A STRUCTURAL ANALYSIS OF THE BENUE TROUGH, NIGERIA FROM GEOPHYSICAL DATA

BY

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NOVEMBER, 1982

ABSTRACT

The main aim of this study was to produce an aeromagnetic map of the Benue trough in order to resolve some of the peculiarities of the trough namely, its origin, evolution its lateral spreading.

Gravity and magnetic data were acquired for this study and interpreted.

From the interpretations and results of the aeromagnetic data, the Benue trough is characterised by areas of magnetic lows through its entire length especially along its flanks. The amplitudes of these anomalies vary from -60 to -300 gammas and the depths to the top and bottom for causative bodies vary from 200 to 3000 m and 3500 to 14000 m respectively.

The magnetic lows along the flanks mark the probable structural boundary between the trough and the other complexes.

The central anomaly has been attributed to a fracture zone within the trough which provides a possible explanation to its abnormal width. This has been further interpreted to indicate the possibility of two rifts within the trough.

The study indicates the absence of oceanic crust beneath the trough, thus no seafloor spreading unlike the Red Sea,

The interpretation of the Shendam to Takum gravity profile confirms the magnetic interpretation. Gravity lows are observed at the edges of the trough; and that the trough consists of two synclines separated by the Wukari anticline.

Finally, the study has revealed that the Benue trough is a tensional continental rift valley filled with Cretaceous sediments.

DEDICATION

To my parents, Mr. and Mrs. Ashiekaa Pila who despite their hardships allowed me to pursue my studies.

ACKNOWLEDGEMENTS

The author sincerely expresses his gratitudes to Prof. D.E. Ajakaiye for agreeing to supervise and to make available the aeromagnetic maps used in this study; and Dr. M.B. Awad whose restless efforts supervised and made this work a success.

Prof. D.H. Hall, Mr. Tom Miller and Mr Al Carswell, all of Department of Earth Sciences University of Manitoba, Canada are gratefully acknowledged for their advices and contributions on the data reduction techniques.

The author is also grateful to the crew that accompanied him during gravity field survey.

Mrs. V. Ashiekaa of A.T.C. Makurdi is equally acknowledge for her financial support and endurance.

The author acknowledges all who contributed in one way or the other to make this work possible.

The author acknowledges Messrs Adedzwa and C. Zever who typed the final copy of the thesis.

Finally, the author is grateful to the Benue State Scholarship Board for providing funds for the trip to Canada.

TABLE OF CONTENTS

		PAGE
	ABSTRACT	ii
	DEDICATION	iv
	ACKNOWLEDGEMENT	v
	TABLE OF CONTENTS	vi
	LIST OF TABLES	ix
	LIST OF FIGURES	x
	LIST OF APPENDICES	xii
I	INTRODUCTION	
	1.1 Background and aim of the study	1
	1.2 Previous Geophysical Work in the Benue Trough	4
	1.3 Aeromagnetic data Acquisition	11
II	Geology of Benue Trough . . .	13
	2.1 Geology of Benue trough . . .	13
	2.2.1 The Lower Benue trough . . .	16
	2.1.2 The Middle Benue trough . . .	18
	2.1.3 The Upper Benue trough . . .	21
	2.2 Structures in the Benue trough	
	2.2.1 Folds	25
	2.2.2 Faults	26

2.2.3 Vocanism in Benue trough 27
2.3 Theories of the Origin of Benue trough 29
2.3.1 Rift Orign 30
2.3.2 Tripple Junction theories ... 30
2.3.3 A geopsyncline with folding involving the basement 33
2.3.4 A combination of a rift valley and geosyncline 33
2.3.5 A Zone with periodic "on and off" Hotspot 34
2.4 Economic Geology 36
2.4.1 Lead - Zinc Deposits ... 36
2.4.2 Barytes 37
2.4.3. Brine/Salts 37
2.4.4 Limestone 38
2.4.5. Coal 38
2.4.6 Radioactive minerals ... 40
CHAPTER THREE - MAGNETIC METHODS
3.0 The Earth's main magnetic field 41
3.0.1 The main field 41
3.0.2 Perturbation of the main field 47
3.0.3 Magnetic Surveys 49

3.0.4 Airborne magnetic surveys ... 49
3.0.5 Airborn fluxgate magnetometer 51
3.0.6 Optically Pumped Magnetometer 54
3.0.7 Proton Resonanse Magnetometer 57
3.1 Statistical Properties and Power Spectrum of Aeromagnetic data 60
3.2 Filtering Techiques 68
3.3 Interpretation and Analysis of the Aeromagnetic data 75
3.3.1 Modelled Magnetic Anomalies B_1 to B_7 7?
3.3.2 Interpretation of Profiles across the Benue trough 91
3.4 Deduction 102
3.4.1 Correlation of Profiles with Surface Geology 102
3.4.2 Width of the Benue trough ... 104
3.4.3 Origin of Benue trough ... 107
3.4.4 Seafloor Spreading 108
CHAPTER FOUR - GRAVITY METHODS 112
4 Introduction 112
4.1 Field Survey 113

4.2	Data Reductions/Baselevels ...	115
4.2.1	Corrections to Gravity data ...	115
4.2.2	Anomalies	117
4.3	Interpretation and Analysis ...	118
CHAPTER FIVE - CONCLUSION		127
5.0	Introduction	127
5.1	Summary of Results	127
5.2	Deductions from results of present study	129
5.3	General Conclusion	135
5.4	Suggestions for future work ...	139
CHAPTER SIX - REFERENCES		145.

LIST OF FIGURES

			PAGE
Fig.	1.1 :	The Benue Valley ...	2
"	1.2 :	Gravity Pattern in Benue trough	7
"	2.1 :	Mineralisation in Benue trough	39
"	3.0.1	Geomagnetic field and its elements	42
"	3.0.2	Airborne fluxgate magnetometer	52
"	3.0.3	Optically Pumped Magnetometer	55
"	3.0.4	Proton Resonance Magnetometer	58
"	3.1	The Rectangular Vertical Sided Parallepiped used for models	64
"	3.2	Power Spectrum against frequency	69
"	3.3	Aeromagnetic map of Benue trough (3 km)	81
"	3.3a:	Aeromagnetic map superimposed on Geology of Benue trough	78
	3.3b	Faults and Folds ..	97
"	3.3.1:	Anomaly B_1 ...	82
"	3.3.2:	" B_2 ...	84
"	3.3.3:	" B_3 ...	86
"	3.3.4	" B_4 ...	88
"	3.3.5	" B_5 ...	89
"	3.3.6	" B_6 ...	91

Fig. 3.3.7 Anomaly B_7 ... 92
" 3.3.8: The J - J^1 profile across Benue Trough 95
" 3.4.1: Profile A - A^1 with Geology cross section 103
" 3.4.2: Profile A - A^1: Continued Aermagnetic field (Subsurface structure) 105
" 3.4c: Exaggerated Magnetic Pattern across Mid - Atlantic ridge (Seafloor spreading) ... 109
" 3.4.d: Profiles across Beune trough (Possibly Seafloor Sepreading) 111
" 4.1: Bouguer, Regional, Residual Anomalies with surface geology 121
" 4.2: Correlation between Bouguer anomaly and elevation 124
" 4.3: Correlation between Gravity and Magnetic profiles across the Benue trogh 122
" 4.4: Interpretation of Shendam to Takum profile 125

Fig. 5.2a: Benue trough compared with other rift valleys - Total magnetic intensity 130

" 5.2b: Comparism with other rift valleys Gravity 131

" 5.2c: Benue trough as part of World's rift system 133

LIST OF TABLES

			PAGE
Table	1.1	Densities of Formations/Rocks in the Benue trough ...	8
"	1.2	Densities of Sediments in the Upper Benue trough as determined by different authors ...	9
"	2.1	Cretaceous Sedimentary Sequence in the Lower Benue trough ...	15
"	2.2	Sedimentary Sequence in the Middle Benue Valley	17
"	2.3	The Stratigraphy of Upper Benue Trough	20
"	2.4	Stratigraphy of Benue Trough	23
"	3.3.2a	Comparism of Sediments thicknesses from Various Authors ...	99
"	3.3.2b	Rock densities ...	100
"	3.3.2c	Magnetic Susceptibilities of rock samples in Benue trough ...	101
"	4.3	The Observed Positive Regional Anomaly in Benue Trough ...	119

LIST OF APPENDICES

Appendix A

Basic Principle of the "POPT" ---------- 141

Appendix B

Principal Parameters for Shendam -

Takum Profile ---------- 144

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND AND AIM OF THE PROJECT.

The Benue Trough forms the most important part of a system of linear sedimentary basins which contain the Niger, Benue and Gongola rivers (Fig. 1.1) The trough is filled with Cretaceous rocks which are strongly folded. The width of the trough and its peculiarities has led to the hypothesis that it is formed as a result of rifting.

The controversy over the trough as to its origin, evolution and structural stratification has generated a lot of interest. In the past three decades, several geologists and geophysicists have carried out various surveys in the area in an attempt to determine the origin and evolution of the trough and its economic potentials (Cratchley and Jones, 1965; Offodile, 1975 - 6; Ajakaiye and Burke, 1973; Ajayi, 1979 etc.).

In the present survey, the area of the trough under consideration lies along the Benue River

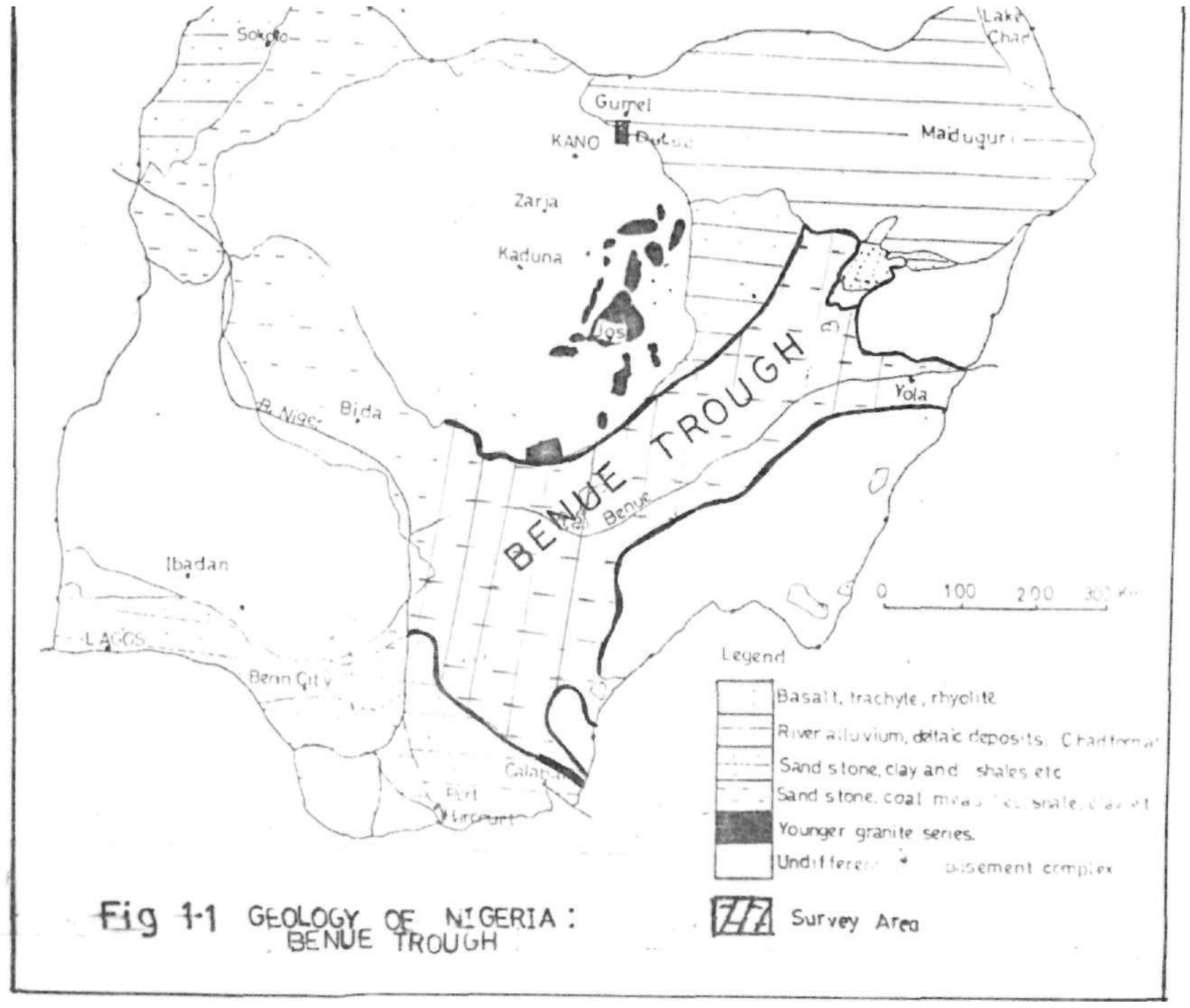


Fig 1-1 GEOLOGY OF NIGERIA : BENUE TROUGH

between the North-central and Eastern parts of Nigeria. The northern flank is bounded by the Jos Younger Granite Zone and the Southern flank is bounded by the Adamawa and Cameroun High lands.

Many theories have been proposed to explain the origin of the Benue Trough. These theories include:-

a. the rift origin (King, 1950)
b. a spreading ridge (Burke, et al, 1970)
c. a subduction zone (Grant, 1971)
d. a geosyncline with folding involving the basement (Lees, 1952)
e. a combination of a rift valley and a geosyncline (Cratchley and Jones, 1965).

These theories seem to contradict instead of complement each other. The theories have failed to explain (Ajayi, 1979, 1981) why the width of the trough, 150 - 240 km, is much wider compared to normal rift valleys of width 55 ± 10 km; and why the sediments are folded with their axis almost parallel to the axis of the trough.

In order to throw more light on the issue in

question, the author has carried out a careful analysis of the aeromagnetic maps data set available for the area.

The main aim of this project was to analyse the aeromagnetic data in order to obtain a magnetic map of the Benue Trough with a view to determing the origin of the trough and to attempt to explain further the evolution and structural stratification; and economic geology of the trough.

1.2 PREVIOUS GEOPHYSICAL WORK IN THE BENUE TROUGH.

Other geophysical methods have been employed in the survey of parts of the Benue trough. These methods include gravity, ground magnetics and radiometrics - to a lesser extent. Cratchley and Jones (1965) carried out a gravity survey of the entire Benue Trough. This survey was aimed at confirming the rift origin theory. It was partially successful in its aims except that the station spacing (5 km) was too large for any detailed study.

Gravity work by Ajayi (1979, 1981) in the middle

Benue trough concluded that the trough is part of the World's rift systems when compared with other rift systems - such as the East African, Afar and the Red Sea rifts.

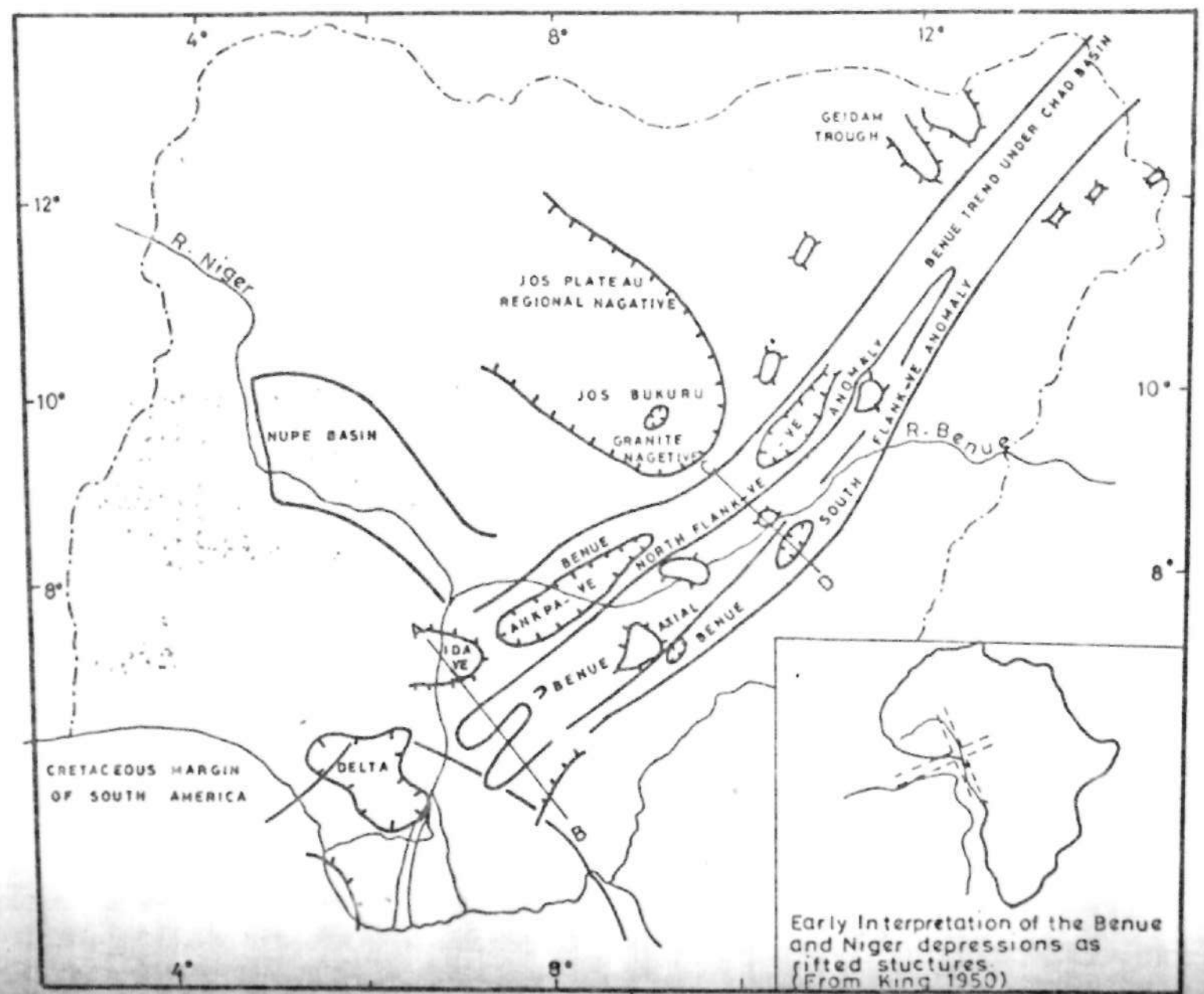
Adighije (1979) concluded that the Benue trough owes its origin to the compressional and tensional forces within the mantle and not to a rift system as proclaimed by many. He also observed that the axis of the trough approaches the surface from the lower to the upper Benue trough at depths of 31.5 km to 30 km, respectively. A similar view had earlier been proposed by Osazuwa (1978).

These gravity surveys revealed that the Benue trough is characterised by central gravity "highs" over Amar, Awe Gboko in the middle Benue and Kaltungo in the upper Benue trough. These "highs" are flanked on both sides by gravity "lows" (which correspond to areas of thickest sediments), (Cratchley and Jones, 1965). The Source of the gravity high has been ascribed to a zone of intrusions in which oldest Cretaceous sediments and the underlying basement are close to the

ground surface, and contain igneous material of intermediate to basic compositions. The gravity and magnetic lows correspond to the area of thick sediments. Fig. 1.2. The magnetic anomaly observed were rather intense and reveal rocks of high susceptibilities, mainly ironstone and basalts. Gravity work of Ajakaiye and Burke (1973) has given the same results as stated above.

The areas of local anomaly in Wase, Awe, Ribi are characterised by Bouguer anomaly of up to 6- to 9 mgals observed, and values less than 0.7 mgals near the salt springs themselves (Osazuwa, 1978, Umego, 1978). The salt springs are thought to originate at the contact between transit ground water and the salt body. The salt dome at Ribi is about 300 - 500 m in diameter, at depth of 150 - 230 m with an estimated mass of 6.1×10^8 tonnes.

Radiometric surveys have also revealed that the extent of radioactive materials in the sediments vary from 0.5-2.5 microrontgen per hour and 0.5 to 1.0 microtontgen per hour for the Kerikeri formation. In the lower Benue trough, the scientillations count



(After Ajakaiye and Burke, 1972)

Densities of Formations/rocks in the Benue Trough.

Rock Type/Formation	Density x $10^3 kg/m^3$
Lafia formation Ferrigeneouss stone,	2.56 ± 0.186
Awe, Keana/Makurdi sand stones.	2.40 ± 0.161
Albian Shales siltstone and gritstone	2.60 ± 0.151
Granites	2.56 ± 0.041
Rhyolites	2.65 ± 0.048
Vessicular Basalts	2.65 ± 0.068
Non-vessicular Baselts/trachytes	2.90 ± 0.027

(Adapted from Ajayi, 1979)

Table 1.1

Densities of sediments in the Upper Benue Trough as determined by different authors.

AUTHOR \ FORMATIONS	Bima/Muri.	Pindiga	Yolde	Gombe
Osazuwa (1978)	2.21	2.17	2.36	2.52
Ajayi (1979)	2.37	2.40	2.56	2.62
Adighije (1981)	2.20	2.48	2.53	2.65

Table 1.2

rises to 9 microrontgen per hour, with mean of 2 microrontgen per hour.

The occurance of uranium in the trough is associated with fault system.

The densities of sediments also vary from oldest to the youngest and these values also depend on the authors involved. Tables 1.1 and 1.2.

The Cretaceous clays have densities of 2.27 - 2.42 ($\times 10^3$) kg/m^3 and the Chad formation has density of clays as 2.31×10^3 kg/m^3 (Myada, 1978).

1.3 AEROMAGNETIC DATA ACQUISITION

The aeromagnetic data used in this study was obtained from the Geological Surveys of Nigerian in the form of contoured aeromagnetic maps in gamma units.

In June 1974, the Geological Survey of Nigeria, carried out an Airborne magnetic survey across the entire country in which the project area forms a part. The flying was completed in October 1975 and the final maps were completed in March 1976.

The topographical details of these maps were based on 1:50,000 topographical series of the Federal Surveys of Nigeria.

The flight or survey parameters are as listed below based on the information included on the maps.

Flight direction ---------- $0^{o}/180^{o}$

Tie line direction ---------- $90^{o}/270^{o}$

Nominal flight spacing ---------- 2 km

Nominal Tie line spacing ---------- 10 km

The nominal flying altitude above mean sea level varied from 77.00 to 152.40 m.

The regional correction on the aeromagnetic data

was based on I G R F (epoch date 1st Jan. 1974) with variations of -2.06 to -2.44 γ/km to the North and -0.98 γ/km to the East. The average inclination across the survey area varied from I = 10^{o} in the North to I = 5^{o} (Aeromagnetic maps, Airborne Geophysical series, Geological Survey of Nigeria, 1976).

CHAPTER TWO

2.1 GEOLOGY OF BENUE TROUGH

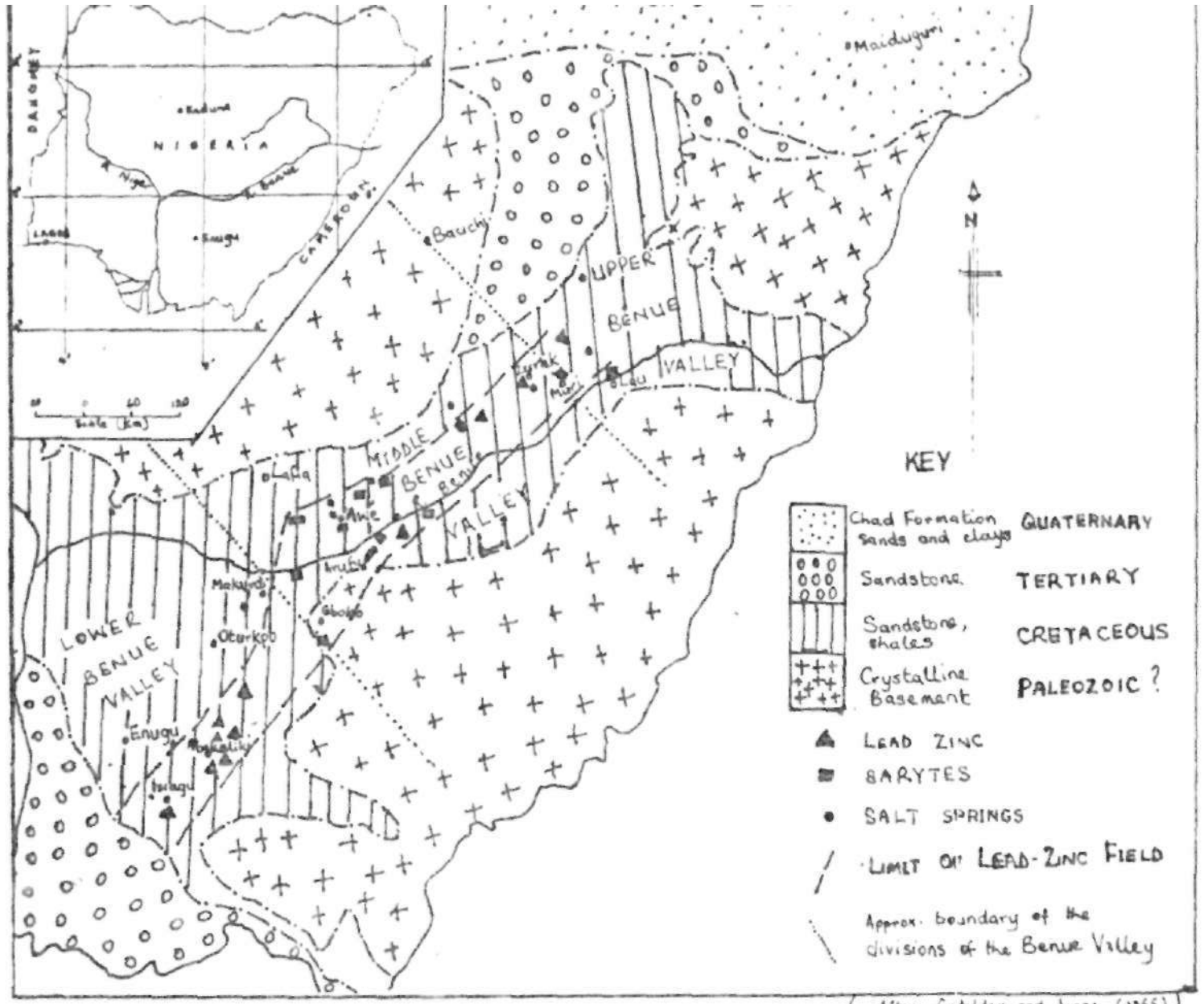
The Benue Valley comprises a linear sedimentary basin 160 to 250 km wide, filled with Cretaceous rocks whose ages vary from the middle Albian to Maestrictchian (Offodile, 1976) and is bounded on either side by granities and gneisses of probably lowermost Palaeozoic age which make up the crystalline basement. The stratigraphical and structural conditions are continuous from the lower to the upper Benue. The sediments of the trough continue into the Nigerian coastal basin (Cratchley and Jones, 1965) and are marked by

i "the continuity of the paleontological zonation with coastal marine formations.

ii the series of long narrow folds with ENE-WSW trend linked with the Southern folds of Abakaliki Sedimentary area.

iii the narrow Lead-zinc mineralisation belt running from Abakaliki to the upper part of the trough"

The Benue Trough is divided into three sections viz



After Cratchley and Jones (1965) in Ajakaiye (1970)

Fig 1·1 a THE BENUE VALLEY

Cretaceous Sedimentary Sequence in the Lower Benue Trough

AGE			Formation
Upper Cretaceous	Maestrichtian		Nsukka formation
	Senonian	Senonian	Nkporo shales
		Santonian	
		Coniacian	Awgu shales
	Turonian		Makurdi formation
	Cenomainian		Ezeaku shales
Lower Cretaceous	Albian		Asu River Group

(After Reyment, 1965)

Table 2.1.

the lower middle and upper Benue Trough. Other names used in literature for the same sections are South Benue, Lafia-Muri and North-East regions respectively.

2.1.1 THE LOWER BENUE TROUGH

The stratigraphical sequence as given by Reyment (1965), Table 2.1 consists of the lower and upper Cretaceous sediments. The deposition of sediments started during the middle Albian (lower Cretaceous) and ended about the Maestrichtian.

This region consists of the Ezenku/Makurdi formations, Awgu Shales and Nkporo Shales/Nsukka formation

The Turonian age marked the deposition of shales known as Ezeaku shales. These consist of flaggy calcerous and non-calcereous shales, sandy limestones and calcerous sandstones. The deposition of the Makurdi formation took place at the same time as the Ezeaku shales. The Makurdi formaion overlies the Albian shales and consists of a thick mass of current bedded, coarse-grained sandstones as described by Cratchley and Jones (1965).

The Awgu shales were deposited in the Senonian stage and consist of fossiliferous grey-blue shales

Sedimentary Sequence in the Middle Benue Valley.

Age		Formation	Characteristics
Paleocene Danian		Volcanics	basalts, rhyiolites
Maestritchian		Lafia formation	Sandstones, loose sands mudstones, clays continental deposition
Senonian	Campanian	Awgu	black shales, sandstones, limestones, coal seams
	Santonian		
	Coniacian		
Turonian		Ezeaku	Calcerous shales, sandstones, lime stones.
Cenomian		Keana	current bedded s/stones gritty, arkosic-Deltaic
		Awe	sandtones, shales, clays
Albian		Asu River Group	dark grwy-silkstones, mudstones, clays - marine
Plaeozoic		Basement	Undifferentiated

(After Cratchey and Jones, 1965; Offodile, 1976; Ajayi, 1979.

Table 2.2.

associated with subordinate limestones and calcerous sandstones.

The Nkporo shales, overlying the Awgu shales, consist of marine shales and arenaceous sandstones.

The Nsukka formation is the youngest Cretaceous sediments in the lower Benue. It consists of carbonaceous shales, snadstones and some thin coal seams (Cratchley and Jones, 1965).

2.1.2 THE MIDDLE BENUE TROUGH

This section of the trough consists of the Asu River Group, Awe, Keana Sandstones, Unnamed marine sediments and Lafia Sandstones.

The Asu River Group is the oldest sedimentary deposit in Nigeria. It is Albian in age and lies uncomfortably on the crystalline Paleozoic basement (Cratchley and Jones, 1965; Oyawoye, 1970). It is thought to have been deposited as a result of the transgression of the ocean water immediately after the rifting of the trough, and consists of dark shales of marine origin. At the base of this formation, micaceous

siltstones, mudstones and clays can be found (Offodile, 1976).

The Awe formation, deposited during late Albian regression, is characterised by whitish sandstones, though to be transitional beds between marine and fluviate sandstones (Offodile, 1976). Salt springs and lakes can be found within this formation (Belter and Bojarski, 1971; Offodile, 1976).

The Keana sandstones overlying the Asu River Group in some part of this section, consists of poorly sorted feldspathic, coarse-grained, gritty pebbly sandstones. Cratchley and Jones (1965)related it to be lateral equivalent of the Bima sandstones of the upper Benue trough.

The unnamed marine formation overlies the Awe formation. It consists of shales, clays, siltstones and shelly sandstones with some coals.

The Lafia formation is the youngest in the middle Benue and was deposited from the campanian to early Maestrichian (Offodile, 1976; Ajibade; 1977). It consists of coarse-grained sandstones. Loose sands,

The stratigraphy of Upper Benue Trough.

Stage	NORTH	SOUTH
Paleocene	Kerikeri formation	Basalts
Maestritchian	Gombe sandstone	
Turonian - Senonian	Pindiga	Sekule formation Jessu " Dukul "
Upper Cenomanian	Yolde formation	Yolde "
Cenomanian (Lower)	Binna Sandstones	+ unnamed Marine deposits

(After Carter el al, 1963)

Table 2.3.

mudstones and clay which are said to be lateral equivalent to Gombe sandstones of the Upper Benue Valley. This formation is continental and was brought about by the trans-saharan seaway to the middle Benue Valley.

2.1.3 THE UPPER BENUE VALLEY

The stratigraphy of this area as proposed by Carter et al (1963) is given in Table 2.3. This consists of the Bima Sandstones, Yolde formation, Pindiga, Gombe and Kerikeri formations; Sekule/Dukul formation.

The Bima sandstones are at the base of the sedimentary succession overlying the Basement complex. The formation consists of agrillaceous rocks and coarse grained sandstones.

The Yolde formation is a transition between the continental Bima sandstones and the succeeding marine formation, described by Falconer (1911) as "passage beds" between sandstones and the marine Turonian. It consists of thinly bedded sandstones alternating with mudstone and shelly limestone.

The Dukul formation which marked the beginning of

the widespread shallow marine transgression covers the upper Benue trough during the Turonian. It consists of shales interbedded with thin limestone.

The Jessu/Pindiga formations are characterised by sandstone, sandy mudstone and shales deposited as a result of marine transgression from Turonian to Senonian.

The Sekule formation consists of a sequence of pale greenish shales with thin bands of silliferous limestones, the shales being much thicker than the limestones (Barber et al, 1954).

The Gombe and Kerikeri formation marked the end of the sedimentary sequence in the upper Benue trough. The Gombe sandstones consists of well bedded fine to coarse grained sandstones, silkstones and shales with poor quality of coals. The Keri-keri formation is tertiary in age (Jones and McConnell, 1965).

A compilation of the stratigraphical sequence of the Benue Trough as found in available literation is shown in Table 2.4.

The proposed classification may differ from the earlier workers due to the conflicting nature of the

STRATIGRAOHY OF BENUE TROUGH

GEOLOGICAL STAGES		LOWER BENUE	MIDDLE BENUE		UPPER BENUE	
		OTUKPO-MAKURDI	KEANA/ARUFU	BASHAR-MURI	NORTH	SOUTH
MAESTRICHTIAN		Upper Coal Measures			Keri-keri	
		False Bedded s/stone		Gombe Sandstones	Gombe S/stone	Lamja S/stone
		Lower Coal Measures	Lafia s/stones			
SENONIAN	CAMPANIAN	Nkporo Shales				Numanah shales
	SANTONIAN		Marine deposits	Kumberi	Pindiga fm	Sekule fm
	CONIACIAN	Awgu Shales	Awgu Shales			
TURONIAN	UPPER	Ezeaku Shales	Ezeaku fm.			Jessu fm
	LOWER	Makurdi s/stone,				Dukul fm
CENOMANIAN			Awe fm	Awe fm	Yolde fm	Yolde fm
			Keana s/stone	Muri s/stone		
ALBIAN		Asu River Group	Asu River Group	Marine Deposits	Bima Sandstone	Bima Sandstone
ALGONKIC AND PRE-CAMBRIAN			Crystalline Basement			Marine transitional deposits

Table 2.4

(Adapted From: McConnel 1949, Farrington, 1952; Carter et al 1963 Cratchley & Jones, 1965; Offodile 1976.

Nomenclature and age classification used by the various texts from which the results in the table 2.4 were deduced.

Consequently, the overall structural stratification (table 2.4) can undoubtedly be modified when more detail geological studies are carried out in the Benue Trough.

2.2 STRUCTURES IN THE BENUE TROUGH

The main structures found in the Benue Trough are folds, faults, current bedding and cross-bedding. The last group of these structures are found mainly in Keana and Lafia formations (Offodile, 1976). From statistical analysis, offodile observed that current beddings exists almost parallel to the anticlines of this area. These structures were probably formed in the Albian stage in which the basement was involved. (Farrington, 1952).

2.2.1 FOLDS

The Cretaceous rocks were subject to a series of folds which are thought to be formed as a result of repeated deformative forces (compressional and tensional). The folding of sediments in the trough run parallel to the axes of the trough (Adighije, 1979). In general two stages of folding have been identified, the first in the Albian and the other in the San tonian. The folds hardly dip more than 10^{o} (Cratchley and Jones, 1965).

In the middle Benue, the large structures of the Keana anticline trends some 64 km in the North-eastly direction from the Keana Village. Other minor folds including those of Obi, Giza, Agyaragu have the Giza synclinorium as their base (Ajayi, 1979). The folding in this area is thought by previous workers (Cratchley and Jones, 1965; Burke et al, 1970; Burke and Dewey, 1974; Ajayi, 1979) to have occured in the Turonian through the Senonian Fig 3.3.C.

The Upper Benue is characterised by the folding which trends parallel to the axis of the trough (Ajayi, 1979). The dominant fold is the Lamurde anticline which is an assymetrical fold trending for over 80 km in the east-North-east.

2.2.2 FAULTS

Another characteristic feature in the Benue trough are the faults. Faulting, which resulted from the tensional forces, spreads through the length of the trough. Faulting was not severe in the lower Benue. The only identified fault, in the middle Benue, trends

parallel to the axes of the nearby folds and stretches for 10 km near Giza. The other faults have only been inferred (Offodile, 1976). There are two types of faulting in the middle Benue (Offodile, 1976; Reyment, 1952) associated with the Lead-Zinc mineralisation and barytes respectively, all of which trend ENE-WSW. There are virtually no slikensliding since the beds displacement are not obvious (Kogbe et al, 1979; Ajayi, 1979).

In the upper Benue, faulting is of secondary importance except for the faulting of the pre-Bima sandstones (Offodile, 1976).

2.2.3 VOLCANISM IN BENUE TROUGH

The Benue trough is marked by a lot of igneous activities. This is shown by the occurence of intrusive and extrusive rocks of all forms. The intrusives, reported to have taken place during the late post Albian, are associated with the anticlines and the lead-Zinc belt (Cratchley and Jones, 1965; Wright, 1975). The intrusives are distributed throughout the Benue trough but are more widespread in the lower Benue in the Lead-Zinc belt

slightly outside the Benue valley proper. They occur in forms of dykes, sills, domes, plugs, etc.

The volcanism was accompanied by mineralisation throughout the trough. This implies that the trough underwent these stages folding - minor fracturing - volcanism and lastly mineralisation.

2.3 THEORIES OF THE ORIGIN OF THE BENUE TROUGH.

The controversy over the origin and evolution of the Benue trough has been a source of discussion for the past three decades. The trough is occupied by the upper Cretaceous sediments which have been compressionally folded predominantly in the direction ENE-WSW with little faulting volcanic activities and mineralisation. The trough is occupied by up to 6000 m of marine and fluvio-deltaic sediments ranging from Albian to Maestritchian in age.

Various theories have been proposed in an attempt to explain the origin and evolution of the trough. These include:-

a. the rift origin (King, 1950)
b. a spreading ridge (Burke, et al, 1970)
c. a subduction Zone (Grant, 1971)
d. a geosycline with folding involving the basement (Lees, 1952)
e. a combination of a rift valley and a geosyncline (Cratchley and Jones, 1965)
f. a Zone with "on and off" Hotspot-Cretaceous Hotspot (Olade, 1975).

2.3.1 A RIFT ORIGIN

It has been generally accepted that the Benue Valley has a rift structure due to major faults along the trough (King, 1950; Carter et al, 1963; Cratchley and Jones, 1965; Ajakaiye and Burke, 1972; e.t.c.). Their conclusion was based on stratigraphical, structural and geophysical data available at their disposal (gravity, magnetic, seismic, e.t.c.). The rift theory was first postulated by King (1950). This proposal was supported by Kennedy (1965) who was of the opinion that the trough is a tensional rift similar to the Red Sea. Wright (1968, 1970) suggested the same idea except that he related the rift to the separation of the South American plate from the African plate. He also explained that the folding of the sediments was caused by an "elastic rebound" of the African Continent a result of the separation.

2.3.2 THE TRIPPLE JUNCTION THEORIES

The concept of ocean spreading and plate tectonics has introduced a new dimension to the studies of the Benue trough. A lot of evidences put forward to support the origin of the trough need be proved by detailed field work.

i A SPREANDING RIDGE OR SUBDUCTION ZONE

From magnetic data, Burke et al (1970) proposed the possibility of a ridge - ridge - ridge (RRR) triple junction beneath the present Niger delta. The Zone of high gravity values (Bouguer Anomaly) identified by Cratchley and Jones, (1965); Ajakaiye and Burke, (1972) correspond to the zone of short-lived ridge. Burke and Dewey (1974) suggested that the zone of high gravity values correspond to a subduction zone created by the accretion of the two African plates (West African and the Congo Creations located to the north and south of the trough respectively). The folding was explained by the authors as being due to the collision of the two plates.

ii A ZONE OF LITHOSPHERIC SPREADING.

The triple junction beneath the Niger delta was attributed to a ridge-ridge-fault (RRF) by Grant (1971) instead of an RRR junction. He concluded that the oceanic transformed faults of the Gulf of Guinea form the arm of the triple junction. The African and South American continents were thought to have moved

apart along the faults (Romanche's and St Paul's) for about 20 million years before they finally separated. The strain in the African plate is thought to be responsible for the local volcanism in the trough and in the Northern Brazil due to prolonged movement of the two plates, along the fault line (Grant, 1971).

The similarities with the Red Sea, Gulf of Aden-Afar triple junction for which the overall resemblance is striking, was cited as a supporting evidence for the triple junction theories.

The presence of salt, the distribution of gravity values along the trough, magmatism, as well as lead-zinc mineralisation are said to have resulted from " --- involved geothermal heavy-metal-bearing brines circulating under the influence of a deeper geothermal reservoir, as such occur at several locations along the present day line of lithospheric spreading ---" (Grant, 1971).

The RRR triple junction model proposed by Burke (1970) was challenged by Nwachukwu (1972) for lack of surficial evidence. The citation of the Red sea as having

similar rift valley characteristics raised more questions which could only be resolved with field data.

2.2.3 A GEOSYNCLINE WITH FOLDING INVOLVING THE BASEMENT

On the basis of the great thickness of the trough, coupled with the fact that there are no marginal faults in the trough, Lees, (1952) proposed that the trough is of geosyncline type. This idea was later supported by Stonley (1966) who was of the opinion that the trough was a sort of "miniature geosyncline" based on the great thickness of the Cretaceous sediments in the Benue trough.

2.2.4 A COMBINATION OF A RIFT VALLEY AND GEOSYNCLINE

Cratchley and Jones (1965), using geological and gravity data proposed that a combination of the rift and geosyncline theories can be used to explain the origin of the trough. They maintained that the areas of high gravity values correspond to a combination of the crust thinning beneath the trough and shallow basement. This might involve some folding (to explain the existence of folds in the trough). The narrow gravity trough are

possibly due to less dense Cretaceous rocks on the either sides. The authors maintain that the absence of marginal faults on the surface cannot prevent the conclusion that the trough is a rift valley. The faults could be buried by the sediments, thus, masking them from the surface. Offodile (1976) suggested that the marginal zones of low gravity values could be explained in terms of rifting of the trough while the zones of high gravity values could be due to the variation in the thickness of the sediments along the trough, with respect to the basement.

2.2.5 A ZONE OF PERIODIC "ON AND OFF" HOTSPOT

This theory was proposed by Olade (1975) who tried to explain the evolution and origin of the trough without . ‹ the tectonic theories. He assumed a Cretaceous "Hotspot" beneath the Niger delta which caused the upwelling of the mantle plume resulting in the doming and rifting of the Benue trough and formed an RRR triple junction with Benue trough as one of its arms. The Benue arm failed to develop into an ocean basin and was subsequently filled with Cretaceous sediments (Olade,1975).

The subcrustal contraction caused by the ceasation of the mantle upwelling resulted into the compressive folding of the Albian sediments in the trough.

These theories discussed above do not agree with each other, though, most of the authors are in partial support of the rift origin. There are not enough surface evidence, particularly the lack of any surface marginal faults. The theories, on the other hand, have given a wide scope for further research. Detailed groundwork and surveys can provide very useful data to support or disprove any desired theory(ies).

The origin of the trough is still unresolved and there is presently no evidence to reject or accept any of these theories.

2.4 ECONOMIC GEOLOGY OF BENUE TROUGH

As discussed earlier, the valcanism in the trough was accompanied by mineralisation. Minerals are distributed throughout the length of the trough (Offodile,1980) Those of economic value include lead, zinc, brine/salt barytes limestone, coal, uranium (to a lesser extent) and high grade crystalline rocks which are used for road construction and building. These minerals are discussed below.

2.4.1 *LEAD-ZINC DEPOSITS*.

These minerals exist in a narrow belt which extends south-east to the north-east of the trough and are believed to have been deposited under mesothermal conditions, that is, they are of hydrothermal origin (Farrington, 1952, McConnell, 1949). The minerals are thought to have occured before the end of the Turonian corresponding to the end of the basic and ogneous activities in the Benue trough (Grant, 1971; Ajayi, 1979) The lead-zinc minerals are impregnated in vertical fracture zones and their silver content decreases with depth. These minerals can be found around Arufu, Muri and Zuruk. Fig. 2.1 .

2.4.2 BARYTES

Barytes occur in Keana, Awe and Lau. They are associated with the lead-zinc, occuring in coarse sandstones. An estimated 40,640 tonnes of the mineral can be obtained at depths of 18.3 in (Offodile,1980). The mineral is of high demand in the oil industries and as such extensive surveys have been carried out in order to exploit this mineral deposits.

2.4.3 BRINE/SALT

The occurance of brine in the Benue trough is in the form of lakes and springs, which are found near the axes of the anticlines. The notable ones are those of Keana and Awe lakes and brine springs. These areas have been exploited by the natives as local salt industries. The temperatures of the salt are found to be between 28^{o} and 35^{o} C (Beltaro and Bojarski, 1971) Detailed study of the salt areas reveal that the concentration decreases with depth and the salinity increases towards the Keana lake and spring (Offodile, 1976, 1980).

The Nigerian Mining Corporation has carried

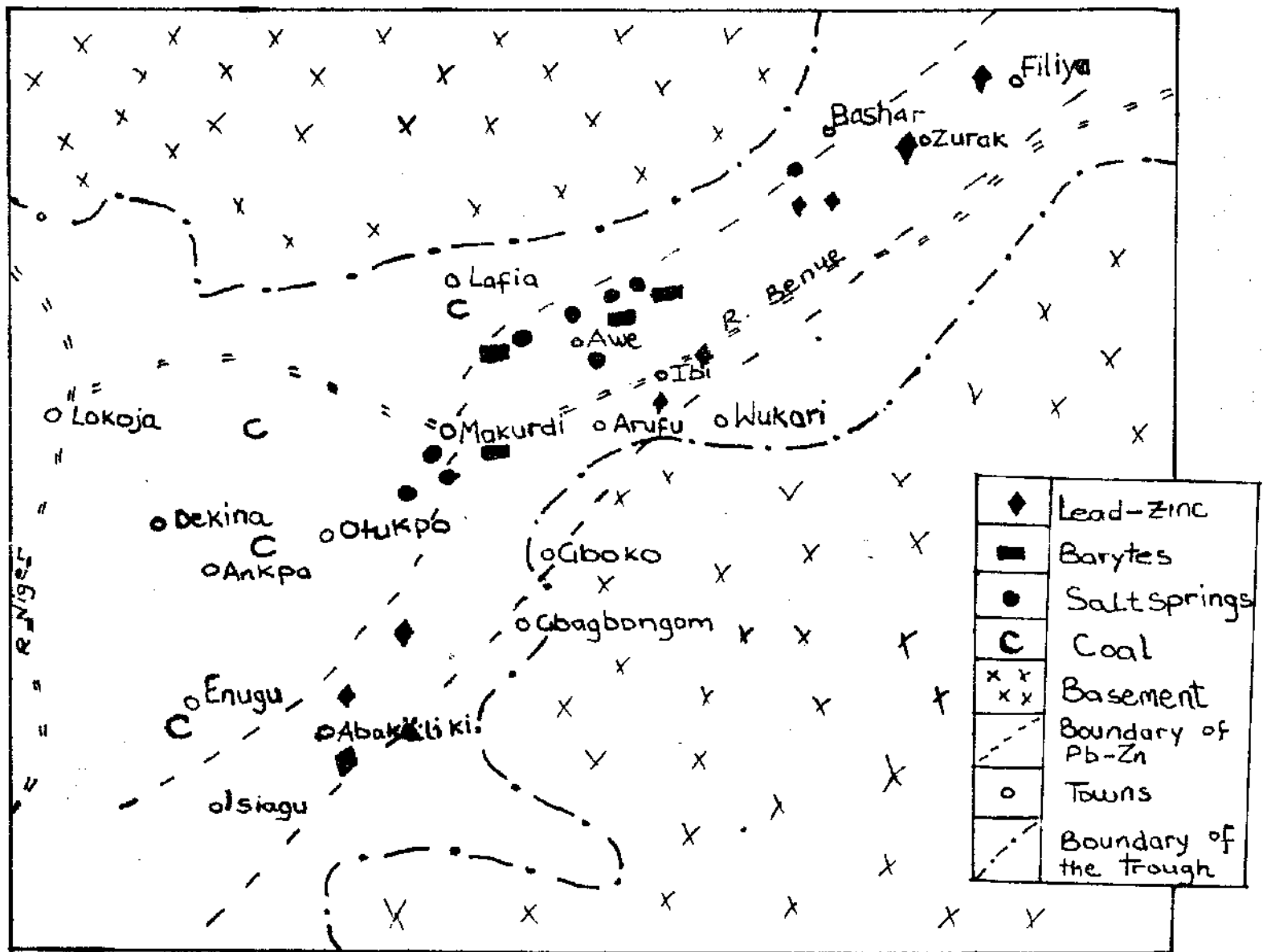
feasibility studies for the rock salt deposits and the salt dome (personal communication Ajayi) Previous feasibility studies revealed that the local production of the salt was estimated to be about 5,900 tonnes per annum (Adefuye, 1977).

2.4.4 LIMESTONE

Limestone is one of the most important mineral in the trough, with widespread occurance from lower Benue areas around Makurdi to the upper Benue areas. The limestone occured in the Albian - Turonian formations. The most prominent outcrop at Yandev, near Gboko, which is the base for the present Benue Cement factory. Production of the cement has since begun at the factory with a daily output of nearly 2,000 bags.

2.4.5 COAL

The mineral occurs in the Gombe Sandstone in the upper Benue and Lafia in the Awe formation (Offodile,1980). The coal deposits at Lafia are said to be of high grade while those of Gombe are of low grade type. The Nigerian Steel Development Authority have explored the areas with



Adapted from Offodile (1977)

Fig. 2·1 MINERALISATION IN BENUE TROUGH

the hope that the coal deposits here will serve as a coking coal for the Complex iron and steel projects at Ajaokuta in Kwara State. A good exposure of the coal can be seen 48 km east of Lafia/Ajayi, 1979).

2.4.6 RADIOACTIVE MINERALS.

Some radioactive minerals have been reported to occur in the middle and upper Benue valley in the areas of Dekina-Ankpa and the sandstones of Yolde, Bima and Dukul formation respectively. The ore in the middle Benue has been surveyed and durther detailed studies are being carried out for possible exploitation of the uranium ore. Other radioactive elements such as Thorium and Lead-229 do not occur in abundant qualities (Offodile, 1979, 1980).

CHAPTER THREE

MAGNETIC METHOD

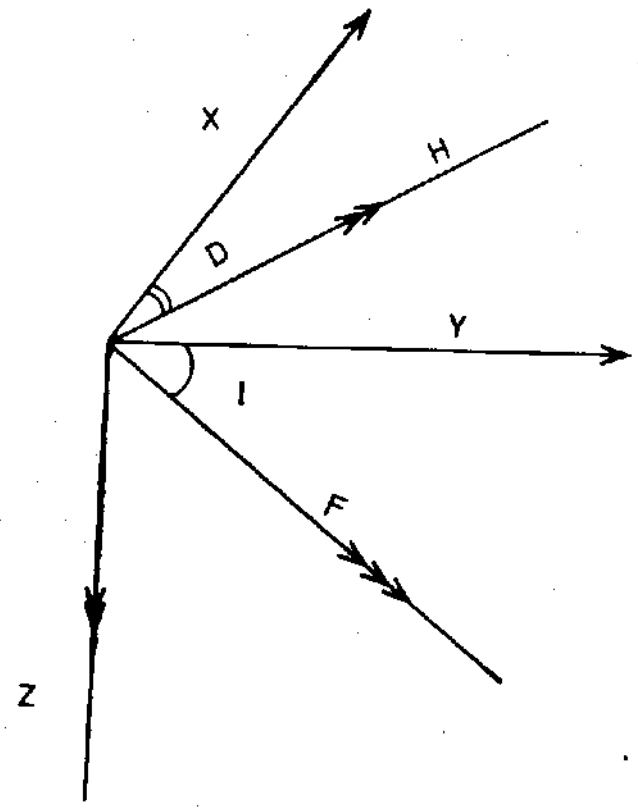
3.0 THE EARTH'S MAIN MAGNETIC FIELD.

One of the physical properties of the Earth which could be measured at the surface is the earth's magnetic field. There is a magnetic field associated with the Earth which approximates to a dipole magnet. The geomagnetic axis of this dipole makes an angle of 11.5° with the rotation axis and intersects the surface at the geomagnetic pole. At any point on the Earth's surface, the magnetic field is defined by its strength, and direction which are usually expressed in terms of magnetic elements.

The total magnetic field, F, is represented by a vector F, making an angle I with the horizontal component 'H' The angle measured between the magnetic meridian is the Declination, D. (Fig 3.0.1)

3.0.1 THE MAIN FIELD

The Earth's magnetic field is predominantly that of a magnetic dipole, as earlier mentioned, such as that produced by a sphere of uniform magnetisation or a current loop. The stength of the dipole was



D = Declination
I = Inclination
F = Total field
H = Horizontal field
Z = Vertical field

Fig. 3.0.1 GEOMAGNETIC FIELD AND ELEMENTS

7.96×10^{15} Wb.m in 1975. The "South" end of the dipole was in the northern hemisphere at $78.6o^{o}$ N latitude and 289.55^{o} longitude and drifting westward at about 0.014 deg/year. The dipole strength is decreasing by 0.05% per year. This "Secular Drift" implies a possible field reversal in thousand years. There is ambiguous evidence of several reversals in the past with time scales of 70,000 to 100,000 years between reversals (Haymes, 1971).

The plane perpendicular to the Earth centred dipole is the "Magnetic Equator". The field is weakest there, being about 3×10^{4} nT at the surface of the Earth. The field strentth increases as the magnetic latitude increases from 0 to 90 degrees. At the geomagnetic equator, the field is horizontal relative to the earth's surface.

The low in magnetic intensity at about 25^{o} S. 45^{o} W refered to as the "BRAZILIAN Anomaly" together with the high at about 10^{o}N. 100^{o}E implies that the centre of the magnetic dipole is offset from Earth's centre. In 1975, the eccentric dipole was off set

474.2 km in the direction of 19.5° N. 146.9° E (J. Bartels, 1936). The eccentric dipole is moving outward at 2.4 km/year, westward at 0.19 deg/year and northward at 0.23 deg/year. The eccentric nature of the dipole can be described mathematically as a quadrupole distribution of magnetisation..

The fact that the field rotates with the Earth is a clear indication that the field originates within the Earth. A coherent dipole field of this nature can be produced either by a uniformly magnetised sphere or by a current loop. However, calculations of the magnetisation required lead to values much higher than those observed in the Earth's crust. Magnetisation deeper than the crust is unlikely because the "Curie point" (that is, the temperation at which a magnetised material loses its magnetisation) of iron is reached only 20 km below the Earth's surface (Haymes, 1971).

An alternative theory postulates a DYNAMO effect in the outer core of the earth is driven by thermal convection currents (Garland, 1971)

Basically, a dynamo is a conductor driven in a magnetic field such that it acts to sustain that field. The theory has been refined to include a primary current which produces the dipole, plus secondary currents or whirl pools near the core - mantle boundary which produce local dipoles. These secondary dipoles are then superimposed to produce the observed multipole nature of the field, as well as local anomalies, which are large surface areas where the magnetic field deviates appreciably from the dipole field. The creation and decay of the whirlpools may cause the secular drift. Another theory of the secular drift is that the core is rotating more slowly than the mantle and crust. Thus, the magnetohydrodynamic theory postulates that the coupling between the mechanical and electrodynamic forces in the fluid core is responsible for the Earth's main magnetic field.

Although the exact nature of the field generator is unknown, the fact that it is internal suggests that the field can be conveniently described as a solution to a boundary value problem.

The lack of surface electric currents implies that outside the Earth, the magnetic field $\underline{B}$, has zero curl.

$$\nabla \times \underline{B} = 0 \quad \ldots\ldots\ldots 3 - 0 - 1$$

which means that the field can be expressed as a gradient of a scalar potential, V

$$\underline{B} = -\nabla V \quad \ldots\ldots\ldots 3 - 0 - 2$$

The absence of magnetic monopoles implies that

$$\nabla \cdot \underline{B} = 0 \quad \ldots\ldots\ldots 3 - 0 - 3$$

Substituting Eq (3 -(0 - 2) into Eq 3 - 0 - 3) yields Laplace's equation:

$$\nabla^2 V = 0 \quad \ldots\ldots\ldots 3 - 0 - 4$$

which, because of the spherical nature of the boundary at the Earth's surface, has a solution conveniently expressed in spherical harmonics as

$$V(r,Q,\emptyset) = a \sum_{n=1}^{k} \left(\frac{a}{r}\right)^{h+1} \sum_{m=0}^{n} \left(g_n^m \cos m\emptyset + h_n^m \sin \emptyset\right) P_n^m(\theta) \quad \ldots\ldots 3 - 0 - 5$$

a - equatorial radius of the earth g_n^m, h_n^m - Gaussian Coefficients r, θ, ∅ - geocentric distance, coelevation and East Longitude

$P_n^m(\theta)$ - Legrendre functions.

The n = 1 terms are called dipole; n = 2, quadrupole; the n = 3 octupole. The object of the core-dynamo theory is to determine the Gaussian coefficients emperically by least - squares fit to magnetic data.

The set of Gaussian coefficients to degree 8(n in e.g 3 - 0 - 5) and order 8 (m in eqn.3 - 0 - 5), comprises the International Geomagnetic Reference Field (IGRF, 1975) (Leaton, 1976)

).2 PERTURBATION TO THE MAIN FIELD.

The primary source of geomagnetic field perturbations is the sun. The sun constantly emits a neutral plasma called the SOLAR WIND. The action of the solar wind is to distort the Earth's field at high altitudes. The plasma is highly conductive, compresses the field and does not allow the Earth's

field to enter it. At about 10 Earth radii the plasma breaks up so that some of the charged particles are trapped in the geomagnetic field, thus, causing changes in the magnetic field at those places.

Although the solar wind is farily constant, it is frequently augmented by energetic bursts of plasma emitted by solar flares. When this plasma encounters the geomagnetic field, it compresses the field further giving a rise in field intensity on the surface of the Earth. This rise, called "Sudden commencement, initiates what is refered to as MAGNETIC STORM. This can be of the order of about 400 nT* to 2000 nT.

The sun is also responsible for the diurnal variation of the geomagnetic field. Solar electromagnetic radiations ionise some atmospheric atoms and molecules at an altitude of roughly 100 km, producing the E - layer of the ionosphere. The sun's gravitational field then exerts a tidal force causing the ions and electrons to rise. The interaction of the charged particles with the geomagnetic field produces a rather

* Tesla (T) is the Unit of magnetic field for a charge of one coulomb moving with a speed of 1 m/s, perpendicular to unit field experiences a force of one newton.

complex current system which creates a magnetic field. The variation of the Earth's magnetic field due to this effect ranges from 20 to 200 nT.

3.0.3 MAGNETIC SURVEYS

There are basically three types of magnetic surveys. These include Terrestial, Marine and Air borne magnetic surveys.

In terrestial surveys, measurements are taken on the surface of the Earth; while in Marine surveys, measurements are taken from the oceans, seas and the Airborn magnetic surveys, measurements are taken above the surface of the Earth.

These measurements are carried out with the aid of the magnetometers discussed in the next section.

3.0.4 AIRBONE MAGNETIC SURVEYS.

In some areas, the readings of the ground magnetometers become meaningless because inhomogenuity of magnetic material near the surface affect the instruments and other areas are not accessible by land (for example, Forest, Marshy mountainous areas).

In order to survey such areas, the Airborne magnetic surveys are carried out in such areas.

The Airborne surveys eliminates the effects due to very shallow disturbances, effects due to magnetic sediments at shallow depths. The survey is fast, accessible to all areas (Jungle, mountainous areas, ocean).

In order to take measurements in the desired area, the magnetometer is attached to the plane by means of a cord, 80 - 100 m long at which the magnetic effect of the plane is negligible. The outer case of the magnetometer is streamlined for maximum stability and minimum air resistance. The magnetometer is fed with fins to prevent rotation.

The magnetic effects due to plane must be known before the survey is carried out, if the magnetometer is mounted on board.

The flight pattern of the Airborne survey is the rectangular grid type over the area of interest or across a large area. The line spacing, depends on the shape, dimensions and depths of the target.

The Aircraft is flown at constant mean height above the ground surface.

3.0.5 AIRBORNE FLUXGATE MAGNETOMETER

The Airborne Fluxgate Magnetometer is an instrument used to measure the earth's magnetic field produced by external sources.

The instrument consists of a magnetically sensitive element upon which the externally applied magnetic field reacts, with the production of "signal" voltage which may be measured and recorded in terms of the intensity of the applied field. Its sensitivity is good enough to measure a change in an applied field of one gamma, and depends on the magnetic elements present. The reactors present in the element are sensitive to ambient fields of relatively low intensity. The element has two strips of high permeability material, such as mumetal. Each of the strips are wound with identical exciting winding and are connected to a common source of cyclic excitation in such a way as to produce magnetisation in opposite directions in the two parallel strips.

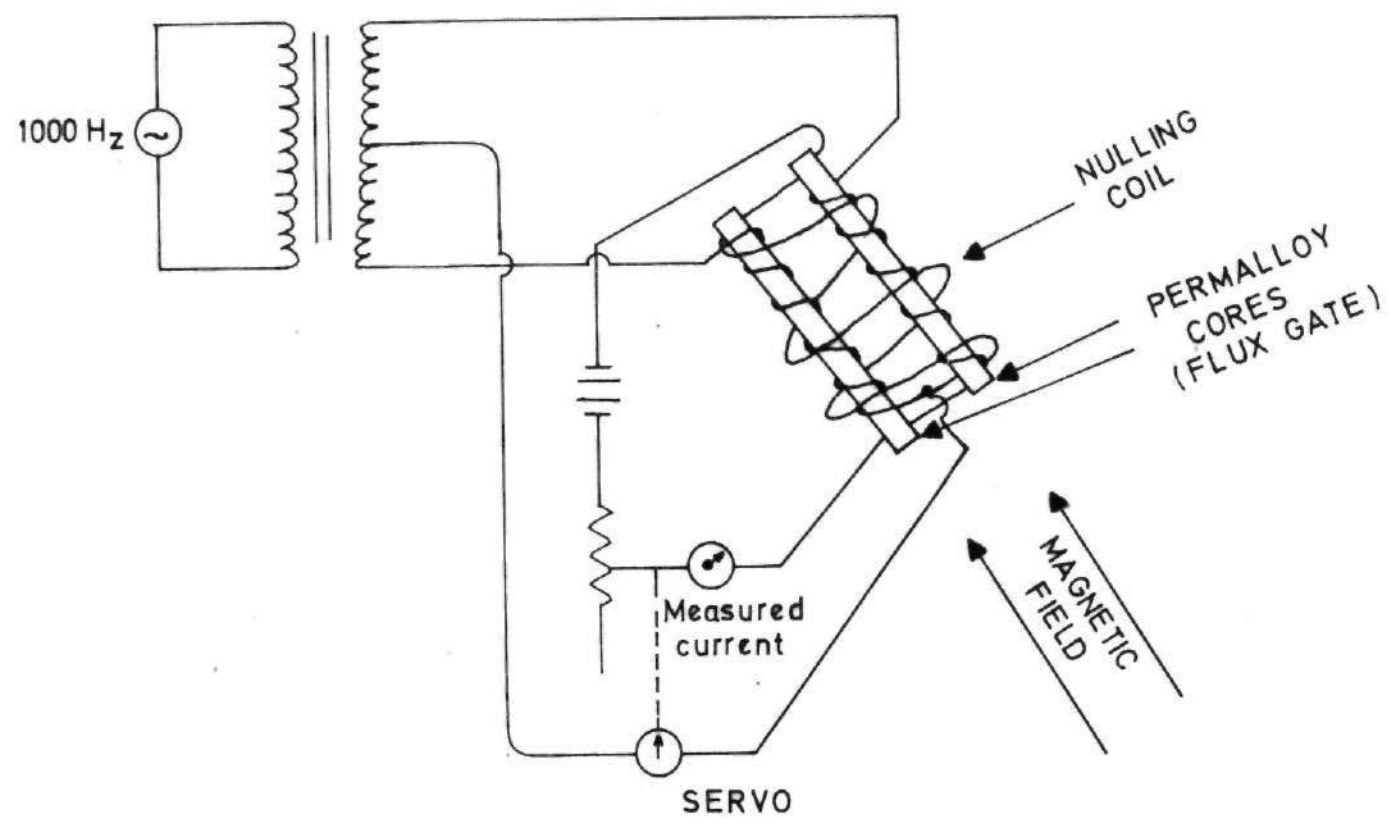


Fig. 3.0.2 FLUX GATE MAGNETOMETER.

The servo motors of the instrument are small two - phase induction motors which are phase - sensitive devices. The excitation of the first winding is taken from an oscillator that is synchromised to the frequency of rotation by means of contact that closes for an instant during each rotation. The two servo motors are 90^{o} - degrees apart.

The instrument recorder works on a null basis as follows:- A potentiometer circuit provides a constant flow of current. Any desired fraction of the current can be passed through the secondary winding of the element to annull the magnetisation induced in the cores by the earth's field. An attenuator is provided for fine adjustment over a range of 500 gammas. The recorder itself can adjust this attemuator automatically.

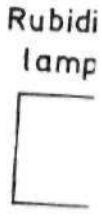
The magnetometer measures the magnetic field component along the axis of the strips and must be oriented with the field if the total intensity is to be measured.

3.0.6 OPTICALLY PUMPED MAGNETOMETER.

The optically pumped magnetometer measures the total field of the earth. It makes use of the principle of the transition of electrons within energy levels. When irradiation takes place, electrons may acquire large amount of energy to be raised to higher energy levels. The accumulation of these electrons at that energy level may cause them to loose their energy and return to a lower energy level. The energy released can be used for amplification in case of high beam to produce a laser. The technique of over population of one energy level is known as OPTICAL PUMPING.

The atoms used in this instrument have magnetic sub-energy levels which are suitably spaced to give a measure of the weak magnetic field of the earth. The elements with such atoms are caesium, rubidium, sodium, and helium. Their spin axis lies parallel or antiparallel to the external magnetic field.

The instrument consists of a vapour cell on to which polarised light is illuminated after which it is refocused onto a photo cell. The axis of the



Fi

beam is inclined approximately 45° to the earth's total field, causing electrons to precess about the axis of the field at the Larmour frequency, exactly as in case of protons in nuclear precession magnetometers. At one half in the precession cycle, the atoms will be parallel to the light beam direction, and another half cycle later, they will be more antiparallel. More light will be transmitted in the first half cycle than the second. Thus, the precession produces a variable light intensity which flickers at the Larmour frequency. If the photocell signal is amplified and fed back to the coil wound on the cell, the coil amplifier system becomes an oscillator, whose frequency is given by

$$F = \frac{2\pi f}{g} \quad \ldots\ldots\ldots \quad 3 - 0 - 6$$

F - earth's field; f - frequency.

g - gyromagnetic ratio of the electrons

$= 1 \times 10^{-7}$

The sensitivity of the instrument is very high, magnetic field variation of the order of 0.01 gamma

can be measured. Over the years improvements have been made to increase the sensitivity to 0.005 gamma, by reducing the errors due to drift and random instrumental errors, and motion of the single detector. The schemmatic diagram of the optically pumped magnetometer is shown in (Fig 3 - 0 - 3)

3.0.7 PROTON RESONANCE MAGNETOMETER.

The proton Resonance Magnetometer works on the principle that in the presence of magnetic field, the spin axis of small proportion of the protons in a proton-rich liquid such as water H_3o become alligned in the direction of the field. The instrument measures the proton - resonance frequency. The proton (hydrogen) nucleus has a magnetic moment because of its spin. The spin axes are normally oriented randomly and precess the earth's magnetic field direction. A polarising field normal to the earth's magnetic - field direction is impressed on the nuclei for a short period of time to polarise the nuclei and is then removed. The nuclei, now oriented together,

precess about the earth's magnetic field, H at a frequency, f_L (Larmour frequency) which is directly proportional to the strength of the earth's field. In so doing, a voltage at the precession frequency is induced in a measuring coil. As the protons gradually relax into random orientation, the induced fild strength drops to zero. The induced frequency is measured by a counting device (Fig) to determine the value of the earth's magnetic field. The Larmour frequency is given by:

$$f_L = \frac{\gamma H}{2\pi} \qquad \ldots\ldots\ldots 3 - 0 - 7$$

Where = gyromagnetic ration

($2\pi/33.4868$ hz/gamma for protons

H - earth's magnetic field

fL- Larmour frequency.

The value of has been determined by measuring H in a known magnetic field. For the normal earth's field of about 50,000 gammas, the gyromagnetic ratio has value of 0.267520 hz/gamma and the Larmour frequency has the value f_L = 2100 hz. To determine

the strength of unknown magnetic field, the working relation is given by:

$$H = 2.34874 \times 10^{-4} f \quad \ldots\ldots 3 - 0 - 8$$

f - the procession resonance frequency.

The proton Resonance magnetometer is reliable because there are no mechanical parts (liquid). It is fast (about 15 seconds/reading. It measures absolute total field with removal of region field due to the dipole field of the earth.

3.1 STATISTICAL PROPERTIES AND POWER SPECTRUM OF AEROMAGNETIC DATA.

The aeromagnetic field is a complex phenomenon arising from more complex distribution of magnetisation in the earth's crust. The interpretation is often based on various constraints of a geometrical body whose magnetic field matches the observed anomaly often in the least square sense (Naidu, 1968).

Statistical methods are used for the interpretation and analysis of these anomaly fields, based on the concept that the magnetic field is a random function. The relationship between the spectrum of the magnetic field and the magnetisation has been established (Naidu, 1968). It assumes the concept of homogenuity, that is, a statistical structure does not vary from place to place a unit from one part of the map is the same as that from any part of the map.

The statistical properties of the aeromagnetic data were determined using the following equations:-

$$M_X = \frac{1}{mn} \sum_{m=1}^{m} \sum_{n=1}^{n} x(m,n) \text{ ------ } 3.1.1$$

$$\sigma^2 = \frac{1}{mn} \sum_{m=1} \sum_{n=1} \left[x(m,n) - m_x \right]^2 \text{ --3.1.2}$$

$$\gamma = \frac{1}{mn} \sum_{m=1}^{m} \sum_{n=1}^{n} \left[x(m,n) - m_x \right]^3 \text{ --3.1.3}$$

Where

M_X is the mean

σ^2 is the variance

γ is the skewness

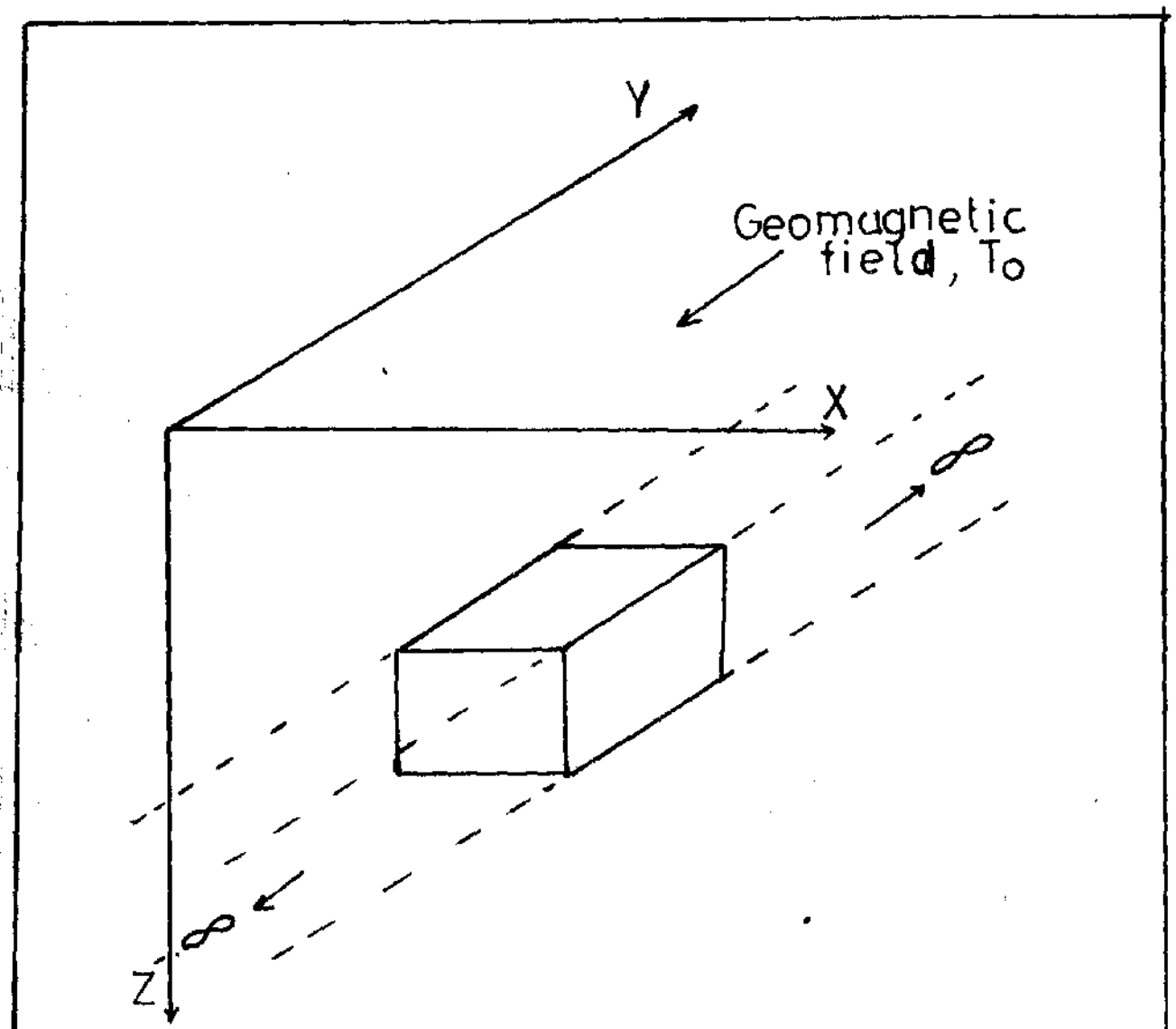


FIG 3·1: THE RECTANGULAR VERTICAL-SIDED PARALLEPIPED USED FOR MODELS

statistical model for aeromagnetic field analysis. the variation of these properties influence the shape of the power spectrum. Detailed theoretical analysis and derivations have been published (Spector, et al 1968; Bhatha - Charyya, 1966; Naidu, 1969, 1970; e.t.c) on the basis of which computer programs have been designed to calculate and display the power spectrum of the aeromagnetic field data.

POWER SPECTRUM OF AEROMAGNETIC DATA.

The use of power spectral analysis in the potential field across an area often yield information about the subsurface geologic structures in the area. This method of analysis was employed in the study of the Benue trough. The aeromagnetic data along various profiles in the area were analysed using the one-dimensional power spectrum technique. The statistical characteristics of the profiles yielded some information on the structural setting of the Benue trough.

The spectal analysis of the magnetic field data, f(x) in the frequency domain was carried out. The

Fourier Transform integral for one-dimensional power spectral in the frequency domain is given by

$$F(w) = \int_{-\infty}^{\infty} f(x)\, e^{-jwx}\, dx \qquad \text{(3-4)}$$

and the inverse relation is

$$f(x) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(w)\, e^{jwx}\, dw \qquad \text{(3-5)}$$

The function, f(x) is periodic with Sinusoids e^{jwx} of all angular frequencies, w, in the range ($-\infty$ to $+\infty$), and with a complex f(w). The power spectrum of f(x) is then defined as

$$P(w) = F(w) * F^{*}(w) \qquad \text{(3-6)}$$

Where $F^{*}(w)$ is the complex conjugate of F(w).

The steps taken to obtain the power spectrum of the profiles were as follows.

a. Profiles of considerable lengths 40 to 60 km were selected on the contoured aeromagnetic map depending on the extent of the anomalies and the area of interest in the trough. These lengths were defined by the x, y - coordinates (x_1, y_1); (x_2, y_2) taken in the north-south.

east - west direction or diagonally across the area.

b. The auto correlation function, a(t), of the data series (x_0 x_1 x_2 ------x_{N-1}) was calculated using

$$a(t) = \frac{1}{N} \sum_{t=0}^{N-1-t} (x_{t+1} - x_t \quad \text{------- (3-7)}$$

$t = 0, 1, 2$ ------ m

For stable estimates, the value of m depends on the length of the profile.

c. The computed auto correlation coefficients r_o, r_1, r_2 ---------- -rm) were then fed in the fast fourier Transform algorithm for the calculation of the power spectrum. This is because the power spectrum and auto correlation are fourier Transform pairs, that is

$$a(t) = \frac{1}{2\pi} \int P(w)\, e^{iwt} \, dt \quad \text{-----(3-8)}$$

$$P(w) = \int a(t)\, e^{-iwt} \, dw$$

d. The Fourier Transform at f = 0, Δf, $2\Delta f$ ---- $m\Delta f$; where $f = F_{Nq}/m$ were evaluated. The raw estimates, P_o, P_1, P_2 -------P_m of the power spectrum were obtained

e. Even though the power spectrum was smoothened to an extent, there was the problem of "non-clear - cut" breaks in some of the profiles when plotted on a logarithmic graph paper. (Fig. 3.2)

Few profiles were analysed in the study area and plot of the power spectrum verses the frequency of a profile taken across the project area is shown in fig 3.2

The short breaks in the amplitudes of the power spectra which appeared at different places along the profiles hardly correlated with the regional geology of the project area.

The slopes of the best fitted lines on the graphs were interpreted as corresponding to the depths of the possible layers of magnetisation. From the theory of the one-dimensional power spectrum (Spector, 1968), the slope on the bilogarithmic plot is given by

$$-S = -2h$$

$$\therefore h = \frac{S}{2} \qquad \text{---------} \quad (3 - 9)$$

So, half the value of the slope gives the depth extent of the magnetic layer to the surface.

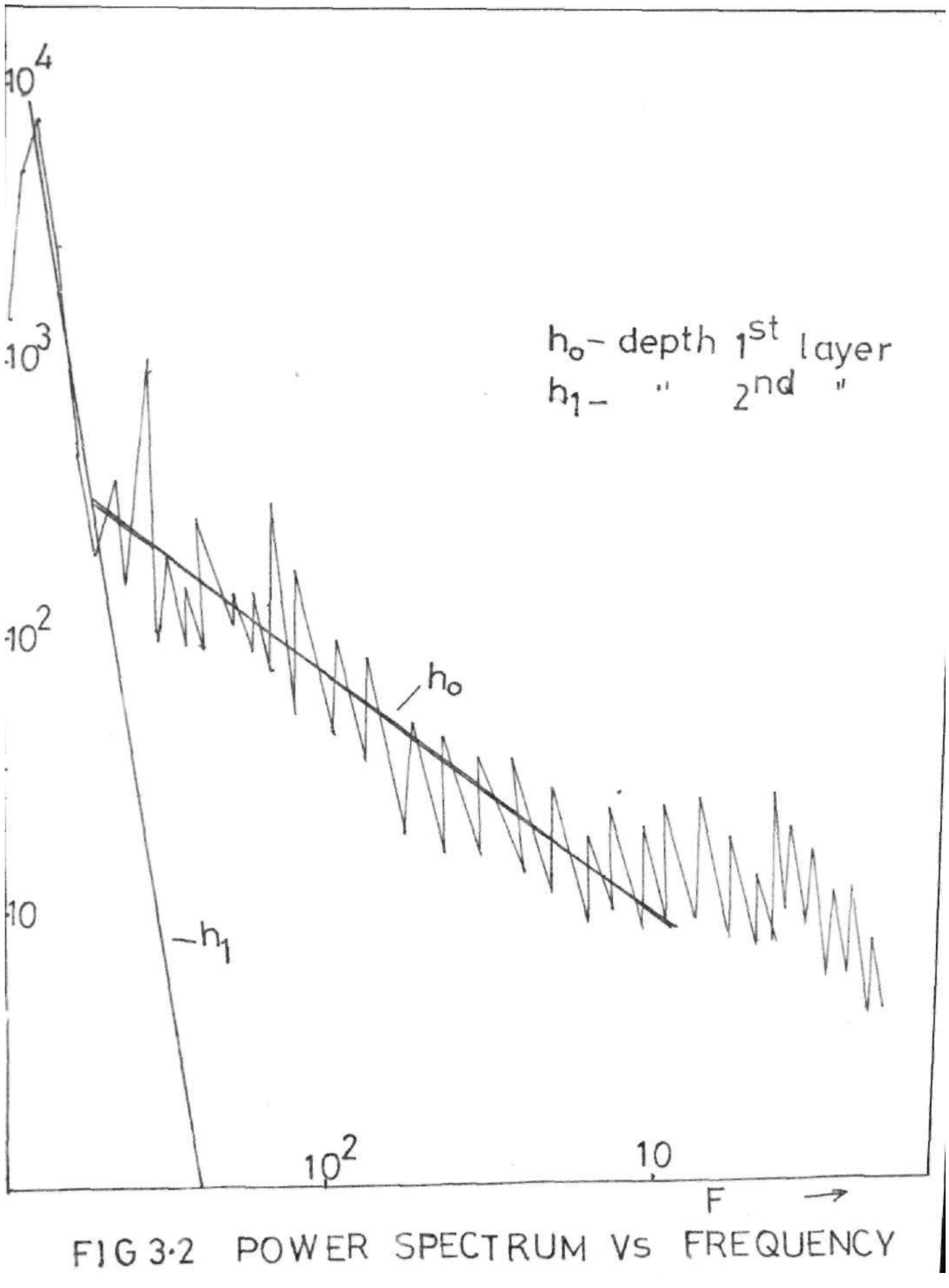


FIG 3·2 POWER SPECTRUM Vs FREQUENCY

It must be noted here that all the processes involved in the spectral analysis of the aeromagnetic data were computarised using a programme refered to as "Magfa". The power spectrum amplitudes and the corresponding frequencies were obtained as outputs and were manually plotted on the logarithmic paper.

3.2 Filtering techniques.

The application of 2-dimensional analysis and filtering in the analysis of geophysical data has been carefully studied and documented (Bhattacharyya, 1965; Dorby and Davies, 1967; Zurfluch, 1967; etc).

The assumption used in the filtering process is based on the fact that the near surface, that is, higher frequency components of the field can be isolated from the lower frequencies caused by deep subsurface structures.

The theory of the two-dimensional filters in the space and frequency domains provide the main frame-work of the filtering process. A data set of 2-dimension f(x, y) in the space domain can be transformed to the wavenumber domain by means of the 2 - dimensional fourier Transformation F(u,v), where

$$F(u,v) = \int_{-\infty}^{\infty}\int f(x,y)\, e^{-i2\pi(u + v)}\, dxdy \qquad \text{-----(3-10)}$$

and the inverse Transform

$$f(x,y) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\int F(u,v)\, e^{i2\pi(u + v)}\, dudv \qquad \text{------(3-11)}$$

Where

u, v are the wavenumbers.

The convolution of the 2 - dimensional data with a 2 - dimensional filter in the space domain is given by

$$g(x,y) = \int_{-\infty}^{\infty}\int h(x-\lambda,\ y-\beta)\ K(\lambda,\beta)\, d\lambda\, d\beta \qquad \text{--------(3-12)}$$

Where

g(x, y) - output of the convolution process

h(x, y) - input data

k (λ , β)- linear filter.

In the frequency domain, the convolution becomes

$$g(u,v) = H(u,v)\ K(u,v). \qquad \text{--------------(3-13)}$$

A given data set can beconverted into the frequency domain by applying the Direct Fourier Transformation. The digitised aeromagnetic data in the study area to be converted into the frequency domain was passed into the Fast Fourier Transformation routine. The filtering was achieved in the frequency domain and smoothened by tapering.

Then, an inverse Fourier Transformation was performed to convert the data to the space domain.

The filtering which was carried out in this study was by was of upward continuation of the data to certain elevations. The data set was upward continued to heights of 3, 4, 5, 8, 10 km above the ground surface. The essence as discussed in the filtering processes is to remove the effects due to bodies or near surface structures at the expense of the deep rooted bodies.

USE OF FOURIER SERIES IN FILTERING.

The Fourier Series has proved to be a very useful tool in the analysis of potential field data. The method was applied in the estimation of subterranean mass

distribution for a given gravity anomaly field but has since been developed further and modified to apply also to the magnetic field anomaly (Bhattacharyya, 1965). The series has been modified to take care of finite lengths of data set and the end effects of potential field data (Tsay, 1976).

A brief summary of the theory of the Fourier Series is given below. Consider an observed anomaly, T which satisfies the Laplace's equation and boundary conditions, as follows:-

$$\nabla^2 T(x, Z) = 0 \quad \text{---------- (3-14)}$$

i $T \rightarrow 0$ as $Z \rightarrow \infty$ at heights above measured evevation;

ii $T \rightarrow$ measured anomaly as $Z \rightarrow$ measured elevation; if $T \ll$ the earth's field.

The solution to the above equation for T is given by

$$T(x, z) = \sum_{m=0}^{\infty} \left[\exp(-2\pi \frac{mz}{L}) \left(A_m \operatorname{Cos} 2\pi \frac{mx}{L} + B_m \operatorname{Sin} 2\pi \frac{mx}{L} \right) \right] \text{-----(3-15)}$$

in a 2 - dimensional case (Henderson, 1970), where

L - length of data set in the x - direction

A_m, B_m are harmonic coefficients of the Fourier series expansion.

For Z = 0, equation (xiv) becomes

$$T(x) = \sum_{m=0} \left[A_m \text{ Cos } 2\pi \left(\frac{mx}{L}\right) + B_m \text{ Sin } 2\pi \left(\frac{mx}{L}\right) \right] \qquad \text{-------(3-16)}$$

which is a profile of the observed anomaly expanded into a finite Fourier Series. If T is given within the interval x = o to x = L, the harmonic coefficients A_m, B_m in equation (xv) can be determined by the expressions:-

$$A_o = \frac{1}{L} \int_o^L T(x)\, dx$$

$$A_m = \frac{2}{L} \int_o^L T(x) \text{ Cos } 2\pi \left(\frac{mx}{L}\right) dx \qquad \text{-----(3-17)}$$

and

$$B_m = \frac{2}{L} \int_o^L T(x) \text{ Sin } 2\pi \left(\frac{mx}{L}\right) dx$$

The theory of the filtering of potential data discussed above is based on the assumption that the analytical form of T(x) can be given only if there are finite number of harmonic coefficients A_m and B_m. However, the observed anomaly, T(x) is usually digitised at certain number of points, as was the case in the present study, without any analytical expression.

The data for this study was sampled at intervals of 3 km equally spaced in both x, y - directions, at sampled points, T(k, x); k = o 1, 2, ---- 2N +1 (harmonic coefficient); N is number of points and x is the sampled interval. Thus, equations (xv) become

$$T(k, \quad x) = a_o + \sum_{m=1}^{N+1} \left[a_m \text{ Cos } (\Omega mk \Delta x) + b_m \text{ Sin } (\Omega mk \Delta x) \right]$$

Where

$$a_o = \frac{1}{2N+1} \sum_{K=o}^{N} T(k, \Delta x)$$

$$a_m = \frac{2}{2N+1} \sum_{k=1}^{N} T(k, \Delta x) \; \text{Cos} \; (\Omega mk \, \Delta x)$$

and

$$b_m = \frac{2}{2N+1} \sum_{k=1}^{N} T(k, \Delta x) \; \text{Sin} \; (\Omega mk \, \Delta x)$$

$$= \frac{2\pi}{2N+1} \Delta x$$

The above discussions on the spectral analysis and filtering techniques explain the basis for the some of the subroutines in the "Magfa" computer program.

A computer program based on the Talwani (1964) program for the interpretation of magnetic anomalies caused by 2 - dimensional bodies of arbitrary called "POPT" which means program optimisation, was used intensively for the modelling of the magnetic anomalies in the study area. A brief theory of "POPT" is given in appendix A

3.3 Interpretation and Analysis of the Aeromagnetic data.

The digitisation was done on a square grid at intervals of 3 km. The values of the total field magnetic intensity at the grid points were recorded. These data values were checked, punched, fed into the computer and these were combined to a single contoured map refcred to as "supermap".

The areas of magnetic lows were identified and designated B_1 to B_7 Fig 3.3 - Model interpretation was carried for these anomalies. Profiles across these anomalies which cut across the Benue trough were extracted from the supermap for modelling. With the aid of the computer algorithm plotted it was possible to plot all these points along the extracted profile against distance. These profiles were then modelled using the POPT program.

Using the World's total magnetic intensity chart the total intensity contour line of value 33,000 gammas passes through Nigeria, just north of the study area. Based on the above value, an interpolated value of 32,850 gammas was used as a baselevel to obtain the

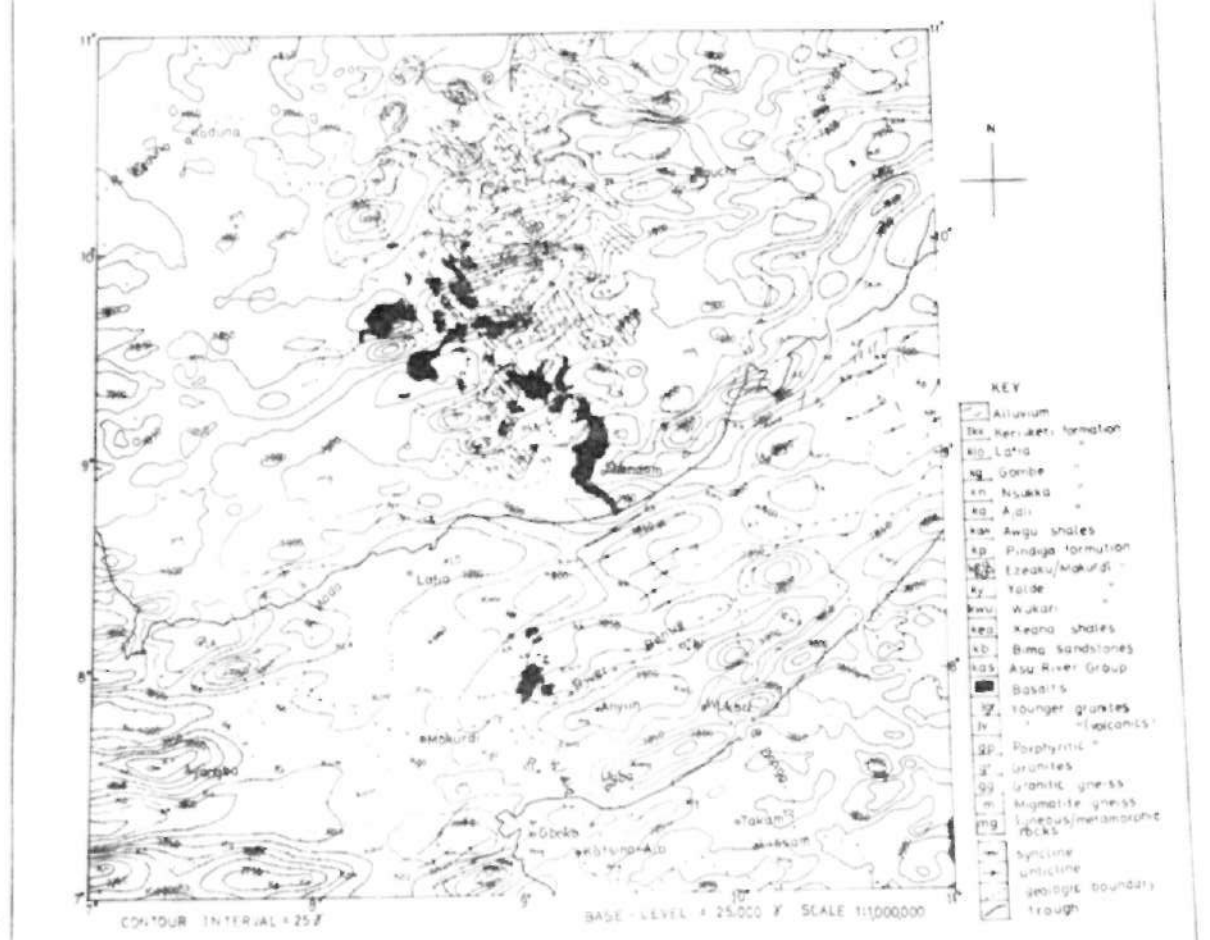


FIG 3:38: AEROMAGNETIC MAP SUPERIMPOSED ON GEOLOGY OF BENUE TROUGH

residual anomaly which was then modelled. As it will be observed in Figs 3.3.1 to 3.3.8, only the residual and the computed anomalies have been plotted.

The intensity of magnetisation of 0.3×10^{-3} e.m.u was used as the mean contrast between the basic/intermediate intrusions and the sedimentary/basement rocks (based on the work of Ajakaiye (1970) on the Younger Granites of the central Nigeria). This gives a magnetic susceptibility contrast of the order of 16×10^{-6} e.m.u. This value however, was optimised where the contrast was higher than the above value.

The causative magnetic body was described by four distance - depth coordinates along the profile, since the third axis extended to infinity. With an assumed initial shape of the body in two-dimensions, the POPT program was then used to obtain a best fit between the observed and calculated fields along the profile.

It is necessary to state here that the achievement of a fit between the observed and calculated effects is no guarantee that the shape so arrived at is correct, for an equally good fit might be observed from a

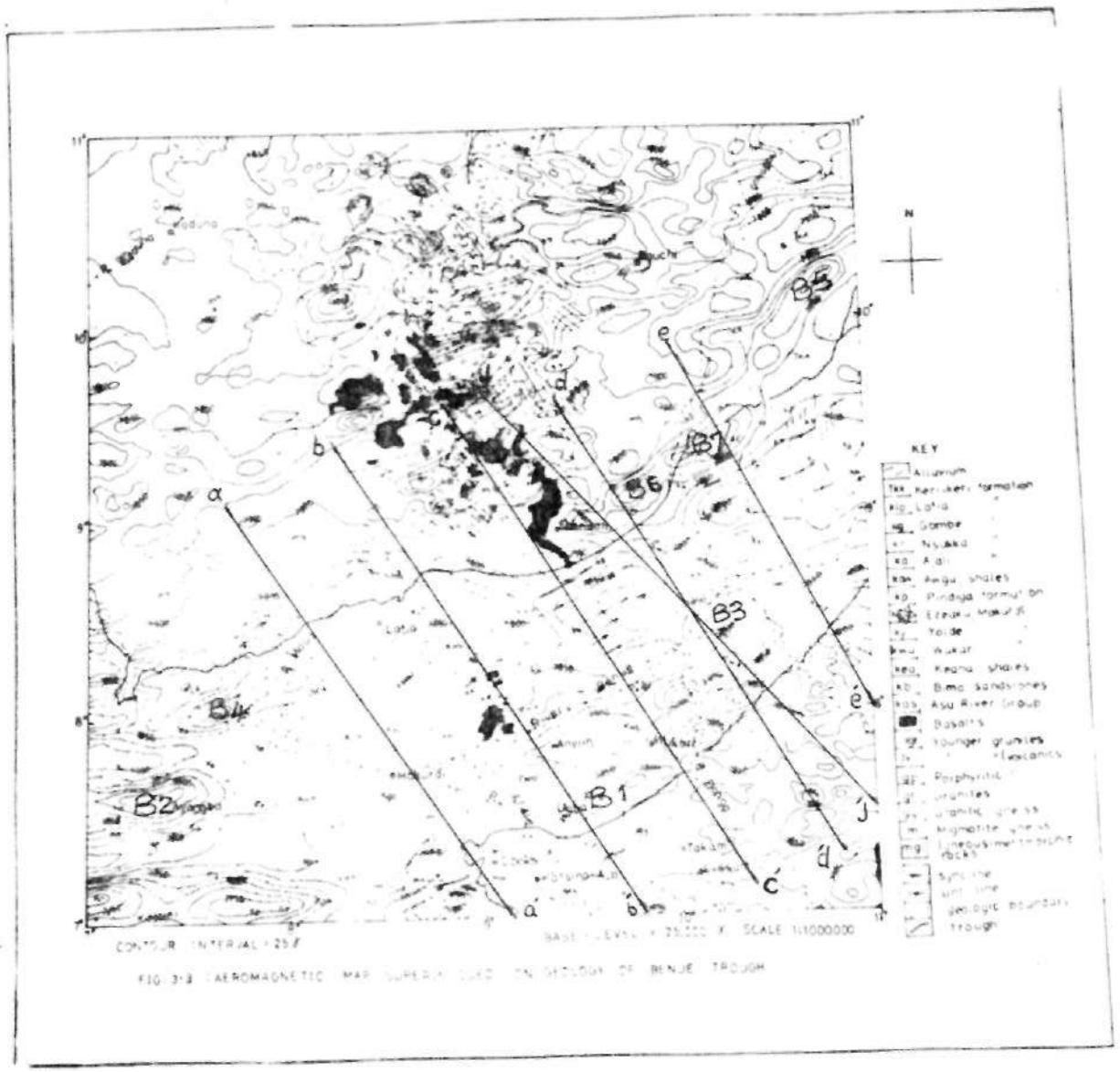
different distribution and polarisation of the material. Therefore, any magnetic distribution or geologic condition given as the cause of the given distribution of magnetic intensity at the surface depends on additional controls such as faulted zones observed on the surface, actual contact between different rocks or geological boundaries which produce magnetic contrasts (Nettlelon, 1940, 1973; Bott and Smithson, 1977).

3.3.1 Modelled magnetic anomalies B_1 to B_7

Quantitative interpretation along profiles extracted across the anomalous areas shown in fig 3.3 was attempted as discussed below.

Anomaly B_1

The anomaly B_1, fig 3.3.1 , which is on the Southern flank of the Benue trough extends from Anyiin (10 km South of Benue River) to Wukari with a lateral extent over 70 km. Five profiles were taken across the anomaly and the central and most accepted one was modelled and interpreted. With the magnetic baselevel discussed above and magnetisation intensity of



CONTOUR INTERVAL = 25 γ

BASE LEVEL = 25,000 γ SCALE 1:1000000

FIG 3:3 AEROMAGNETIC MAP SUPERIMPOSED ON GEOLOGY OF BENUE TROUGH

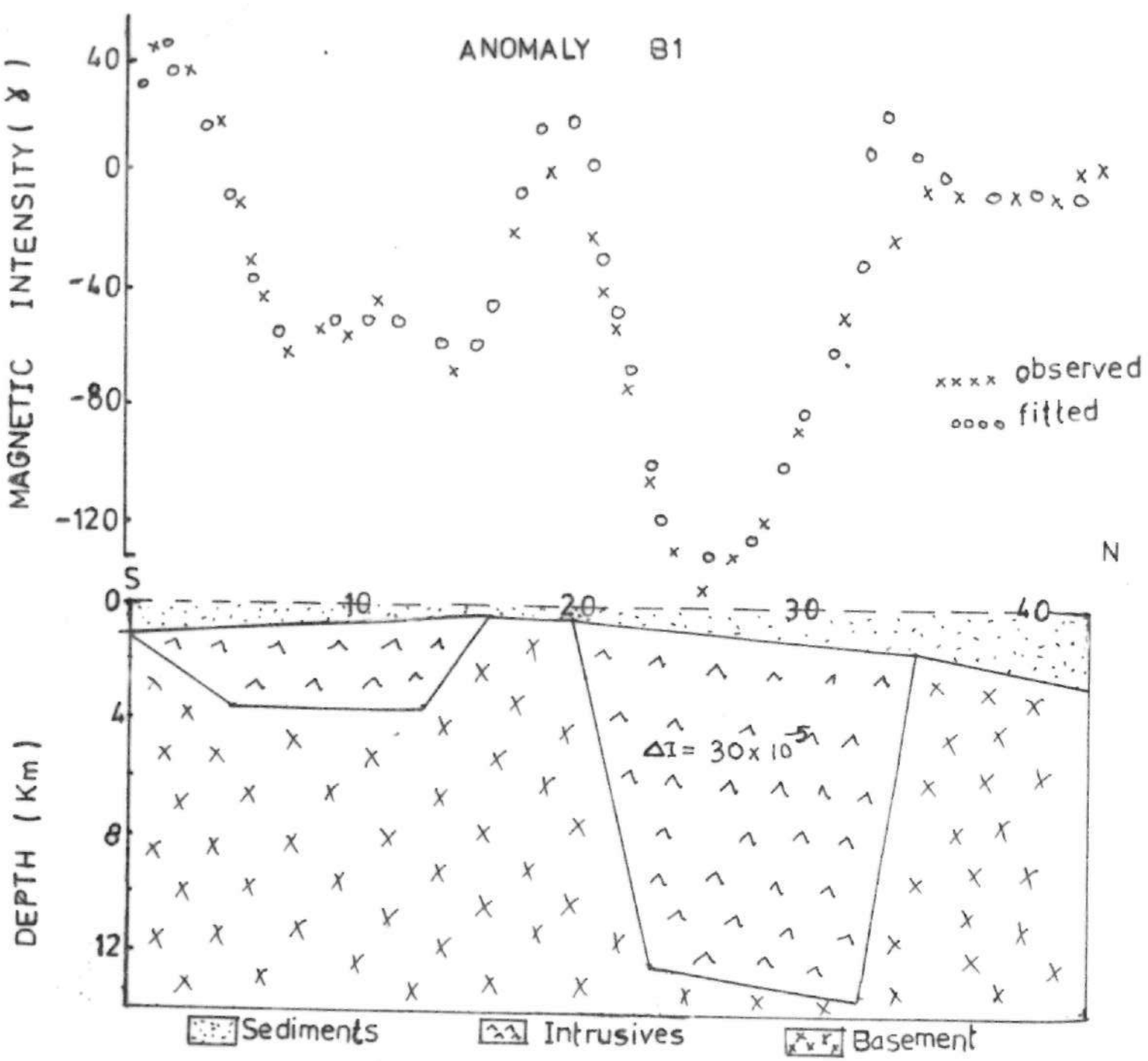

ANOMALY B1
MAGNETIC INTENSITY (γ)
40
0
-40
-80
-120
xxxx observed
oooo fitted
N
S
0
10
20
30
40
4
8
12
DEPTH (Km)
ΔI = 30 x 10⁻⁵
Sediments
Intrusives
Basement

Fig 3·3·1

30 x 10^{-5} e.m.u, the anomaly has an amplitude varying from - 70 to -130 gammas along the profile. The model best fit of the observed anomaly is shown in fig 3.3.1. The depths to the top of the anomalous body varies from 0.5 to 1.5 km and to the bottom 12.0 to 13.5 km.

Anomaly B_2

The anomaly has an amplitude of the order of -160 gammas along the modelled profile. It lies in the Northern Part of Ayangba in the middle Benue trough. The depths to the top of the causative body vary from 0.9 to 1.7 km while depth to the bottom vary from 10.5 to 12.6 km. The intensity of magnetisation is same as in anomaly B_1.

From previous works, the magnetic lows in this area has been attributed to great sediment thickness. The depths of the sediments obtained vary from one author to another, for example, Borehole and Stratigraphic information has depths varying between 0.975 to 1.2 km (Adighije, 1980, 81), while the present study has depths varying from 0.9 to 1.7 km. shown in fig 3.3.2.

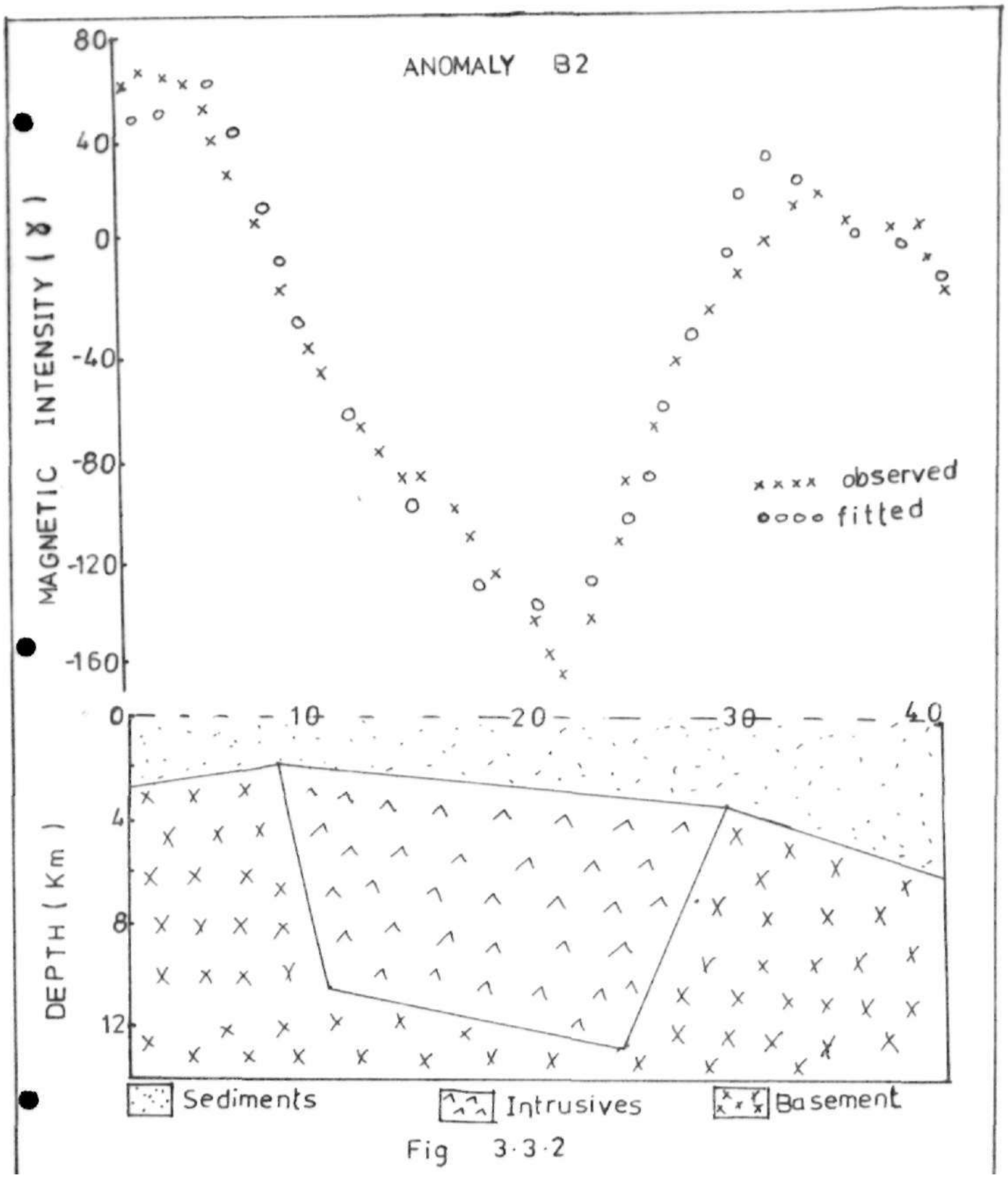

ANOMALY B2
MAGNETIC INTENSITY (γ)
80
40
0
-40
-80
-120
-160
xxxx observed
oooo fitted
DEPTH (Km)
0
10
20
30
40
4
8
12
Sediments
Intrusives
Basement

Fig 3·3·2

Anomaly B_3

This anomaly is of particular interest due to the fact that it lies almost centrally between the Northern and Southern flanks of the middle Beune trough fig. 3.3.

The magnitude of amplitude along the modelled profile vary from -80 to -160 gammas. The intensity of magnetisation of 55×10^{-5} e.m.u. obtained for the model with the best fit is indicative of an intermediate intrusion. The depths to the top of the causative body vary from 0.4 to 1.5 km, the depth of the sediments increasing away from the centre of the anomaly. These values are comparable to those obtained by Ajayi (1979). This anomaly extends towards Makurdi. The depths to the bottom of the anomalous body vary from 12.0 to 13.5 km fig 3.3.3 This anomaly has been interpreted to be caused by intermediate intrusion through a fault zone in this part of the trough.

Anomaly B_4

This anomaly lies on the northern flank of the Benue trough marking the contact between the sediments and the basement complex. The intensity of magnetisation

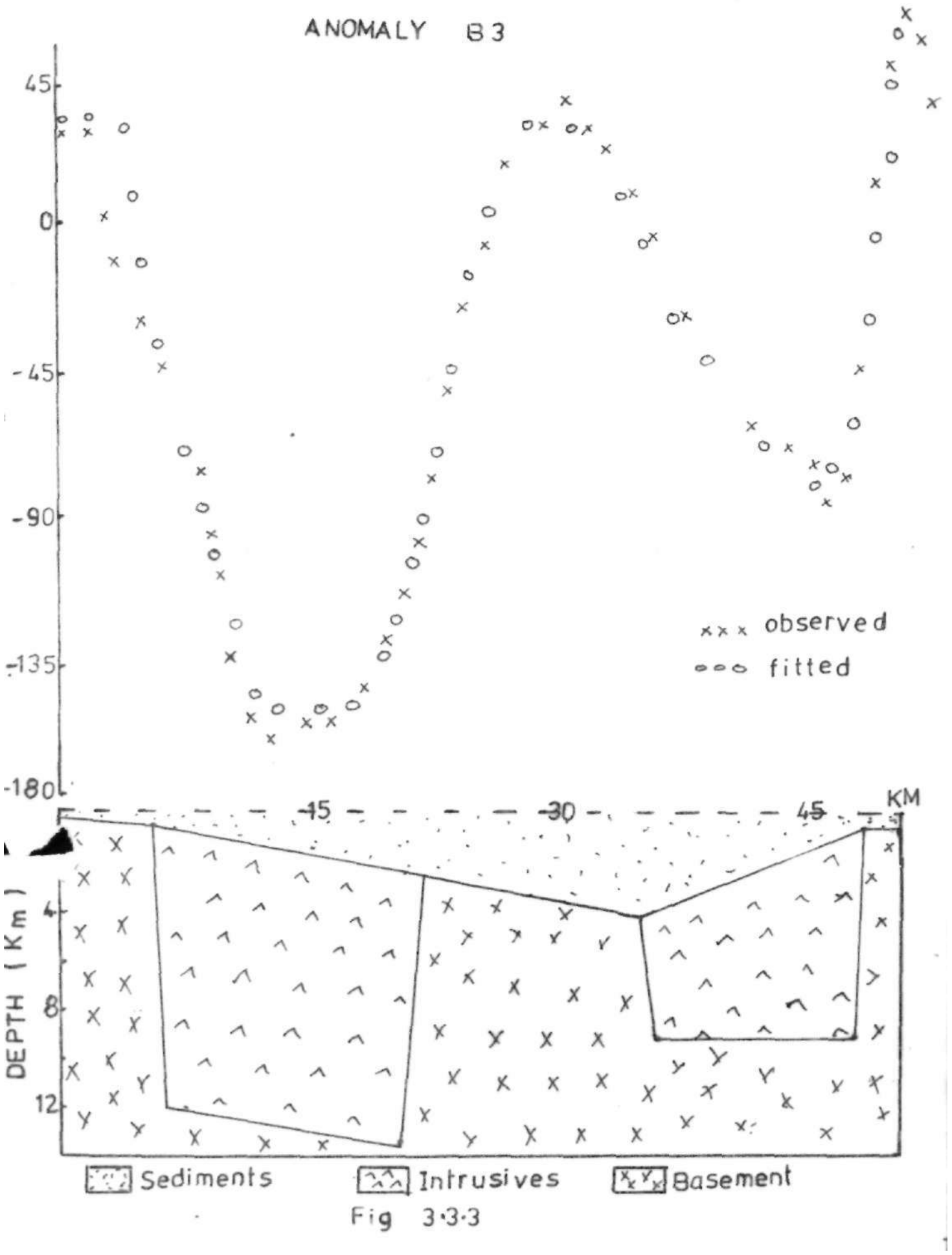

ANOMALY B3
45
0
-45
-90
-135
-180
xxx observed
ooo fitted
15
30
45
KM
DEPTH (Km)
4
8
12
Sediments
Intrusives
Basement

Fig 3·3·3

of this anomaly is similar to those obtained for anomaly B_1

The amplitudes of the anomaly vary from -60 to -70 gammas (fig 3.3.4). The depths to the top of the causative bodies were found to vary from 0.3 to 3 km. in the north - south direction along the profiles taken across the anomaly. The depths to the bottom from the model vary from 12.0 to 13.5 km. The anomaly has a lateral extent of about 60 km along the northern flank of the trough.

Anomaly B_5

This anomaly lies just outside the Benue trough in the Chad formation with a lateral extent over 30 km.

The model indic tes that the causative body has an intensity of magnetisation of 45 x 10^{-5} e.m.u. The depths to the top of the causative body varies from 0.5 to 1.5 km and bottom with depths 10.5 to 11.5 km. The amplitude of the anomaly vary from -60 to -100 gammas along profiles taken across it. Fig 3.3.5.

This study reveals that this anomaly is caused by basic to intermediate intrusion underlying the sediments in the Chad formation.

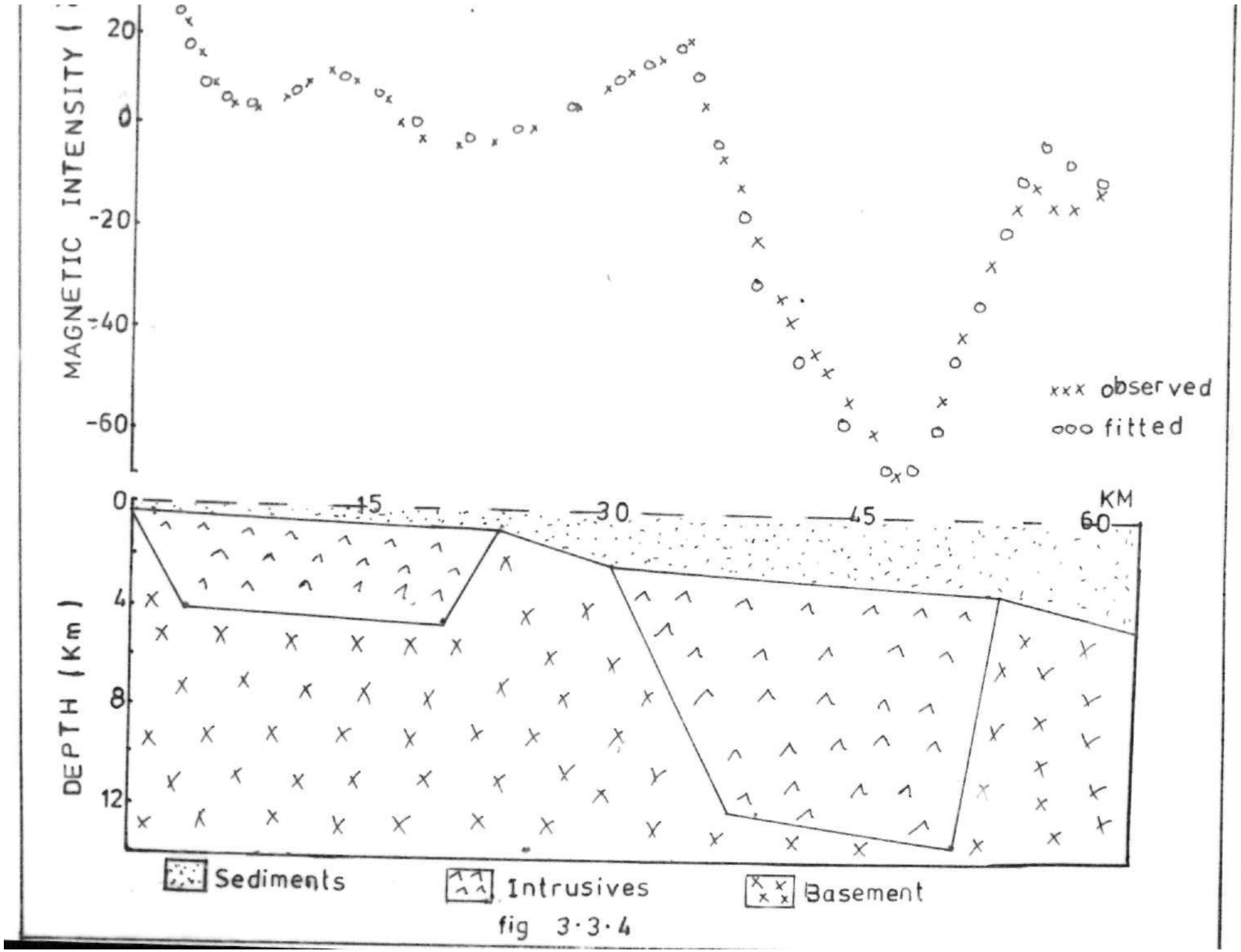

MAGNETIC INTENSITY
20
0
-20
-40
-60
xxx observed
ooo fitted
0
15
30
45
60
KM
DEPTH (Km)
4
8
12
Sediments
Intrusives
Basement

fig 3·3·4

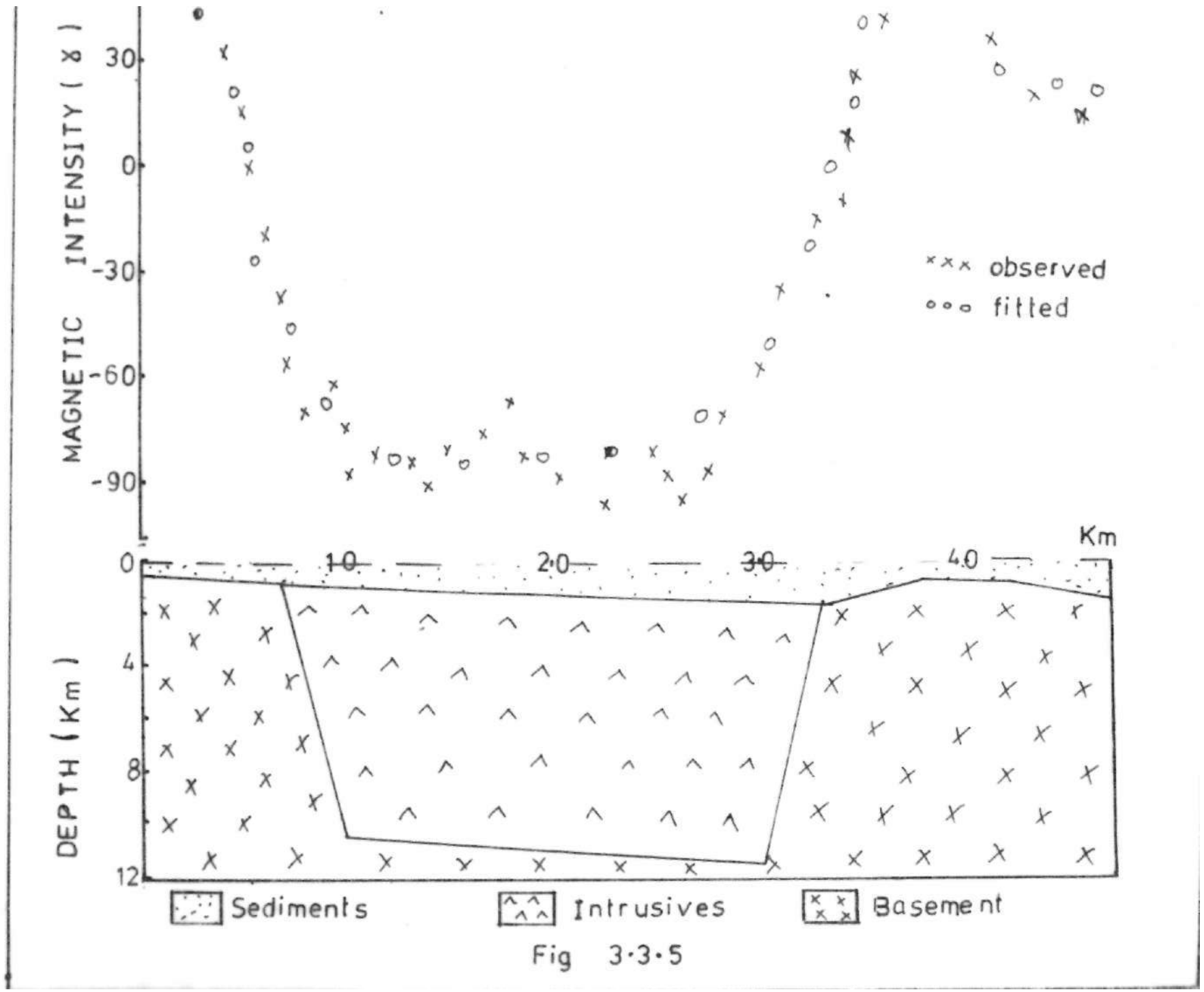

MAGNETIC INTENSITY (γ)
30
0
-30
-60
-90
xxx observed
ooo fitted
Km
0
10
20
30
40
DEPTH (Km)
4
8
12
Sediments
Intrusives
Basement

Fig 3·3·5

Contrary to this study, previous workers in this area (Ajakaiye, personal communication) have attributed the magnetic lows in this area due to a deep basin within the Chad formation, at depths not less than 1 km.

Anomalies B_6 and B_7

These anomalies like anomaly B_5 lie outside the Benue trough in the Jos Younger Granite complexes area Fig 3.3. These were modelled with an intensity of magnetisation of 30×10^{-5} e.m.u. The amplitudes of the anomalies vary from about -130 to -300 gammas. These anomalies are so close to each other that one can probably suggest that these have a common source. The depths to the top of the causative bodies vary from 0.3 to 1.5 km while to the bottom vary from 12.5 to 13.5 km, with a lateral extent of not less than 50 km. Fig 3.3.6 and 3.3.7.

It can be deduced from the above discussions that the zones of relative magnetic lows along the flank of the trough mark the boundary of the basement and the sediments which fill the trough. The basic to intermediate intrusives are found along the flanks and

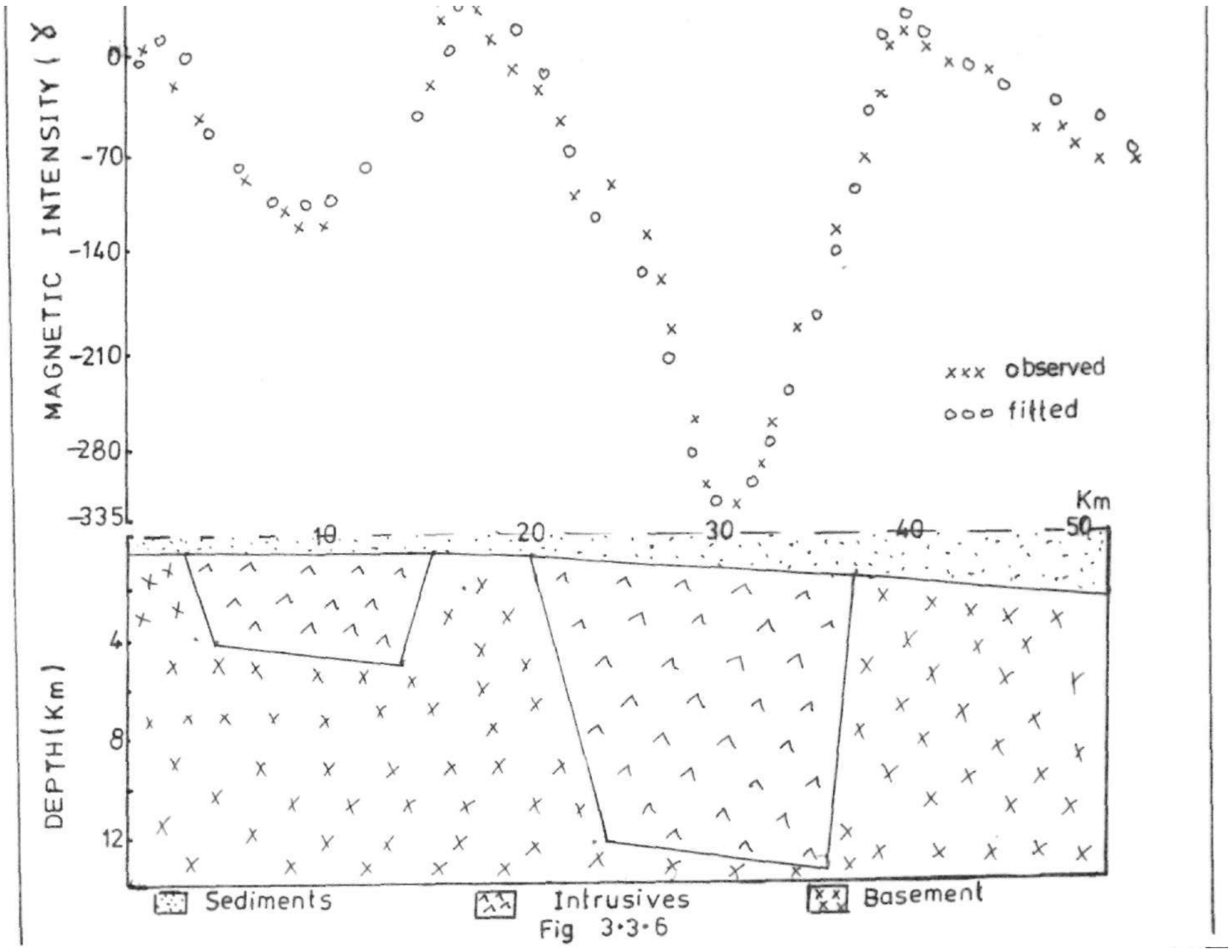

MAGNETIC INTENSITY (γ
0
-70
-140
-210
-280
-335
xxx observed
ooo fitted
Km
10
20
30
40
50
DEPTH (Km)
4
8
12
Sediments
Intrusives
Basement

Fig 3·3·6

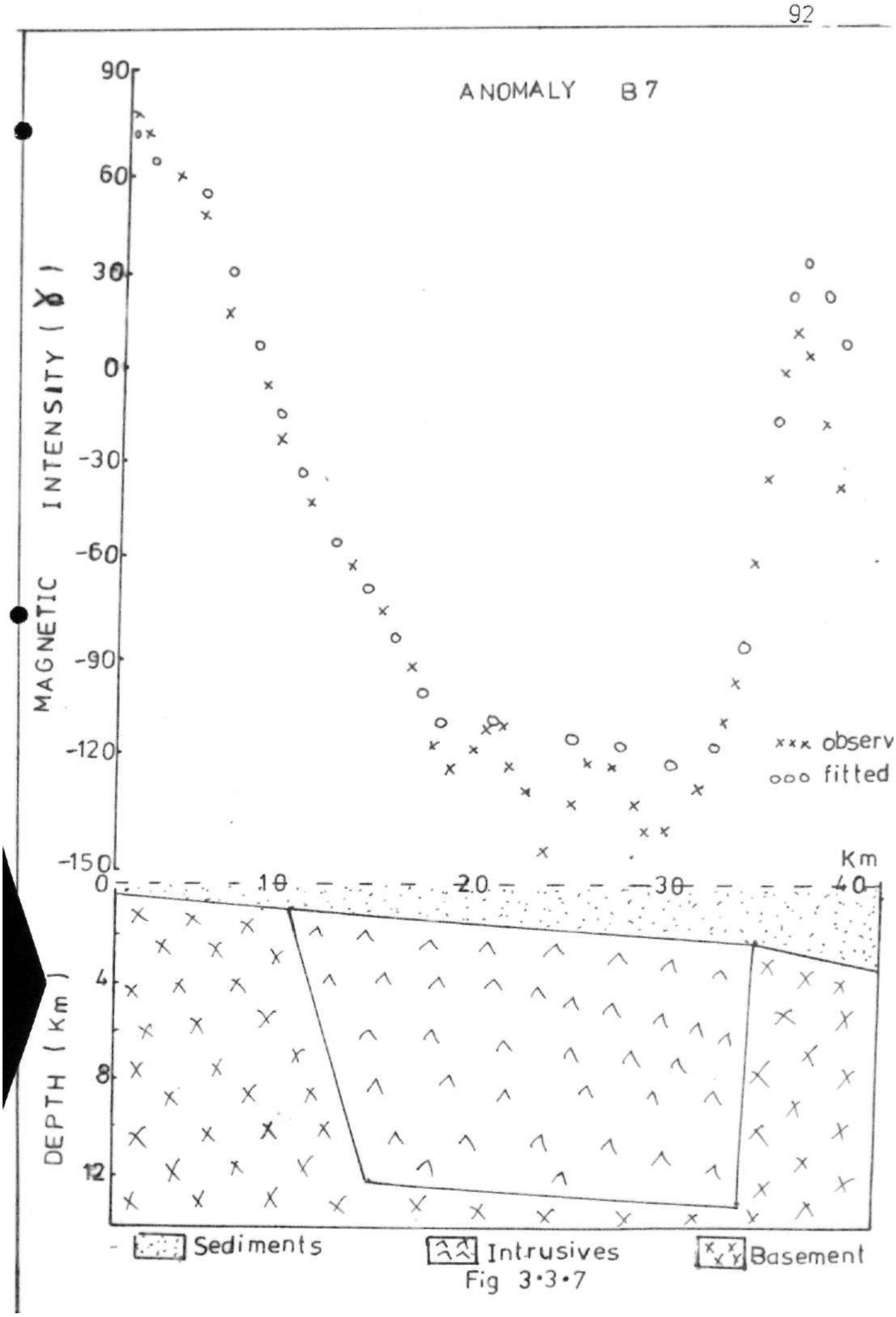

ANOMALY B7
MAGNETIC INTENSITY (γ)
90
60
30
0
-30
-60
-90
-120
-150
xxx observ
ooo fitted
0
10
20
30
40
Km
DEPTH (Km)
4
8
12
Sediments
Intrusives
Basement

Fig 3·3·7

about the centre of the trough. These intrusives are deep rooted implying that the fractures along which they escaped to the surface and beneath the sediments are also deep rooted.

The magnetic lows in the lower Benue trough have been attributed to areas of deep sediments' thicknesses (Ajighije, 1979). The lows in the middle Benue trough have been attributed to basic intermediate intrusion which separate the trough into two nearly equal halves (Ajayi, 1979). The intrusions must have occured along fracture zone within the trough.

These anomalies clearly indicate that the trough must have originated as a result of rifting and upliftment as the South American and the African continents drifted apart.

3.3.2 Interpretation of Profiles across the Benue Trough.

In order to correlate the magnetic field patterns, six profiles were taken across Benue trough within the project area, and these were labelled A - A^1 to E - E^1 and J - J^1 (Fig 3.3). All these profiles extended to the basement complex on either flanks of the trough.

The basement/sedimentary boundaries are clearly defined and are characterised by magnetic lows on either flanks of the trough. These contacts do not exactly correspond to the mapped geological boundaries Fig. 3. 4.1. Also, there is a central magnetic low in the upper part of the study area which separates the trough in nearly equal halves. This magnetic low has been interpreted to be due to intermediate intrusion from the model.

The depths of sediments (not estimated for these profiles in this study) vary considerably along the trough (Ajayi, 1979).

The profiles consist of lows and highs which are indicative of intrusive materials within the trough. These profiles have also been used for section 3.4d.

The J - J^1 Profile

This profile cuts across the trough from the Jos Younger granite area to the Adamawa volcanic mountains. Fig. 3.3.8. The magnetic anomaly along the profile indicates two central highs with three lows within the trough. This profile was modelled using the POPT program revealing that the depths to the top of the bodies causing the magnetic lows varied from 0.4 to

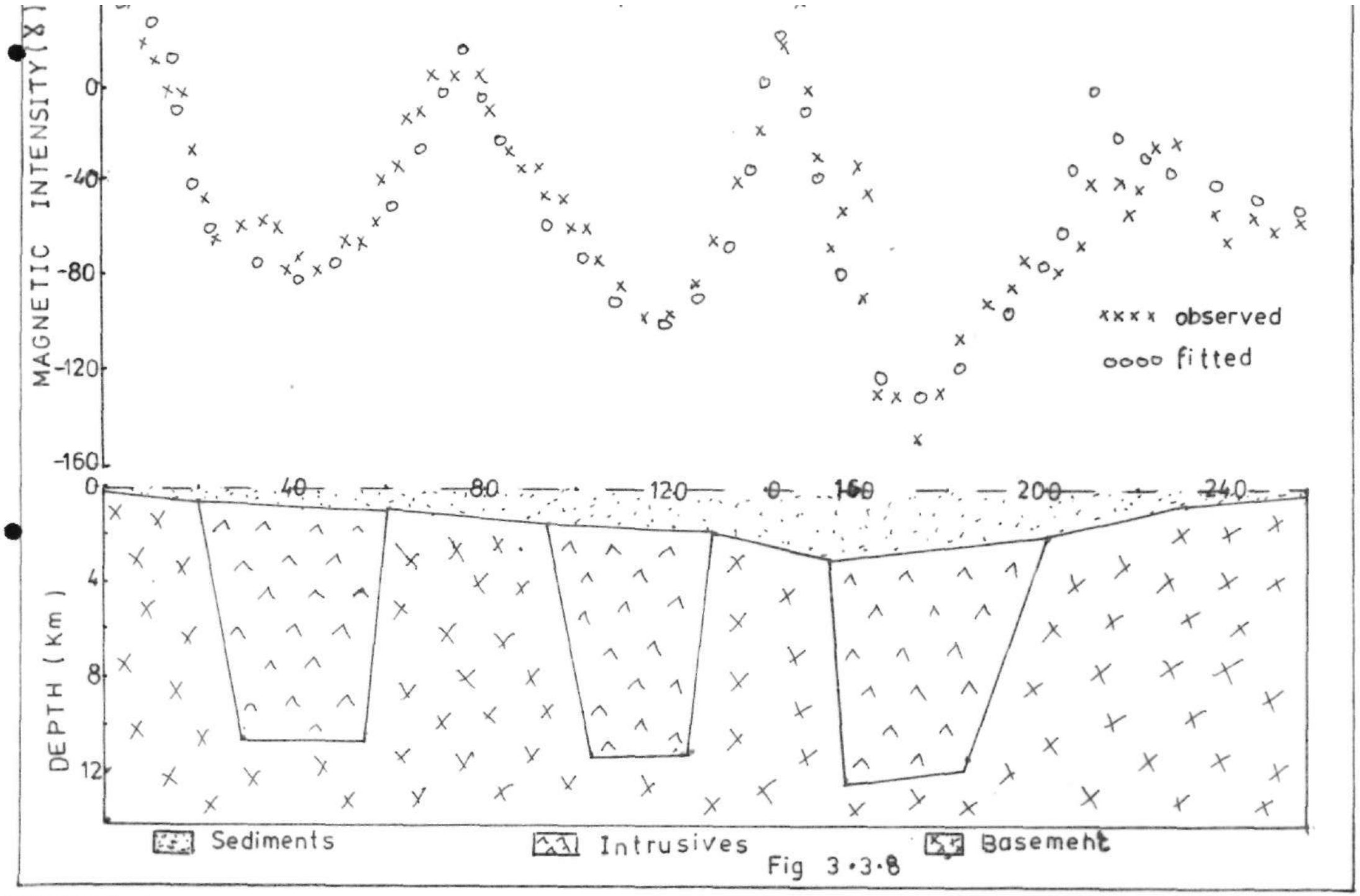

MAGNETIC INTENSITY (γ)
0
-40
-80
-120
-160
xxxx observed
oooo fitted
0
40
80
120
160
200
240
DEPTH (Km)
4
8
12
Sediments
Intrusives
Basement

Fig 3·3·8

2.6 km (Fig 3.3.8). The occurance of a central low in this part of the trough indicate that there is a fracture zone in the area through which basic/intermediate materials escape beneath the sediments of the trough. This may explain the abnormal width of the trough.

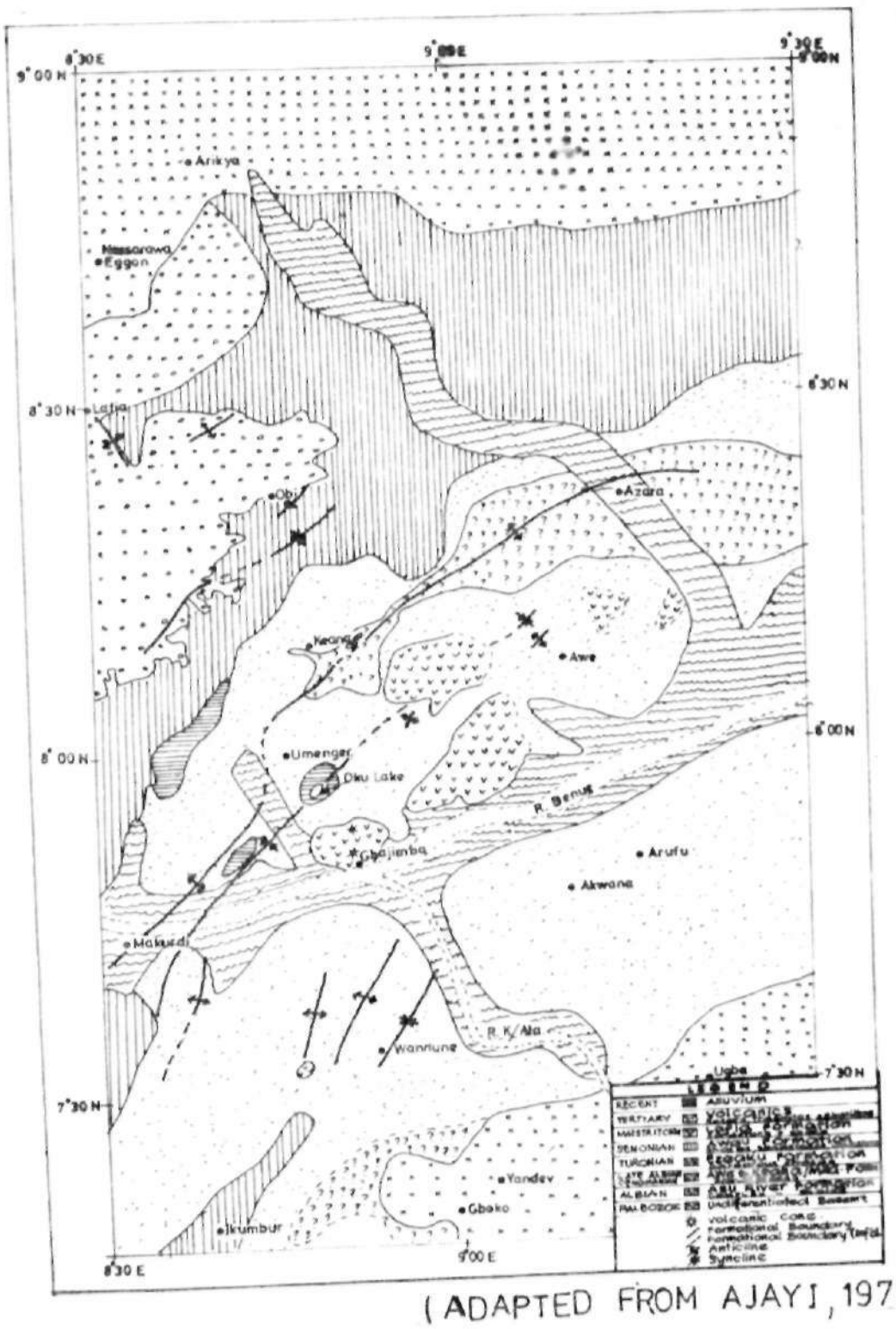
Faults.

Faulted areas have been observed by previous workers between Wukari and Donga (Cratchley and Jones, 1965) and in the Kaltungo area of the upper Benue trough (Chukwu - Ike, 1977; Osazuwa, 1978).

The analysis of the profiles and the continued aeromagnetic profiles reveal that fault planes can be infered from the profile by considering the inflection points between the lows and the highs. Thus, a series of faults have been infered beneath the sediments, which might have occured before or after sedimentation. This may explain the absence of marginal faults on the surface unlike the East African Rift System whose faults are observed on the surface (Girdler, 1965).

Folds

There are a number of folds, anticlines and synclines scattered along the entire trough. These



(ADAPTED FROM AJAYI, 1979)

FIG 3·3 C: FAULTS AND FOLDS

include the Lamurde anticline, Gizo, Wanune and Wukari anticlines and the Kadarko synclinorium, plus many minor unnamed ones Fig. 3.3.c. These folds have been attributed to the compressional forces during the Coniacian and Santonian times and the Maestritchian times which gave rise to the post- Maestritchian folds Fig. 3.3. C. The folding of sediments in the trough have been explained also as a result of an elastic "rebound" of the African plate as the South American plate drifted apart. Beaumont (1978) attributed the folding of the sediments in the trough as a consequence of the movement of the African plate about the equator and the accretion of the Western and Congo cratons.

Depths of Sediments in Benue trough

The Benue trough is sediment- filled valley with depths of sediment varying along the entire length of the trough.

A careful examination of the Table 3.3.2a reveals that the depths obtained by previous and present study differ considerably possibly due to the locations of the profiles considered by the various authors.

Comparism of Sediments Thickness From Various Authors.

Benue Trough Area	Sediment Thickness (m)					
	1	2	3	4	5	6
Upper	5487			6000	2500 *5600	2500
Middle	3658			3000	3000-6000	3500
Adoka-1 Long $7^{o}551$ let 7^{o} 30'			975.6	1200		
Lower		4500		4500		
Aiddo -1 lat 6^{o} 51' long 7^{o} 50'			3215	3000		

1. Cratchley and Jones, 1965 (2) Adighije, (1976)
3. Borehole information (4) Adighije (1981)
5. Osazuwa (1978) (5*) Ajayi, (1979)
6. Present study

Table 3.3.2a

Rock Densities

Age	Rock Type	Average Density $x10^3$ kg/m^3
Tertiar	Basalt:	
	Vesicular	2.72
	non-vesicular	2.90
	Ironstone	3.42
(Turanian) Cretaceous	Ferriginous - sandstone	2.56
	Sandstone	2.38
	Shale	2.52
	Ferruginous grit	2.69
	Bima Sandstone	2.29
	Albian sheles	2.65
	Silt stone	2.60
	Grit stone	2.62
	Other sand stones	2.47
Palaeozoic	Quartzites	2.60
	Rhyolite	2.64
	Pegmatite	2.59
	Granite	2.59
	Gneiss	2.78
	Granite, acid gneiss	2.65

(Adapted from Ajakaiye, 1981)

Table 3.3.2b.

Magnetic Susceptibilities of Rock Samples in the Benue Trough

Rock Type	Area in Benue trough	Mean Magnetic Susceptibilities $x10^{-6}$ e.m.u
Sandstone	Lower	19
Ferrugimous sand-stone		30
Siltstone		13
Lime stone		26
Granite	Lower	392
Porphyritic granite		1384
Biotic granite		788
Audesite		33
Pegmatite	Lower	115
	Lower	17
Gneiss	Lower	73
Gneiss (Metasomatic)	Upper	357
Gneiss (amplibole)		882
	Lower	1460
Migmatite	Upper	467
	Lower	87
Schist	Lower	355
Basalt (olivine)	Lower	1380
	Upper	1462
Diorite	Lower	1328
Phonolites	Lower	33

(Adapted from Ajakaiye, 1981)

Table 3.3.2C

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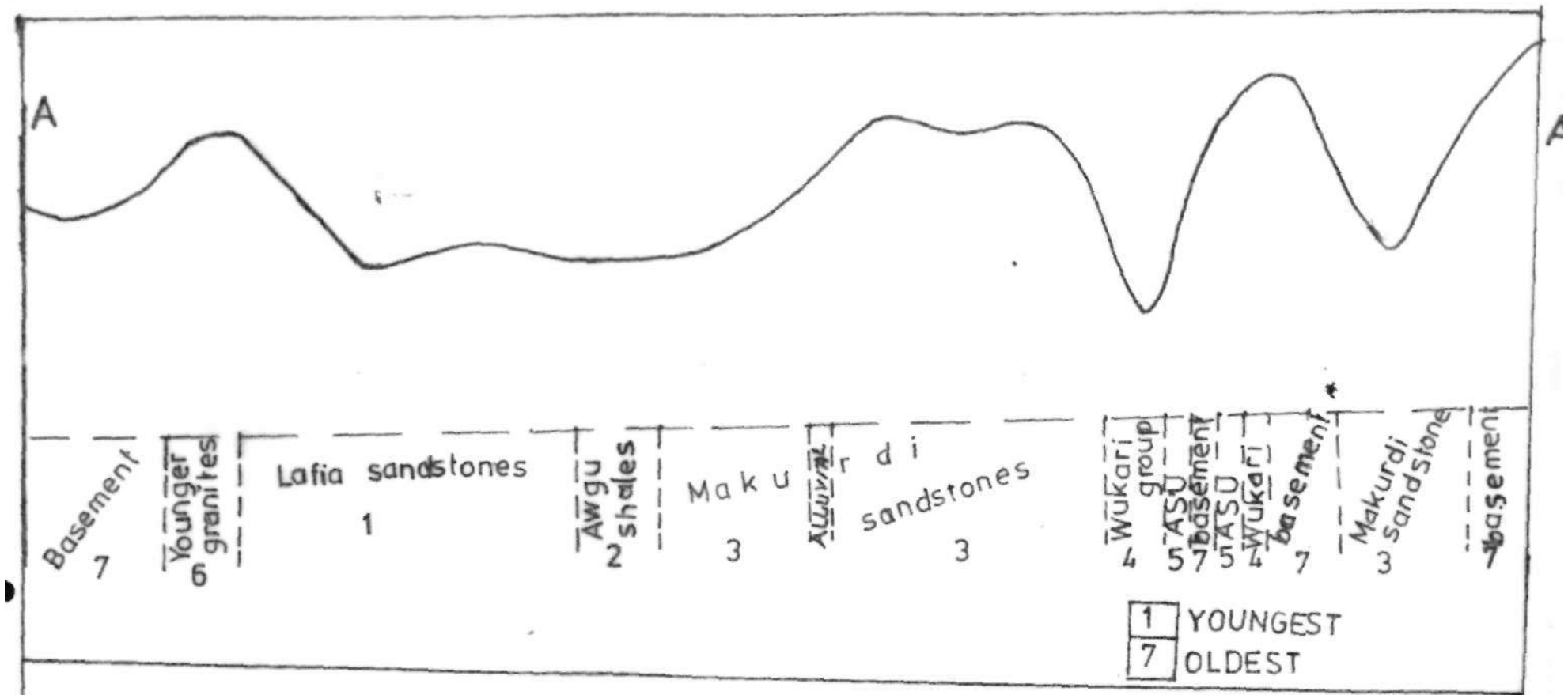
Depths up to 6000 m have been obtained in the upper Benue trough (Cratchley and Jones, 1965); 3000 to 7000 m in the middle Benue trough (Ajayi, 1979) and depths up to 4500 in the lower Benue trough (Adighje, 1981).

3.4 DEDUCTIONS FROM PRESENT STUDY.

3.4.1 CORRELATION OF THE PROFILES WITH SURFACE GEOLOGY.

The geological formations in the Benue trough vary in composition and texture from the lower to the upper parts of the trough (Offodile, 1975). A detailed geological mapping of the entire area especially the middle Benue trough is yet to be carried out completely. Most of the published geological data has been isolated studies as shown in table 2.4 where formations of the same age, composition and texture have different names depending on the authors.

The magnetic anomaly along profile A - A^1 (Figs 3.4.1 and 3.4.2) was studied in detailed in order to correlate



PROFILE A-A′ WITH GEOLOGY CROSS-SECTION

Fig 3·4·1

the surface geology and the possibe subsurface structure. The magnetic data along this profile was upward continued up to 5 km above the ground surface in order to eliminate the effects due to near subsurface structure. A correlation between the magnetic profile and the surface geology along the same profile Fig. 3.4.1 . Fig 3.4.2 shows the possible subsurface structure determined from the upward continued aeromagnetic data. Similar patterns were estimated for other profiles which have not been included in this study.

3.4.2 The Width of the Trough.

One of the perculiarities of the Benue trough is its abnormal width, 160 to 250 km, about three times that of a normal rift 50 ± 15 km (Holmes, 1964). The width of the Benue trough has made the trough really controversial as to its origin as a rift valley as was postulated by King (1950), Wright (1968, 1970) and Kennedy (1965).

From the analysis of the profiles across the trough, it can be observed that there is a central high marked

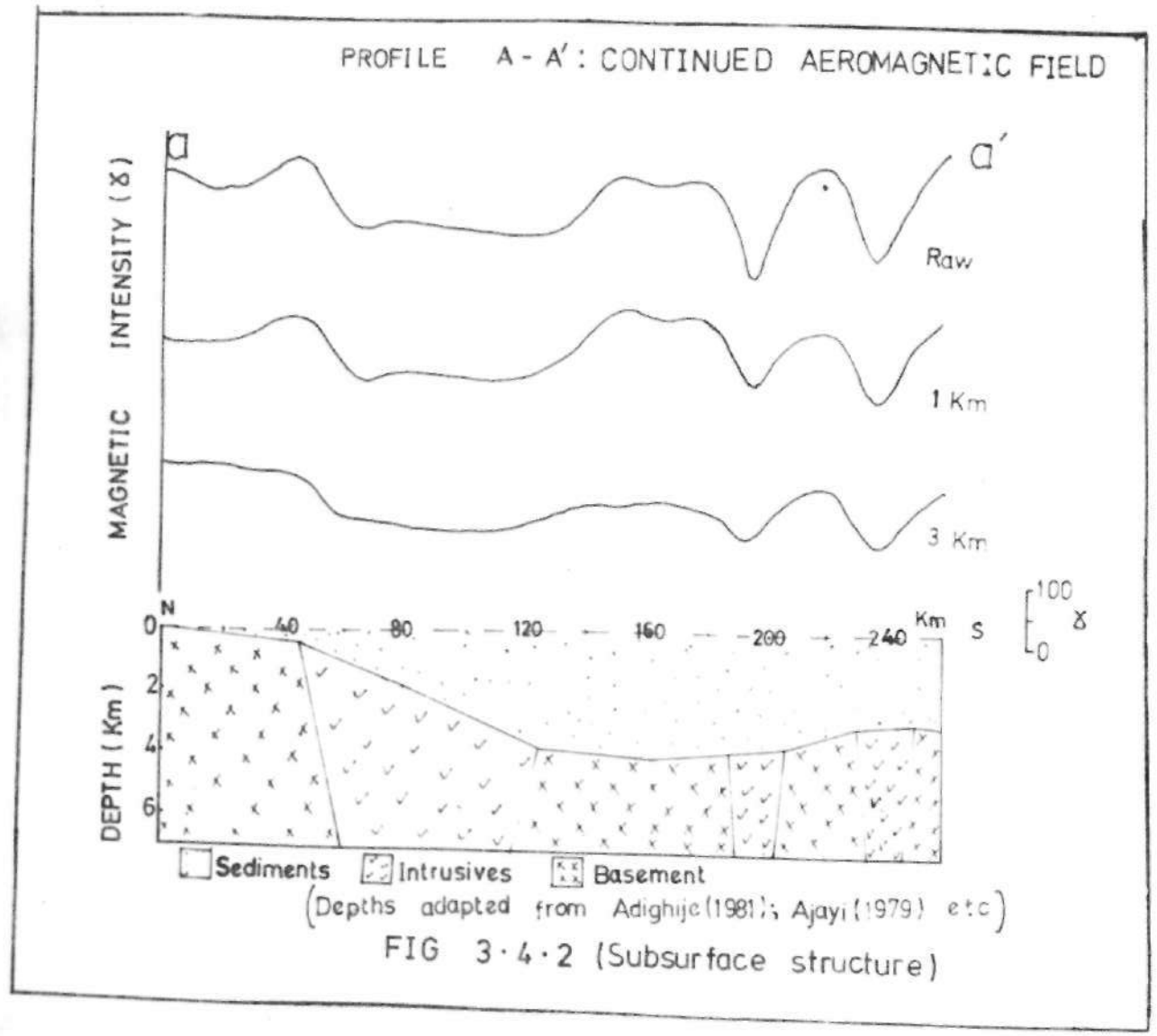


FIG 3·4·2 (Subsurface structure)

on both sides by areas of magnetic lows which correspond to areas of great sediment thickness. The width of the trough from these profiles range from 160 to 250 km.

The analysis of the profiles reveal that there are other faulted zones within the trough. The idea of double rifts within the trough has been postulated by Ajayi and Ajakaiye (1981). This may possibly explain the abnormal width of the Benue trough. Also on the basis of the viscoelastic theories of Beaumont and Sweeney (1979), the load on the grabens by thick sediments can cause an increase in the width of the trough up to five times its orginal width during regional isostatic adjustments. It has been documented that there was rapid deposition of sediments in the Benue trough (Stonley, 1966) causing excess load on the viscoelastic lithosphere which could result in an increase in the size of the graben.

The above discussion reveals possible causes for the increase in width of the Benue trough. The large width of the Porth valley which has similar characteristics as the Benue trough has been attributed to the extra faulting within the trough.

3.4.3 The origin and evolution of the Benue trough.

The Benue trough is essentially a tensional fracture system which subsided intermittently, at first rapidly, from mid - Albian to early Senonian times accumulating well over 6000 m of deltaic, continental estuarine and marine sediments with rare intercalated alkaline basic lavas - volcanic intrusions (Ekine, 1979). The late Senonian and Maestritchian Sediments witnessed a compressional folding predominantly along the north-east to south - west axes. This was accompanied by faulting and volcanic activities which have been associated with the lead-zinc mineralisation zones (Offodile, 1976).

From the analysis of the profiles in the present study the intermediate igneous intrusions from the model are deep rooted over 12 km implying deep rooted fractures in the trough.

These observations support a rift origin for the Benue trough as suggested by Wright (1968, 1970); Cratchley and Jones (1965); Ajakaiye and Burke, 1972); Ajayi and Ajakaiye, 1981). Though, there is the

absence of surface marginal faults, such faults are probably buried under the thick sediments of the trough.

3.4.4 Seafloor spreading

One of the other controversial issues about the Benue trough is the possibility of occurance of oceanic crust beneath the sediments.

The theory of seafloor spreading was first hypothesised by Hees (1960, 1962) and Dietz (1961, 1962) based principally on the study of tectonic activities in the mid-oceonic ridges. The Transform faults along which plates move relative to one another constitute zones through which molten material beneath the ocean are ejected, forming ridges/seamonts. Thus, these are cooled and spread beneath the ocean or even surface to form islands/island arcs. In the centre of the ridges, young molten materials are found and the older materials away from the centre. In order to ascertain the possibility of seafloor spreading based on the above hypothesis, younger formations should be found about the centre of the Benue trough and the older formations towards the basement complex. This is obviously not the case with

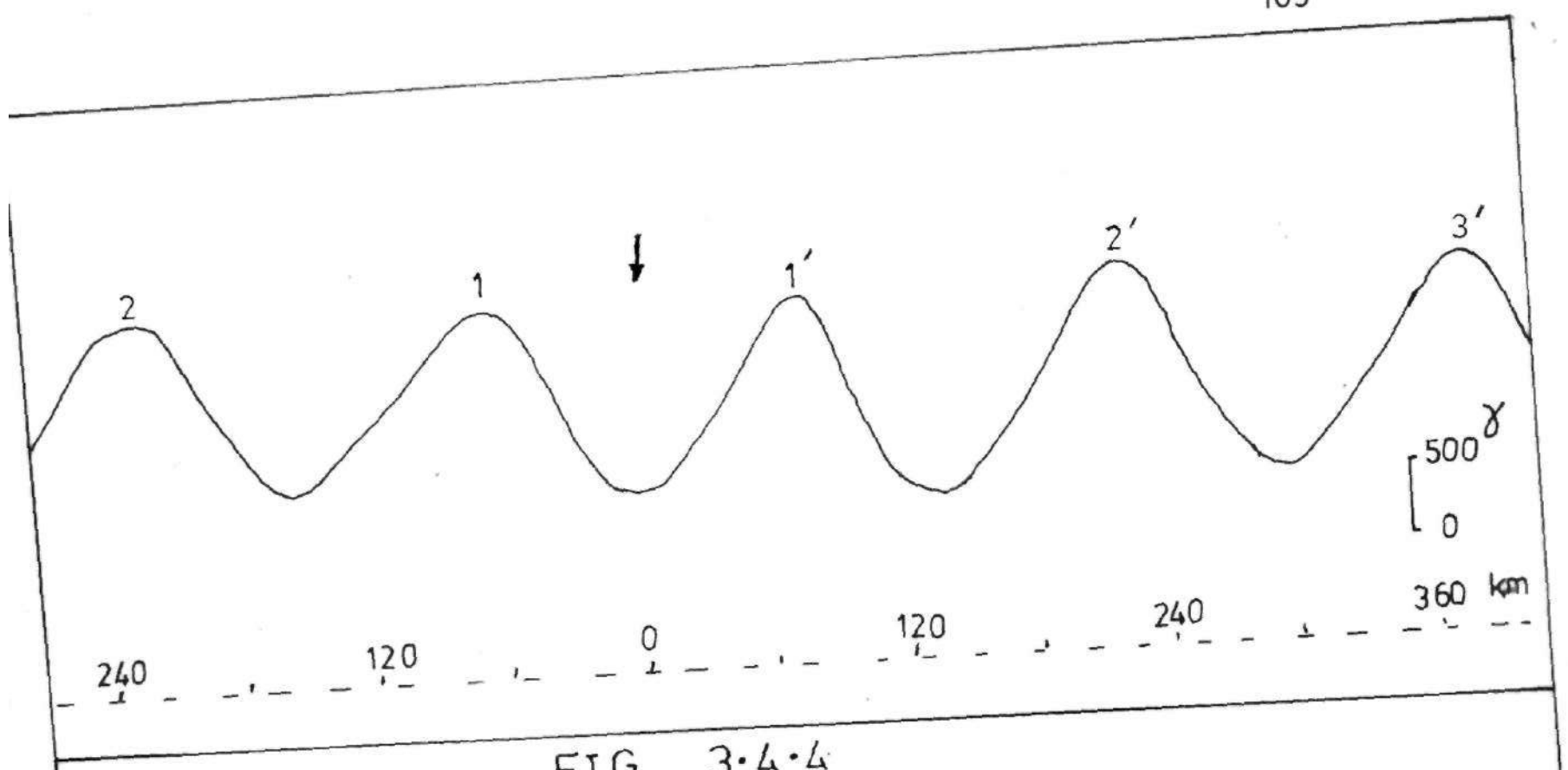


FIG 3·4·4

EXAGGERATED MAGNETIC PATTERN ACROSS MID-ATLANTIC RIDGE (SEA-FLOOR SPREADING)

the trough. The surface geology has no particular pattern similar to the above description.

Magnetic studies by various authors over ocean ridges and rifts associated with oceanic crust beneath their sediments, indicate that these features are characterised by high magnetic intensities of the order of 500 gammas. The studies reveal that there is a consistent pattern of the magnetic field from the centre to the either sides of the ridges. For example, if the centre of the ridge is located at the point marked "C" in fig 3.4. d, there will be corresponding crest/troughs on either sides.

A careful examination of the profiles taken across the Benue trough (fig 3.4 e) indicate that such a pattern nearly exists when the point marked "[illegible]" is regarded as the centre of the trough and the corresponding crests marked 1, 1^1; 2, 2^1 are considered. A comparism between the geology and magnetic profiles hardly confirms the seafloor theory in the Benue trough.

The high amplitudes of magnetic anomalies are not observed in the Benue trough.

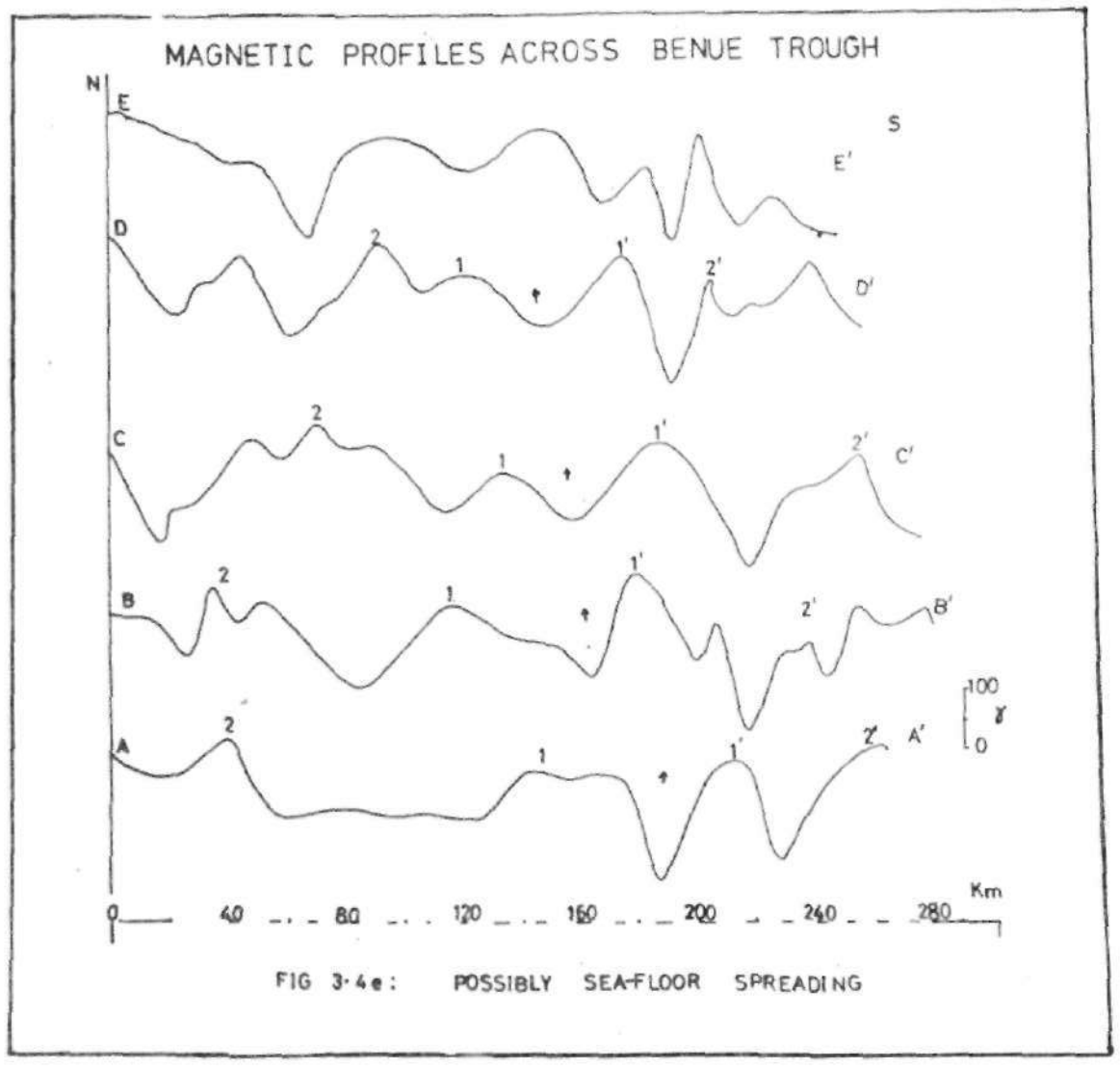


FIG 3·4e: POSSIBLY SEA-FLOOR SPREADING

CHAPTER FOUR

GRAVITY METHOD

4.0 Introduction

The gravity survey was carried out along 2 profiles to confirm some of the features obtained in the project area. The main profile, 220 km long starts from Shendam and runs through Yelwa, Ibi, Wukari, Takum terminating at Lissam Fig 3.3. The profile also passes through a section of the magnetic anomaly, B_1 (Fig 3.3b). In addition to this main profile, another profile, 90 km long which also crosses B_1 was also selected on a motorable road.

The selected profile covers the entire width of the Benue trough from the Jos basement complex to the Adamawa mountains in the northern and southern flanks of the trough respectively.

Measurements were taken at 1 km interval. The base stations were established at distances of 10 to 15 km in order to ensure that the time interval between measurements at two base stations was less than two hours.

4.1 Field Survey

The Warden gravimeter No 135 with scale constant of 0.926 g.u per division, 2 Wallace and Tiernan altimeter models and a Psychrometer were used for the collection of field data. All the instruments were read at the same time for all the occupied gravity stations.

The gravity base stations were established at kilometer posts and only in very few cases were on actual benchmarks. Most of the detail stations were located at kilometer posts, where these were not available, the vehicle meter indicator was used to estimate the one km interval with an accuracy of ± 20m.

The field crew and instruments were transported using the motor vehicle.

Most of the gravity stations were not established on benchmarks because benchmarks were hardly available or found due to their destruction by road construction companies and change of course of some of the roads. Benchmarks were found only along Yelwa - Ibi road and the gravity station were located on these benchmarks. Only three base stations were

established on standard benchmarks, SBM, at Shendam, Wukari and Takum, which were unaffected by road works. All the base stations were "looped" for both gravity and height effects along the entire profile using the ABABBBC looping technique (Nettleton, 1940, 1976). The time interval between observations at any two base stations was less than two hours to ensure linear drift of the instruments (Ajakaiye and Verheijen, 1971). The usual drift curves were then plotted.

The main problem encountered during the field work was the unavailability of map sheets 112 (Shendam) and 273 (Takum) on scale of 1: 50,000. The only available map was on scale 1: 100,000 which minimised the accuracy in the determination of the latitudes and longitudes for the gravity stations. Also the maps were produced in 1969 and 1974, while the aerial photograph were taken in 1963 and 1964, so that the roads marked on them had either been altered or undergone considerable reconstruction, thus, it was difficult to locate the gravity stations on the maps.

The cost of obtaining height values for the benchmarks was also a constraint (Federal Surveys, Jos).

4.2 Data Reduction

The gravity data was reduced to Potsdam and IGSN Systems using the value of 9781023.50 g.u obtained by Ajakaiye (1970) at Shendam and the heights 638.87 ft and 628.70 ft for Shendam and Wukari respectively obtained from the Federal Survey headquarters at Makurdi. These heights were used as baselevels for the determination of the other measured heights.

For latitude effects, the International Gravity Formula of 1967 and the tables of gravity variation compiled by Ajakaiye and Verheijen (1979) were used in which a value of 9781547.811 was adopted for Shendam.

The data obtained was reduced using a programmable calculator and corrected for drift, latitude elevation as described below.

The drift rate, d, was calculated using the relationship.

$$d = \frac{(R_B - R_A)\,K - (G_B - G_A)}{t_B - t_A} \qquad \text{--------- (4-1)}$$

Where

R_A, R_B are instrument readings at the base stations A and B, G_A, G_B are absolute gravity values at the base stations A and B and t_A, t_B, their corresponding observation times.

K is the instrument constant (0.926 g.u/div for gravitmeter and 10ft/div for altimeters).

The same formula (i) above was used for the heights with H instead of g.

For any intermediate detail station the relationship below was applied.

$$g_x = g_A + (R_x - R_A)\,K + d\,(t_x - t_A) \qquad \text{----------(4 - 2)}$$

g_x, t_x are observed gravity value and time at any intermediate detail station.

The recorded dry and wet temperatures were corrected for temperature and humidity using the humidity factor from the Smithersonian Meteorological conversion charts and tables. Since two altimeters were used the mean value of the corrected heights as recorded by the altimeters was used for the free Air and Bouguer corrections.

The elevation correction is usually carried in two components, that is, the Free - Air and the Bouguer corrections. The Free - Air correction, (F.A.C) was applied using the formula

$$F.A.C. = \frac{dg}{dz} h \quad \text{---------- (4 - 3)}$$

Where

dg/dz is vertical gravity gradient, 3.086 g.u./m.

h is the station elevation relative to sea level.

The Bouguer correction, B.C was also applied to the gravity data using the well known formula

$$B.C. = 2\pi G \rho_m h \quad \text{---------- (4 - 4)}$$

Where

G - Universal gravitational constant,

$6,\ 67 \times 10^{-8}$

ρ_m - mean crustal density

h - thickness of the slab.

4.2.2 Anomalies

After all the above corrections were applied to the gravity data, the Free - Air Anomaly was calculated using

$$F.A.A = g_x - (g_t - FAC) \text{----------(4 - 5)}$$

Where gx is observed gravity value at station x

gt is theoretical gravity value at the same station, FAC is free Air Correction.

The Bouguer anomaly, B.A., was also computed using the formula

$$B.A. = g_x - (g_t - \frac{dg_h}{dz}) - 2\pi G\rho mh. \text{ ------(4-6)}$$

The regional anomaly was estimated from the pattern of the Bouguer anomaly and a smooth curve was drawn sloping on both sides of the sedimentary region. (Fig 4.1).

The Residual anomaly was obtained by calculating the differences between the Bouguer and regional anomalies. (Fig 4.1). This residual anomaly was modelled using a 2 - dimensional computer program.

The density constrasts used for the modelling vary along the entire profile as can be observed in Fig. 4.4.

4.3 Interpretation and Analysis.

a. The Positive Regional anomaly

The regional positive anomaly with sloping flanks over the adjacent basement areas has been interpreted as being due to uplift of the mantle and correspondingly

Author	Assumed density contrast between crust and mantle ($x10^3$ kg/m^3)	Thickness of the thinned crust (km)	Mantle uplift (km)	Width of Moho (km)
Kogbe and Artsybashev (1977)*	0.17	22.0 - 37.0	10.0 - 12.0	190 - 220
Osazuwa (1978)*	0.29	25.0 - 28.0	2.0 - 5.0	-
Adighije (1979)*	0.57	27.0 - 28.5	1.5 - 3.0	70 - 170
Ashiekaa (1982) (Present Study)	0.33	25.0 - 28.5	6.0 - 8.5	-

* Adapted from Ajakaiye (1981).

Table 4.3

thinner crust beneath the trough than beneath the flanking basement (Cratchley and Jones, 1965; Artsybashev and Kogbe, 1974; Osazunwa, 1978; Adighije, 1979). The thickness of thinned crust, mantle uplift and the density contrasts between the crust and mantle as determined by the various authors is shown in Table 4.3.

In the present study, using a density contrast of 0.33×10^3 kg/m^3 between the crust and the mantle the thickness of the thinned crust was estimated to vary between 25.0 km to 28.5 km with mantle uplift of 6.0 to 8.5 km.

b. Shendam - Takum Profile

This profile which runs across the Benue Trough was interpreted in order to study the existing regional structures giving rise to the observed residuals along the width of the trough. It was hoped that the structures beneath the profile might confirm the structures observed in the magnetic data interpretation.

The residual gravity along the profile has three well defined lows with amplitudes varying from -12 to -18.5 mgals; two of which lie on the flanks of the trough.

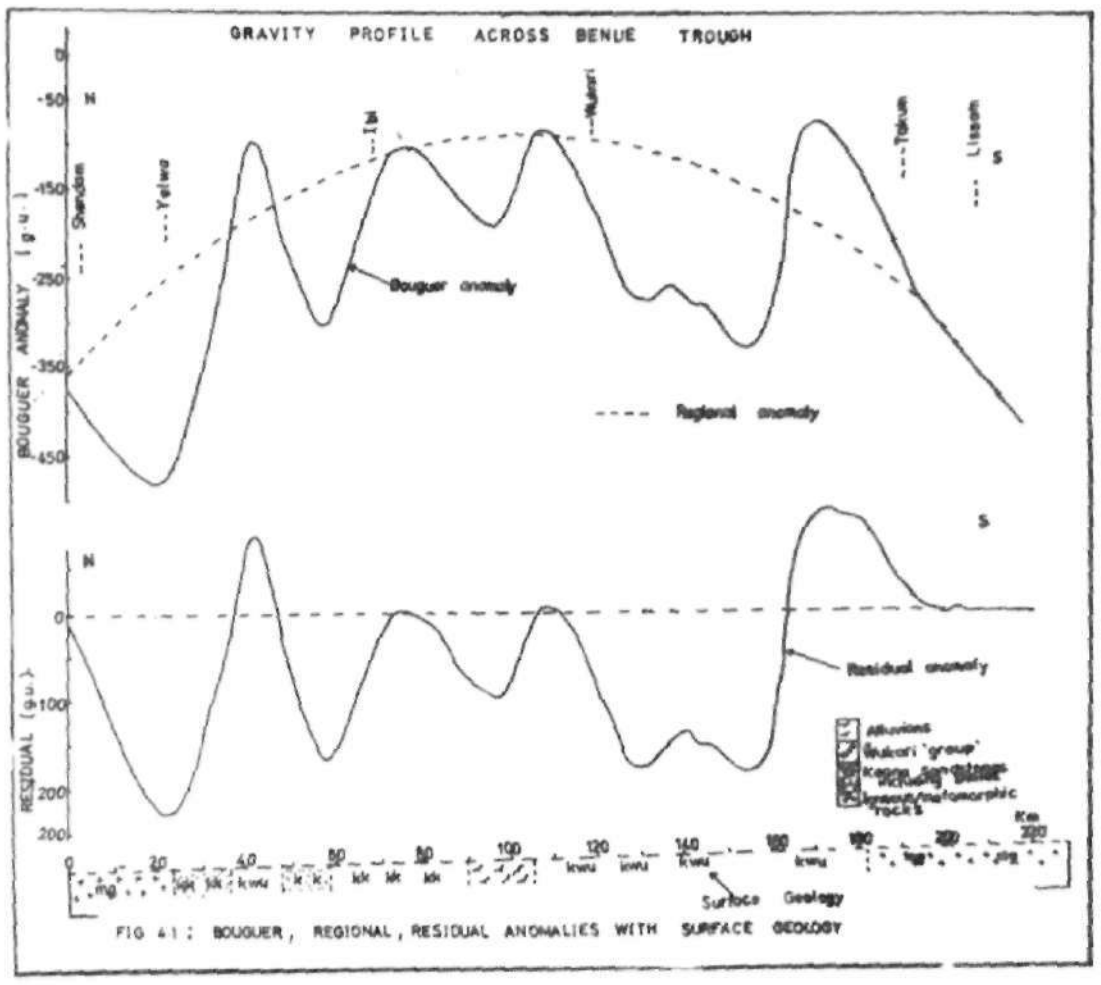
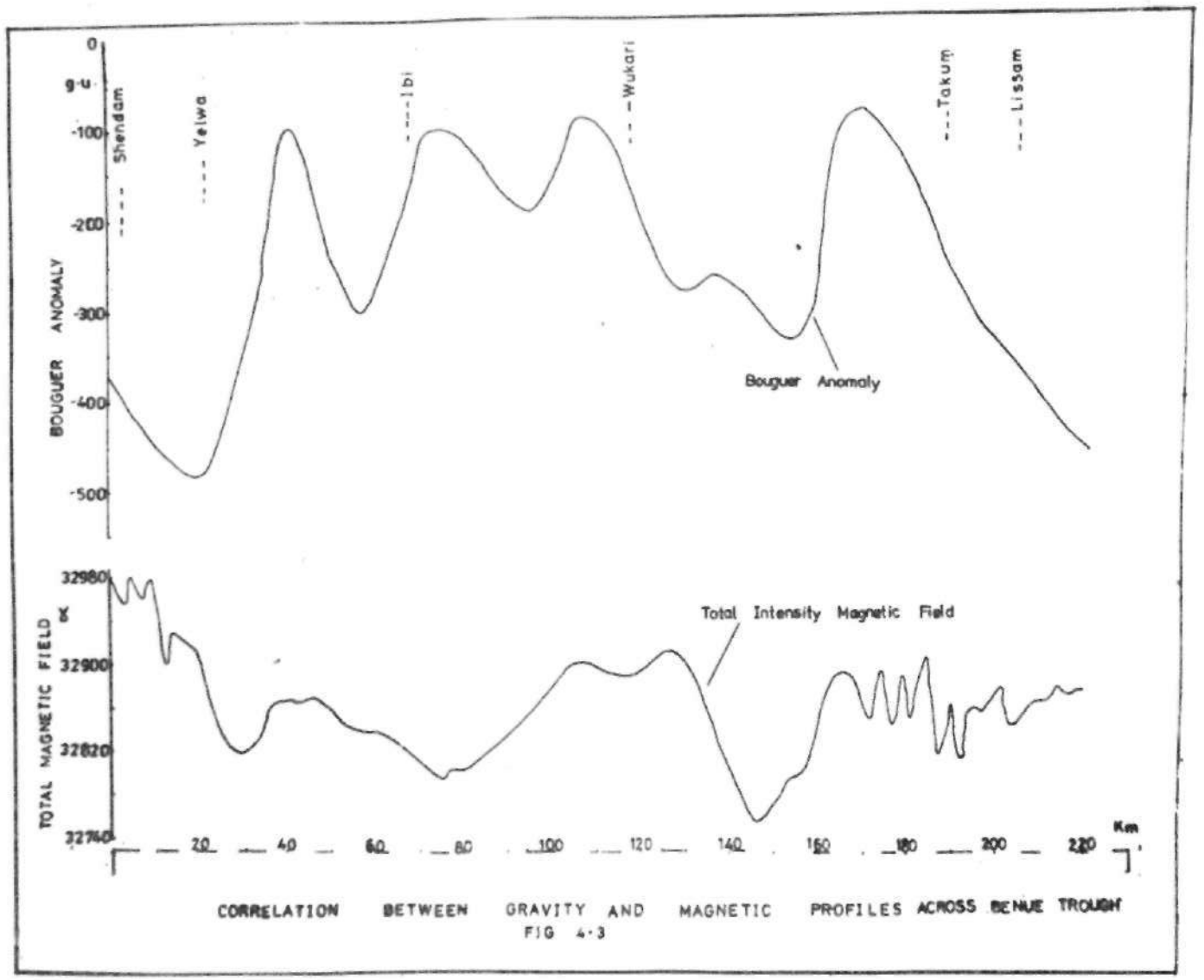


FIG 41 : BOUGUER, REGIONAL, RESIDUAL ANOMALIES WITH SURFACE GEOLOGY

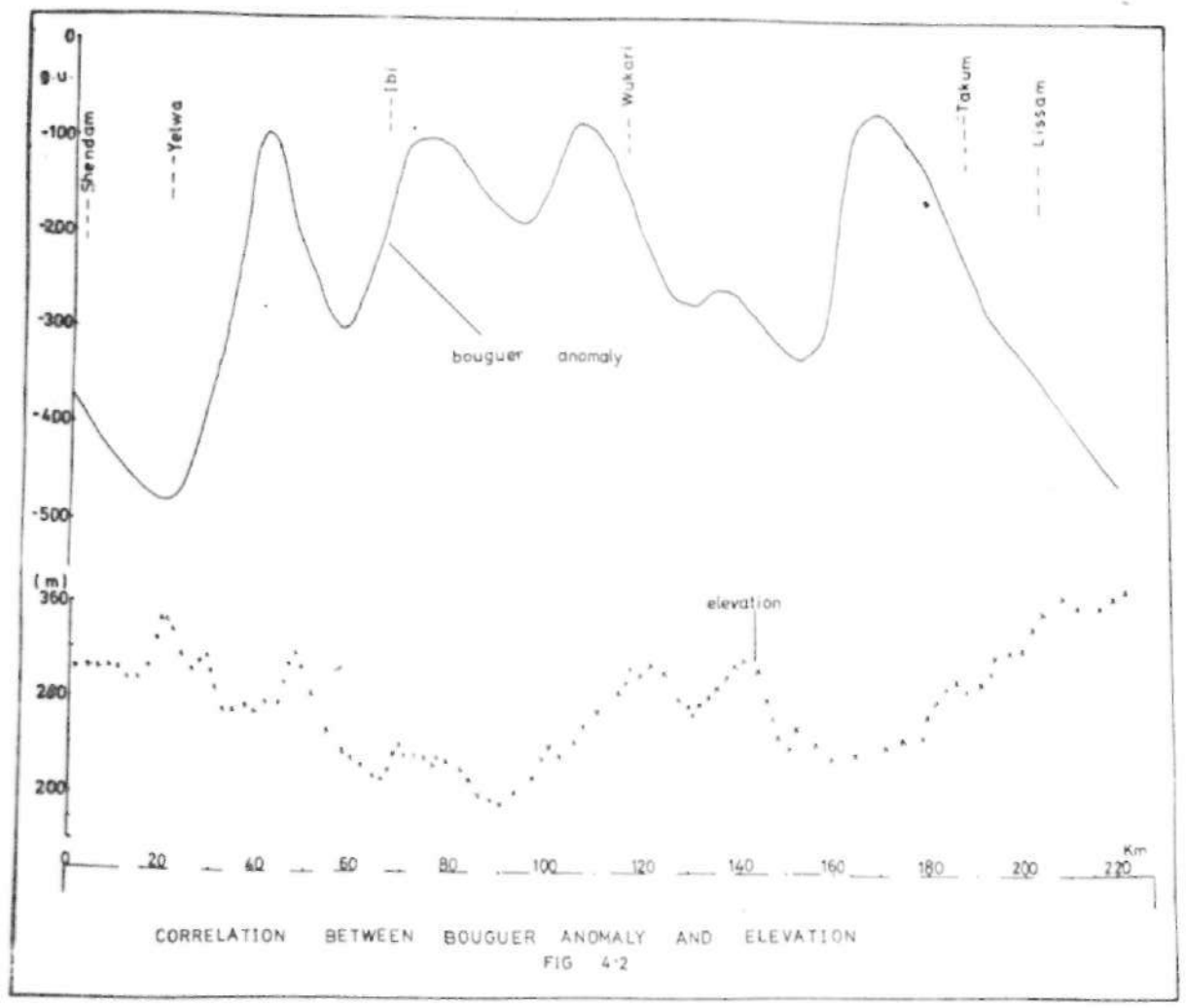


CORRELATION BETWEEN GRAVITY AND MAGNETIC PROFILES ACROSS BENUE TROUGH
FIG 4·3

There are two major highs located at about 8 km South of Yelwa and 10 km North of Takum respectively. The subsurface geology along the profile is shown in Fig. 4.4.

The examination of the profile Fig 4.2 indicates that it cuts across two major synclines lying between Yelwa - Ibi and south of Wukari with the Wukari anticline separating the synclines.

The interpretation model shows that the sediment thicknesses vary from 200m to 3000 m. The thickest sediments occuring around Ibi and Wukari. The depths to the top of the three pronounced lows vary from 500 to 3000m. The positive residual anomalies earlier mentioned can be accounted for by an igneous intrusion of density 2.76×10^3 kg/m^3 shown in fig 4.4. The central relatively high anomaly is attributed to an intermediate to basic body beneath the sediments with a density of 2.82×10^3 kg/m^3, probably basaltic in nature since basaltic outcrops are found 30 km south west of this profile (Ajayi, 1979) and this is also in agreement with the interpretation by Osazuwa (1978) for a similar profile north of the present one in the upper Benue trough.



CORRELATION BETWEEN BOUGUER ANOMALY AND ELEVATION
FIG 4·2

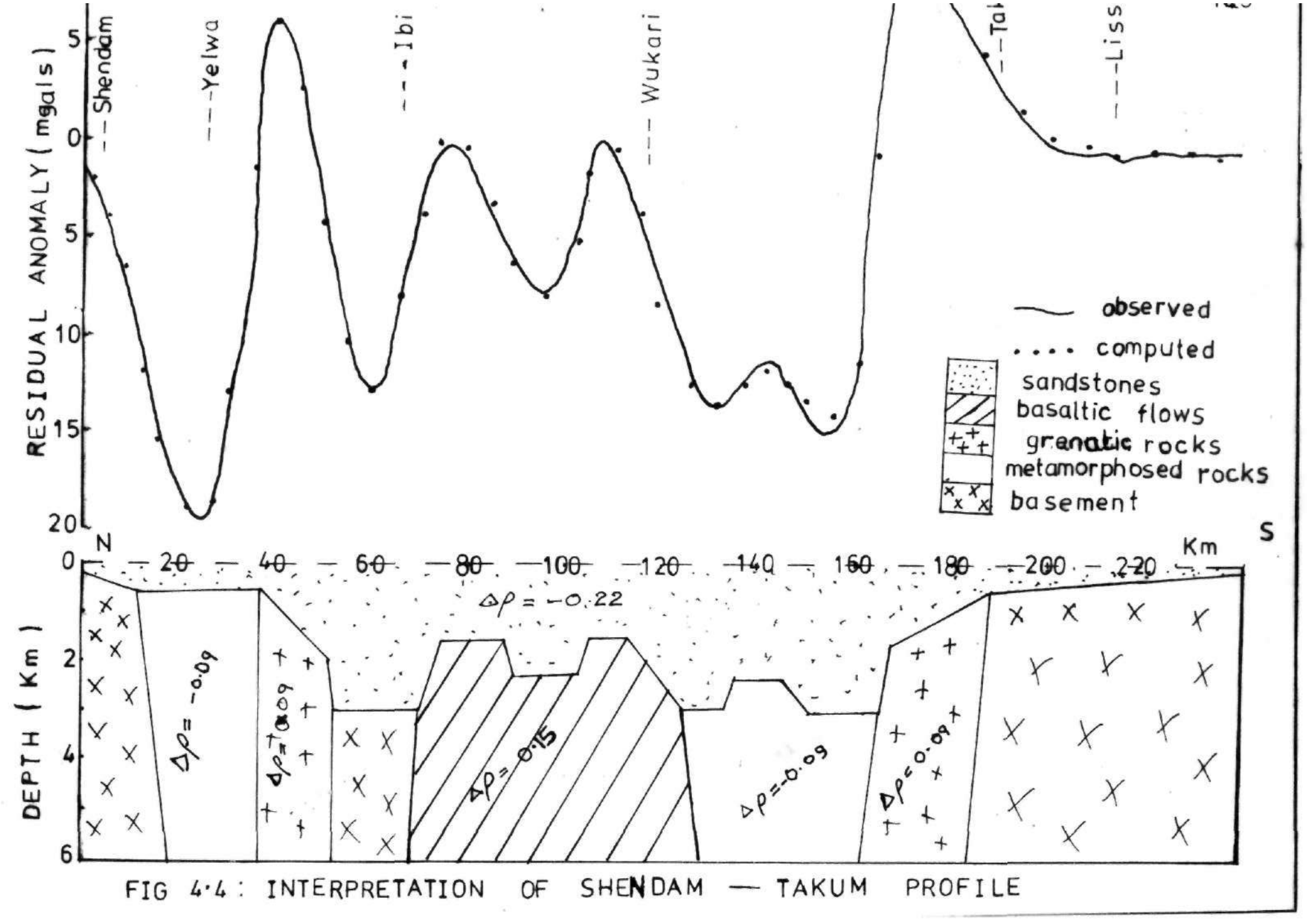


FIG 4·4 : INTERPRETATION OF SHENDAM — TAKUM PROFILE

The interpretation of the profile shows that the Benue trough consists of two synclines separated by the Wukari anticline along this profile. A similar view was proposed by Ajayi (1979).

CHAPTER FIVE

CONCLUSION

The origin of the Benue trough has been a controversial subject. The aim of the present study was to throw more light on the origin and evolution of the trough from aeromagnetic data, with a gravity profile across the trough to supplement the analysis and interpretation.

These were carried out as described in the previous chapters. The summary and deductions from this study are discussed below.

5.1 Summary of Results.

The results from this study have been discussed intensively in chapters III and IV.

The Benue trough is characterised by zones of magnetic and gravity lows along the flanks and central parts of the trough. The interpretation of the magnetic anomalies across the Benue trough discussed above have been basically aimed at ascertaining the origin and evolution of the trough. The anomalies indicate deep rooted basic intrusions at the basement/sediments boundaries and in the central part of the middle Benue trough.

The analysis of the gravity profile indicates that there are two major synclines along the profile across the Benue trough separated by the Wukari anticline. Similarly, the central low observed in the magnetic map of the trough separates the trough into nearly two halves especially in the middle Benue trough. The positive residual anomalies near the flanks of the trough are made of igneous intrusions which occur at shallow depths of 200 to 500m.

The absence of outcrop of oceanic crust in the Benue trough coupled with the fact that local volcanics exist along the central ridge of the trough, it is more probable to deduce that the Benue trough did not attain the present stage of the Red Sea.

The excess width of the trough has been attributed to the additional faulted zones in the central part of the trough. These faulted zones have been interpreted as double rifts in the trough (Ajayi and Ajakaiye, 1981).

5.2 Deductions from Results of Present Study.

The Benue trough is filled with thick Cretaceous Sediments whose ages vary from late Albian to Maestritchian times which is a typical characteristic of almost all rift valleys (Cratchley and Jones, 1965). Girdler 1963; Girdler et al, 1969).

The magnetic and gravity patterns of the Benue trough are similar to those observed in other rift zones and basins in other parts of the world. The width of the trough from the present study varies from 100 to 250 km which is comparable to that of the Red Sea which is about 200 to 300 km. The width of the trough is much larger than a normal rift 50 ± 15 km. The Perth Basin, Western Australia has a width of well over 100 km which is of the same order of magnitude as that of the Benue trough Fig. 5.2a and b. (Hawkins, et al 1969).

The gravity and magnetic anomalies observed over the flanks of the Benue trough are similar to those observed across the central and southern Perth Basin (Hawkins et al 1969); the East African rifts (Girdler et el, 1969; and Raft River valley, Idaho (Mabey, et al, 1978).

BENUE TROUGH COMPARED WITH OTHER RIFT VALLEYS — TOTAL MAGNETIC FIELD

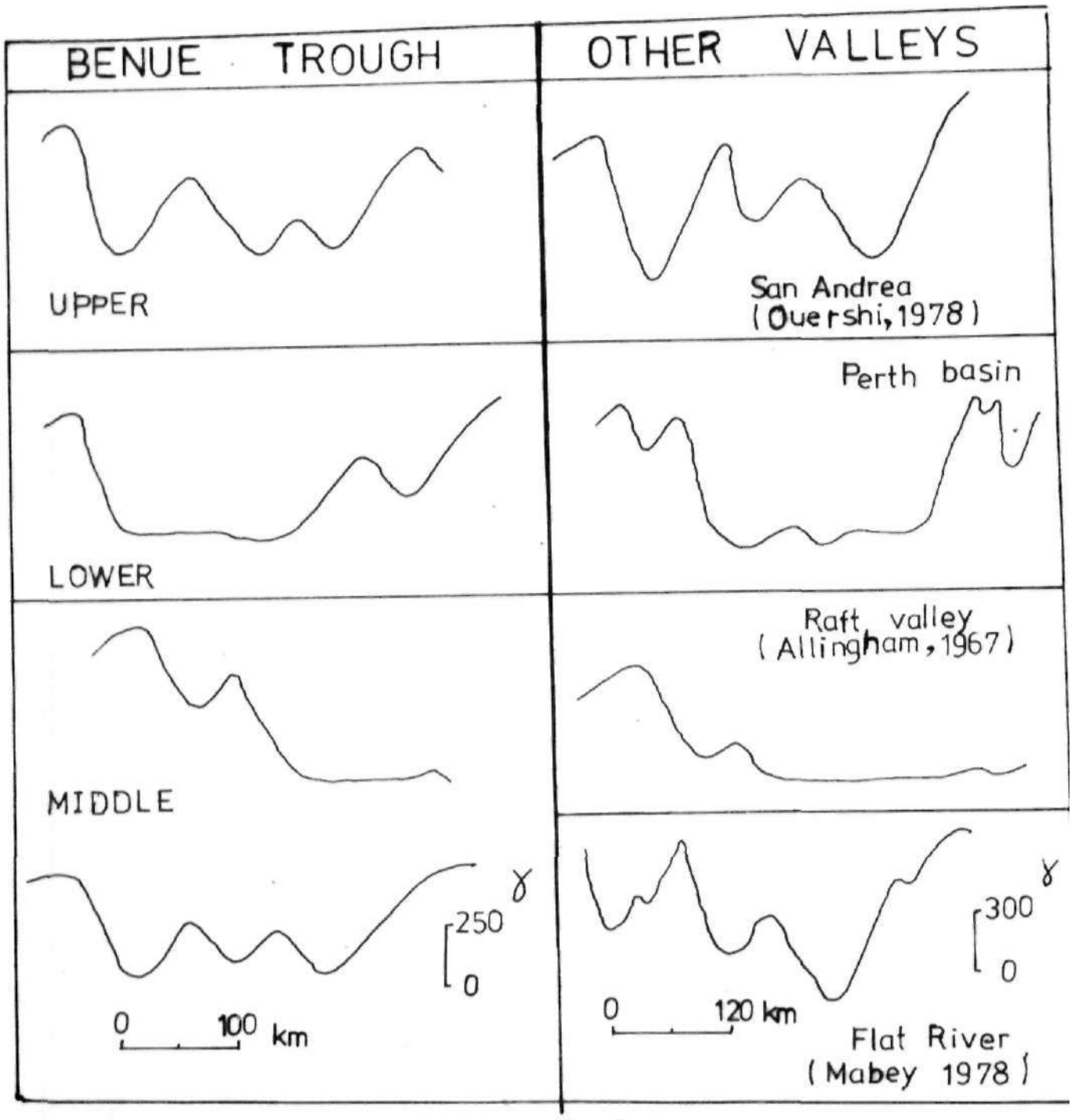


FIG. 5·2·1

COMPARISM WITH OTHER RIFTS — GRAVITY

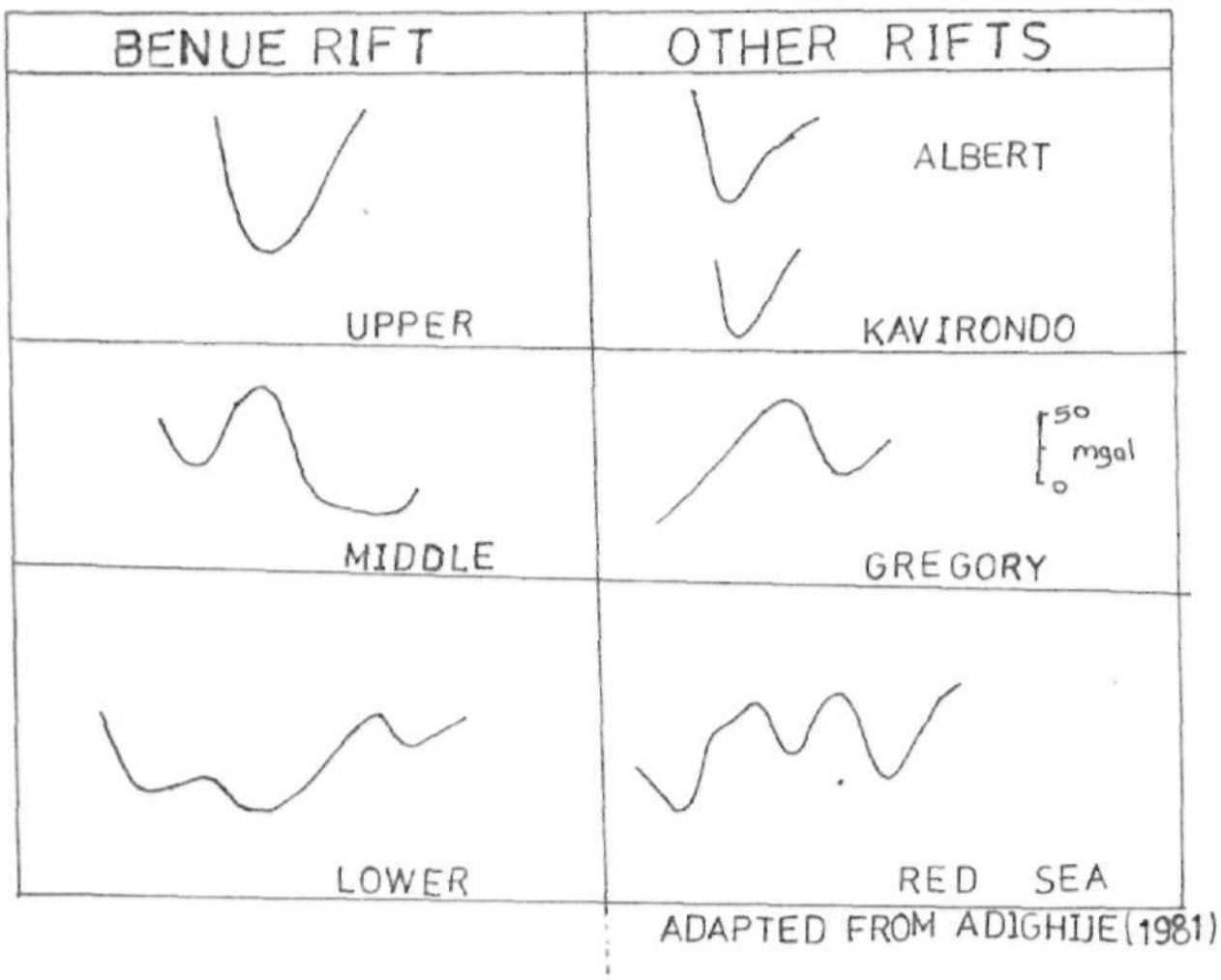


FIG 5·2 b

The major difference between the Benue trough and the Red Sea is that the later is an intercontinental rift (Milanovsky, 1972) which is capable of developing into an ocean basin (Burke, 1978) while the former has been a "failed" Continental rift or aulocogen (Olade, 1975). On the other hand the low angle faults in the Perth basin are visible on the surface while those of the Benue trough are buried under thick Cretaceous sediments of about 400 to 7000m. Hence the absence of marginal faults on the surface (Cratchley and Jones, 1965; Ajakaiye and Burke, 1978; Ajakaiye, 1970 and 1981).

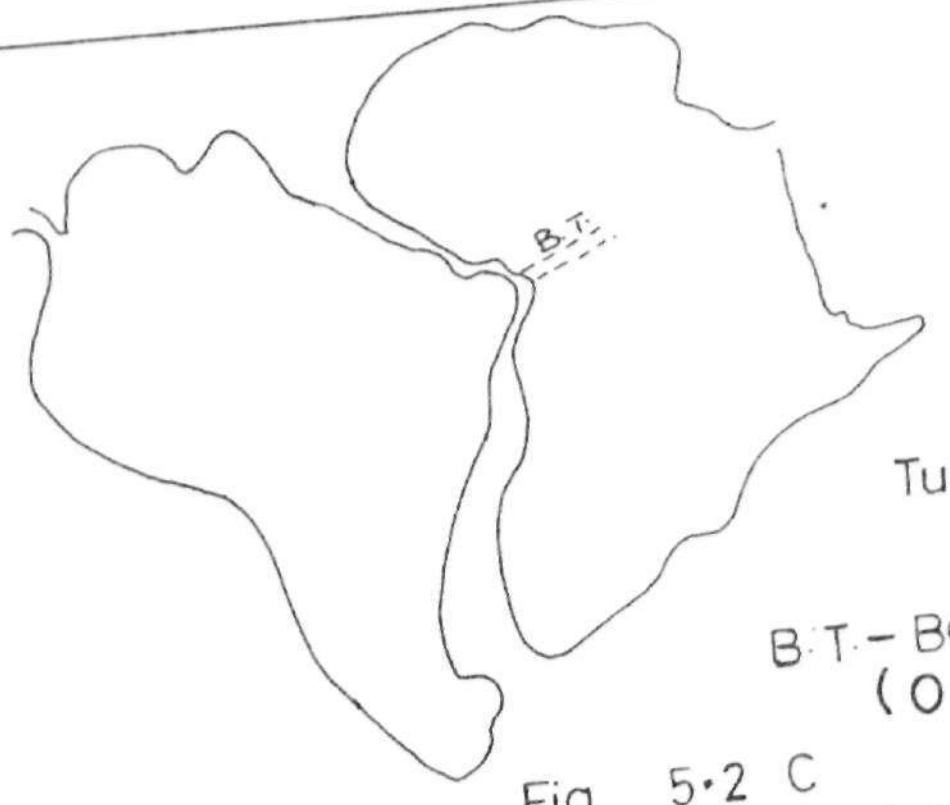
The pattern of the magnetic profiles across the Benue trough are quite similar to those observed across the Perth Basin and the Raft River valley with the lateral extent of the fault zones clearly defined.

The high amplitudes of the magnetic and gravity anomalies, 500γ and 300 to 500 mgal in the Red Sea have been associated with the presence of oceanic crust beneath the sea while the lower amplitudes of less than 250γ and 100 mgal can not be attributed to the presence of oceanic crust beneath the Benue trough.

AS PART OF WORLD'S RIFT SYSTEM



mid-Albian



Turonian

B.T.- Benue trough
(OLADE 1975)

Fig 5·2 C

The large magnetic anomalies over 500γ in the Red Sea have been interpreted as due to large magnatic material from the mantle embedded in the rift system (Drake and Girdler, 1964). The magnetic highs in the Red sea have been associated with zones of volcanic injections while those in the Benue trough are due to shallow basement and some volcanic injections resulting, either from the accretion of the Western and Congo cratons. and the existence of local volcanism, mainly, basic to intermediate igneous rocks.

The magnetic intensity amplitudes of the Benue trough, 100 to 250γ, are much smaller compared with those of Perth Basin 300 to 500γ or the Lachlam fold belt 300 to 500γ.

The present study has also indicated the possibility of two rifts within the Benue trough, as postulated by previous workers (Ajayi and Ajakaiye, 1981). Other rifts of the world are known to consist of more than one graben, for example, the Perth Basin, where the faults trending north-north westerly cross the graben, thus, widening the width of the basin (Hawkins, et al 1965) or one rift for example,

the East African rift system which has been resolved into the western and eastern rifts (Girdler et al, 1969) and the San Luis Basin, Colorado (Davies, 1978) each of which has two grabens separated by a horst.

There is general recognition that the World's rift system broadly follow the median lines in the ocean basins but occasionally intersect the landmasses as in the cases of the Gulf of Aden, Gulf of California and Guinea (Girdler and Drake, 1964). The Gulf of Guinea acts as a connecting point for the Benue trough.

From the geophysical studies so far carried out in the Benue trough (Cratchley and Jones, 1965; Ajakaiye and Burke, 1972; Ajayi, 1979; Osazuwa, 1978; e.t.c) and the present study it can be deduced that magnetic and gravity lows occur through the entire length of the trough from the Niger delta to the Yola rift; and that the trough is of rift origin.

5.3 General Conclusions.

The interpretation of the magnetic and gravity anomalies indicate that the Benue trough is a rift structure in which the initial rifts might have occured along the central axis.

The interpretation and analysis of the anomalies along the parallel profiles across the trough indicate a central low in the middle Benue trough suggestive of possibly zone of faulting (refered to by Ajayi, 1979 as double rifting). This might explain the abnormal width of the trough due to additional faulting. Since rapid deposition of thick sediment was reported in the trough (Reyment, 1965), the abnormal width may also be explained in terms of excess load on the initial grabens, due to lithospheric isostatic adjustments (Beaumont and Sweemey, 1978).

Volcanic activities which occured through the entire length of the trough are said to be associated with the load-zinc mineralisation zone.

The present study has revealed the occurence of magnetic and gravity lows along the flanks of the trough which are due to deep rooted material located within deep fracture zones.

The depth to the basement/magnetic material vary from 100 to 300 m along the flanks and 400 to 3500m within the trough.

The absence of out crops of the oceanic crust and the complex geological patterns in the Benue trough marred the occurence of seafloor spreading, implying that the trough did not advance to the stage attained by the Red Sea.

The lower Benue trough is characterised by magnetic lows which can be attributed to thick sediments (Offodile, 1976; Adighije, 1979).

Though not used intensively in the analysis and interpretation of the magnetic anomalies, the spectral analysis of the magnetic data reveal that high frequency anomalies dominate for first 40 km decreasing with decreasing frequency. The spectral interpretation has been used partly for the depth determination only considering the size of the anomaly map, a digitising interval of 3 km can not give the best interpretation using spectral analysis as a tool. For better results digitising intervals of 0.30 to 0.50km have been recommended.

The interpretation of the aeromagnetic and gravity profiles across the trough suggest that within the trough the sediments and basement are strongly

folded with fold axes trending paralled to the length of the trough. Fault zones have been infered from the profiles and seem to occur all through the entire length of the Benue trough.

The magnetic and gravity anomalies in general display similarities to those observed over other continental sediment - filled rift valleys. The Gulf of Aden, and the Red Sea, parts of East African rift system; flat River-Cabanne valley, Perth basin and the Gulf of California where the world rift system intersect the continents are also characterised by the thinning up of the crust beneath the rift as is the case with the Benue trough.

In conclusion, the present study has revealed that the Benue trough is a tensional continental rift valley which has been associated with the separation of the South American plate from the African plate. (Olade, 1975).

The gravity studies carried out by both the author and other previous workers bear very close relationship to the magnetic patters observed in the interpretation of the aeromagnetic data of the Benue trough.

5.4 Suggestions for Future Work.

It is evident that the trough has a lot of peculiarities - its width, depths of sediments, shallow basement and mineralisation zones, could be resolved by further studies. Many theories have been proposed by many authors as earlier mentioned which seem to contradict each other and which do not satisfactorily explain any of these perculiarities of the Benue trough. A detail geophysical study of the entire Benue trough is, therefore, essential. Such studies should include a detailed aeromagnetic interpretation and analysis of the entire trough digitised at 0.5 km instead of the 3 km used in the present study. A 3 - dimensional modelling techniques should be used.

A detail gravity survey of the trough at less than 1 km spacing would be useful even though there may be time and financial constraints.

Other geophysical methods such as seismic reflection/refraction can be undertaken in order to ascertain the variations in layering across the

trough. This can help throw more light on the lithologies of the sediments.

A ground magnetic survey can be carried out to aid the interpretations of the aeromagnetic anomalies observed in the Benue trough.

Drilling, though expensive, can be carried out in the trough at selected areas in order to determine the depths to basement and secondly for core samples in order to determine the direction of remnant magnetisation and susceptibilities of the samples. This may add more evidence to the possibility of seafloor spreading.

A geological mapping of the middle Benue trough, especially should be carried out in detail.

A geochemical analysis of the rock samples (both sedimentary and igneous rocks) be carried out in order to ascertain the mineral content in the samples

A microseismic survey can be carried out in order to determine the presence or absence of any microseisms in the trough since most continental rifts are aseismic in nature.

APPENDIX A

Basic Principles of the POPT

The "POPT" program is the modification of Talwani's 1964 program for the interpretation of the magnetic anomalies caused by 2 - dimensional bodies of arbitrary shape. The program calculates the magnetic field from one or more two - dimensional (infinitely long) polygon shapes. Starting with an initial shape, magnetisation and baseline substraction values, the program optimises these parameters until a reasonable fit to a measured field profile is obtained. The program also calculates the magnetic inclination and declination of the profiles.

For this study, the program POPT was further modified to include end corrections for the modelled bodies. The program assumes that the shape of the anomalous body is infinitely long and perpendicular to the direction of the profile. For this study, infinitely long was assumed to imply that the length of the anomaly must be at least five times its width. Thus, only anomalies of the above catagory

and of interest were modelled. Also, the program tends to give better results for a profile which cuts across the centre of the body. The maximum number of bodies that can be modelled on any profile is twenty (20), each having all the parameters earlier mentioned for optimisation procedure.

The basic input parameters for the program POPT consists of

(i) Earth's total field in gammas

(ii) Inclination and declination of the Earth's magnetic field.

(iii) Flight height and profile number.

(iv) Numbe. of bodies and points to describe that body(ies)

(v) Inclination and Declination of magnetic vector

(vi) Optimisation level and Base level

(vii) Magnetisation in EMU

(viii) The dimensions of the profile (s) and the subsequent its field data

The following are also specified on the Input program:- Reference distance; the angle between the flight line and the profile.

In this study, the program was modified to calculate the magnitudes of the Inclination and Declination of the magnetic field vectors.

THEORY OF POET.

The field strength of a 2 - dimensional body which extends to infinity in one direction on either sides of the body is given by

$$Fx = 2(Jx\ Z_1 + J_y\ Z_2)$$

$$Fy = 2(Jx\ Z_2 - J_y\ Z_1)$$

Where

$$Z_1 = \sum_{\text{sides}} \left[X_b^2 \quad \theta + \frac{X_b\ Y_b}{R_b^2} \ln (r_1/r_2) \right]$$

$$Z_2 = \sum_{\text{sides}} \left[\frac{X_b^2}{R_b^2} \ln (r_1/r_2) - \frac{X_b\ Y_b}{R_b^2} \quad \theta \right]$$

X_b, Y_b are x, y components of side R_b

r_1, r_2 are distances from each corner of the side of length, R_b to the station.

θ is the angle subtending side R_b at the station.

Detailed derivations and solutions to these equations have been documented by Talwani (1965).

APPENDIX. B

PRINCIPAL PARAMETERS FOR SHENDAM - TAKUM PROFILE

Station	Latitude	Longitude	Height (m)	Observed Gravity (+9780000)	Bauguer Anomaly (g.u)	Residual Anomaly (g.u)	Aeromagnetic Intensity +25000
001	8.87°	9.53°	194.12	1041.19	-302.34	-6.00	7977
010	8.85	9.62	204.42	988.68	-330.15	-46.00	7980
020	8.80	9.66	198.41	933.98	-381.26	-18.30	7114
030	8.71	9.66	159.49	933.98	-381.26	-130.00	7811
040	8.59	9.65	205.89	1069.62	-298.00	+70.00	7868
050	8.50°	9.67	129.59	1234.83	-134.26	-60.00	7860
060	8.43	9.71	102.29	1161.17	-240.54	-120.00	7842
065	8.38	9.70	119.41	1197.47	-159.14	-80.00	7832
070	8.34	9.71	116.54	1201.89	-150.67	-20.00	7814
080	8.26	9.72	90.90	1293.22	-88.11	-6.00	7806
090	8.17	9.75	103.76	1235.29	-99.08	-58.00	7841
100	8.09	9.78	126.87	1137.92	-131.35	-60.00	7874
105	8.06	9.80	159.31	1121.93	-73.24	-2.00	7890
110	8.00	9.79	159.18	1092.13	-92.31	0.00	7905
125	7.88	9.80	199.10	878.35	195.92	-120.00	7913
130	7.83	9.82	155.21	934.62	-215.34	-130.00	7905
140	7.75	9.88	205.91	823.86	-208.42	-110.00	7820
150	7.66	9.90	136.40	915.77	-231.95	-138.00	7772
155	7.62	9.90	171.83	803.90	-263.40	-148.00	7797
160	7.57	9.91	195.66	766.79	-243.33	-120.00	7860
165	7.53	9.92	156.76	980.37	-96.06	+30.00	7860
175	7.46	9.95	146.57	1012.78	-64.54	+90.00	7900
195	7.27	9.96	206.85	689.60	-227.65	+12.00	7820
200	7.25	9.99	249.25	587.71	-241.02	0.00	7868
220	7.18	10.10	251.70	494.49	-314.79	0.00	7892

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