufu Formation, appears to show some good relationship with Pb increase. The silicified brecciated ferruginized siltstone (DC 297A) is highly mineralized with crystal galena (Pb content = 2.3%, Zn = 605 ppm, DC 297A, Table 3.8 Ser. No. 34; Pit A23). The Fe content (as Fe_2O_3) is 3.35 in this same sample. Fig. 6.66F shows that the carbonate-rich sediments contain more sulphide (galena) mineralization than equivalent marine Albian shales.

The above behaviour of lead in parts of the study area is consistent with its geochemical character in its geochemical cycle. Rankama and Sahama (1949 p. 736) have shown that lead is precipitated in sediments rich in organic remains and becomes absorbed and enriched in hydrolyzate and oxidate sources of the Lead.

In the study area only galena mineralization is present. The absence of zinc mineral either primary or secondary is quite striking. Elsewhere in this work it has been shown that this is probably due to difference in bed-rock geochemistry. If it is accepted that the lead and other base metals were leached from the underlying K-feldspar rich granitic basement and surrounding sediments by hot circulating hydrothermal mineralizing solution which rose along permeable (open fracture) zones within the Albian marine sedimentary pile when the

abundance of ferromagnesium mineral-rich igneous bodies (Olade 1978, 1979; Olade and Morton 1980) and in the Wase-Zurak area to the north, predominantly underlain by hornblende-biotite-pyroxene rich-granitic Basement Complex rocks (Oyawoye 1970). This hiatus can be explained as being due to difference in bedrock geochemistry.

Hanor (1979) has shown that other potential sources of lead and zinc mineral sulphides in sediments include silicate, carbonate (aragonite) and other inorganic phases in the central Mississippi Valley Type Lead-Zinc Deposits. He argues that the isotopic composition of lead in this district is consistent with lead having been derived from the underlying Palaeozoic sandstones and/or shallow Pre-Cambrian basement rocks. Lead in this region may substitute for feldspars and micas during burial diagenesis.

In this respect it is re-emphasised that the Pb isotope age of 620 m.y. (Grant 1971B, Jacobson 1963) obtained from galena in lead-zinc vein cutting Cretaceous rocks in the study area and other parts of the Benue Trough could only be explained by considering it to represent the time at which the non-radiogenic lead (Pb 204) separated from its uranium-host during emplacement in basement rocks. The Benue Valley appears to be marked by a geothermal high which causes water circulation through the basement and sediments. Large volumes of warm circulating water, possibly saline water, can collect minute amounts of base metal from host rocks which are concentrated in subsequent deposition in restricted environments controlled by temperature, pressure, Ph and Eh.

3. Barium

In the farmlands, 1 to 4 kilometres northwest of Arufu,

underlain by flaggy whitish, medium to coarse-grained feldspathic, silicified sandstones of the Awe Formation, pieces of barite (BaS_04) were seen on the yam heaps during the present study, although no outcrop of barite veins was encountered. The possibility of occurrence of barite veins in the area may be proved by a sub-surface investigation. Ba^{2+} high concentration of upto 1700 ppm (DC. 153A in Table 3.8 Appendix A) may be locally important in the above area. The pieces of barite were seen near northeast trending closely spaced vertical fractures containing shiny speck and fibrous stringer type of galena mineralization.

The formation of barite in the above terrain is consistent with the geochemical character of barium in its geochemical cycle. According to Rankama and Sahama 1949) barium (Ba^{2+}, ionic radius = 1.43A) is extensively substituted for potassium (K^{+}, ionic radius = 1.33A) and is thus enriched in rocks carrying potash feldspars eg the underlying Pan African granitic Basement Complex and feldspathic or arkosic sandstones of the Keana and Awe Formations. The migrating hydrothermal solutions probably extracted barium from the surrounding rocks (and enriched in relation to potassium), along permeable (open fissure) zones in the sedimentary sequence. The solutions were subsequently deposited as barite at favourable structural sites or beds controlled by temperature, Ph, Eh. The barite vein deposits in (i) Azara-Akiri-Wuse area (underlain by the Keana Formation) respectively, in 1:100,000 sheets 232 (Akiri) and 233 (Ibi), and other parts of the Middle Benue, probably originated under the above suggested conditions.

In the Azara-Akiri-Wuse area the barite veins (hosted by the Keana and the Awe Formations), it is observed that most of the deposits have some subordinate galena associated with the mineral. In the Ibi

area underlain by the Keana Formation, the barite deposits occur unassociated with any galena.

Ba^{2+} (ionic radius = 1.43A) may replace Pb^{2+} (ionic radius - 1.32A) in some lead minerals. This is consistent with the reported association of galena with barite deposits in the Azara-Akiri-Wuse area of the Middle Benue Trough (Offodile 1976).

4. Fluorine

At Arufu and Akwana crystalline (DC 423) to subcrystalline (DC 265B, 155B) purple fluorite occurs and associated with massive galena (DC 239, 240D, 279A) along ENE trending fracture (fault) zones in silicified, brecciated limestone, in places completely silicified to jasperoid-like varieties (DC 153B, 265B, 149, 262). Fine grained dolerite sills (DC 185, 185A; Table 4.11A-B) are seen about 105 metres north of Arufu workings. The formation of fluorite in this locality is probably related to lime-skarn (Smirnov, 1976) late hydrothermal temperature range 150°C - 200 °C. However, no igneous body was found near the Akwana Galena-Fluorite Deposit, (Fig.5.59 Appendix D). Probably an undiscovered blind igneous body may be nearby (Figs. 3.20 and 3.21 Back folder).

But at Juwudu Hill about 3 kilometres SW of Akwana, a massive whitish grey bedding plane variety of fluorite (DC 242, 278) occurs also in Albian silicified limestone and is associated with the crystal (cubic) galena deposit (pits A33-A35, Fig. 3.21). This bedding plane replacement variety appears to have a probable diagenetic - hydrothermal origin and appears to resemble the Illinois-Kentucky fluorite deposit of central Mississippi Valley (Currier 1944, Hanor 1979).

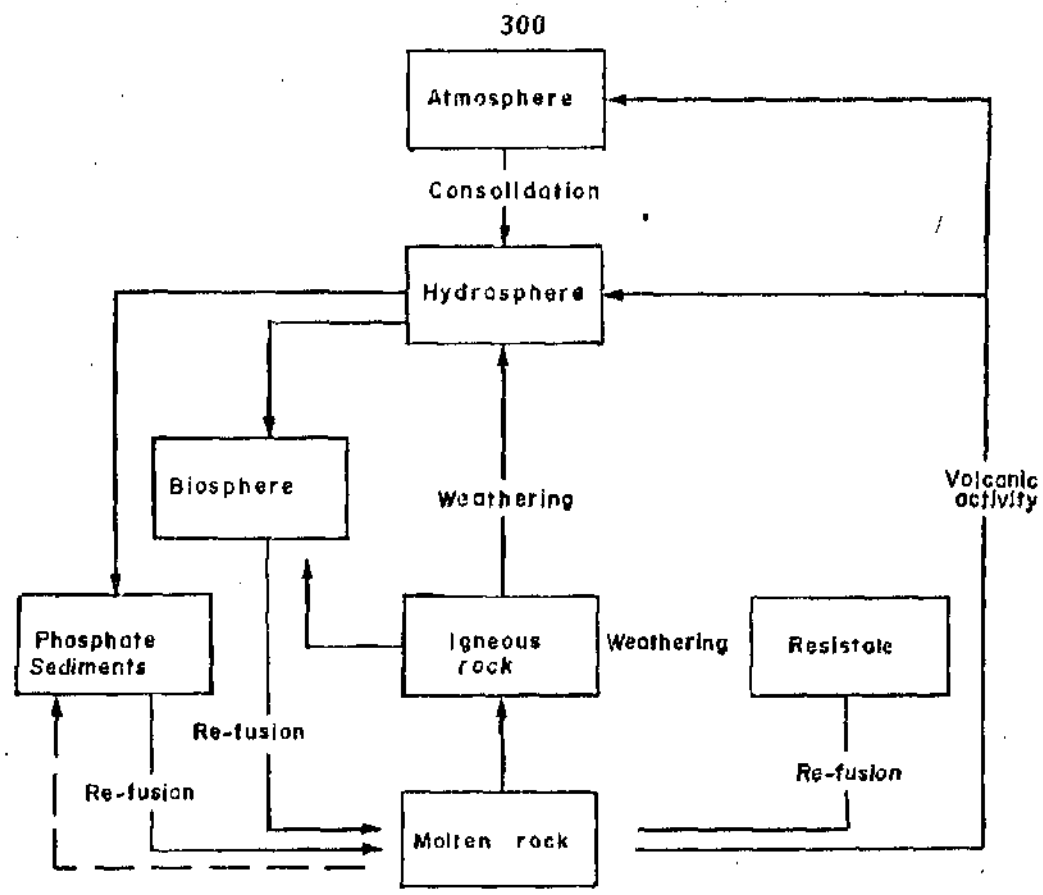


FIG.6.67A: The Geochemical cycle of fluorine (After Rankama and Sahama 1949, P.763)

Rock (Troger 1934)	F Average ppm.
Amphibole Rocks	3,000
Anorthosites, peridotites, pyroxenites	100
Gabbros, Dolerites	300
Diorites, Granodiorites	200
Granites	500
Alkaline pyroxenites	1,500
Melilite Rocks	1,500
Malignitates, Shonkinites	1,500
Nepheline Syenites	800
Monzonites	1,000
Syenites	600

FIG.6.67B: Contents of fluorine (Halogen Element) in igneous rocks.

The present host rock (DC 242, 278; Table 3.8, pit A34) for the crystal galena-fluorite mineralization, is cherty, jasperoid-like in hand specimen. This cherty material consists of silicified limestone interbedded with siltstone-shale containing clastic K-feldspar, accessory turmaline, zircon and altered titanum minerals and crustified ferrugineous material (DC 242, 278, Ser. Nos. 49-50, Table 3.8, Appendix A).

In the later part of chapter 5 of this work it is suggested that fluorspar deposition seems to be genetically related to rifting (in the Arufu-Akwana-Juwudu area) which probably provided access for the fluorine that probably leaked upward from the lower crust or upper mantle along the rift zones (cf. Van Alstine 1976). The geochemical characteristics of fluorine in its geochemical cycle (Fig. 6.67) is consistent with this view.

5. Copper

In general copper follows lead and zinc in the Bed 2 silicified limestone-siltstone-shale member of the Uomba Formation (Figs.5.60 and 5.61, Appendix D); in the ore bodies the abundance of Cu never exceeds one quarter that of Zn. Bogue (1952) has reported the presence of some secondary copper minerals - azurite and malachite- around this locality.

The relative scarcity of Cu or small proportion in the study area (the ore deposits) may possibly indicate the relative instability of secondary copper complexes at low temperatures rather than scarcity of Cu in the depositional environment where the metalliferous solutions were generated.

6. Silver

The reported occurrence of silver lode in the Arufu area (McConnell 1949, Bogue 1952) associated with massive galena-fluorite deposit, has led to postulations regarding the origin and mode of emplacement of the fluorite. McConnell (optcit) believes that the dominance of fluorite and the high values in silver which occur at Arufu recall the ore-fields of the English Pennines and suggest a deeper mezothermal zone (Farrington 1952).

Probably owing to the fact that the reported silver lode must have been exhausted during the mining operations in the area between 1895 and 1925 (McConnell 1949), no traces of native silver were observed during the present investigation. The silver was reported to have been marketed by the native Jukuns for earrings and bangles.

However, geochemical profile soil sampling during the present investigation around the massive galena-fluorite old mine workings about 200 metres north of Arufu at vertical sampling depths of 6 centimetres, 18 centimetres, 36 centimetres showed systematic silver increase in depth (see soil samples S 63-64; Fig. 5.61, Appendix D).

Also the results of stream sediment sampling carried out along River Mai-Tunku about 5 kilometres NE of Arufu show that the silver content was up to 50 ppm. This area is mineralized with disseminated galena in closely spaced parallel vertical fractures within Albian siliceous limestone interbedded with silty sandstone siltstone and grey sandy shale, (see DC 266, 151F, 151H, pit A17-A18; Table 3.8, Appendix A).

Outside the mineralized fracture zones around Arufu, the Ag contents were generally below 4 ppm. The highest value in the mineralized siliceous limestone was 62ppm Ag (in specimen DC 151H,

Table 3.8., Pit A18) at depth level of 2 metres. The Ag contents are proportional to the Pb content of the ore bodies.

7. Cobalt and Nickel

The highest cobalt and Ni values occur within the ore bodies where the maximum values of 60 ppm Co and 90 ppm Ni were recorded (Table 3.8). Figure 6.60A indicates that Co/Ni ratios are commonly greater than 1 in the ore bodies but generally less than 1 in the grey green-black, sometimes pyritic shales and other sediments.

8. Other Elements

A variety of other elements (B, Cr, Li, Mn, Co, Ni, Cu, P, Rb, V, U, Ba, Sr) were selectively determined in addition to Pb and Zn and Ag. In the mineralized zones at Arufu Pb, Zn, Ag show anomaly contrasts of 50.88, 1.26 and 6.91, respectively (Table 6.19A). Cu, Co, Ni, on the other hand, generally indicate low contrasts of less than 1.0, which may reflect a low degree of mineralization Table 6.19A).

The other elements (with the exception of uranium) equally did not show any significant contrasts. Ba high concentration of 800-1700 ppm may be locally important in the northern and SW out outskirts of Arufu.

6.4 Trace Elements in Sulphides

Samples of limestone, siltstones, and silicified, brecciated rocks were visually classified as minerlaized of barren depending on whether or not they contained visible mineralization. The samples were then analysed and contrasts in metal concentration determined between mineralized and barren rocks (Tables 6.19A-B).

Lead shows the highest contrasts of 36.07, 17.58, 50.88 in

galena in limestone, siltstone and silicified siltstones, respectively. In the above samples Zn has contrasts of 0.94, 1.95, and 1.26 respectively. Cobalt and nickel consistently show contrasts of less than 1.0. This is interpreted as indicating very low mineralization of these two metals.

The silicified sandy-silty limestone sample (DC 262C, pit A13, Table 3.8, Appendix D) interbedded with black shale along the E-W trending fracture zone, about 400 metres NNE of Arufu village, contains the highest Ni content of 100 ppm and is associated with irregular pyrite-quartz veinlets in open fissure infillings traversing the outcrop. The identification of nickel in pyrite may suggest that this element may be useful as indicator of bodies of sulphides within the silicified limestone-black shale-siltstone sequence.

Figure 6.54E shows the Co/Ni relationship in soils over the Albian silicified, dolomitized mineralized limestone-shale-siltstone rocks in the Arufu Fracture zone. Figure 6.66A shows a similar relationship of cobalt (Co) to Ni (nickel) in the rocks themselves.

In the light of a review of trace elements in sulphides as indicators of ore genesis (Loftus-Hills and Solomon 1961) the matrix pyrite in the sample DC 279 (see Table 3.8; Pit A2 Serial No. 17) with low nickel (45 ppm) and low Co:Ni ratio of 0.44, is of sedimentary origin whereas the pyrite associated with vein quartz in DC 262C, with a very low nickel content of 30 ppm and higher Co: Ni ratio, is probably of DIAGENETIC origin or possibly, hydrothermal origin.

6.5 Geochemical Drainage Sediment Survey

6.5.1 Introduction

The geochemical Drainage Sediment Survey technique was applied during the present investigation as a method of locating both

TABLE 6.18: RESULTS OF AAS ANALYSIS OF SOME DRAINAGE SEDIMENT AND SOIL SAMPLES.

Sample No.	Locality	PH of Stream	U ppm	Pb ppm	Zn ppm	REMARKS
M921	Juwudu Hill	7.5	75	900	200	Galena-Fluorite
R921	Underlain by Albian		100	100	220	Ore Field.
L921	Silicified (Cherty) Siltstone-DC.341 drained by R. FoFi		90	850	190	
M233	R. Duhu draining	7.5	100	200	30	Near Contact
R233	Slopes South of		120	200	30	with basement
L233	Tseinho Compound 8km.SE of Anyiin Underlain by Albian Silicified (Cherty) Yellow-brown Siltstone DC. 344.		100	250	36	Older granite body.
M145	Rafin Gishiri	7.0	100	100	20	
R145	(Gboloboji)		150	110	22	
L145	draining Slopes 1km. S.W. of Anyiin Underlains by Albian Silicified (Cherty) Siltstone with Yellow-reddish DC. 167		100	197	19	
M12	R. Gishiri Slopes	7.5	45	300	72	
R12	of ridge underlain		80	300	73	
L12	by Albian Silicified fine sandstone-siltstone-DC. 177B 1km north of Arufu		50	295	69	
S63			50	170	50	Residual
S64			70	190	60	Soil with
S65			80	206	70	225 ppm
S66			100	246	80	Cu near DC. 177B.
M128	Igbur	7.0	60	1908	200	Contact
R128	Stream bed		60	1003	210	with Igbur
L128	Underlain by fossiliferous Albian Silicified Siltstone DC. 337.		60	100	202	basement

TABLE 6.19A: METAL VALUES (PPM) OF ROCKS

Sample No.	Pb	Zn	Ag	Co	U	Ni
DC.		Mineralized Limestone				
147	18,000	550	15.5	20	-	17.2
150	14,000	500	16.2	18	-	15.4
272	24,000	580	16.0	21.0	-	17.0
163	24,000	582	16.6	22	-	17.4
163D	24,000	580	17.0	23	-	18.0
		Barren Limestone				
266	280	600	7.6	23	-	17
165	500	582	6.6	24	-	18
275	290	580	6.0	24	-	18
		Mineralized Siltstone				
162	18,000	582	8.8	15	-	14.0
162A	17,000	490	1.5	13	-	14.0
163E	8,000	482	1.0	14	-	14.8
164	2,000	452	1.8	60	-	54.0
		Barren Siltstone				
267	320	138	1.6	152	-	34
268	800	140	1.8	150	-	30
166	800	492	1.8	150	-	30
Mineralized Silicified Brecciated Siltstone in Fracture Zone 160						
160	22,000	324	20.4	20	20	19.0
152B	27,000	194	25.4	10	15	10.4
161	18,000	90	24.5	11	25	11.0
149	16,800	582	28.4	40	20	31.2
		Barren Silicified Brecciated Siltstone in Fracture Zone.				
152	350	100	2	56	2	60
153	346	250	2.4	55		58.3
163A	350	270	2.8	60	4	60.8
163B	345	327	2.7	57	3	58.1
163C	720	328	2.6	60	5	64.8

TABLE 6.19B CONTRAST BETWEEN AVERAGE METAL CONTENTS OF MINERALIZED AND BARREN ROCKS.

	Average Metal Content (ppm)					
	Pb	Zn	Ag	Co	U	Ni
Mineralized Limestone	20,000	553.00	16.08	20.25	-	16.75
Barren Limestone	356.67	587.33	6.73	23.67	-	17.67
Contrast	56.07	0.94	2.39	0.86	-	0.9
Mineralized Siltstone	11.250	501.50	3.28	25.50	20	25.2
Barren Siltstone	640	256.67	1.73	150.67	3.5	31.33
Contrast	17.58	1.95	1.190	0.17	5.71	0.80
Mineralized Silicified, Siltsone in Fracture Zone	22,400	369.33	23.43	13.67		13.47
Barren Silicified, Brecciated Siltstone Fracture Zone	440.25	293.75	2.63	58.00		60.50
Contrast	50.88	1.26	8.91	0.24		0.22

individual galena deposits and the entire mineralized fault zone marine Albian sedimentary terrain of the study area (within the Middle Benue Trough), on a primary reconnaissance basis.

The Drainage survey was divided into two parts:

(a) An orientation geochemical study over a selected area of 7 square kilometres around the Arufu Fracture zone known to be mineralized with galena, as prelude to

(b) routine geochemical reconnaissance survey.

6.5.2 Geochemical Orientation Study

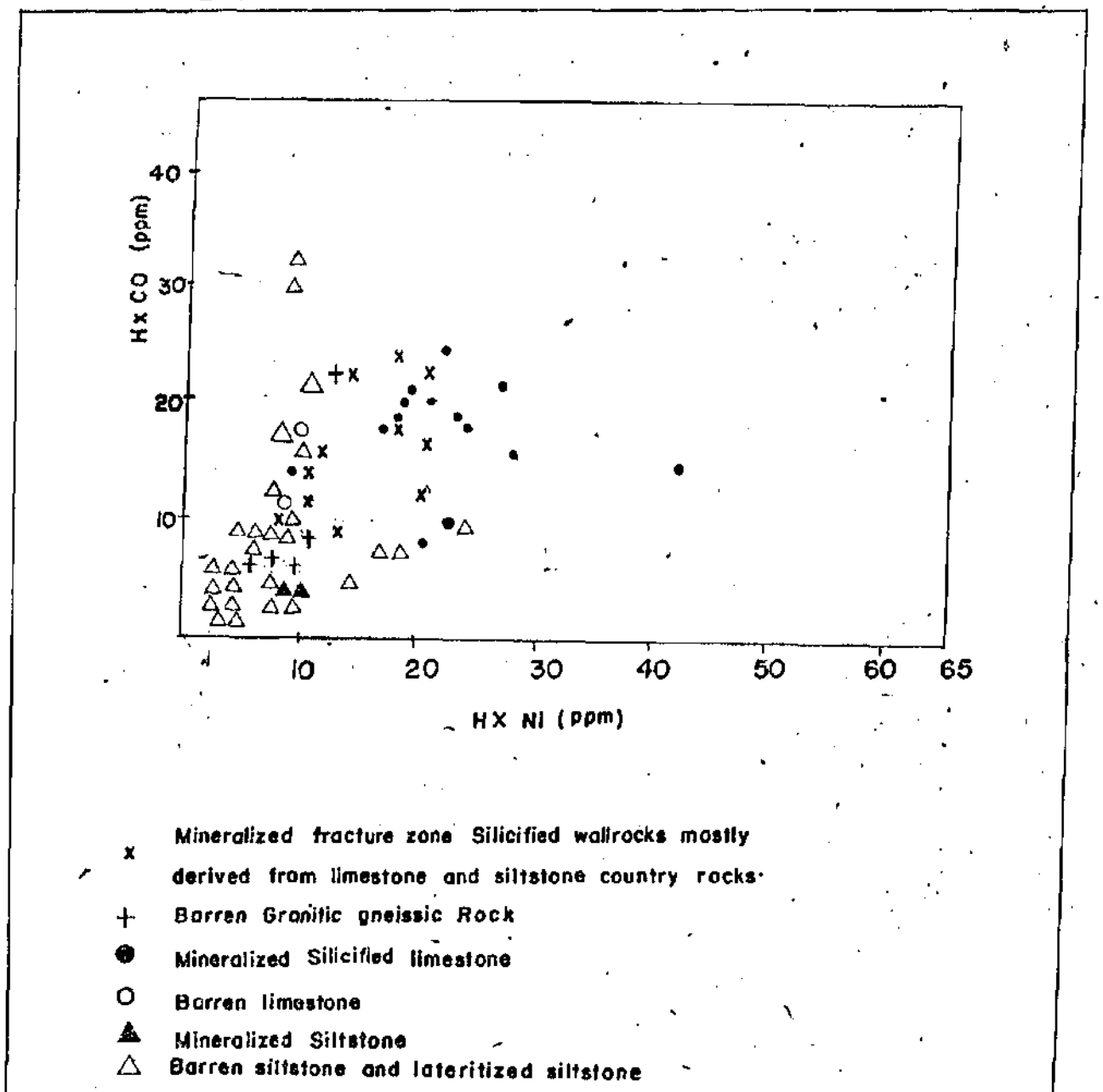
Orientation preparatory to undertaking the drainage geochemical survey was concerned mostly with:

(a) determining the relative merits of sampling water, alluvial sediment and soil from seepage areas associated with the galena showings that provide the source of anomalous pb metal concentrations.

(b) examining the feasibility of geochemical stream sediment technique in prospecting for Pb-Zn and the other associated minerals and to establish optimum sampling depth (in the soil) or sampling intervals (along the streams) that could be adopted on a regional reconnaissance basis in the study area or any follow-up surveys.

The orientation study was carried out over a selected area of about 7 square kilometres around the Arufu Fracture zone mineralized with galena in silicified, brecciated Albian Limestone-black shale-siltstone-fine sandstone sequences and drained by over ten streams.

FIG·6.54E Relationship of Hxco to HxNi in soils overlying the Different rock units in the Arufu fracture zone (at a depth of 12cm) Data on Minus 80mesh size.



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A total of 380 samples of drainage sediments (consisting of middle stream sediments and bank samples), residual soil and groundwater in wells and mine workings, were obtained from mineralized fracture zones, while the remaining 150 samples came from other parts (mostly barren areas).

During the survey, analytical work initially entailed the use of simple colorimetric field tests and the determination of Ph, and later the use of atomic absorption spectrophotometry (AAS) in the laboratory.

Soils

Four main types of soil profile can be distinguished in the study area in relation to rock types, physiography and structure. Thus in the upland area typical soil profiles associated with the brecciated limestone-black-shale-siltstone-fine sandstone sequences, contain, in the upper 42 centimetres, loose textures, yellow or yellowish brown to grey sand, overlying partly indurated lateritic stony horizons. The lateritic horizon passes into a clay-rich, mottled layer which overlies limestone.

Over the basement granitic gneisses and older Granites soil profiles are brown, often sandy, stony and lateritic and generally coarser in texture.

Hydromorphic soils are found in the marshy(FADAMA) areas or where seasonal flooding occurs, and are generally composed of 20 centimetres thick black humic top soil, overlying pallid, mottled sands.

No evidence of large scale soil movements were observed and it is thus assumed that the soils in the area investigated are largely residual.

Analysis and Results

The drainage and soil orientation samples were sieved to minus 80 mesh and digested for analysis by both cold extraction (CX) and Hot Aqua Regia extraction (HX) techniques according to the procedure outlined by the United Nations Exploration Plan No. DP/UN/COL-72-001/10 of 1976, in order to determine which one gives higher anomaly/background contrast values.

The solutions were filtered, and Pb, Zn, Cu, Ni, Co, Ag etc. determined by atomic absorption spectrophotometry (AAS). In both hot extraction (HX) and cold extraction (CX) methods ten percent of all samples were analysed in duplicate and precision estimated. Results indicated a precision better than ± 20 at 95% Confidence Level (Howarth and Thompson 1976).

Comparison of the results shows that the cold extraction method (Table 6.22B) gives higher anomaly/background contrast values than the hot aqua Regia Extraction Technique (Table 6.22A).

Distribution of Metals in Residual Profile Soil Samples

Before embarking upon the orientation study, an optimum sample depth was established by analysing both mineralized and barren samples associated with each major rock unit. The results of the analyses of residual profile soil samples from below a depth of 18 centimetres were not used because of the presence of hard laterite. In the old mine workings to the north (pit A16) and NE of Arufu (Pit A7-9) the lateritic crust attains a thickness of up to two metres passing down to clay-rich mottled horizon overlying limestone. This precluded the procurement of a complete set of samples. During the analyses samples were subjected to both cold (CX) and hot aqua regia (HX) extraction methods and the results compared (Tables 6.22A and 6.22B).

The CX metal contrast values range 73.36 and 81.98 for Pb and 15.13 to 16.72 for Zn, while HX values vary from 16.26 to 20.79 for Pb and from 7.67 to 20.79 for Zn.

Traverses were then carried out in order to investigate the lateral variation in metal contents of soils overlying mineralized fracture zones underlain by the various Albian sedimentary rock units as well as of soils overlying their barren equivalents. The spacing between samples in mineralized fault zones was at intervals of 5 metres from the centre for a distance of 30 metres and at 15 to 20 metres intervals for a distance of 60 metres either side. Soil samples over barren rocks were collected at 50 to 200 metres intervals depending upon the availability of soil.

Threshold and mean background lead and zinc values were estimated from the results of the analyses of soil samples obtained at a depth of 18 centimetres. Table 6.23 summarises the method of calculation in the siltstone rocks. Cu, Ag, Co, and Ni mostly had background values and were therefore omitted.

Distribution of Metals in Drainage Samples

Samples were taken of the silt-sand material in beds of the four streams and their tributaries, two of which were assumed to be flowing through mineralized fault zones and the other two flowing through barren areas. The orientation samples were analyzed for Pb, Zn, Cu, Ag, and Co, and the average contrasts in the metal contents between mineralized and barren samples calculated, Provisional threeshold values were also estimated (Hawkes and Webb 1962, Onuogu and Ferrante 1963).

Figure 6.53 illustrates the metal dispersion trains along the bed

TABLE 6.21A: METAL VALUES (PPM) OF MARSHY "FADAMA" SOILS

Area with high (7.5-9.5) PH								Area with low (6-7.5) PH						
Sample No.	PH	Pb	Zn	Cu	Ag	Co	Ni	Sample No.	Pb	Zn	Cu	Ag	Co	Ni
L8A	5.5	152	1221	18	0.2	13	24	S157	101	12	8	0.02	77	
M5	5.5	223	219	8	1.0	14	16	S158	101	12	8	0.2	8	
L6		418	182	13	0.5	7	12	S159	92	23	8	0.2	10	
L67		440	241	20	0.5	16	23	S127	113	85	8	0.002	10	
L8		399	214	18	0.2	13	24	M34	156	140	8	0.002	18	
L9		395	119	18	0.0215		5	S151	198	32	8	0.002	7	
R6		51	57	8	0.5	8	15	S152	296	17	8	1.0	8	
R7		445	267	8	0.5	18	12	S153	107	12	8	1.0	10	
R8		145	156	8	0.7	12	11							

TABLE 6.21B: CONTRASTS BETWEEN AVERAGE METAL CONTENTS OF HIGH AND LOW PH MARSHY SOILS

	Average Metal Content (ppm)					
	Pb	Zn	Cu	Ag	Co	Ni
High PH marsh soil	296.44	297.33	13.22	0.46	12.56	15.7
Low PH marsh soil	133	41.63	8	0.30	10.88	16.5
Contrast	2.23	7.14	1.65	1.55	1.15	0.9

TABLE 6.21C: METAL VALUES (PPM) OF GROUND WATER

Groundwater in Mineralised Area								Groundwater in Unmineralised area							
Sample No.	U	Zn	Pb	Cu	Ag	Co	Ni	Sample No.	Zn	U	Pb	Cu	Ag	Co	Ni
W1	4	30	7	25	0.3	3	5	W5	30	2	1	20	0.002	2	5
W2	5	30	4	25	0.5	2	4	W6	30	2	1	20	0.25	2	6
W3	1	31	4	25	0.5	3	6	W7	31	8	1	20	0.5	2	1
W4	2	32	4	25	0.5	2	5	W8	32	1.0	1	20	0.25	2	1

TABLE 6.21D: CONTRASTS BETWEEN AVERAGE METAL CONTENTS OF GROUND-WATER IN MINERALIZED AND UNMINERALIZED AREAS.

	Average Metal Content (ppm)						
	Zn	U	Pb	Cu	Ag	Co	Ni
Groundwater in Mineralized area	31.73	3	4.75	25	0.5	2.5	3
Groundwater in Unmineralized area	31	1.7	1	20	0.25	2	3.23
Contrast	1.75	1.94	4.75	1.25	2.0	1.25	1.54

TABLE 6.21E CX METAL VALUES (PPM) OF SOIL PROFILES - LIMESTONE AREA

Profile depth (cm)

					Over mineralized limestone		
Lead	2445	4130	4080	Zinc	180	510	538
Content	355	460	450		515	1020	1020
(CX)	4330	4350	4330		617	730	730
	4425	4475	4450	Zinc	588	811	820
	4595	4750	4700	Content	1495	1495	1550
	4525	4650	4600	(CX)	209	218	240
	3460	3460	3310		1340	1340	1340
Average	3447.86	3753.57	3702.86		706.29	874.86	891.14
					Over Barren Limestone		
	10	46	5		37	51	55
Lead	22	40	40	Zinc	80	100	100
Content	101	101	94	Content	12	12	23
(CX)	35	44	40	(CX)	55	52	52
	92	40	82		53	23	23
	22	16	12		43	76	76
Average	47.80	47.83	45.17		46.67	52.33	54.83
Contrast	73.36	78.48	81.98		15.13	16.72	16.25

TABLE 6.22A: HX METAL VALUES (PPM) OF SOIL PROFILES - LIMESTONE AREA

Profile depth (cm)	6	12	18		6	12	18
				OVER Mineralized Limestone			
	2900	2900	2900		221	512	512
	326	423	423		75	75	86
Lead	2900	2900	2900	Zinc	510	508	510
Content	2900	2950	2950	Content	510	510	510
(HX)	1648	1648	1648	(HX)	612	630	630
	1570	1588	1588		612	620	620
	1550	1570	1636		612	625	625
Average	1970.57	1997	2006.43		450.29	479.14	499
				Over Barren Limestone			
	75	110	94		77	72	67
Lead	23	6	6		17	15	32
Content	208	188	187	Zinc	92	74	67
(HX)	26	26	24	Content	17	17	14
	208	108	108	(HX)	92	92	62
	187	160	160		57	57	50
Average	121.17	99.67	96.50		58.67	54.50	48.67
Contrast	16.26	20.04	20.79		7.67	9.12	10.25

TABLE 6.22B CX METAL VALUES (PPM) OF SOIL PROFILES -

Profile depth (cm) 6	12	18		6	12	18
Over Mineralized Silicified Clastic Brecciated Rock in Fracture Zone						
1855	1910	1910		297	379	379
Lead 4395	4485	4470	Zinc	529	562	594
Content 378	1639	1600	Content	100	110	275
(CX) 133	253	97	(CX)	384	459	614
537	1598	589		22	40	51
Average 1459.6	1777	1733.2		266.4	310	382.6
Over Barren Silicified Clastic Brecciated Rocks in Fracture Zone						
Lead 54	57	50	Zinc	48	55	57
Content 59	59	37	Content	53	53	52
(CX) 85	85	72	(CX)	53	53	57
35	35	60		58	58	70
Average 58.25	59	54.75		53	54.75	61.5
Contrast 58.06	30.12	31.66		5.03	5.66	6.22

of bed of Mai-Tunku stream draining the fracture zone about 5 kilometres NE of Arufu village. Lead is characterized by intense anomalies but short dispersion whereas zinc is dispersed a considerable distance but has a less intense distribution pattern. Cu, Co, Ni, generally indicate low contrasts varying from less than 1.0 to slightly over 1.0 which may indicate a low degree of mineralization in these elements. Provisional threeshold values for lead and zinc are estimated as 220 ppm (pb or Zn) for stream bed sediments and 230 and 260 ppm respectively for the bank sediments.

"Fadama" Soil Samples

The results of the analyses or samples collected from marshy headwater (Fadama) areas are given in Tables 6.21A and 6.21B. It can be seen that the samples from high Ph (7.5-9.5) areas generally have higher metal contents than those from low Ph areas. This may well reflect a higher degree of mineralization in high Ph areas, but further investigation would be required for a confirmation.

Some higher or erratic zinc results are associated with the headwaters of the Utiange stream which drains the Albian siltstone terrain assumed to be barren, about 2 kilometres east of Arufu. In Table 6.21A, sample L.8A has 1221 ppm Zn. Lead also shows high values (1522 pm Pb).

Water Samples (Old Mine Shafts and Wells)

Water samples were collected from older mine pit and water wells in assumed mineralized or barren areas. The Ph of the water was determined at each sample site (Fig. 5.57C back pocket). All the water samples were analyzed for Pb, Zn, Ag, Cu, Co, Ni and Uranium, and the average contrasts between mineralized and barren samples were calculated. (Tables 6.21C and 6.21D). Although all the samples appear

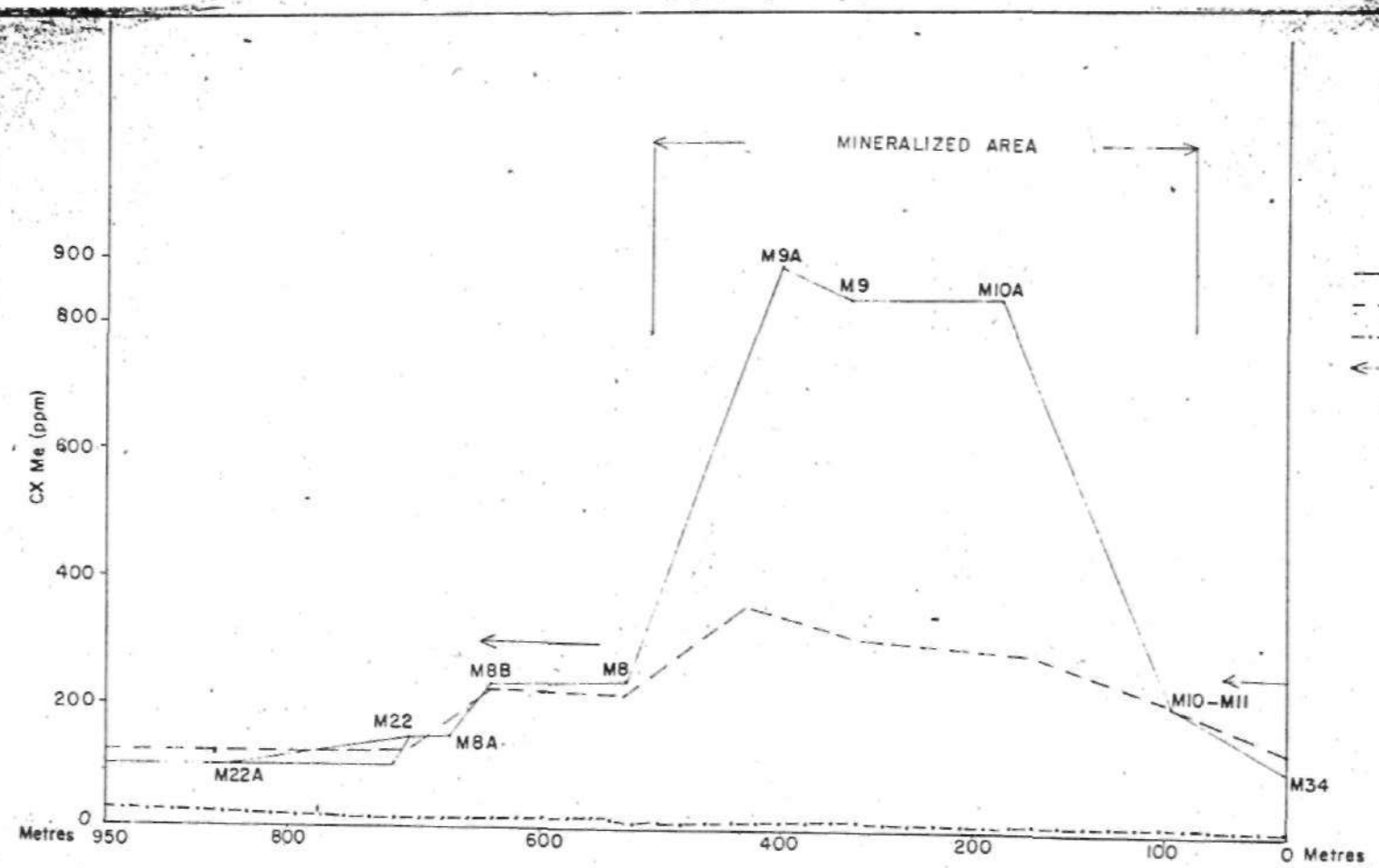


FIG. 6.53 : LONGITUDINAL DISTRIBUTION OF STREAM SEDIMENT ANOMALY ALONG RIVER MAITUNKU. DATA ON MINUS 80 MESH

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TABLE 6.23 ESTIMATION OF PROVISIONAL THRESHOLD VALUES OF LEAD AND ZINC CONTENTS OF SOILS FROM BACKGROUND DATA - SILTSTONE AREA.

Pb Content (ppm)	No. of Observations
10	5
20	6
30	2
40	2
50	16 Mean background
60	2 = 50 ppm
70	1
80	1
90	5
100	4
110	3
160	1 Threshold value (exceeded
Total	48 by 2½ percent of total Observations = 110 ppm
190	1 Erratic high
210	2 Valuesomitted
220	3 from estimation
230	1 of threshold
240	2
270	3
300	3
400	4
1800	3
4000	1

Zn Content (ppm)	No. of Observations
10	8
20	1
30	1
40	4
50	26 Mean backgroun
60	1 = 50 ppm
70	1
80	1
90	1
100	3
120	3
130	1 Threshold valu (exceeded
Total	52 by 2½ per cen of total Observations 120 ppm.
160	2 Erratic high
180	1 values omitte
200	2 from estimati
250	2 of
300	2 threshold
500	1
600	1

to contain only background metal values, reasonable contrasts are indicated between assumed mineralized and barren samples.

6.5.3 Recommedation for Follow-up of the Geochemical Orientation Study

1. The result of the orientation survey showed that by sampling the stream sediments of the study area it was possible to outline geochemical dispersion patterns of Pb and Zn anomalies in streams draining the source rock of areas of the minerlaization. By virtue of the more significant contrasts shown by Pb and supported by field examination it is known that Pb (as galena) is the major sulphide mineralization of the study area. Zn showed local erratic concentrations but no major anomalies as are indicated by its relatively lower contrasts in the various host rocks. Geologically and physically no zinc mineral either primary or secondary has been encountered in any part of the study area.

2. In view of the relatively low drainage density in the main areas of minerlization it would appear that sampling of stream sediments would be more useful for the study of Pb-Zn mineralization on a regional rather than local basis at 500 metres sampling intervals. It was therefore recommended that the follow up survey should consist of a regional geochemical reconnaissance survey covering mostly the Albian to Early Cenomanian marine terrian since field evidence appears to show that the galena mineralization is confined to the above stratigraphic level.

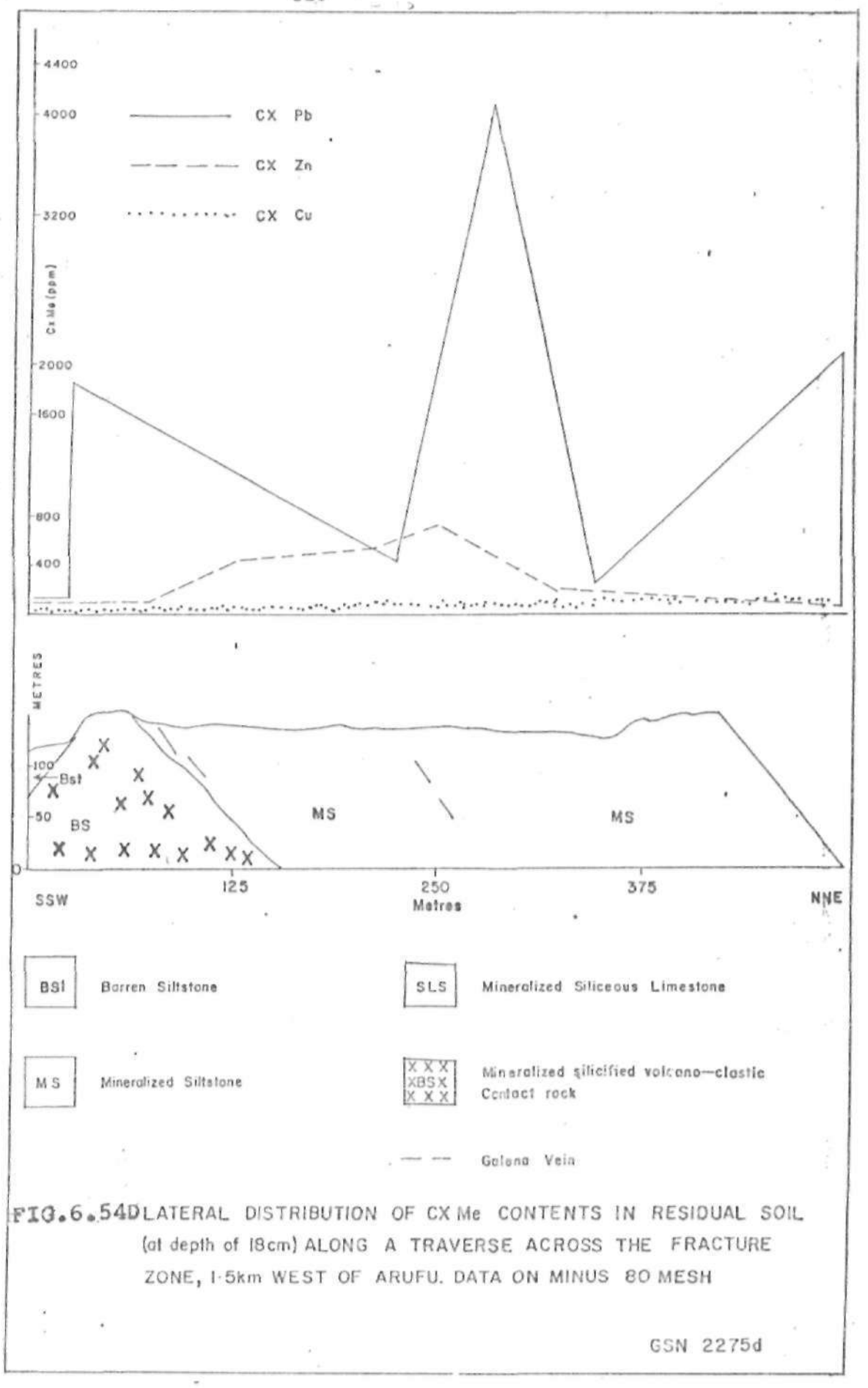


FIG.6.54D LATERAL DISTRIBUTION OF CX Me CONTENTS IN RESIDUAL SOIL (at depth of 18cm) ALONG A TRAVERSE ACROSS THE FRACTURE ZONE, 1·5km WEST OF ARUFU. DATA ON MINUS 80 MESH

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3. The contrasts in Pb and Zn contents between the soil samples from mineralized limestone areas and soil from barren areas, suggest that systematic profile soil sampling and analysis may be helpful in locating the suboutcrop of the galena mineralization (cf. Cole and Rose 1984).

4. From available results, a sample depth of 18 centimetres appears to be the most suitable. However, it is possible that a deeper horizon will give higher metal contrasts, but the presence of hard laterite below 18 centimetres at many sample sites did not permit this to be investigat investigated.

5. Results show that the cold extraction method of analysis (of these samples collected from limestone-siltstone terrains hosting the galena mineralization) gives higher anomaly/background values than the aqua regia method. Consequently the cold extraction method was used for all investigation especially these involving limestone samples.

6.5.4 Reconnaissance Stream Sediment Geochemical Survey

Introduction

Based on the results and recommendations of the geochemical orientation a reconnaissance stream sediment survey was carried out over a selected area of about 1000 square kilometres in the Arufu-Buru-Akwana, and the Abeda-Nyosu-Kente areas underlain by:

(a) Pre-Cambrian-Lower Palaeozoic granitic Basement Complex rocks which crop out as uplifted inliers ridges and down-faulted blocks.

(b) Barremian to Pre-Aptian Pre-Asu River Sediments.

(c) Middle-Upper Albian Marine Asu River Group Limestone-black shale siltstone-fine sandstone sequences.

(d) Cenomanian Keana Formation

(e) Late Cenomanian-Lower Turonian marginal marine Eze-Aku Formation consisting of sandstone-shale-limestone sequences. The sampling interval was 500 metres along the streams that drain either into the Benue River to the north, or the Katsina-Ala to the southwest.

Sampling and Analysis

The usual drainage sampling procedure and instrumental AAS analysis used during the experimental orientation study were adopted, including the taking of quality control precautions, instrumental precision and observations. About 2000 drainage sediment samples were collected. Three samples were collected from each site, one from the Middle of the stream (M-sample), one from each of the two banks the right bank (R-Sample) and the Left bank (L-sample). The bank samples were each collected at the break of slope of the valley. All the drainage sediment samples were analyzed for Pb and Zn and Ph. A few samples were also analyzed for Ag, Cu, Ni, Co. In accordance with the recommendations from the orientation study, all extractions were by the cold extractable method (CX) as outlined by the United Nations Mineral Exploration Plan No. DP. UN/COL-72-001 UN/COL-72-001/10 (1976).

Results and Interpretation

From the analytical data obtained from the results of the instrumental (AAS) analyses the following geochemical maps were prepared:

1. Lead Distribution and anomaly maps (Figs. 5.57A Backfolder,) Backfolder, 5.58 Appendix D)
2. Zn distribution map (Fig. 5.57B Backfolder).
3. Ph map (Fig. 5.57C Backfolder).

The analytical quality controls included duplicate analysis of 10% of the samples and the inclusion of standard samples at regular intervals. Acceptable precision was better than ± 20 at the 95% Confidence Level.

All anomalous samples were re-analyzed and when confirmed by field checks, they were resampled at the original site.

The results of the AAS analysis for Pb (Fig. 6.57A Backfolder) show that:

(a) Lead is characterized by intense anomalies but short dispersion trains, e.g. along Mai Tunku stream. These Pb anomalies are confined to the silicified fault zones in the Albian marine Asu River Group Limestone-black shale-siltstone-fine sandstone sequences. No geochemical lead anomalies were detected outside the fault zones in these Albian marine sequences. This corresponds with the findings of actual geological field traverses through the suboutcrop areas of the showings of galena mineralization around Arufu, Buru, Igbur, Akwana, Juwudu Hills, Ruwabi Hill and the Nyosu-Iyorshager area. This reflects structural control of the galena mineralization.

(b) Only low background values of lead concentrations were detected in both the marine Lower Turonian Eze-Aku Formation terrain at Sufa, Tunga, Keffin Moyin and in the

areas underlain by the Cenomanian Keana Formation around Kente and along Rivers Tsafa and Afia. This is indicative of temporal (stratigraphic) control.

(c) Higher Pb concentrations are registered along fault zones in K-feldspar-rich granitic basement terrain drained by River Kyn and the upper sections of River Duhu in the Mohia-Tyoban-Abeda area.

6.6 Summary

The main base metal sulphide mineralization is galena. Lead has been found in anomalous values in the near surface samples examined in the mineralized zones. Therefore any lead mineralization which reaches the surface should be identifiable since lead compounds are not very soluble in neutral water (Ph = 7.0) though they are substantially more soluble than copper at this Ph.

No zinc minerals were found either primary or secondary. During the analyses zinc was not found in above background values in most of the near surface mineralized or barren rock samples or the profile residual soil and stream-sediment samples examined. Zinc is not normally recommended as a geochemical exploration indicator as it is very mobile under ambient conditions more so than copper. Concentrations considerably exceeding 1 ppm in solutions are stable at Ph 7.0 (Hem 1970) and the leached zinc can travel considerable distances.

The identification of nickel in pyrite in the silicified limestone (DC 262C, Pit A13; Table 3.8) in the mineralized Arufu Fracture zone may suggest that this element may be useful as indicator of bodies of sulphide within the silicified limestone-black shale-siltstone sequences of the study area. Nickel is therefore an indirect indicator of

other base metals. Even within the pyrite the concentration of nickel varies and it is necessary to re-examine nickel anomalies even when the the anomaly-background ratio is low. High nickel values in gossans and and related rocks will almost certainly represent nickelian pyrite.

The geochemical characteristics of fluorine are consistent with the view that fluorspar deposition in the Arufu-Akwana-Juwudu Hill area, seems to be genetically related to rifting which probably provided access for the fluorine that leaked upward from the lower crust or upper mantle along the rift zones (cf. Van Alstine 1976).

The diversity of the chemical associations of the silicified mineralized fault zones of the study area means that it is unlikely that there will be consistent indicator elements for use in prospecting. The most promising elements is Pb, with Zn, Cu and Ni all of possible use.

Thus geochemical reconnaissance stream sediment survey has proved a useful tool in exploring for blind galena ore mineralization in this part of the Middle Benue Trough and has shown that detailed follow-up investigations in suitable lead anomalous zones defined (Fig. 6.57A back pocket) and confirmed by actual field checks should concentrate on the marine Albian (Asu River Group) limestone-black shale-siltstone-fine sandstone sequences proximal to silicified major fault zones, unconformities and areas of facies change.

CHAPTER 7

ECONOMIC MINERAL RESOURCES

7.1 Introduction

Chapters 5 and 6 of this work have attempted to discuss some aspects of the mineralization of this part of the Benue Trough in relation to stratigaphic and tectono-structural controls. The original south Atlantic fracture systems, have opened form the south extending north-eastwards to form the Benue Trough, allowing the seawater to invade the continuent as a narrow channel in this direction. As a consequence marine sediments, mainly clays, shales and limestones have been deposited as for north as the Upper Benue Valley, accompanied by igneous activity and sulphide (mostly lead-zinc) mineralization.

This consideration of the form and probably origin of the Benue Trough in the present investigation has led to far reaching implications and expectations of finding certain types of mineral deposits of possible economic significance. Some of these (e.g. the galena-fluorite mineralization, the Arufu and Akwana Brines and Limestones are already known as occurrences, while others have been inferred from indications that are not always conclusive in their interpretation. Thus one of the most important objectives of this research is to assess more precisely the economic potential of this part of the Middle Benue Trough, and to attempt to fill this information gap about this most inaccessible part of the trough.

In the study area nearly all the geological formations encountered present some economic prospects. The results of the present investigation to further our knowledge on the economic potential of the Middle Benue Valley, are tabulated in Table 7.26.

7.2 Base Metal - Lead

The discussions in chapter 5 of this work indicate that the sulphide sulphide of lead (Galena) is apparently the only base metal of economic importance in the study area. With the help of more detailed systematic geological field traverses supported by stream sediment geochemical survey, the more extensive galena speck and fibrous stringer showings characterized by large reserve, but low grade (tenor = 2.3% to 2.7% Pb), have been discovered at other localities apart from Arufu and Akwana.

No zinc mineral was seen either in a primary or secondary form. Gangue minerals associated with the galena deposits include pyrite and quartz. The massive galena is typically characterized by large vughs. Anglessite and carbonates (cerussite) are seen in oxidized zones and old mine dumps.

With systematically planned underground development involving diamond drilling the present situation which has led to the abandonment of the mines since 1925, production may become more economic especially with a continued surge in the prices of lead in the world market (Ford 1980).

It is pertinent however, to re-emphasize the main practical constraints in galena mining in the study area, chief of which is the small size of the ore bodies with their characteristic erratic distribution. Also, the sedimentary wall rocks-silicified, brecciated limestones, shales and siltstones (with anastomizing fractures) at Arufu Akwana, are generally too weak, coupled with the 2 to 3 metres thick lateritic layer that usually forms the roofs of the ore lodes. These are likely to create support problems and mining hazards.

TABLE 7.26: ECONOMIC POTENTIAL OF AKWANA STANDARD SHEET 252, MIDDLE BENUE TROUGH

	MINERAL	REMARKS
1.	Galena (Base metal)	
	(i) Galena specks and fibrous Stringers	Large reserve but low grade (tenor = 2.3 to 2.7% Pb), deposits.
	(ii) Massive Galena	High grade (tenor = 4.5% to over 90% Pb), but low tonnage deposits.
	(iii) Crystal Galena	Large reserve but low grade (tenor = 2.4% to 3.6% Pb) deposits.
2.	Building Materials	
	(a) Limestone	Several large deposits with little or no overburden. Moderately good quality limestone suitable Portland Cement manufacture.
	(b) Stone aggregates	For building and road construction, provided by the crystalline granitic basement rocks and Cretaceous dolerite dykes and sills and Tertiary basaltic volcanics.
	(c) Clay and laterite	
	(d) Special Material Fluorite	Fluorite at Arufu, Akwana and Juwudu Hills associated with galena mineralization as follows: (i) Subcrystalline brownish purple fluorite associated with massive galena at Arufu and Akwana.

TABLE 7.26 (CONT'D)

	MINERAL	REMARKS
		(ii) Massive whitish grey fluorite associated with crystal galena at Juwudu Hill.
3.	Chemical Minerals Salt	Salt from brines at Arufu, Akwana, Nwannan (Buru Hill), Dzahan, and Yatiev.
4.	Water	For water supply.
	(a) Surface water	Abundant from springs sand streams during rainy season. But most of the springs and streams are seasonal.
	(b) Groundwater of meteoritic origin.	Good prospects from the Cretaceous Sandstone formations. But porosity and storage capacity of aquifers are reduced by silicification.

7.3 Industrial Minerals

7.3.1 Limestones

Limestones occur at several stratigraphic horizons of the Uomba Formation (the Lower Sequence of the Asu River Group), namely:

(a) Bed 1 Shelly Limestone which forms the basal part of the Arufu Limestone member of the formation about 2 kilometres NNE of Arufu village (DC 283, 183, 287C).

(b) Bed 2 Fine-medium grained silty limestone. Variously silicified along ENE-WSW to E-W trending fractures zones around north-eastern outskirts of Arufu and River Mai Tunku. In the Tseishan area it occurs over a wide area on both limbs of the Tseishan anticline.

(c) Bed 5 Limestone is similar to Bed 2 and appears to be its cyclical equivalent. It crops out at Akwana where it is highly silicified and brecciated and hosts massive galena and fluorite deposits (DC 155B, 349B, C, D) and is in places interbedded with siltstone and black shale (DC 349E). Around Ruwabi Hill, about 15 kilometres SE of Arufu the Bed 5 Limestone forms an extensive deposit (DC 373-375).

(d) Bed 6 and 7 Limestones consist of very fine compact sublithographic calcilutite limestones which form

(i) the Tseho Deposit about 4 kilometres SE of Akwana village (DC 280 and (ii) the Ibom-Nyam Deposit (DC 347).

The various overburden thicknesses, and suboutcrop areas of the various limestone deposits of the study area are shown in Table 7.27A. These deposits are characterized by overburden varying in thickness from zero to two metres. The overburden consists of laterite and clay. Thus the limestone units of Uomba Formation can be

exploited by open cast mining.

The lithological and chemical similarity between the Ibom-Nyam calcilutic limestone (DC 347, Table 3.9) located in the extreme southern portion of the study are (Fig. 1.1) and Bed 7 of the Yandev Limestone in the adjoining sheet penetrated by GSN borehole Nos. 3005 and 3006, indicates that the Ibom-Nyam limestone of the study area may be a northward extension of the Yandev (Gboko) Limestone (cf. Onuogu 1963). In the study area the Ibom-Nyam Limestone Deposit is considered as belonging to Bed (Unit) 7 of the Arufu Limestone Member of the Uomba Formation.

7.3.2 Extraction and Exploration of the Limestone Deposits of the Study Area

Tables 7.27A and B show the localities of the limestone deposits and their comparative chemical characteristics. Exploratory drilling will be required to estimate the minimum and maximum proved ore reserves.

The various deposits have the advantage of high topographic expressions in ridges and hills standing 10 metres above the surrounding plains and river valleys which usually dissect them. So the problem of probing their overburden depth and outcrop areas is greatly minimized. For example, the Katsina Ala with its characteristic straight and rectangular bends in the Tsekur-Nyam area (in the SW quadrangle of the sheet), flows in a NW-SE direction, dissecting the Ibom-Nyam Limestone Deposit. The outline of Limestone body can easily be determined by standing on the banks of the river. Similar situations exist in the Tseishan Deposit, the Juwudu Hill, Ruwabi Hill and Arufu Limestone Deposits.

TABLE 7.27: OUTCROP LOCALITIES OF THE VARIOUS LIMESTONE UNITS

LIMESTONE UNIT	FORMATION	SUBOUTCROP AREA HECTARES	OVER - BURDEN THICKNESS	LOCALITIES
Bed 1: Shelly Limestone	Arufu Formation	3.3	1metre	2km NNE of Arufu
Bed 2: Sandy Limestone	Arufu Formation	3.3	2metres	In the outskirts of Arufu, Tseisham.
Including S Siliceous Brecciated Varieties				
Bed 5: Silicified Brecciated	Arufu Formation	3.3	2.5m	1km west of Arufu.
Bed 6: Sandy Limestone with Siltstone-shale interbeds	Arufu Formation	2.0	2m	Around Ruwabi Hill
Bed 8: Fine Sublithographic Calcilute Limestone (Arufu Limestone).	Arufu Formation	2.7	2m	Juwudu Hill, and Ibom.
Bed 7: Siliceous-Calcilutite Limestone (Arufu Limestone	Arufu Formation	5.7	2.2m	Nyam Area.
Akahana Limestone	Akahana Formation	8.5	2m	Akahana-Jangeri Area.

TABLE 7.27B: Comparative Chemical Composition of the Different LIMESTONE UNITS

COMPOSITION	BED 1 Arufu Limestone	BED 2 Arufu Limestone	BED 5 Arufu Limestone	BED 6 Arufu Limestone	BED 7 Arufu Limestone	AKAHANA Limestone
	3 Samples wt%	20 Samples wt%	15 Samples wt%	3 Samples wt%	4 Samples wt%	3 Samples wt%
$CaCO_3$	79.9	48	20.9	88.0	87.1	87.2
Weighted $CaCO_3$ average	82.7	53.06	60.0	89.5	88.05	88.0
$CaCO_3$ Maximum	4.20	11.0	11.0	1.5	1.5	1.20
SiO_2 Minimum	6.80	5.0	7.0	3.7	3.88	3.70
Weighted SiO_2 average	6.815	5.03	12.75	4.75	4.83	4.725
SiO_2 Maximum	6.83	6.01	18.5	5.8	6.0	5.85
Average Impurities other than $MgCO_3$	13.15	40.865	42.8	8.95	10.51	12.10
$MgCO_3$ minimum	4.10	1.15	3.4	1.4	1.38	0.80
Weighted $MgCO_3$ average	4.15	6.075	7.2	1.45	1.44	1.0
$MgCO_3$ maximum	4.20	11.0	11.0	1.5	1.5	1.20

Thus pilot mining of the "Open Cast" type can easily be carried out. These limestone deposits can support a Portland cement factory.

7.4 Stone Aggregates

The materials most generally favoured for the production of crushed building stone aggregates and road ballasts are the crystalline (metamorphic and igneous) rocks, and the harder more compact forms of limestone.

In the study area, crystalline basement granitic and gneissic rocks occur as inliers, ridges or down-faulted blocks separated by deep narrow sedimentary basins. These are well distributed in both the accessible or less inaccessible part of the sheet. There are nine of such crystallines basement horst-like inliers in the study area. There are also over ten of Cretaceous axial NE-SW trending doleritic dykes or sills which occur associated with the crestal areas of folds in the Arufu-Buru-Ikwe area. Finally extensive basalt lavas form flat-topped and conical hills of both near the banks of the Benue in the northern portion of the study area.

The metamorphic rocks, granites, dolerites and basalts are good raw materials for stone aggregates.

The extensive flood plain and sand bars on both banks of the Middle Benue and Katsina-Ala Rivers are sources for sufficient quantities of sand for use as constituent of concrete. The problem may be that of accessibility and transportation because of roads and also the apparent inavigability of the two rivers.

Clay

There are interbedded thick clayey horizons in the

Cenomanian Ibi Continental sandstone and the transitional lowermost part of the Eze-Aku Formation in the Kente-Afia and Tsekur-Tseihom areas. Huge quantiites of clay in the Akahana Shale-Limestone Unit in the Sufa-Kefin Moyin area, in the northern parts of the sheet may be tapped if access roads are constructed. The clay will form a good component of the limestone in establishing a Portland Cement Factory.

Laterite

Laterite layers of varying thickness (2-3 metres) form overburden "roofs" of the ore bodies in the galena bearing silicified limestones at Arufu and Akwana.

Lenticular nodular laterites are seen to cap the slopes of flat topped basaltic lava hills and, thick, wide contact zones respectively between the basal Cretaceous rocks and the Pre-Cambrian basement crystalline rocks in the inlier-ridge -host areas separated by local narrow sedimentary basins in the Abeda-Tsejande and Arufu-Igbur areas. The laterites associated with basaltic lava hills, occur as a residual weathering product on partially or wholly decomposed basalt and other basic doleritic rocks.

Laterite makes an excellent material for foundations of roads and buildings, and has been extensively used for building some of the older style of houses.

7.5 Fluorite

In the study area crystalline (cubohexohedral) to subcrystalline, purplish to pinkish fluorite is associated with massive galena (in E-W trending fracture zones) in silicified, brecciated limestones at Arufu and Akwana (DC 423). The massive bluish-whitish grey type occurs (mostly in the Juwudu Hills to the south and

SE and SW of Akwana) associated with crystal galena(DC 242, 278).

In the first crystalline variety, the wall rocks of the host limestones have been strongly silicified and brecciated and punctuated with veinlets of massive galena and subcrystalline, brownish purple fluorite (DC 155B, 265B).

Fluorite (CaF_2) is used mainly as a flux in the making of steel, in the manufactures of opalescent glass, in enameling cooking utensils, for the preparation of hydrofluoric acid. Small amounts of crystalline fluorite are used for lenses and prisms in various optical systems.

In the Nigerian context, fluorite will be required in the iron and steel industry, so the Akwana-Arufu area should be further investigated. This should include underground development involving systematic diamond drilling.

Field experience shows that in the seven reported occurrences the fluorite/galena ratio is consistently 4:1.

7.6 Sandstone

Tabular sandstones predominate in the upper part of the Late Albian to Early Cenomanian Awe Formation (Upper Sequence of the Asu River Group). The Ibi Sandstone contains several large sandstone bodies with moderate iron content.

Sandstones also occur in the transitional Tsekur sandstone-clay-shale sequence (Lower part of the Eze-Aku Formation). It also forms the predominant lithological units throughout the Keana Formation in the Ibi-Kente area.

Also beds of compact arkosic grits or feldspathic sandstones (DC 227) occur in the basal section of the Pre-Asu River

continental sediments in the Amafu area with a persistent strike length of over 8 kilometres.

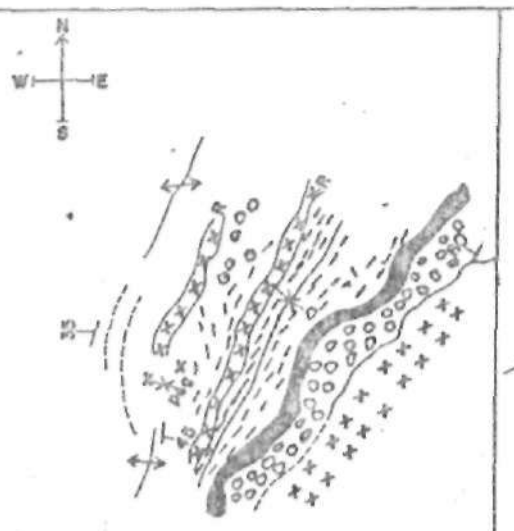
The Tsekur Sandstone-Shale Sequence forms the basal parts of the Eze-Aku Formation in the Andyar-Agbenke area. This sequence appears to have high permeability except where it may be highly cemented towards the crest of the Arufu anticline. Several water-bearing sand bodies and possible trap rocks occur within its outcrops encountered in the interfluvial area between Rivers Ngo and Katsina-Ala in the south-western boundary of the sheet. Other structures capable of acting as good aquifers and as possible traps for uraniferous solutions are shown in Fig. 7.69A-C.

7.7 Chemical Minerals

Salt

Saline waters occur at about eight localities in the project area, as are mentioned in chapter 5 of this work. However, these saline waters cannot be related to any particular marine sedimentary formation within the Albian Asu River Group in which they are confined, even though the Late Albian - Early Cenomanian Awe Formation appears to be most favourable environmentally. During the present investigation, out of the eight occurrences of saline water, four are encountered in the Middle-Upper Albian marine Uomba Formation (Lower Sequence of the Asu River Group) while only two are located in the Late Albian marine Awe Formation (the Upper part of the Asu River Group).

The salt springs of the study area are all associated with closely spaced parallel fractures in the axial areas of folds with NE-SW trending axes. Many of these fractures are masked by superficial cover around the salt ponds. In the Nwannan and Dzahan saline



FIG·7·69C. Pre—ASU River exposure at Tseagu Hill .Km 75—79 · Makurdi Yandev Tarred road

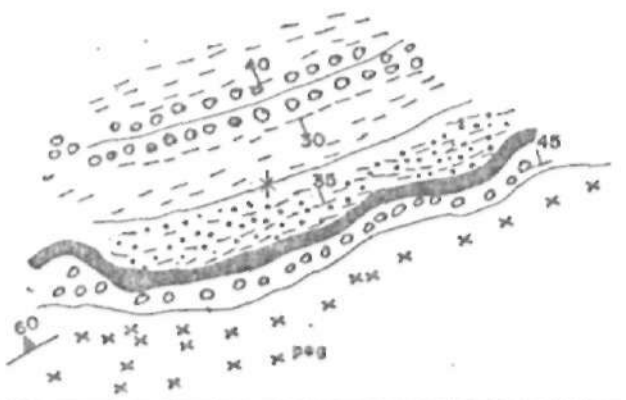
LEGEND

R = Felsic or Rhyolite Vein or Dyke

= Possible zone for U accumulation



FIG·7·69B Pre—ASU River sandstone exposure at Tseagodo Hill road cutting. Km 12 Yandev—Katsina—Ala road



FIG·7·69A Amatu sandstone member (Pre—ASU river Basal continental Grits and Sandstone) Km 22—30 along Katsina—Ala—Wukari Tarred road

LEGEND

Mudstone — clay — siltstone

Felspathic med—coarse sandstone

Arkosic—felspathic—conglomeratic sandstone

Granitic and gneissic basement .

GSN 2455G

springs, the saline water appears as seepages along the bedding plane of the Awe Formation. The flaggy finely laminated fissile shales are interbedded with tabular well-bedded sandstones.

At several localities the saline water issues copiously from the underlying shale-sandstone beds as seepage along bedding planes, particularly in interbedded shales and sandstones. In the Yatiev and Juwudu hilly districts the saline waters are freely flowing at the surface even on the relatively elevated topography along NE-SW trending fractures, giving rise to pools of salty water which form important local sources of salt.

The Yatiev local industry has a substantial production of 100-120 tonnes. It is no exaggeration to state that quantities of salt issuing is solution from the more active salt water along the Benue Trough are such that they could supply all of Nigeria's present domestic and industrial requirements (currently running at over a quarter of a million tonnes yearly), provided an economic energy source is available to evaporate the large quantities of water involved. In the Lower Benue Trough natural gas wells have been reported at different localities within reasonable proximity to some of the salt springs e.g. the Ameri salt pond which is about 20 kilometres south of Abakaliki. The gas could be piped to the saltpond. But in the study area (Middle Benue) and in the Upper Benue, such a possibility is not known.

7.8 Water

7.8.1 Surface Water

Most of the rivers draining into the Benue and Katsina-Ala Rivers in the study area, are perennial, but the flow greatly diminishes during the dry season. Water for domestic or industrial

needs or for irrigation, could be impounded to give a constant supply.

7.8.2 Ground Water

Wells which tap groundwater of probable meteoritic origin are widely used in the villages for domestic water supply. Where these complement the surface perennial streams they appear to be adequate for purely local needs e.g. around Arufu, Akwana and Afia.

In the SW exreme of the study area where there are probably water-bearing sandstone bodies within the transitional Tsekur Sandstone-clay-shale Sequence (Lower part of the Eze-Aku Formation), there are good prospects of supplying the area with ground water.

But in the central Tyoban-Tsekwen-Abeda area underlain by Crystalline basement Older Granites, the inhabitants face acute water supply problems when the few surface streams e.g. the Kyiin and the Uamadu, become intermittent and are found as puddles.

The ground water confined in the marginal fracture zones separating the Cretaceous sediments from the Pre-Cambrian crystalline Basement Complex rocks, can be tapped by sinking boreholes along the NE-SW trending fracture zones.

Even in the Albian Sedimentary terrain, the porosity and permeability of the sandstone and siltstone-shale sequences are in places, greatly reduced by silicification. In the Arufu-Akwana silicified fracture zones the porosity of the sediments has been reduced.

7.9 Hydrocarbons

There may be some possibility of finding hydrocarbons in the Middle Benue Trough based on the geological data obtained from the present geological mapping carried out in the study area similar to those obtained in the Lafia Awe area by previous workers

(cf. Offodile 1976). The stratigraphic traps mapped in the study area consist of sand lenses, areas of facies change (in the Uomba, Awe and Eze-Aku Formations) and deep narrow sedimentary graben basins separating parallel basement ridges. The Arufu anticline (Fig.7.70) like the Keana anticline (Offodile 1976), present possible structural/ stratigraphical oil trap settings, similar to the Sunset-Midway classical example illustrated by Russel (1951).

Source rock materials for hydrocarbons consist of deposited under marine to brackish-water, reducing environment in which organic matter could accumulate, decay and be conserved. These consist essentially of oil shales and some argillaceous limestones. In the study area (in Middle Benue Trough), shales of the Asu River Group (made up of the Uomba and Awe Formations) and the Eze-Aku Formation show a lot of these characteristic. At Ortesh in the Lafia-Awe area of the Middle Benue a marly limestone outcrop in the basal units of the Eze-Aku Formation is known to be highly fossiliferous, with an abundant fauna consisting essentially of Ostracods and foraminifera, has been reported as containing 93% $CaCO_3$ and 1.3% total carbon (Offodile 1976). Petters and Ekweozor (1982) observed that the organic rich (0.5 to 7.4% total Carbon) dark grey and black laminated shale of the Nkalagu Formation (lateral equivalent of Eze-Aku Formation), contains in the main, dwarfed low-diversity benthic microfauna.

The Asu River Shales are in places olive green to bluish, signifying possible anaerobic conditions in which they were deposited. Calcareous horizons occur within the various massive formations, and from all indications it would appear that adequate conditions for the accumulation of oil existed at various times during the sedimentary history of the study area.

The Keana Formation consists of sandstones of fluviatile origin. The Pre-Asu River sands are also of continental origin. Other sandstones bodies occur within the Awe and Eze-Aku Formations and act as reserviour rock. The permeabilities are generally high except in the Keana Formation and the Pre-Asu River Sediments which get highly compacted towards the crest of the Arufu anticline.

Oil has been struck in the Eze-Aku Formation of the Anambra Basin in the Lower Benue. The occurrence of oil seepages in the Awgu shale (Reyment 1965) may indicate that the Awgu shale (TOC = 0.7% wt) has enough quantity of organic carbon required to generate both oil and gas. The TOC (Total Organic Carbon) of the Awgu shale is in excess of both the empirically derived 0.5 wt % TOC minimum content required to designate a bed, a potential source bed as well as the known 0.88 - 2.0% range for acknowledged source rocks.

The sedimentary formations appear to have suffered only limited deformation as a result of episodes of igneous activity in the region. Contact metamorphism is confined to the immediate vicinity of the intrusives and volcanics. So it is doubtful that the igneous activity in the area would have dissipated any hydrocarbons that could have formed.

7.10 Barytes (Barite)

In the farmlands, 1 to 4 kilometres northwest of Arufu, underlain by flaggy, medium to coarse-grained feldspathic silicified sandstones of the Awe Formation, pieces of barytes were seen on the yam heaps during the present study, although no outcrop of the veins was encountered. The pieces of barytes were seen near northeast trending closely spaced vertical fractures containing shiny speck and fibrous stringer type of galena mineralization.

SCHEMATIC SECTION SHOWING STRATIGRAPHIC TRAP-POTENTIAL OF THE CRETACEOUS STRATIGRAPHIC UNIT IN THE ARUFU ANTICLINE

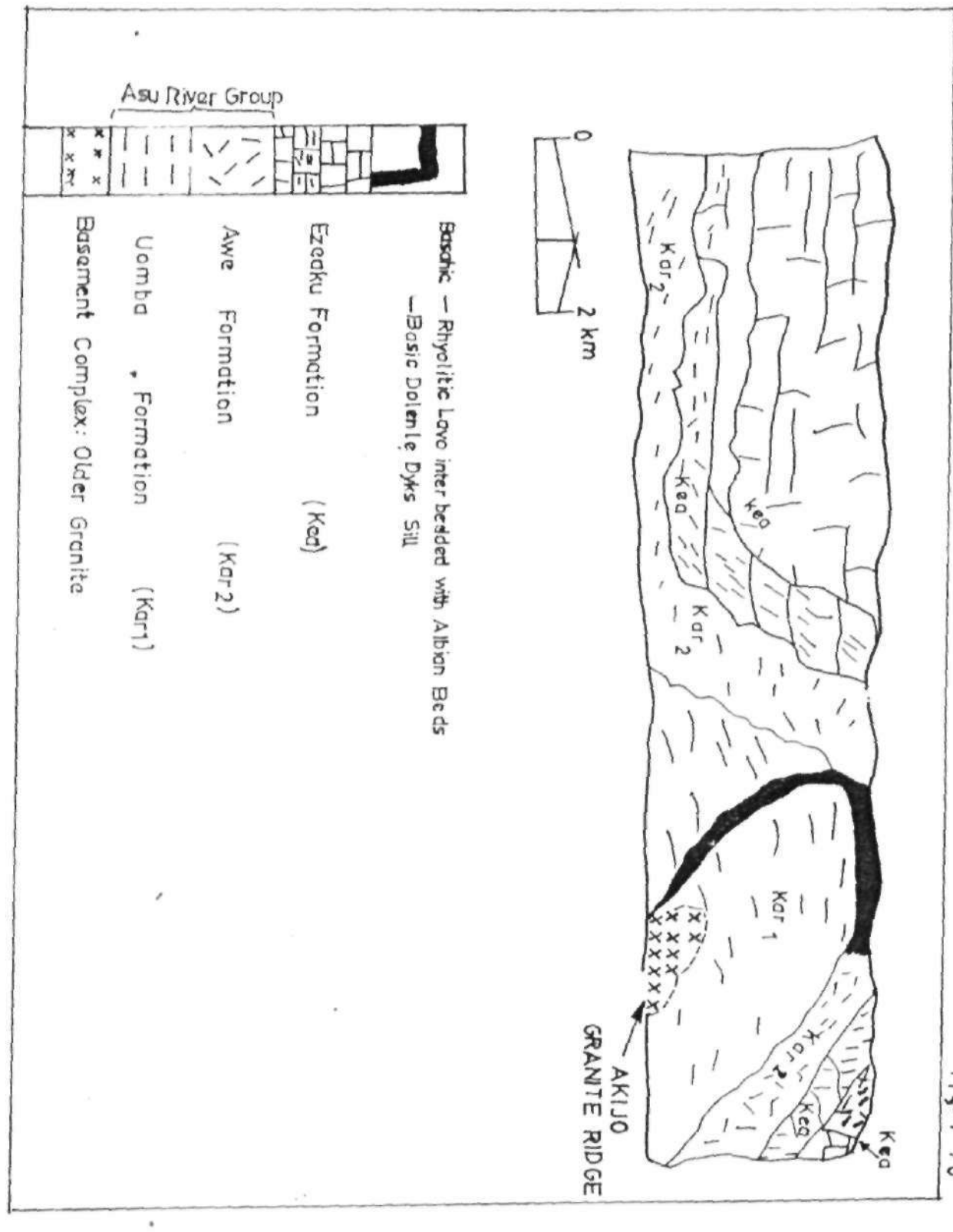


Fig. 7·70

However, in the Azara-Akiri-Wuse area of the adjacent Akiri Sheet 232, important and massive north west or northeast trending occurrences of barytes veins are found associated with subordinate galena. The Azara deposit forms a ridge containing three barytes veins, each about 0.6 to 1.0 metres thick, and dipping 70° to the south and about 1 kilometre long. Offodile (1976) quoted an undated GSN Report 1266 as putting the estimated reserves at 40,000 tons, in depth of 20 metres in this locality. The barytes veins generally are found, invariably traversing the Keana Formation. More recent mapping and subsequent drilling of the deposits by the Nigerian Mining Corporation in Azara area showed a probable reserve of 730,000 tonnes. The barytes is relatively pure with specific gravity ranging from 4.05 to 4.44, and should meet the bulkier requirements in the oil industry as a weighting agent in rotary drilling mud fluids.

In the Ibi area (within the adjoining Ibi Sheet 233) the barytes deposit studied consisted of three veins in coarse-grained, buff-coloured feldspathic and arkosic sandstones (of the Keana Formation) about 0.8km east of Ibi Town. The three veins had a general strike of 195° and averaged 0.9, 0.46 and 1.3 metres. The barytes was exceptionally pure with consistant specific gravity of 4.5. Gangue minerals were virtually absent. The Ibi deposit is not associated with galena mineralization, and should meet some specialized needs like the paper and paint industries.

In the Keana area (within Lafia Sheet 231) important barytes deposits occur at Chiata, 24 kilometres southeast of Keana. At Aloshi 14 kilometres north of Keana, the occurrences are mixed with quartz veins at shallow depth, but the barytes appears to increase in quantity with depth in the Tokura and Zam prospects, the barytes

veins trend in a north-easterly direction, with a strike length of more than 1 kilometre each. Subsurface investigation involving rotary drilling is recommended for precise appraisal of the Middle Benue barytes potential.

CHAPTER 8

DISCUSSION, CONCLUSIONS AND SUMMARY

8.1 Stratigraphy and Structural History

The present investigation has led to the eatablishment of the following startigraphic sequence in the study area, within the Middle Benue Trough.

(cf. Offodile 1976, Kogbo 1981):-

Late Cenom to Lower turonian	Eze - Aku Formation		Akahana Shale-Limestone Unit (Marine) Tsekur Sandstone-Shale Sequence (Marine).
Cenomanian			Keana Formation (Continental).
Albian to Cenomanian	Asu River GP		Awe Formation (Marine) Uomba Formation (Marine).
Pre-Aptian	Pre-Asu River Sediments		Basal conglomorates, sandstone and clays with Tsseagu Hill Rhyolite sill (113 ± 3m.y - Aptian) (Cont.)
Lower Palaeozoic to Late Pre-Cambrian		Basement Complex	Pan African Older Granite Series
Middle Pre-Cambrian			Metasediments: quartzo-feldspathic and Biotite-Muscovite Gneiss
Lower Pre-Cambrian			Gneissic Complex: Granitic Gneiss

The boundary between the Uomba Formation and the Awe Formation appears to be transitional just as that between the Tsekur sandstone-Shale Sequence (Lower part of Eze-Aku Formation) and the Akahana Shale-Limestone Unit (upper sequence of the Eze-Aku Formation). Both boundaries have been shown to be marked by the interfingering of the contact beds (Fig. 1.1, back pocket).

There was probably a brief regression or mild deformation episode during the Cenomanian which restricted the marine only to the southern part of the Benue Trough (the Calabar Flank) and ushered in Continental conditions in the Middle and Upper portions. In the study area this is represented by the various continental sandstone bodies in Kente-Wukari-Ibi area which constitute the Keana Formation. The Cenomanian deformation was perhaps very local (Nwachuku 1972) and may have originated due to reactivation of the basin along basement faults (Hoque and Nwajide 1985). The Keana Formation is believed to be a lateral equivalent of the Bima Formation.

The chemical composition of the Tseagu Hill Rhyolite appears to be similar to the Late Alkaline rhyolites of the Jos-Pankshin Younger Granite ring complexes (Jacobson et al. 1977), associated with continental rifting during the Early Cretaceous proceding the continental separation of South America from Africa and the final opening of the Atlantic Ocean (Wright 1968, 1976,) Grant 1971, Reyment and Tait 1972, Olade 1975). The present investigation also shows that the East African rift alkaline rhyolitic rocks are largely similar to those of the study area but only differ in being poorer in silica (Bailey 1964).

The alkaline affinity of the magmatism in this region suggests that the evolution of the Cretaceous Middle Benue rift structure involved mainly vertical crustal movements (Olade 1978, 1979),

probably related to the on-shore extension of the equatorial oceanic fracture zones along the northwestern and sotheastern margins of the trough (Benkhelil 1982).

Reconstruction of the structural evolution of the study area suggests the following sequence of events:

(a) Mantle upwelling leading to uplift, doming, and thinning of the crust.

(b) Fracturing, rift-faulting differnetial block subsidence and graben formation.

(c) Emplacement of alkaline felsite volcanics (alkaline rhyolites, trachytes) of Aptian age in the Pre-Asu River Continental sediments, followed by intrusion into the block-faulted Albian marine Asu River Group.

It is thought that this sequence of events may have been repeated in a cyclic manner during the early Cretaceous with intercyclic structural deformations as evidenced by the various cycles of igneous activity and periods of faulting and folding in the area of study (cf. Ofoegbu 1984).

It has also been shown that the various cycles of dolerite dyke intrusion possibly re-used old structural lines of weakness and rift faults in the underlying basement block. The absence of rocks from an Oceanic crust involved in the structures confirms the intracontinental nature of the rift structure. Involvement of transcurrent movement in the fracture zones is against any important extension of the crust and consequently the creation of oceanic crust below the Benue Trough during part of the Cretaceous is unlikely (cf. Wright 1976, Benkhelil 1982).

The study concludes that the Cretaceous history of the Benue Trough is closely related to the early stages of the South Atlantic opening. The Middle part of this intracontinental rift structure (as represented by the Arufu-Akwana-Ugba area), formed by the extension on land of equatorial fracture zones, was controlled during its initiation and further evolution partly by wrench (shearing) tectonics, but more importantly by the local tensile tectonics which contributed to the generation of graben structures. The stress field propagated along the Oceanic fracture zones was subjected to readjustment consecutive of changes of relative lithosperic plate motion and the heterogeneities of the Basement Complex rocks (cf. Masse 1983). The old zones of weakness (within the basement) which were re-used by the extensions of the fracture zones, eased the formation of the graben structures.

The predominantly NE-SW or NNE trending conjugate fault systems of the study area display both sheared (mylonitic, slickensided) crushed zones and brecciated en echelon crushed zones. The latter apparently reworked the former. The fault structures and lineaments of the basement inliers and their reactivation and extension into the Cretaceous cover appear to be major features in the dynamics of the trough. These reactivated structures have the same characteristic e.g. an intense deformation preceding and/or contemporaneous with deposition along these faults. It can then be concluded that the NE-SW trending conjugate fault systems which match the continental extensions of equatorial oceanic fractures and which are intersected and offset by NW-SE trending traverse wrenching faults, played an

important role in the origin of the Middle Benue Trough as they controlled the general framework of the Middle Benue in alternating uplift (uplifted horst blocks) with subsidence (graben basins) (cf. Maurin et al. 1986).

The significance of the deeply penetrating Cretaceous marginal and axial basic intrusive rocks in relation to the galena mineralization and their possible relationship to the medial gravity anomaly and rift structure of the Middle Benue Trough, is explained. It is suggested that the concentration of these features along the trough axis as well as the structure of the underlying basement (the crust beneath the trough is probably thinner than beneath the flanking crystalline basement rocks) supports the hypothesis of an axial fault zone associated with the evolution and propagation of the rift structure. The series of ridge areas may also represent areas of uplifted basement or basic intrusions at shallow depth.

8.2 Model for Formation of Evaporite Beds

While the probability of rock salt having been deposited contemporaneously with the sediments may not be unlikely, it is possible that local short-lived arid climatic conditions might have arisen during the subsequent history of the strata allowing local deposition of salt from brine. Such deposition would be most likely to occur within the spaces between the grains making up the sandstones, resulting in a salt-impregnated sandstone. During the present investigation no observations were made to indicate where such deposits were likely to be found.

In this respect it is interesting to note that in the on-going drilling project for salt by a private company (owned by Chief Onwuka Kalu) in the Okposi area of Imo State, underlain by the Asu River

Group shales and siltstones (within the Southern Benue Trough), a thin layer of saliferous mudrock and siltstone has been intersected at a depth of 535 metres (Ekpechi 1985, Pers. Comm.). In the GSN 1980-1982 drilling project aimed at striking at a salt plug or salt dome around Enyigba and Odagire Edda, to the South of Abakaliki, Anambra State (Fig. 8.71) one borehole was sunk at each locality and was bottomed at 207 metres and 407 metres, respectively. These areas are also underlain by the Albian Asu River Group Shales and siltstones. Each of the two GSN boreholes passed through several brine horizons without intersecting any salt plug or salt dome. The saliferous mudrock and siltstone encountered at a depth of 535 metres in the borehole at Okposi may represent short-lived arid climatic conditions that periodically existed in the Benue Trough in the Early Cretaceous during which bodies of saline water were probably isolated during the transgressive-regressive cycles and were subsequently evaporated and brine precipitated. The brine probably impregnated the pore spaces of the clays and silt which compacted to form the saliferous mudrock and siltstone.

If large quantities of water flowed into the Benue Trough continuously or intermittently during the Albian and Lower Turonian transgressive cycles, they would be lost by evaporation thus forming evaporite salt beds. But such a situation would connote a prolonged arid climate during the Cretaceous times in the study area and other parts of the Benue Trough, which appears to be at odds with the lush green vegetation required to make the upper Cretaceous Coal Measures common in different parts of the Middle Benue. However, a migration of this portion of the earth's crust from an arid climate to a wet zone is conceivable (cf. Van Breeman and Bowden, 1973). Agumanu (1986) believes that warm humid tropical climate and probably short-lived arid

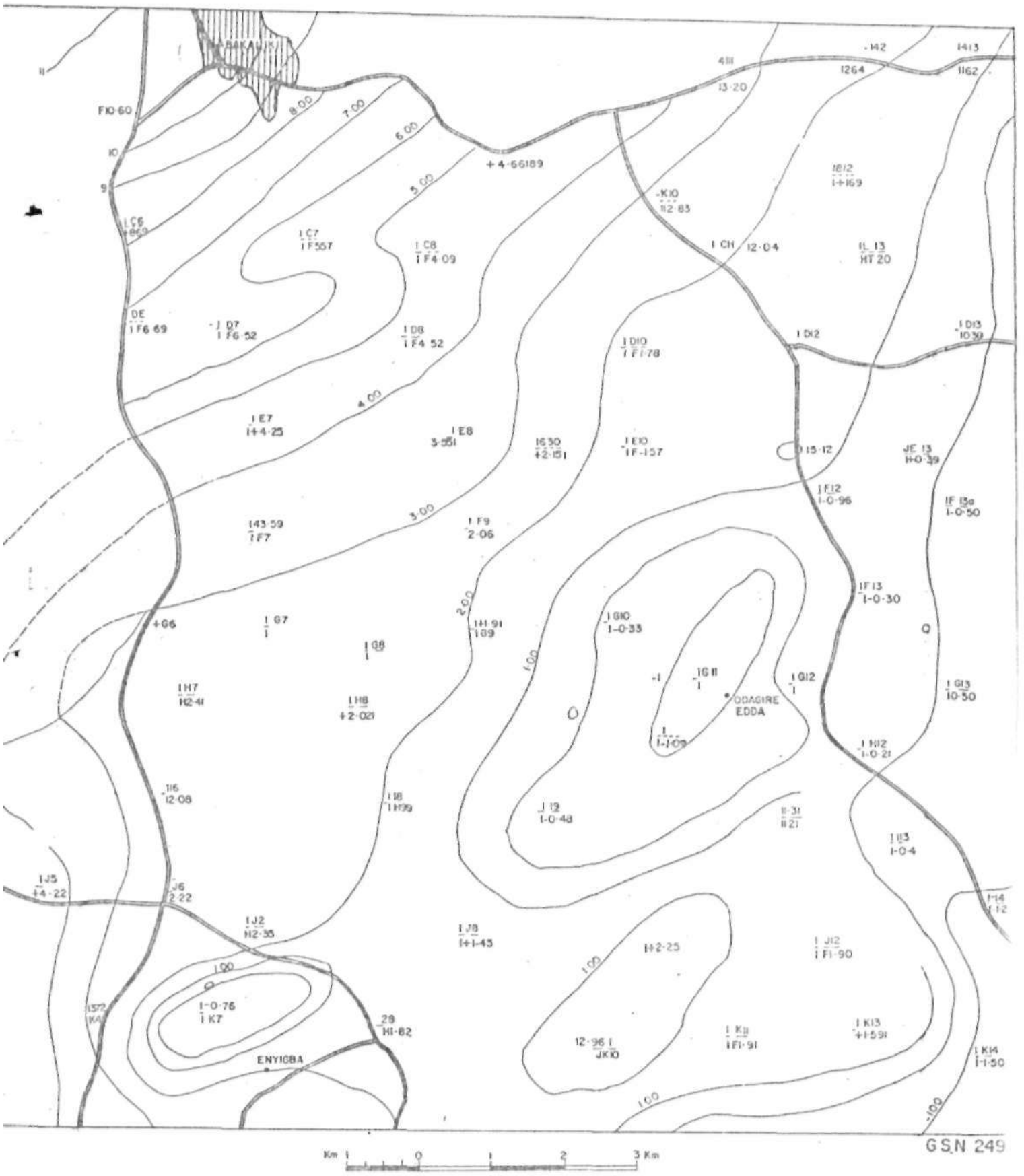


Fig. 8.71 Bouguer Anomaly Map of Aboine River Valley. After Okafor (1973) and Nwachuku et al. (1973).

conditions characterized the Benue Trough during the Cretaceous times.

The present study has shown that saline waters or saliferous horizons occur in many parts of the trough. However, they cannot be related to a particular stratigraphic unit of known age, although they were not encountered in any marine sediments younger than Late Albian to Early Cenomanian in the study area. The brine occurs in the two formations of the Asu River Group, and also in the transitional zone between the underlying Pre-Asu River sediments in the Yatiev area and the basal part of the marine Asu River Group.

B.3 Origin and Evolution of the Benue Trough and Relationship to Mineralization

In the last decade much data have been accumulated so that the general nature and mineral potential in relation to stratigraphic and tectono-structural controls of the Benue Valley may be much better understood. For example different models have been proposed by different authors to explain the origin, evolution, their relationship in the mineral potentials of the Benue Trough as an intracontinental rift structure. These include:

1. A simple rift valley (King 1950) - derived purely from geomorphology
2. A geosyncline with folding involving the basement (Lee 1952, Stonely 1966) - owing to lack of marginal faults and the tremendous thickness of the sediments in the trough.
3. A combination of a rift valley and a geosyncline (Cratchley and Jones 1965) - based on the results from a regional gravity and geological survey of the whole trough.
4. A rift whose origin is related to the separation of South

America from Africa (Wright 1968) - deduced from the fact that the sediments along the Atlantic Coast of both continents get younger northwards.

5. A short-lived spreading ridge or subduction zone (Burke et al. 1970, Grant 1971, Burke and Dewey 1974) - based on geological ground mapping and photogeology.

6. A failed continental rift or aulacogen associated with the break up of South America and the Continent of Africa (Burke and Dewey 1974, Olade 1975, Burke 1977) - based on the tectonic pattern of the trough.

7. A zone of an "on-and-off" Cretaceous hot spot (Olade 1975) - based on the tectonic pattern of the trough. It is a model involving thermal plume (hot spot) which causes crustal rifting in the form of three armed rifts (Burke and Dewey 1973, 1974, Van Breeman and Bowden 1973). These authors suggest that thermal plumes can cause uplifts and rifts and result in triple junctions where they are overlain by continental lithosphere that rests on the asthenosphere. Invariably, according to them, two of the rifts open while the third fails thus providing channels for great rivers. They indicate that some of the failed arms are economically important as they contain mineral deposits including oil.

Adighije (1981) has suggested that the positive gravity anomaly which is observed from residual gravity interpretation in a narrow belt within the floor of the Lower Benue and its distal southwest end could be due to a dense anomalous body or mantle diapir of density 2.90×10^{3} Kg/m^{3} with an average width of 10 kilometres down to the Moho.

His interpretation also suggests that this body increases in width and thickness from north to south in the Lower Benue Trough thus imparting a wedge-shaped geometry to the basin (cf. Hoque and Nwajide 1985).

These workers also believe that the application of Y-shaped triple junction rift model RRR (Burke et al 1970) or RRF (Grant 1971) to the break-up of the Afro-Brazillian plate in early Cretaceous, best explains the final configuration of the Benue Trough (Burke et al. 1970, Grant 1971, Burke 1976, Olade 1975, 1978, 1979, Wright 1981). In this model it is envisaged that the two arms of the RRR rift system each separated to form the South Atlantic Ocean, and the third, the failed (aborted) arm is represented by the Benue Trough as an aulacogen (Olade 1975, Chorowicz 1983).

8. A model by Benkhelil (1982) which attributed the origin of the Benue Trough to the on-shore extension of equatorial fracture zones (probably initiated due to old lines of weakness in the underlying basement) along the northwestern and southeastern margins of the trough during the separation of South America from Africa in Early Cretaceous. This model envisages that transcurrent movement along deep-seated faults of the basement is responsible for the intracontinental rift structure of the trough. Benkhelil proposes that after a period of extension characterized by the sedimentary infilling of the trough and igneous activity, the trough was turned into a folded "Chain" through a short phase of compression by a "convergent strike-slipping mechanism." He believes that

during the extension phase the various graben structures in the upper and middle parts of the trough were generated or initiated (cf. Allix and Popoff 1983). According to this view the Benue Trough was a result of the juxtaposition of pull-apart basins generated along sinistral wrench faults.

The presence of marine silicified Albian siltstones of the Asu River Group (DC 268) in the Arufu area may be indicative of some shearing movement on the Lower Cretaceous rocks probably as a result of strike-slip faulting in a NNE direction. During the present investigation the slickensided surfaces were identified to be associated with D-(Diagonal, Wrench, Shear) sets of fractures. Benkhelil's conclusion appears to be supported by the data of Maurin et al. (1986) which underlines the important role played by the major sinistrial wrench faults as they control the general framework of the Upper Benue Trough. Field evidence in the present study shows that brecciating regime was later superimposed on the sheared fault zones and reworked them (cf. Maurin et al. 1986). Both field and laboratory studies of the data from the project area indicate that it has been tensional through most of its history (Nagy 1976, Wright 1976, 1981, Ngangom 1983).

8B. In opposition to Benkhelil's model (1982), Maurin (1987) suggests an alternative genetical hypothesis which considers the Benue Trough as a major within - plate discontinuity which controls the opening of the southern domain of the south Atlantic together with the Parana

Fault Zone in South America during the Barremo-Aptian. This hypothesis takes into account the diachronic opening of the South Atlantic. According to this view the southern domain of the southern Atlantic opened from the Barremo-Aptian whilst the equatorial domain (eg. Gulf of Guinea) opened from the Albian.

9. Allix and Popoff (1983), Hoque and Nwajide (1985) propose a tectono-sedimentological evolution model of the trough as an aulacogen based on the close relationship between tectonics and sedimentation in the basin, as discussed in chapter 4 of this work.

10. The model of Rift Basin formation proposed by Salveson (1978) involving mostly rift faulting and graben generation, vertical crustal movements (Olade 1979) and subsidence of down faulted basement crustal blocks.

The geological, structural and geochemical data accumulated during the present investigation appear to support 1,2,4,6,7,8,9 and 10 part 3, but run at odds with 5, mainly for the fact that the geological and geophysical data (Ajakaiye 1981, Benkhelil 1982) appear to indicate that the Benue Trough is not underlain by oceanic crust.

In proposing a structural model for the Arufu-Akwana-Ugba district the principle favoured is that throughout the history of rifting and graben generation the strain effect produced by both the application of tensional or compressional stresses is fracturing or fissuring at right angles to the direction of application of that force (Mohr 1978). The Early Cretaceous basic (dolerite) intrusive bodies within the rift zones and graben-like structures have mildly alkaline

rather than tholeiitic affinity, suggesting that the Middle Benue Trough appears to have been mostly ensialic during its evolution (Olade 1978, 1979, Wright 1981; Ajayi and Ajakaiye 1981) characterized by vertical crustal movements with little or no lateral separation. The open fracture (fissure or space) filling mode of occurrence of the galena mineralization, including the Vughy cavity filling, is believed to attest to formation under tensional regime.

The movements and force involved in the formation of the Middle Benue rift structure are shown to be essentially those of uplift (Arttybashev and Kogbe 1974) and tension, developing parallel NE trending fractures and faults followed by differential adjustments (Wright 1981, Allix and Popoff 1983, Nwachuku 1985). The continuation of these movements among the faulted blocks of basment rocks during and after deposition of sediments is also demonstrated. These resulted in both folding and faulting of the strata (Wright 1981, Hoque and Nwajide 1985).

The fault structures and lineaments of the basement inliers in the study area and their reactivation and extension into the Cretaceous NE-SW (as lead-zinc mineralized fault systems) appear to be major structural features in the dynamics of the trough. These reactivated structures have the same characteristics e.g. (i) an intense deformation penecontemporaneous with Albian marine deposition (ii) Brecciating regime is superimposed on the NNE-SSW or NE-SW sheared fault zones and reworked them. It can then be concluded that the NE-SW mineralized (Pb-Zn) conjugate fault systems which match the continental extension of equatorial oceanic fracture zones (which are themselves mineralized with Pb-Zn sulphides at their intersections with the Mid-Atlantic Ridge) played an important role in the origin of the

trough as they control the general framework of the Middle Benue in alternating uplifted (horst) blocks and graben basins.

In the study area (galena) mineralized and brecciated silicified fault structures were produced by deep-seated reactivated movements partly under tensional regime and partly in a general wrenching mechanism active during Cretaceous sedimentation, and reworked the shear zones.

The galena mineralized NE-SW trending conjugate fracture systems of the study area are probably related to the on-shore extensions of the mid-oceanic (equatorial) fracture zones which are themselves mineralized with lead-zinc sulphides along their intersections with the Mid-Atlantic Ridge (Rona 1976) and may have initiated the opening of the Benue Trough during Early Cretaceous. The similar association between lead-zinc mineralization of Albian age and the Amazon (Rift) Fracture zone of Brazil- South America -(Reading 1978) supports the view that the episodes of lead-zinc mineralization may be related to the break-up of the Afro-Brazilian plate in Early Cretaceous.

8.4 Mineralization and Prospect for Exploration

The economic potential of the study area has been emphasized in relation to stratigraphic and tectono-structural controls. It has been shown that ore localizing factors such as fault (brecciated) zones, facies changes, unconformities and other stratigraphic traps have apparently formed blind ores of shiny speck and fibrous stringer galena mineralization in the Mbakpar-Igbur, Nyosu-Iyorshagher and the Buru Hill areas. The presence of galena mineralization in these areas has been indicated by the anomalous dispersion trains of lead obtained from the result of the regional geochemical reconnaissance stream sediment survey. Actual follow-up geological traverses have

confirmed the showing of fine shiny specks of steel grey galena in the above mentioned localities.

Thus a regional approach to both geological and geochemical explorations in the Middle Benue and the entire trough would be more rewarding than the existing practice by which different mining and exploration bodies are engaged in localized ore search around only the known lodes.

Also since the galena mineralization is stratigraphically confined in marine Albian to Early Cenomanian Sediments, all exploration activities should be confined to the Asu River Group of formations (Middle Albian-Early Cenomanian). The salt springs, the galena-fluorite mineralization, the limestone deposits are usually located along the edges of graben depressions and axial regions of folds proximal to major silicified fault zones. Therefore exploration for these minerals should be targeted at the above structures.

The fact that differnt minerals are found in the fractures offsetting other mineral-filled fractures, indicates that a long period of time elapsed between brecciations thus allowing the mineral content of formation waters to change. Some of the brecciated structures seem to have formed shortly after deposition while the majority of them were clearly post-lithification.

Reports of actual salinity at individual salt ponds or springs have been made throughout the whole length of the Benue Trough. But these differ from author to author, most probably due to seasonal variations resulting from admixtures of surface (Meteoritic) water. In the study area the values range from very low-about 1.8% NaCl in the Dzahan area - up to 6.1% NaCl in the Yatiev Salt pond. In discussing

the origin of most evaporatic deposits an attempt is commonly made in distinguishing between marine and continental evaporites. In all the salt springs and ponds studied, the chemical analyses show that the brines are characterized by the presence of double salts in which Na^{+}, Ca^{2+}, K^{+}, Cl^{-} and $S04^{2-}$, are the dominant ions which are understandably the major constituents of marine evaporitic minerals. Most evaporites of continental origin are devoid of double salt of K and Mg chlorides and sulphates which otherwise occur as sylvite, carnallite, Kainite, bischofite in marine evaporites. On the other hand, Na-rich minerals as natron gaylaussite, thermatrite and lazullite occur in continental evaporites.

In the study area the marine limestone-shale-siltstone-sandstones sequences which host the brines, are part of the Asu River Group of sediments deposited at an early transgressive phase of the Albian sea within the study area (Middle Benue Trough). The brine is definitely marine in origin and could have been precipitated from the transgressive Albian sea covering extensive parts of the Benue Trough at the early stages of its evolution. The subsidence (giving rise to the trough) was followed by a period of uplift, regression and continental conditions. During the regression parts of the sea could have been cut off with the formation of hypersaline lakes and swamps, from which further brines were precipitated.

In this respect, it has been emphasized that the tripartite field association of Pb-Zn or barite mineralization, igneous activity (dolerite dykes, sills, interbedded volcanic lavas) and brine may be associated with other factors than a common genetic origin for all of them. The possibility of the occurrence of salt and hydrocarbons is reinforced by the discovery of saliferous horizons in the Late

Cenomanian to Early Turonian limestone and shale-siltstone sequences in the area southwest of Akwana.

Field relationships in the study area show that the fluorite deposits are usually associated with massive galena, and that the formation of fluorite preceded the emplacement of the massive galena. The three fluorite-massive galena deposits at Arufu, Akwana and the Juwudu Hill are localized near or along the edge of a graben-like depression. It is shown that fluorspar deposition seems to be inextricably associated with the Early Cretaceous rifting which probably provided access for the fluorine which leaked upward from the lower crust or upper mantle or near the rift zones. The association of major fluorspar districts and continental rifts and lineaments may be regarded as a regional guide for new fluorite deposit in other limestone terrains within the Benue Trough.

As for the galena mineralization of the study area the hydrothermal solutions were probably only partly connate pore waters in the sediments. They may have been mainly sea water percolating down into the sediments and underlying basement to be warmed and supplied mainly with dissolved lead metal and other metals in lesser amounts, before migrating upwards to precipitate as lead sulphide (galena) in chemically and structurally favourable beds around Arufu, Akwana, Buru, Igbur, Nyosu and Iyorshager areas during the Albian times (cf. Farrington 1952). The concentration of the galena mineralization, and the apparent control by major structural features such as lineaments, faults and palaeohighs on this mineralization supports the above hypothesis that the mineralizing fluids flowed up through these major zones of crustal weakness and precipitated as lead sulphide (galena) in chemically and structurally favourable beds.

The similarity of the lead mineralogy as well as minor element trends in both the Uomba Formation and Awe Formation (both of which constitute the Asu River Group) suggests a common mineralizing event for both stratigraphic units, although mineralization may have occurred over a long period of time and probably was intermittent (episodic) and was probably controlled by basement and rift structures active during sedimentation.

The present investigation has also shown that the nature of the contacts between the three varieties of galena and the two types of fluorite veins in the study area suggests in each case, that the fractures opened more than once in the process of mineralization. The galena veins in the Arufu-Buru Hill area are in places intruded by highly albitized (third cycle) dolerite dykes (Late Albian-Cenomanian) along the same fracture systems which originally controlled mineralization.

The lead isotope age of 620 m.y. (Grant 1971) obtained from galena in veins cutting Cretaceous rocks in the Benue Trough could be explained by considering it to represent the time at which the non-radiogenic lead separated from its uranium host during emplacement in Basement Complex rocks.

The base metals of the sulphide mineralization of the study area are considered to be probably derived (Leached) primarily from the underlying potassium feldspar-rich clays in the semi-consolidated wet marine Albian sediments (along permeable fault zones) still undergoing diagenesis) - Pb, Ti, Sr, from feldspars, Zn, and F from micas - (cf. Schroll 1978). These Cretaceous marine sediments may be regarded as containing recycled lead which was probably extracted from the underlying basement rocks of Pre-Cambrian to Lower Palaeozoic age.

Further lines of research into the source of the lead should include sulphur isotope analysis of the galena occurrences in the study area. From the results one would then be in a position to know whether or not the isotopic composition of the lead corresponds to lead of crustal origin.

Marshall (1969), schroll and Wedepohl (1972) and Pak (1978) have shown that sulphur isotopes associated with sulphides of sedimentary origin, show large ranges of variation (light sulphur) of values e.g. $d^{34}S = -6.0$ to $d^{34}S = -30‰S$, suggesting that bacteria were probably involved in sulphides precipitation of the original sulphates. But sulphides connected with magmatic hydrothermal mineralizing solution rarely vary in $d^{34}S$ composition by more than +5‰ (Hoefs 1973) often in the range of $d^{34}S = 2.5$ to $d^{34}S = +3.5‰$ (Marshall 1969).

Recent data on the stable isotopes study of the lead-zinc ores of the Upper Benue (Ogundipe 1988) associated with sandstones and siltstones of Lower Cretaceous age, indicate that the sulphur isotope ratios $S^{34}s$, in the sphalerite and galena range from +7.9 to +14.3‰ and 5.3 to 17.5‰ respectively. He thus concludes that these data are consistent with sulphides that are depleted relative to contemporaneous Cretaceous seawater sulphate by about +9.5 to 3.5‰ for sphalerites and +12.2 to 0‰ for galena. Two possible sources of sulphide sulphur (cf Schroll and Wedepohl 1972, and Pak 1978) ascribed to this type of isotopic signature are suggested, namely (1) synsedimentary bacteria reduction of seawater sulphate in a closed system and (2) thermal reduction of seawater sulphate.

Similarly hydrogen isotopic measurement of fluid inclusions on the above sphalerite and galena by the same author indicates SD values

ranging from - 23 to 28‰ for sphalerite and - 35‰ for galena. These data may further suggest that the Th, salinity, sulphur and hydrogen isotopic compositions of the ores are consistent with sedimentary basin formation fluids which are dominantly of meteoric origin with possible significant seawater contribution (cf. Hitchon 1968).

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APPENDICES

(a)

(i) Table 3.8

CHEMISTRY AND MINERALOGY OF SAMPLES FROM MINE TRENCHES, PITS AND ROAD CUTS.

Notes:

1. The major elements are expressed as weight per cent oxide, minor elements in parts per million (ppm), and minerals in percentages (estimated from Thin Sections, polished sections and/or mineral assays by modal calculation).

2. A space in the chemical composition indicates that the constituent in question was not determined, in the mineralogy it indicates that the mineral was not found.

Table 3.8 Chemistry and Mineralogy of samples from mine Shafts and Pits

FORMATION NAME	A P L I N E	L I M E S T O N E	-	S H A L E	F O R M A T I O N											Kar
SAMPLE NO.	DC. 264D	DC. 265D	DC. 265B	DC.239	DC.262D	DC.265	DC. 265C	DC.265F	DC.149	DC.240A	DC.147	DC. 272	DC.163D	DC.150	DC.160	DC.152A	DC. 222
PIT NO.	A10	A11	A11	A16	A15	A13	A13	A14	A13	A15	A15	A15	A15	A16	A16	A16	& 217 Saltpond
SERIAL NO.	1	2	3	4	5A	5	6	7	8	9	10	11	12	13	14	15	1 5A
DEPTH (m)	1	1	3	1	1.0	1	3	1	4	1.5	1	3	3.5	1	6	8	1.5
SiO_2	51.69	43.85	60.2		47.3	51.41	53.1	51.28	70.3	2.01	28.0	28.3	29.6	40.0	31.8	62.3	92.19
Al_2O_3	5.1	5.2	10.4		6.4	5.0	9.4	5.1	8.4		2.5	3.4	4.4	4.2	3.9	14.2	0.90
Fe_2O_3	2.62	1.1	1.85		2.8	1.1	3.85	6.0	3.8		1.1	1.1	1.1	4.1	5.3	2.5	1.10
MgO	5.21	11.0	11.0		3.0	5.1	4.0	5.1	2.0		3.1	4.3	4.5	3.04	3.6	3.8	0.27
CaO	23.04	23.6	4.04		24.0	23.6	22.04	23.04	25.0		57.1	54.22	54.1	40.05	43.6	2.6	0.56
FeO	11.41	10.00	10.01		12.0	10.0	7.02	8.0	8.6		7.0	7.02	6.4	7.01	6.0	7.0	2.60
Na_2O	0.05	1.7	0.05		0.05	1.7	0.05	0.05	0.05		0.12	0.12	0.13	0.12	0.14	1.16	0.01
K_2O	0.2	2.7	2.3		0.3	2.0	2.3	0.2	0.3		0.34	0.36	0.41	0.34	0.35	4.42	2.40
TiO_2	0.03	0.46	0.44		0.44	0.03	0.44	0.03	0.44		0.08	0.08	0.08	0.07	0.08	0.09	0.001
P_2O_5	0.03	0.16	0.03		0.03	0.03	0.03	0.03	0.03		0.19	0.19	0.19	0.18	0.18	0.19	0.004
S	-	-	-		3.0	-	-	-	1.0		-	-	0.74	0.83	0.99	0.81	-
MnO	0.01	0.05	0.1		0.12	0.12	0.2	0.32	0.0		0.5	0.9	1.0	0.1	1.2	0.9	-
TOTAL	99.08	100.42	100.42		99.44	100.09	99.44	99.15	99.92		100.03	99.99	100.05	100.94	99.74	100.97	99.595
Pb	2100	3000	4068		10000	3080	4075	1105	16800		4800	24000	240,000	14000	222,000	230,000	120
Zn	200	580	820	550	200	504	815	200	582	560	550	580	582	500	524	600	50
Co	35	40	45		70	40	45	35	45	40	45	40	60	50	55	60	25
Ni	30	30	35		30	25	50	30	40	17	17	17	18	40	45	50	20
V	30	30	70		200	30	70	30	220		10	15	20				10
U	10	6	5		17	5	5	10	20	16	16	21	22	1	1	1	4
Li	5	5	20		20	5	20	5	20	14	16	16	16				5
Ba	110	200	300		300	190	305	115	310	300	300	305	350	240	255	300	100
Sr	10	10	10		10	10	10	10	11	11	11	11	11	10	10	10	5
Rb	10	10	20	20	20	12	20	10	20	20	25	20	21	20	20	20	10
B	15	15	20		20	15	20	20	20	20	20	20	20	15	15	15	-
Ga		2				1					6	6	6	5	5	5	5
Ag	13	47	57		50	40	60	13	60	47	46	48	57	48	68	70	5
As								20									95
Mn	15	60	180		100	60	101	15	190	190	195	200	220	170	190	220	600
Quartz	45	45	400	2.5	40	44	45	55	45	2.5	10	10	10	35	40	61	60
K-Felspar			1				1.0									2	2
Plagioclase		2	15		4	10	4	5	4		0.					1	-
Mica	5	4	1.5		9	4	6	1	9		0.5	0.5	0.5	5	2	3	5.5
Calcite	25	22.5	4		20	20	22	28	22		60	60	60	22	30	1.8	-
Pyrite	2	2	1		4	1.10	1	9	1		1	1	1	1.2	1.5	1.0	-
Magnetite.	9	6	7		7.0	6.0	3.5	9	7						1	1.0	-
Ilmenite/Hematite	9	6	14		4		4		4					6	2	2.0	2
Rutile				2.4						2	2	2	2	2	1.5	1.0	-
Clay		1.5		95		1.5	2.5	1.8		95	5	3.7	5.7	2.4	2.1	1	-
Kaolinite		3	10														
Metal		4	5		5	3.0	10		6.9		2.5	1.5	1.20	20.1	15	10	-
Chlorite/Sericite	4.5	7	1.5		7	10	1	5.2	1.0								
Pyrite						-							1.5	0.34	4	15.2	5.0
TOTAL	99.5	99.7	100	99.9	100	99.6	100	100	99.9	95.5	99	100					

TABLE 4.4: CHEMISTRY AND MINERALOGY OF SAMPLES FROM HAND DRYHOLES AND PITS AND ROAD CUTS

MAJOR ELEMENTS IN OXIDE WEIGHT PERCENT; MINOR ELEMENTS IN PPM; MINERALS IN PERCENTAGES ESTIMATED FROM THIN SECTIONS (MODAL CALCULATIONS).

	POLISHED SECTIONS AND MINERAL ASSAYS													
FORMATION NAME	A R R U F U			LIMESTONE - SHALE FORMATION (Lower Sequence of Asu River Group).							PRE- ASU RIVER BASAL SEDIMENTS.			
SAMPLE NO.	DC. 266	DC.279	DC.279B	DC.279A	DC. 154	DC.151A	DC.151B	DC.151C	DC.151D	DC.151E	DC.260B	DC.261C	DC.319B	DC.227A
PIT NO.	A1	A2	A3	A4	A5	A6	A6	A6	A6	A7	Road Cut	Road Cut	-	Road Cut
SERIAL NO.	16	17	18	19	20	21	22	23	24	24A	24B	24C	24D	24E
FeO	11.6	10.51	10.59	7.5	9.49	8.8	9.99	8.11	9.17	8.14	10.08	2.0	5.0	9.0
SiO_2	15.77	15.5	16.02	2.72	27.9	18.5	19.51	19.62	18.0	9.95	67.0	85.1	83.1	67.04
Al_2O_3	2.43	2.4	2.5	3.69	14.2	2.5	5.46	4.0	2.5	4.04	13.8	7.1	6.2	13.76
Fe_2O_3	5.3	5.4	6.8	3.69	4.6	4.9	1.84	4.7	4.9	4.6	2.5	2.9	1.0	5.5
MgO	2.44	3.5	3.4		3.9	3.4	4.57	4.5	5.4	5.9	5.48	0.66	0.56	3.47
CaO	60.0	60.34	56.49		30.5	57.1	54.59	52.1	57.1	60.5	0.14	0.15	0.15	0.15
Na_2O	0.14	0.13	0.14		1.7	0.12	0.15	0.15	0.12	1.7	0.08	0.05	0.05	0.08
K_2O	0.34	0.40	0.36		2.7	0.34	0.36	0.41	0.34	2.7	3.1	3.7	3.7	3.09
TiO_2	0.08	0.08	0.08		0.45	0.08	0.08	0.08	0.08	0.45	0.002	-	-	0.005
P_2O_5	0.17	0.18	0.19		0.16	0.19	0.19	0.19	0.19	0.16	0.05	0.05	0.06	0.05
MnO	0.81	0.84	0.85		0.80	0.81	0.82	0.85	0.81	0.80	-	-	-	-
S	0.14	0.50	0.49	4.19	3.08	4.14	4.14	4.14	3.44	3.08	0.14	0.07	0.06	0.14
TOTAL	99.42	99.88	100.09		99.40	99.88	99.15	99.01	100.05	100.04	100.002	99.78	99.82	100.083
Pb	10.80	23,000	16800	-	1000	5000	24,000	24,000	4800	1100	150	160	154	100
Zn	150	600	450	590	500	560	580	582	560	506	40	44	49	40
Ni	17	45		45	17	45	40	50	45	17	40	35	40	30
Co	22	20		40	22	17	17	18	18	22	42	30	31	25
Mn	200	290	300	390	200	195	200	220	190	200	455	425	400	500
V	15	15	10		15	10	15	20	10	15	63	60	61	60
U	1	1	1		1	16	21	22	16	1	8	2	3	230
Li	15	10	25		15	16	16	16	16	15	65	15	16	116
Ba	300	320	310		300	300	305	350	300	300	280	265	250	264
Sr	110	115	10		110	11	11	11	11	110	15	20	76	17
Rb	20	20	20		20	20	20	25	20	20	130	170	163	190
B	13	14	13		13	20	20	20	20	13	-	10	3	9
Ga	10	10	10		10	6	6	6	6	10	-	4	-	5
Ag	7.6	10	60	60	9	46	50	57	46	9	5	3	3	2
As				100							100	111	100	120
Quartz	12	14.3	10.3		48	15	10	10.5	11.0	15	60	74.7	74.5	60
K - felspar											2	3.0	2	2.5
Plagioclase	1				1.9				1.1	2.2	2			2
Mica	5	5.0	5		1	1.1	5	5	2.9	-	30	15.0	15	29.5
Calcite	80	78.0	40		29	80	80	79.5	81.0	79	-			-
Pyrite		0.2	1.6	1	2	1.1	1.0	1.0	0.7	1.0				
Limonite/Hematite				1.4	3.4						4	3	4	4
Cerussite		0.2	2	2		0.1	0.2	0.2	1.0					
Galena	1.9	2.4	2.0	95		1.4	2.7	2.7	1.0	0.7				
Fluorite		-	28.4	-										
Barite					1.0									
Apatite					1.0						1		1	1
Kaolinite		-			0.7							2.0		
Chlorite	0.8				15.2	1.3	1.0	1.0	1	2.0	1.9		1	
Carbonaceous Material											0.9	0.5	2	9.9
TOTAL	99.8	99.8	99.8	99.4	99.8	100.0	99.9	99.8	99.9	99.9	99.8	98.2	99.7	0.10
Equivalent $CaCO_3$	80.0	79.0	59.0											100.0
Equivalent $MgCO_3$	2.5	3.5	3.4											

TABLE 3.6 (CONTINUED)# NB. MACRO ELEMENTS AS LIGHT FEACCENT OXIDES. MINOR ELEMENTS IN PPM ESTIMATED IN PERCENTAGES
ESTIMATED FROM MODAL CALCULATIONS OF THIN SECTIONS, FOLLOWED SUCCESSIVE AND MINIMAL ANALYSES.

FORMATION NAME	A P E Z U	L I V E S T O N E - S H A L E	P O R P H Y R I O N	
SAMPLE NO.	DC. 266A	DC.15'1F	DC.15'1D	DC.15'1H	DC.16'4J	DC.16'3D	DC.15'3A	DC.16'2A	DC.29'YE	DC.29'YA	DC.29'Y8	DC.16'J3	DC.16'62	DC.16'83	DC.29'YC	DC.29'7C	DC.1'
PIT NO.	A'1/	A'1C	A'1C	A'1C	A'1H	A2C	A22	A23	A23	A23	A25	A2b	A27	A27	A2'/	A27	A2
SERIAL NO.	25	2b	27	28	29	3U	31	32	33	34	35	3b	37	3B	39	4U	4'
PPO	4.4	b.4	2.4	2.9	10.4	b.9	4.4	7.49	0.49	0.43	2.19	2.07	2.29	2.4B	2.3A	6.23	4.(
SiO_2	1b.U	1b.4	19.2	17.9	19.9	72.b	02.7	03.09	03.3	01.4	03.4	03.1	03.9	09.79	83.3	83.2	83.(
Al_2O_3	2.43	2.3	3.49	4.3	4.2	4.B	2.3	2.6	1.B	1.B	2.3	2.3	2.B	2.7	1.bH	2.(
Fe_2O_3	3.33	4.B	2.01	1.92	4.3	7.3	2.4	2.4	2.3	2.3	2.3	2.4	2.51	2.22	3.33	1.(
MgO	3.3	3.9	3.39	4.3	3.9	0.3	0.2	0.3	0.4	0.3	0.4	0.3	0.31	0.41	0.31	0.(
CaO	3b.7H	3b.2	bU.U1	b1.1	3H.3	0.C3	0.C4	0.3	0.UB	0.C3	0.U4	U.U4	U.3	U.H9	0.07	0.0B	U.(
Na_2O	0.13	0.34	0.37	0.42	1.7	0.C9	0.U5	0.U6	0.U3	0.U3	0.U3	U.UB	U.07	0.34	0.UB	U.(
K_2O	0.3B	0.24	0.2B	0.41	2.7	0.E	1.4	1.1	0.7	0.B	1.3	1.39	1.1	1.12	0.24	U.B	1.(
TiO_2	U.09	0.UB	0.UB	0.UB	0.46	0.UB	0.24	0.25	0.09	0.09	0.1U	0.27	0.25	0.27	0.UB	0.09	0.(
P_2O_5	0.17	0.19	0.19	0.19	0.16	0.U1	0.1U	0.1U	0.U2	0.1U	0.1U	U.11	0.1U	0.U3	0.U3	0.02	0.(
MnO	U.Y4	0.C1	0.B2	0.B3	0.Y9	0.01	0.01	0.U1	0.01	0.01	0.15	0.02	0.01	0.01	0.01	0.01	0.(
TOTAL	9C.Cb	99.90	99.56	99.19	100.05	99.bU	99.Y4	99.W7	100.03	100.12	99.79	99.bU	99.Y6	100.08	99.Y8	100.U5	99.(
S	4.1N	4.14	4.14	3.14	2.04	3.4	0.3U	1.3N	4.U1	4.12	3.33	2.23	3.45	1.25	4.1	4.2b	4.(
TOTAL	99.9	99.3	100	100.0	99.9	99.7	100.0	100.0	100.0	100.0	100	99.8	99.9	99.9	99.9	100	
Jadeite	C.C	1.C															
Diopside	C.C	1.C															
Albite	3.4	1	C.4	1	1	1.9	1.1	1.C	0.9	1	1	2	1.4	0.7	1	1.(	
Hypersthene																	
Cordierite																	
Nepheline	0.6	2	1	1.0	4.2		2.3	4.1	4.0			1	1	1			
Kaliophilite																	
Calcite	73.4	72	30	C0	69	2	1	1	1.4	1	1	1	1	1	2		
Anhydrite																	
Gypsum	C.C	3	1		2.9			3								2.4	
Magnetite	2.0	3	1	0.1		14	12	9	11	12	4	2					1(
Ilmenite	3.0	3	1					3									
Quartz	C.C	12	11	11	16			1	0.4	4	9	9	13	12	12	12	1(
Orthoclase																	
Albite	2.7	2U	3U	3U	19	2U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	2(
Anorthite	2.C	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2(
Diopside	3.C	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3(
Hypersthene	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(
Cordierite																	
Nepheline																	
Kaliophilite																	
Calcite	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(
Anhydrite																	
Gypsum																	
Magnetite	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(
Ilmenite	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(
Quartz	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(
Orthoclase	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(
Albite	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(
Anorthite	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(
Diopside	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(
Hypersthene	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(
Cordierite	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(
Nepheline	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(
Kaliophilite	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(
Calcite	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(
Anhydrite	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(
Gypsum	1.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1(

TABLE 4.8 (CONTINUED)

FORMATION NAME	A P U F U		F C P M A C I O N (LOWER ASU RIVER STORE)									Pre-Asu River Sediments				
SAMPLE NO.	DC. 199	DC.240B	DC.408	DC.155A	DC.155B	DC.155C	DC.155D	DC.155E	DC.242	DC.278	DC.155F	DC.154A	DC.154	DC.156	DC.221	DC.350	DC.
PIT NO.	A40	A31	A-F Tselsham	A51	A51	A52	A53	A54	A54	A54	A55	A55	A56	A30	Yatiev Salt Fond	-	
SERIAL NO.	42	43	43A	44	45	46	47	48	49	50	51	52	53	54	55	56	
DEPTH (M)	1.4	1	0.30	2	5.2	0.4	0.14	1	1	2	0.14	0.4	0.4	0.04	-	-	
SiO_2	83.59		4.6	19.60	18.9	18.0	66.06	52.56	30.55	30.2	35.06	72.0	82.0	82.3	81.0	71.0	3
FeO	5.0	6.91	6.0	11.49	10.14	10.19	4.27	5.71	6.11	6.8	12.01	10.0	9.0	7.0	10.0	5.0	9
Al_2O_3	4.61		7.2	3.2	4.6	2.5	3.10	3.24	6.25	6.0	5.24	2.6	2.59	2.6	1.1	11.2	4
Fe_2O_3	1.30	2.29	1.52	8.2	5.5	4.1	4.8	5.5	2.3	1.5	8.4	4.1	0.11	0.12	5.20	4.2	
MgO	1.5		4.38	13.04	11.0	3.4	3.24	5.05	5.05	6.8	5.04	7.4	5.4	5.4	0.12	1.6	4
CaO	3.05	.	70.4	37.05	40.9	57.1	0.60	26.04	40.04	41.0	31.1	0.05	0.05	0.4	0.05	0.064	3
Na_2O	0.05		0.17	0.12	0.16	0.12	0.04	0.12	1.12	1.16	0.13	0.05	0.06	0.049	0.005	0.005	0
K_2O	0.06		0.4	0.54	0.42	0.34	3.0	0.36	0.36	0.42	0.4	1.59	1.4	1.42	1.51	1.6	6
TiO_2	0.06		0.1	0.07	0.09	0.08	0.47	0.07	0.88	0.09	0.06	0.24	0.24	0.241	0.001	0.12	
P_2O_5	0.01		0.21	0.18	0.19	0.19	0.42	0.18	0.19	0.19	0.17	0.10	0.10	0.11	0.01	0.21	
MnO	0.01	0.04	0.04	0.083	0.81	0.74	0.80	0.82	0.81	0.80	0.81	0.80	0.31	0.80	-	0.02	0
S	0.77	5.0	4.849	2.07	2.64	3.70	2.40	4.07	4.07	3.24	2.07	0.30	0.31	0.31	0.04	5.03	
TOTAL	99.09		99.769	99.443	99.83	97.97	99.22	99.20	98.71	99.1	99.58	99.31	99.55	99.15	99.015	99.829	9
Cu	100		95	100	50	60	120	90	100	50	90	175	100	100	31	40	
Pb	720		213	62220	72300	14,000	8000	20000	210,000	455,000	211.00	750	750	700	110	24090	2
Zn	100		57	624	600	540	80	600	540	600	600	300	1000	109	40	506	
Co	80		80	50	60	50	90	50	60	60	50	40	60	60	20	3030	
Ni	65		54	40	50	40	60	40	50	50	40	40	65	50	25	20	
Mo	250	-	-	-	-	-	-					3	3	3	869	-	
V	60		10			10	115					1	1	1	10	90	
U	9		3	1	1	10	5	1	1	1	1	3	3	3	6	10	
Li	10		10			1	10								9	40	
Ba	150		415	540	500	510	210	740	524	500	740	300	250	104	100	200	
Sr	40		200	410	405	242	110	310	310	310	319	100	86	45	10	10	
Rb	15		25	20	20	15	115	20	20	20	20	25	26	27	150	120	
B			23	15	15	24	115	15	5	15	15	75	75	40	-	68	
Ga			11	5	5	20	11	5	5	5	5	15	10	17	7	9	
Sc	10		7	14	40	27	10	14	14	10	14	7	3	7	6	10	
Zr			200				500	400	450	500	410	250	50	250	50	40	
Quartz	76	0.9	[illegible]	22.1	24.9	15	60	44	40	45	40	80	80	81	90	65.8	
K-feldspar			30				5		5	5	5	4	4	5	1.50		
Plagioclase			1				2					1	1	1.8	-	5	
Mica	15		2		5	2	20		5	3	5				1.0	15	
Calcite			42.6	55	40	70	1	52.2	22.2	22.2	22.2			1	-		
Pyrite	1	2	0.5	1.1	1.0	2	2	1.2	1.2	1.0	1.2			1	-	0.6	
Marcasite	1			1.0	1			1.0	1.0	1	1.0			1	-	0.5	
Hematite-Limonite	4	5	1.0	9.0	2.0	2	5	5.0	5.0	4	5.0	6	6.0	10	5	5	
Cerussite				2.0	1	2		2.0	2.0	1	2.0				-		
Galena	62			7.2	2.2	1.0	1.0	2.8	3.8	5	3.4				-	1	
Fluorite				2.4	0.7	2.0		5.0	3.2	14.5	9.2				-		
Dolomite			1.5		10.0	4.1		2.0	4.0	4.5	4.5						
Apatite	1		1	0.1	0.1					0.5		1	1.0	1			
Chlorite	2		1	1	1	1	4			1		8	8		2	1.0	
Opal			1	1	1	1		5	5	2	2					4	
TOTAL	100	99.0	99.5	100.0		97.6	100	100	99.4	100	100	100	100	99.8	99.5	99.9	
[illegible]									21.9	22.5							

APPENDIX (a) ii.

TABLE 2.5.

Showing Sedimentation and both Marine and tectonic movement around Arufu, Akwana, Abeda-Ugba and Adjacent areas.

Keywords: Uplift, Rift Faulting, Subsidence and Sedimentation

STAGES OF CRETACEOUS SYSTEM	SETTING	DEPOSITS
4. Post-Turonian	Elevation, marine regression and erosion: compressive folding in SANTONIAN? accompanying broad regional uplift; compressional movement (Compressive stress) due to adjustment motion after complete separation of South America from Africa in Late Cretaceous and opening of south Atlantic Oceann; Continental Alkaline basalt magmatism along rejuvenated old structural lines in the basement mostly transversal to the axis of the trough in Buru, - Sufa, Tunga area etc. Faults in underlying basement reactivated during the compression; sediments deposited upon thinned and SUBSIDED Crust were drape folded during the Campanian - Santonian folding phase which was accompanied by uplift and vertical movement,	4. No post-Turonian Marine or Molass Deposits preserved in the study area probably due to continued uplift and erosion, except Tertiary to recent alluvial deposits on both banks of Riv Benue Katsina-Ala, and some lateritize slopes. All sediments (Pre-Albian to Lower Turonia ages) folded together wi ENE-WSW Trending axes e.g. The Arufu Anticline) and NE-SW axes predominantl in other a as. More intense folding in older (Albian) sediments as result of readjustments that occurred in trough itself during basin development: (i) (i) intermittent uplift of the surrounding broad plateau region durin Upper Cretaceous following Continental rupture. (ii) Downwarping and differential movement of faulted crust blocks giving rise to drape-folding of overlying basal Lower Cretaceous sedime together with the faulted basement bloc (faults in underlying basement form during extensional movements in (a) Tseagodo - Yatiev area (b) Arufu ar (c) Fiyayi - Kasaar areas.
3. Early Turonian	Widespread epicontinental marine transpression of late Cenomanian; Early Turonian marine transgression all over West Africa - shallow marine, coastal environment during period of low input of terrigenous material due to low run off from land resulting from (a) reduced erosional effect of Post - Albian uplift (b) Lowering (SUBSIDENCE) of the Palaeoslope.	3. Preserved in central parts of trough in the area mapped - Akwana shale-lime limestone consisting of hard grey to black shales and siltstones, calcareous sandstones and sandy shale, Limestones places fossiliferous and shelly.

TABLE 2.9: CONT'D

ES OF ACEOUS SYSTEM	SETTING	DEPOSITS
pper Albian-enomanian	Intermittent differential uplift, down-warping, doming of basement blocks; marine regression, faulting, compression - folding with ENE trending axis in Arufu, Buru and Penda - Cheachia (NE of Ugba) areas, and formation of new rocks within the uplifted folded belt (Middle Benue Trough) *Contemporaneous and/or penecontemporaneous* Extrusive Volcanism and intrusion of midplate (continental) dolsritic rocks, into wet, semiconsolidated Albian to Cenomanian sediments; dykes aligned parallel to axis of the trough. Magmatic - hydrothermal and diagenetic - hydrothermal solutions along fractures in uplifted and domed areas (e.g. in Fiyayi area) altering, mixing with and incorporating country rocks, depositing hydrothermal materials at suitable site, along the fractures. Petrochemical and structural affinities of igneous rocks are characteristic of tensional regime during emplacement Rising of mineralizing waters, materials, associated with escape of magma leading to deposition of base metal sulphides (Lead-Zinc etc.), sulphates (barytes), fluorides of calcium (fluorite) etc. - indicative of upwelling of *subcrustal* materials. Rising mineralizing waters probably also associated with emanation of heavy metal bearing concentrated brines in the deeps of the trough appearing as warm and salt water now issuing from springs in central (axial) parts of the trough eg. Arufu - Akwana area, in places showing close association between mineral lodes and these emanations (Arufu-Akwana - Buru area) in others, no close association eg Afia - Nyoosu area. Predominantly Olive green to bluish colour of Asu River shales may signify anaerobic	2. Regression of Albian sea accompanied by gentle Oscillations of Coastline resulting in deposition of rapidly alternating, well bedded micaceous, tabular, calcareous sandstones (typical of Fiyayi Formation ....) with slide rocks and in places interbedded with Volcanic lava (eg the Ibi area, and in Andyar area - Andyar Basalt) containing tectonized fragments of Pre-to Late Albi rocks, often along localized sedimentar basins between downfaulted - reactivate (Uplifted) horstlike basement inliers; blocks and ridges aligned paralled to trend of trough. - Deposition in unstab marine environment; shallow marine to brackish water, tidal flat with Callia and other worm burrows in the Kasaar-Fiyayi and Akwana areas. Isolated segments of withdrawing s as saline lakes and pools within the synclinal basin drying and possibly leading to evaporitic sequence. Deltaic - brackish - continental conditions initiated due to retreat of Albian sea leading to deposition of (i IBI CONTINENTAL SANDSTONE: in the NE a SE parts of the study area. (ii) Tsai Sandstone - shale Formation in west an SW extremes of the study area. Three varieties of galena (i) Gra disseminated type in limestone and siltstone forming ENE-WSW trending ar fracture zones or ridges paralled to of trough (Around Western, northern a outskirts of Arufu Buru, Igbur, weste outskirt of Akwana, etc.) Series of fractures within the RIFT contributin base metals to marine sediments at t of deposition and soon after - during consolidation and burial processes

STAGES OF CRETACEOUS SYSTEM	SETTING	DEPOSITS
2. Upper Albian Cenomanian (cont'd)		2. cont'd (iii) Crystalline type arour Juwudu Hills to south of Akwana, der from (i) and (ii) by remobilization annealing motion after dilation of earlier ore structures leading to crystallization of undeformed coarse crystalline galena (Olade 1976).
1. Pre-Barremian (Neocomian?) Aptian (?) - Middle Albian	Widespread domal uplift probably due to push by South America as it rotated against West and NW - Africa during break up of Gondwanaland. Vertical and tensional movements along old structural lines of weakness in the basement leading to downfaulting and subsidence of downfaulted basement blocks allowing formation of NE - SW trending RIFT like trough (off Gulf of Guinea triple junction) bordered by more stable platforms, followed by widespread transgression with opening of South Atlantic as South America was separating from Africa. (Murat 1970, Wright 1976, Olade 1976). Benue Trough (Rift Structure) was probably initiated by on-shore extenstion of (equatorial) mid-oceanic (South Altantic) fracture zones during the earlier stages of separation of South America from Africa in Early Cretaceous (Benkhelil 1982, Maurin et al. 1986).	1. IN RIFT-LIKE TROUGH Erosion and initation of continent conditions followed by shallow marin condition; initial deposition of bad sorted non-calcareous, conglomeratic arkosic (feldspathic) sandstone, g clays, in subaerial parts or coastal plains of fluviatile alluviation concomittant alkaline magmatism (eg Tseadogo-Tseagu Rhyolite of K-Ar age 113 ± 3 m.y); and tectonised altered Xenoliths of basement gneisses (Uzuakpunwa 1974). As Middle Albian marine transgre quickly moved up the Benue Trough to Abeda - Akwana - Arufu and Ugba area deposition of Asu River Group shale siltstones in centre of basin; marin brecciatic to conglomeratic material along active fault scarps; while on platforms or shelves equivalent shel limestone and - well sorted limeston (ARUFU LIMESTONES), with ammonite Elobiceras, corals and pelecypods (oyster banks), calcareous sandston and shales. Disseminated Galena mineralization in silicified siltst limestone followed by massive Gal mineralization by op fracture (space) filling in silicif brecciated limestones, siltstones ar sandstones, (Galena - fluorite mineralization confined to limeston terrain).

TABLE 3.7 CHEMISTRY AND MINERALOGY OF SOME CARBONATES AND TERRIGENOUS SEDIMENTS

Major Element in oxide weight percent, Minor Elements in PPM, Minerals in percentages estimated from Thin, Polished Sections and Mineral Assays. T = Trace, NT = Not Determined

FORMATION NAME	Kar.									Kon.		Kb		Kar.			
SAMPLE NO. DC	183	287C	280	281	282	347	212	214	287A	322	330	226	189	336	199	200A
SERIAL NO.	1	2	3(a)	3(b)	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	6.83	6.80	5.8	5.81	5.01	3.68	53.27	30.40	53.30	5.85	3.70	60.1	48.12	53.27	49.9	40.44
Al_2O_3	2.20	2.23	2.2	2.23	2.18	0.42	10.96	6.76	10.94	2.22	0.40	2.5	12.80	10.96	14.2	8.75
Fe_2O_3	0.93	0.91	0.3	0.94	0.96	0.50	4.75	4.66	6.77	0.94	0.70	2.6	4.85	6.75	4.6	4.66
MgO	3.05	3.45	1.4	1.15	2.05	0.80	2.39	1.90	5.40	1. 2	0.80	4.6	2.55	2.39	4.9	1.87
FeO	6.20	7.3	10.9	2.0	10.0	3.0	3. 0	3.90	4.70	5.01	3.11	6.01	7.02	8.04	9.0	11.0
CaO	50.12	45.95	59.12	56.39	58.12	69.60	10.14	30.96	9.12	49.40	52.58	13.0	10.77	8.13	10.5	0.96
Mno	1.13	1.05	1.04	0.05	0.05	0.04	0.07	0.04	0.07	0.05	0.06	-	0.09	0.07	0.09	0.08
Na_2O	0.20	0.25	0.17	0.17	0.19	0.66	1.84	0.87	1.82	0.19	0.66	0.07	0.60	1.84	1.7	0.84
P_2O	0.45	0.41	0.4	0.37	0.46	0.09	3.16	3.20	3.18	0.35	0.99	1.20	3.60	3.16	2.7	1.88
TiO_2	0.09	0.85	0.1	0.09	0.11	0.06	0.70	0.49	0.70	0.07	0.06	T.	0.78	0.70	0.46	0.49
P_2O_5	0.17	0.18	0.2	0.19	0.19	0.24	0.19	0.18	0.16	0.18	0.24	0.11	0.65	0.19	0.16	0.17
SO_3	0.46	0.45	0.5	0.45	0.44	0.44	0.55	0.88	0.65	0.45	0.44	0.33	1.12	0.66	0.88	0.88
Ignition Loss	30.06	31.04	10	31.06	20.06	30.06	11.53	24.76	1.64	35.16	38.06	9.40	7.05	3.53	2.10	14.75
	99.89	99.87	99.93	100.0	100.12	100.09	99.74	100.0	99.65	100.07	100.17	100.01	100.02	99.69	100.19	99.77
Pb	599	582	600	9000	9620	300	200	206	800	150	160	165	310	300	310	301
Zn	90	80	90	280	290	127	50	52	220	30	80	25	100	98	90	100
Co	80	75	71	70	74	80	60	61	60	60	65	10	60	65	65	60
Ni	90	96	90	85	84	80	75	76	75	61	67	11	70	72	72	70
Mn	-	-	-	-	-	-	-	-	-	-	-	575	-	-	-	-
Y	8	9	8	8	7	8	100	109	101	8	8	10	390	85	80	86
U	5	6	4	5	5	5	2	2	9	1	1	1.5	110	9	10	10
Li	9	8	9	8	10	10	20	25	22	9	10	10	20	19	20	20
Ba	300	350	330	332	305	400	450	400	500	400	409	490	400	399	400	400
Sr	430	420	400	410	439	430	160	155	162	410	400	55	150	149	146	146
Mo	20	19	20	20	25	15	134	130	132	20	21	30	130	125	130	130
B	15	16	19	17	18	20	85	80	90	16	15	-	80	78	80	74
Ga	5	6	10	19	10	7	4	5	4	5	6	-	5	4	5	4
AE	16	15	21	20	25	16	17	18	17	10	11	10	12	15	16	17
AS	216	230	216	213	217	220	200	205	209	180	161	150	20	21	25	30
Quartz	5	6	5.4	5.4	6.4	5.1	43	25	43	5	3	54.2	40	45	40	21
K-Felspar	T	T	-	-	-	T	-	-	-	-	-	-	-	T	-	1.5
Plagioclase	4.1	1.0				3.0				1			3.4	1.5		1.1
Mica	2.5	2.6	5.4	3	3	2.1	23	25	23.0	-	4	-	15.0	10	25	30
Calcite	77.7	86.81	88	87.9	87.1	90.8	24.4	48.2	23.50	87.2	90.8	35.0	25.4	14.5	25	29.3
Pyrite	1.0		1.2	1.3	1	-	1.0									
Tourmaline																
Zircon	T	T											2.0	1.8		
Rutile							1.0									
Magnetite																
Hematite	1.0			1.0	1.0		3.0			1.1	0.5		3	2.2	1	
Limonite	1.3			1.0			4.6	1.0		1.0	0.2		2	2.5	2	1
Barite		1.0					1.0									
Organic Matter	0.5	0.5	0.4	0.4	0.3	0.1						0.5		0.4		
Apatite	1.2	1.1		T	T	1			0.1							
Chlorite	0.5	0.5				0.5	10.0		10	4.5	0.5	10	10	20	18	10
TOTAL	99.4	100.0	99.4	100.00	100.0	99.6	100.6	99.9	99.6	99.0	100.0	99.8	99.8	100.0	100.0	99.9
Equivalent $CaCO_3$	79.9	86.81	88	87.9	87.1	2	18.45	48.2	18.50	87.2	90.	35.0	25.4	14.5	25	29.3
Equivalent $MgCO_3$	4.	4.32	1.4	1.4	1.	5	5.0	0	5.0	1.2	1.	9.	4.8	5.0	2.	4.9

TABLE 3.10: CHEMISTRY AND MINERALOGY OF REPRESENTATIVE CLASTIC SEDIMENT SAMPLES From THE VARIOUS MIDDLE TO LOWER CRETACEAN FORMATIONS

MAJOR ELEMENTS IN OXIDE WEIGHT PERCENT; MINOR ELEMENTS IN PPM MINERALS IN PERCENTAGES ESTIMATED FROM POLISHED AND THIN SECTION.

Formation Name	Kar_1 Normal Marine				Mar_2 Regressive Marine			Kar Continental		Kb Continental			Kea_1 Transitional			Kea_2 Marine		
ROCK TYPE:	Calc. Sandstone		Green-Black Shale		Silty well bedded Shale	Sandstone		Sandstone		Sandstone-Siltatone-Clay			Sandstone-Shale			Sandstone-limestone-Shal		
Sample No DC)	DC210	319A	205	254	299 & 302	300	DC368AC & 243	293 & 227	294	224	308A	253A & B	251B	251A	258A	230	529	230
Serial No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14A	14	15	16	17
DEPTH (m)	-	-	2.5	6.0	-	-	-	1.1	2.3	1.5	1	3.7	3.5	7	-	-	-	-
SiO_2	65.94	10.0	51.57	51.01	70.4	4.5	42.9	76.4	73.32	71.0	71.0	69.1	64.0	63.1	63.4	71.0	68.9	63.9
Al_2O_3	13.15	10.5	15.0	16.46	13.4	16.3	16.8	9.5	11.31	9.2	11.2	13.1	13.7	16.49	9.8	11.2	9.1	13.8
Fe_2O_3	2.48	1.4	2.0	2.06	1.8	8.0	5.6	1.4	1.0	4.7	2.4	3.6	1.8	2.47	7.3	3.6	2.2	5.10
MgO	0.001	0.33	0.91	1.15	0.70	2.7	1.9	0.33	0.12	1.5	1.8	1.6	2.0	1.0	0.62	1.6	1.3	2.1
FeO	6.09	10.0	7.02	11.04	4.98	14.0	15.0	9.6	4.0	11.0	9	7.0	5.0	6.0	13.3	8	4.0	10.6
CaO	3.09	4.6	0.08	0.78	0.07	0.60	2.3	0.6	1.53	0.63	0.66	0.64	0.58	1.11	0.01	0.64	0.21	0.48
MnO	0.70	-	0.09	0.01	0.001	0.001	-	-	-	-	-	-	0.10	-	-	-	0.01	-
Na_2O	3.30	0.07	0.68	0.41	0.10	0.06	4.84	0.07	2.34	0.006	0.003	0.005	0.07	0.30	0.08	0.005	0.05	0.07
K_2O	5.43	2.20	6.0	5.16	2.50	4.29	5.16	5.16	5.36	3.61	3.59	3.60	4.30	5.10	2.20	3.6	3.3	4.3
P_2O_2	-	0.03	0.06	0.31	0.03	0.16	0.40	0.03	0.03	0.20	0.22	0.21	0.13	0.13	0.02	0.21	0.19	0.13
TiO_2	-	0.001	0.06	0.02	-	0.01	1.70	0.001	0.001	0.12	0.12	0.12	0.50	0.65	-	-	0.001	-
S	-	0.90	5.0	7.29	1.3	2.2	2.90	0.80	0.04	0.04	0.04	0.04	0.42	0.11	3.3	0.04	0.18	0.40
SO_3	-	-	-	-	-	-	-	-	-	-	-	-	-	0.64	-	-	-	-
Ignition Loss	-	-	11.47	4.03	4.699	4.27	-	-	-	-	-	-	7.4	2.63	-	-	8.57	-
TOTAL	100.19	100.0311	100.07	99.72	99.98	100.091	99.5	99.83	00.05	100.016	100.023	99.689	100.00	99.53	99.83	99.895	100.02	99.88
Pb	215	223	200	205	125	309	240	200	230	220	115	100	200	200	250	205	160	270
Zn	90	85	100	102	65	10	91	75	70	51	62	500	100	140	111	60	60	100
Ni	60	56	30	34	40	120	150	60	61	67	62	65	30	40	100	25	70	70
Co	70	65	40	42	42	129	105	70	72	69	70	66	40	50	112	90	75	23
Mn	-	10	-	-	-	-	150	100	200	1000	2650	950	-	100	50	950	-	73
V	270	220	304	30	170	130	110	260	250	271	73	70	120	160	210	70	270	210
U	10	5	10	100	10	5	10	155	122	15	8	10	5	10	5	2	2	4
Li	25	20	30	40	10	30	25	20	20	39	41	40	40	15	25	40	30	44
Ba	90	25	130	140	180	270	260	100	150	300	291	280	300	60	100	280	210	300
Sr	15	10	30	34	10	30	260	20	41	24	26	25	30	10	10	25	10	10
Rb	105	105	30	30	140	230	50	100	103	121	110	120	290	4	110	25	10	20
B	-	-	185	180	185	180	240	-	-	-	-	-	-	170	135	160	135	290
Ga	10	5	13	15	15	20	2	4	3	3	5	4	20	7	8	10	11	4
Ag	60	88	300	505	204	200	5	10	10	4	5	3	8	-	5	3	8	9
As	62	60	45	38	50	35	35	45	49	57.5	60	60	45	35	50	53.0	52	50
Quartz	12	11	4	4.5	-	-	10	20	24	3	3	2	4	6	1	2	1	2
K. Felspar	2	-	2	2.5	-	-	2	10	7	-	-	2	4	6	1	2	1	2
Plagioclase	9	25	24	23	24	40	38	6	7	19	20	20	21	25	35	20	20	20
Mica	5	-	5	9	15	10	10	4	1	-	3	3	9	16	-	7	5	10
Chlorite	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	2	-
Dolomite	1	-	5	6	-	1.0	2.0	2	2	2.5	1	-	-	2	1	1	1	-
Pyrite	-	-	-	-	1	-	5	-	-	-	-	-	-	-	-	-	-	-
Magnetite	2	2	5	4	1	5	5	4	4	2	4	4	4	1	2	2.5	4	1
Hematite	1	-	-	2	2	1	1	-	-	-	-	-	1	2	-	-	-	-
Tourmaline	1.5	-	2	2	1.0	-	1	2	1	1	-	1	2	2	1	-	-	3
Zircon	3.4	1.4	-	2	-	1.0	2.0	-	-	1	-	-	1.0	-	-	-	-	-
Leucoxene	-	-	-	-	-	0.7	-	2	2	2	3	1	3.0	1	1	3.5	2	2
Hatite	3.4	1.4	7	5.0	1.0	-	3.0	1	1	-	2	-	-	-	-	-	-	-
Limonite	1.0	0.6	1	1.1	1.0	0.7	1.0	1	1	-	1	1	2.5	1	0.8	4	4	1
Monazite	1	-	-	0.9	-	-	-	-	-	-	-	-	-	1	-	2.0	3	-
Sphene	99.9	100	100	100	100	99.7	100.0	100.0	100.0	100.0	100.0	100.0	99.5	100	99.8	100	100	100
TOTAL																		

TABLE 6.2A. RESULTS OF AN ANALYSIS OF STREAM SEDIMENTS

OF STREAM DRAINING BURU HILL MINERALIZED ZONE M/= MIDDLE STREAM SEDIMENTS: R, L = RIGHT AND LEFT BANK SOIL SEDIMENTS RESPECTIVELY.

Sample No.	PH of Stream Water	Cx Pb ppm	Cx Zn ppm	Cx Ag ppm	Cx Cu ppm	Cx Ni ppm	Cx Co ppm	Remarks
T533		60	5	0.3	13	8	10	March, 1980
R533		220	27	0.4	20	12	26	NW - SE
L533		50	5	0.6	20	12	26	Trending incised
T534		300	65	0.6	20	11	15	Valley of
R534		300	63	0.5	16	13	15	R. Buru and
r534		495	41	3.0	18	9	6	its NNE-SSW trending
T535	7.0	500	62	0.7	8	12	11	dry narrow
R535		500	63	0.8	10	6	9	deep valleys
L535		500	60	0.8	10	8	13	of its tributary streams
L535A		1000	207	3.0	15	9	10	dissecting & draining
T536		500	63	0.5	18	10	14	Southern slope of Buru Hill
R536		510	65	1.0	10	6	15	in Axial
L536		505	60	0.5	18	13	24	area
T537		520	60	1.0	23	6	15	of Buru
R537		503	67	3.0	8	13	24	anticiine, with
L537		495	55	0.5	23	16	17	NE-SW axis. Flakes of
T552	7.0	517	65	3.0	25	15	15	Steel grey
R552		500	60	0.5	18	16	10	granular
L552		420	60	0.8	15	9	10	disseminated galena
T553		450	58	0.9	81	10	14	in NNE trending
R553		430	45	0.5	85	9	10	narrow
L553		50	6	0.7	15	10	14	parallel
T554	7.5	50	6	3.0	8	11	17	vertical fractures
R554		250	30	2.0	15	16	16	associated
L554		20	6	1.0	20	15	15	with-saline spring (DC. 430) and barren albitized dolerite dyke (DC. 178).

TABLE 6.25B: RESULTS OF AAS ANALYSIS OF DRAINAGE SEDIMENTS SAMPLES FROM IGBUR STREAM DRAINING THE IGBUR VALLEY DISSEMINATED GALENA ZONES: 0.25KM WEST OF IGBUR VILLAGE.

Sample No.	PH of Stream Water.	Cx Pb ppm	Cx Zn ppm	Cx Ag ppm	Cx Cu ppm	Cx Ni ppm	Cx Co ppm	Remarks
M65	7.5	500	60	0.9	15	8	10	June, 1980.
R65		500	65	1.0	20	12	20	
265		1000	200	0.6	20	12	15	
M466	7.5	450	66	0.8	25	10	14	
R66		299	50	0.9	16	13	14	Disseminated
L66		400	60	1.0	18	10	11	Galena
M127	8.0	300	51	3.0	8	13	16	Mineralization
R127		200	30	2.1	10	7	9	in NNE
L127		300	48	0.7	11	9	10	trending
M128	7.5	500	66	0.8	14	10	12	vertical
R128		460	64	3.0	19	12	13	parallel
L128		960	180	1.7	11	11	15	fracture
636	7.0	500	65	0.5	10	6	8	zone in
R636		500	66	1.0	12	13	14	Albian
L636		500	62	1.0	22	6	7	Silicified
M637	6.0	600	70	3.0	23	13	13	Siltstone.
R637		300	42	0.5	8	16	17	Outcrop
L637		600	65	3.0	24	15	15	of basement
M638	6.5	1000	202	0.8	26	16	16	(Igbur
R638		290	40	0.9	27	9	10	Inlier)
L638		1111	220	0.5	25	10	14	about 5m
M639	6.0	500	60	0.9	18	9	10	west of
R639		420	45	1.2	16	10	14	the Ore
L639		500	6.1	2.1	15	11	17	body.
M640	6.0	300	45	3.0	80	16	16	
R640		300	40	1.5	70	15	15	
L640		300	44	0.9	15	10	10	
M641	6.0	200	33	2.3	8	11	11	
R641		150	36	1.2	20	9	10	
L641		300	44	3.0	30	17	17	

TABLE 3

SAMPLES FROM UAVANDE STREAMS DRAINING MINERALIZED ZONES IN NYOSU-IYORSHAGHER AREA.

Sample No.	PH of Stream Water	Cx Pb ppm	Cx Zn ppm	Cx Ag ppm	Cx Cu ppm	Cx Ni ppm	Cx Co ppm	Remarks
M684		968	201	1.0	19	10	10	June, 1980
R684		809	170	1.0	20	11	20	Upper and
L684		860	180	0.9	29	21	23	middle section
M685		1000	210	0.7	31	29	30	of NW-SE
R685		1000	200	0.9	32	12	15	flowing R. Uavande
L685		160	189	0.6	34	10	11	andits
M686		1011	220	1.2	26	13	14	tributaries
M631	5.0	1000	205	1.9	25	10	11	draining
R631		1120	260	2.0	24	13	14	Iyorshagher
L631		1009	210	1.6	23	15	16	Nyosu hilly area
M632	2.5	1190	275	2.5	22	7	9	underlain by
R632		1086	226	3.0	29	9	10	fine-Albian
L632		1000	201	3.0	32	10	12	sandstone-
M634	7.0	1000	200	0.9	32	12	16	siltstone and
R634		989	195	0.9	31	11	14	grey-greenish
L634		1080	209	1.0	19	6	8	black, sandy
M635A	9.5	1000	205	0.6	29	113	14	shales and
R635A		1000	210	0.5	34	6	7	mudstone
L635A		1000	209	0.9	36	13	13	mineralized
M635B	9.5	1121	280	1.3	31	16	16	in finely
R635B		1100	206	1.5	39	15	16	granular "steel
L635B		1000	200	1.9	40	15	15	grey" Shiny
M635C	7.0	1125	220	2.0	41	17	17	specks of
R635C		1300	250	3.0	42	10	14	galena
L635C		720	120	3.1	40	11	9	dispersed
M635D	6.0	1000	200	0.9	20	10	10	within the
R635D		1000	201	0.8	21	13	10	marine
L635D		960	194	1.5	20	15	15	sequence in
M635	6.5	1000	200	2.0	25	10	10	NNE - SSW
R635		260	49	0.9	26	9	10	Parallel -
L635		605	130	0.8	27	17	17	Vertical fractures.

Appendix
(B)

Tables 6.20 A and B showing respectively physical and chemical Tests for radio active content of selected silicified sedimentary and other prospective rocks from the study area.

TABLE 6.20A RADIO ACTIVE TEST FOR SOME SAMPLES

SAMPLE NO.	BACKGROUND READINGS IN COUNTS PER SECOND	INSIDE READING IN COUNTS PER SECOND	OUTSIDE READINGS IN COUNTS PER SECOND
DC.344	112.5	112.5	171.5
DC.341	112.5	125	162.5
DC.288B	112.5	125	175
DC.167	112.5	125	175/162.5
DC.177B	112.5	112.5	162.5
DC.337	112.5	125	162.6
DC.177A	112.5	112.5	168.5
DC.377	112.5	113.5	162.5
DC.344	112.5	118	168
DC.221	112.5	112.5	150
DC.222	112.5	112.5	150
DC.227	112.5	112.5	150
DC.421B	112.5	112.5	150

TABLE 6.20B ANALYSIS OF SOME SAMPLES FOR RADIO ACTIVE ELEMENTS

SAMPLE NO.	U ppm		Y ppm	
DC.167	395		382.27	
DC.177B	285.7		444.08	
DC.288B	276.99		222.93	
DC.341	294.12		111.41	
DC.344	237.75/	231.05	434.65/	222.43
DC.337	113.24		241.64	

TABLE 6.20C CONTRASTS BETWEEN AVERAGE METAL CONTENTS OF MINERALIZED AND BARREN STREAM SEDIMENTS

	U ppm	Pb ppm	Zn ppm
MINERALIZED SILICIFIED CHERTY	100	555.6	119.6
BARREN SILICIFIED SILTSTONE	1.16	123.5	121.6
CONTRAST	86.2	4.5	0.98

Appendix

C)

(1) Tables 4.14a - C and 4.15

Showing statistical measurements of marginal fractures and fold axes in the Study area.

Table 4.14A STATISTICAL MEASUREMENTS OF MARGINAL FRACTURES

LOCALITY: Road cuttings and Exposures in FIYAYI - ARUFU - AKWANA - YATIEV AREA, 1:100,000 SHEET 252 (AKWANA)

FORMATION: "ASU RIVER GROUP" BEDS (Middle - Late Albian)

ROCKS: Limestone and/or conglomeratic sandstone, as basal beds, shales, mudstones, siltstone in alternating Sequence.

BEDDING: $10^{\circ}/10$ NW or SE, $135^{\circ}/45^{\circ}$ NE or SW to $N30^{\circ}E/10^{\circ}NW$ or to $N45^{\circ}E/45^{\circ}NW$

SE QUADRANGLE

Joint and Faults

Loc. No	Evaluation	Attitude	Space Filling
64	3	145/52NE(50°)	gapping
Yatiev	3	145/52NE(50°)	quartz
	3	140/52NE(50)	quartz
	3	140/50NE(55°)	
	3	145/54NE(50°)	
	3	145/52NE(45°)	
	2	50/0	
	2	50/0	
	2	50/0	
	2	45/0	
	2	105/50NNE(15°)	
	2	105/50NNE(15°)	
	2	100/50NNE(20°)	
	2	105/45NNE(15°)	
	2	20/58SE(110°)	
	2	20/60SE(110°)	
	2	115/50SE(115°)	
	4	95/vertical	Brine and quartz

Loc. No	Evaluation	Attitude	Space and Filling
64	4	360°/Vertical	Brine and quartz
	4	160°	quartz
	4	145/Vertical	
	4	130	
	3	125/Vertical	
	3	50/51 NNW (310°)	
	2	130/58°NE (40°)	
	2	95/Vertical	.uartz and Pyrite
65	3	160°Vertical	
	2	360° Vertical	
66	4	155/22NE (65°)	quartz geode Vesicular
	4	155/60SW (245°)	quartz
	2	60/Vertical	Vesicular quartz
64	4	130/30-50NE (40°)	
Yatiev	4	130/30-50NE (40°)	
	4	135/30-50NE (40°)	
	4	135/30-50NE (40°)	
	4	130/30-50NE (40°)	
64	4	130/30-50NE (40°)	
Yatiev	4	140/30-50NE (40°)	
	4	130/30-50NE (40°)	
	2	160/10NE (40°) B	
	2	160/10NE (40°)B	
	2	170/10NE (40°)B	
	2	160/10°NE (40°)B	
	2	160/10°NE (40°)B	
	2	360/10E (90)	
	2	360/10E (90)	

Loc. No	Evaluation	Attitude	Space and Filling
	2	360/10E (90)	
	2	360/10E (90)	
	2	130/55NE (40)	
	2	95/Vertical	
	3	130/30-50 NE (40)	
	3	130/50NE (40)	
	3	130/40 NE (40)	
	4	135/30 NE (40)	
	3	130/40 NE (40)	
	3	130/50NE (45)	
	3	140/40NE (45)	
	3	130/50 NE (45)	
	2	160/10SW (250)	
	2	170/5SW (260)	
	2	160/10SW (250)	
	2	160/5SW (250)	
	2	360/5E (90)	
	2	360/10E(90)	
	2	360/10E (90)	
	2	360/10E (90)	
	2	360/10E (90)	
62C	4	130/41SW (220)	
Nomke-	4	145/41SW (235)	
haghor/	2	90/Vertical	
Takor	2	95/Vertical	
	2	50/20NW (335)	
	2	65/35NW (335)	

Loc. No	Evaluation	Attitude	Space Filling
	2	40/64 NW (330)	
	3	145/52 NE (50)	
	3	145/52 NE (50)	
	3	140/52 NE (50)	
	3	140/52 NE (50)	
	3	145/54 NE (50)	quartz
61C	3	145/52 NE (45)	quartz
	2	50/0°	
	2	50/0°	
	2	50/0°	
	2	50/0°	
	2	45/0°	
	2	105/50 NNE (15)	
	2	105/50 NNE (15)	
	2	20/58 SE (110)	
	2	20/60 SE (110)	
	2	115/58 SE (115)	
	2	95/Vertical	
	3	360/Vertical	
	4	145/Vertical	quartz
63	2	45/5 SE (135)	
Lahaci	3	95/Vertical	
	3	135/30 NE (40)	
	3	150/Vertical	
122	3	45/Vertical	
	2	310/20 NE (75)	
123	3	45/Vertical	

Loc. No	Evaluation	Attitude	Space Filling
	2	300/20 SW (75)	
	3	345/20 SE (75)	
Meyian	3	340/30 NE (75)	
	2	30/Vertical	
125	3	45/Vertical	
Agar	2	360/Vertical	
	3	130/Vertical	
	3	135/54 SW (50)	
	2	120/50 NE (15)	
126	3	45/Vertical	Galena
Ubur-	3	50/51 NW (310)	
Kyar	3	130/30 SE (40)	
	3	140/52 NE (45)	
	2	50/Vertical	
	3	330/Vertical	Limonite & quartz
127	4	45/Vertical	
Agie	3	50/60 NW (310)	
	3	130/30 SE (40)	
	3	145/Vertical	
	3	140, 52 NE (30)	
	3	140/50 SE (55)	
	1	160, 10 NE (40)	
	1	170/10 NE (40)	
	2	160/10 SE (40)	
	1	160/10 SE (40)	
	2	30, 60 NW (310)	
	1	30/58 NW (310)	

Loc. No	Evaluation	Attitude	Space Filling
	4	340/Vertical	
	3	350/Vertical	
83	3	300/Vertical	Calcite & quartz
	3	45/NW (315)	
	4	300/Vertical	quartz
83	3	350/Vertical	
84	2	175/15 NE (45)	
	2	45/20 SW (240)	
	3	130/20 SW (240)	
	3	110/45 NE (15)	
62B	4	135/Vertical	
Irim	3	50/51 NW (310)	

STATISTICAL MEASUREMENT OF FRACTURE

TABLE 4.14B. IN BASEMENT TERRAIN IN AROFU IGBUA-ABADA AND YATIEV AREAS

LOCALITY: OUTCROPS UNDERLYING BASEMENT INLIERS, RIDGES AND BLOCKS.

FORMATION: PRECAMBIAN - LOWER PALAEOZIC BASEMENT COMPLEX.

ROCK TYPES: GRANITIC GNEISS, OLDER GRANITES, ETC.

FOLIATION: 65/65SE (110°), 10°/80°NW (305°), 45°/30°NW (300°) 265/70°NW (300 to 350°)

JOINTS AND FAULTS

LOCALITY AND NUMBER	EVALUATION	ATTITUDE	SPACING FILLING	LOCALITY AND NUMBER	EVALUATION	ATTITUDE	SPACING FILLING
30.110	3	285/Vertical		IGUGA	1	240/Vertical	
Arofu	3	235/80SW(255)		INLIER	3	5/Vertical	
Inlier	2	5/Vertical		108.33	3	30/Vertical	
	2	264/Vertical			3	30/80NW(330)	
	3	190/Vertical			3	340/Vertical	
	3	190/77NW(280)			2	95/Vertical	
	2	145/Vertical			2	360/Vertical	
	2	139/Vertical			2	170/Vertical	
	2	360/Vertical			3	125/Vertical	
	2	360/80E(90)			2	50/51NW(320)	
	2	140/Vertical			2	130/58NE(40)	
	3	290/Vertical			2	95/Vertical	
	4	130/Vertical			2	120/Vertical	
	4	132/Vertical			3	175/Vertical	
	4	130/Vertical			3	165/Vertical	
	2	100/Vertical			2	10/Vertical	
	2	105/Vertical			3	165/41SW(353)	

LOCALITY AND NUMBER	EVALU-ATION	ATTITUDE	SPACE FILL-ING	LOCALI-TY NUMBER	EVALUA-TION	ATTITUDE	SPACE FILL-ING
	2	10/Vertical			2	30/Vertical	
	3						
	3	270/Vertical			2	[illegible]/64NW(330)	
	3	270/135(180)			2	65/[illegible]W(335)	
	4	130/Vertical			2	5/Vertical	
	4	130/Vertical			3	170/Vertical	
64A	4	145/Vertical		64A	3	165/45[illegible](255)	
[illegible]	4	130/5[illegible](40)			3	160/[illegible](225)	
nagher	2	60/Vertical			3	170/Vertical	
	2	5/Vertical			2	30/Vertical	
	2	10/Vertical			2	10/Vertical	
	3	165/415W(255)			2	65/Vertical	
	3	170/415W(255)			2	300/Vertical	
	4	140/Vertical			3	190/Vertical	
	2	200/Vertical			2	230/Vertical	
	2	190/Vertical			2	257/Vertical	
	3	175/Vertical			3	150/Vertical	
	4	143/Vertical			3	155/Vertical	
62B	1	240/Vertical			3	145/Vertical	
Knisugh	3	6/Vertical			3	130/Vertical	
	3	35/Vertical		36A	4	145/Vertical	qtzo-felsp. pegma-titic mater-ial
	3	30/80NW(330)		[illegible]aama	4	100/Vertical	
	2	95/Vertical		[illegible]gch	2	15/60[illegible]/105°	
	2	360/Vertical			3	10/60[illegible](100)	
	2	170/Vertical			3	20/55[illegible](110)	
62D	4	360/Vertical			3	100/Vertical	
CHEACHIL	4	355/Vertical			3	110/Vertical	

LOCALITY AND NUMBER	EVALUA-TION	ATTITUDE	SPACE FILL-ING	LOCALITY NUMBER	EVALUA-TION	ATTITUDE	SPACE FILL-ING
	4	5/Vertical			3	120/Vertical	
	4	10/Vertical			2	165/Vertical	
	3	170/Vertical			2	170/Vertical	
64A	4	130/Vertical			2	180/Vertical	
Ridge	4	120/Vertical			2	190/Vertical	
	4	125/Vertical			2	195/Vertical	
	3	50/49NW(320)			1	200/Vertical	
	2	130/58NE(40)			3	45/Vertical	
	2	96/Vertical			3	50/Vertical	
	4	120/Vertical			3	55/Vertical	
	3	175/Vertical			3	240/Vertical	
	3	10/Vertical B			3	247/Vertical	
	3	15/Vertical B			3	250/Vertical	
	3	20/Vertical B			3	150/Vertical	
86B	4	180/Vertical	Bio-tite		2	47/50SE(137)	
Tsheno - gudu	4	175/Vertical			2	45/45SW(230)	
	4	178/Vertical			3	240/Vertical	
	3	155/Vertical			3	245/Vertical	
	3	160/Vertical			3	243/Vertical	
	3	170/Vertical			3	250/Vertical	
	3	40/50SE(125)			3	245/Vertical	
	3	40/45SE(130)			2	245/Vertical	
	2	45/47SE(135)		139	3	145/Vertical	
3km S. of Mbeda	2	130/Vertical			4	45/Vertical	

TABLE 4·14B Continue

LOCALITY: TYOBAN Quarry and Envirous, Hills, Ridges.

ROCK TYPE: Pan African Older Granite in the Precambrian Basement Complex terrain, The granite is in some places foliated and in others massive.

FOLIATION: 20°/50°SE (110°) or 165°/60°NW (500°)
170°/Vertical or 120°/80°SW (210°)
150°/60°NW (345°) or 150°/ 60°SW (255°)

LOCALITY AND NUMBER	EVALUA-TION	ATTITUDE	SPACE FILL-ING	LOCALI-TY AND NUMBER	EVALUA-TION	ATTITUDE	SPACE FILL-GING
56-58	4	360/Vertical		58-58	2	200/Vertical	
Tyoban	4	5/Vertical		Tyoban	2	210/Vertical	
	4	10/Vertical		Quarry	2	200/Vertical	
	4	355/Vertical			2	195/Vertical	
	4	19/Vertical			2	195/Vertical	
	4	180/Vertical			3	165/Vertical	
	3	320/Vertical			3	165/Vertical	
	3	315/Vertical			5	160/Vertical	
	3	320/Vertical			2	170/Vertical	
	3	317/Vertical			3	170/Vertical	
	3	315/Vertical			3	175/Vertical	
	4	360/Vertical			1	150/Vertical	
	4	360/Vertical			1	155/Vertical	
	4	180/Vertical			2	265/Vertical	
	3	45/Vertical			2	265/Vertical	
	3	45/Vertical			2	270/Vertical	
	3	45/Vertical			2	270/Vertical	
	3	43/Vertical			2	270/Vertical	

LOCALITY AND NUMBER	EVALUA-TION	ATTITUDE	SPACE FILL-ING	LOCA-LITY AND NUM-BER	EVALUA-TION	ATTITUDE	SPACE FILL-ING
	3	40/Vertical			2	265/Vertical	
	3	190/Vertical			3	45/Vertical	
	3	190/Vertical			3	315/Vertical	
	3				4	360/Vertical	
	3	165/Vertical			2	270/Vertical	
	2	165/35E(255)			4	180/Vertical	

Table.4.11a:

STATISTICAL MEASUREMENT OF SILICEOUS (CHERTY) STRUCTURES (Joints, Fractures, faults etc) ON FOLDED, DEFORMED SILICIFIED ALBIAN SEDIMENTS.

LOCALITY: Igbur - Arufu - Akwna, Anyin - Wende, areas.

FORMATION: ASU RIVER GROUP BEDS (MIDDLE - LATE ALBIAN)

ROCK TYPE: Silicified (Cherty) Siltstone, sand -stones and limestones.

BEDDING: 10°/30°NW or SE to 135°/70°, NE of SW

Locality or No	Evaluation	Attitude	Space-filling & Remarks	Locality or No	Evaluation	Attitude	Space-filling & Remarks
1-2	4	260°/Vert	Some gaping			6°/52°(260°)	Tight
1-2	4	260°/Vert	20-40mm others filled with galena quartz fluorite, calcaloite veins		4	6°/57°W(260°)	Tight
Arufu	4	265°/80NW(290°)			4	6°/60°W(260°)	Tight
Outskirts	4	266°/85°NW			4	6°/65°W(260°)	Tight
					4	6°/65°W(260°)	Tight
					2	310°/60°SW(250°)	Filled with siliceous (Opaline) Material
						310°/Vert	
	3	360°/Vert	Tight or filled with Siliceous Cherty Material and calcite of Pyrite.				
	3	175°/Vert					
	3	10°/Vert				310°/60°SW(250°)	
						310°/Vert	
				4	2	324°/Vert	Silicified (Cherty) limestone and siltstone with patches or dissemination of galena fluorite and
					2	324°/80°ENE	
				NNW		320°/Vert	
					2	315°/Vert	
				Arufu	2	315°/80°ENE	
	3	5°/Vert			2	310°/Vert	
	2	320°/Vert	Tight		2	322°/Vert	
	2	310°/Vert	Tight			Also with water	
	2	315°/Vert	Tight				

Locality or No	Evaluation	Attitude	Space-filling & Remarks	Locality or No	Evaluation	Attitude	Space-filling & Remarks
½Km	3	135°/Vert	Slickensides on siliceous (Cherty) rock Within finely bedded grey siltstone				
NW of	3	135°/47° SW(263°)					quartz, flourite and quartz along bedding
Arufu	3	130°/47° SW(220°)					
	3	134°/47° SW(224°)					
	3	138°/Vert					
5	2	310°/60° SW(250°)	Capping10-20mm of filled with (Cherty) Siliceous material	8	3	300°/Vert	
¾Km	2	315°/60° SW(225°)			3	300°/89° NE((930°)	Deformed
¾Km	2	310°/Vert			3	190°/Vert	Cherty structure in Silicified siltstone
north	2	310°/Vert			3	185°/Vert	
of	2	230°/Vert			3	180°/Vert	
Arufu					3	175°/Vert	
					4	270°/Vert	
6	2	20°/15° SE(130°)			4	270°/85° NE	
N-S	2	20°/45° SE(130°)			4	250°/Vert	Galena
trending	2	10°/15° SW(220°)			4	247°/Vert	
Silicified (Cherty) Siltstone ridge	2	20°/45° SW(220°)					
			(181/186)	(181/186) Around Tsead Zum	4	45°/Vert	Capping
					4	50°/Vert	100-200 filled with siliceous
					4	48°/Vert	
					3	140°/Vert	

Locality or No	Evaluation	Attitude	Space-filling & Remark	Locality or No	Evaluation	Attitude	Space-filling & Remark
7	3	355°/Vert	Capping 10-20mm in places filled with crystal-line galena, quarts and Iron Oxide		3	140°/Vert	(Cherty) ferrugeneous material quarts crustification and water R. Uhuver Head stream source area
½Km	3	324°/Vert			3	140°/Vert	
west	3	195°/Vert			3	145°/Vert	
of	3	175°/Vert			3	130°/Vert	
Arufu	3	195 /Vert					
	3	185°/Vert				area	
		45°/60°SE(135°)	Sili - ceous (Cherty) Material and dark brown iron oxide (Hematite)		2	80°/Vert	Tight
		45°/50°SE(135°)			2	75°/Vert	
		45°/Vert		181 Tsea guda Hill Oxide	2	82°/Vert	
					4		
					4		
	2	180°/Vert		185	3	100°/74°NNE (10°)	
	2	170°/Vert		Iyorja	3	60°/Vert	Tight
	2	40°/19°SE(130°	Gapping Ones	87	3	40°/Vert	Gapping 100-
	3	140°/Vert	Gapping Ones	87	4	40°/Vert	Gapping 100-
	3	145 /Vert	filled with silicoeous (Cherty Material and water (Headstream) source area of R. Duhu	Tsegbande Ator	4	45°/Vert	180mm filled with siliceous cherty material and pink felspar
					4	45°/Vert	
					4	60°/Vert	
					3	135°/Vert	
					3	145°/Vert	some Tight gapping some filled with (a) siliceous material (b) Crusty ferr material (c) water.
					3	140°/Vert	
182	3	85°/57°S(170°)	Tight				

Locality or No	Evaluation	Attitude	Space-filling & Remark	Locality or No	Evaluation	Attitude	Space-filling & Remark
Around	2	180°/Vert	Tight				
Wande	2	40°/19°SE(130°)	Tight				
	3	145°/Vert	Tight				
	3	140°/Vert	Tight	85			
				Around	33	150°/70°NE(60°)	Some gapping
				Kulungu	3	130°/85°NE(60°)	filled with
184	3	100°/Vert	Tight		3	130°/Vert	quartz and
3km	3	100°/74 NNE			4	105°/Vert	fer Crustification some
south	3	60°/Vert(10°)			4	80°/Vert	tight mostly Some gapping 180mm.
of Iyorja	3	45°/Vert					
					4	75°/Vert	
				86B	3	130°/50°E(90°)	Pegmatitic
					3	40°/50°SE(125°)	Vein
					2	45°/50°SE(130°)	Tight

	881 NORTHERN LINE			882 SOUTHERN LINE		
FOLDED STRUCTURE	ATTITUDE	LOCALITY	UNDER LYING FORMATION	ATTITUDE	LOCALITY	UNDER LYING FORMATION
MAIN LOGO ANTICLINE	50°/32°NW(320°)	Right bank of R. Akpon -dope near Ake -reke Compd. 0 1½km NE of Ugba	Kar_2	45°/25°SE(135°)	near NW of Ogonyi Compd.	Kar_2
				65°/27°SE(153°)	Headstream area around Compd. of Suwave Loc. 144	
	70°/30°NW(340°)	Around the Compd. near banks of R. Akpon dope flow -ing SW Loc. 144	Kar_2	140°/15°SW(230°)	Hill slope around Iyorkase Compd.	
				125°/25°SW(215°)	1Km South of Tsetsum Compd.	Kar_1
	135°/18°NE(45°)	Ihim Compd. right bank of R. Logo flow -ing in SE-NW direction Loc. 62B		135°/13°SW(225°)	SW Outskirts of Henda Compd. Loc. 65	Kar_1 Shale
				140°/17°SW(230°)	1½km NE of Ariuyen Compd.	
	155°/25°NE(65°)	1km north of Penda Compd. near left bank of R. Logo Loc. 65	Kar_1 Shale	130°/17°SW(220°)	R. Logo Bridge C. 12km north of Ugba Village Loc. C 911	Kar_1
				160°/15°SW(250°)	Behind Cabo Compd. near left bank of R. Logo Loc. 67	Kar_1 ripple Marks SST parallel bedded
	150°/19°NE(60°)	Right bank of R. Logo C. 12km NNE of Ugba Village		265°/20°north (355°)	1km north of Right bank of R. Logo 4km NW of Cabo Loc. 848.	
	60°/25°NW(330°)	Left bank of R. Logo C. 3.5km NW of Cabo Compd. Loc. 844				

FOLDED STRUCTURE	NW LIMB ATTITUDE	NW LIMB LOCALITY	SE LIMB ATTITUDE	SE LIMB LOCALITY	UNDERLYING ROCK UNIT
A M A M U F O L D	45°/24°NW(315°)	Left bank of stream near Tseem Compd. 2km NW of Agberke Loc. 22B	45°/25° (175°)	Road cutting around Agber-ke Compd. Loc.222B	Kar_1
	55°/24°NW(315°)	1km SE of Myame Compd.	75°/30°SSE(165°)	About ¼km SW of Ntam Compd.	
	50°/32°NW(320°)	bank of stream to SW of Tsea-vure Compd.	72°/31°SE(162°)	bank of stream around Tseabaka Compd.	
	67°/29°NW(337°)	14km NE of Getun Compd.	65°/20°SE(155°)	Bank of river Buru ½ SE of Yorhemba Compd.	Kar_2
	110°/20°NNE(20°)	Banks of Buru river near Yorhemba Compd. Loc. 24	65°/30°SE(155°)	1km SW of Harekaa Compd.	
	45°/30°NW(315°)	1km SW of Agbayungo Compd.			
	45°/25°NW(315°)	½km SW of Agbayungo Compound.			

	881			882		
	E OR SE LIMB			W OR NW LIMB		
NAME AND OF FOLD	ATTITUDE	LOCALITY	UNDER LYING FORMATION	ATTITUDE	LOCALITY	UNDER LYING FORMATION
M S T R U C T U R E	36°/10°NW(304°)	Loc. 168 northern out-skirts of Ikpex Compd.	Kar_1 Mud-stone and shale	160°/44°E(270°)	Loc. 166, 2km SW of Ogua Compd. near contact with western margin of Iyoban Older Granite	Kar_1 Sil-ceous Silt-stone shale
	175°/15°S(85°)	Loc. 105A Southern out-skirts of aban-doned Tsehese Compound	Kar_1 Sandy Shel-Silt-stone	47°/65°E	Loc. 107 2.25km NW of Adodo Compound	Kar_1 Sil-ceous clayey silt-stone
	37°/15°NW(107°)	Loc. 107 Around Adodo Compound	Kar_1			

	SE LIMB			NW LIMB		
FOLDED STRUCTURE	ATTITUDE	LOCALITY	UNDER LYING FORMATION	ATTITUDE	LOCALITY	UNDER LYING FORMATION
Maxwell	48°/10°NW(318°)	About 1km NW of Nyongh Compd. 7km NE of Tsekur Loc. 218	Kar_1	45°/10°SE(135°)	Around Compd. of Akabe	Kar_2 SS/S
	35°/8°NW(305°)	Southern outskirts of Tsehair Village Loc. 187	Kar_1	45°/14°SE(135°)	Around Compd. of Tseagbana Nyibarm and Agbeyonon Loc. 89A	Kar_2
	30°/10°WNW(285°)	Near war Compd.C. 5km SW of Tsekur Loc. 213	Kar_2	45°/30°SE(135°)	Around Segebadim Compd. 2.5km west of Tsehair	Kar
	235°/20°NW(325°)	2km SW of Tsekwar Village	Kar_1	30°/20°SE(135°)	8km SW of Tsehm Village Loc. 210	Kar_1
	65°/10°NW(335°)	near Igbaanwam Compd. Loc. 215		50°/10°SE(140°)	2km north of Doga Compd. Loc. 84C	Kar_1
	35°/12°NW(305°)	Right bank N-S floving stream 1km SE of Akabe Compd. Loc. 89A		180°/20°E(90°)	Loc. 269 A 1.5km east of Tsenhee Compd. and 2km NW of Loc. 269 right bank of R. Achagba	Kar_1 HShale and Siltstone
	55°/17°NW(325°)	0.75km N of Doga Compd. Loc. Loc. 84C	Kar_1			
	175°/25°W(265°)	Loc.269A C.1.25km SW of Loc. 269 and 1.8km SE of Tsevhee Nyamka Compd.	Kar_1 shale and siltstone	30°/20°SE(140°	Loc. 168 1km SSE of the Compd. of Jov.	Kar_1 Mudstone siltstone
	left bank of R. Achagba					

FOLD STRUCTURE	ATTITUDE	LOCALITY	FORMATION	ATTITUDE	LOCALITY	FORMATION
S E S E H A N T I C	55°/123° (145°)	Loc.227 Crest/Hari of flat topped hill rock ridge north of north of Kpan Compd.	Sandstone Limestone	20°/11°NW (290°) 5°/14° (275°)	To the north and NE of Tsenyamkume Village	Kari Shale Siltstone
				11.5°/80° (227°)	Loc. 294° About 1.75km Udaa Compd.	Kar_1 Siliceous Clayey Siltstone
	5°/15° (95°)	To the north and NE of Tsenyamkume Village	Kar_1 Shale Siltstone	170°/12 (200°)	Loc.285° left banks of R.Yoti flowing in Direction 25°C 2km SE of Udaaa Compd.	Kar_1 Siliceous Clayey
	180°/70 (90°)	about 2.25km south of loc 284 and 1.5km West of the Compd. of Isebabe	Kar_1 Siliceous Siltstone	45°/70°NW (315°)	In southern outskirts about 2km of Kyam compd.	Kar_1 Siliceous
	35°/82° (103°)	Loc.288 Centhe hill slopes in contact area near southern margin of Udama Granite	Kar_1 Siliceous Siltstone			
	5 /60	Loc. 288A 0.75km South of loc. 288 further contact between cretaceous sedi - ments and precambian				

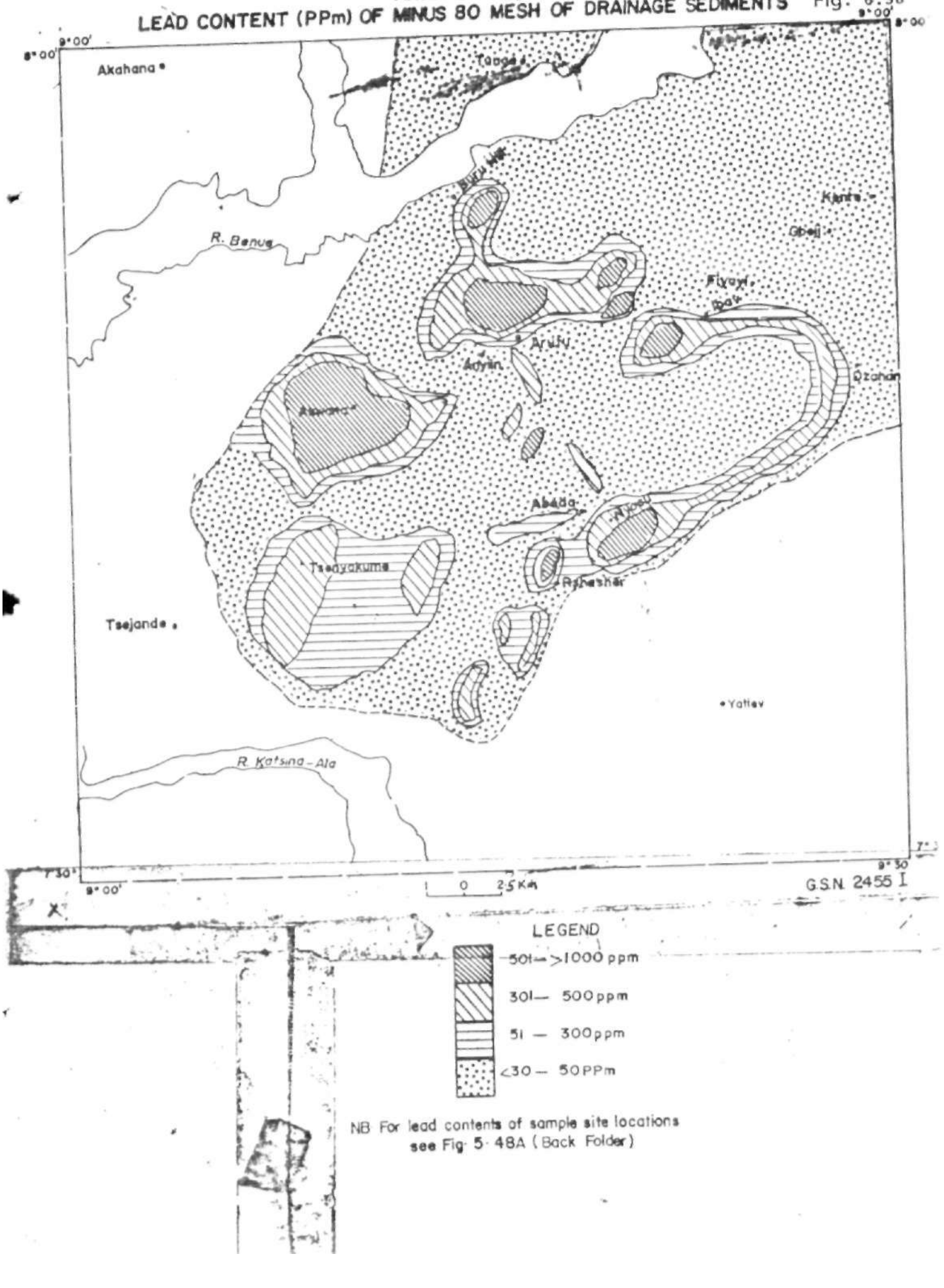
Appendix
(d)

Pit Logs showing (basemetal) element Variations with depth in soil profiles.

SHEET 252

AKWANA

LEAD CONTENT (PPm) OF MINUS 80 MESH OF DRAINAGE SEDIMENTS Fig. 6.58



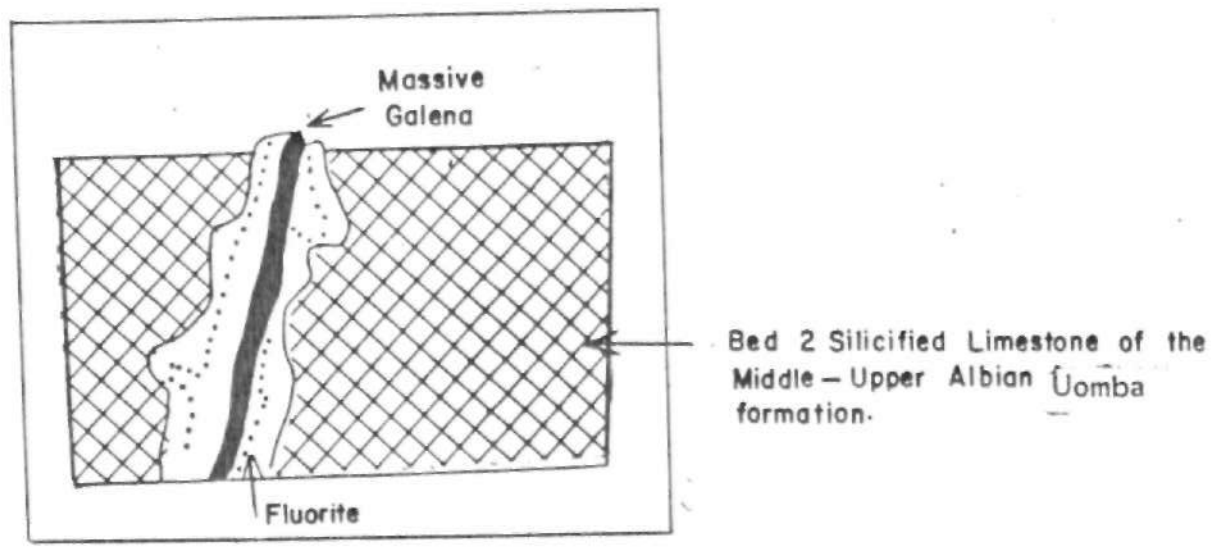


FIG 5:59: Skarn without Intrusion Model (Burt and Rose 1979, P. 229) Proposed for the Emplacement of Galena–Fluorite Deposits at Arufu and Akwana.

G. S. N. 2460 A

PIT LOGGING FORM

SHEET			PIT NO.	PIT LOCATION	
252 (AKWANA N.E.) 1:50,000			A5-A6	2Km. N.E. OF ARUFU	
LOGGED BY	DATE	SAMPLED BY	DATE	ELEVATION	DEPTH
D. U. CHUKU	17-5-78	D. U. CHUKU	17-5-78	137·16m a.b.s.l.	1·50m

SAMPLE NO.	DEPTH INTERVAL Cmx	DIAGRAMATIC LOG Lithology		HxPb ppm	HxZn ppm	HxAg ppm	HxCo ppm	HxNil ppm	CxCu ppm
S92	0 — 6		Silty and gritty sand	1620	475	0·8	15	20	20
S93	6 — 12			4595	475	3·0	15	25	25
	12 — 18		Fine clayey sand	1350	480	4·0	20	28	23
S94	18 — 24		Fine sand with fragments of siltstone	1400	485	8·2	30	29	34
	24 — 36			16500	490	12·5	35	30	38
S95	36 — 48		Laterite and Lateritized weathered siltstone	17500	495	17·8	45	40	40
DC163F	48 — 60			19000	492	22·8	61	59	52
DC164	60 — 84			20000	452	35·5	60	58	63
Rx21A	84 — 96								64
DC163	96 — 108		Siliceous limestone with Galena	2·4%	582	46·6	22	18·8	65
	108 — 120								
	120 — 130								
DC163D	130 — 140		Siliceous limestone with Galena	2·4%	582	57·6	23	18	70
	140 — 150								

FIG. 5·60: Variations in some (basemetal) element abundances at Pit A5-A6 (about 2Km N.E. of Arufu Village).

GSN 2456Q

SHEET			PIT NO	PIT LOCATION	
252(AKWANA N-E·) 1:50,000			A16	400m. N. E. of Arufu	
LOGGED BY	DATE	SAMPLED BY	DATE	ELEVATION	DEPTH
D. U. CHUKU	17-5-78	D. U.CHUKU	17-5-78	137·16m. a. b. s. l.	1·20m-3m.

SAMPLE NO	DEPTH INTERVAL	DIAGRAMATIC LOG								REMARKS
	Cm	Lithology		Pb ppm	Zn ppm	Ag ppm	Co ppm	Ni ppm	Cu ppm	CxMe
S63	0—6	Silty and gritty sand		4595	490	46	27	15	85	CxMe
S64	6—12			4750	1490	49	17	15	100	CxMe
S64A	12—18	Fine clayey sand		4700	494	50	37	15	110	CxMe
S64B	18—24	Fine sand with frag ments of siltstone		4700	495	52	47	15	120	CxMe
S64C	24—36			4700	495	52	57	15	126	CxMe
S64D	36—48			4700	495	57	57	15	13	CxMe
RX3	48—60			1800	499	58	60	58	135	CxMe
DC151A	60—48	Siltstone								
	84—96									
	96—108									
Rx5 DC150	108—120			14000	500	60	18	15·4	140	HxMe
RX6	120—130			24%	582	64	21	18·8	150	HxMe
DC151	130—140	Siliceous limestone with Gole na.								
	140—150									
	150—200									
	200—300									

Fig. 5·61 Variations of base Metal elements at Pit A16 (about 400m. N.E. of Arufu Village)

GSN 2456[P]