REMOTE SENSING INTERPRETATION OF THE GEOLOGY OF PARTS OF KADUNA, NIGER, KWARA AND SOKOTO STATES, NIGERIA

by

ALBERT N. UDOH

A Thesis Submitted to the Postgraduate School, Ahmadu Bello University, in Partial Fulfilment of the Requirements for the Award of Master of Science Degree (Geology)

Department of Geology
Faculty of Science
Ahmadu Bello University
Zaria.

SEPTEMBER, 1987

DECLARATION

I, Albert Nkeruwem Udoh declare that this thesis is my own work and has not been submitted in any form, for the award of any degree or diploma in any other University or Institution. Information derived from published or unpublished work of others has been duely acknowledged in the text.



Signature of Candidate.

CERTIFICATION

This Project report/thesis/dessertation titled Remote Sensing Interpretation of the Geology of Parts of Kaduna, Niger, Kwara and Sokoto States, Nigeria, by A. N. UDOH, meets the regulations governing the award of the degree of M.Sc. Geology of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Michael Woakes — Date: 23/6/88

Mr. Michael Woakes

Chairman, Supervisory Committee.

Ajibade — Date: 23/6/88

Dr. A.C. Ajibade

Member, Supervisory Committee.

E.C. Ike — Date: 23/6/88

Dr. E.C. Ike

Head of Department.

Date: 9-2-89

Dean, Post Graduate School.

A C K N O W L E D G E M E N T

I am in the first place, grateful to the Almighty God for His mercy and for making everything possible. Secondly, I want to express my gratitude to the authorities at the Geological Survey Department and the Ahmadu Bello University, Zaria for approval to undergo this course.

I wish to express my gratitude to Dr. A.C. Ajibade and Mr. M.E. Woakes for accepting my undergoing this course under them and for their guidance throughout its duration.

I also express gratitude to all the members of staff at the Geological Survey Department, the Ahmadu Bello University, Zaria, the Federal Forestry Department, Ibadan and the Kaduna Polytechnic Kaduna who in various ways contributed to the success of this work.

In the Geological Survey Department, I will like to recall such names as J.A. Ogunkoya, E.A. Fabunmi and others in the Cartography section whose names would form a list were they to be mentioned one by one. Other names in the Geological Survey Department are D.A. Otalor, J.J. Ashama, T.N. Popoola, Kate Onwukeme - all secretarial staff; E.P. Ajaero, A.E. Agumanu, P.O. Oluyide, C.S. Nwajide who are my professional colleagues whose views and assistance proved quite helpful.

At the Department of Geology, A.B.U., Zaria, I found the entire staff and some students I associated with, quite friendly and helpful.

These alone provided the necessary atmosphere to pursue the work to an end. Dr. Abba is always ready to assist while Mr. Woakes is conscientious and patient.

The foresight of the Director of the Federal Forestry Department in providing a SLAR coverage for the country is acknowledged. At the Kaduna Polytechnic, Dr. V.P. Sharma and Mr. Odeyemi assisted me, in reproduction. I am grateful to them.

I am also grateful to my late parents whose contributions saw me to where I am and to my wife and children whose role in the family enables me to strive here and there.

A B S T R A C T

The fact that geological formations and structures appear as ground surface features and are observable on remote sensing data sources, permits the use of. such data sources in this type of investigation. The geological features themselves also display characteristics which are either distinctive, or, allow inferences to be made as to their attitude.

Landsat images served as the main sources of information studied but these were supplemented by SLAR and aerial photographs for detailed study of critical areas. Field checks were carried out along selected routes for ground truthing of image interpreation.

Thus, the image-study and ground-truth verification of the area of study shows the banded gneiss as the most extensive rock type within which other rock types occur. It is variably migmatised with several types of migmatites distinguished. It is interpreted as the oldest rock unit and basal to the metasediments.

Two metasedimentary groups are distinguished structurally; an earlier group of generally arcuate formations and a later group of the formations which trend N-S.

The later group forms two major N-S belts; the Zuru Schist Belt (ZSB) and the Kusheriki Schist Belt (KSB). These belts, as 1:1,000,000 images revealed and were confirmed by field observation, contrast in their principal rock types; relatively more abundant meta-psammites in the ZSB while meta-argillites are dominant in the KSB.

The Older Granites are also relatively more abundant in the KSB. These differences are important in understanding the relationship between the major formations and indicate the depositional pattern of the assemblages the belts contain. The dominantly psammitic assemblage in the ZSB and the dominantly argillaceous assemblage in the KSB, are, respectively, deposits in sedimentary troughs, in which the psammitics settled as traction and marginal materials and the argillites as suspension materials, farther off, in deeper waters. This establishes the relationship between the belts and the deposits would appear as lateral facies and contemporaneous.

Although structural as well as age differences have been recorded here and there among the metasediments, these are considered local phenomena in a complex region whose regional evolution has been studied in this work.

The Older Granite bodies are more abundant and more varied in the east of the studied area and, in part, complicate the structures of the metasedimentary belts.

TABLE OF CONTENTS

		Page No.
CHAPTER 1		
	Title	i
	Declaration	ii
	Certification	iii
	Acknowledgement	iv
	Abstract	vi
	Table of Contents	viii
	List of Tables	xiv
	List of Figures	vi
	List of Plates	xvi
	Abbreviations	xviii
	Definitions	xix
	Dedication	xx
	INTRODUCTION	1
1.1	Location	1
1.2	Previous Remote Sensing Investigation	1
1.3	Geography	3
1.3.1	Relief and Drainage	3
1.3.2	Mean Annual Rainfall and Wind	5
1.3.3	Vegetation	7
1.3.4	Culture and Population	7

CONTENTS (Continued)

		Page No:
1.4	Geology	7
1.4.1	The Basement Complex Rocks	7
	Aspects of NW Nigerian Schist Formations	9
	Field relationship of the metasediments	11
	Geochronology	15
1.4.2	Sedimentary Rocks	16
	The Middle Niger (Nupe) Sandstones and the Illo Group	16
1.5	Project Objectives	18
1.6	Methodology	19
CHAPTER 2:		
	REMOTE SENSING	22
2.1	General	22
2.2	Sensor Types Useful In Geology	24
2.3	Usefulness of Remote Sensing In Regional Geology	25
CHAPTER 3:		
	INTERPRETATION - GENERAL	27
3.1	Elements of Interpretation	27
3.1.1	Tone	27
	Tonal signature of gneiss-migmatite complex	28

CONTENTS (Continued)

		Page No:
	Tonal signature of the metasediments	32
	Tonal signature of the Older Granites	32
	Tonal signature of the Nupe Sandstones	35
3.1.2	Topographic Expressions of Basement Complex Rocks	36
	Topographic expressions of the Older Granites	39
	Topographic expressions of the metasediments	39
3.1.3	Patterns of Drainage and Joints	40
3.2	Elements in Lineament Detection	42
3.3	Elements in Structural Interpretation	45
3.4	Factors Affecting Imagery Interpretation	45
3.5	Availability of Images	52
3.6	Choice and Assessment of Images	53
CHAPTER 4:		
	NTERPRETATION - LITHOLOGICAL	54
4.1	The Rock Groups In the Area	54
4.2	Subdivisions of the Rock Groups	56
4.2.1	Subdivisions of the Crystalline Basement Complex Rocks	56

CONTENTS (Continued)

		Page No:
4.2.2	Subdivision of the Metasediments	57
	The arcuate metasedimentary formations	60
	The linear north-south metasedimentary formations	62
4.2.3	Subdivisions of the Older Granites	63
4.3	The Zungeru Mylonites	64
4.4	Distribution of the Basement Complex Rocks of the Area	68
4.5	Subdivisions of the Nupe Sandstones	68
4.6	Aerial Similarities Between the Nupe Sandstones and the Illo Group	69
CHAPTER 5:		
	INTERPRETATION - STRUCTURAL	73
5.1	Basement Complex Trends	73
5.1.1	North-South Structural Trends	73
5.1.2	East-West Trends	74
5.1.3	Arcuate Trends	74
5.2	Lineaments	76
5.2.1	Lineament Types	76
	NE - SW lineaments	76
	NW - SE lineaments	78

CONTENTS (Continued)

		Page No:
	N - S lineaments	79
	E - W lineaments	80
5.2.2	Distribution of Lineaments in the Basement Complex	80
5.2.3	Lineaments in Schist Belts Relationships	83
	Lineaments and discreteness of troughs and belts	83
5.2.4	Lineaments and Mineralisation	85
5.3	Folds	87
5.3.1	Fold Types	88
	The arcuate folds	88
	North-South oriented folds	90
5.3.2	Age Relationships of Folds	92
CHAPTER 6:		
	EVOLUTION OF THE N-W NIGERIAN BASEMENT COMPLEX	93
6.1	General	93
6.2	The Gneissic Infra-Structure	94
6.3	Cycles of Sedimentation	94
6.4	Trends of Metasediments Affected by Older Granite Intrusions	96

CONTENTS (Continued)

		Page No:
6.4.1	Effect of Intrusion on Continuity of Metasedimentary Belts	96
6.5	Lineaments and the suggested Discreteness of Schist Belts.	97
6.6	The Extent of the Metasedimentary Cover	99
6.7	The Emplacement of the Older Granites	100
6.8	Models on the Evolution of the Schist Belts	101
6.8.1	Some Previous Models on Schist Belts Evolution	101
6.8.2	Deductions from Apparent Depositional Pattern of the Metasediments	102
6.9	Conclusion	105
6.10	Suggestions for Field Work	106
	REFERENCES	107

LIST OF TABLES

Table:		
1.1	Details of the Landsat Images Examined in this Work	20
1.2	Details of Data Bases	21
3.1	Factors Affecting Image Interpretation	46

LIST OF FIGURES

Figure		Page No.
1.1	Location Map of Project Area	2
1.2	Drainage and Geology of Part of NW Nigeria	4
1.3	Rainfall Map of Part of NW Nigeria	6
1.4	Development of the Nigerian Synclinorium	10
1.5	Distribution of the Zungeru Mylonites	13
2.1	The Landsat Spacecraft	23
3.1	Landsat Geological Map of Eastern Part of Project Area	33
3.2	Photogeological Details of Makichi and Kubo Folds	
3.2a	Landsat Map of Nupe Sandstone and adjoining Basement	37
3.3	Interpretation of SLAR cover of the Nupe Sandstone	43
4.1	Landstat Structural Map of Part of NW Nigeria	55
4.2	Photogeology of the Zungeru Area	66
4.3	Geological Map of Ibeto Area	
5.1	Truncating N-S and E-W Fold Trends	75
5.2	Lineament - Boundary of Crustal Blocks	81
5.3	Lineament Boundary of Metasedimentary Formation	84
5.4	Correlation of Nigeria Lineaments with South Atlantic Fracture Zones	86
6.1	Depositional Trough of the Zuru Schists and the Kusheriki Schists	103

Figures - 3.2 and 4.3 at Back Cover.

LIST OF PLATES

Plate		Page No.
i	Landsat Image No. E-1486 - 09292 - 4 Showing the Zuru Schist Belt	29
ii	Hand Camera Photograph of Pegmatised Banded Gneiss just West of Ibeto on Kontagora - Yelwa Road	30
iii	Landsat Image No. E-1484 - 09182 - 5 Showing the Birnin Gwari - Minna - Kaduna Area	34
iv	Landsat Images No. E-2355 - 09123 - 6 Showing Nupe Sandstone - Basement Complex Boundary	38
v	SLAR Image Covering a Part of the Zuru Schist Belt and Part of the Nupe Sandstone and Adjoining Basement Complex Areas	44
vi	Landsat Image Showing the Masking Effect of Cloud	47
vii	SLAR Image of Kusheriki - Birnin Gwari - Kaduna Area Showing Regional Structures of the Metasediments there.	51
viii	Hand Camera Photograph of Gidan Ladan Migmatite	58
ix	Hand Camera Photograph of Kaduna Migmatite	58
x	Hand Camera Photograph of the Migmatite Outcrop just east of Lapai	58
xi	SLAR Image of Part of the Zuru Schist Belt and the Dome Features at Ibeto	59

LIST OF PLATES (Continued)

		Page No.
xii	Hand Camera Photograph of Quartzitic and Amphibolitic Rocks in the River Kaduna Gorge at Zungeru	67
xiii	The River Kaduna Gorge at Zungeru	67
xiv	Mesas at Wuya	71
xv	Mesa Rock Sequence at Kutigi	71
xvi	Landsat Image showing the South-eastern extremity of the Nupe Sandstone in the Area	72

ABBREVIATIONS

B/W	Black and White
BGSF	Birnin Gwari Schist Formation
ERTS	Earths Resources Technology Satellite
E-W	East-West
GSN	Geological Survey of Nigeria
K/Ar	Potassium Argon
KPF	Kusheriki Psammite Formation
KSB	Kusheriki Schist Belt
KSF	Kushaka Schist Formation
MSS	Multispectral Scanners
NASA	National Aeronautics and Space Administration
NE-SW	Northeast-Southwest
NOAA	National Oceanic and Atmospheric Administration
NW-SE	Northwest-Southeast
N-S	North-South
RBV	Return Beam Vidicon
SLAR	Side-looking Airborne Radar
ZSB	Zuru Schist Belt
ZSF	Zuru Schist Formation.

DEFINITIONS

Arcuate Formations:- these are formations that are seen in plan view to be arcuate with gentle curves.

Arcuate Folds:- are folds which in plan view are seen to be arcuate or curved, typically with curl-like forms.

Argillite:- a formation with photo characteristics typical of units with a preponderance of relatively finer textured sediments.

Linear Formation:- a formation that maintains a straight direction, or grain, through most of its extent.

Linear Folds:- in plan view, this folds type displays no discernible curve except for the hinge zone.

Meta-argillite:- a metamorphosed equivalent of an argillite as defined above.

Meta-psammite:- a metamorphosed equivalent of a psammite as defined below.

Plutonism:- a process of intrusive rock formation from molten material.

Psammite:- a psammite is defined here as a rock composed mainly of sandy particles; sandstone.

D E D I C A T I O N

TO: Irene, Juliet, Harding, Marian,

Christopher, Anita and Godelia

Chapter I

INTRODUCTION

1.1 Location

The part of NW Nigeria covered by this work includes the area of the present Niger State. Other States which are partly covered by it, are Kwara, Sokoto, and Kaduna and the Federal Capital Territory (see Fig. 1.1)

Several interstate highways and lesser roads traverse the area. These make a good access network over the entire area. Also, the Lagos - Kano railway makes a NE-SW course across the area from Mokwa in the extreme SW to Kaduna in the NE. Although not navigable throughout the seasons, the River Kaduna flows, for the most part, SW and close to the railway.

1.2 Previous Remote Sensing Investigations

Several works on remote sensing have been carried out in the whole or part of the area. These include the map of Nigeria produced by Dessauvagie (1974) which is in part based on aerial photo interpretation and the satellite - image based study of Nigeria by Chukwu-Ike (1977). Unpublished records of the Geological Survey of Nigeria showed that the mapping of 1:250,000 sheet 31 (Kusheriki) carried out by Truswell and Cope (1963) was supplemented with aerial photo interpretation by J.A. Allum (1956). Mc Curry (1978) carried out the mapping of the degree sheets 19 (Zuru) 20 (Chafe) and part of 9 (Katsina). According to her, the initial work was photogeological and this was supplemented by field traverses.

Other previous investigations which covered parts of the area are the lineaments studies of Kogbe (1981) and that of Udoh (in press).

1.3 Geography

1.3.3 Relief and Drainage

Landscape features in the area fall into three groups; hills, plains and valleys. The hilly areas are characterised by grouped and isolated inselbergs of granites and gneisses and ridges of metasediments. In the sedimentary basins, flat-topped hills form from rock sequences preserved by hard caps. Some of the plains form from underlying basement complex rocks which have been weathered and dissected by numerous valleys and some are due to flat-lying sandstones.

The elevation above sea level drops southwards and southwestwards from the northern hinterland and the eastern highs of the Jos Plateau, down towards the Niger valley. Around Kaduna and Zaria, heights vary between 633m and 500m. In the central parts of the area, including Kontagora, heights vary from 305m to 610m and between 167m - 300m around Minna and Zungeru.

The area is dissected by the rivers which contribute to the River Niger drainage system. Prominent among these is the River Kaduna. Others are the Rivers Malendo and Kontagora which drain the NW of the area and the Rivers Gbako and Gurara which drain the east, centre and south along with River Kaduna. These rivers constitute the left-hand tributaries of the River Niger which drains the landmass west of Jos Plateau and the northern plains but is separated from the Sokoto basin

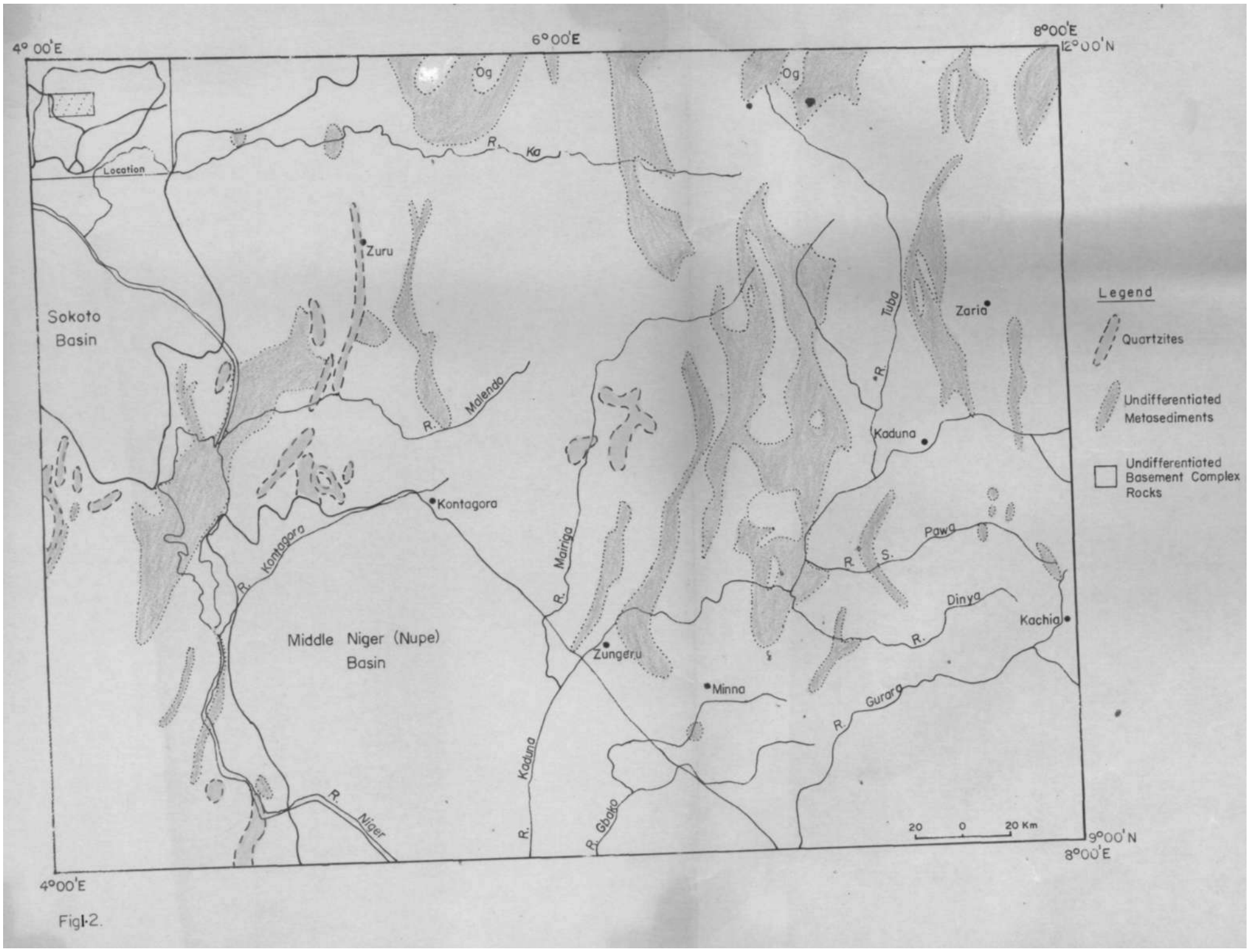


Fig. 1.2

Fig. 1.2 Drainage and Geology of part of NW Nigeria (from GSN 1:2,000,000 Geological Map of Nigeria 1984 Edition).

drainage system by a major E-W divide at approximately 11!30'N. The major left-hand tributaries of the River Kaduna are Rivers Sarkin Pawa and Dinya. They rise from the hilly country around Kachia in the east of the project area. Lesser rivers in the area are the Rivers Tubo and Mairiga. They flow N-S and drain the northern parts of the area (see fig. 1.2).

1.3.2 Mean Annual Rainfall and Wind

More than 60% of the area lies within the 1016mm - 1270mm mean annual rainfall range including Kontagora and Zaria (figure 1.3). The mean annual rainfall around Kaduna and Minna is between 1270mm - 1524mm. Rainfall in the area is heaviest in the S.E. part of the project area which grades into the Plateau highlands. This makes the town and villages in the S.E. of the area, for example, Kachia the wettest with 1524mm - 2032mm mean annual rainfall while west-wards, the area gets progressively drier. Rainfall in the area reflects inland location generally and the local influences of the Jos Plateau.

The country's climate is controlled by the southwesterly and northeasterly air-masses which blow across the country from the Atlantic Ocean and the Sahara Desert. The southwest wind is dominant but the northeast winds blows during the harmattan months, that is, November to February. The project area is affected by the harmattan dust and haze during these months.

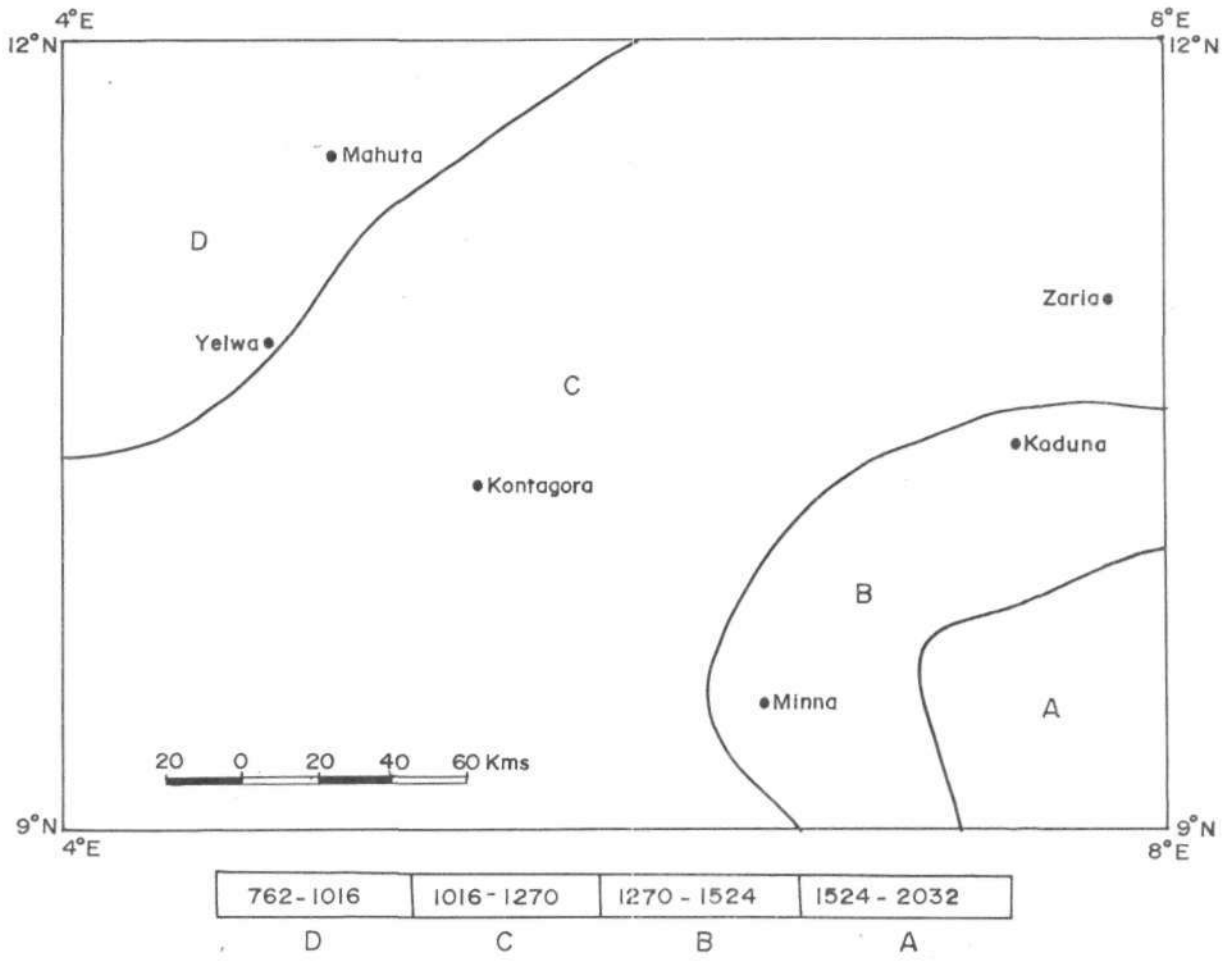


Fig. 1.3 Rainfall Map of Part of NW Nigeria. Rainfall decreases north and westwards from the southeast of the area (from the Nigeria National Atlas).

1.3.3 Vegetation

The vegetation in the area is Guinea Savanna which is characterised by mixed communities of trees, shrubs and grasses which dominate a lower stratum. The forest canopy is generally light. Associated with this forest type are riparian forests characterised by subordinate forest species and various palms and climbers. In the area, this forest type is usually on the flood plains of rivers or streams.

1.3.4 Culture and Population

The area is under a dominant influence of Hausa-Fulani culture. This is followed by the Gwarian domain which extends from parts of Zaria Province into the Federal Capital Territory. The Nupes occupy the SW part of the area while the Katab people are found in the S.E.

The population distribution in the area has changed with the political and administrative changes that have taken place in the country in recent years. For example, Minna, like Kaduna, is now a state government seat. The seat of the Federal Government is now being moved to Abuja. Other developments in the area include construction of highways and lesser roads and dams etc. These changes enhance accessibility of the area. They also entail a shift in population distribution of the area.

1.4 Geology

1.4.1 The Basement Complex Rocks

The basement complex rocks of the project area lie within the Pan African mobile belt (Turner, 1983) and

within the Western Province of the Nigerian basement (Fitches et al 1985) which lies approximately west of longitude 8°00'E. This is characterised by low-grade schist belts in a predominant gneiss-migmatite basement, both of which are intruded by granitic rocks.

Figure 1.2 is a summary of the occurrences and distribution of the major rock types in NW Nigeria. The gneissic complex forms the dominant infrastructure into which the schists are infolded. Geochronological investigations (Grant et al, 1972; Grant 1970; Ogezi, 1977; Ajibade, 1980, Egbuniwe, 1982 etc.) have revealed the polycyclic nature of the basement complex rocks with ages ranging from the Liberian (2700 My) to Pan African (450 My). Banded gneisses and lit-per-lit gneisses have been considered to be the oldest basement complex rocks (Oyawoye, 1970). From an investigation at Ibadan in SW Nigeria, the banded gneisses according to Grant et al (1972) and Oyawoye (1970) appear older than the granite gneiss from which a whole rock Rb - Sr age of 2190 $\pm$ 30 My was obtained (Grant et al, 1972).

The low metamorphic grade metasediments which occur in more or less N-S belts west of longitude 8°00'E. have been described as "Younger Metasediments" (Mc Curry, 1976) to distinguish them from those she considered older. They are also considered to be restricted to the area west of longitude 8°00'E but Ajibade (1980) cites occurrence of schists further east of this longitude.

Several types of the Older Granites have been identified in Northern Nigeria (e.g. Mc Curry, 1976). These types include the basic and intermediate rocks, migmatites and granites. The same author also

showed age difference in the emplacement of these granites and jointly with Wright (Mc Curry and Wright 1971) post-tectonic granites were distinguished from syntectonic types on the basis of field relations.

Aspects of NW Nigerian Schist Formation: the metasediments, more than any other rock group, pose a problem as to their history, and, according to Ajibade (1980) it is unclear whether the schist belts evolved as a single event or whether at least some of them are of different ages and belong to different geotectonic cycles. Overprinting of events within the basement complex and the differences within the schist belts have rendered correlation difficult and controversial.

Plate tectonic processes were called up by several authors (e.g. Burke and Dewey 1972; Mc Curry, 1976; Black, 1980; Ajibade 1980; Egbuniwe 1982; Turner, 1983; Fitches et al, 1985) to explain observations on several facets of the Nigerian crust and its supracrustal covers.

Within the context of the West African region, a Himalayan-type event has been postulated (Burke and Dewey, 1972) for most of the crust east of the West African craton with a collision between the passive cration in the west and the active crust in the east. An example of this is shown in figure 1.4 which is a model by Vaniman (1976) to explain the development of the Nigerian synclinorium.

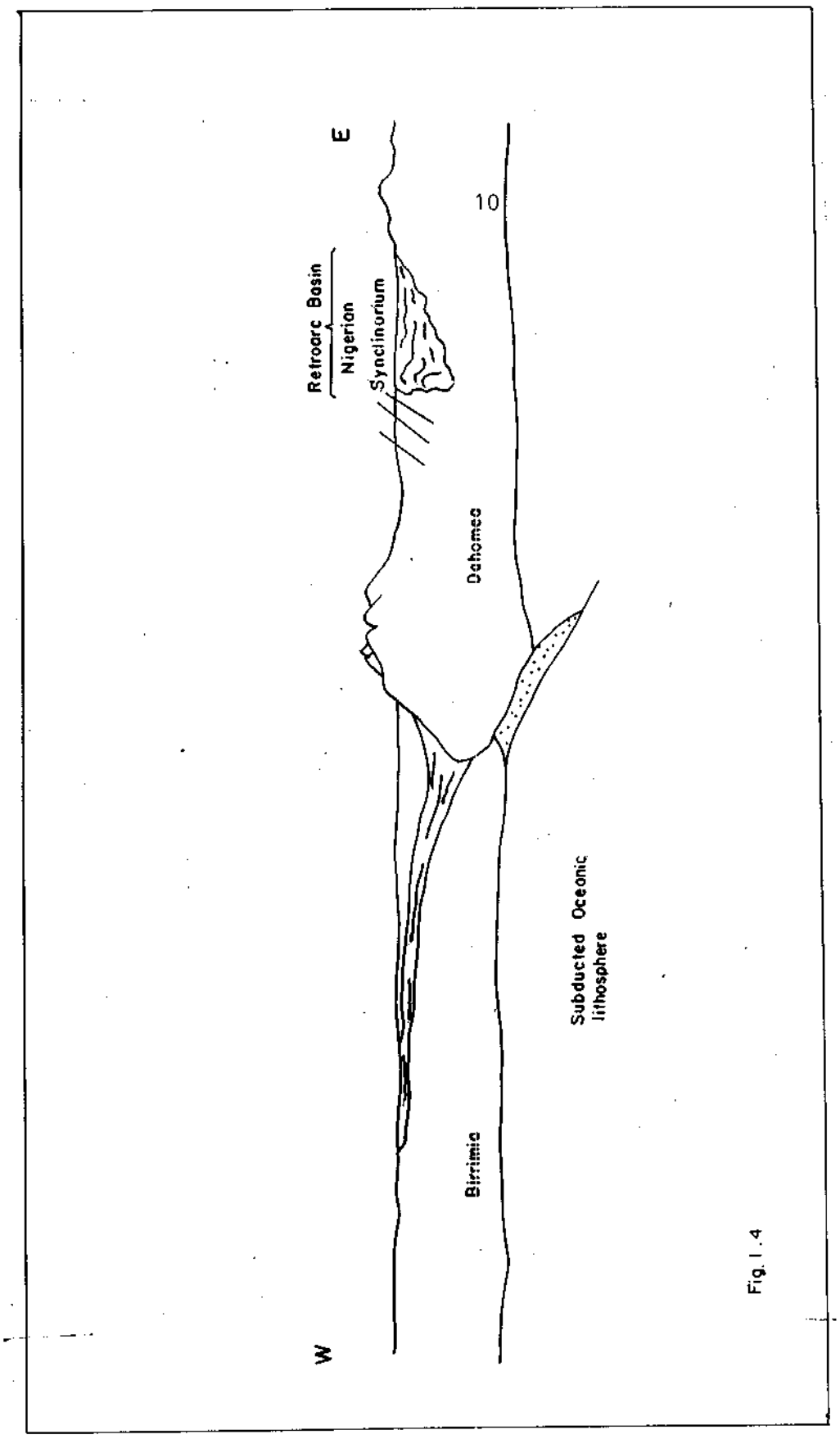


Fig. 1.4 Development of the Nigeria synclinorium Through Plate Tectonic Processes, (After D.T. Vaniman, 1976).

In his own account of the West African scene Black (1980) described the formations and structures in the region. It is obvious from his account, that the Hoggar in the south of Algeria and the Benin-Nigeria crust to the south display features that are correlative. The Pan African event is believed to have imposed N-S structures on the region including NW Nigeria of which the area covered by this investigation is a part.

Field Relationships of the Metasediments Several suggestions have been made on the field relationships of the metasediments with one another and with other rock groups (Truswell and Cope 1963; Mc Curry 1976; Grant 1978; Ajibade, 1980; Turner, 1983). Truswell and Cope (1963) recognised three formations in the Kusheriki area: These are the Kusheriki Psammite Formation, the Kushaka Schist Formation and the Birnin Gwari Schist Formation. They considered the rocks of these formations to have formed under the same orogenic cycle. As such, they found no stratigraphic and structural breaks between them.

Reasoning on basis of structural styles however, Grant (1978) found that the Kushaka Schist Formation and the Birnin Gwari Schist Formation, are different and are adjacent Kibaran and Pan African belts. But Ajibade et al (1979) and Ajibade (1980) disagree with Grant (1978) on the foregoing, arguing that the Kushaka Schist Formation and the Birnin Gwari Schist Formation have been through the same number and styles of deformation and they therefore saw no age disparities between them as Grant (1978) suggested. The field

KASHIM IBRAHIM LIBRARY
AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA.

relationship of the metasediments with the gneissic basement is also not clear and controversial. Truswell and Cope (1963) for example, saw the relationship of the metasediments with the gneisses as gradational arising from a stratigraphically controlled migmatisation front. This view contradicts those of Mc Curry (1976) and Ajibade (1980) both of whom saw breaks between the metasediments and gneisses. Also, Chukwu-Ike (1977) proposed structural and age differences in the schist formations of the Kusheriki area and in his discussion on the lineaments of the area, suggested that the N-S metasedimentary belts, of which the Birnin Gwari schist Formation is one, are lineament-bound.

Also, a cataclastic assemblage (the Zungeru mylonite) flanks the Birnin Gwari Schist Formation and provides the structural evidence for Ajibade's suggestion of a structural break in the relationship of the gneisses with the metasediments in that region. Ajibade adopted the name 'Zungeru Mylonites' for this assemblage which has been identified by different names by several authors (Russ, 1957; Ajibade 1971; Truswell and Cope 1963 etc.). Some authors' views on the Zungeru Mylonites differ from Ajibade's. Grant (1978) for example, sees the cataclastic assemblage as part of the basement gneisses, whose structures and textures were destroyed in the deformation associated with the folding of the overlying Birnin Gwari Schist Formation. Turner (1983) considered the assemblage and associated amphibolites as metavolcanics.

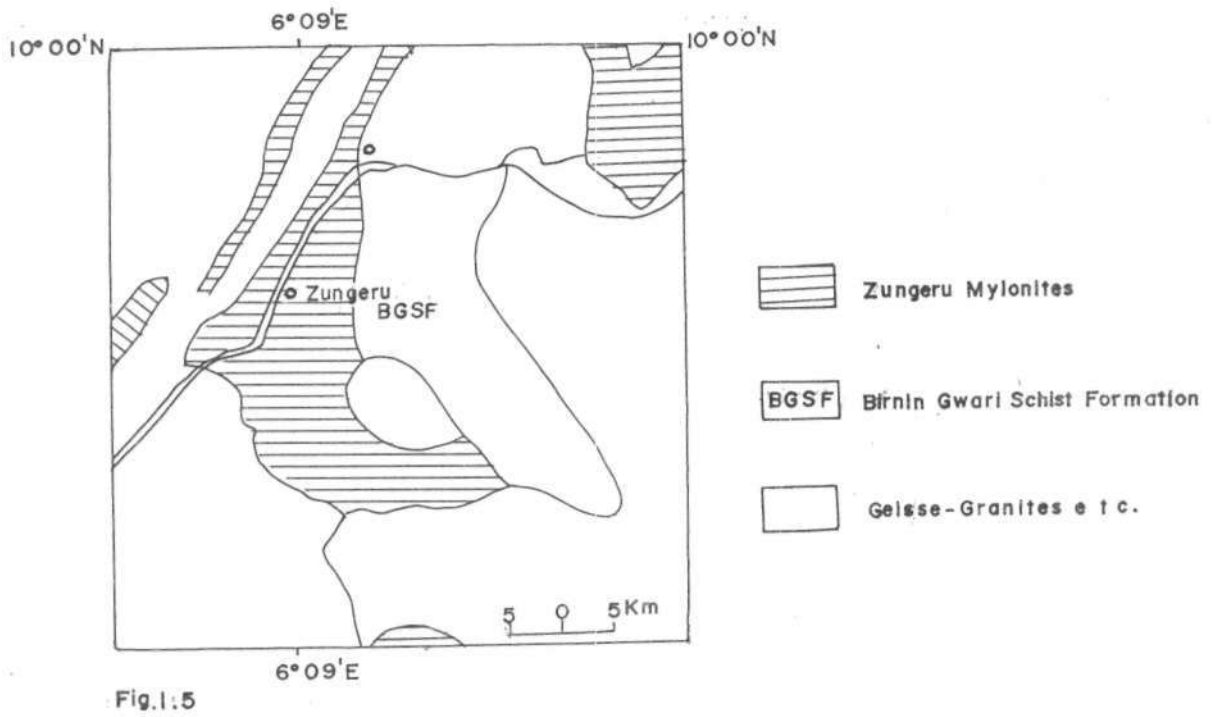


Fig.1:5

Fig. 1.5 The Distribution of the Zungeru Mylonites (Ajibade, 1980) in the Zungeru area (after Ajibade, 1980).

This unit has also been identified as rhyolitic lava and keratophyritic rocks (Bafor, 1979) which have been metamorphosed, but which still display geochemical features of both plate accretion and plate consumption environments.

In addition to the foregoing, the field relationships of the metasediments with the Older Granites, as well as the structural styles of the individual schist formation in the Kusheriki area have been considered so distinctive as to serve as the basis for separating the schist formations in the area into age groups. Turner (1983) considered the relative positions and abundance of the Older Granites within the individual metasedimentary belts and distinguished between two metasedimentary groups. The first group which he considered earlier is assigned a 1100 My (Kibaran) age while the latter is believed to belong to the Pan African orogeny. Ajibade (1986) interpreted the foregoing relationship differently. Drawing attention to hitherto unknown volumes of granitic intrusions in the metasedimentary belts, he (Ajibade) considered the field relationships of the metasediments with one another as simple save for the copius volumes of intrusive rocks whose effects induce the apparent contrasts (e.g. varied trends) in the metasediments.

The foregoing interpretation by Ajibade (1986) appears to be in line (although with modification) with part of Truswell and Cope's (1963) conclusions. As earlier stated they saw the metasediments as belonging to the same orogenic cycle. A less controversial aspect of the metasediments is the assumption of cycles of sedimentation. It

seems Nigerian basement complex geologists generally accept that metasediments belonging to different ages exist in the basement complex. Several writers (e.g. Odeyemi, 1976; McCurry, 1976; Onyeagocha, 1984 etc.) on the Nigerian basement complex distinguish between Older and Younger Metasedimentary basement complex units on the basis of cross-cutting basement trends and lithologies.

Geochronology Numerous results have been obtained from several geochronological investigations of the Nigerian basement complex rocks. Ajibade (1980) grouped published age dates on the Nigerian basement into three periods as follows:-

(a) Eburnean (2000 ± 200 My) and older

(b) Kibaran (1100 ± 200 My)

(c) Pan African (600 ± 150 My).

The majority of age determinations in Nigeria are Pan African. Ogezi (1977) established a Pan African age for the emplacement of the Older Granites. He obtained ages of 679 ± 65 and 794 ± 73 on the Maiinchi granodiorite and on the coarse "Porphyroblastic" Zaria granite respectively. According to him, the Pan African event probably started about 794 ± 73 My while widespread ages of 600 My probably marked the peak of a later but similar event.

The Older Granites, more than any other components of the Nigerian basement complex, appear to give consistent isotopic ages with numerous determinations centered on the Pan African. According

to Ajibade (1980) variations within the Pan African age range may indicate the episodic nature of the event.

The ages of the metasediments are controversial. The ages so far suggested (Mc Curry, 1976, Ogezi, 1977; Grant et al 1972 etc.) are mainly radiometric or ages based on field relations. And the ages suggested for some metasediments include Pan African (e.g. Turner, 1983) ,Katangan (Mc Curry, 1976) Kibaran (Ogezi 1977 and Grant et al, 1978). Ogezi (1977) obtained an age of 1068 $\pm$ 65 on the phyllitic metasediment from the Maru formation. This age according to him, suggested a Kibaran (1000 My) event in NW Nigeria.

1.4.2 The Sedimentary Rocks

The Middle Niger (Nupe) Sandstones and the Illo Group: sedimentary rocks of Cretaceous age occur in the study area. These are the sandstone of the Middle Niger (Nupe) Basin and the Illo Group of the southern Sokoto Basin. The former occurs in the south-central part of the project area while the latter occurs in the northwestern part. According to Reyment (1965) it has been suggested that the Nupe Sandstones and the Illo Group (which consists of terrestrial grits and pisolitic and nodular clays) are equivalent.

Accounts of the Nupe Sandstone have been given by several authors (Jones, 1958; Reyment, 1965; Adeleye, 1976; Adeleye and Dessauvagie, 1972; Adeleye, 1979). Several of these accounts contained descriptions of the sandstones of the Nupe Basin and the sequencies of the Illo Formation.

Other works on the basin were mainly palaeontological (e.g. Kogbe, 1979; Reyment and Reyment, 1978 and Petters, 1978) and the deductions from them presented the basins as regional features which possibly linked the South Atlantic with the Tethys.

Investigations of relevance to this work are those of Kogbe (1981) and Ajakaiye and Ojo (1976). Kogbe (1981) interpreted the Landsat images of part of central Nigeria, the northern extremity of which falls in the south of the present work.

Kogbe (1981) recognised three major sets of lineaments in the area. These are the N-S, NE-SW and NW-SE types. He observed that the N-S type are truncated by the other types. From this observation, he suggested that an important tectonic episode occurred in Nigeria during the post Precambrian period. According to him, the part of the River Niger covered by the image is structurally controlled by NW-SE lineament. This lineament - drainage relationship in his opinion confirms the "general" view that the Benue Valley is a rift structure. The rift-origin of the Niger Valley is suggested by the same reasoning. Other accounts on Nigerian lineaments have been given (e.g. Chukwu-Ike, 1977; Udoh, in press ; Oluyide and Udoh, 1985). Ball (1980) also recognised conjugate strike slip fault systems in the Hoggar and Nigeria with the offset of the N-S mylonitic shear zones by the NE-SW and NW-SE types.

While Kogbe et al (1981) suggested a rift origin for the Nupe Basin, Ajakaiye and Ojo (1975) considered it as a local subsidence feature which showed no fault-contacts at its boundaries. Their

interpretations were based on observations made during a gravity measurement investigation of the basin which is characterised by negative bouger anomalies and local positive anomalies in some parts which they explained as indicating high density basement rocks and masses of probable schistose composition.

1.5 Project Objectives

The 1:250,000 Sheet No. 31 (Kusheriki) mapped by Truswell and Cope (1963) is a part of this project area and covers parts of present Niger and Kaduna States which are underlain by metasediments and other rocks of the basement complex. The mapping of this sheet, according to Jacobson in the preface to Truswell and Cope (1963) commenced when aerial photographs became available after the World War II. The availability of aerial photographs marked the beginning of systematic mapping by the Geological Survey of Nigeria.

The choice of sheet 31 was based among his other reasons on the need to establish the relationships of the metasediments with the rest of the basement. Since the commencement of this regional geological mapping, much has been learnt but there is much yet to be known about the Nigerian basement geology. NW Nigeria, which includes sheet 31, is therefore considered a good area of the Nigerian landmass where further regional studies with remote sensing data bases can complement other methods in elucidating basement features because of good rock exposure and detailed mapping of some parts.

The aim of this work is therefore to contribute to the present knowledge of the Nigerian basement complex geology by carrying out a regional geological study of part of NW Nigeria and using mainly Landsat, Side-Looking Air-borne Radar (SLAR) images and aerial photographs as remote sensing information sources. Deductions about the evolution of the basement complex are also made from the results of the study.

1.6 Methodology

Interpretation, irrespective of image-type was recorded visually on transparencies from which dyeline copies were produced. For interpretation of the entire NW Nigeria (Fig. 4.1) individual transparencies were mosaiced and the features contained therein transferred on to another overlay superimposed on the mosaic. Dyeline end-product was generated using an ammonia diazo printer.

As indicated in the previous section, Landsat images served as the main information source. SLAR images served as supplementary information as well as illustrations. This is because of the difficulty in obtaining them which prevented production of separate scene maps from them. Aerial photographs were used where details were needed. Several scenes of the various images were examined and their details are given in table 1.1 and 1.2.

Interpretation was followed by field-checks on several selected roads for ground-truth verification.

IMAGES	LIBRARY REF. NUMBER	SCENE IDENTIFICATION NUMBER	DATE	MSS BAND	QUALITY
	1206	E-1107-09255	7-11-72	Composit Band 4, 5, 7	Good
	1104	E-1522-09285	27-12-72	Composit Band 4, 5, & 7	Good
	1104	E-1486-09292	21-11-73	5	Good
	1105	E-1107-09262	7-11-72	6	Poor
Landsat	1105	E-1287-09263	6-5-73	5	Poor
	1105	E-2355-09123	12-1-76	7	Poor
	1105	E-1107-09262	7-11-72	5	Poor
	1107	E-1160-09202	30-12-72	5	Good
	1107	E-1520-09172	12-12-73	5	Good
	----	E-1017-09261	9-8-72	5	Poor
	0905	E-1107-09264	7-11-72	7	Poor
	1007	E-1484-09182	19-11-73	5	Fair
	1008	E-1231-09154	11-3-73	5	Fair
		E-1576-09274	19-2-74	7	Fair
	----	E-1520-09181	25-12-73	5	Fair

Table 1.1 1:1,000,000 Landsat Images Examined in this work.

Table 1.2 Details of Data Bases:

IMAGES	SOURCE	CONTRACTOR	SCALE	FORMAT	GROUND COVERAGE	COLOUR	PRESENTATION
Landsat	N.A.S.A.	-	1:1,000,000	18mmx18mm	32,400km2	B/W	Monoscopic
S.L.A.R	Forestry Dept. Ibadan	Motorola Inc. Ltd.	1:1,000,000 1: 500,000 1: 250,000	-	-	B/W	Monoscopic
Aerial Photo Indexes	Federal Survey, Lagos	Canadian Aeroservices Limited	1: 100,000	-	-	-	Monoscopic
Aerial Photo-graphs	Federal Survey, Lagos	Canadian Aeroservices Limited	1: 40,000			B/W	Sterescopic

* *N.A.S.A. - United States of America's National Aeroneutics and Space Administration.

B/W - Black and White.

Chapter 2

REMOTE SENSING

2.1 General

Sabins (1977) defined remote sensing as the collection of information about an object without being in physical contact with it. He also described it as being restricted to methods that record the electro-magnetic radiation; reflected or refracted from an object. This definition excludes geophysical surveys which according to him, record force fields. Implied in the foregoing definition is a benefit of not only information gathering but also that of large surface coverage as well as short time of investigation completion. Also implied is an advantage of object identification and correlation.

From the foregoing, it is obvious that there is a tool available (remote sensing) for diverse earth-surface surveys including geology. These surveys are usually followed-up with field verification.

The conventional aerial photography is the original form of remote sensing. Technological developments in the 1960s led to acquisition of images in wavelengths other than the visible. This includes the use of micro-waves. About a decade after, that is, in the 1970s, later developments led to acquisition of images of the earth from space craft. An example of such a space craft is the Landsat 1 (see Fig. 2.1) the payload of which included multispectral scanners (MSS) and return bean vidicon (RBV) cameras.

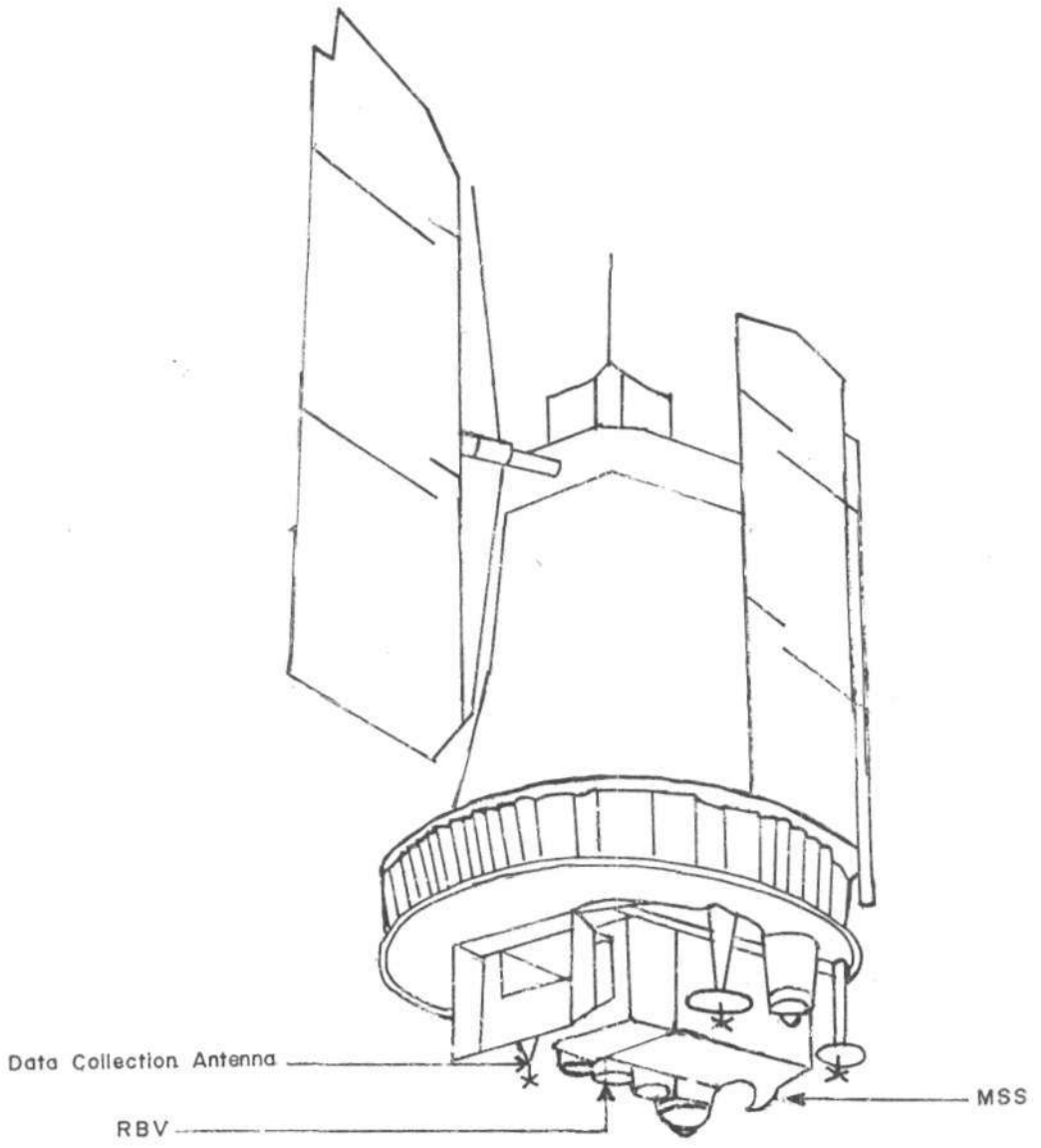


Fig. 2.1: The Landsat Space Craft. (from NASA Illustrations).

With above mentioned developments, new remote sensing terminologies have similarly been coined (Reeves et al, 1975) to encompass the various developments that have taken place. Thus, the term "imagery" and "image analysis" are used where the end product is produced by non-photographic techniques of remote sensing e.g. multispectral scanners and SLAR.

2.2 Sensor Types Useful In Geology

Sensors are devices that receive electromagnetic radiation and convert it into a signal that can be recorded and displayed as an image or numerical data. Remote sensors provide special tools for the earth scientists including the geologists. The tools serve to determine remotely, the location and distribution of landscape features (e.g. rocks). Each sensor type provides information that makes the worker more effective in his job and provides new insight into his problems. A wide variety of sensors useful in geology are available and these include the Landsat multispectral scanners, Side-Looking Airborne Radar (SLAR) and the aerial camera.

Literature abounds on sensors which include the MSS, SLAR and aerial photographic cameras. Radar systems are described in detail by Moore et. al (1975). Typical SLAR systems have been described (Reeves et al 1975; Meckel, 1972; Sabins 1977 etc.) to aid the interpreter in understanding radar image-forming process. Also, details of aerial cameras and aspects of aerial photography have been described and

discussed by many authors (e.g. Allum, 1966; Barret and Curtis, 1976; Reeves et al, 1975; Sabins, 1977 etc.).

2.3 Usefulness of Remote Sensing In Regional Geology

Aerial photographs and other remote sensing images have been found useful and irreplaceable in many geological investigations such as regional geological mapping. This is because land surface features are evident in them with remarkable detail. Such detail according to Abdel - Gawad (1975) includes geological formations and structures, the distinctive features of which are discernible on images.

These features form the elements of image interpretation, and as Meer Mohr (1977) puts it, the amount of information obtainable in any field geological investigation depends on available exposure and accessibility. Here lies, in part, the usefulness of remote sensing in geology as it often supplies additional information which in many cases, cannot be obtained otherwise.

For the above reasons, Viljoen and Viljoen 1975 (as cited in Chukwu-Ike, 1977) found Landsat images "ideally suited to the study of diagnostic macrostructures" in South Africa. Also, Isaachson et al, 1973 (also cited by Chukwu-Ike, 1977) concluded that bedrock geology such as boundaries between major tectonic provinces, lithological contacts, foliation trends within gneisses as well as lineaments could be regionally studied on Landsat images.

In another example, Drury and Holt (1980) interpreted Landsat images on 1:1,000,000 scale and were able through reconnaissance structural analysis to decipher a pattern of tectonic evolution in the South Indian craton from the Archaean times to the late Proterozoic. In the same manner, Chukwu-Ike (1977) described the usefulness of Landsat images in his study of the tectonic trends and "domains" of the Nigerian basement and in elucidating the tectonic sequence of events in the area.

Further examples on Nigerian geology include the works of Mc Curry, 1978; Allum 1956; Udoh (in press), Oluyide and Udoh 1985 etc. All but the last two of these works are aerial photograph-based studies. These works have already been indicated under previous works on the area.

Elsewhere in Africa, Hepworth (1970) produced tectonic province and trendline maps of N.E. Tanzania from aerial photographs and was able, through their use, to determine some tectonic domains in the area.

In most of the works cited, large areas of land are involved. The advantage of regional coverage by remote sensing images therefore appears to be a great advantage as the method covers more than a field geologist normally would.

Chapter 3

INTERPRETATION - GENERAL

3.1 Elements of Interpretation

Barret and Curtis (1976) defined interpretation as the act of examining images for the purpose of identifying objects and judging their significance. Attention is commonly given to all terrain features in the course of interpretation and errors arise from failure to do this. Interpretation is therefore a deductive process in which an identification of certain key elements leads on to the recognition of others.

Terrain features, for example, drainage, landform, vegetation and cultivation are interpreted in terms of certain elements which have been enumerated elsewhere (e.g. Meckel, 1972; Barret and Curtis 1976; Reeves et al, 1975 etc.). These elements include, tone, topographic expression, pattern, density, texture and shape.

3.1.1 Tone

Different terrain objects interact differently with radiant energy. These differences are recorded on black and white Landsat images and aerial photographs as shades of grey which correspond directly with feature characteristic, for example the colour of a rock. Tone in Side-Looking Airborne-Radar (SLAR) images depends on the position, elevation, reflective ability of an object and its inclination to radar-look direction. Tone in SLAR is also affected by the dielectric constant of the object.

In the project area, the tonal signatures of the various rock groups and some sub-units, within them, appear to be distinctive and allow their broad differentiation. The gneiss migmatite terrain, for example, can be distinguished from the terrains underlain by the metasediments as well as those areas underlain dominantly by granitic rocks. The sediments of the Middle Niger Basin, that is, the Nupe Sandstones, also display tonal signature which markedly constrast with the basement complex areas. The tonal signatures of the major rock groups in the area form the subjects of the following sub-sections.

Tonal Signature of Gneiss Magmatite Complex In the project area, the rock types which constitute the gneiss-migmatite complex include banded gneiss, granite gneiss, migmatites and granites. The areas that are underlain by these rocks are characterised by light grey tones on both Landsat images and aerial photographs.

Tone alone, has however proved insufficient for any further sub-division of the gneiss-migmatite complex. An examination of Plate I, for example, shows preponderantly light grey tone areas and bands both within and bordering the Zuru Schist Formation (ZSF). Area C of this plate is seen in the field as underlain by hill-forming granite gneiss, while area C2 of same plate is underlain by migmatised banded gneiss (Plate II) which is locally augen. As seen in Plate I (areas C and C2) these lithological types display the same grey tone on black-and-white image. There is no way of differentiating them without field follow-up or use of larger scale data source (e.g. aerial photographs) on which other useful criteria can be employed. Also,

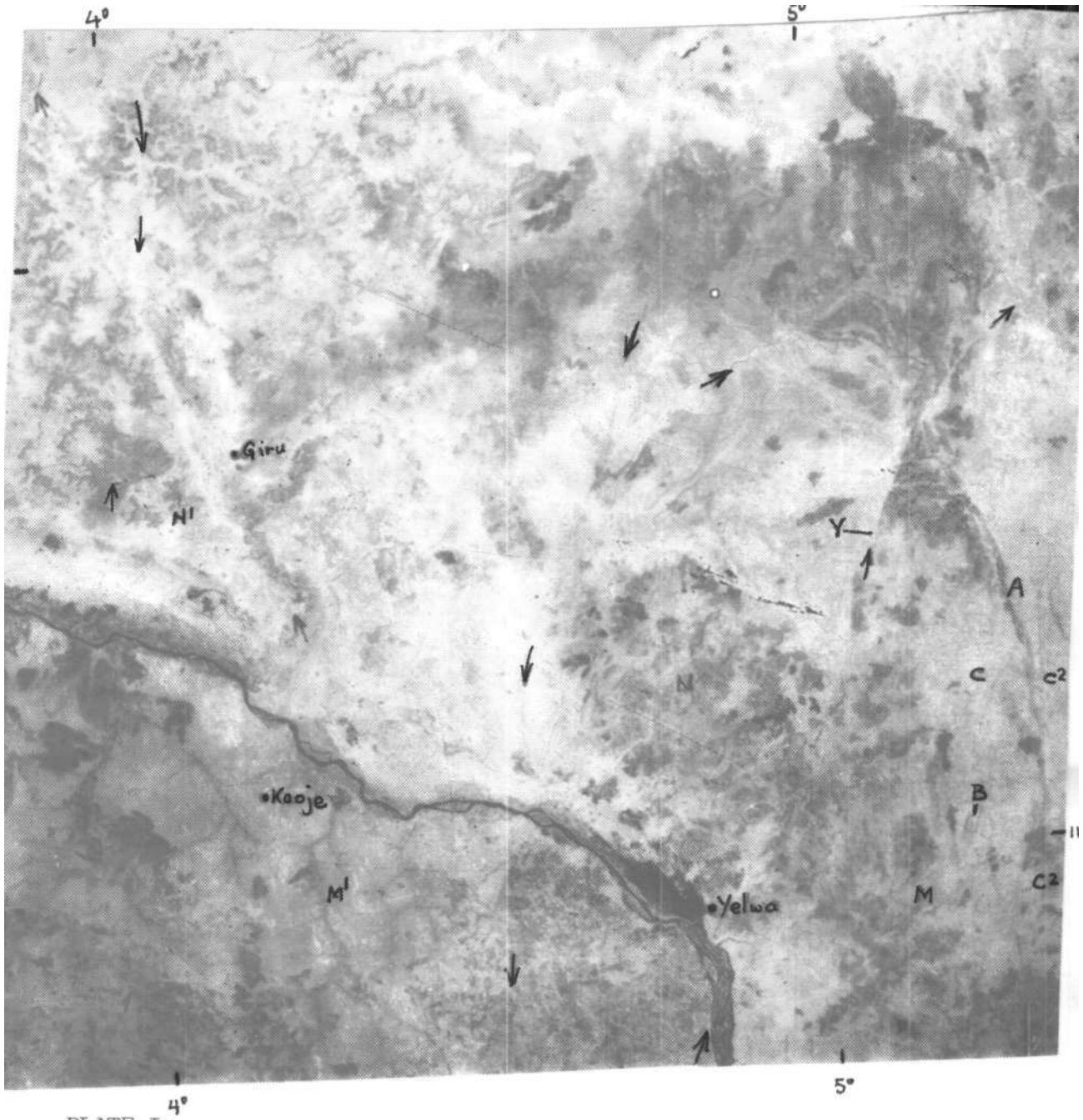


PLATE I:

Landsat 1. Image No. E.1486-09292-4 showing the Zuru Schist belt (ZSB) at A. Note the dark-toned quartzite ridges at A and light-grey areas of granite gneiss and banded gneiss at C and C2 respectively. Arrows indicate lineaments. Note the Yelwa Lineament at Y and its change of course to the NE on entering Basement Complex. Also note the regular N-S trends of quartzite ridges to the east of the Yelwa Lineament and irregular (mainly E-W) trends to its west. The Illo Sediments of the Sokoto Basin occur at M1 and N1. Note the Mesa landscape at N1. Also note the motley signature and coarse dendritic drainage pattern at M1.

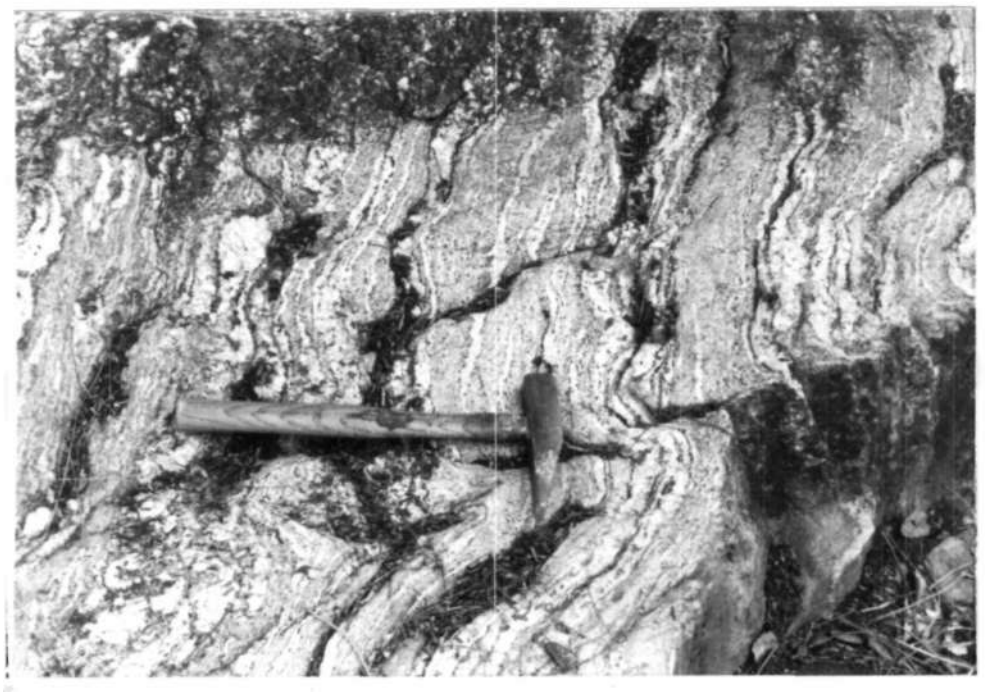


PLATE II:

Outcrop of pegmatised banded gneiss, taken just west of Ibeto outside the eastern part of the Zuru Schist Formation. Note the light-colour of the rock.

the preponderance of light tone on all the images of the area corresponds with the prevalence of gneisses, migmatite and granites in the area. The basal position of the gneisses is deducible from their occurrence both within and between the metasedimentary belts.

Tonal Signature of the Metasediments The various areas underlain by metasediments display dark grey tones which contrast markedly with light grey areas of rocks described in the above section. This contrast permits aerial mapping and differentiation of these two broad rock groups using Landsat images or aerial photographs. A further examination of Plate I which covers the ZSB reveals the occurrences of dark-toned bands, in a predominantly light-toned terrain. The dark-tone bands are seen in the field to correspond with the quartzites of the ZSB. In the east of the project area, that is, in the Kusheriki - Minna - Bishini area where another major schist belt occurs, broad areas and belts of metasediments are distinguishable as is shown in Fig. 4.1 which is the Landsat geological interpretation map of the general area.

Generally, the dark-grey tone signature of the metasediments on the black-and-white Landsat images appears to be due to fine-grain size of the various component rock types. Other factors may include varied colours of the rocks and their tendency to form brown soils and laterites.

Tonal Signature of the Older Granites The Older Granites mineralogically contain similar essential minerals to the gneisses. Similarity of tone is therefore expected. Which is why occurences of Older Granites of small aerial extent in the gneisses are generally difficult to map with Landsat images. But granite outcrops of batholithic intrusives (e.g. pophyritic granites) are detectable within the gneis-

KASHIM IBRAHIM LIBRARY
AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA.

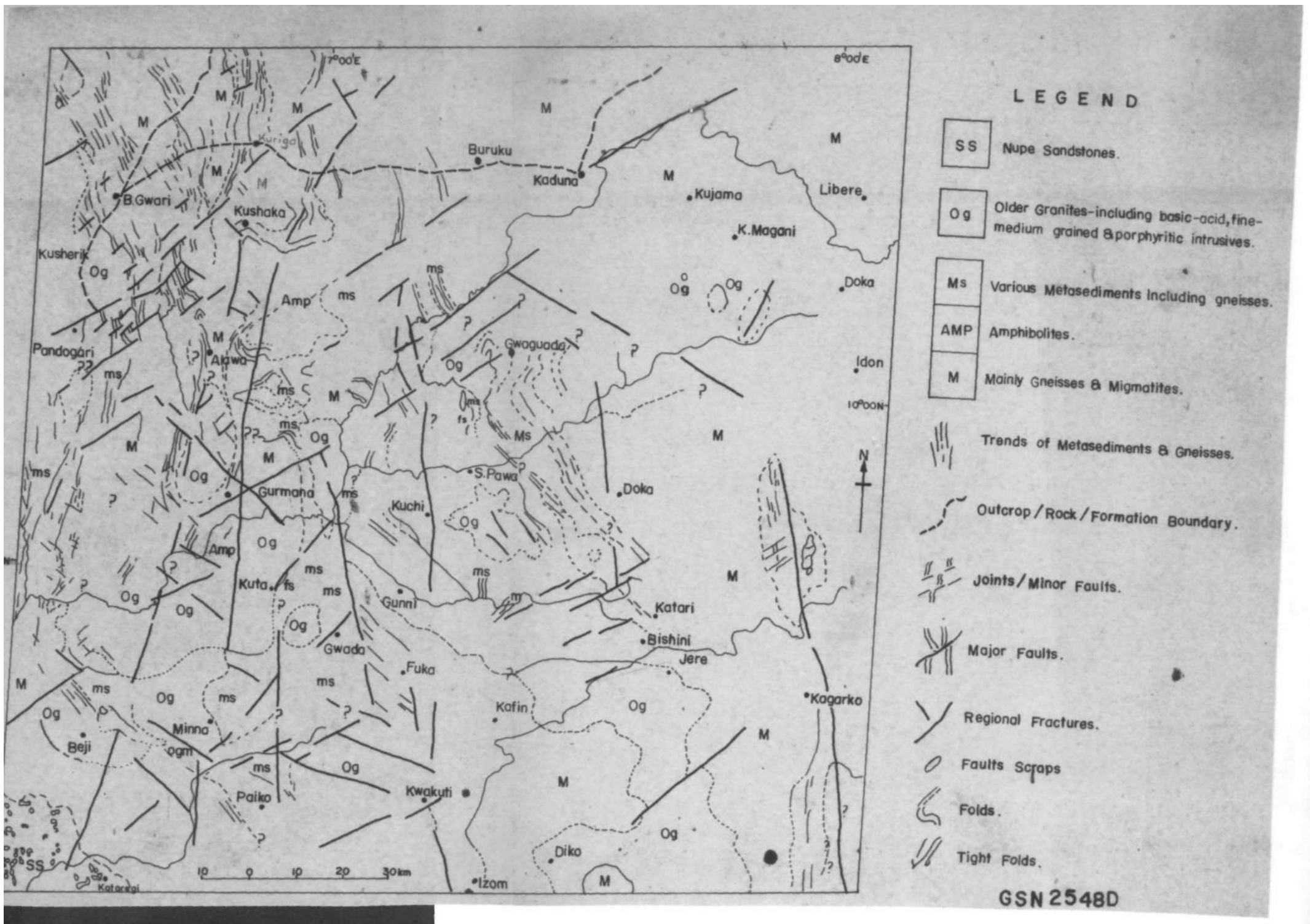


Fig. 3.1: 1:000,000 Landsat Geological Map of Eastern Part of Project Area. Produced from Landsat Imagery No. E-1484-09182, Plate III.



PLATE III:

Landsat Image No. E-1484-09182-5 displaying the major geological features in the Birnin Gwari - Minna-Abuja-Kaduna area. Note the bands of the BGSF at A; a sequence of the KSF at B; Kakuri - Bishini Schists at D; Porphyritic granites at Og. Note the textural variations in drainage at 1, 2, 3 and 4.

Arrows indicate major lineaments. See outline of geology in Fig. 3.1.

ses on the basis of shape and extent of outcrops. Where this is possible, the gneiss-granite boundary remains indeterminate on images due to the similar signature of the residual overburden which can be attributed to similarity in essential mineral constituents. An example of the preceding statement is seen in the NE part of Plate III at Og4 where an occurence of Older Granite is depicted by hills (inselbergs) in a general light grey tone terrain of migmatite. The area is Kajuru in the S.E. of Kaduna. In contrast with the preceding relationship the boundaries of the Older Granites in the metasediments are distinct on Landsat but not so on SLAR. This relationship is seen on Plate III at Og3. The distinctness of granite boundaries within the metasediments may be due to the sharp contacts of the Older Granites with them (metasediments) as Mc Curry (1976) pointed out and their intrusive relationship as evidenced by their "shouldering" relationship with the metasediments. See Plate III at Og3. The tones of the more basic types of granites of small aerial extent are difficult to detect on Landsat images because of small image-scale. Thus, whereas basic intrusive rocks of the Older Granite cycle occur here and there on the field, especially in the Minna - Bishini area, their occurrences are no where recorded in this work on Landsat-derived map.

Tonal Signature of the Nupe Sandstones A combination of grey hues and smooth texture differentiates broad basins of the Nupe Sandstones from the generally light-toned and rough-textured areas of basement complex rocks.

On Landsat image (Plate IV) the sediment - basement complex contact can only be approximately drawn because small outliers mask the unconformity and interplay with the light-toned basement complex at the boundary to impart a motley signature to the image.

The grey tones of the Nupe Sandstones as displayed in Plate IV are attributable to field-observed dark colours of the sediments. The sediments are generally ferruginous to which they owe their tone. Detection of sub-units within the sedimentary sequence on the basis of tone alone appears impossible with Landsat image.

3.1.6 Topographic Expression of Basement Complex Rocks

Topographic expressions of the various rocks in the area are more or less a measure of their relative resistance as they respond differently to processes of weathering and denudation. Using Landsat images or aerial photographs, several rocks of the basement complex can be differentiated on the basis of their topographic expression.

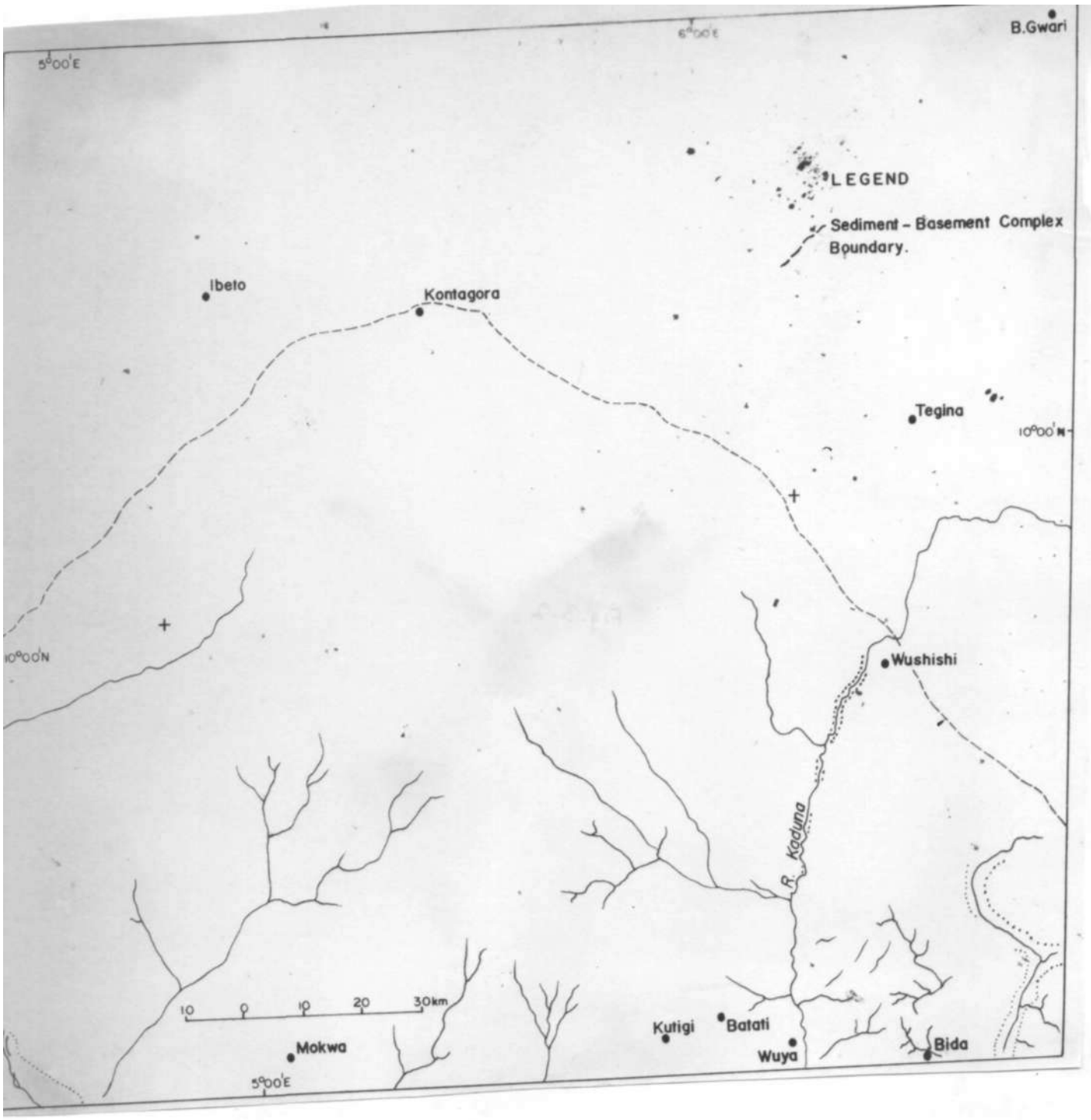


Fig. 3.2: 1:1,000,000 Landsat Interpretation showing sandstones boundary with Basement Complex. Note limit of the Sandstones swinging northwards around Kontagora. Produced from Landsat Image No. E-2355-09125 of 12/1/76.

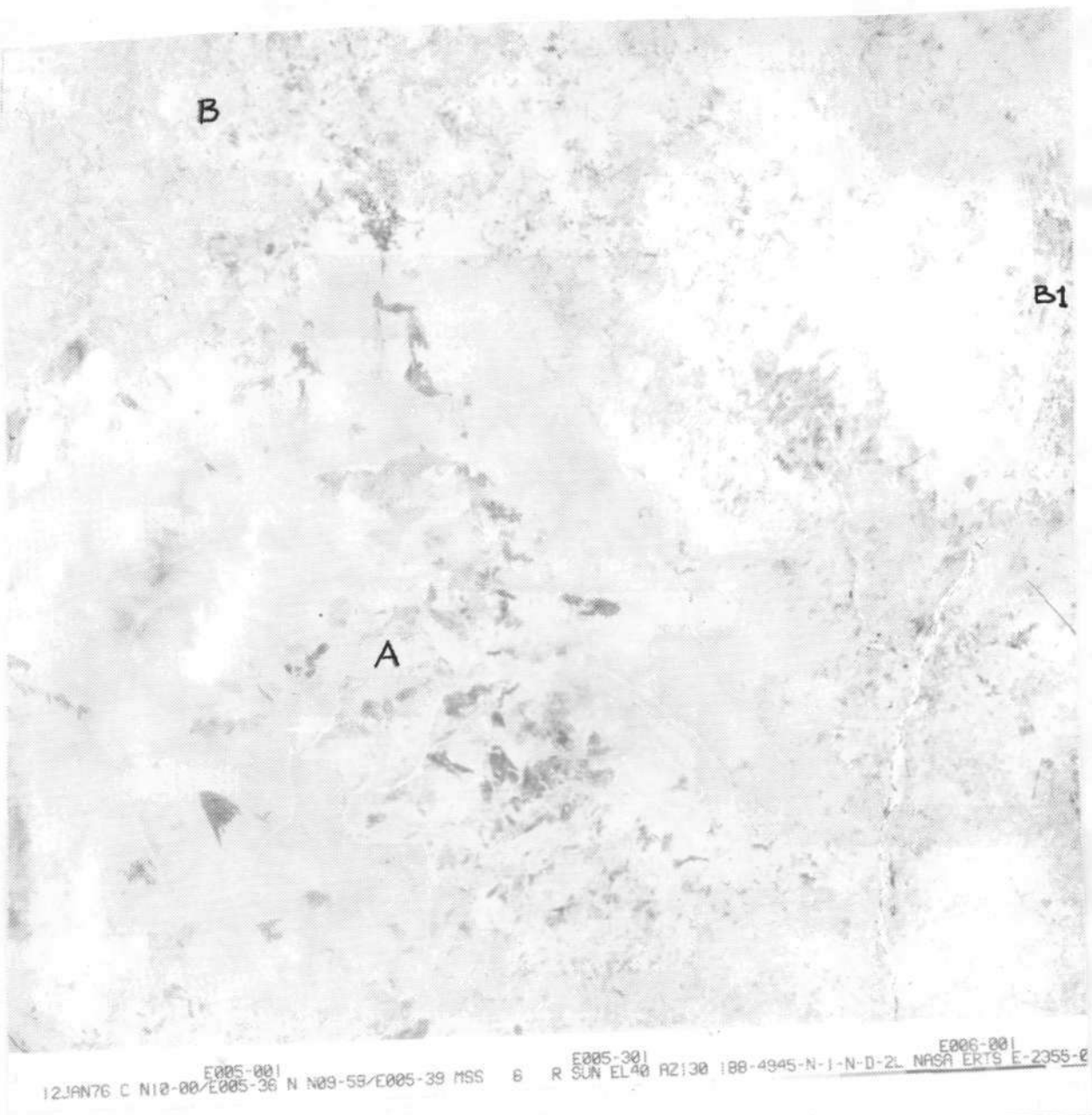


PLATE IV:

Landsat Image No. E-2355-09123-6 covering the Nupe Sandstones - A; Basement Complex - B; BGSF. - B1 and Rivers Kaduna and Mairiga - R. Note the tonal contrast of the Sandstones with the Basement Complex. Also note development of coarse dendritic drainages on the sandstone and poor resolution of drainages on the Basement Complex. See outline of rock group boundary in Fig. 3.2.

Topographic Expression of the Older Granites: Granites form high hills. This is notably so of the porphyritic variety, the terrains of which invariably include prominent inselbergs, domes and whalebacks, grouped or isolated. For example, the Kusheriki and Bassa granites (Plate III - Og2 and Og3) and several other occurrences of this rock type are descernible on the same plate. Other granite types, for example the Minna fine-grained granite and the Jere biotite granite form less prominent hills which are not detectable on Landsat images on the basis of topographic expression alone.

The more basic members of the Older Granite Group (e.g. the tonalites seen in the field around Minna town) are poorly exposed. They therefore do not form prominent features detectable at the scale of Landsat images.

Topographic Expressions of the Metasediments The metasediments according to Truswell and Cope (1963) tend to form strike ridges. These ridges are displayed on images (e.g. Plate I at A and Plate III at A) as near parallel bands and lines. The bands and lines in Plate I (at A) which cover the ZSB are those of a quartzite.

The most prominent feature of the metasediments here include the phyllite member of the Birnin Gwari Schist Formation (BGSF). On the image of the Zungeru region (Plate III at A) this rock forms hilly ranges which run E-W from Minna to Zungeru from where they swing into a N-E direction. Because this rock unit forms a marker unit, it permits the Landsat study of major trends of the BGSF.

Several other rock types in the metasedimentary formations show strike ridges. These rocks include amphibolites and quartz schists. The relative topographic expressions of these rock differ. Because of the scale of Landsat images, the various rocks types which form these ridges are indistinguishable whereas with aerial photographs they can be distinguished.

The granite gneisses also are detectable on Landsat on the basis of the prominent ranges which they form.

3.1.3 Patterns of Drainage and Joints

The patterns of drainage and of joints as keys to rock identification and differentiation appear useful mainly in the basement complex areas that are underlain by migmatites and in the sediments of the Middle Niger (Nupe) sandstones. Elsewhere in the area, for example on areas of granite gneisses and metasediments, the courses of rivers (which exploit joints and other fractures) are poorly displayed on the images used. As Chukwu-Ike (1977) puts it, second order and lesser order tributaries of rivers, are generally poorly resolved on Landsat images of Nigeria. One wonders why Nigeria specifically? The explanation may be, at least from this area of study, that drainage is generally coarse-textured on granites and these rocks abound in the area.

While the foregoing is so, the pattern of drainage in some areas of the basement complex is basically angular and variations occur only in texture rather than in their pattern. This pattern is developed extensively around Kaduna, and, on a lesser scale, due south of the

town towards Abuja, as well as just SW of Minna town and around Birnin Gwari - see Plate III (at 1, 2, 3 and 4). Varieties of this pattern have been seen in the field to be associated with different migmatite types.

The pattern of drainage on the Nupe sandstones is dominantly dendritic. The rivers are prominent in contrast to those on the basement complex rocks (Plate IV). The dominance of this drainage pattern in the basin is an indication of the general homogeneity of the sequence as well as the general absence of structural control. These indications contrast with the basement complex areas where foliation and joints impose an angular pattern on the drainage systems.

A coarse dendritic drainage pattern appears to be a feature of an extensive plain which characterises the Nupe basin. The plain, from field verification, is underlain by varied sandstone sequencies, notably the ferruginous sandstones and laterites.

Local development of radial centrifugal patterns are seen on both SLAR and Landsat images of the basin. This development is around Kutigi and Batati. Associated with the radial pattern are mesas which are well displayed on SLAR images of the basin - see Plate V. Several sandstone sequencies are preserved under these mesas.

Local increase in drainage density is also displayed in certain area of the basin. This is in the S.E. part of the basin, in the environs of Lapai. The local increase is associated with lithological change from brown sandstone to grey stiltstone.

3.2 Elements in Lineament Detection

Some fractures and faults occur as significant lines on images. On Landsat images (e.g. Plate I) these lineaments show up as lines due to changes in image tones. The topographic expression along such lines may not be detected in some cases while in others positive or negative features may occur on them. This is so with the Kalangai fault mapped by Truswell and Cope (1963) in the Kusheriki area.

The varied image tone which helps to depict the occurence of a lineament (i.e. fracture or fault) may be associated with several landscape features (e.g. soil, vegetation, drainage etc.). Local variations of these features in a linear manner are indicative of lineaments.

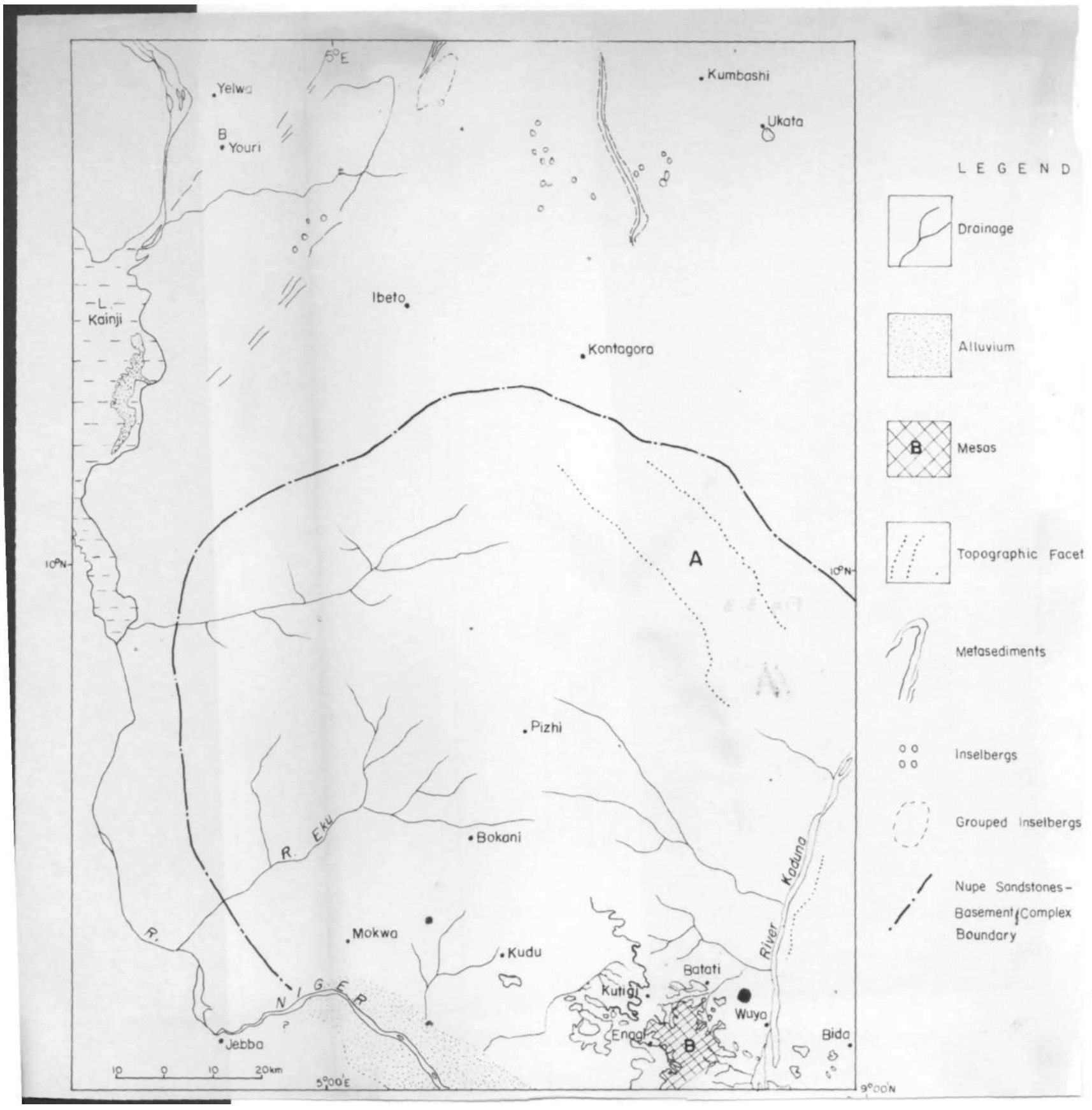


Fig. 3.3 1:1,000,000 - Side-Looking Airborne Radar Map of Nupe Sandstones and Adjoining Basement Complex Area. GSN 2548C.

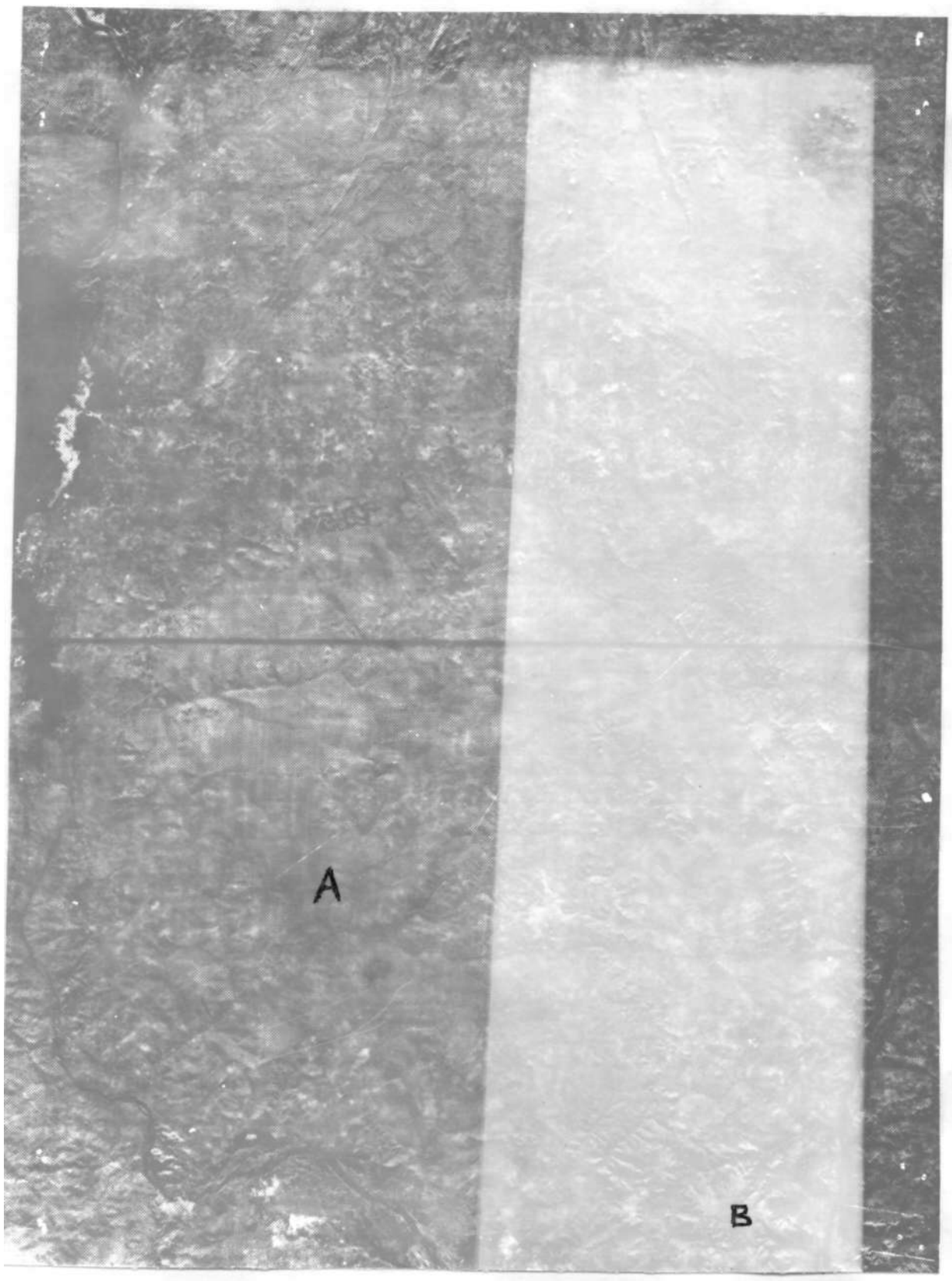


PLATE V: SLAR Image of Part of Zuru Schist Belt (ZSB) and the Nupe Sandstones. Note the extensive plain (A) with coarse dendritic drainage; the mesa features at (B) with radial drainage. See outline of Physiographic Features in Fig. 3.3.

3.3 Elements in Structural Interpretation

In this writer's opinion, tone and pattern appear to be the most important elements in structural interpretation using small scale data bases such as Landsat images. On such data bases, changes in lithology and attitude of rocks are manifest as variations in tones or variations in drainage or outcrop patterns. The metasediments in the area, for example, tend to form strike ridges as has earlier been mentioned (section 3.1.2). The attitudes of these ridges as seen in the Zuru and Kushaka areas help to define episodes of deformation. Where the strike ridges apparently truncate one another (as with a sequence of the Kushaka Schist Formation and Birnin Gwari Schist Formation see Plate III at P.) evidence of structural domains may be suspected as Chukwu-Ike (1977) suggested.

3.4 Factors Affecting Images Interpretation

Chukwu-Ike (1977) enumerated in general, the factors which affect the amount and type of information obtainable from satellite images (Table 3.1). The factors which affect Landsat images also affect aerial photographs, because both are derived from sensors which depend on solar illumination and which also sense the same visible portion of the electromagnetic spectrum.

TABLE 3:1 FACTORS AFFECTING IMAGE INTERPRETATION

Object Space Factors	Factors Affecting Interpretability
Shape Length - Size (area)	PHYSICAL: Inherent limits set by physical characteristics of imaging systems.
Exposure Level Actinic Brightness	IMAGE FACTORS: Sharpness, focus, aberations, Scale, image motion, grain detail and shape transfer function.
Contrast	PHOTOGRAPHIC FACTORS: Exposure - transfer function, Latitude, Printing and Projection losses. PSYCHOPHYSICAL: Inherent limits set by viewing process; sharpness of image, contrast of image, single or mosaic, stereo or non-stereo. PSYCHOLOGICAL: Inherent limits set by the human being visual acuity experience motivation skill intelligence prior knowledge environment (Modified after Mac Donald (1957) and Chukwu-Ike (1977)).

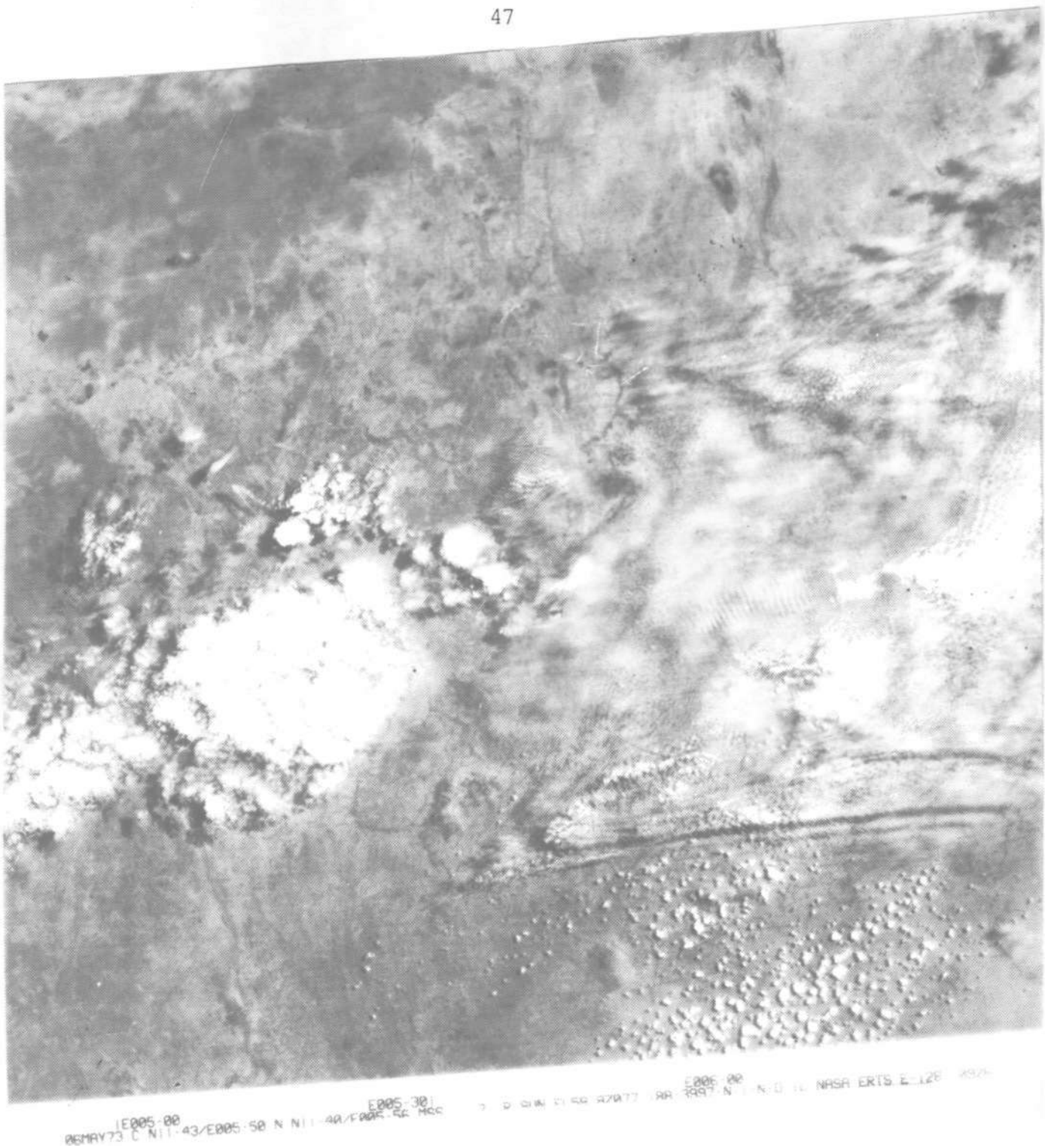


PLATE VI: Landsat Image No. E-1287-0921

Note Cloud-cover.

Meteorological conditions, cloud cover and haze, are the most important factors that affect the information content of the Landsat images of this area. This factor (i.e. cloud cover) is demonstrated in Plate VI. The area covered by this plate is the north-central part of the area under investigation and it is underlain by basement complex rocks. It lies between the ZSB in west and the B G S F in the east of the area. But for the general light-tone of the image which is presumed to reflect a basement composed dominantly of acid rocks (gneisses, migmatites and granites) the geology is generally obscured. Another factor which affects image content is the man-caused seasonal bush-burning which leaves large dark patches and tracks on the land surface which are also sensed. On images, burnt areas are displayed as dark patches which tend to obscure subtle differences of soils and rocks. For various reasons, rural dwellers in the area, as elsewhere in the north of Nigeria, take to bush burning. This is commonly done in the dry season between the months of November and March.

The factors which affect the interpretability of SLAR images differ from those enumerated for Landsat and aerial photographs. By reason of longer wavelengths, SLAR is independent of meteorological conditions such as cloud cover and haze. Its image-signature is determined by its system and terrain properties. The system properties according to Sabins (1976) include polarisation, depression angle and wavelength. Terrain properties include object dielectric

constant and surface roughness. Still other factors are radar-look direction (to which radar shadows and high lights are related) and image-geometry and distortion which include radar lay-over.

As seen in this work, the greatest disadvantage in the use of SLAR image is in object distortion and lack of tonal distinction of rock types and these are important in remotely sensed geology. Another disadvantage is the "missing" of features where the SLAR - look direction and object orientation coincide.

PLATE VII: SLAR Image of Kusheriki - Kushaka-Kaduna area showing structures of the metasediments.

A = Makichi fold; B = Kubo fold

C - D = Kushaka fm. with refolding at D.

G - G = and H - H = lineaments.

E and F = Kusheriki and Bassa Granite respectively.

L - L = Curved drainage following refolding at D.

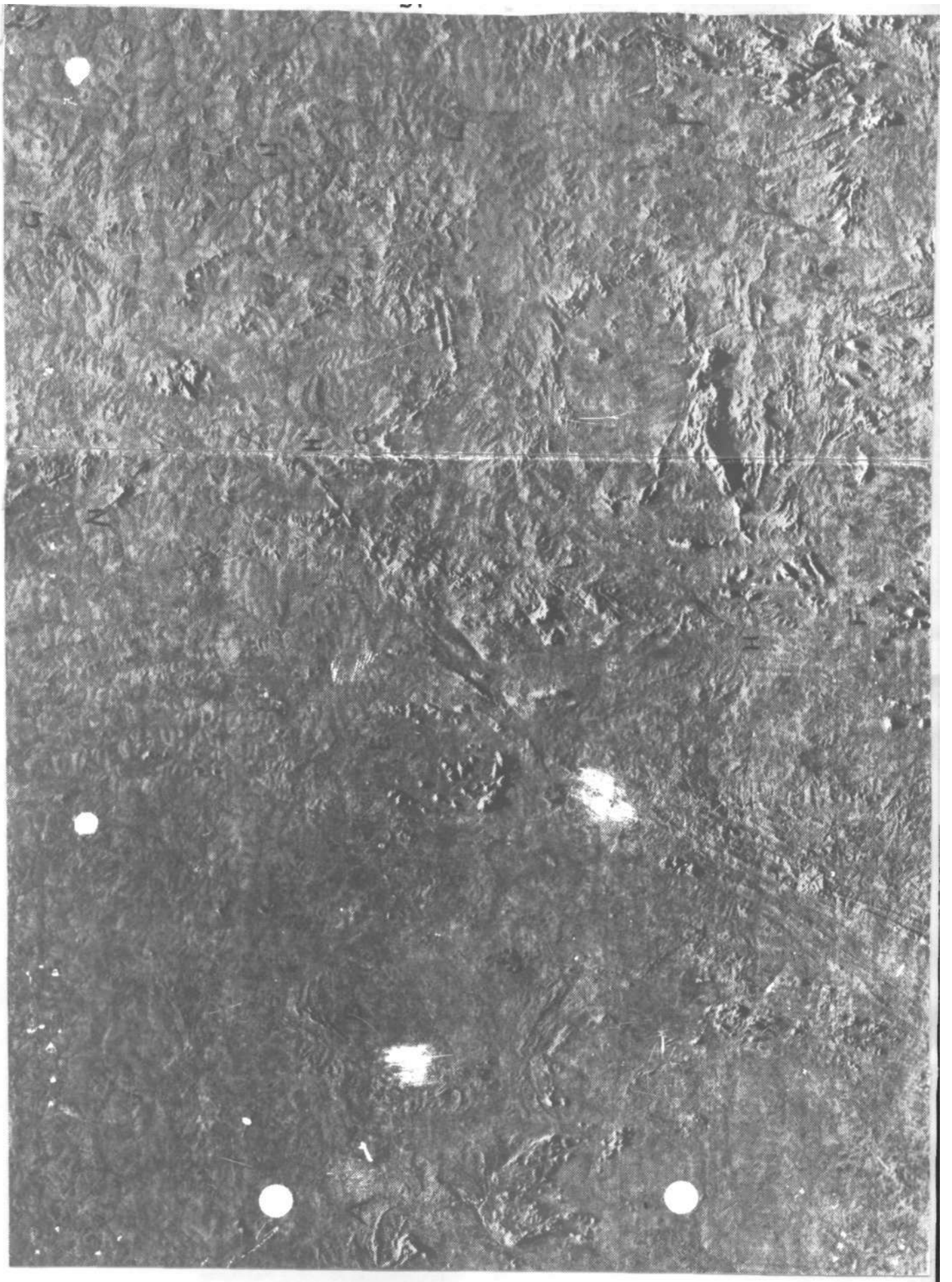


PLATE: VII: SLAR Image of Kusheriki - Kushaka - Kaduna area showing structures of metasediments. (ref. P. 55).

These disadvantages are seen in the radar image of the Kusheriki-Minna-Bishini part of the area (Plate VII). In this image, the courses of rivers, including the major ones like the River Kaduna, are distorted and difficult to map. Also, the various tones which correspond to major rock types on Landsat are absent. Several other distortions exist. Structures are however generally well displayed on SLAR, for example, the varied trends of the metasediments in the Kusheriki - Kushaka area.

3.5 Availability of Images

The Landsat images used here are those of Landsat 1. They were obtained from the EROS Data Centre, South Dakota, U.S.A. The images at 1:1,000,000 are in black and white. The sale of these products are now the responsibility of the United States of America's National Oceanic and Atmospheric Administration (N.O.A.A.).

Side-looking Air-borne radar (SLAR) images are obtainable at the Nigeria's Federal Department of Forestry at Ibadan where the films and other SLAR products covering the entire country were deposited by Motorola Mars Incorporated of U.S.A. This Company, under contract with the Forestry Department, flew a nationwide radar mission for Forestry purposes. The images acquired now serve other purposes, for example geology. Aerial photographs including their print lay-downs are obtained from Nigeria's Federal Survey Department in Lagos. Prints are in black and white and at 1:40,000 scales. Larger (i.e. 1:25,000) prints are now being produced.

3.6 Choice and Assessment of Images

For the present work, no choice could be made as to the quality and the Landsat-image-type desired as one got only what was available of the Landsat 1 standard prints. Acquisition of recent sensor products or procurement of facilities for product enhancement for interpretation purposes have been rendered difficult by tedious import and foreign exchange procedures.

However, for a regional study of this type, the 1:1,000,000 Landsat images used, were found suitable because of their small scale and their regional coverage. It was found during the present investigation that approximately 6 of these images cover the entire area which would have taken more than 3,200 aerial photographs at the scale 1:40,000.

Some of the Landsat images examined in this work are in bands 5 and 6. These bands and band 7 are from experience, best for geological interpretation because topographic features show well in them. One would expect good quality but this is not so, for the images are often poor with haze and cloud cover. Because of the poor quality of the Landsat images they are used here mainly for illustration.

Chapter 4

INTERPRETATION - LITHOLOGICAL

4.1 The Rock Groups In The Area

In the preceding chapter, the rock types which occur in the area, were differentiated on the basis of the various signatures which they display on the images used. These rock types include the banded gneiss, granite gneiss, migmatites, the Older Granites, the metasediments and the sediments of the Middle Niger (Nupe) Basin and the Illo Group of the Southern Sokoto Basin.

The gneisses, migmatities and the Older Granites which constitute the crystalline basement complex, can be said to occur throughout the area. This is especially true of the banded gneiss. Field checks along selected routes show the banded gneiss to be a sea within which other rock types occur. They are for example seen to occur between and within the major schist belts in the area.

Two major belts of metasediments occur in the area. These are the ZSB in the western part of the project area and the KSB in the east of the area. Between the belts, lies a wide area of crystalline basement complex with minor schist belts here and there.

The KSB is a composite of several other smaller schist belts. These belts have been described by several authors (e.g. Russ, 1957, Truswell and Cope, 1963, Vaniman, 1976; Bafor, 1979; Ajibade, 1980; Turner, 1983 etc.).

A new addition in the Zungeru area is a belt of light-toned rock which is found in the field to be a felsic gneiss with which a medium grained biotite granite and mica schist are associated (Fig. 4.1).

The belt is named here as Jiwawa belt and it has not been previously reported. The Jiwawa belt was revealed from a detailed photo-study of the drainage on the sediments of the Middle Niger (Nupe) Basin.

Maestrichtian sediments have been deposited in several basins in Nigeria (Reyment, 1965) including the Middle Niger Basin. Only the northern extremity of the basin which is north of latitude 9°00'N falls within the area under investigation and this lies in the south-central part of Figure 4.1. The larger part stretches south-and-south-eastwards outside the area along the Niger Valley towards Lokoja.

That part of the basin in the area is roughly 180km. from west to east and about 140km. from the plain of the River Niger in the south, to the basement complex unconformity near Kontagora in the north. Several accounts of the basin's lithologies, which are essentially sandstones, have been published (Adeleye, 1971; Adeleye and Dessauvagie, 1970 etc.). Several Landsat and SLAR images cover the part of the basin within this area, for example Plates IV and V.

4.2 Subdivisions of the Rock Groups

4.2.1 Subdivisions Of The Crystalline Basement Complex Rocks

The difficulty in sub-dividing the various components of the crystalline basement complex has already been stated (section 3.1.1) as far as the use of Landsat images at 1:1,000,000 scale is concerned. Where image quality is good however, some rocks within this group e.g. the migmatites, can be differentiated, where attention is paid to a combination of criteria, for example, a combination of tone, drainage and vegetation-distribution and texture (section 3.1.3).

On this basis, some migmatite - types in the area are distinguishable. These are shown in Plates VIII, IX and X. The terrain underlain by the migmatite with dominant palaeosome in characterised by a relatively moderate textured angular drainage (see Plate III - 3). Around Kaduna, Plate IX, a coarsely-drained migmatite is distinguished in the field, by its dominant grano-aplitic neosome. In the east of Lapai (Plate X) the gneiss-type is banded; locally migmatitic or agmatitic. The metasome varies. Around Minna, the metasome is dominantly dioritic and the drainage on it is sub-dendritic (see Plates III and IV). These varied metasomes may be related to distinct magmatic phases or episodes, for example, the dominantly dioritic metasome of the Minna migmatite; the subordinate granodioritic metasome of the Doka-Katari migmatite in the south of Kaduna and the prevalent grano-aplitic metasome of the Kaduna migmatite may each represent successive phases of granite intrusions.

4.2.2 Subdivisions of the Metasediments

The metasediments (section 3.1.1.2.) were distinguished from the crystalline basement complex rocks on the basis of the dark tones of their strike ridges which are displayed as dark bands on images (e.g. Plate I). Two major belts of these bands occur in the area and these respectively correspond with the trend of rocks in the ZSB in the west and the KSB in the east of the area. The two belts are thus characterised by lines on images. These lines run more or less N-S. The N-S trends of rock units in the two belts distinguish them from



PLATE viii: Migmatite with Dominant Palaeosome from Gidan Ladan.



PLATE ix : Migmatite with Dominant Metasome Exposed on Rock Road, Tudun Wada, Kaduna.

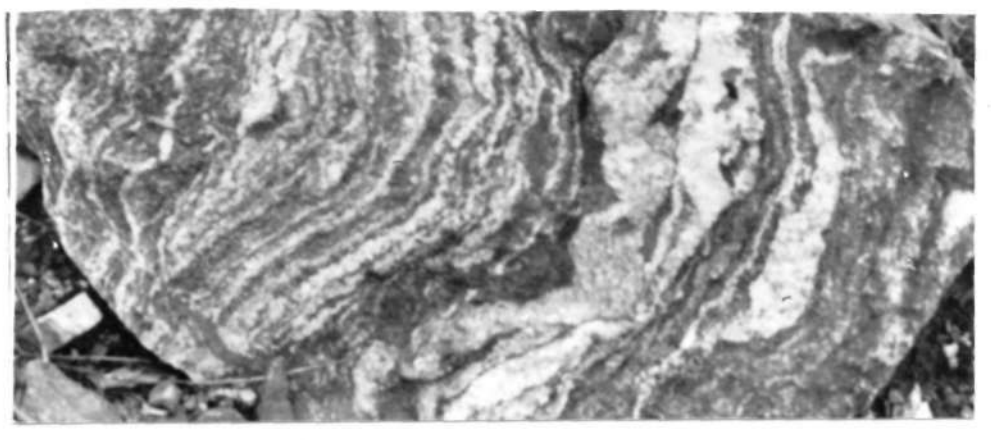


PLATE x : Migmatitic banded Gneiss - At Road cutting just east of Lapai.

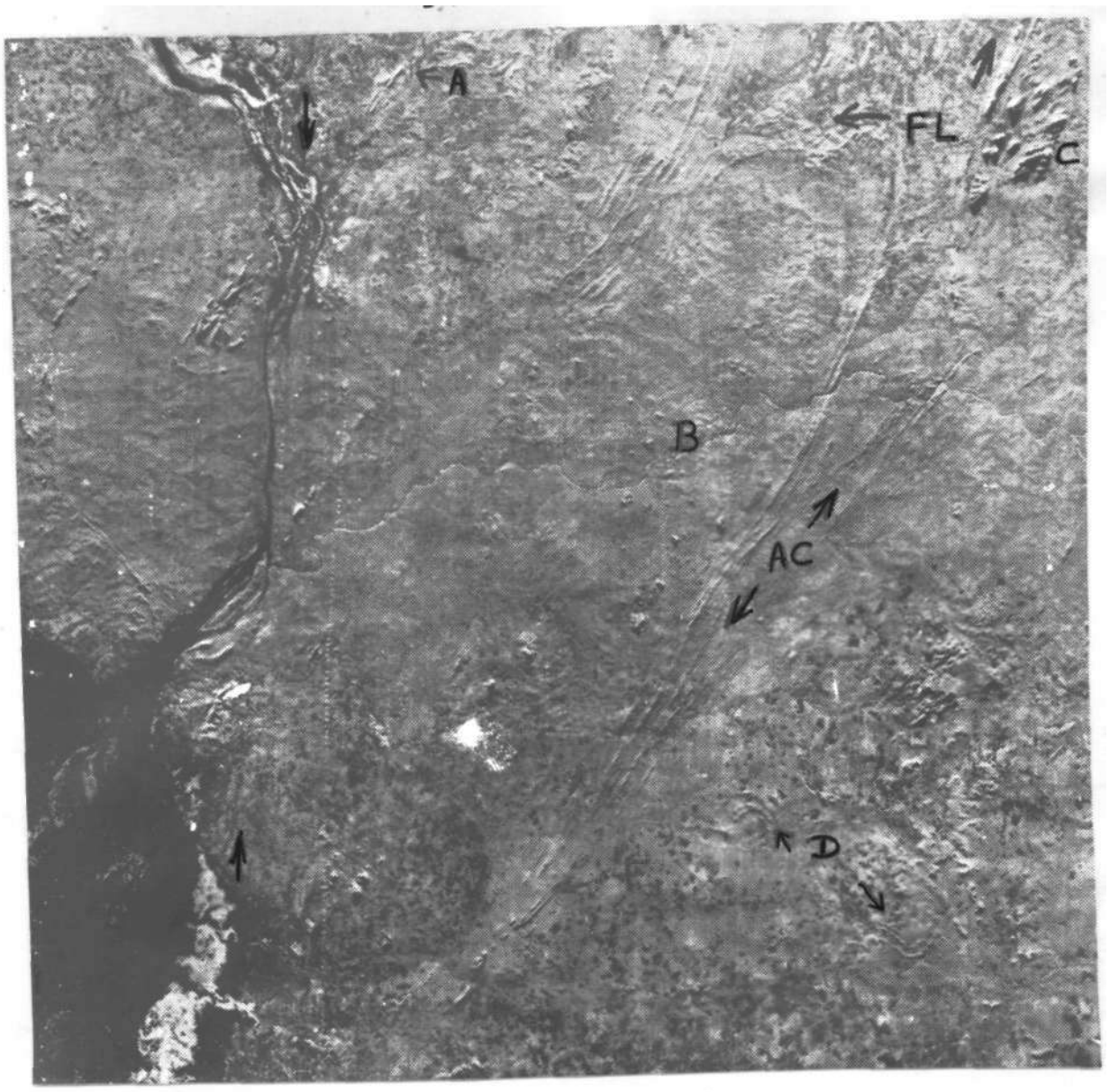


PLATE XI: 1:500,000 SLAR image of the ZSB. Arcuate structures of the Ibeto domes are seen at D. At B and C are hills of porphyritic granite. The ridges at AC correspond with the eastern flank of the Zuru Schist Belt. Note the fold closures at A, F and FL. Also note the E-W trends of closures at A and FL. Folds AC and B in the Belt trend NNE.

the metasedimentary rocks which lie outside the two belts and on dominantly gneissic terrains (e.g. the Ibeto, the Makichi and Kubo quartzites (see Plates VII-A; VII-B and XI). This later group of metasediments are distinguished from the N-S type on basis of tone and structure.

Several Schist Formations have been identified within the two belts especially the KSB (e.g. the Zuru Schist Formation (ZSF) in the west of the area; the Kusheriki Psammite Formation (KPF); the Kushaka Schist Formation (KSF); the Birnin Gwari Schist Formation (BGSF) in the east of the area). These formations and their component rock types, are difficult to delineate on images even with a field knowledge of the area. Where differentiation is done, boundaries of the various formations are still difficult to demarcate especially with SLAR images. This difficulty does not exist with aerial photographs by reason of scale and presentation. The various belts are however distinguishable mainly on the grounds of their structural styles. Two broad structural groups and associated lithologies are described below.

The Arcuate Metasedimentary Formations Two types of arcuate metasedimentary formations are distinguishable. These are those which occur in gneissic terrains and those which lie within the major schist belts. Chukwu Ike (1977) made similar distinctions. Among these formations which occur in the gnessic terrains are the Ibeto quartzites, the Makichi and Kubo quartzites. In the second group belong

the KSF which lies within the KSB (see Plate VII at C-D). Other formations which belong in this group are shown in Plates III at B, VII at A and B and XI - D. The arcuate formations which occur in gneissic terrain presumably predate the arcuate type within the schist belt. The reason for this assumption is the restricted mode of occurrence of the formmer.

A quartzite forms the dome features seen at Ibeto in the west of Kontagora and at the unconformity of the Middle Niger (Nupe) basin sediments with the basement complex. Mc Curry (1976) described the quartzite as feldspathic. It is seen interbedded with a relatively softer unit suspected to be a mica schist.

The Makichi and Kubo quartzites are distinguished by their high relief. They are similar to the Ibeto quartzite by their dominant psammite composition and thin beds also suspected to be of mica schist. Their high metamorphic grade is indicated by their recorded (Truswell & Cope, 1963) content of sillimanite.

The KSF is revealed (Plate VII-CD) as E - W bands which in the field correspond with a prominent quartzite that is associated with a fine-grained gneiss, phyllitic schist and amphibolites some of which are prominent features. The full extent of the KSF is not mappable on small scale images. Several localities at which Truswell and Cope (1963) mapped the various sequencies of this formation lie on N - S linear features which coincide with the trends of the BGSF. This means that not all recorded occurrences of the KSF are detectable. It also means that while some sequencies as at Kushaka form arcuate

topographic features, some are linear and trend N.S. The latter cannot be differentiated from other formations which also trend N-S.

Generally, not all arcuate formations are detectable on images for reason of aerial extent. Some are large enough but are not detectable because of poor image quality.

Linear North-South Metasedimentary Formations The formations which form the linear north-south group generally strike N-S. Some constitute the ZSB and the KSB and have been described by several authors (e.g. Russ, 1957, Truswell and Cope 1963 etc.)

The Zuru Schist Formation (ZSF) occurs as bands (Plates I and XI) in the ZSB. The bands in the field, correspond with quartzite ridges. From this study, the main rock type of the Formation, and, indeed the belt, is a quartizite which is seen in the field to be flaggy and micaceous. The quartzite forms a folded unit with cores of granite gneiss. The unit is intruded by varieties of granite, notably the acid types of which only the porphyritic type is well exposed and prominent enough to be readily detectable on images.

In section 4.2.2., the various formations in the KSB were named and the difficulty in giving their details including their boundaries was expressed. The existence of several formations made up of varied rock types in the KSB contrast with the dominantly metapsammitic assemblage in the ZSB. A comparison of Plate I which covers the ZSB and Plate III which covers the KSB, reveals a marked contrast in the tonal signatures of the two belts. The tone in the ZSB is uniform

while shades of grey tone characterise the KSB. This contrast corresponds with the various lithologies in the two belts. While the ZSB is dominantly psammitic the KSB is dominantly argillaceous.

Other rock types which also contribute to the dark grey tonal signature of the KSB include, phyllite which is one of the main rock types of the belt and amphibolites which are very prominent in some places (e.g. Plate III - B2). From the contrast in their assemblages, the two schist belts would appear to be different environments of deposition. This forms the subject of a later chapter.

4.2.3 Subdivisions of the Older Granites

Virtually all compositional and textural types are seen to display similar outcrop pattern within the schists. The Older Granite types seen in the KSB, for example, include the Kusheriki Granite, the Bassa Granite and the Minna Granite. These are respectively shown on Plate III at Og2, Og3 and Og5.

The Kusheriki Older Granite (Og2) is ovoid in shape; it is porphyritic with a distinct (sharp) contact with the enclosing BGSF. Its long axis is also oriented along the N-S strike of the BGSF.

The Bassa granite (Og3) is seen in the field to be fine-grained, medium-coloured and poorly foliated. It exhibits similar relationship with country rocks as the Kusheriki porphyritic type.

Also, the Minna Granite (Og5) which is not different from the above two types in its pattern and relationship with country rock is seen in the field (Udoh, in preparation) to be an acid-basic complex

of diorite and (usually) biotite-muscovite granite. In the field, the granite appears derived from the diorite by feldspathisation. Their contact relationship is gradational.

The equigranular (i.e. unfoliated) biotite granite appears rare and seems related to the gneisses only. It is difficult to map on images. It could be concluded that while various compositional and textural varieties of the Older Granite series are detectable on images, their field relationships with country rocks are similar without indications of their sequence of emplacement.

4.3 The Zungeru Mylonites

An assemblage of basement complex rocks termed, the Zungeru Mylonites by Ajibade (1980), flanks the BGSF on either side (see Fig. 1.5). The significance of this assemblage lies in the interpretation Ajibade (1980) gave to it and his use of it, as evidence for a structural break in the relationship of the gneissic basement with the metasediments (ref. section 1:4.2.2.). Different names have been given to this unit by several authors on the area (e.g. Russ, 1957, Truswell and Cope, 1963, Turner, 1983, Bafor 1979 etc.).

A photogeological interpretation of the assemblage in the Zungeru area (fig. 4.2) reveals the assemblage as composed of bands of light and dark toned resistant rocks. These light and dark toned bands, seen on photographs, respectively correspond to quartzitic and amphibolitic rocks (Plates XII and XIII) which occur with finely streaked, microscopically augen gneissose rock.

The mylonite is photogeologically conformable with the trend of rocks in the Zungeru area specifically and in with the KSB generally.

It is obvious from the foregoing, that image-study cannot contribute to the suggested (Ajibade, 1980) structural significance of the assemblage because images and photographs do not display the structural details of the rocks seen in the field.

The following observations may however be helpful in the structural interpretation of the Zungeru area:-

(a) the outcrop areas of the mylonites in the Zungeru area are traversed by regional lineaments as are other parts of the KSB (fig. 4.1).

(b) the gorge in the Zungeru area suggests entrenchment of the River Kaduna on a lineament. Evidence for a lineament influence on the river at Zungeru, is provided by the narrowness of an otherwise wide channel there at Zungeru.

(c) both the River Kaduna at Zungeru and the inferred lineament there, respectively strike N32°E like the several prominent NE-SW to NNE-SSW lineaments observed in the entire area.

Cataclastic rocks occur throughout the KSB and some may be attributable to the numerous regional lineaments which traverse the area. These lineaments impart cataclastic texture on quite a wide range of rocks in the KSB including the cataclastic porphyritic granite outcrops at Garun Gabas and Yakilla which are in the vicinity of the Zungeru mylonite.

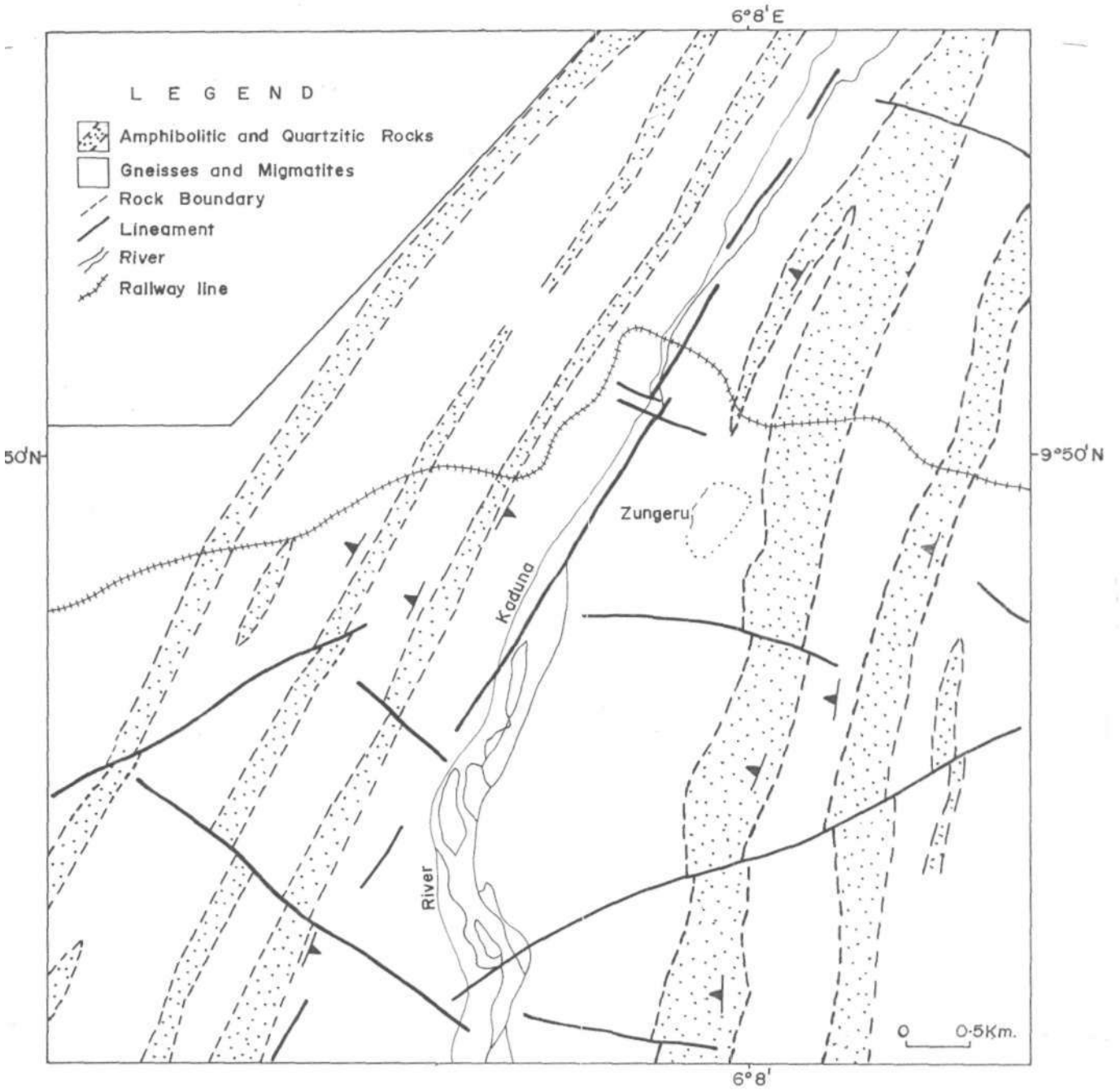


Fig. 4.2: Photogeology of Zungeru Area showing NE-trending Outcrops of amphibolitic and quartzitic rocks (cf plates XV and XVI).
Note the gorge at Zungeru.



PLATE XII: N-E trending outcrops of dark and light coloured rocks in the River Kaduna gorge at Zungeru, looking north. At SE corner is the quartzitic rock. Note banding and steep westerly dip. Also note the amphibolitic rock in the west central part of the Photograph.



PLATE XIII: The River Kaduna gorge at Zungeru. The Channel is narrowest here (c.f. Fig. 4.2).

4.4 Distribution Of Basement Complex Rocks Of The Area

The basement complex rocks in the west and the east of the project area show marked contrast in type and relative abundance. For example, the Older Granites occur more in the east of the area judged from the many inselbergs seen throughout the Kusheriki area. The mafic varieties appear more extensive here too. This is noticeably so in the central Kusheriki area. The migmatite - types earlier differentiated (section 3.1.3) are considered related to these granite types.

Also observed in the area, is the relative preponderance of meta-argillites (notably phyllites and mica schists) in the KSB., while dominantly psammitic assemblages characterise the ZSB.

4.5 Subdivisions Of The Nupe Sandstone

Three dominant landscape features are discernible and are typical of the Middle Niger Basin sediments. These are the plain, the mesa-landscape and a motley south-east area. Plates IV and V show the plain and mesa features. The motley south-east area of the basin is shown in Plate XIV.

From published works (e.g. Adeleye, 1971; Adeleye and Dessauvagie, 1972) and field - checks, the landscape features mentioned above, are associated with distinctive lithological sequencies. For example, the plain is due to flat-laying ferruginous sandstones which are locally oolitic, pisolitic and lateritic. The mesa features at Bida, Batati and Kutigi (Plate

XV) show varied sequencies of siltstone, thin-bedded ironstone, brown sandstone with iron caps (Batati village) or brown and fine sandstone, grit, silty mudstone, ferruginous sandstone, arkosic sandstone and iron capping (Kutigi village - see Plate XV); some of the sequencies appear in cyclothermic rhythm. The mesa and butte sequencies are preserved by hard ironstone caps.

In the field, the motley south-east area reveals a contact between a brown sandstone and an underlying grey siltstone. Outliers of the brown sandstone on the siltstone give the light and grey and motley signature of this scene.

4.6 Aerial Similarities Between The Nupe Sandstones And The Illo Group

A study of the Landsat image covering the southern extremity of the Sokoto Basin (Plate I) shows some similarities between the Nupe sandstones and the Illo group of the Sokoto Basin which itself is the southern part of the larger Iullemmeden Basin.

It was stated earlier that save for local variation in density, a dendritic drainage pattern is developed over the entire Middle Niger (Nupe) Basin. The same pattern is developed over the Illo and Kaoje parts of the Sokoto Basin (see Plate I - M1). Similar interpretation of absence of structural control etc. can as well apply to the Illo area. Other drainage characteristic common to the two sediments is drainage coarseness.

Mesa landscapes are also seen around the confluence of the River Sokoto with the River Niger (Plate I - N1) similar to that of the Middle Niger Basin. Also, the motley signature described as characterising the southeast of the Nupe basin is also seen in the south of Illo area. Similar rock type in the south east of Nupe basin are suspected. The foregoing similarities between the sediments of the two basins, suggest similarity in rock types.



PLATE XIV: The River Kaduna at Wuya on Bida-Mokwa Road. Note the Mesas in the horizon. This is typical of the motley terrain.

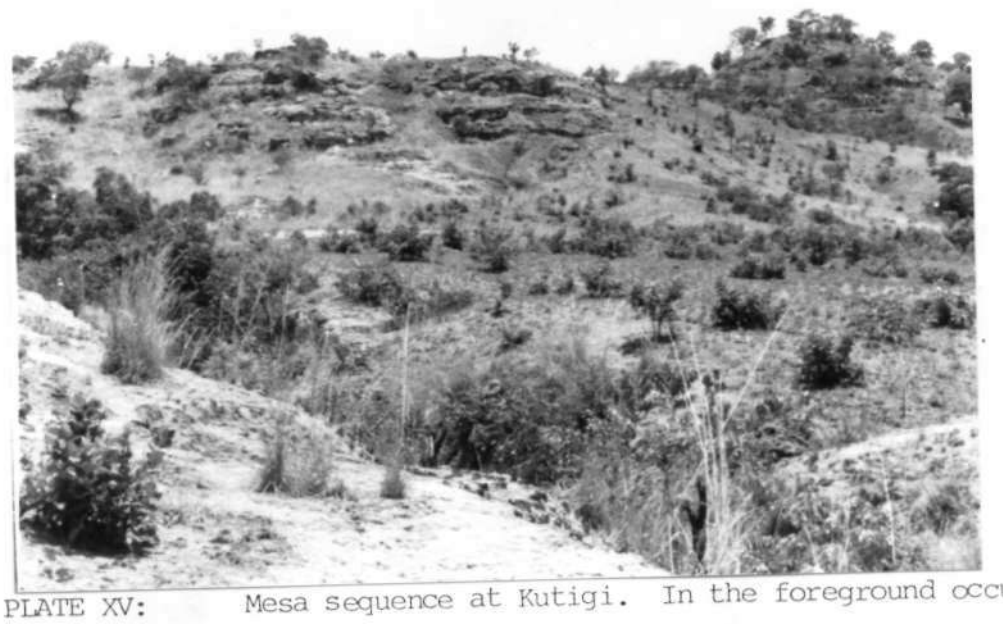


PLATE XV: Mesa sequence at Kutigi. In the foreground occurs grits. At the top are, interbedded iron stones, ferruginous sands tones, arkoses, siltstones and mudstones.

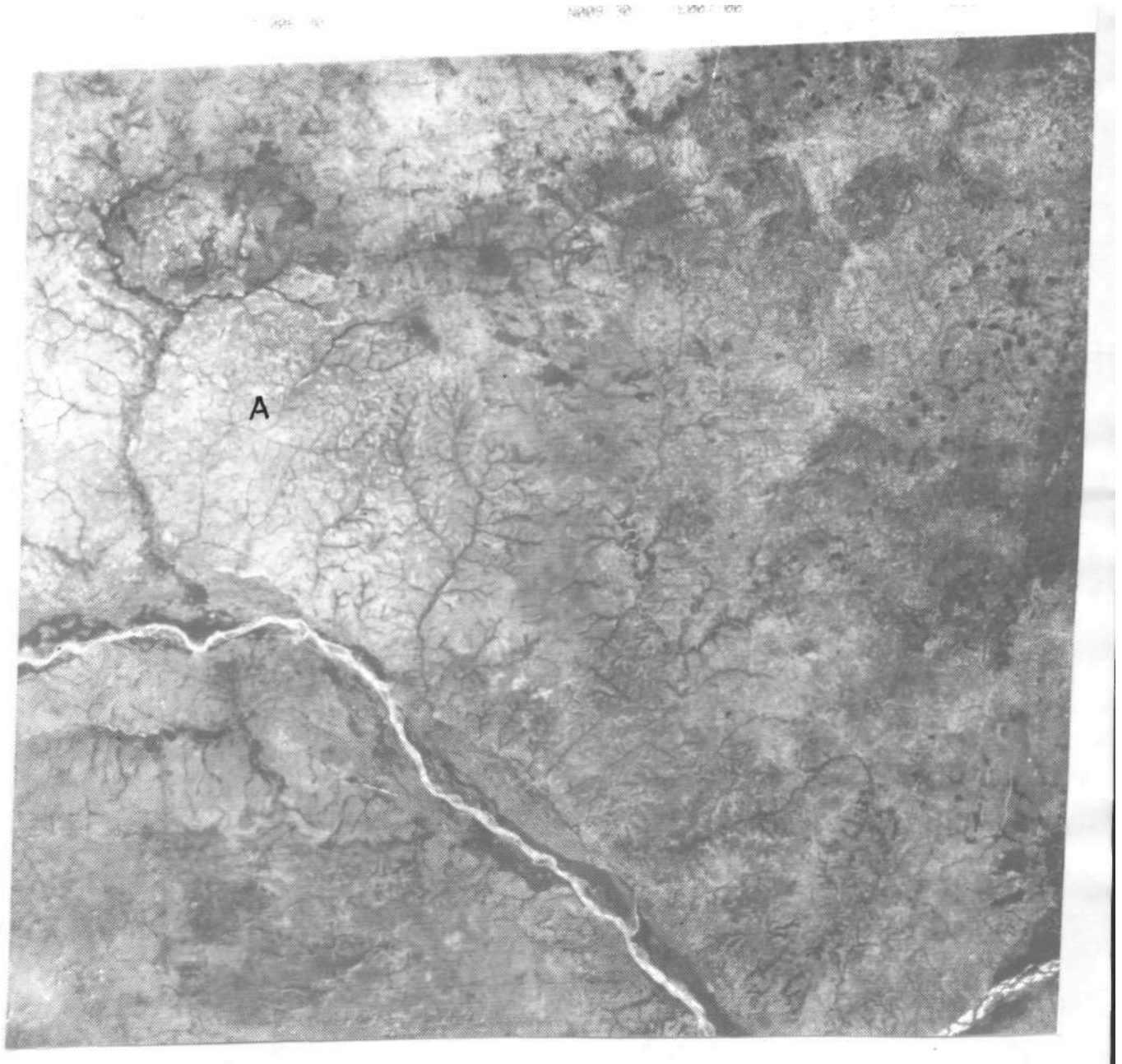


PLATE XVI: Landsat image showing south-eastern extremity of the Middle Niger (Nupe) Basin in the area. Note the light and grey motley patches at A. Note the relatively denser drainage at A and mapped out in Fig. 4.3.

Chapter 5

INTERPRETATION - STRUCTURAL

5.1 Basement Complex

5.1.1 North South Structural Trends

The dominant basement complex trend in the entire area is N-S. Several authors (e.g. Clifford, 1970 ; Black, 1980, Turner, 1983 etc.) described this trend as a Pan African orogenic feature imposed on earlier structures. The trend here includes N-S trend of foliation, N-S trends of rock outcrop ridges and N-S trends of fold axes. Figure 4.1, a Landsat - derived structural map of part of NW Nigeria, shows the various trends in the area.

The trends in the figure are mainly those of the metasediments. Those of the gneissic basement, known to be N-S also, are poorly displayed on the images. The granite bodies detectable on images have the longer axes of their ovoid shapes also oriented N-S.

The N-S trends of the metasediments concentrate in two major belts which are those of the ZSB and the KSB and are characterised by great lateral extent, extending north-south beyond the area into neighbouring Niger Republic. The N-S trend of the Zuru Formation for example, is of hundreds of kilometers long and is only concealed by Mesozoic and Cenozoic sediments in the northwest, west and south-centre of the area.

These trends are seen (e.g. as in Plate I-B) in converge indicating the presence of fold closures. As seen in the ZSB, some closures (e.g. Plate V) are tight while some are open. Although the general trends in the two belts are more or less N-S, the tight folds are seen to be earlier than the open ones.

5.1.2 East-West Trends

The existence of E-W trends in the area are seen at various scales. In Plate III at A1, the BGSF is seen trending eastwards towards Minna while at B2 the bands of the KSF are also seen trending eastwards. In the Bussa area of the ZSB (Fig. 5.1) certain structures and the rocks associated with them are seen to be oriented E-W. From these observations, two E-W trend types appear discernible. There are those which seem to be part of fold closures while others are relicts of earlier cycle of sedimentation over which the later and dominant N-S trend is superimposed.

5.1.3 Arcuate Trends

Arcuate trends are exhibited by those metasedimentary formations described (section 4.2.2.1) as arcuate. One of such units, is the Makichi quartizite described (Truswell and Cope 1963) as traceable through 270° of arc.

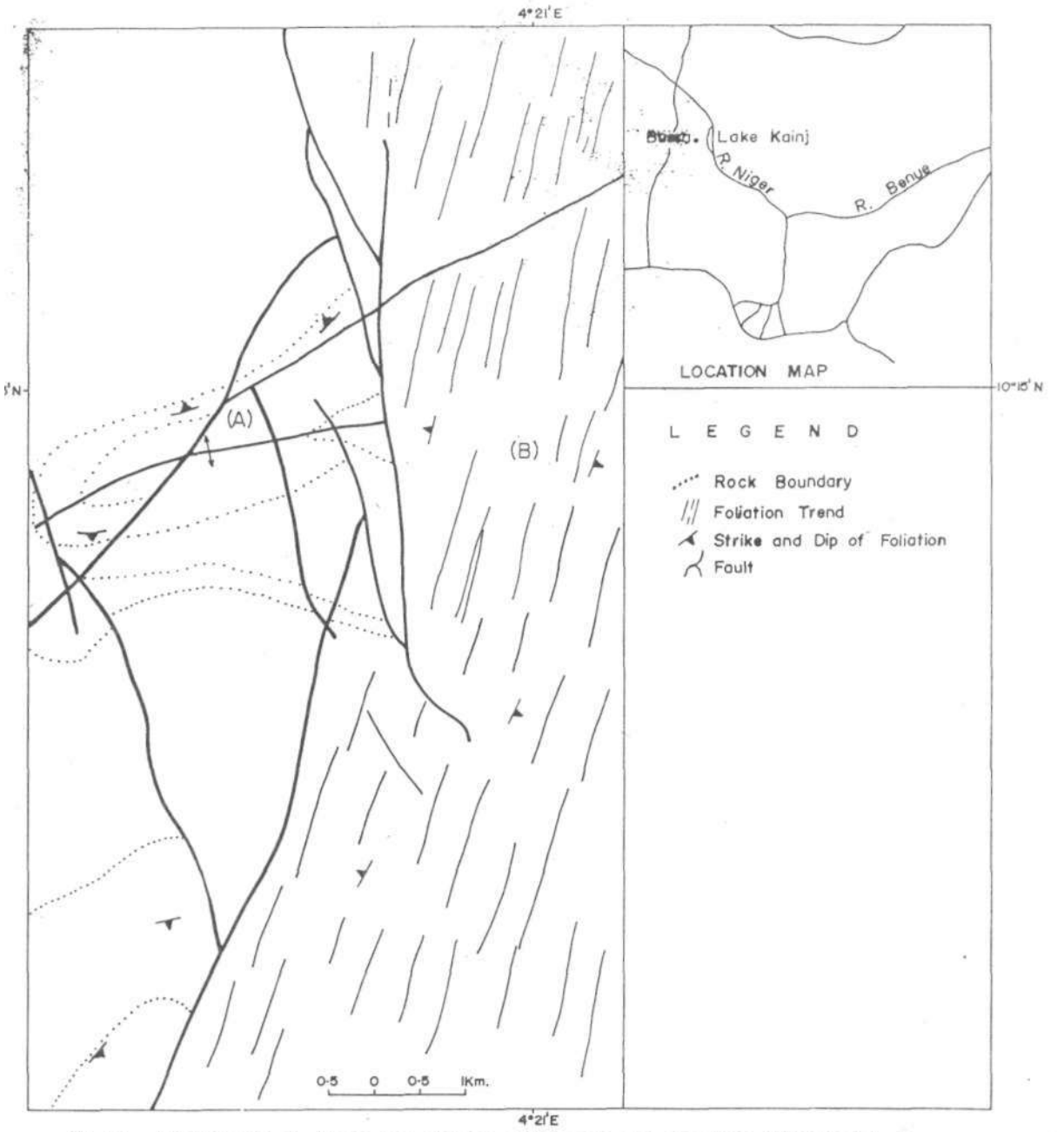


Fig. 5·1 Photogeology of Bussa Area showing earlier rocks and structures (A) truncated by later North—South ones (B) along N—S fracture zone

5.2 Lineaments

Lineaments are defined here as linear features on images and aerial photographs which represent zones within which there has been movement. Several investigations (e.g. Dessauvagie, 1974; Chukwu-Ike, 1977 and 1979; Udoh, 1981; Kogbe, 1981 etc.) have revealed the existence of regional lineaments on the Nigerian scene. In some of these investigations (e.g. Chukwu-Ike, 1977 and 1979 and Kogbe, 1981) these lineaments have been classified on the basis of their orientation into sub-types which are; NE-SW; NW-SE; E-W and N-S.

The regional advantage of Landsat and SLAR images is seen in their use for such study. It is however unfortunate that the Landsat images that are available for this work, are not the best obtainable because specially processed images (e.g. high-pass and low-pass filter images) have been produced in black and white or in colour. This type of images permits optimum display of lineaments. This means that any account on Nigerian lineament using standard Landsat products is not exhaustive. Despite the limitation of available images, the display of lineaments in the various scenes of this area is remarkable and the following are observations obtained from them.

5.2.1 Lineaments Types

NE-SW Lineaments: Several NE-SW lineaments occur in the area. Some of these are shown in Plates I, III and Fig. 4.1). Lineaments are generally more prominent in the schist belts. The major NE-SW lineaments seen

traversing the ZSB include the Yelwa lineament, the Yauri lineament and the Rabah lineament. The Yelwa lineament is the most prominent among these. The NE-SW lineaments in the KSB include the Kalangai fault of Truswell and Cope (1963) and those which control the major drainages in the Minna area; referred to here, as the Kada lineament, the Gwagwada lineament and the Gurara lineament (see fig. 4.1).

The Yelwa lineament (Plate I and fig. 4.1) strikes NNE and is traceable from the west of Lake Kainji to Mahuta in the north from where it curves more eastwards towards the Maru Schist Formation and Gusau. Although it is indistinct within the basement, it is nonetheless mapped here, as bifurcated just east of Mahuta with the two branches striking in the same ENE direction, but, with the left-hand branch traversing the southern extremity of the same formation and apparently disappearing under the sediments at Katsina.

The Yelwa lineament appears here, to serve as a boundary between two structurally distinct domains; one of irregular fold trends and structures on its western side; the other, a domain of regularly disposed NNE and N-S parallel structures (reference section 5.1.3 and fig. 4.1).

The Yelwa lineament has been described (Wright, 1976) as a dextral wrench fault. Drag folds are seen to occur on this lineament. Other faults in the area which seem to be its subsidiaries, that is, the Yauri and Rabah lineaments, were seen in the field as cataclastic zones characterised by intense shearing of schistose rocks in the bed of the River Malendo at Bin Yauri and cataslastic porphyritic Older Granite outcrops at Anaba on the Kontagora - Yelwa Road.

Eastwards in the area, the NE-SW lineaments, already named above as traversing the KSB, define the persistent NE-SW courses of the major rivers (i.e. the River Kaduna, the River Sarkin Pawa and the River Gurara) which flows across the belt and across the regional grain of the various formations there. One of these lineaments here, the Kalangai, has been described (Truswell and Cope, 1963; Chukwu-Ike 1977 etc.) as dextral wrench fault. According to Chukwu-Ike (1977) the Kalangai fault has a displacement of about 10km.

NW-SE Lineaments The NW-SE lineament type is not as prominent in the area as the type described in the foregoing section. Two sets of this lineament-type occur in the area (see fig. 4.1). These are the Gwagwada and the Gunu lineaments. One of these, the Gwagwada lineament, traverses the central part of the area cutting across the KSB in the east of the area and the ZSB as far west as Mahuta. The other lineament, the Gunu lineament, is traceable through Minna in the southeast and Yelwa in the northwest. The Gwagwada lineament is seen as discrete gashes in the terrain (Plate VII at NM). It is not unlikely that a NW-SE fault with a sinistral displacement, mapped by Truswell and Cope (1963) at Maganda, near Kubo, is a subsidiary of the Gwagwada lineament. If this is so, then the dextral NE-SW and the sinistral NW-SE lineament types observed in this area can be envisaged as related complementary shears which some authors (e.g. Moody and Hill 1956 and Ball, 1980) have described.

In this area, the NE-SW lineament seems better developed than the NW-SE type. This is reflected in their prominence and regionality in the area.

In a regional sense, major dextral and major sinistral wrench faults are known in the Nigerian Basement Complex and that of the Ahaggar (Truswell and Cope, 1963; Ball, 1980 etc.). In Nigeria some of these faults trend east or west of North (e.g. the NW-SE lineaments which according to Kogbe et al (1983), structurally controlled the Mid-Niger valley.

N-S Lineaments The lineaments classified here as the N-S type are so only to an extent because in some places, they are N-S, and, in other places, they strike NNE. Their attitude differs within the metasediments and the basement. Within the metasediments their trend is N-S and NNE in the gneissic complex. This observation contradicts that of Chukwu-Ike (1977) who mapped numerous N-S lineaments of short lateral extent disposed at regular intervals across the country. Only a few of his N-S lineaments are confirmed here. It is not implied that his observation is not correct especially as the images used here for lineament study are the standard and unprocessed Landsat products.

The N-S Lineaments mapped here occur mainly within the metasedimentary belts. These have been mapped out here (see fig. 4.1).

The N-S lineaments are of short lateral extent having apparently been truncated by numerous NE-SW and NW-SE types.

E-W Lineaments The existence of E-W lineaments in the area is generally inferred from the east-west alignment of certain drainage systems (e.g. the River Gulbin Ka, which is seen (fig. 4.1) to flow E-W across the strikes of the various metasedimentary belts and formations in the area. Entrenchment of these drainages in structurally weak basement complex zones is implied and such E-W zones appear rare compared with the higher frequency of other types. The view has been expressed by Oluyide and Udoh (1985) that E-W lineaments now occur as relicts having been overprinted by later events, which is possibly why they are rare and generally of short lateral extent. The regional ones seen in the area are the inferred Gulbin Ka lineament and the E-W lineament north of Zaria interpreted by Chukwu-Ike (1977 and 1979) and this is shown in fig. 5.2. These two E-W lineaments are inferrable from Landsat images. A host of others are only detectable on larger scale data bases such as 1:100,000 aerial photo indexes. This is so for the silicified E-W lineaments in the southeast of Kakuri sheet mapped by Vaniman (1973).

5.2.2. Distribution of Lineaments In the Basement Complex

Lineaments are exhibited more within metasedimentary belts than within the gneissic basement. The inhomogeneity of the

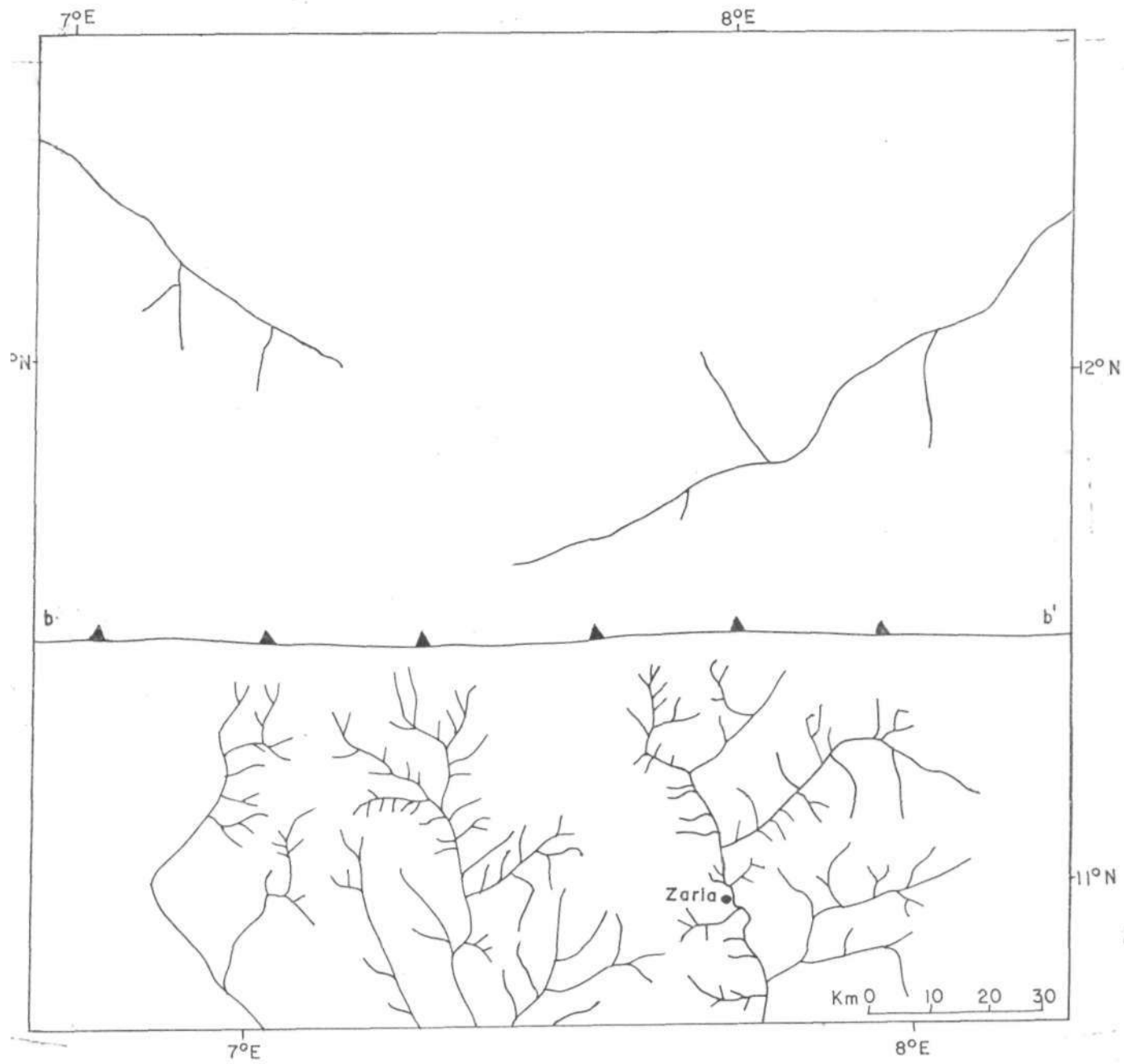


Fig. 5.2: E-W Lineament: inferred crustal boundary of Chukwu-Ike (1979). Note drainage difference on either side of the lineament - bb'.

metasedimentary belts in terms of diversity of rock types accounts for this contrast. Even then, some lineaments, notably the N-S type, seem more abundant in some places than in others. This is so when the frequency of lineaments in the ZSB and the KSB are compared. They are more abundant and regularly disposed in the latter. It seems this pattern follows the differences in tectonic activity in the two belts.

They are more abundant and regularly disposed in the latter. It seems this pattern follows the difference in tectonic activity in the two belts.

5.2.3 Lineaments in Schist Belt Relationships

Lineaments and Discreteness of Troughs and Belts The importance of lineaments, notably the N-S type, is seen in the interpretation given to them and their relationships with certain geological formations and schist belts in the NW Nigerian scene. Chukwu-Ike (1977) for example, deduced from his Landsat study of the area, that N-S metasedimentary troughs exist in the NW Nigerian schist belts and that these troughs are lineament-bound. The Older Granites according to him are located at these trough-lineament boundaries. His observation is shown in Fig. 5.3. This figure shows that the BGSF is lineament-bound. Its eastern boundary is shown as terminating against N-S lineaments (i.e. the Guwa and Minna lineaments) of this writer. This observation by Chukwu-Ike (1977) implies the discreteness of certain belts and formations in this area.

The following are this writer's comments on Chukwu-Ike's view based on image study and field verification of the same area:

(a) Major lineaments occur on the east flank at BGSF as fig. 5.3 shows.

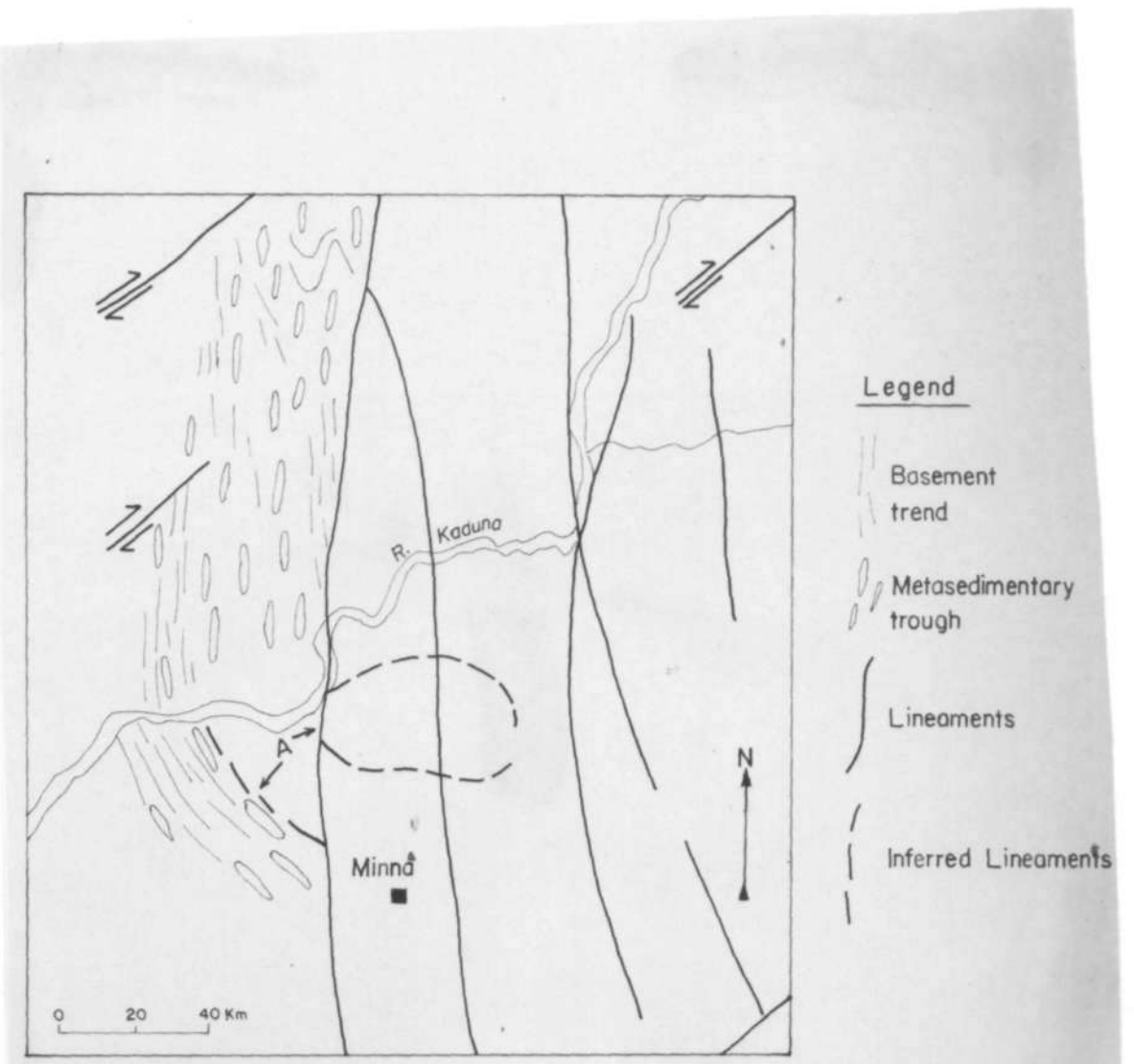


Fig. 5.3.
Note the suggested (Chukwu-Ike, 1977) lineament boundary of metasedimentary trough at A.

Fig. 5.3: The BGSF in the Zungeru - Minna area. Note the suggested (Chukwu-Ike, 1977), trough lineament boundary at A. Compare with Fig. 4.1 where the trough is mapped in this work as continuous to Minna and untruncated by the Guwa lineament as above scheme portrays.

b) These lineaments merely seem to provide down-dropped blocks within which the metasediments have been preserved. This may be the role of the lineaments in the general area notwithstanding lineament occurrence along formation boundaries.

c) There may be need however, to further examine the above relationship in the field.

5.2.4 Lineaments and Mineralisation

The NW Nigerian scene, and indeed, the entire country is now known from previous and recent field and remote sensing investigations (e.g. Russ, 1957; Truswell and Copè 1963; Dessauvagie, 1974; Wright, 1976; Chukwu-Ike 1977; Ananaba and Ajakaiye, 1987 etc.) to be traversed by numerous lineaments of varied extent, orientation and association. Certain lineaments among these, that is the NE-SW lineaments have been suggested (Wright, 1976) to have connections with the oceanic fracture zones in the South Atlantic (see fig. 5.4).

Connections have also been suggested between lineaments and mineralisation by several authors (such as Badgley, 1959; Norman, 1969; Thamm, 1974; Wright,1970 and 1976; Chukwu-Ike, 1977 and 1979; Ananaba and Ajakaiye, 1987 etc.).

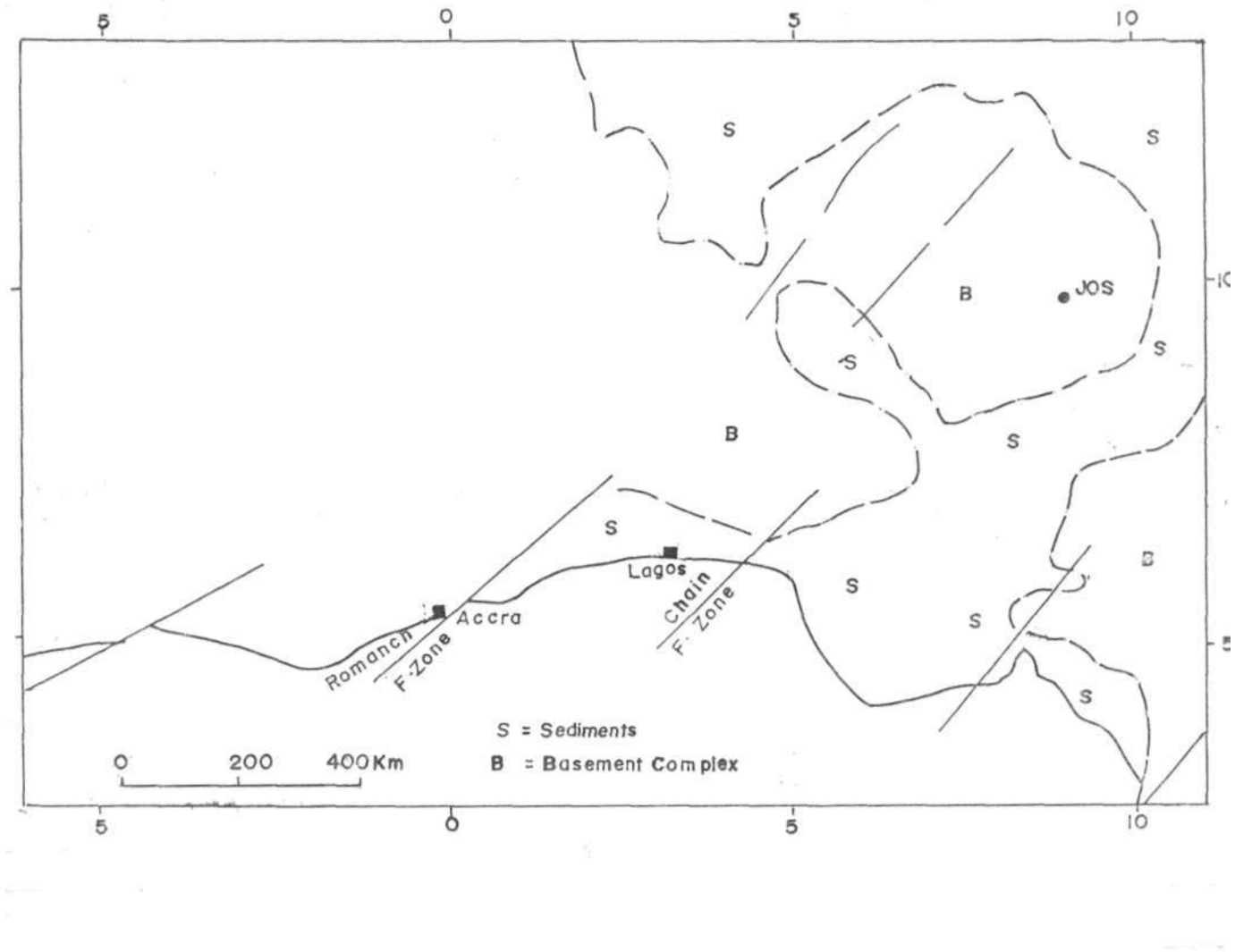


Fig. 5.3: A correlation of some Nigerian lineaments with certain South Atlantic Fracture Zones (after Wright, J.B. 1976).

In Nigeria, the location of gold, won mainly as alluvial deposit has long been puzzling. Although several investigators have examined possible occurrences of certain minerals along Nigerian lineaments (Woakes, personal communication) it is suggested here that a combined geological, geophysical and geochemical investigation of favourable mineral sites along known lineaments and associated structures and formations be considered and carried out for the much desired discovery of mineral resources in Nigeria. As Badgley (1959) suggested, favourable mineral locations may occur where lineaments intersect or where associated with suitable geological conditions such as intrusions.

5.3 Folds

In plan, two main fold types are distinguishable in the area in the metasedimentary structures. The first type of folds, apparently earlier structures, are generally arcuate or sinuous and invariably occur discordant with their gneissic enclave. This fold type appears as remnants of earlier and once extensive basement complex features now preserved in the gneissic basement and commonly of small areal extent. They are commonly antiformal with no discernible difference between their core features and the surrounding gneissic basement.

The second fold types contrast with the first in their linear orientation and extent. This later group to which belong the N-S folds of the ZSB and the KSB apparently postdates those of the first group on which they appear superimposed and discordant.

Generally, the folds, irrespective of the groups they may belong, are more complex than aerial data bases portray. Several field observations (e.g. Ajibade 1980) reveal several episodes of deformation in the rock outcrops of the area. These are medium scale structural features which are beyond the resolution of the techniques used here.

Regionally, however, evidence of refolding of folds in the two groups are obtainable from images (e.g. Plates V and VII). Axes of earlier and later folds may be co-linear as with the N-S fold group or differently oriented as with those fold structures with curved outlines.

5.3.1 Fold Types

The Arcuate Folds: the fold structures described here, include the Jiwawa synform, the Ibeto domes, the Makichi and Kubo and the Kushaka folds.

The Jiwawa fold lies due west of Zungeru (fig. 4.1). The aerial photo print lay down of sheet 162 (Akere) shows this structure to be crescentic with changes in trend from NNE, N-S to NNW. The aerial photograph stereomodel of the structure reveals a tight nose in the north as well as assymetry and steep westerly dips on both limbs. In the field, the structure is associated with felsic gneiss, quartzitic and mafic rocks and marble. This assemblage contrasts markedly with the Ushama syncline assemblage and that of the BGSF. The Jiwawa fold may be one of the relict older structures.

From structural and lithological observations, the synform seems discordant with the rest of the area.

The Ibeto domes are small structures detectable on the SLAR image (Plate XI) which covers the Ibeto area. The domes occur in gneissic terrain just outside the eastern flank of the ZSB. The structures display (fig. 4.4) steep outward dips and show no discernible relationship with their gneissic enclave. Their cores which show no contrast with the surrounding basement display no indication of the mechanism of doming. It is however suspected that they are intrusion - induced because a poorly exposed mesocratic biotite granite was found in the field in the core of one of the structures.

Although the domes are considered here as intrusion-induced other causes of domes are possible. For example, in the central Damaran Belt of Namibia, Barnes and Downing (1979) attributed the formation of domes to intrusion and a combination of intrusion and crustal shortening. And in SW Nigeria, Jones and Hockey (1964) reported the occurrence of a dome at Iwere. The Iwere dome according to them, was seen to have a core of muscovite gneiss.

The Makichi and Kubo folds are complex structures (Plate VII at A and B) with details shown in figures 3.2a and 4.4. The Makichi fold is arcuate with changes in direction of trend from NE through the east etc. to SW. Details of this structure are shown in figure 4.4. The Kubo fold structure is not fully determinable photogeologically because its trends merge with basement trends. N-S minor and later folds are superimposed on its main structure.

The Kushaka fold forms a part of the KSB and unlike those fold structure described above, it occurs within a schist belt. This structure has been referred to (Chukwu-Ike, 1977) as the Udawa lunate fold. On the SLAR image of the area (Plate VII-D) the fold structure is revealed by a prominent band which corresponds with outcrop ridges of a quatizite. An earlier deformation of this structure follows an E-W axis. A later (F2) deformation is detectable through the curvature of geomorphological features at D (Plate VII).

The Kushaka structure and its associated rock types appear more complex and wider in distribution than they have hitherto been considered. For example, the structure is seen to swing at Shiroro from E-W to the N-S fold structure observed at Shakwatu and its environ in the east of Minna. This area is characterised by numerous intrusions. As Ajibade (1986) pointed out, the structure Kushaka possibly owes its varying trends to intrusions between which its several sections seem separated.

The N-S Oriented Folds: This fold type unlike the type described in the last section, has its axis oriented more or less north-south. It is more prominent and dominates the NW Nigeria scene. In this group belong the complex ZSB and the KSB regional folds. This fold type is the Pan African structures of several authors (e.g. Black, 1980; Turner, 1983 etc.).

The ZSF and the BGSF form the largest fold structures in the area. The overall appearance of the former is antiformal while the later is synformal. Within these regional folds are lesser order co-linear folds whose closures are detectable with Lansat images (e.g. Plate I at B).

The folds in this group are more complex than the simple and straight features which images display. Rock outcrops seen in the field and which occur as lines on images, are for example, seen to display several generations of deformation. In the Zungeru area as a further example, Ajibade (1980) identified at least four episodes of deformation. The Landsat image of the same area (Plate III at A) shows only lines which correspond with rock outcrops. This contrast reveals the limitation of Landsat and other small scale data sources in structural interpretation of a complex terrain as the details seen in outcrops are not observable in the images.

However, evidence for at least two episodes of folding are obvious. This is revealed by the tightness or openness of folds. In Plate V for example, a fold (Plate V at C) displays a tight closure and another (Plate V) at D) is open. This later feature has been described (e.g. Chukwu-Ike, 1977) as later than the first.

In the last paragraph of section 5.1.3 the structural trends on the western side of the Yelwa lineament were discribed as irregular.

The fold trends in this area are not classifiable with the sub-types described above. They seem to constitute a distinct domain separated from the eastern area by the Yelwa lineament.

5.3.2 Age Relationships Of Folds

The various fold-types described above, can be ascribed to distinct age-classes. The arcuate fold structures presumably predate the more regional and generally N-S oriented type; the latter is superimposed on the arcuate ones.

Age distinctions have been made (e.g. Egbuniwe) 1982) between the folds which have been considered here as belonging in the N-S oriented group. The Anka and the Maru formations are thought, for example, from methods other than remote sensing, to be Pan African (450 + 200 My) and Kibaran (1,000My,000My) respectively. The folds associated with these formations are oriented N-S on images. The differences in age within the same group such as Egbuniwe (1982) observed, are not seen on images.

Chapter 6

EVOLUTION OF THE NORTHWEST NIGERIAN BASEMENT COMPLEX

6.1 General

The early sections of this work, were discussions of the aspects of the geography of the area, the sensor types and characteristics of the images used, and the geology of NW Nigeria. The area under investigation was seen to lie in the drier part of Nigeria characterised during the wet and dry seasons by respectively cloudy conditions and haze and dust. These seasons, together with other factors combine to give the savanna type of vegetation seen in the area.

Because of the type of vegetation cover in the area and the climatic conditions which prevail, NW Nigeria can be described as suitable for a regional remote sensing based study of this type.

Exposure of rocks is remarkable, unlike in the southern part of the country where both forest and climatic conditions obscure both topography and geology.

With the prevalent conditions in NW Nigeria therefore the amount of information extractable from images depends almost solely on system resolution and image quality. Discrimination of the various rock types remains a major limitation of the small - scale images (Landsat and SLAR) used in this work. Rock groups are however well resolved. So also are their associated regional structures. This advantage enables deductions to be made on the geology of the area.

6.1 The Gneissic Infra-structure

The banded gneiss (Plate II) together with the granite gneiss form the gneissic complex of the area (section 3.1.1.1). This complex was described in the same section as characterised by light grey tone on the black and white images used. This is the most prevalent tone in the entire area. In the field, the dominant rock type of the complex, is the banded gneiss, within which other gneisses occur and into which the granites intrude.

It is observed that the tonal signature of the gneisses is obscured mainly in those areas where the major schist belts (i.e. the ZSB and the KSB) occur and areas where there is overburden.

The inferences drawn from the above paragraphs are that the gneissic rocks notably the banded gneiss is the largest rock type in the area; it is basal and therefore formed a one-time platform for the various metasediments. These deductions are supported by the field observations of Vaniman (1976) in the Bishini area of NW Nigeria. According to Vaniman (1976) the gneisses and migmatites are structurally and stratigraphically below the metasediments. Russ (1957) thought of the gneisses as ancient metasediment series. They are also considered among the oldest rocks of the basement complex by Oyawoye (1970).

6.3 Cycles of Sedimentation

Apart from Truswell and Cope (1963), most workers on the Nigerian basement complex seem to recognise the polycyclic nature of the complex. Cycles of sedimentation seem recognised also. This is seen

in the works of some authors (e.g. Oyawoye, 1965 and Mc Curry, 1976 etc.) who distinguished an earlier (Older) metasedimentary sequence from a later (Younger) one.

In this work, the metasediments which occur as remnants on the gneissic basement and those which form the dominant N-S feature of the area are thought to belong to different cycles of sedimentation. The former type is presumed older because of their small areal extent; their association with the gneisses and other characteristics which Mc Curry (1976) and Chukwu-Ike (1977) have enumerated. Some of the formations which apparently belong in this group have been named in section 4.2.2. The foregoing is not to state that still older cycles do not exist. The various complex folds displayed by the older formations (e.g. the Makichi and Kubo quartzites) may depict still older relicts among the group. The structurally more complex Makichi quartzite (with indication of several episodes of deformation) would on structural grounds, appear oldest.

Instances are seen where remote sensing method is unhelpful in age-differentiation among structurally similar formations. The Anka and Maru formations are, for example, displayed as N-S trending formations on images. They would here belong to the younger metasedimentary group. But deduction from field observations (e.g. Egbuniwe, 1982) suggests respectively, a Pan African and Kibaran ages, for the Anka and Maru Formations.

6.4 Trends of Metasediments Affected by Older Granite Intrusions

6.4.1 Effect of Intrusions on Continuity of Metasedimentary Belts

Intrusions of Older Granites in the Kusheriki and Kushaka areas have caused structural complications in the metasedimentary belts. As shown in figure 3.2a each individual belt has its distinct trend and is separated from others by intrusive bodies. Between these bodies, the belts are seen to have been squeezed and disoriented so that belts which might have been once coherent, are now in discrete sections with individual sections presenting their own structural style, depending on the effects of plutonism on it. In interpreting the relationships of the belts in this area, account should be taken of the effects of Older Granite intrusion on the belts in the area.

The above observation agrees with the recent observation by Ajibade (1986). Ajibade drew attention to the hitherto unknown extent of the Older Granites in the Kusheriki-Minna area. According to him, an appreciation of this extent is critical to the interpretation of the geology of the area, and, possibly other areas of the Nigerian Basement Complex. This observation implies that the relationship of the belts here, is structurally simple but for the effects of the Older Granite intrusions.

6.5 Lineaments and the Suggested Discreteness of Schist Belts

The present study shows a concentration of lineaments mainly in the metasedimentary belts (see fig. 4.1). Lineaments are relatively fewer within the gneissic basement of the area. The importance of lineaments in the Nigerian basement complex geology appears to lie in the interpretation that Chukwu-Ike (1977 and 1979) gave to the relationships between Landsat N-S lineaments and N-S schist belts and intrusions.

According to Chukwu-Ike (1977), Landsat images, suggest that the Older Granites are controlled by major N-S lineaments located at the metasedimentary trough margins. From this interpretation, he considers some N-S metasedimentary troughs as 'discrete and suggests that some metasedimentary troughs and belts, are separate from one another.

Among the examples cited by Chukwu-Ike (1977) to illustrate his observations, are the metasedimentary troughs and lineaments in the Zungeru-Minna region (fig. 5.3).

At the outset of this writer's observations on lineaments (section 5.2), it was stated that the images used for lineament mapping were not the best obtainable and that the present account on lineaments was not exhaustive. An examination of the present images for evidence to support Chukwu-Ike's suggestions enable the following comments to be made:

(1) that N-S lineaments occur largely within schist belts and appear to have uncertain relationship with them.

(2) that, with the BGSF, both Guwa and Minna N-S lineaments (fig. 4.1) appear only to create down-dropped blocks within which metasediments are preserved.

(3) that northwards, the Bassa Granite (fig. 4.1 - J2) appears controlled by the Guwa lineament at the eastern margin of the BGSF.

(4) that the Shakwatu segment of the KSB (fig. 4.1 - F) appears bounded on both flanks by lineaments.

(5) that intrusions in many areas appear controlled generally by all types of lineaments.

(6) that the elongated shapes of the batholitic granites may in part be due to country schistosity.

The various lineaments mapped by Chukwu-Ike as bounding the BGSF, are difficult to confirm. One single evidence against Chukwu-Ike's suggestion is that both on images and in the field, the Zungeru W-E branch of the BGSF is traceable from Zungeru to Minna across the two major (Guwa and Minna) lineaments in the area. This author's opinion is to suggest a detailed examination of lineament-schist belt relationships, because while on the one hand the discreteness or lineament-boundary of troughs is in doubt, on the other hand, some belts within the KSB appear discrete.

6.6 The Extent of the Metasediment Cover

The metasediments, irrespective of the groups into which they have been classified here, were, in the opinion of this writer, once extensive. The evidence for this assumption as several authors (e.g. Mc Curry, 1976) have already advanced could be found in the widespread occurrence of the metasediments even within the gneisses.

Certain terrains that are now underlain by migmatites, appear to have once been areas of metasediments. In the earlier part of this work, for example, some migmatites were distinguished (section 4.2.1) on the basis of drainage pattern and density. One of the migmatite types, the one described as migmatite with dominant palaessome, is considered here as a former metasedimentary sequence that have been changed by metamorphism and intrusion. The dominance of palaessome in this migmatite and its sharp contact with intrusive bodies (a feature which McCurry (1976) found between granites and metasediments) are taken here as the strongest evidence for a one time metasedimentary nature of the migmatite which extends eastwards beyond the Kajuru area mapped by Udoh (1973).

The foregoing line of argument differs from the view expressed by Chukwu-Ike (1977) who provided evidence in support of erosion of the metasediments but with the vestiges of their troughs preserved in the migmatites.

6.7 The Emplacement of the Older Granites

The Older Granite features observable on small-scale images such a Landsat include their relationship with country rocks, their shape, and their orientation. These features are notable where Older Granites intrude the metasediments, but the difficulty in mapping the Older Granites within the gneissic basement was stated in earlier sections (i.e. sections 3.1.1.3 and 3.1.2.1). It is found in this work that several compositional and textural types of the Older Granites are detectable on 1:1,000,000 Landsat images. These types include large acid-basic bodies (e.g. Minna Granite) and the porphyritic granite.

The granites generally appear intrusive judged from their relationship with country metasediments. Their generally avoid shape with their long axes oriented along the regional N-S grain of the country rocks reveals their being subject to the same deformation that imposes the general N-S grain on the entire area.

It may therefore be interpreted that the granites predate that deformation or were syntectonic. Although McCurry and Wright (1971) recognised post tectonic granites, there is no image evidence for such. Such granites probably evolved from processes that can be inferred only from detailed field study, as, for example, the derivation of a porphyritic granite at Minna through feldspathisation of a diorite.

KASHIM IBRAHIM LIBRARY
AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA.

6.8 Models on the Evolution of the Schist Belts

6.8.1 Some Previous Models on Schist Belts Evolution

Several plate tectonic processes were called upon (Burke and Dewey, 1972; Mc Curry, 1976; Vaniman, 1976; Ajibade et al, 1979; Ajibade, 1980, Egbuniwe 1982; Turner, 1983 etc.), to explain the origins of the Nigerian metasedimentary trough and other aspects of the NW Nigerian metasedimentary formations.

Burke and Dewey (1972) considered all the metasediments in the reactivated basement, to have been involved in the Eburnean (2,000 M.y) and Pan African (600 M.y.) events. The idea of Burke and Dewey (1972) was modified by Vaniman (1976) to explain the development of the Nigerian synclinorium which he (Vaniman) considered as a major sedimentary trough with location, orientation and magnitude of a retro-arc basin in the Pan African collison of Dahomea with Birrimea (fig. 1.4). According to him, the K/Ar ages (500-600 M.y.) of the metasediments obtained by Harper et al (1973) permits his interpretation.

Mc Curry (1976) believed that the schist belts represent remnants of a Katangan (1:000-800 M.y.) sedimentary cover on the basement that was infolded, metamorphosed and intruded by granites during a Himalayan - type collision orogeny.

Ajibade (1980) in his account, saw all the schist belts as Kibaran (1,100 M.y.) and ensialic. He saw the schist belts as similar to the "tectonic elements" or "furrows" of Helwig (1974) and Dott (1974) who identified these elements as elongate depositional basins

of contrasting topography and lithology within an orogen. These elements, according to Ajibade (1980) were precursors to the later Pan African mobile belt, in which there was rejuvenation of pre-existing structures and granite plutonism during a thermo-tectonic event.

6.8.2 Deducations from Apparent Depositional Pattern of the Metasediments

The ZSB and KSB appear to serve as keys to deciphering some of the schist belts problems such as their origin and their relationships with one another. The principal lithology which each of the belts contains appears to provide the clue. The ZSB is principally psammitic while the KSB is principally argillaceous.

The psammites of the ZSB and the argillites of the KSB, are, respectively, not unlikely, to be deposits in a sedimentary trough, in which the psammites, were deposited as traction load and the argillites deposited further off as suspension materials. Krumbein and Sloss (1963) demonstrated such a pattern of sedimentation in their discussion on lateral variation in sediment deposition in shallow seas.

The ensialic sedimentary trough in which the ZSB and the KSB formed, could be as shown in figure 6.1 which envisions a deeper trough for the KSB.

If this is true, then the mainly psammites in the ZSB and the mainly argillites in the KSB are explained. The picture, in addition to the foregoing, establishes the relationship between the various

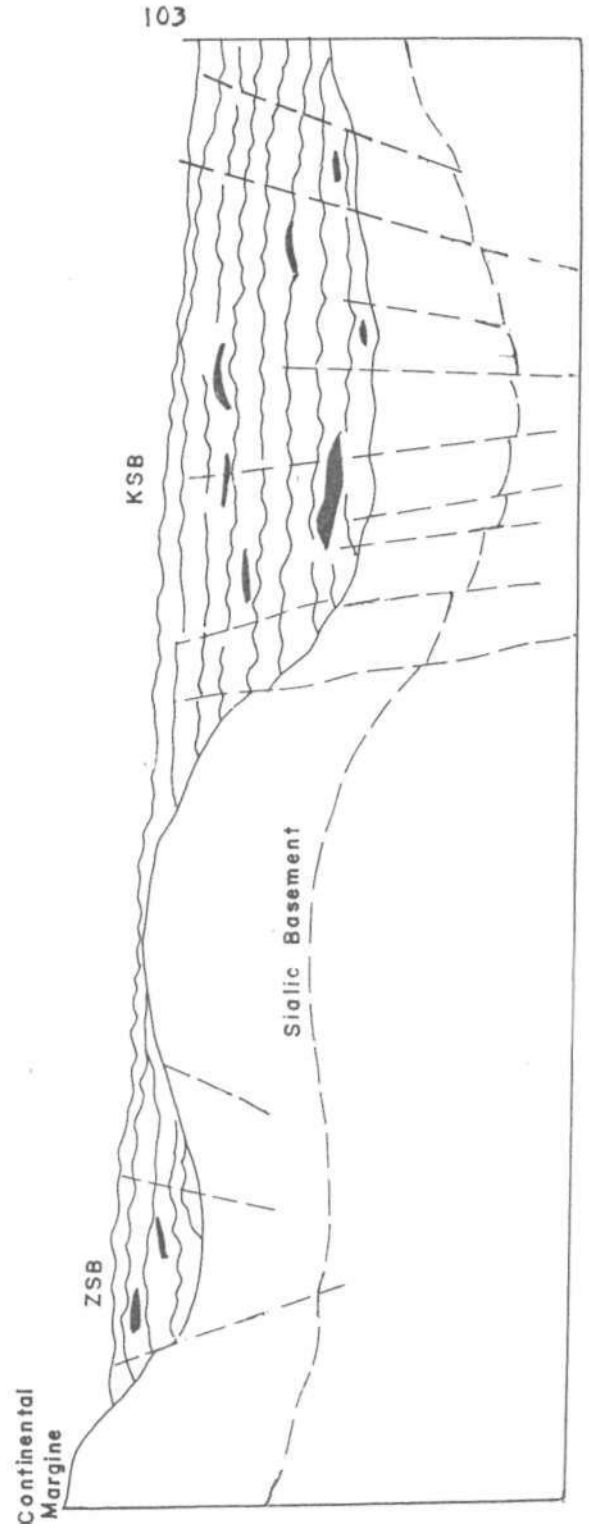


Fig. 6.1: Depositional Trough of the Zuru and Kusheriki Schists.

formations within the ZSB and the KSB. These formations would appear as lateral facies and therefore contemporaneous sediments.

That the ZSB formed in a shallower trough and the KSB in a deeper trough is supported by their principal rock types. A further indication is the reported occurrences of turbidites in the KSB (e.g. Truswell and Cope, 1963; Ajibade, 1980 etc.).

It seems pertinent to mention here, the suggestion of Truswell and Cope (1963) and the observations of Vaniman (1976). Truswell and Cope (1963) thought of the formations within the KSB as forming under one crogeny. Vaniman (1976) correlated some sequencies of the KSF which is a part of the KSB, with the schist belts in the Kakuri-Bishini area. These works suggest that the rocks in the KSB belong to the same sedimentary episode. The presence of older relicts is not precluded and these only indicate still earlier episodes where they are observed.

In a regional sense, Black (1980) drew attention to the continuity that exists between the formations and the structures in the Ahaggar (southern Algeria) and the Benin-Nigeria terrain within which this area lies. The overall Pan African trend he described is seen in the area. The troughs that held the ZSB and the KSB, could be smaller basins within the general tectonic picture that Black (1980) described.

6.9 Conclusion

It is deducible from the observations in the preceeding chapters that:

(i) Both the gneissic basement and the supracrustal cover possibly had the same origin from normal sedimentary processes in similar geological troughs but at different geological times.

(ii) The principal lithologies indicate the origin of the metasediments as contained in this chapter, and that earlier formations could have originated in the same manner.

(iii) The earlier features and the simple relationship between the formations which belong in the same cycle have been complicated by varied episodes of plutonism, cataclasis and metamorphism.

(iv) Images interpretation strongly suggest discreteness of some formations and domains, in spite of the above relationship. Whether or not image account is correct, this relationship is recommended for field investigation.

6.10 Suggestions for Field Work

Some parts of the area did not lend themselves to easy interpretation. This is expected in a complex terrain such as the NW Nigerian basement complex. The problem areas as well as other features and their associations which could be promising from the viewpoint of mineral and water resources form the basis of this recommendaion:

(i) The structurally distinct areas on either side of the Yelwa lineament and the suggested lineament-boundary of the BGSF may be further examined to see whether the formations are discrete or whether the formations are merely preserved in down-dropped blocks.

(ii) To understand the basement complex geology of NW Nigeria, it is suggested that the role of lineaments and plutonism be further examined because it appears these features (as Ajibade 1986 pointed out on granite plutonism) complicate the history of the basement complex.

(iii) In mineral and water resources exploration it is worthwhile examining the regional localisation of minerals and ground water along the lineaments mapped here and elsewhere (e.g. Chukwu-Ike, 1977).

REFERENCES

Abdel - Gawad, M. 1976) Use of Satellite Photography for Mineral Exploration and Groundwater Studies In: Proceedings UN/FAO Seminar On Remote Sensing of Earth Resources and Environment (Ed. Abdel-Hady Mohammed) Cairo Egypt.

Adeleye, D.R. (1971) Stratigraphy and Sedimentation of the Upper Cretaceous Strata Around Bida, Nigeria. Unpub. Thesis of University of Ibadan.

Adeleye, D.R. (1976) The Geology of the Middle Niger Basin. In: Geology of Nigeria pp.283-287 (Ed. Kogbe, C. A.) Elizabethan Publishing Co. Lagos.

Adeleye, D.R. (1979) A Review of the Maastritchtian Palaeogeography of the Southern Iullemmeden and Nupe Basins. Journal of Mining and Geology Vol. 16 1979 No. 2.

Adeleye, D.R. and Dessauvagie, T.F.J. (1972) Stratigraphy of the Niger Embayment near Bida, Nigeria, In: African Geology (Ed. Dessauvagie, T.F.J. and Whiteman, A.J.) University of Ibadan, Ibadan pp.181-186.

Ajakaiye, D.E. and Ojo, S.B. (1976) Preliminary Interpreation of Gravity Measurements in the Middle Niger Basin Area, Nigeria In: Geology of Nigeria (Ed. Kogbe, C.A.) pp. 295-307 Elizabethan Publishing Co.

Ajibade, A.C. (1971) The Geology of the Country around Zungeru, Northwestern State of Nigeria. Unpublished M.Sc. Thesis University of Ibadan.

Ajibade A.C. (1980) Geotectonic Evulution of the Zungeru Region, Nigeria. Unpublished Ph.D. Thesis of University College of Wales, Aberystwyth.

Ajibade, A.C. (1986) Field Relations In the Basement Complex of the Kusheriki - Minna Area (Unpublished paper).

Ajibade, A.C., Fitches, W.R. and Wright, J.B., (1980). The Zungeru Mylonites, the identification of a major tectonic unit in the NW Nigerian basement. Revue de geol. dynamique et de geographie Physicque in press.

Allum, J.A.E. (1956) Photogeological Interpretation of Zungeru sheet (163) Unpublished G.S.N. data.

Allum, J.A.E. (1966) Photogeology and Regional Mapping. Pergamon Press.

Atlas of the Federal Republic of Nigeria - Federal Surveys Department, Lagos.

R E F E R E N C E S (Cont'd)

Badgley, P.C. (1959) Structural Methods for the Exploration Geologist. Harper and Row Publisher, New York.

Bafor, B.E. (1979) Volcanogenic-Sedimentary Formations In Parts of Central and Southwestern Nigeria and their Mineral Potentiality. Unpublished Ph.D. Thesis of the University of Belgrade.

Ball, E. (1980) An Example of very Consistent Brittle Deformation Over a Wide Intra Continental Area: the Late Pan African Fracture System of the Tuareg and Nigerian Shield. Tectonophysics 61 No. 4 (1980) pp. 363-379 Elsevier Scientific Publishing Co. Amsterdam.

Barnes, F.H.J. and Downing, N.K. (1979) Origin of Domes in Central Damaran Belt, Namibia. Revue de Geologie Dynamique et de Geographie Physicque Vol. 21 Fesc. 5 pp. 383-386 Paris.

Barret, E.C. and Curtis, L.F. (1976) Introduction to Environmental Remote Sensing Chapman and Hall, London.

Black, R. (1980) Pre Cambrian of West Africa. Episodes, Vol. 1980 No.4.

Barke, K.C. and Dewey, J.F. (1972) Orogeny in Africa. In: African Geology (Ed. Dessauvagie, T.F.J. and Whiteman A.J.) pp. 583-608. University of Ibadan Press Ibadan, 1970.

Chukwu-Ike, I.M. (1977) Regional Photogeological Interpretation of the Tectonic Features of the Central Nigerian Basement Complex: A Satellite Imagery Based Study. Unpublished Ph.D. Thesis of University of London.

Chukwu-Ike, I.M. (1979) The Utility of Landsat Images in the Structural Reconnaissance for Minerals in Nigeria (Unpublished Data).

Clifford, T.N. (1970) The Structural Framework of Africa. In: African Magmatism and Tectonics (Ed: Clifford, T.N. and Gass, I.G.) pp. 1-26. Oliver and Boyd. Edinburgh.

Dessauvagie, T.F.J. (1974) A Geological Map of Nigeria. Nigerian Minning and Geosciences Society.

Dott, R.H. Jr. (1974) The Geosynclinal Concept. In: Modern and Ancient Sedimentation (Ed: Dott, R.H. and Shaver, R.H.) Soc. Econ. Palaeont Mineral Sp. Publication, 19 p. 1-13.

Drury, S.A. and Holt, R.W. (1979) The Tectonic Framework of the South Indian Craton; a reconnaissance involving Landsat Imagery. Tectonophysics 65 (1980) Ti - T15 Elsevier Sc. Publ. Co. Amsterdam.

Egbuniwe, I.G. (1982) Geotectonic Evolution of the Maru Belt N.W. Nigeria. Umpubl. Ph.D. Thesis of University College of Wales Aberystwyth.

R E F E R E N C E S (Cont'd)

Fitches, W.R.; Ajibade, A.C.; Egbuniwe, I.G.; Holt, R.W. and Wright, J.B.; (1985) Late Proterozoic Schist Belts and Plutonism in NW Nigeria. Journal Geol. Soc. London Vol. 142 1985 pp. 319-337.

Geological Survey of Nigeria, 1:2,000,000 Geological Map of Nigeria 1984 Edition.

Grant, N.K. (1970 Geochronology of Precambrian Basement Rocks from Ibadan, Southwestern Nigeria. Earth and Planet. Sci. Lethers, 10, pp. 29 - 38.

Grant, N.K. (1978) Structural Distinction between a metasedimentary cover and an underlying basement in the 600 M.Y. - Old Pan African Domainn of Northwestern Nigeria. Geol. Sec. of Amer. Bull No. 89 pp. 50 - 58.

Grant, N.K. Hickman, M. Burkholder, F.R. and Powell, J.L. 1972) Kibaran Metamorphic Belt in Pan African Domainn of West Africa. Nature, Phys. Science 238 pp. 90-91.

Harper, C.T. Sherrer, G., McCurry, P. and Wright, J.b. (1973) K - Ar Retention Ages from the Pan-African of Northern Nigeria. Geol. Soc. Amer. Bull 84 pp. 919-926.

Helwig, J. (1974) Eugeosynclinal Basement and a College Concept of Orogenic Belt. In: Modern and Ancient Geosynclinal Sedimentation (Ed. Dott, H. Jr. and Shaver R.H.). Soc. Econ. Palaeont. and Min. Sp. Publ. No. 19.

Hepworth, J.V. (1970) Photogeology and the Tectonics of the Mozambique Belt in N.E. Tanzania In: African Geology (Ed. Dessauvagie, T.F.J. and Whiteman, A.J.) uNIVERSITY OF iBADAN, iBADAN.

Hills, E.S. (1970) Elements of Structural Geology. Chapman and Hall Limited and Science paperbacks.

Isaachsen, Y.W., Frakunding, R .H. and Forster, S. (1973) Evaluation of ERTS Imagery for Spectural Geologycal Mapping in Diverse Terrains of New York State. Third Earth Resource Tech. Satellite - 1 Symp. Vol. 1 Sect. A. p. 691.

Jones, H.A. (1958) The Oolithic Ironstones of the Agbaja Plateau, Kabba Province Record, Geol. Surv. of Nigeria pp. 20 - 43.

Jones, H.A. and Hockey, R.D. (1964) The Geology of Part of Southwestern Nigeria. Geol. Survey of Nigeria Bull. No. 31.

Kogbe, C.A. (1979) Geology of the South Eastern (Sokoto) sector of the Iullemmeden Basin. Bull. Dept. of Geology, Ahmadu Bello University, Zaria, Nigeria. Vol 2 No. 1. 1979.

R E F E R E N C E S (Cont'd)

Kogbe, C.A. (1981) Geological Interpretationnof Landsat Imageries of Part of Central Nigeria. Journ. of Mining and Geology Vol. 18 1981 No. 1 pp. 66-69.

Kogbe, C.A.; Ajakaiye, D.E.; and Matheis, G.; (1983) Confirmation of A Rift Structure Along the Mid - Niger Valley, Nigeria. Journal of African Earth Sciences 1983 Vol. 1 No. 22 pp. 127-131.

Krumbein, W.C. and Sloss, L.L. (1963) Stratigraphy and Sedimentation. W.H. Freeman and Co. San Francisco.

McCurry, P. (1976) The Geology of the Precambrian to Lower Palaeozoic Rocks in Northern Nigeria - A Review In: Geology of Nigeria (Ed. Kogbe, C.A.) pp. 15 - 39. Elizabethan Press, Lagos.

McCurry, P; (1978) Geology of Degree Sheets 19 (Zuru); 20 (Chafe) and Part of 9 (Katsina) Nigeria. Overseas Geology and Mineral Res. No. 53. Institute of Geological Sciences.

McCurry, P. and Wright, J.B.; (1971) On Place and Time in Orogenic Granite Plutonism. Geol. Soc. Amer. Bul. 82 pp. 1713 - 1476.

McDonald, D.E. (1957) Resolution As A Measure of Interpretability. Photogramm. Engineering XIX pp. 58 - 62

Meckel, J.F.M.; (1972) The Geological Interpretation of Radar Images. (Unpublished Manual). Inst. of Aerial Surveys and Earth Sc. (I.T.C.) Holland.

Meer Mohr, H.E.C. (1977) Fracture Analysis From Aerial Photographs. (Unpublished Manual) Inst. of Aerial Surveys and Earth Sci. (I.T.C.) Holland.

Moody, J.D.; and Hill, M.J.; (1956) Wrench Fault Tectonics Bull. Geol. Soc. of Amer. Vol. 67 pp. 1207 - 1246.

Moore, R.K.; Chastant, L.J.; Porcello, L.J.; Stephenson, J.; and Ulaby, F.T.; (1975) Microwave Remote Sensors. In Reeves R.G., Ed. Manual of Remote Sensing pp. 399 - 537 American Society of Photogrammetry.

Norman, J.W.; (1969) The Role of Photogeology in Mineral Exploration. Transactions/Section B. Institute of Mining and Metallurgy Vol. 78 1969.

Odeyemi, I.B.; (1976) Preliminary Report on the Field Relationships of the Basement Complex Rocks Around Igarra, Mid-Western Nigeria. In Geology of Nigeria (Ed. Kogbe, C.A.) pp. 59 - 63 Elizabethan Press Lagos Nigeria.

R E F E R E N C E S (Cont'd)

Ogezi, A.E.O.; (1977) Geochemistry and Geochronology of Basement Rocks from NW Nigeria. Unpub. Ph.D. Thesis of University of Leeds England.

Oluyide, P.O.; and Udoh, A.N.; (1985) Preliminary Comments on the Fracture Systems of Nigeria (Unpublished data).

Onyeagocha, A.C.; (1984) Petrology and Geologic History of N.W. Akwanga Area in Northern Nigeria. Journal of African Earth Sciences Vol. 2 No. 1 1984 pp. 41 - 50.

Oyawoye, M.O.; (1965) Review of Nigerian Pre-Cretaceous. In: Aspects of the Geology of Nigeria by R.A. Reyment. Ibadan University Press 1965.

Oyawoye, M.O.; (1970) The Basement Complex of Nigeria, In African Geology (Ed. Dessauvagie, T.F.J. and Whiteman A.J.) University of Ibadan pp. 67 - 99.

Petters, S.W. (1978) Maasttrichtian - Palaeocene Foraminfera from NW Nigeria and Their Palaeogeography. Acta Palaecont. Polonica, 23 131 - 152.

Reeves, R.G.; Anson, A. and Landen, D.; (1975) Manual of Remote Sensing. Amer. Soc. of Photogrammetry. Virginia U.S.A.

Reyment, R. A. (1965) Aspects of the Geology of Nigeria: Ibadan University Press.

Reyment, R.A. and Reyment, E.R. (1978) The Palaeocene Trans-Saharan Transgression and its Ostracod Fauna. Proceedings 2nd Symposium. Geol. of Libya Tripoli 1978.

Russ, W.; (1957) The Geology of Parts of Niger, Zaria and Sokoto Provinces. Geol. Survey of Nigeria Bull No. 27.

Sabins, F.F.; (1977) Remote Sensing: Principles and Interpretation. W.H. Freeman and Co. San Francisco.

Thamm, N.; (1974) The Distribution of Oil and Natural Gas Deposits in the Earth Crust in Relation to the Mineralisation with Ni, Pt and Cr along Great Circles (abs): Conf. on the New Basement Tectonics, 1st Salt Lake City 1975; Proceedings Utah Geol. Assoc. Public No. 5 p. 617.

Turner, D.C.; (1983) Upper Proterozoic Schist Belts in the Nigerian Sector of the Pan African Province of West Africa. PreCambrian Research Vol. 21 Nos. 1-2 Elsevier Science Publishers - Amsterdam.

REFERENCES (Cont'd)

Truswell, J.F.; and Cope, R.N.; (1963) The Geology of Parts of Niger and Zaria Provinces, Northern Nigeria; Explanation of 1:250,000 sheet No. 31. Geol. Survey of Nigeria Bull No. 29.

Udoh, A.N. (1973) The Geology of 1:100,000 sheet 145 (Kajuru) Unpubl. Geol. Survey of Nigeria Report.

Udoh, A.N.; (In Press) An Interpretation of Satellite Imageries of Nigeria 7°40N. Proceedings of Symposium on PreCambrian Geology of Nigeria.

Udoh, A.N.; (In Prep) Geology of 1:100,000 Sheet 164 (Minna).

Vaniman, D.T.; (1973) The Geology of 1:100,000 sheet 144 (Kakuri) Unpubl. Geol. Survey of Nigeria Report.

Vaniman, D.T.; (1976) The Godani Granodioritic Plutons, Nigeria: Petrology and Regional Setting. Unpublished Ph.D. Thesis of the University of Califonia.

Viljoen, R.P.; and Viljoen, M.J.; (1975) ERTS - 1 Imagery: An Appraisal of applications in Geology and Mineral Exploration. Mineral Sci. E<ngng. 7 (2) pp. 132 - 167.

Wright, J.B.; (1970) Controls of Mineralisation in the Older and Younger Tin Fields of Nigeria. Econ. Geology. 65 pp. 945 - 951.

Wright, J.B. (1976) Fracture Systems in Nigeria and Initiation of Fracture Zones in the South Atlantic Tectonophysics 34 pp.T43-T47.

KASHIM IBRAHIM LIBRARY
AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA.