COMPARATIVE SEDIMENTOLOGICAL STUDIES OF THE LAFIA, KEANA AND AWE FORMATIONS WITH REFERENCE TO THE AWGU AND ASU RIVER FORMATIONS

BY

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QUOTE

"It is a popular delusion, that the scientific enquirer is under an obligation not to go beyond generalization of observed facts.....
but anyone who is practically acquainted with scientific work is aware that those who refuse to go beyond the facts, rarely get as far.

T. H. HUXLEY.

D E D I C A T I O N

Dedicated to my parents, Mr. & Mrs. G.U. OHIKERE, who would have wished to share these moments with me, and to my beloved sister, Mrs. C.R. Baye nee OHIKERE, to her I owe everything.

ACKNOWLEDGEMENT

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I wish to thank the technical staff of the Geology Department, Ahmadu Bello University, Zaria for their help in the laboratory work on this project.

Finally, much thanks also to my good friends for having shown concerned interest in this work.

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ABSTRACT

The area under investigation is part of the Middle Benue, this region is made up of Cretaceous sediments of marine to fluvio~deltaic environments,,

Sedimentation in the Benue valley is believed to be related to the breaking up of South America from Africa, parting the way for a northward transgression of marine waters from the great atlantic

The sediments studied are represented by the Lafia, Keana and Awe Formations respectively and also by the Awgu and Asu river shales; these sediments are thought to range in age from Cenomanian to Maastrichtian (Offodile, 1976).

Petrological and sedimentological analysis were carried out on the data and samples collected from the field work. The results of sedimentological analysis included granulometric, heavy and light minerals and clay mineral analysis.

From granulometric analysis, it was observed that the sandstones were deposited in one as more depositional cycle (Lafia and Awe Formations) or were reworked after deposition (Keana Formation) in certain parts of the studied area. Generally, the sandstones are medium to coarse grained, poorly sorted, and positively skewed.

Heavy mineral analysis shows the presence of assemblages of zircon, tourmaline, rutile, staurolite and kyanite, and opaques (iron oxides?). This indicates an igneous-metamorphic

source rock for the sandstones.

The light mineral analysis shows the presence of quartz and mica, with quartz grains generally being the most dominant mineral. Their morphology indicates a relatively strong weathering conditions and short distance of transportation.

Results from the clay mineral analysis shows the presence of kaolinite, illite and chlorite in decreasing order of abundance relatively.

These results prove that these sediments under study in the Benue basin owe their origin to the Nigerian basement complex, which is composed of granites, gneisses, and migmatites. These are found to the north and south of the mapped area.

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CHAPTER ONE

INTRODUCTION

1.1 AIM OF PROJECT:

The primary aim of this special project is to provide an adequate training in sedimentology and writing of geological report, and also to carry out a detailed geological study of some lithologic units in a comparative form. These are formations located in the Middle Benue of Nigeria. The report is meant to aid the detailed understanding of the geology of the Middle Benue.

The report is to be submitted to the Department of Geology for the partial fulfilment of the requirements for the award of a bachelor of science (Hons.) degree in geology.

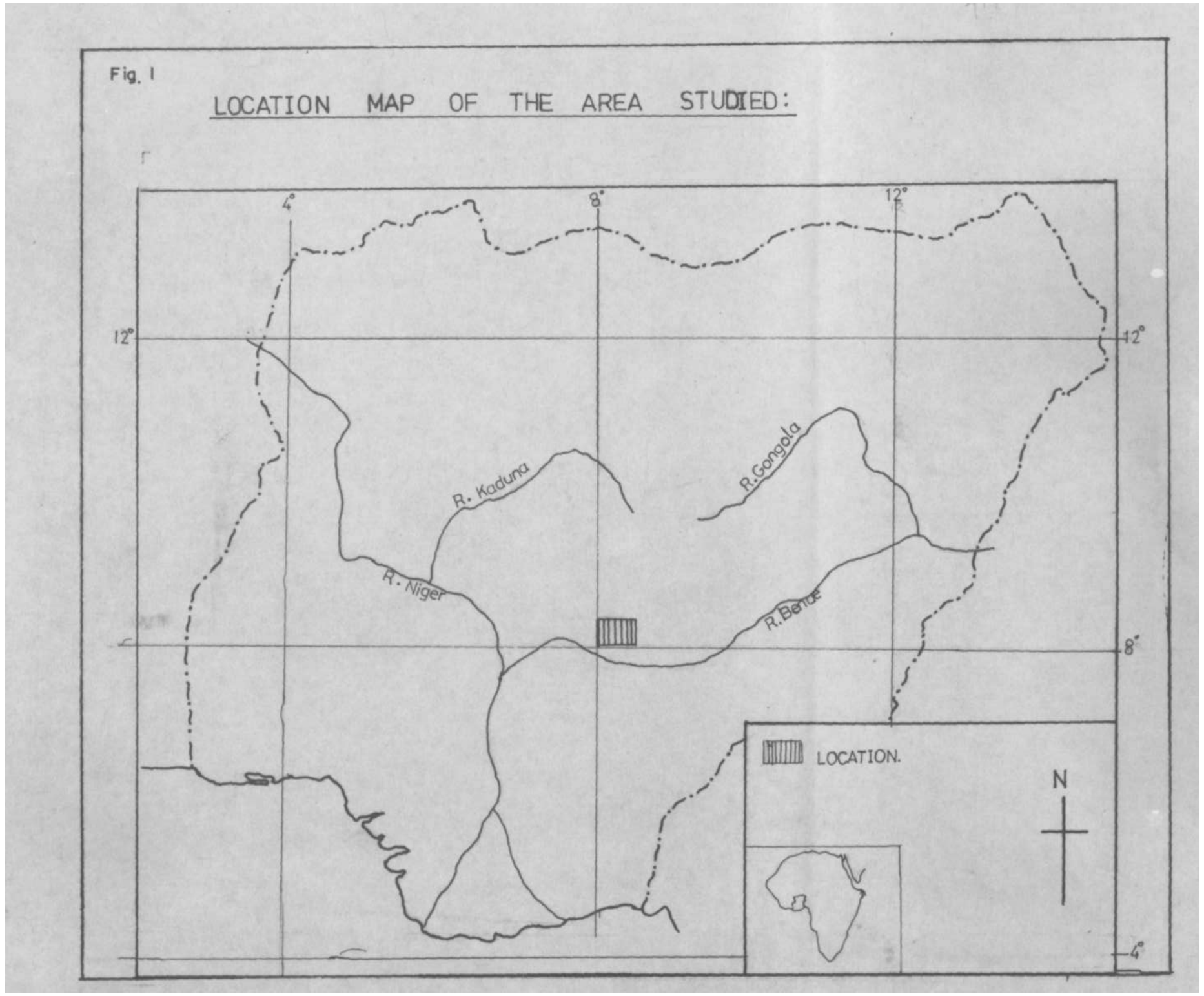
1.2 LOCATION AND ACCESSIBILITY:

The area studied is in the Plateau State of Nigeria Fig. 1. It is bounded by Latitudes 8^{o}-$8^{o}30'$ North and Longitudes $8^{o}30'$-$9^{o}10'$ East on Sheet number 231 of the topographic map of Nigeria on a scale of 1:100,000.

The main access road into the area is the Lafia - Makurdi road which passes through Obi. Most of the other roads are still untarred and are lateritic. In areas

Fig. I

LOCATION MAP OF THE AREA STUDIED:



that are not accessible by a road, footpaths were useful. Few footpaths traverse this area due to the widely dispersed nature of the settlements in the area.

1.3 PREVIOUS WORK:

The earliest geological work in this area was initiated by the Geological Survey of Nigeria. The Middle Benue is such an interesting area geologically, that it has received attention from various workers, though it used to be one of the least documented areas in Nigerian geology.

Earlier workers in this area includes Falconer (1911), who studied and correlated the sandstones in the Lower, Middle, and Upper Benue. Farrington (1932), outlined a stratigraphic sequence for the Middle Benue valley. The area was mapped by the Shell-B.P. in 1957, using aerial photographs and little field investigation. Apart from these, Cratchley and Jones (1965), carried out a geophysical survey of the Benue valley, Reyment (1965) also presented a geological outline of the area. Whiteman and Burke (1970), Mackenzie (1970), and Dessauvagie (1970), investigated the area as part of a regional study of the Benue rift structure.

A comprehensive geological study of this area was done, more recently by M.E. Offodile (1976), he mapped the Lafia Sheet 231, scale 1:100,000 and identified some new formations.

1.4 METHODOLOGY:

Samples from various outcrops of the Keana, Awe, Lafia and Awgu Formations were collected during a 2 days fieldwork. Laboratory methods of study include granulometric analysis to determine the grain size parameters, and to aid the determination of sorting coefficient, and the degree of maturity of the sediments and their environment of deposition. The sieving method was employed. Heavy and light mineral analysis were carried out too; with the objective of studying the chemical and marphologic nature of the rocks. Thin sections were made and studied.

Clay mineral analysis for oriented and non-oriented samples were also carried out using the X-ray diffraction method.

CHAPTER TWO

PHYSIOGRAPHY

2.1 RELIEF:

The relief of the area is generally undulating, it is not an area that is highly elevated. It is possible to regard it as part of the great predominant plain that slopes down from the Jos Plateaux, and undulates into the Benue trough.

2.2 CLIMATE:

This area is located within the Middle belt of Nigeria, thus the area experiences a moderate temperature, pressure and rainfall. The rainfall is seasonal and the mean annual rainfall of the area is about 150cm. Temperature range is from about 25^{o}-35^{o}C. The climate is the typical savanna type with dry season.

2.3 VEGETATION:

The area is covered with tall grasses and some scattered low bushes and trees. The river valleys have thick bushes, thorns and trees, for example along the Asu river. This type of vegetation is the tropical grassland and savannah type.

2.4 DRAINAGE:

The area is well drained with a dendritic type of drainage pattern. This pattern is well developed in the area, all the rivers flow in a direction almost parallel to one another in a north-south directions, and they empty into the river Benue. The main rivers are:

i) The Guma River

ii) River Ma

iii) Asuku River

iv) Ankwe or Dep River

The Guma river is the most outstanding river in the studied area.

2.5 SETTLEMENT AND LAND USE:

There is a dispersed type of settlement. This might be in order to be near the abundant farming areas. The major occupation of the people is farming.

CHAPTER THREE

GENERAL GEOLOGY OF THE AREA STUDIED

3.1 SOME ASPECTS OF THE GEOLOGY OF THE AREA STUDIED:

The Benue valley can be subdivided geographically into an Upper, Middle and Lower Benue valley. The Lafia, Keana and Awe areas fall within the Middle Benue area. In the Middle Benue valley however, there are six sedimentary formations. The oldest, the Asu river Formation, which occupies the crest of the Keana anticline, and on either side there is the Awe, Keana and Ezeaku Formations. The Awgu, and Lafia Formations are the youngest.

3.2 LITHOLOGY AND PETROLOGY OF OBSERVED ROCK TYPES:

The observed rock types were mostly sandstones and some shales. The Lafia sandstones have a characteristically brick red colour, the reddish colour may be due to iron-enrichment as a result of the continental conditions that existed all through its period of deposition and after. They are medium to coarse grained and are coarsely consolidated. The A_{wgu} Formation comprises of shales, grey to black in colour.

The sandstones of the Keana and Awe are yellowish to light brown in colour. They are medium to coarse grained and are made up mostly of quartz. A few grains of feldspars and muscovite are present, with zircon as accessory, as observed under the microscope. The sandstones are friable and loosely consolidated. Blackish shales constitute the Asu River Formation.

3.3 SUPERFICIAL DEPOSITS:

Weathering of the lithological units gave rise to the superficial deposits. The colour and texture of these deposits vary from place to place, depending on the underlying strata. The soil covering the Lafia Formation is red, sandy to clayey type, the Awgu Formation, in contrast with the Lafia is covered by a darkish grey soil. The distinctive colours of the soils provides a guide for distinguishing the formation in places where actual exposures do not occur.

3.4 LAFIA FORMATION

In the Middle Benue valley, the Lafia Formation forms the youngest lithological unit. Several workers have tried describing it, but it remains an object of confusion. Falconer (1911), called it "Upper Grits and Sandstones", Farrington (1952) referred to it as the

"Sandstones of Lafia/Makurdi", Cratchley and Jones (1965) described it as the Lafia sandstone, Dessauvagie (1972), also used this term to describe the formation, and Offodile (1976) used the term "Lafia Formation". The author considers the term "Lafia Formation" more appropriate since this includes not only sandstones, but other lithologic units found in the area. The formation is made up of ferruginized sandstones, red loose sands, it is found in and around Lafia town. The sand is coarse grained and indurated. The characteristic red colour is a distinguishing factor of this formation (see Plate 1), and according to Offodile (1976), ferruginization of the fluviatile sandstone of this formation is probably due to syndepositional features, which is as a result of strong oxidizing tendency that might have existed in the continental conditions that prevailed.

3.5 THE AWGU FORMATION:

This has been described by various authors. It was referred to as the Awgu-Ndeaboh shales by Simpson (1954) and it was described as a bluish grey shale with occasional intercalations of fine grained, light yellow calcareous sandstones with thin shaly limestone. Reyment (1965) used the term "Awgu Shales" and Offodile (1976)

called it the Awgu Formation. But its been found to have a marine origin, and it consists predominantly of black shales, sandstones and limestones (see Plate 2).

3.6 KEANA FORMATION: (see Plate 4)

This formation is thought to be a time equivalent of Falconers (1911) "Muri Sandstones" or "Lower Grits and Sandstones". But the term "Keana Sandstone" was used by Cratchley and Jones (1965) to describe the formation. The sandstones are massive, medium to coarse grained. The Keana Sandstones consists mainly of poorly sorted feldspathic coarse grained, gritty commonly arkosic sandstones.

3.7 AWE FORMATION: (see Plate 5)

This was recognised, first by Falconer (1911), who described it as a mappable entity, and he called it the "Passage beds". He noted the formation to be comprised of white sandstones and carbonaceous shales at Awe. Cratchley and Jones (1965) were second to recognise this unit, but according to Offodile (1976), both investigations placed it very high in the stratigraphical sequence. The formation is characterised by flaggy, whitish, medium to coarse grained sometimes calcareous sandstones, and is interbedded with carbonaceous shales as clays.

3.8 ASU RIVER FORMATION:

This forms the oldest known Nigerian marine sedimentary formation. Sedimentation started in the Lower Cretaceous with the deposition of the Albian shales and limestone of the Asu river group. It has been described in various literature. Bain (1924) referred to it as the "Lower Shales", Tattam (1944) described the unit as the "Cross River and Benue Shales", while Simpson (1954) used the term "Asu river series".

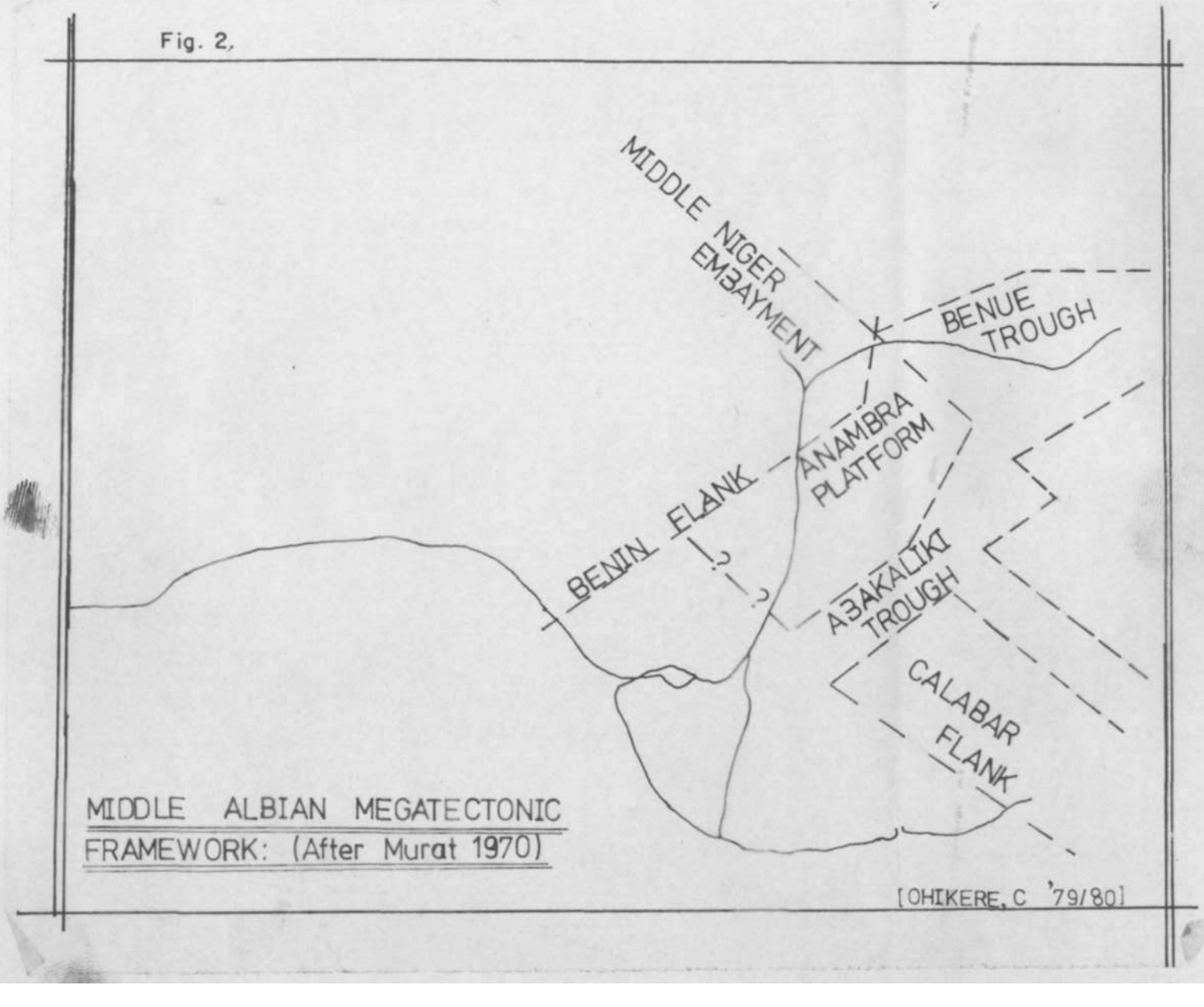
3.9 GEOLOGICAL HISTORY OF THE BENUE:

The geological history of the Benue valley is divided into two major phases, the tectonic phase and a phase of deposition.

3.9-1 THE TECTONIC SET UP:

The origin of the Benue trough is closely related to the concept of plate tectonics. There is a lot of literature available on this topic, but this is best discussed in the context of Murat's (1970), megatectonic framework of the southern Nigeria sedimentary basin (see Fig. 2). He worked on the idea that the Benue trough belonged to the first of the three major tectonic phases that produced the sedimentary basin of the southern Nigeria, during the Albian time. Murat, put

Fig. 2,



MIDDLE ALBIAN MEGATECTONIC FRAMEWORK: (After Murat 1970)

[OHIKERE, C '79/80]

forward a north-east-southwest faults which resulted in the formation of the Abakaliki-Benue trough. However, in 1975, Wright put Murat's set up into doubt, due to what he referred to as lack of a conclusive evidence (Offodile 1976).

There are two major plate tectonics model accounting for the origin of the Benue trough, these are by Burke et al (1970), and Grant (1970), they tend to portary the Benue trough as originating as a triple junction, of which one area failed to develop. Burke et al (1970), put forward the R-R-R (ridge-ridge-ridge) triple junction, this accounts for the present arrangement of transform fracture zones in the Gulf of Guinea regions. While Grant (1970) proposed the R-R-F (ridge-ridge-fault) triple unction, for the origin of the trough, with the Northern Gulf of Guinea coast being the transform fault in the latter case. Burke et al, in addition saw the evolution of the Benue trough as being intimately connected to that of the South Atlantic ocean, this is observed from a reconstruction of the relationship of the South American and African plates shortly after the opening of the South Atlantic.

3.9-2 THE DEPOSITIONAL CYCLES:

It is possible that there were three main cycles of deposition in the Benue trough (Murat 1970); (see Fig. 3).

i) Middle Albian to Cenomanian Cycle:

This event is marked by the deposition of shales and siltstones in the centre of the basin; and equivalent limestones were formed on the shelves, these range in age from Middle to Late Albian. This marine transgression produced the Asu River Group. During the Late Albian to Cenomanian age, the regressive phase of this transgression occurred, giving rise to the Awe, Keana, and Bima cycles respectively.

ii) The Late Cenomanian to Early Turonian Cycles:

This brought about the epicontinental transgression, giving rise to the Ezeaku Shale group, there are evidences to prove this, and that is the presence of a fossil, Kanibiceras Septemseriatum which is found in the lowermost part of the Ezeaku Formation (Offodile 1976). This regressive phase gave rise to the Hiatus and Makurdi Sandstones, it took place in the Lower Turonian.

iii) The Coniacian Cycle:

This depositional cycle reached its peak in the Coniacian after it started in the Late Turonian. This

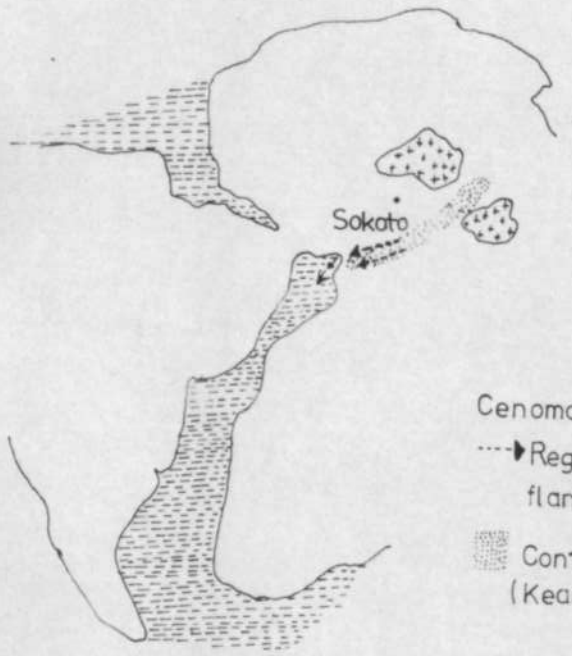
THE DEPOSITIONAL CYCLES OF THE BENUE VALLEY:

I



The Middle Albian Transgression into the Benue Valley.

II

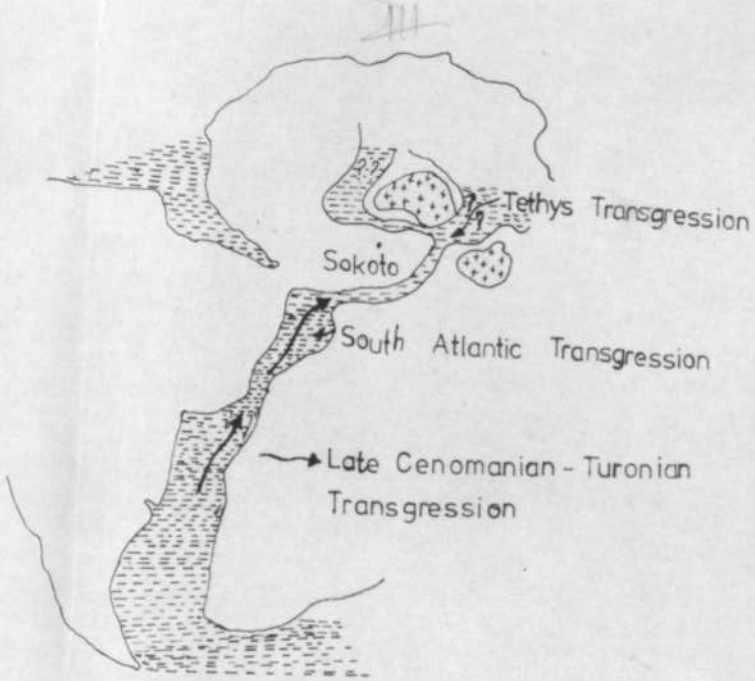


Cenomanian Regression

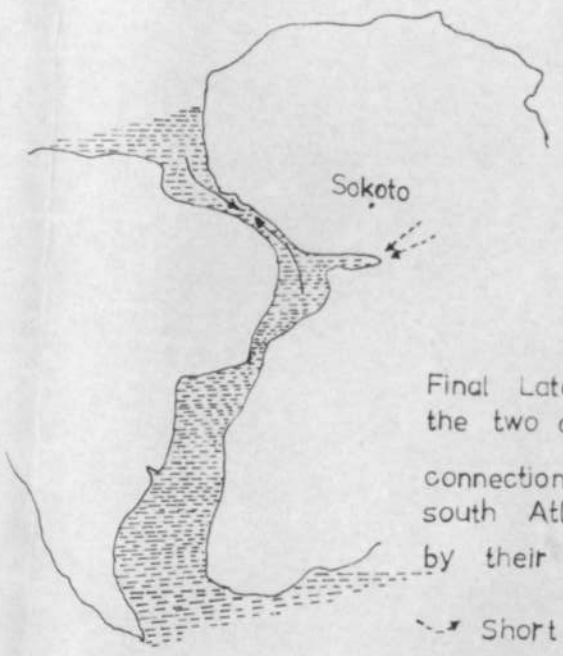
Regression to Calabar flank.

Continental Deposits (Keana Formation)

III



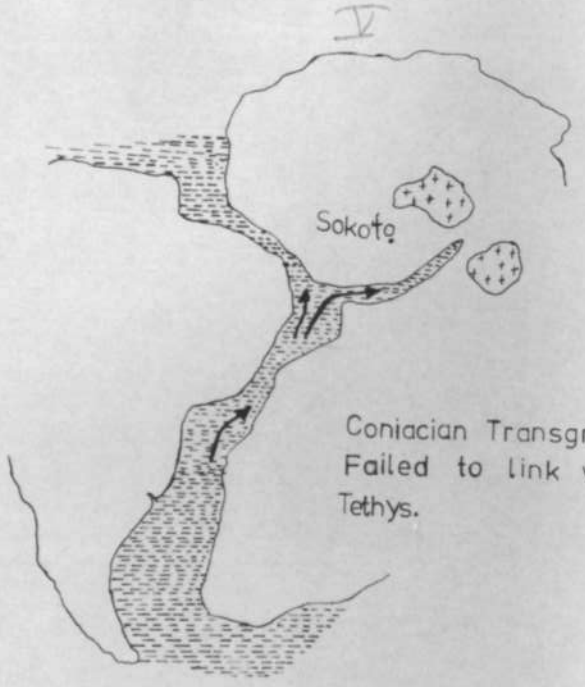
IV



Final Late Turonian seperation of the two continents with the connection of the north and south Atlantic. This is followed by their drifting apart.

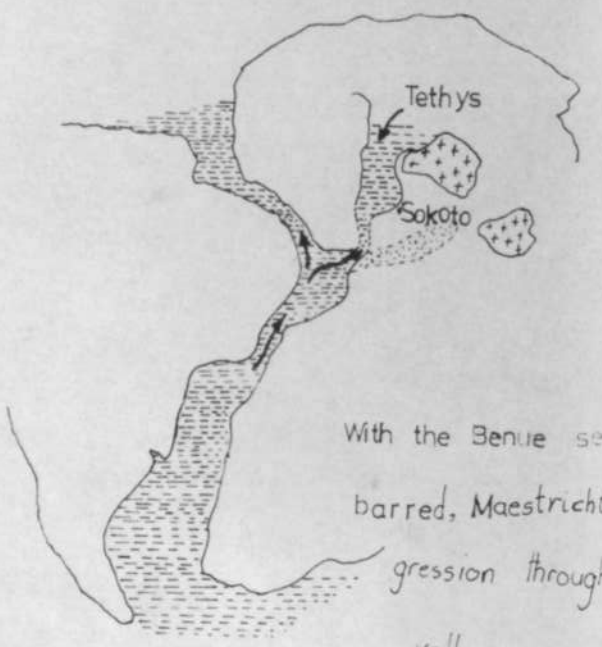
Short regressive movements accompanying this event.

V



Coniacian Transgression. Failed to link with the Tethys.

VI



With the Benue sea-way barred, Maestrichtian transgression through the Niger valley.

Continental deposits formed in the old sea way. (Lafia Formation).

transgression was shallow, like its predecessor, and also partly trans-continental. Abundant vegetation and swampy environment characterises the shorelines, which led to the development of a coal measure sequence.

The end of the marine transgressions in the Middle Benue valley was marked by this Coniacian transgression, it gave rise to the Awgu Formation. This Coniacian transgression was followed by a regressive phase which took place during the Maastrichtian forming the Lafia Formation.

There is a final return to continental condition which prevails till today, and is responsible for the laterite capping in some formations.

3.9-3 THE STRATIGRAPHIC SEQUENCE OF THE MIDDLE BENUE BASIN:

Many authors have proposed a stratigraphic sequence of the Middle Benue Basin, including those of Cratchley and Jones (1965) (see Table 1a), and Offodile (1976). Offodile has established a much more detailed stratigraphic sequence, for the Benue valley by using fossil evidences (see Table 1b). Another stratigraphic sequence has also been put forward by Kogbe et al (1978) for the Makurdi Sheet 251 (see Table 1c). The sequence proposed by Offodile is much more relevant to the aid of this project.

The three sequences mentioned can be seen in tables 1a (after Cratchley and Jones 1965); 1b (after Offodile); and 1c (after Kogbe et al 1978).

Table 1a - Stratigraphic sequence of the Benue Basin as proposed by Cratchley and Jones (1965)

arranged in a northeasterly

	MAASTRICHTIAN	LAFIA SANDSTONE
UPPER CRETACEOUS	Turonian-Senonian Late Cenomanian	Unconformity Unnamed Marine deposits Unnamed Transition
LOWER CRETACEOUS	Albian	Asu River Group
		Unconformity
		Basement

Table 1b - Stratigraphic sequence of the Benue Basin as proposed by Offodile (1976)

	MAASTRICHTIAN ?	LAFIA FORMATION
UPPER CRETACEOUS	Santonian - Campanian	Volcanics
	Coniacian	Awgu Formation
	Late Turonian	Hiatus
	Early Turonian	Eze-Aku Formation
	Late Cenomanian	Keana Formation/ Makurdi Sandstones
		Hiatus
	Early Cenomanian	Awe Formation
LOWER CRETACEOUS	Albian	Asu River Group

Table 1c - Stratigraphic sequence of the Makurdi Sheet 250 as proposed by Kogbe et al (1978)

POST CRETACEOUS	AGE	FORMATION
	Maastrichtian	Lafia Formation
	Santonian and Campanian	Volcanics
	Coniacian	?Awgu Formation
	Late Turonian	?Hiatus
	Early Turonian	Eze-Aku Formation
	Late Cenomanian	Makurdi Formation
	Albian	Asu River Group

CHAPTER FOUR

SEDIMENTOLOGICAL ANALYSIS

4.1 GRANULOMETRIC ANALYSIS:

4.1-1 INTRODUCTION:

Grain size and grain size distribution forms the most important properties of clastic sediments, and these are determined by the grain size analysis. They are important in the sense that they are closely related to the physical forces acting during transportation and deposition of such a sediment. Statistical measures can be obtained from such grain size analysis and this aids in describing the sediments, the agents involved during transportation, the depositional processes, as well as the depositional environment. Any population of sedimentary particles can be interpreted using this type of analysis.

4.1-2 METHODOLOGY:

Samples from the Awe, Keana, Lafia and Asu River Formations were mechanically analysed for grain size distribution. Sieve analysis (sieving) was the method used for the determination of grain size distribution.

Equipment : Sieves of mesh width 100um, 600um 500 um, 250 um, 125 um, 75 um, 63 um plus a receiver collecting grain sizes less than 63 um. Electric balance, sieve brush and mechanical shaker.

Procedures: 200 gms of sample is used. The samples are crushed with soft pad in a cleaned out mortar. 200 gms of samples was weighed, The set of sieves were arranged in order of decreasing mesh size with the coarest at the top, the weighed sample is poured gently poured into the top sieve. The stack of sieves was covered and placed in a mechanical shaker, which shakes for 30 minutes. After thorough shaking the weight of material retained in each sieve was measured and expressed in percentage weight of the original sample (200 gms) (see Table 2a-m). The trapped grains in the sieve were removed by using the sieve brush.

Disadvantage: There is no doubt that some fragile grain particles were damaged when grinding out the samples, this may affect our results.

4/1-3 PRESENTATION OF RESULTS:

Three graphic methods were used to present the results of the weight and cumulative percentages obtained from the sieving methods. The graph was plotted

by using the phi scale of Krumbein (1934). The results of grain size analysis were presented on:

1) Histograms

2) Cumulative Curves

3) Frequency Curves

For each sample, the three graphs were plotted within the same boundary with the Ø scale units on the X-axis, and weight percentages on the Y-axis (see Figs. 4, 5 and 6).

The histogram and the cumulative distribution curve methods are qualitative, while the frequency distribution curve is a quantitative method. This quantitative method is used for determining the grain size parameters indirectly, because certain percentile measures from corresponding 'phi' values are read off from the curve, and it is these percentile measures that are used in calculations of parameters for grain size (see Table 3).

From the curves the following percentiles were read off for each sample Ø5, Ø16, Ø25, Ø50, Ø75, Ø84, Ø95. Using the values obtained from the percentiles, a few grain size parameters were computed, these parameters were defined by Folk and Wand (1957).

Folk and Ward proposed some statistical measurements for the description of clastic sediments, quantitatively and qualitatively, the parameters proposed are:

a) Inclusive graphic standard deviation (σ_1)

b) Inclusive graphic skewness (SK1)

c) Graphic kurtosis (KG)

d) Graphic Mean (Mz)

These parameters were calculated as follows: (see Table 4)

a) Inclusive standard deviation σ_i - This is a good measure of sorting of sediments. Sorting is a measure of total spread of grain size distribution. This sorting coefficient as proposed by Folk and Ward is given by;

$$\frac{\text{Ø84} - \text{Ø16}}{4} + \frac{\text{Ø95} - \text{Ø5}}{6.6}$$

There is another scale proposed by Folk and Ward (1957), this is the descriptive scale of sorting, it is used to describe the degree of sorting as obtained from the above calculation.

TABLE OF DESCRIPTIVE SCALE OF SORTING

Inclusive Standard Deviation	Descriptive Scale of Sorting
< 0.35 Ø	Very well sorted
0.35 - 0.50 Ø	Well sorted
0.50 - 0.71 Ø	Moderately well sorted
0.71 - 1.00 Ø	Moderately sorted
1.00 - 2.00 Ø	Poorly sorted
2.00 - 4.00 Ø	Very poorly sorted
> 4.00 Ø	Extremely poorly sorted

b) Inclusive Graphic Skewness: (SK1) - This is a measure of the degree of assymetry, as well as whether the curve has an assymetrical scale on the left or right. This is again proposed by Folk and Ward (1957):

$$\frac{Ø16 + Ø84 - 2Ø50}{2(Ø84 - Ø16)} + \frac{Ø5 + Ø95 - 2Ø50}{2(Ø95 - Ø5)}$$

When the assymetrical scale is to the left, this is negative skewness and it implies that there is an excess of fine material, however, if the assymetrical scale is to the right, the skewness is positive indicating an excess of coarse material.

The descriptive scale of Folk and Ward is as follows:

Skewness Value SK1	Descriptive term
-1.00 to -0.30	Very negatively skewed
-0.30 to -0.10	Negatively skewed
-0.10 to +0.10	Near symmetrical
+0.10 to +0.30	Positively skewed
+0.30 to +1.0	Very positively skewed

c) Graphic Kurtosis: (KG) - This is a measure of the peakedness of the distribution curve. It indicates the departure of sediments from normality. Proposed also by Folk and Ward (1957)

$$\frac{Ø95 - Ø5}{2.44(Ø75-Ø25)}$$

If the curves are broad and flat, they are said to be platykurtic, if distribution curves are steep they are referred to as being leptokurtic. If on the other hand, they are neither platykurtic or leptokurtic, they are called mesokurtic curves.

TABLE OF DESCRIPTIVE SCALE OF KURTOSIS

Kurtosis	Descriptive Terms
< 0.67	Very Platykurtic
0.67 - 0.90	Platykurtic
0.90 - 0.11	Mesokurtic
0.11 - 1.50	Leptokurtic
1.50 - 3.00	Very Leptokurtic
> 3.00	Extremely Leptokurtic

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d) Graphic Mean: (Mz) - This is a parameter that gives an overall measure of an average size of the grains.

This graphic mean as proposed by Folk and Ward is given by:

$$Mz = \frac{\emptyset 16 + \emptyset 50 + \emptyset 84}{3}$$

Wentworth proposed a descriptive scale for the above calculated measure in 1922.

TABLE OF DESCRIPTIVE SCALE OF GRAPHIC MEAN

DIAMETER Ø (Mz)	Class of Sediment
-1 to 0.0	Very coarse sand
0.0 to 1.0	Coarse sand
1.0 to 2.0	Medium grained sand
2.0 to 3.0	Fine grained sand
3.0 to 4.0	Very fine grained sand
4.0 to 5.0	Coarse silt

4.1-4 EVALUATION OF RESULTS:

In all, thirteen samples were analysed from the Lafia, Keana and Awe Formations respectively. From the results obtained in the calculations of parameters of grain size and their descriptions, the following was observed generally (see Table 5):

i) Inclusive Standard Deviation

The analysis generally shows that:

15.4% of the samples were moderately sorted

84.6% of the samples were poorly sorted.

ii) Graphic Skewness:

7.7% of the samples were near symmetrical

30.8% of the samples were positively skewed

61.5% of the samples were very positively skewed.

iii) Graphic Kurtosis:

7.7% of the samples were very platykurtic

46.2% of the samples were platykurtic

23.1% of the samples were Mesokurtic

23.1% of the samples were Leptokurtic

iv) Graphic Mean:

15.4% of the samples were coarse sand

76.9% of the samples were medium grained sand

7.7% of the samples were fine grained sand

4.1-5 INTERPRETATION AND COMPARATIVE STUDIES:

Generally, from the results obtained, most of the samples were poorly sorted i.e. the particles are concentrated in the medium to coarser size range (see Table 5). This tends to imply that most of the sediments were not transported far away from their source areas. As the degree of sorting is proportional to energy of transfer, the poor sorting could be as a result of a relatively low energy of transporting medium over a relatively short distance.

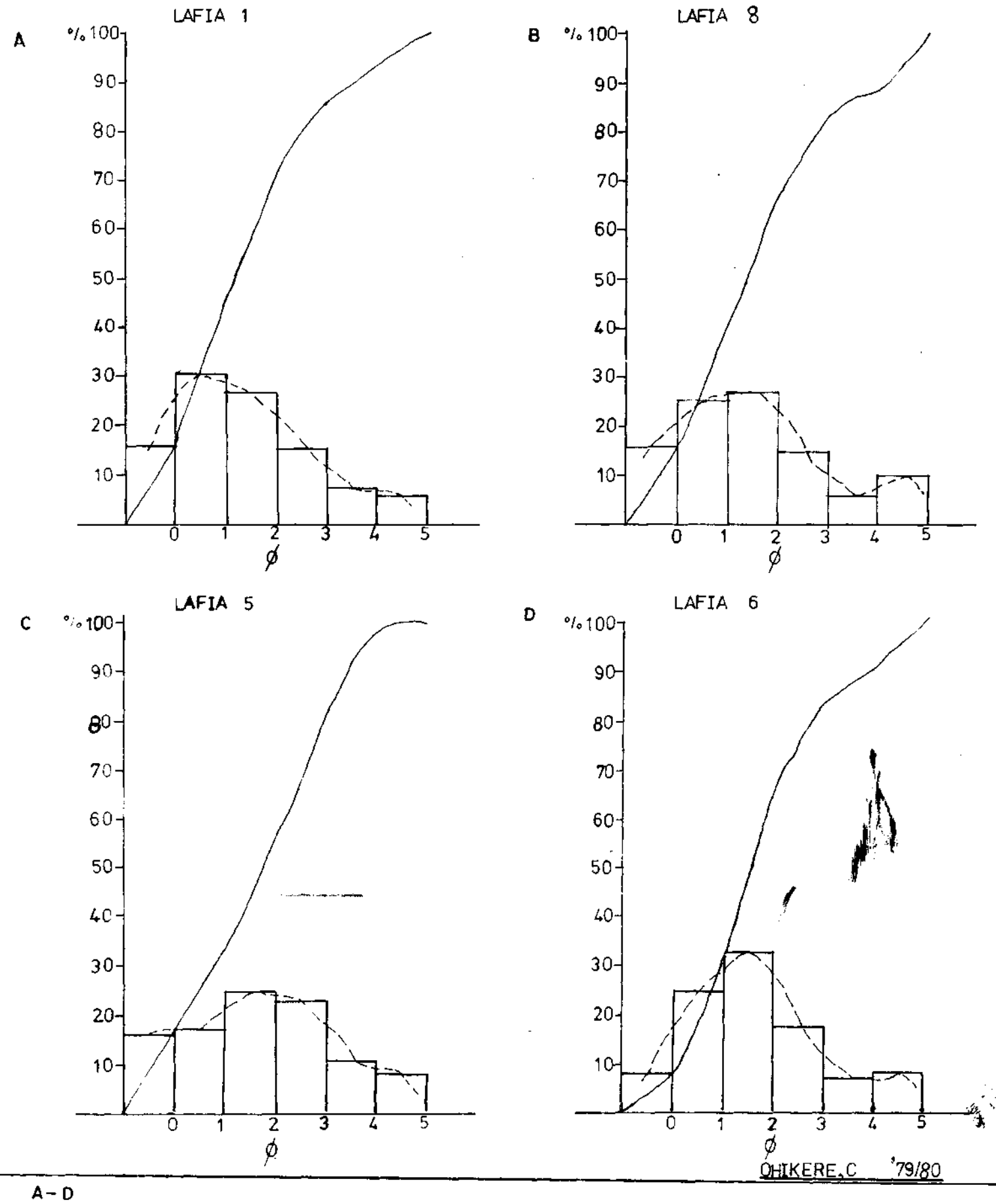
The graphic mean results shows that a greater proportion of the samples have an excess of medium grain materials (76.9%). In the Lafia Formations, the medium grain size indicates that these sediments were deposited in one depositional cycle. In the Awe Formation there are fine, medium and coarse grain sediments, it is probably as a result of reworking after deposition in situ, and this must have affected the grain sizes of the sediments.

The combination of positive skewness and poor sorting observed from the granulometric analysis of the Lafia, Keana and Awe Formations shows that the sediments are of fluviatile origin. In the absence of paleocurrent analysis, the direction of deposition cannot be inferred.

The manifestations of all sorts of Kurtosis (see Table 5) by the analysed samples makes it difficult to infer the actual distance of transportation. The Lafia and Awe sediments tends to be more platykurtic, with the Keana sediments being mostly mesokurtic.

The histograms shows varying peaks in the three formations studied. In the Lafia sandy clay, there is a unimodality of grains, that is the presence of one peak, depicting a single depositional phase for the

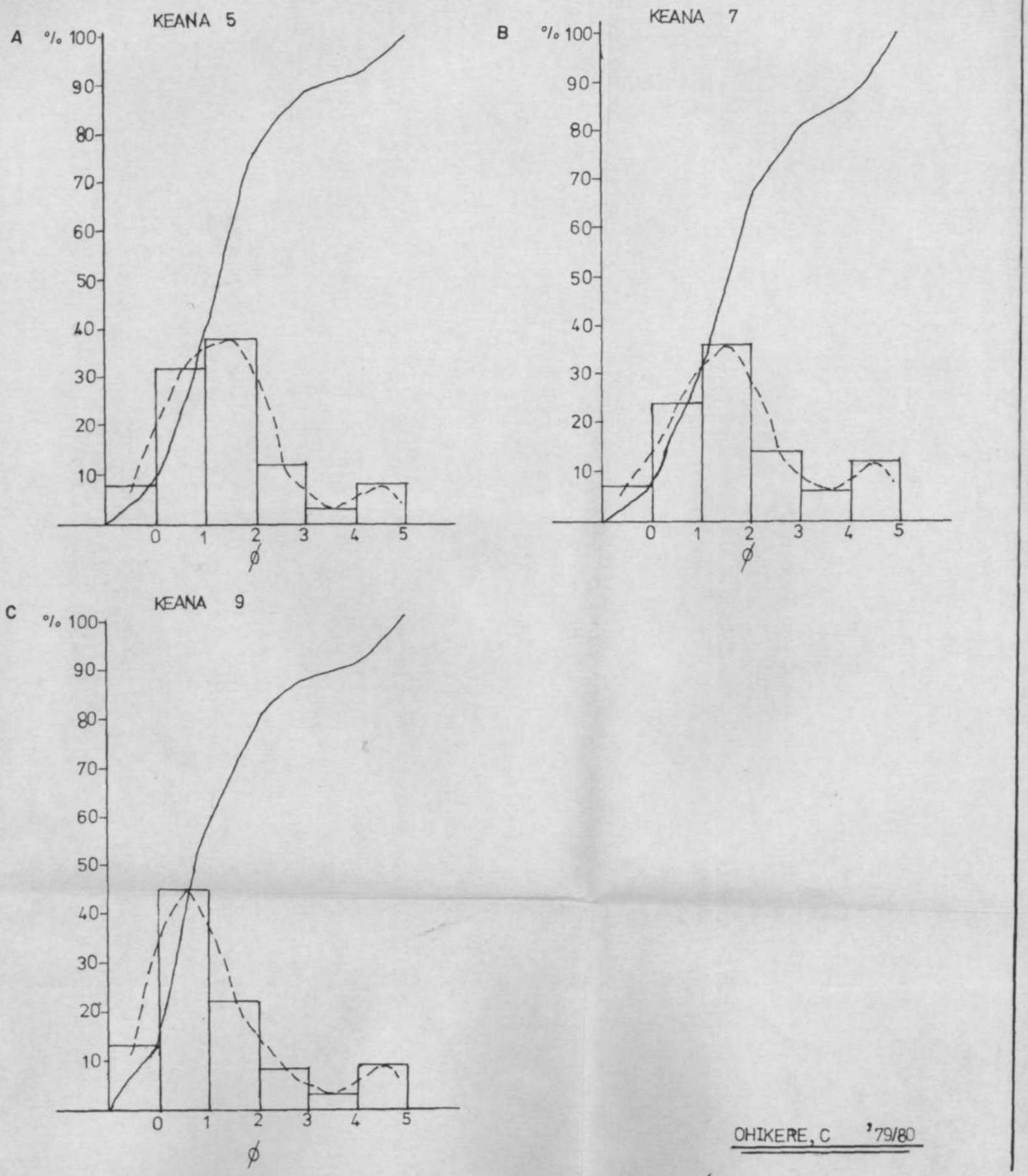
GRAPHICAL REPRESENTATION OF RESULTS OF GRAIN SIZE ANALYSIS FOR LAFIA FORMATION:



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Fig. 4, A–D

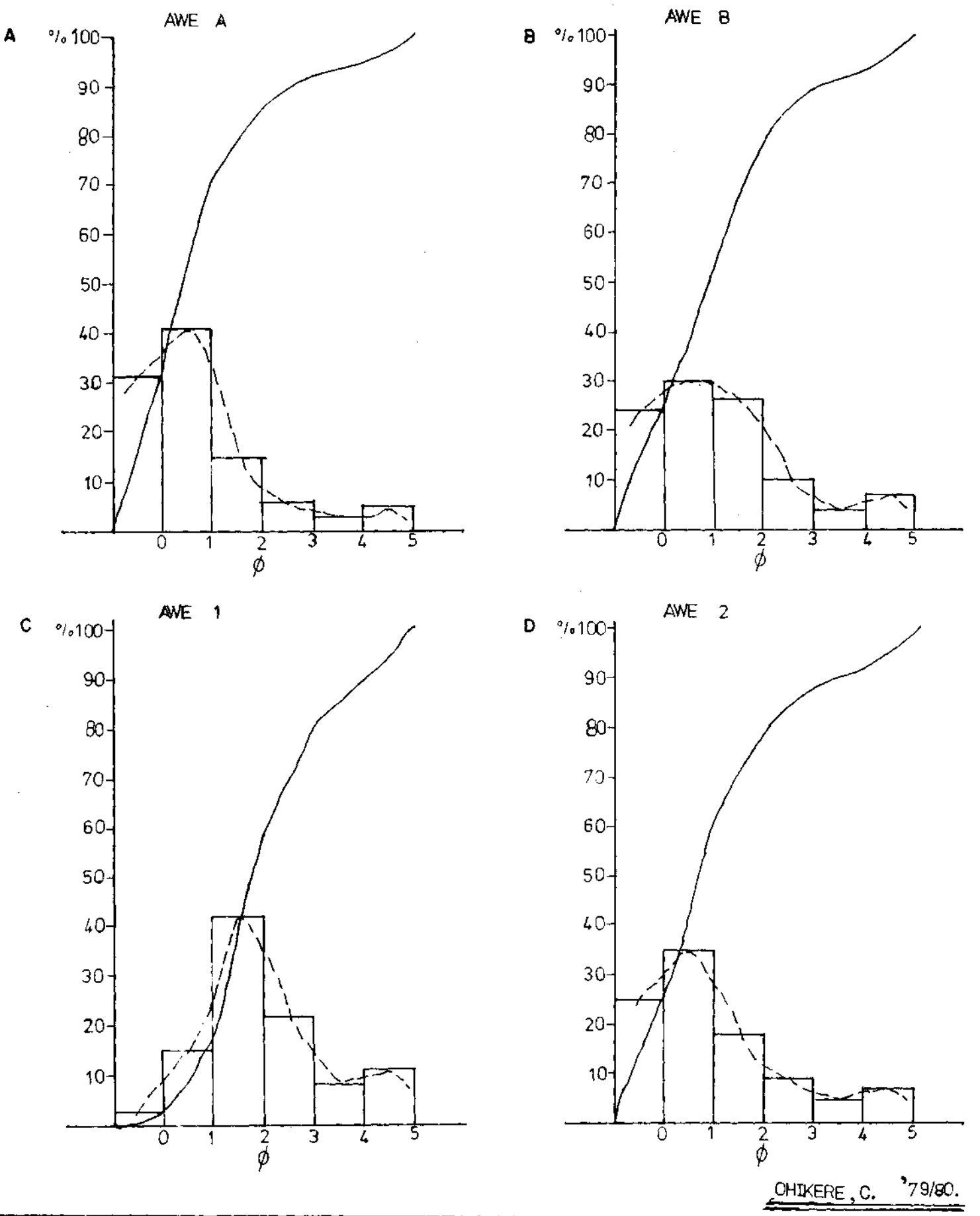
GRAPHICAL REPRESENTATION OF RESULTS OF GRAIN SIZE ANALYSIS FOR KEANA FORMATION:



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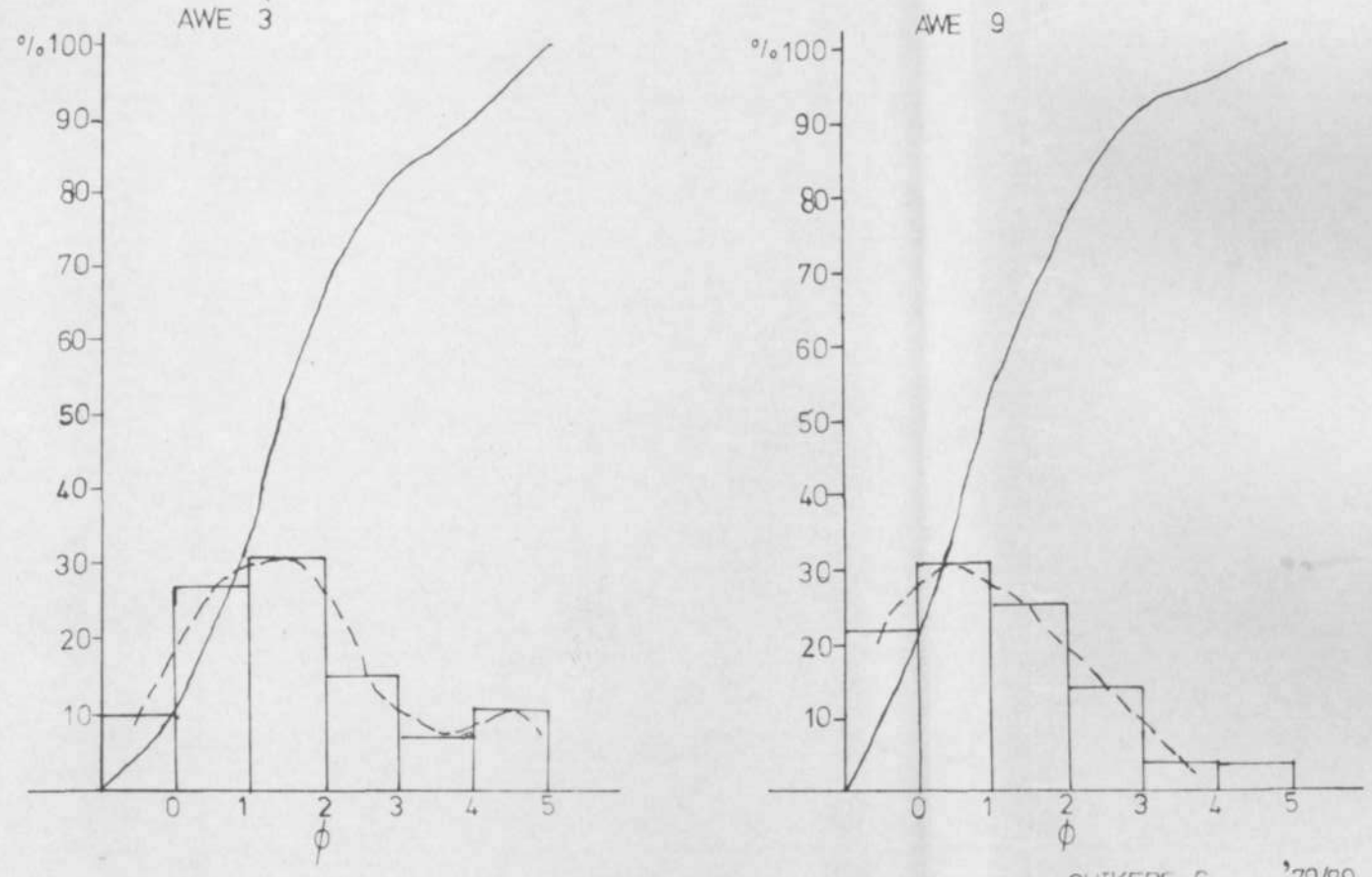
Fig,5. A–C.

GRAPHICAL REPRESENTATION OF RESULTS OF GRAIN SIZE ANALYSIS FOR AWE FORMATION:



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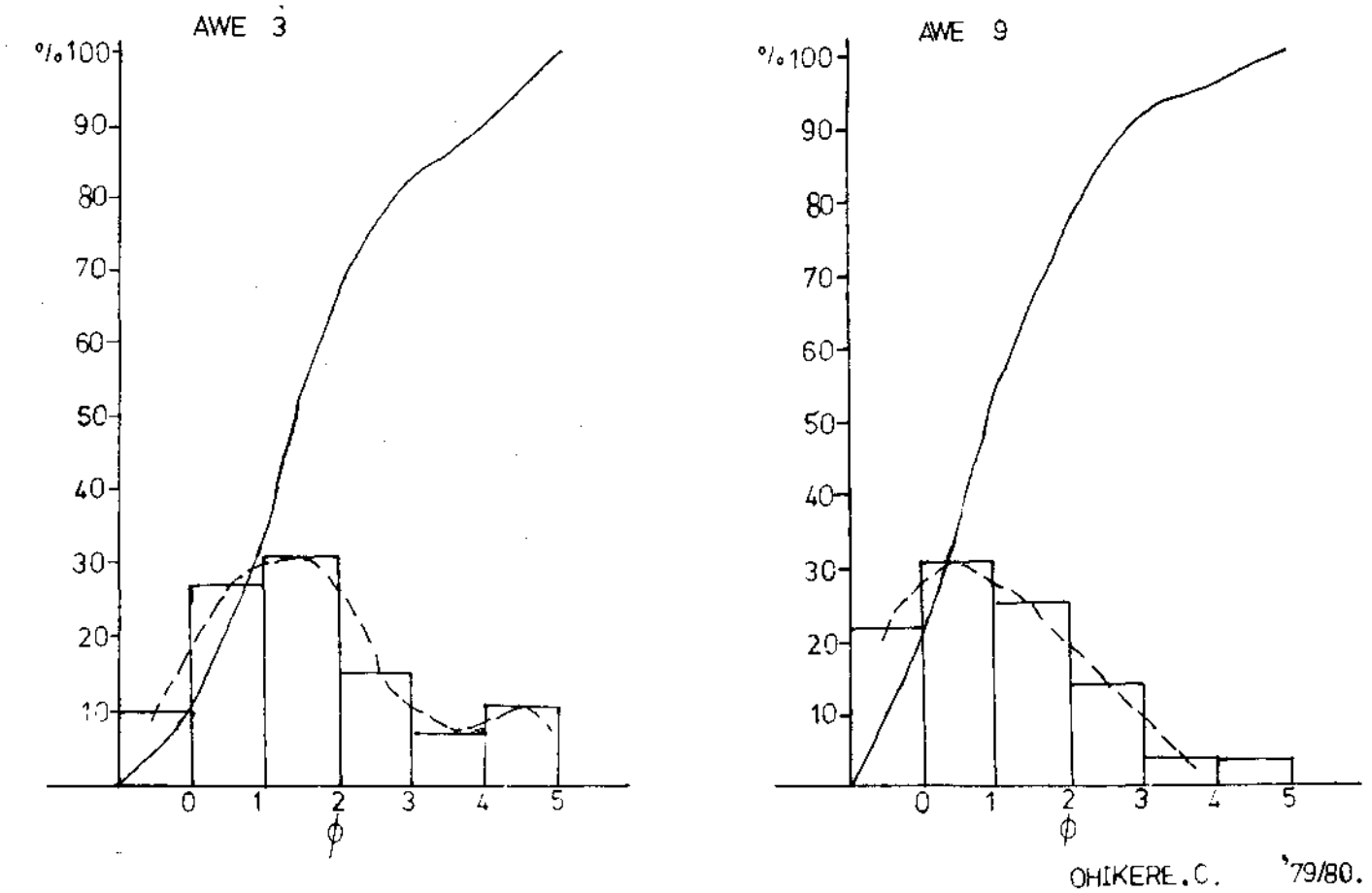
GRAPHICAL REPRESENTATION OF RESULTS OF GRAIN SIZE ANALYSIS FOR AWE FORMATION:



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Fig,6 E & F

GRAPHICAL REPRESENTATION OF RESULTS OF GRAIN SIZE ANALYSIS FOR AWE FORMATION:



OHIKERE.C. '79/80.

Fig,6 E & F.

sediments (see Figs. 4 & 6), whereas in the sandstones of Keana and Awe Formations, there is a bimodality in the pattern of distribution (see Fig. 5), which implies that the sediments were deposited by two or more depositional phases respectively, or were reworked in situ after their deposition.

4.1-6 CONCLUSION:

The sediments of the Lafia, Keana and Awe Formations are of fluviatile origin, this is in agreement with previous works on the Makurdi Formation carried out by Kogbe et al (1970),of which the Lafia has been through only one depositional phase, while the Keana and Awe sediments have been reworked.

The textural features mentioned earlier on, suggests a fluviatile sedimentary environment. See Figs. 9a and 9b for graphs showing distinction of the various environments of deposition of the sediments analysed (after Friedman 1961, 1967).

Table 2a - m - Results of Sieving Analysis

	Sieve Aperture	Ø(Phi)	wt.	wt%	Cumm.%
A					
Lafia 8	1.00	0	32.2	16.12	16.12
	0.500	1	51.2	25.64	41.76
	0.250	2	53.0	26.54	68.30
	0.125	3	30.6	15.32	83.62
	0.063	4	12.7	6.36	89.8
	Receiver	5	20	10.01	99.99
	Total		199.7	99.99	
B					
Lafia 6	100	0	16.5	8.30	8.30
	500	1	48.7	24.50	32.8
	250	2	65.0	32.70	65.5
	125	3	36.4	18.31	83.81
	63	4	15.0	7.54	91.35
	Receiver	5	17.2	8.65	100.00
	Total		198.8	100.00	
C					
Lafia 5	100	0	23.6	15.78	15.78
	500	1	25.3	16.91	32.69
	250	2	36.7	24.53	57.22
	125	3	35.0	23.40	80.62
	63	4	17	11.37	99.99
	Receiver	5	12	8.02	100.01
	Total		149.6	100.01	

	Sieve Aperture	Ø(Phi)	wt.	wt%	Cumm.%
D					
Lafia 1	1.00	0	19.7	15.51	15.51
	0.500	1	38.7	30.47	45.98
	0.250	2	32.7	25.74	71.72
	0.125	3	18.6	14.64	86.36
	0.063	4	9.3	7.32	93.68
	Receiver	5	8.4	6.61	100.29
	Total		127.0	100.29	
E					
KN 5	1.00	0	11.2	7.56	7.56
	0.500	1	47.2	31.85	39.41
	0.250	2	56	37.79	77.2
	0.125	3	17.5	11.81	89.01
	0.063	4	4	2.70	91.71
	Receiver	5	12.3	8.30	100.01
	Total		148.2	100.01	
F					
KN 7	1.00	0	14	6.98	6.98
	0.500	1	47.3	23.57	30.55
	0.250	2	72.7	36.22	66.77
	0.125	3	28.8	14.35	81.12
	0.063	4	12.4	6.08	87.2
	Receiver	5	25.5	12.71	99.91
	Total		200.7	99.91	

	Sieve Aperture	Ø(Phi)	wt.	wt.%	Cumm.%
G					
KN 9	1.00	0	24.9	12.65	12.65
	0.500	1	89.1	45.28	57.93
	0.250	2	42.5	21.60	79.53
	0.125	3	16.5	8.38	87.91
	0.063	4	5.8	2.95	90.86
	Receiver	5	18	9.15	100.01
	Total		196.8	100.01	
H					
Awe A	1.00	0	62	31.13	31.13
	0.500	1	80.8	40.56	71.69
	0.250	2	29	14.56	86.25
	0.125	3	11.6	5.82	92.07
	0.063	4	6.0	3.01	95.08
	Receiver	5	9.8	4.92	100.00
	Total		199.2	100.00	
I					
Awe B	1.00	0	47	23.74	23.74
	5.00	1	59	29.80	53.54
	0.250	2	51	25.76	79.3
	0.125	3	19.7	9.95	89.25
	0.063	4	8.3	4.19	93.44
	Receiver	5	13	6.57	100.01
	Total		198.00	100.01	
J					
Awe 1	100	0	5.0	2.54	2.54
	500	1	30.0	15.23	17.77
	250	2	82.0	41.62	59.39
	125	3	43.0	21.83	31.22
	63	4	15.0	7.61	88.83
	Receiver	5	22.0	11.17	100.00
	Total		197.00	100.00	

	Sieve Aperture	Ø(Phi)	wt.	wt.%	Cumm.%
K					
Awe 2	100m	0	50.0	25.10	25.10
	500	1	70.7	35.49	60.59
	250	2	36.5	18.32	78.91
	125	3	18.0	9.04	87.95
	63	4	9.0	4.52	92.47
	Receiver		15.0	7.53	100.00
	Total		199.2	100.00	
L					
Awe 3	100	0	20.4	10.15	10.15
	500	1	54.1	26.93	37.08
	250	2	61.4	30.56	67.64
	125	3	30.5	15.18	82.82
	63	4	13.5	6.72	89.54
	Receiver		21	10.45	99.99
	Total		200.9	99.99	
M					
Awe 9	100	0	44.2	22.43	22.43
	500	1	62.0	31.45	53.88
	250	2	48.3	24.51	78.39
	125	3	26.8	13.60	91.99
	63	4	7.3	3.71	95.70
	Receiver		8.5	4.31	100.01
	Total		197.1	100.01	

TABLE 3 - Ø GRAIN DIAMETER READINGS PERCENTILES
OBTAINED FROM CUMULATIVE FREQUENCY CURVES

Sample Number	Ø5	Ø16	Ø25	Ø50	Ø75	Ø84	Ø95
Lafia 1	-0.7	0.0	0.3	1.2	2.1	2.8	4.1
Lafia 5	-0.7	0.0	0.5	1.8	2.8	3.2	3.8
Lafia 6	-0.4	0.4	0.7	1.5	2.5	3.0	4.5
Lafia 8	-0.7	0.0	0.4	1.4	2.5	3.0	4.6
KN 5	-0.4	0.2	0.5	1.3	2.0	2.6	4.4
KN 7	-0.3	0.4	0.8	1.5	2.6	3.5	4.6
KN 9	-0.6	0.0	0.2	0.8	1.8	2.4	4.4
Awe A	-0.8	-0.5	-0.2	0.5	1.2	1.9	4.0
Awe B	-0.8	-0.4	0.0	0.9	1.9	2.5	4.3
Awe 1	0.3	0.9	1.2	1.8	2.7	3.4	4.5
Awe 2	-0.8	-0.4	0.0	0.7	1.8	2.6	4.4
Awe 3	-0.4	0.2	0.6	1.4	2.5	3.2	4.5
Awe 9	-0.8	-0.3	0.1	0.9	1.8	2.4	3.8

TABLE 4 - RESULTS OBTAINED AFTER USING THE FORMULAE FOR CALCULATING THE VARIOUS PARAMETERS

SAMPLE NUMBER	Standard Deviation (σ)	Graphic Skewness (SK1)	Graphic Kurtosis (KG)	Graphic Mean (Mz)
Lafia 1	1.22	0.39	0.77	1.33
Lafia 5	1.27	0.63	0.55	1.67
Lafia 6	1.27	0.74	0.93	1.63
Lafia 8	1.24	0.55	0.77	1.47
KN 5	1.21	0.52	1.09	1.37
KN 7	1.33	0.82	0.98	1.8
KN 9	1.18	0.25	0.97	1.07
Awe A	0.84	-0.01	1.31	0.63
Awe B	1.06	0.19	0.75	1.00
Awe 1	1.27	1.28	1.15	2.03
Awe 2	1.10	0.17	0.82	0.97
Awe 3	1.37	0.66	0.88	1.6
Awe 9	0.99	0.15	0.72	1.00

TABLE 5 - DESCRIPTIVE TERMS OF RESULTS

SAMPLE NUMBER	INCLUSIVE STANDARD DEVIATION	GRAPHIC SKEWNESS	GRAPHIC KURTOSIS	GRAPHIC MEAN
Lafia 1	Poorly sorted	Very positively skewed	Platykurtic	Medium grained sand
Lafia 5	Poorly sorted	Very positively skewed	Very platykurtic	Medium grained sand
Lafia 6	Poorly sorted	Very positively skewed	Mesokurtic	Medium grained sand
Lafia 8	Poorly sorted	Very positively skewed	Platykurtic	Medium grained sand
KN 5	Poorly sorted	Very positively skewed	Leptokurtic	Medium grained sand
KN 7	Poorly sorted	Very positively skewed	Mesokurtic	Medium grained sand
KN 9	Poorly sorted	Positively skewed	Mesokurtic	Medium grained sand
Awe A	Moderately sorted	Near symmetrical	Leptokurtic	Coarse sand
Awe B	Poorly sorted	Positively skewed	Platykurtic	Medium grained sand
Awe 1	Poorly sorted	Very positively skewed	Leptokurtic	Fine grained sand
Awe 2	Poorly sorted	Positively skewed	Platykurtic	Coarse sand
Awe 3	Poorly sorted	Very positively skewed	Platykurtic	Medium grained sand
Awe 9	Moderately sorted	Positively skewed	Platykurtic	Medium grained sand

CHAPTER FIVE

MINERALOGY

5.1 HEAVY MINERAL ANALYSIS

5.1-1 INTRODUCTION

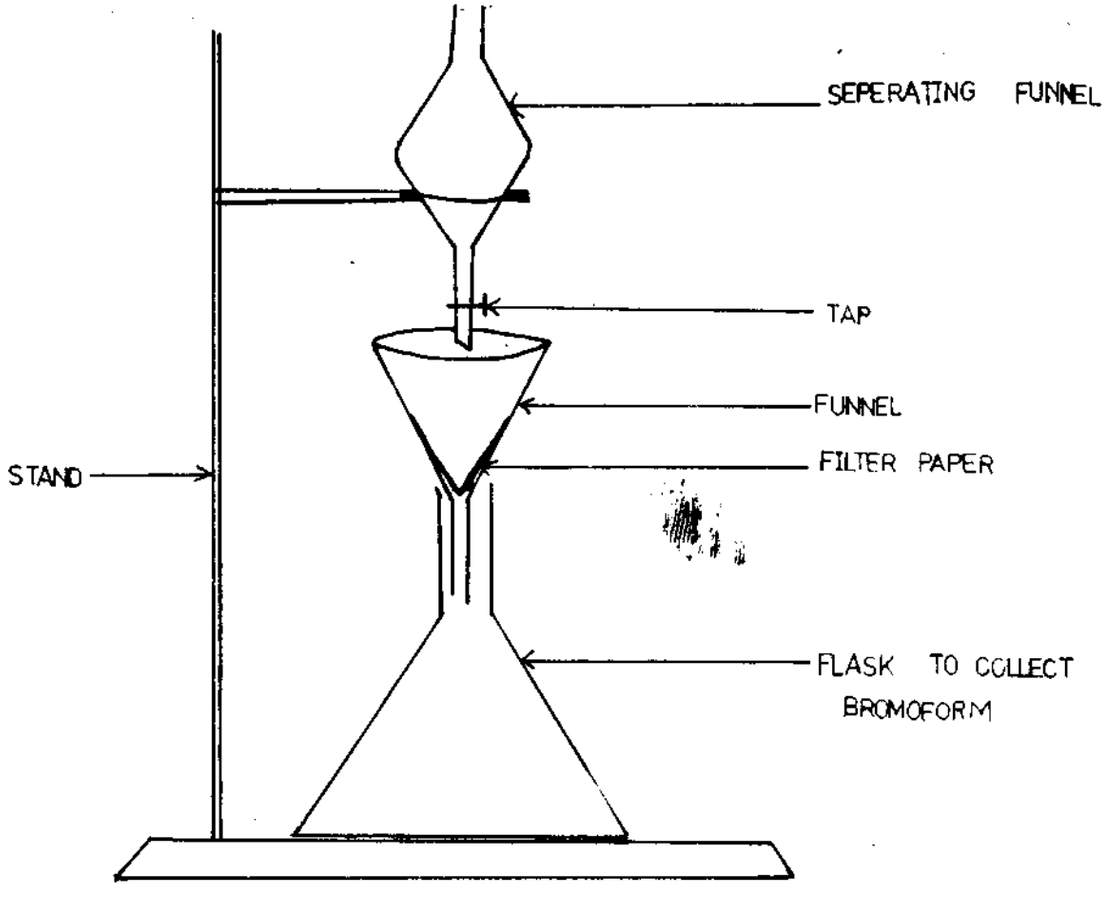
Minerals having a specific gravity greater than 2.89 are termed heavy minerals. These minerals are separated usually in a liquid whose specific gravity is about 2.89, in this case bromoform Ch. Br is used, this has a specific gravity of 2.88. The principle of this analysis is that minerals with different specific gravities can be separated from each other by a liquid whose specific gravity lies between those of the two minerals. This separation is based on the fact that the heavy minerals will sink in the liquid, leaving the lighter minerals to float on the surface. Certain heavy minerals are characteristic of particular rock types i.e. igneous or metamorphic rock types. The aim of this analysis is to determine the source of the sediments by studying the heavy minerals present in them.

5.1-2 METHODOLOGY:

Grain sizes of sediments used were between 63 Um-- 125 Um. The sieved fractions retained in sieves of diameter 63-125 um were analysed together for each

sample. The sample is poured into a beaker containing 100 ml. of concentrated hydrochloric acid, and brought to boil over a bunsen flame for about 20 minutes, this cleans the grains covered up by iron oxide. The sample is washed with water till its clear of the acid, and then it is dried in an oven. The sample is poured into a separating funnel (see set up in Fig. 7) containing bromoform and allowed to settle, this is done under a fume chamber. After stirring with a stirring rod, the heavy minerals sank to the bottom of the separating funnel while the lighter minerals remained on the surface of the bromoform liquid. Separation was then carried out by opening the tap of the separating funnel and allowing only the heavy minerals to pass through onto a filter paper. The samples were rid of bromoform using acetone. The heavy minerals obtained were then dried in an oven, the same was done for the light minerals.

The heavy and light minerals were identified under a binocular microscope. Each sample was treated in this manner and separately. Recycling of the liquid bromoform was also done to minimize wastage of the liquid.



AN EXPERIMENTAL SET UP OF HEAVY MINERAL ANALYSIS.

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Fig 7.

5.1-3 PRESENTATION OF RESULTS:

Minerals recognised are as follows:

The heavy minerals present are:

1. Zircon
2. Tourmaline
3. Rutile
4. Staurolite
5. Kyanite

(see Table 6 for percentage values of the Heavy Mineral Analysis).

The light minerals present are:

1. Quartz
2. Micas.

5.1-4 DESCRIPTION AND DISTRIBUTION OF HEAVY MINERALS:

Six samples were analysed, one each from the Lafia and Asu River Formation and two each from the Keana and Awe Formations respectively. The heavy minerals found in the samples were ultrastable through stable to moderately stable (Pettijohn et al 1972 p. 305).

The heavy minerals observed are zircon, tourmaline, rutile, kyanite and staurolite respectively; these minerals are present in all the formations studied but they differ in their proportion (see Fig. 8) and

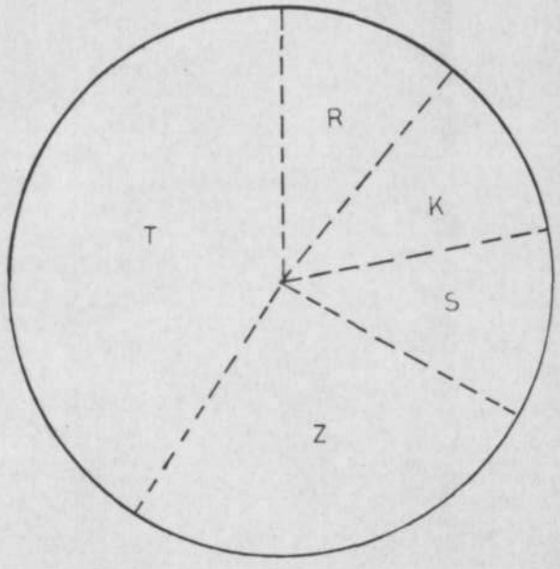
morphology.

In the Lafia Formation, the heavy minerals are dominated by the tourmaline grains, some of the grains have inclusions, these inclusions are probably bubbles, they are mostly subrounded to subangular. Zircon grains are second in relative abundance and also have inclusions. Most of the crystal faces are not well defined, but a few have well marked edges. Rutile, kyanite and staurolite are also present but in a small amount, they occur mostly as subrounded grains.

However, in the Keana Formation, zircon is the most abundant heavy mineral and most of them show well defined angular crystal faces, and inclusions (see Plate 6). Some of the zircon grains have outgrowths, this characteristic is also observed in the tourmaline grains. Staurolite and kyanite are observed, but they are relatively few, their crystal faces are not well marked.

Sandstones of the Awe Formation are characterised by the dominant presence of tourmaline and zircon minerals. The tourmaline grains subrounded show little or no crystal face, inclusions are present. Some of the grains have outgrowths. Zircon grains are full of inclusions, they are fairly abundant, their crystal edges are not well defined. Rutile grains were also observed, but very small amount of staurolite were seen.

GRAPHICAL REPRESENTATION OF THE APPROXIMATE DISTRIBUTION OF HEAVY MINERALS:

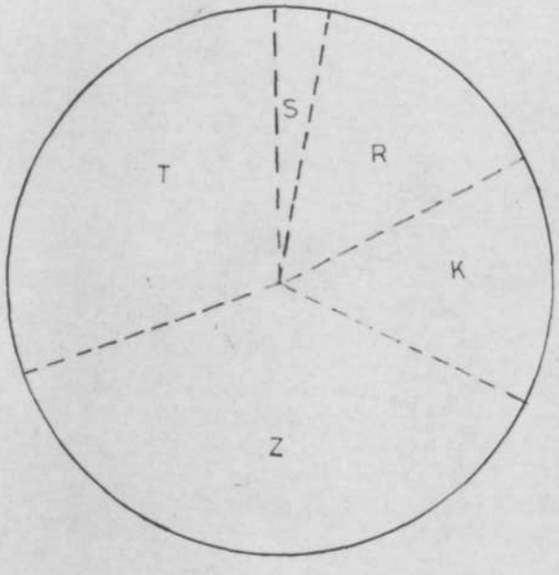


Lafia 8

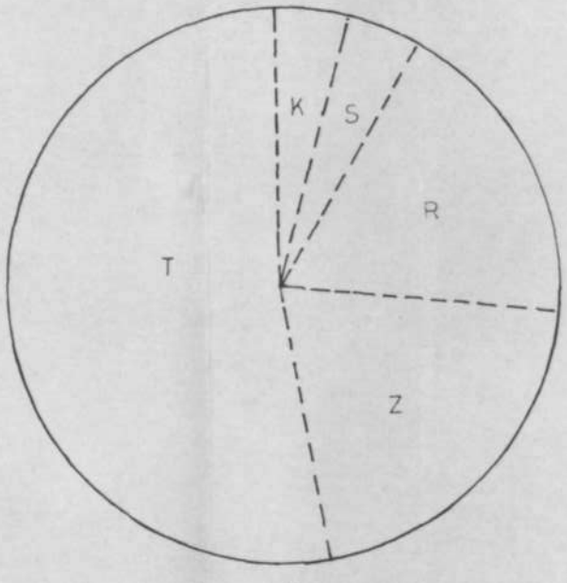
Z rcon
T urmaline
R utile
K yanite
S taurolite

Fig 8.

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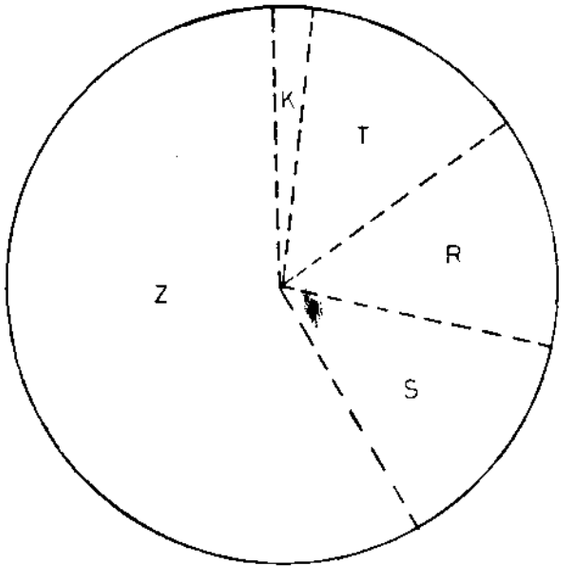


Awe 2

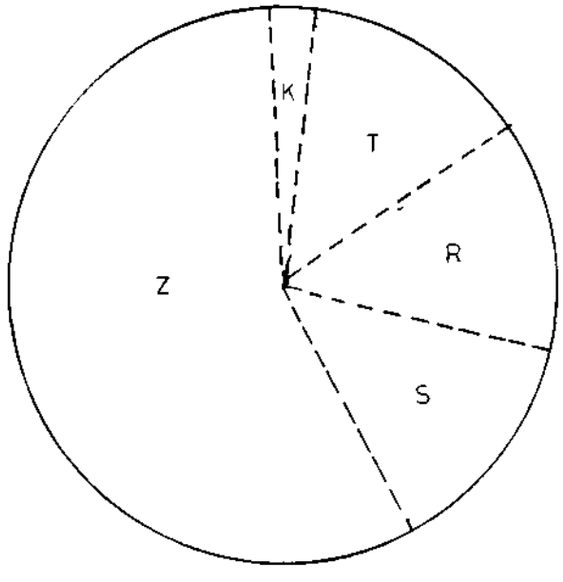


Awe 9

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Keana 5



Keana 7

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5.1-5 INTERPRETATION AND COMPARATIVE STUDIES:

The heavy minerals are used as indices of provenance, and also as indicators of the degree of weathering.

From the relative abundance of these minerals we could infer that the source rocks are acid igneous (as indicated by the presence of zircon, tourmaline and rutile), and medium grade, regional metamorphic rocks (as indicated by the presence of kyanite and staurolite). Both rock types are present in the Nigerian basement complex, the complex is composed of granites, gneisses, and migmatites. These are found to the North and South of the mapped area.

From the morphological features of the heavy minerals observed in the Lafia sandstone (subangular-subrounded grains), we could infer that the sediments have undergone a slight degree of transportation, whereas in the Keana and Awe Formations there are grains having outgrowths, which is an indication of relatively strong chemical weathering conditions. The Keana and Awe Formations also might have experienced a short distance of transportation, as the crystal faces of the grains are not well marked.

5.1-6 CONCLUSION:

From this heavy mineral analysis of the sediments, it can be deduced that the Lafia, Keana and Awe Formations are from the same source rocks, the Nigerian basement complex.

Though the source rock is the same for the various formations, the proportion of the minerals and their morphology indicates a relatively strong weathering condition, and a short distance of transportation for the following reasons: The most abundant minerals observed were zircon and tourmaline, these are minerals which are very resistant to weathering, so that their presence in such high amounts, with crystal faces not well marked indicates a relatively strong weathering condition, but such minerals like kyanite and staurolite which are succeptible to weathering are present in a very small amount, compared to these resistant minerals, this tends to imply that they have been through a relatively strong weathering condition, where most of them have decomposed.

The morphology of the minerals, mostly subrounded to subangular, with traces of crystal faces still observable, tends to indicate a short term transportation, if it were for a long term transportation most of the grains would be rounded to subrounded without crystal faces present.

Thus the Lafia, Keana and Awe Formations have experienced a strong weathering condition over a short time, but in the Keana and Awe Formations where outgrowths were observed, these tends to indicate a strong chemical weathering condition (E.J. Pettijohn 1975).

TABLE 6 - RESULTS OBTAINED FROM THE CALCULATION OF THE PERCENTAGE VALUES OF HEAVY MINERALS

LOCALITIES	MINERALS	PERCENTAGE VALUES	DEGREE
Lafia 8	Zircon	35	93
	Tourmaline	55	147
	Rutile	15	40
	Kyanite	15	40
	Staurolite	15	40
	Total	135	360
Keana 5	Zircon	65	207
	Tourmaline	15	48
	Rutile	15	48
	Kyanite	3	9
	Staurolite	15	48
	Total	113	360
Keana 7	Zircon	65	207
	Tourmaline	15	48
	Rutile	15	48
	Kyanite	3	9
	Staurolite	15	48
	Total	113	360

LOCALITIES	MINERALS	PERCENTAGE VALUES	DEGREE
Awe 2	Zircon	35	122
	Tourmaline	35	122
	Rutile	15	52
	Kyanite	15	52
	Staurolite	3	12
	Total	103	360
Awe 9	Zircon	15	76
	Tourmaline	35	178
	Rutile	15	76
	Kyanite	3	15
	Staurolite	3	15
	Total	71	360
Asu River 1	Zircon	35	104
	Tourmaline	65	193
	Rutile	3	9
	Kyanite	15	45
	Staurolite	3	9
	Total	121	360

5.2 LIGHT MINERAL ANALYSIS:

5.2-1 DESCRIPTION AND DISTRIBUTION:

In all the cases studied, the light minerals are generally composed of quartz and micas, with quartz being always dominant, and in some cases no mica minerals. Quartz maybe colourless or milky white. It occurs mainly as subangular to subrounded grains, sometimes though in a few cases they are rounded. The mica flakes are present as single flakes.

In the Lafia and Keana Formations no mica flakes were observed. Though present in the Awe Formation, they are relatively very few. Feldspar is generally absent.

5.2-2 INTERPRETATION AND COMPARATIVE STUDIES:

From the abundance of quartz, a very stable and resistant mineral, and the absence of feldspars, it could be inferred that the sediments have undergone a relatively strong weathering phase.

There are no mica flakes in the Lafia and Keana Formations, and they are composed of quartz grains which are subrounded to subangular. However, the Awe Formation has quartz being abundant, with a few flakes of mica, this tends to suggest a nearby source for the

sediments. From the mineral composition, the rock can be named as quartz arenite (E.J. Pettijohn 1975).

5.2-3 CONCLUSION:

From the morphology and composition of the light minerals, it is not doubtful that the Lafia, Keana and Awe Formations have been through a relatively strong weathering condition and short distance of transportation.

5.3 CLAY MINERAL ANALYSIS:

5.3-1 INTRODUCTION:

X-ray diffraction method uses the principles of Bragg's law, which is expressed as follows:

$$n\lambda = 2d \sin \theta$$

where λ = wavelength of X-ray radiation

d = spacing between similar planes of atoms (Å)

θ = the angle between incident X-ray beam and the plane of atoms (degrees)

n = the order of the plane expressed as whole numbers or integars.

The basic principles of this method of analysis of X-ray determination of minerals is the fact that each crystalline substance has its own characteristic atomic structure which diffracts X-ray in a characteristic manner.

5.3-2 METHODOLOGY:

Two samples of each rock types were prepared. One in dry powder form; there are generally the non-oriented samples, while the other is in suspension, and these represents the oriented samples. The oriented samples was prepared from clay suspension on glass slides which were allowed to dry in the oven at a temperature of about $60^{o}C$.

Both the oriented and non-oriented samples were run on the X-ray diffractometer. The X-ray diffraction was carried out on a Phillips diffractionometer unit using:

Phillips X-ray generator	PW 1140/90
Phillips copper X-ray tube	PW 2233/20
Phillips vertical goniometer	PW 1050/80
Phillips channel control unit	PW 1390
Phillips goniometer supply	PW 1393
Phillips single pen recorder	PW 8203

The diffractionometer was set at 40 KV and 30 mA. Readings were taken at the rate of 1^{o}/min. at a frequency of about 1×10^{3} Hz. The recording was done from 6^{o}-35^{o}.

The diffractogram was recorded on a chart showing the position and relative intensity of the diffraction peaks. From the diffraction patterns on the charts 2θ angles and the relative intensities were measured for each peak. The corresponding d-values and clay minerals were then obtained with the aid of given tables.

5.3-3 PRESENTATION OF RESULTS:

The results of the X-ray diffraction analysis were recorded automatically on a graph sheet as peaks of varyring intensities corresponding to various minerals. This result has been included in one of the theses submitted.

5.3-4 EVALUATION OF RESULTS:

The 2θ angles (angle of incidence of the X-rays), of the various peaks, were read off from the graphs in order of decreasing intensities. The corresponding d-values were obtained from the X-ray powder diffraction index card for common clay minerals. The type of mineral was then inferred from the 2θ angles and d-values. The results were evaluated and interpreted as shown in Table 7.

5.3-5 DISTRIBUTION AND COMPARATIVE STUDIES:

In all, twenty-five samples were analysed (oriented and non-oriented), these were from the Asu, Awgu, Lafia, Keana and Awe Formations respectively. Minerals observed were quartz, kaolinite, illite and chlorite.

The clay minerals observed are kaolinite, illite and chlorite. In general terms, considering all the formations together, kaolinite is the most common mineral

TABLE 7 - RESULTS OF CLAY MINERAL ANALYSIS

Sample Number	I/Io	2θ	2d (Å) Value	Estimated Mineral
Asu R. 2 (Powder)	100	26.60	3.35	Quartz
	33	20.80	4.27	Quartz
	20	27.30	3.27	-
	19	19.80	4.48	-
	18	9.50	9.31	-
	17	25.20	3.53	-
Awgu 1 (Slide)	100	26.70	3.34	Quartz
	41	20.80	4.27	Quartz
	26	25.00	3.56	-
Lafia 1 (Powder)	100	26.50	3.36	Quartz
	44	20.80	4.27	Quartz
	42	12.00	7.38	Kaolinite
	42	22.50	3.95	-
	34	32.80	2.73	-
	20	24.80	3.59	Kaolinite
	16	9.50	9.31	Kaolinite
Lafia 3 (Powder)	100	26.50	3.36	Quartz
	32	20.80	4.27	Quartz
	23	24.70	3.60	Kaolinite
	22	20.00	4.44	Kaolinite
	20	12.10	7.31	Kaolinite
	17	33.50	2.68	-

Sample Number	I/Io	2θ	2d (Å) Value	Estimated Mineral
Lafia 6 (Powder)	100	26.60	3.35	Quartz
	59	24.90	3.58	Kaolinite
	55	20.70	4.29	Quartz
	50	12.20	7.26	Kaolinite
	50	20.00	4.44	Kaolinite
	36	9.40	9.41	-
	32	33.20	2.70	-
Lafia 5 (Powder)	100	26.50	3.36	Quartz
	54	24.80	3.59	Kaolinite
	53	20.60	4.31	Quartz
	46	12.20	7.26	Kaolinite
	44	19.80	4.48	Kaolinite
	34	34.80	2.58	-
	28	9.50	9.31	-
Lafia 5 (Slide)	100	26.80	3.33	Quartz
	85	24.90	3.58	Kaolinite
	77	12.30	7.20	Kaolinite
	54	20.00	4.44	-
Lafia 7 (Powder)	100	26.50	3.36	Quartz
	45	24.80	3.59	Kaolinite
	38	12.30	7.20	Kaolinite
	36	20.80	4.27	Quartz
	33	19.80	4.48	Kaolinite
	25	34.80	2.58	-
	21	9.60	9.21	-

Sample Number	I/Io	2θ	2d (Å) Value	Estimated Mineral
Lafia 7	100	12.30	7.20	Kaolinite
(Slide)	97	26.60	3.35	Quartz
	97	24.80	3.59	Kaolinite
	63	20.67	4.29	Quartz
	51	27.50	3.24	-
Lafia 8	100	26.60	3.35	Quartz
(Powder)	53	20.80	4.27	Quartz
	49	24.80	3.59	Kaolinite
	46	20.00	4.44	Kaolinite
	44	34.80	2.58	-
	43	12.30	7.26	Kaolinite
	34	33.50	2.68	-
	31	9.40	9.41	-
Lafia 8	100	26.60	3.35	Quartz
(Slide)	91	24.80	3.59	Kaolinite
	91	12.20	7.26	Kaolinite
	79	20.60	4.31	Quartz
	76	19.80	4.48	Kaolinite
KN 7	100	26.50	3.36	Quartz
(Powder)	63	20.80	4.27	Quartz
	28	27.30	3.27	-
	23	25.20	3.53	-
	17	27.80	3.21	-
	17	25.50	3.49	-
	15	30.80	2.90	-

Sample Number	I/Io	2θ	2d (Å) Value	Estimated Mineral
KN 5	100	26.50	3.36	Quartz
(Powder)	53	20.80	4.27	Quartz
	21	27.50	3.24	-
	15	25.60	3.48	-
	14	9.60	9.21	-
KN 5	100	26.80	3.33	Quartz
(Slide)	42	21.00	4.23	Quartz
	24	27.70	3.22	-
	17	23.20	3.83	Kaolinite
	15	12.40	7.14	Kaolinite
KN 9	100	26.50	3.36	Quartz/Illite
(Powder)	65	27.60	3.23	-
	34	16.10	5.51	-
	27	30.10	2.97	-
	26	24.40	3.65	-
	26	20.80	4.27	Kaolinite/Quartz
	25	22.10	4.02	-
	23	23.60	3.77	Kaolinite
	21	12.70	6.97	Kaolinite
	20	19.90	4.46	Illite/Kaolinite
	18	33.90	2.64	-
	17	15.00	5.91	-
	15	29.80	3.00	-
	12	30.90	2.89	-

Sample Number	I/Io	2θ	2d(A) Value	Estimated Mineral
KN 9 (Slide)	100	28.00	3.19	--
	88	26.70	3.34	Quartz/ Illite?
	84	24.30	3.66	Kaolinite
	81	19.90	4.46	Illite/Kaolinite?
	75	12.20	7.26	Kaolinite
	75	20.80	4.27	Kaolinite
	81	22.00	4.04	-
	50	9.00	9.83	Illite
	47	30.50	2.93	-
Awe B (Powder)	100	26.60	3.36	Quartz/Illite?
	59	24.00	3.71	Quartz
	58	13.40	6.61	-
	44	34.80	2.58	-
	42	21.00	4.23	-
	42	28.00	3.19	-
	38	24.40	3.65	-
	36	20.00	4.44	Illite
	33	22.10	4.02	-
	31	30.00	2.98	-
	28	9.40	9.40	Illite
Awe 1 (Powder)	100	26.60	3.35	Quartz/Illite?
	34	22.00	4.04	-
	32	28.00	3.19	-
	28	24.40	3.65	-
	28	20.80	4.27	Quartz
	27	20.00	4.44	Illite
	21	30.00	2.98	-
	20	9.30	9.50	Illite

Sample Number	I/Io	2θ	2d (Å) Value	Estimated Mineral
Awe 9	100	26.60	3.35	Quartz/Illite
(Slide)	41	20.70	4.29	Quartz
	35	27.20	3.28	-
	23	24.80	3.59	Kaolinite
	22	12.00	7.38	Kaolinite
	18	8.70	10.16	Illite
	16	17.50	5.07	Illite
Awe A	100	26.60	3.35	Quart/Illite
(Powder)	62	27.80	3.21	-
	60	33.60	2.67	-
	47	25.20	2.55	-
	40	10.40	8.51	-
	40	20.80	4.27	Quartz
	38	12.60	7.03	Kaolinite
	37	24.00	3.71	Kaolinite
	37	19.80	4.48	Illite/Kaolinite?
	35	21.90	4.06	Kaolinite
Awe A	100	28.00	3.19	-
(Slide)	100	26.40	3.36	Illite/Quartz
	89	24.20	3.68	-
	79	20.00	4.44	Illite/Kaolinite?
	68	12.00	7.38	Kaolinite
	64	8.80	10.05	Illite
Awe 3	100	26.40	3.36	Quartz/Illite
(Powder)	60	25.50	3.49	-
	46	20.70	4.29	Quartz
	28	15.00	5.91	-
	18	8.80	10.05	Illite
	18	19.70	4.51	Illite

Sample Number	I/Io	2θ	2d(Å) Value	Estimated Mineral
Awe 3	100	26.70	3.34	Quartz/Illite?
(Slide)	32	20.90	4.25	Quartz
	23	8.70	10.16	Illite
	21	25.20	3.53	Kaolinite
	20	27.50	3.24	-
	20	12.20	7.25	Kaolinite
	17	17.80	4.98	Illite
	16	19.90	4.46	Illite/Kaolinite?
Awe 6	100	26.60	3.35	Quartz/Illite?
(Powder)	65	23.50	3.79	Kaolinite
	62	33.60	2.67	-
	62	13.00	6.81	-
	40	20.80	4.27	Quartz/Kaolinite?
	40	19.80	4.48	Kaolinite/Illite?
	37	34.80	2.58	-
	33	12.10	7.31	Kaolinite
	31	9.00	9.83	Illite
Awe 6	100	26.70	3.34	Quartz/Illite?
(Slide)	86	12.20	7.25	Kaolinite/Chlorite?
	83	27.50	3.24	-
	83	24.90	3.58	Kaolinite/Chlorite?
	69	19.80	4.48	Kaolinite/Illite?
	66	8.50	10.40	Illite
	62	6.40	13.89	Chlorite

Note:

The blank spaces under estimated minerals are the unidentified clay minerals.

Key:

θ = angle of incidence of X-rays.

d = Interplanar spacing

I/Io= Relative intensities of the diffraction peaks

followed by illite. Chlorite is present in an extremely minute amount, it was observed in one sample from the Awe Formation (Awe 6).

In the Lafia Formation, the dominant clay mineral is kaolinite. no other mineral was observed, the same pattern applies in the Awgu Formation.

However, in the Keana Formation, Kaolinite is again the most common mineral present, but unlike in the Lafia and Awgu Formations, illite minerals were also present. Another pattern of distribution was observed in the Awe Formation, where the illite mineral is almost dominant, with kaolinite occurring in almost equal amounts.

5.3-6 INTERPRETATION AND CONCLUSION:

It has been suggested that clays were formed mainly as weathering products of either feldspars, muscovite, biotite, or other ferromagnesian minerals, this is obtained from the mineralogy of clays, by H.H. Read (1976 p. 412-416). These minerals are found in both igneous and metamorphic rocks, this suggests that the source rock for these clays is either a metamorphic or an igneous rock, or even both.

It is not possible to deduce from the clay mineral assemblages, the conditions at the time of deposition of these clays, because clay minerals are subject to alteration, with changing conditions of temperature, pressure, water content as well as the acidity of the environment (H.H. Read 1976).

In the Lafia and Awgu Formations Kaolinite is the dominant clay mineral present, whereas in the Awe and Keana both kaolinite and illite were observed.

However, the presence of kaolinite implies an acidic environment, while the presence of illite indicate a neutral environment, but clay minerals preserve a record of the environment from which they came rather than of the environment in which they were finally deposited.

5.4 PETROGRAPHY - Thin Section:

Only one sample, from the Awe Formation was studied (see Plate 7).

5.4-1 MEGASCOPIC DESCRIPTION:

The hand specimen is generally fine grained, with an equigranular texture. The weathered portion has a brown colouration, while the unweathered part is light brown. There is a non-directional alignment of minerals. Shiny flecks of minerals which are most likely white micas were observed, and also quartz grains were present.

5.4-2 MICROSCOPIC DESCRIPTION:

The minerals observed were quartz (90%), feldspars (5%), muscovite, and some iron minerals; Goethite (limonite). Accessory minerals observed are zircon grains.

Quartz grains shows undulated extinction (extinction going through the grains, this indicates mechanical stress on the grains). Grains generally are not well rounded, and no cement observed between the grains.

5.4-3 CONCLUSION:

As this methods of study was carried out for only one locality in one of the formations being studied, a clear conclusion cannot be obtained. However, the absence of cement in the section indicates that the sediments have probably undergone diagenesis, the undulated extinction in quartz and the predominance of quartz minerals, indicates that the sediments went through a high rate of transportation, the undulation in grains also indicates mechanical stress on the grains.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 A COMPARISON OF THE SANDSTONES IN THE AREA OF STUDY:

The sandstones in the Lafia, Keana and Awe Formations are probably all of fluviatile origin (see Figs. 9a and 9b), but they have varying depositional history.

The Lafia sandstones seem to have been deposited during one depositional phase, whereas the Keana and Awe sandstones show evidence of two or more depositional phases (see cumulative curves Figs 4, 5 and 6).

The Awe and Keana sandstones are of early to late Cenomanian age, (Offodile, 1976), whereas the Lafia Formation is Maastrichtian (Kogbe, 1978; Offodile 1976). The sandstones that make up the Awe and Keana Formations were greatly affected by the tectonic activity that took place during the Santonian. They were greatly folded whereas the Lafia Formation which was deposited after the folding was not affected by this folding episode (see Fig. A).

The sandstones in the Lafia Formation are all highly ferruginized and they are made up of red sands which are coarse grained and indurated. The ferruginization of the fluviatile sandstone of this formation

most probably resulted from strong oxidixing tendencies that might have existed in the continental environment that prevailed (Offodile 1976). While in the Keana and Awe Formations, the sandstones are non-indurated, friable and loosely consolidated.

The Lafia, Keana and Awe Formations are from the same source rocks, the Nigerian basement complex, and they have experienced a strong weathering condition over a short period of time.

There is a dominance of kaolinite in the Lafia Formation, which tends to imply an acidic environment of deposition, whereas the Awe and Keana Formations consists predominantly of kaolinite and illite which is indicative of a more neutral environment of deposition.

In the Awgu Formation, there is also a dominance of kaolinite, implying an acidic environment of deposition as in the Lafia Formation.

In conclusion, it has been observed that the sandstones of the older formations (Awe and Keana) differ slightly from the sandstones of the younger (Lafia) Formation in colour, lithology, induration, compaction and cementation.

Furthermore, from field and laboratory investigations, it is apparent that a consistent distinction between the Awe and the Keana Formations (Offodile 1976), is impossible. Although, Falconner 1911, described some Passage beds, consisting of carbonaceous shales and sandstones at Awe, the Passage beds, are not consistent in their lithology, and at Keana they consist of whitish sandstones, fine to medium grained, and reddish when exposed, (see Plate 5). These characteristics are quite similar to those observed in the Keana sandstones.

Since a formation is described as a mappable unit, with distinct boundaries drawn upon changes in lithology (Kogbe, 1978). The Awe and Keana Formations could be partially lateral equivalents with the Awe Formations probably slightly older.

It was impossible to differentiate outcrops of the two formations (Awe and Keana) in the field.

6.2 RECOMMENDATIONS:

This area of study has been and is still a subject of some controversy. I would therefore suggest that the area should be further studied to put more light on the nature of the source of provenance of the sediments, not only of the area in consideration, but of the Benue basin at large. I would also recommend a thorough study of the structural elements in the area as this is closely related to the sedimentological history of the basin.

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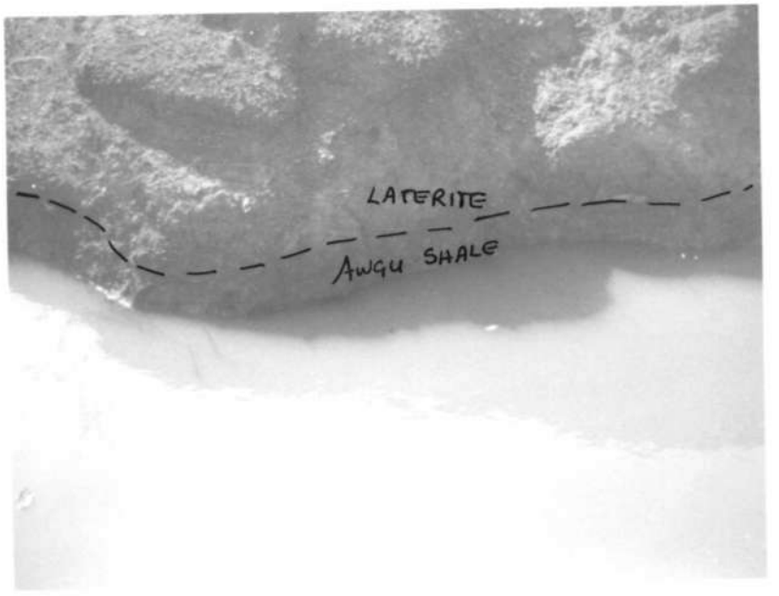
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A P P E N D I X

SAMPLE NUMBER	GRANULO-METRIC ANALYSIS	HEAVY MINE-RAL ANALY-SIS	LIGHT MINE-RAL ANALY-SIS	THIN SEC-TIONS	CLAY MINERAL ANALYSIS	
					ORIEN-TED	NON-ORIENTED
Lafia 1	x					x
Lafia 3						x
Lafia 5	x				x	x
Lafia 6	x					x
Lafia 7					x	x
Lafia 8	x	x	x		x	x
Agwu 1					x	
Kn 5	x	x	x		x	x
Kn 7	x	x	x			x
Kn 9	x				x	x
Awe A	x				x	x
Awe B	x					x
Awe 1	x					x
Awe 2	x	x	x			
Awe 3	x				x	x
Awe 4				x		
Awe 6					x	x
Awe 9	x	x	x		x	
Asu R. 1		x	x			
Asu R. 2						x



Plate 1: Characteristic red colour of the Lafia Formation



late 2: Awgu shale outcropping along a stream valley.



Plate 3: Mud cracks in the Keana Formation



Plate 4: Weathered section of the Keana Formatic



Plate 5: Typical view of the Awe Formation

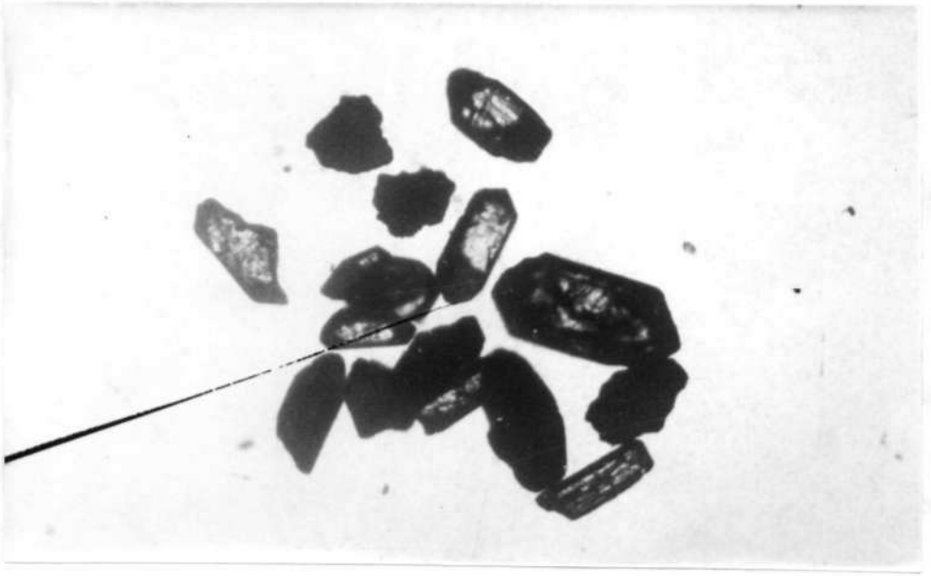


Plate 6: Prominence of zircon in the Keana Formation



Plate 7: Awe sandstone (thin section).