STRATIGRAPHY AND SEDIMENTOLOGICAL STUDIES OF THE ALBIAN TO MAASTRICHTIAN SEDIMENTS AROUND LAFIA TOWN, LAFIA SHEET 231NW MIDDLE BENUE TROUGH, NIGERIA

BY

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES AHMADU BELLO UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF MASTER OF SCIENCE IN GEOLOGY

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Declaration

I declare that this work entitled "**Stratigraphy and Sedimentological Studies of the Albian-Maastrichtian sediments around Lafia town, Lafia Sheet 231 NW, Middle Benue Trough of Nigeria**" has been carried out by me. The information derived from the literature has been duly acknowledged. This Dissertation has never been presented anywhere for a degree or diploma in this institution or another.

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Certification

This Dissertation entitled **Stratigraphy and Sedimentological studies of the Albian-Maastrichtian sediments southeast of lafia town, Middle Benue Trough**, **Nigeria** by me meets the regulations governing the award of the degree of Master of Science (M.Sc) of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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Dean, School of Postgraduate Studies Sign

Dedication

I dedicate this work to my mother, Miss Christiana Bature for her financial, moral and spiritual support in the course of this work. May the Lord continue to bless and keep you in good health

Acknowledgement

My acknowledgement goes to God Almighty who is the source of my existence, purpose and everything good in this life.

I would also like to acknowledge and appreciate my supervisors, Prof. Halidu Hamza and Dr. Ibrahim Hamidu for their support and guidance. They were always ready to attend to me anytime, anywhere. I would also like to acknowledge all the staff of Geology Department for their support in one way or the other, most especially Drs. Jolly Byami and Yusuf Ibrahim Abubakar.

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Abstract

The middle Benue Trough is one of the three segments of the larger NE-SW trending Benue Trough. As is the case with the Upper Benue Trough, there does not seem to be any recent work dedicated to the Geology of the Middle Benue Trough. Recent works on the stratigraphy and sedimentological studies of the Albian to Turonian sediments of the middle Benue Trough, covered areas around Keana and Awe respectively (all within sheet 232 NW). This work covered Areas within Lafia (Sheet 231NW). The study area is located southeast of Lafia town. It is accessible by some major roads which includes: Lafia to Makurdi, Doma to Agyaragu and Lafia to Keana. Reconnaissance study was first carried out in the study area on a scale of 1:100000 followed by a detailed field mapping on a scale of 1:50,000. In the course of the field work, the lithostratigraphic successions in the study area was established, sedimentary structures were identified and samples collected for petrographic and sieve analysis. Stratigraphic study in the study area indicates the occurrence of three formations namely; the fluvial Lafia Formation (Campano-Maastrichtian), the shallow marine Awgu Formation (Turonian-Coniacian) and the transitional Awe Formation (Albian-Cenomanian). A total of 12 samples were collected for granulometric analysis, and 11 samples for Petrographic analysis. The Lafia Formation consist of ferrugenised sandstone at the base, clay and clayed loosed sands. Petrographic and sieve analysis revealed that the Ferrugenised sandstone range from fine-medium grain. It is moderately sorted, strongly fine skewed and is a Quartz arenite. More than 60% of the crystals are monocrystalline which is indicative of igneous provenance. The Awe Formation consists of fine-grained white sandstone, with some intercalations of white clay and laminated shale. The sandstones are fine-grained and poorly-moderately sorted which coupled with the bivariate plot that indicates a transitional conditions between shallow marine and fuvial systems. The sandstones of the Awe Formation range from Arkose to Subarkose. The presence of monocrystalline quartz and plagioclase feldspars are all indicators of igneous provenance. The Awgu Formation consists of sandstones that are fine grained, very poorly sorted and strongly fine-skewed. The sandstones of the Awgu Formation are Quartz Arenites. There are ostracodes, echinoderms, and ammonites fossils within the shaley limestone and limestones of the Awgu Formation. This is an indication of a shallow marine environment of deposition. The Sedimentary structures in the study area include; beddings, mudcracks, faults, joints and veins and unconformity. The bedding planes are indications of break in deposition of the sediments while the mudcracks indicates long exposure to a dry warm climate. Other Methods of studies such as aeromagnetic studies, palynological studies and diagenetic studies should be carried out for more geological information of the study area to properly characterise the Middle Benue Trough

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

The Benue Trough is a sediment-filled elongated NE-SW trending depression that originated from the opening of the Atlantic Ocean. It is a failed arm of a rift-rift-rift triple junction developed over a Cretaceous hotspot located below the present-day Niger Delta (fig 4). (Cratchley and Jones 1965; Burke *et al*., 1970). This trough has been divided into three sections namely Upper, Middle and Lower Benue Trough by Cratchley and Jones (1965). The structural and stratigraphic settings of the trough have attracted the attention of geologists and many hypotheses have been advanced for its origin (King, 1950; Lees, 1952; Carter *et al*., 1963; Cratchley and Jones, 1965; Dessauvagie, 1969; Burke *et al*., 1970; Olade, 1975; Offodile, 1978). The rift tectonic/strike model seems the most widely accepted mode of origin. The Nigerian Benue Trough is an intracratonic rift structure whose evolution is related to the Early Cretaceous opening of the South Atlantic Ocean and the Gulf of Guinea (Akande *et al*., 2011). Fig. 1 is the map of Nigeria showing sedimentary basins.

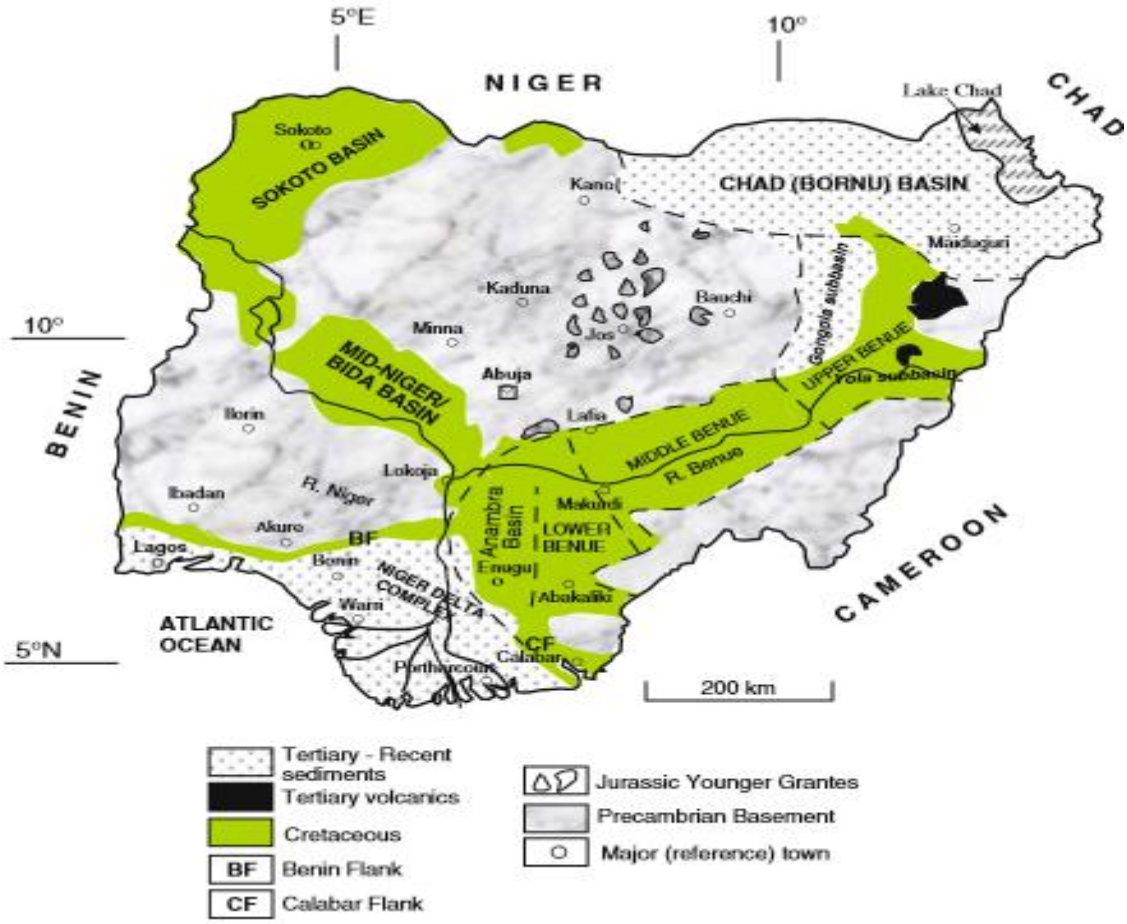


Fig.1: Map of Nigeria showing Sedimentary Basins (Obaje, 2009)

1.2 Aim and Objectives of the Study

1.2.1 Aim

The aim of this work is to study the stratigraphy and sedimentological characteristics of the Albian to Maastritchtian sediments around Lafia town and their sedimentary structures.

1.2.1 Specific objectives

Fieldwork was carried out in order

- To establish the lithostratigraphic successions in the study area.
- To identify the sedimentary structures and interprete them.

Grain analysis was carried out in order

- To establish the environment of deposition of the sediments.
- To provide an account of the provenance of the sediments

1.3 Location and Accessibility

The study area is located within the middle Benue Trough of Nigeria. It lies between latitudes **$8^{o}13^{'}$ N to $8^{o}28'$ N** and Longitudes **$8^{o}32'$ E to $8^{o}47'$ E**. The study area covers about 770km^2 (Fig 2). The study area was accessible by the major roads that extends from Lafia to Obi, Lafia to Makurdi and other minor roads. The study area is located in Nasarawa State of Nigeria as seen in Fig. 2 below

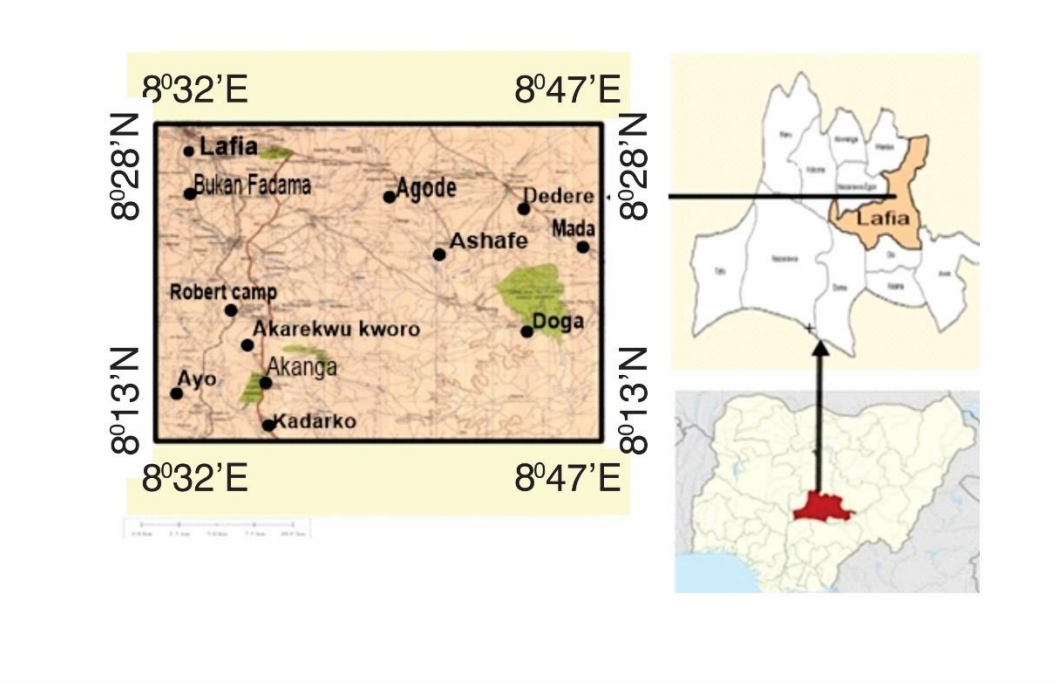


Fig.2: Map of Nigeria Showing the Study Area (Not to scale)

1.4 Relief and Drainage

The study area consist of undulating lowland with most parts of the State (Nasarawa State) lying within the Benue Trough. The highland areas of the State occurs towards the north, notably in Wamba, Eggon and Akwanga Local Government Areas. The Eggon hills has an average height of about 1200m above sea level

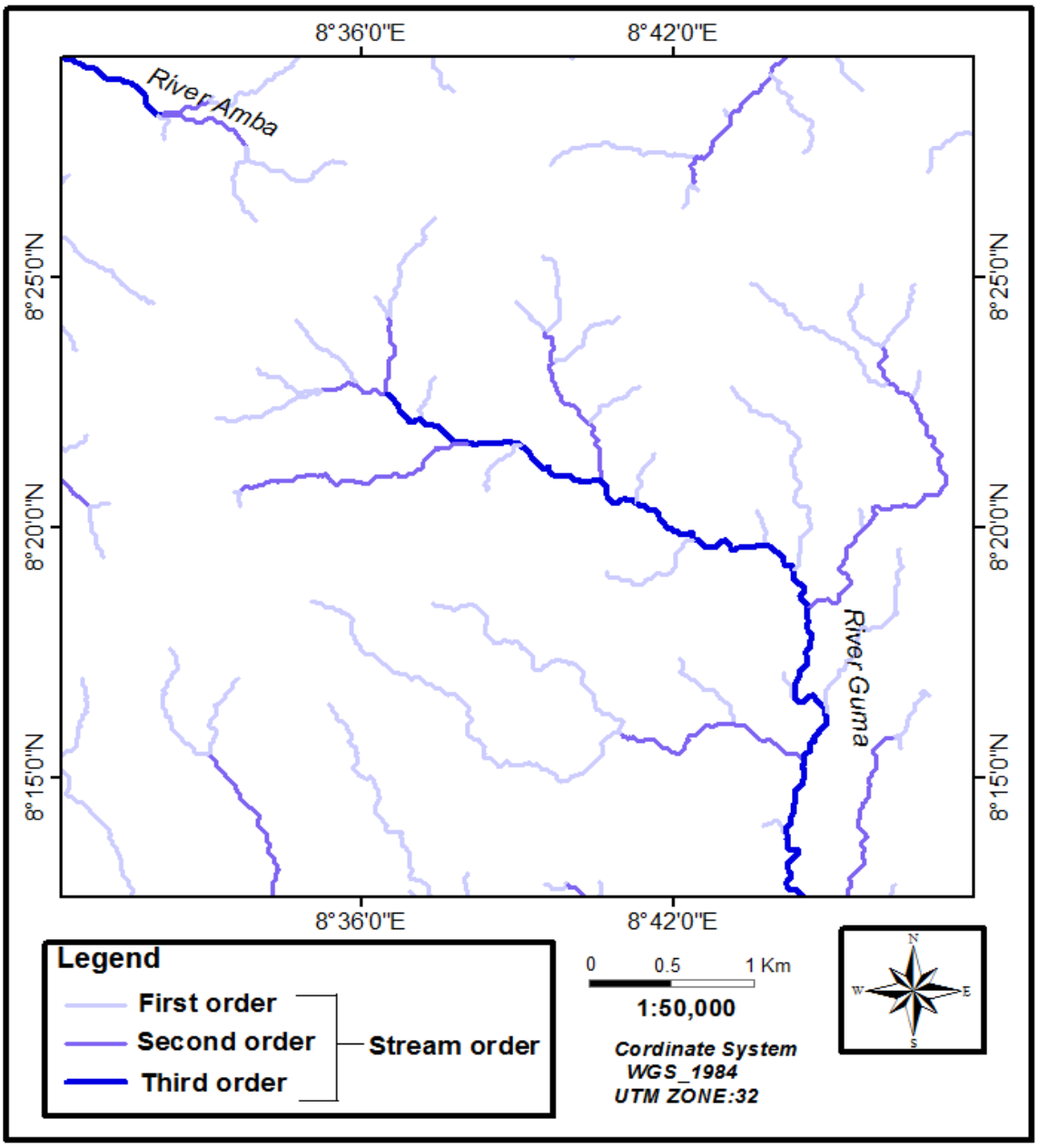


Fig. 3: Map of the study area showing drainage pattern

The study area is drained by numerous fast flowing streams/rivers that take their source from the Jos Plateau and flow through the area to the River Benue. The drainage pattern is dendritic (Fig. 3)

1.5 Climate and Vegetation

The study area occur within the tropical humid climate. The climate can be characterised into two seasons: the wet and the dry seasons. The wet season starts from the beginning of May and ends in October while the dry season begins by November and ends in April. During this dry `season, harmattan begin by December and ends in February. The annual rainfall range from 200mm to 1100mm.

About 90% of the rain falls between May and September with the peak of rainfall between July and August.

Temperatures are generally high during the day particularly between the months of March and April. The mean monthly temperature in the study area ranges between 20^0C and 34^0C with the highest temperature being in the months of March/April and the lowest temperatures being in the months of December/January

The vegetation is of the guinea savannah type. This is a transition zone between the forest region of the south and the true savannah of the north; therefore, it has both the characteristics of the forest and the grassland. The vegetation on the hilly part of the study area is made up of shrubs and isolated trees. Trees of economic value, including locust bean, shea butter, mango, citrus and banana are scattered across the study area.

1.6 Human Geography

There are several tribes within the study area. In Lafia, the largest town, there are different tribes with almost equal proportion. These tribes includes Kanuri, Tiv, Alago, Koro, Eggon, Hausa, Fulani and Gwandara. Southwards towards Giza town, the most dominant tribe is the Koro tribe around the towns of Akelekwu and Agyaragu. This is followed by the Tiv tribe that live around the towns of Ajor, Kadarko, Uchin, and Giza. The third dorminant tribe is the Alago around the

towns of Keana, and Giza. The dominant occupations of the people in the area are farming and cattle rearing. The Farmers produce yams, guinea corn, maize e.t.c. The Fulani tribe on the other hand are involved in milk and meat production.

CHAPTER TWO

LITERATURE REVIEW AND GEOLOGICAL FRAMEWORK

2.1 The Middle Benue Trough

The Trough has a linear NE-SW trend, which is a segment of the larger Benue Trough of Nigeria. It extends northeastwards as far as the line joining Bashar and Mutum Biyu (Fig. 1). This boundary marks the southern limits of the Gombe Sandstone and the Kerri-Kerri Formations while the older sediments of the Upper Benue Trough undergo lateral facies changes in this area. The axial basement high of the Middle Benue Trough ("the Keana ridge" of Ajayi and Ajakaiye, 1986). On the southeastern flank are a "Wukari" and a "Mutum Biyu SubBasins" with inferred sediment thicknesses of 1.9 to 3.8 km, and on the northwestern flank a minor "Shendam Sub-Basin" and a "Sub-Kadarko Basin" with sediment thicknesses of 2.4 to 5.3 km respectively (Zaborski, 1998). It is a fundamental tectono-sedimentological feature in the evolution of the Cretaceous and Tertiary geology of Nigeria (Nwajide, C.S. 1990). It is filled with Cretaceous rocks of ages ranging from middle Albian to Maastritchtian with a length of about 800km (Cratchley and Jones, 1965; Avbovbo, 1980). The thickness of these rocks has an average of about 6km in the Lower Benue Trough to about 3km in the middle Benue and to about 5km in the Upper Benue Trough (Offodile, 1976). The position of the Benue Trough in the evolution of Nigerian geological features is such that most other sedimentary basins (Bida, Anambra, Dahomey and Niger Delta) are genetically related to it (Nwajide, C.S 1990)

The Cretaceous rocks filling the Trough bordered on the sides by the metamorphic basement of probably Proterozoic age. Numerous intrusive bodies such as thin dyke-like bodies intrude this metamorphic body. It can be assumed that prior to its inception that is, before the break-up of the Gondwana supercontinent, no part of the Nigeria landmass had any sedimentary cover. (Cratchley and Jones, 1965)

The West and Central African rift system (WCARS) was formed as a resultant effect of the separation of African and South American Continents, which led to the development of a closely linked rift system in the West and Central African regions. The system is divided into the West African Rift Subsystem (WARS) and the Central African Rift Subsystem (CARS). Both were developed within the Pan–African lines of lithospheric weakness (Guiraud and Maurin, 1992 on page 69). They are thus intra-cratonic Cretaceous rift systems that were recognized based on extensive gravity data, which indicated that there is a strong interaction between oceanic and intra-continental tectonics (Fairhead, 1992).

The middle Benue Trough remains one of the three segments of the larger NE-SW trending Benue Trough. As is the case with the northern Benue Trough, there does not seem to be any much work dedicated to the Geology of the Middle Benue Trough (Nwajide, 1990)

2.2 Origin and Evolution of the Benue Trough

The origin of the Benue Trough is a subject of debate until the concept of plate tectonics and sea floor spreading was postulated. It is related to the opening of the Atlantic Ocean.

2.2.1 Lee's Compressional Theory

Lees (1952) regarded the Benue Trough as a compressional downwarp, the folding being deduced by deep-seated basement contraction. Owing to the fact that the Benue Trough has no marginal faults in the geological section across the trough, which shows the underlying basement as being folded, he indicated that it could be a compressional feature. This contradicts the Kings' theory.

2.2.2 Rift theory

Kings (1950) regarded the Benue Trough and the Bida Basin as extensions due to stresses of the rifts, which produced the Atlantic Ocean. This led to the separation of the South American continent from the African continent.

Cratchley and Jones (1965) also proposed that the Benue Trough was a rift and based on gravity data, inferred marginal faulting or step faulting along most of its middle and Upper parts, the faults being concealed within Cretaceous sediments.

2.2.3 Triple Junction Theory

Burke *et al.,* (1971, 1972), Burke and Whiteman (1973) and Burke and Dewey (1974) developed a model according to which the Benue Trough was regarded as a failed arm of a rift-rift-rift triple junction developed over a Cretaceous hotspot located below the present-day Niger Delta (Fig 4)

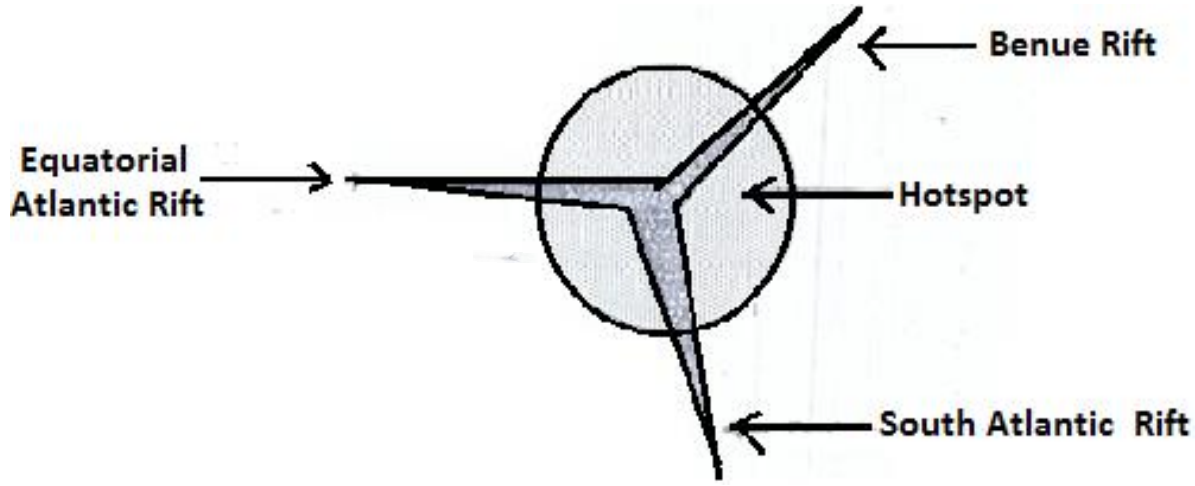


Fig 4: The Triple Rift Junction (*Burke et al.*, 1972)

2.2.4 Strike-slip Fault and Compressional Origin

Benkhelil (1982, 1989) believed that the Trough is not a tensional feature but a sinitral strike-slip and that the Trough is a collection of pull-apart Sub-basins and uplifted blocks. He noticed that a rift should have faults along its margin but there are no faults here, instead the main fault parallel

to the axis of the trough occurred along its axis. Furthermore, the sedimentary succession was thinnest along the axis of the trough, whereas the axial region was one of the shallow basements dissected by NE-SW trending fault; this basement is partially exposed in the Upper Benue Trough (Zaborski, 2000).

Zaborski (1998, 2003) envisaged that the Benue Trough shows features of rift and strike-slip structures. Its origin and evolution cannot be fully explained on the basis of just one of the theories mentioned above, but it is best regarded as rift with very strong sinistral strike-slip component superimposed upon it.

The middle Benue Trough is one of the three segments of the larger NE-SW trending Benue Trough. As is the case with the Upper Benue Trough, there does not seem to be any recent work dedicated to the Geology of the Middle Benue Trough. Recent works by Ephraim Ishaya (2016) and Tunji Falujugbe (2015) on the stratigraphy and sedimentological studies of the Albian to Turonian sediments of the middle Benue Trough, covered areas around Keana and Awe respectively (all areas fall within sheet 232 NW). This work covered Areas around Lafia town (Lafia sheet 231NW).

2.3 Stratigraphy of the Middle Benue Trough

2.3.1 Stratigraphy

In the Middle Benue Trough, the stratigraphic succession includes six formations. These successions are made up of Albian Arufu, Uomba and Gboko Formations, generally referred to as the Asu River Group (Offodile, 1976; Nwajide, 1990). The Precambrian basement is overlain unconformably by the Asu River Group. The Asu River Group is overlain by the late Albian-early Cenomanian Keana and Awe Formations and the Cenomanian-Turonian Ezeaku Formation. The late Turonian-early Santonian coal bearing Awgu Formation lies conformably on

the Ezeaku Formation. In the Markudi area, the Markudi sanstone interfingers with the Awgu Formation. The mid-santonian was a period of folding throughout the Benue Trough followed by the deposition of the post-folding Campano-Maastrichtian Lafia Formation after which there was widespread volcanic intrusion of basalts, phonolites and trachites mostly in the form of cone and lava sheets that seldom exceeds a few square kilometres in extent (Offodile, 1976; Obaje, 1994).

Fig. 5 is a Lithostratigraphic sub-division of the Cretaceous rocks of the Benue Trough

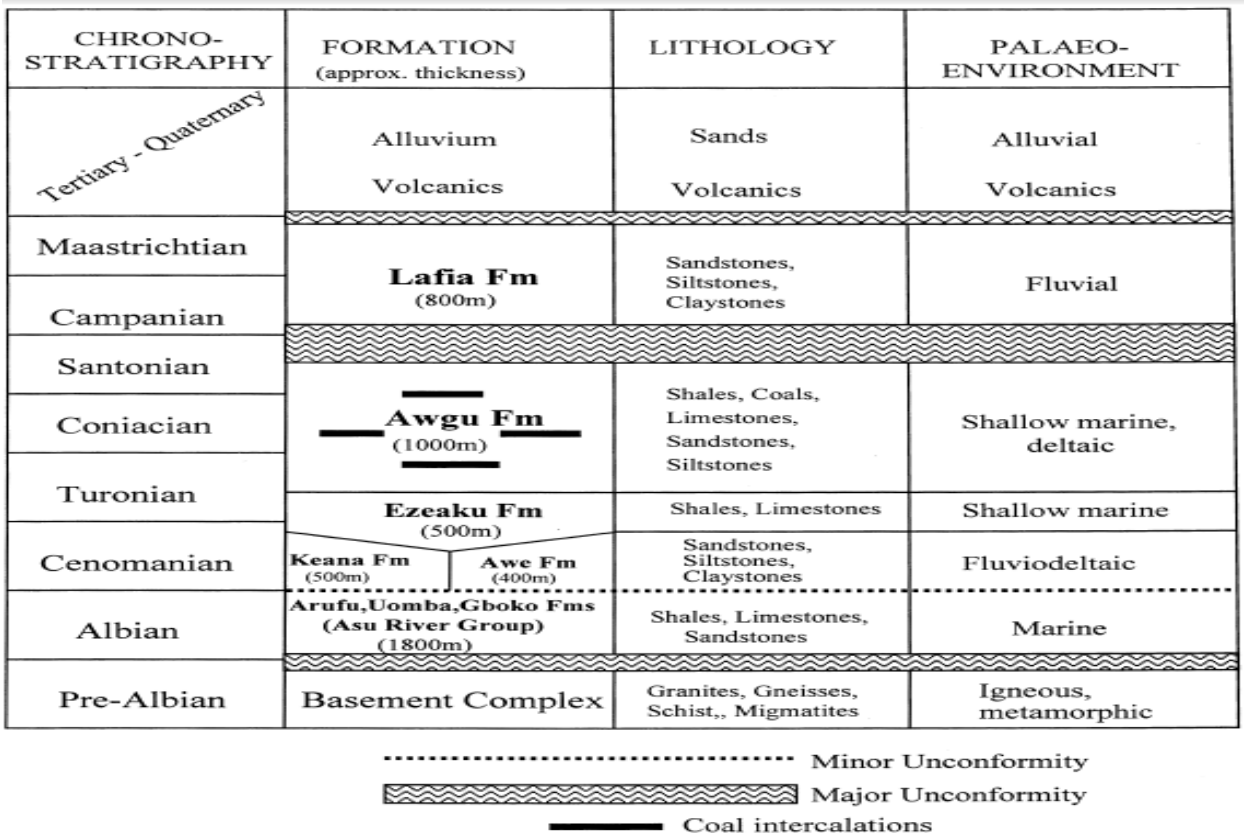


Fig 5: Stratigraphic successions in the Middle Benue Trough (After Obaje and Ligouis 1996)

2.3.1.1 Asu River Group

Different workers have attempted to name this Formation. Tattam (1944) described the lithological unit as the "Cross River and Benue Shales", while Simpson (1955) used the term 'Asu River series'.

Previous works on the stratigraphy of the Benue Trough have also given differing subdivision of the Asu River Group. Reyment (1955) subdivided the Asu River Group into five formations,

namely Uomba Formation, Abakaliki shales, Arufu limestone and two unnamed formations while (Offodile, 1976; Nwajide 1990), subdivided the Asu River Group succession into the Albian Arufu, Uomba and Gboko Formations.

The succession outcrops mainly in the Keana Anticline east of Keana town and south of Azara; and in the area around Gboko with a type section in the quarry of the Benue Cement Company near Yandev.

The lithologic composition of the Asu River Group includes limestones, dark shales, micaceous siltstones, mudstones and clay (Offodile, 1976; Obaje, 1994). The transgression is believed to have been caused by the changes in the sea floor resulting from the initial growth of the mid Atlantic ridge. There was apparently an abundant supply of argillaceous material from the continent, under a very low gradient, and low energy conditions. The deposition of the Abakaliki lead-zinc deposits hosted within a sequence of carbonaceous shales of the Asu River Group also occurred during this period (Akande *et al.,* 1993).

2.3.1.1a Uomba Formation

The type locality was designated by Reyment (1965) at the Uomba River in Taraba State. It consists of sandstones, sandy shales and shales. It contains *Cytropidoceratids* and *Diploceratid* ammonites. This is one of those units of the central Benue Trough awaiting detailed characterisation; no further information beyond that of Reyment mentioned above appears to have been published. The Uomba Formation [= "Asu River Formation"] outcrops on the Keana anticline to the east of the town of Keana. Benkhelil *et al.* (1988) reported shale-dominated lacustrine facies with channel fill sequences in the lower Asu River Group east of Keana town with the sediments being fossiliferous, containing Late Middle Albian ammonites *Oxytropidoceras* (Offodile and Reyment, 1977).

2.3.1.1b Arufu Formation

It does not seem to have been studied in any detail. It appears to be only a local occurrence and is intricately associated with Lead-Zinc mineralization. The occurrence of the ammonite *lobiceras sp*. places it as a stratigraphic equivalent of the Abakaliki Shales (Nwajide, 1996).

2.3.1.1c Gboko Limestone

The type locality of the Gboko limestone is at Yandev, a village between Egede hills and Gboko in Benue State. Limestone occurences were first reported around the village in 1950 by the prospectors of the Amalgamated Tin Mines of Nigeria (Nwajide, 2013). Detailed study including drilling and laboratory investigations by the Geological Survey of Nigeria, which estimated the reserves at about 70 million tonnes of limestone with 88% $CaCo_3$ content formed basis for the establishment of the Benue Cement Company. Studies of the biofacies and carbonate microfacies include those by Nair and Ramanathan (1984). Najime (2010) described a 120m thick section of Gboko Formation exposed at the Benue Cement Company Quarry comprising of limestones, shales and clays with its members as Akpagher, Mayenge and Ikumbur and on this basis, he placed the Gboko Formation in the Lower Benue Trough

2.3.1.2 Awe Formation/Keana Formation

This formation is being proposed as a formal lithostratigraphical unit (Offodile and Reyment 1976). Falconer (1911) noted the formation to comprise white sandstones and carbonaceous shales at Awe. This formation formed the second cycle of sedimentation in the Middle Benue Trough and the Awe formation was deposited as passage (transitional) beds during the Late Albian-Early Cenomanian regression. As the Albian sea regressed, accompanied by minor forward and backward movements of the coastline (oscillation), it resulted to an interplay of shallow marine and transitional marine conditions with the deposition of rapidly alternating

medium to coarse sandstones and shales. Its typical sections occur around the town of Awe (Offodile, 1976). The formation consists of whitish, medium to coarse-grained calcaereous sandstones, carbonaceous shales and clays (Falconer, 1911).

The Keana Formation resulted from the Cenomanian regression, which deposited fluvio-deltaic sediments. The formation consists of cross-bedded, coarse-grained feldspathic sandstones, occasional conglomerates, and bands of shales and limestones towards the top. Massive outcrops occur at Keana, Noku, Chikinye and Azara (Obaje, 1994). The Bima Sandstone, the Keana and Makurdi Formations are thought to be possibly, part of the same lithological unit, which appears to get progressively younger in age, from the northeast to the southwest.

The sandstones are typically massive, heavily current-bedded, and fine to very coarse, sometimes very conglomeratic. The sandstones are fluiviatile in origin. No fossils were found in the field area, though, as in the Awe Formation, worm tracks and burrows are abundant in the basal parts.

2.3.1.3 Ezeaku Formation

The formation was first recognised by Shell-B.P. geologist, as Ezeaku Shales; they also noted it contains oil seeps (Offodile, 1976).

The trangressive movements responsible for deposition of Ezeaku Formation have been shown, from the palaeontological evidence, to have started during late Cenomanian. The sediments are consist of mainly calcareous shales, micaceous sandstones and beds of limestones. The deposition took place probably in shallow marine coastal environment. This formation has outcrops at Ortesh, River Tokura, about 20km east of Keana town (Obaje, 2009). The limestones contain bivalve *Exogyra olisiponensis* (Sharpe) (Offodile, 1976). Further, away from the continents, predominantly argillaceous materials were deposited including clay and shales (Offodile, 1976)

2.3.1.4 Awgu Formation

The Awgu Formation has been variously described by different authors (Offodile 1976; Obaje, 2000). (Offodile, 1976) estimated the thickness to be about 700m. Tattam (1944) described it first, as the Cross River-Benue Shales and then, as the Awgu Sandstone and Shales. Simpson (1955) named it the Awgu-Ndeaboh Shales, taking an informal name of the Shell-B.P. geologists. Reyment (1965) described the type locality between Awgu and Ndeaboh in the Anambra State of Nigeria and found bluish grey-bedded shales with occasional intercalations of fine-grained, pale-yellow calcerous sandstones and shaly limestone. In the Middle Benue Trough, a similar sequence, marine in origin, was found to consist essentially of black shales, sandstones, limestones, and coal seams. The coal seams appear to be confined to the northern parts of the study area, though deeper and possibly older coal bearing strata may occur further south. The Agwu Formation belongs to the Turonian-Santonian cycle. The coals, which are of bituminous rank, were subdivided into three facies types by Obaje and Ligouis (1996) as follows:

- A vitrinite-fusinite facies believed to have formed in telmatic wet forest swamps along and within lagoons
- A trimaceratic facies, dominated by vitrinite with subordinate liptinite and inertinite, believed to have formed within deltaic plain, limno-telmatic clastic marsh environments.
- A shaly coal facies, containing more than 25% mineral matter, mostly clay minerals and pyrite, believed to have formed under greater marine influence

The formation outcrops at the bank of River Dep in Shankodi, 7km to the west of the village

of Jangwa. The occurrence of low diversity arenaceous foraminifera in the Awgu Formation indicates depositon in marshy, deltaic and shallow marine conditions (Obaje, 1994).

2.3.1.5 Lafia Formation

This is the youngest of all the formations in this area of the Middle Benue Trough. Different workers have described it differently. Falconer (1911) called it the "Upper Grits and Sandstones", and had described an unfossiliferous, non-salt-bearing, brick red grit, with white spots of feldspathic material. Farrington (1952) referred to it as the "Sandstone of Lafia/Makurdi". Cratchly and Jones (1965) termed it the Lafia Sandstone, and included the Rafin Kwoli coals. This coal sequence is thought to belong to the upper part of the Awgu Formation. The Lafia Formation as understood here, covers thinly the Awgu Formation in the middle Benue Trough, and occupies most areas to the west and northwest of the area described. It is believed to have been deposited during the Campanian-Maastrichtian cycle, which is a continental condition (fluviatile). The formation has sections in and around the town of Lafia and along the bank of River Amba on the Lafia-Doma road. The formation consist essentially of continental ferruginised sandstones, red, loose sands, flaggy mudstones and clay. Erosional processes and development of rivers and lakes led to flow of the fluviatile sandstones of the Lafia Formation built up in that general direction and increased in thickness. Ferruginisation is probably syndepositional arising from strong oxidation which also persisted and iron-enrichment resulting in the ironstone capping of the formation.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

For the success of this research, methods such as desk study, detailed fieldwork were used. Sieve and petrographic analyses were the methods used to analyse the samples collected from the field.

3.2 Desk study

This involved a detailed literature search into the more relevant previous works carried out in the area. Materials such as textbooks, maps and journals were used for this purpose.

3.3 Detailed Fieldwork

A reconnaissance survey first carried out from the 14th to 18th July 2017 to identify the sedimentary structures, rock types and other geological structures within the area of study. This was followed by a more detailed fieldwork from the 14th to 22nd of February 2017 during which sections were logged, samples were collected and more geological structures were identified and recorded. 12 samples were collected for petrographic analysis (Table 4.1) and 11 samples for Petrographic analysis (plates I, is a basaltic flow, II, III, IV, V, VI, VII, X, and XI are sandstone photomicrograph, XII is a limestone while XIII is a shaley limestone). Equipment used for this work were as follows; Camera, Measuring Tape, Ruler, Global Positioning System (GPS), compass clinometre, hammer, chisel and topographic map. Geologic hammer was used to break samples for analyses and fieldwork was carried out during the dry season

3.4 Laboratory Analyses of Samples

The following methods were employed for the analyses of samples collected from the field: Sieve and, Petrographic analyses.

3.4.1 Sieve Analysis

This analysis also known as granulometric analysis was carried out on the sandstones samples of the study area in the sedimentology laboratory, Department of Geology Ahmadu Bello University, Zaria. 12 samples were collected for granulometric analysis. The parametres determined included the graphic mean, graphic skewness, graphic standard deviation, and graphic kurtosis.

A sieve is a device containing squared openings of specified slot sizes, where only the particle smaller than that size can pass through the sieve with proper orientation. The sieve is constructed of wire mesh

Procedures: The test was carried out by stacking a number of standard sieves, ranging in sizes from the smallest at the bottom to the largest at the top. In this experiment, the sieves were stacked in the following series: pan, 0.75µm, 0.15µm, 0.3µm, 0.63µm, 1.18mm

100 gram of disaggregated rock sample was poured into the topmost sieve and all were placed on the shaker for a period of 10 minutes until the particles were separated and retained on the different sieve sizes as mentioned above.

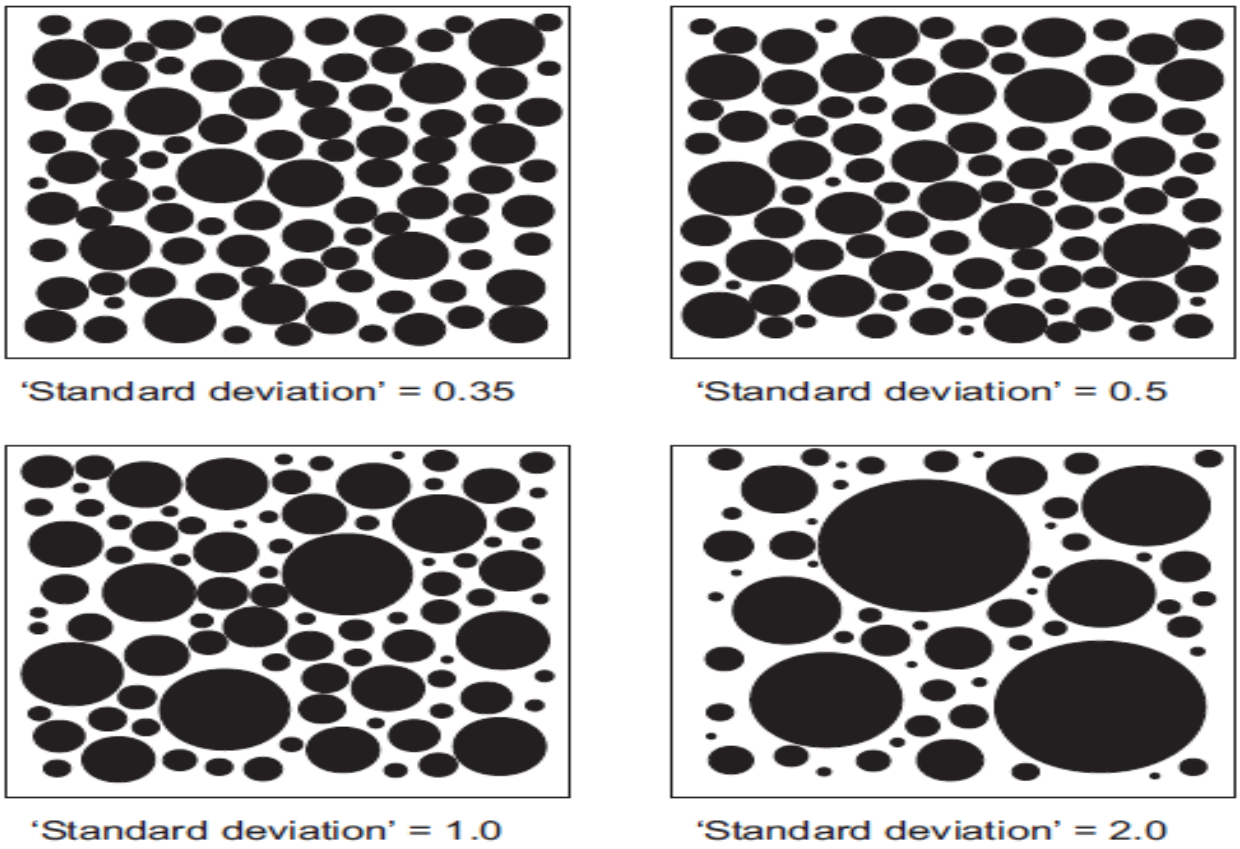


Fig.6**:** Graphic illustration of sorting in clastic sediments.

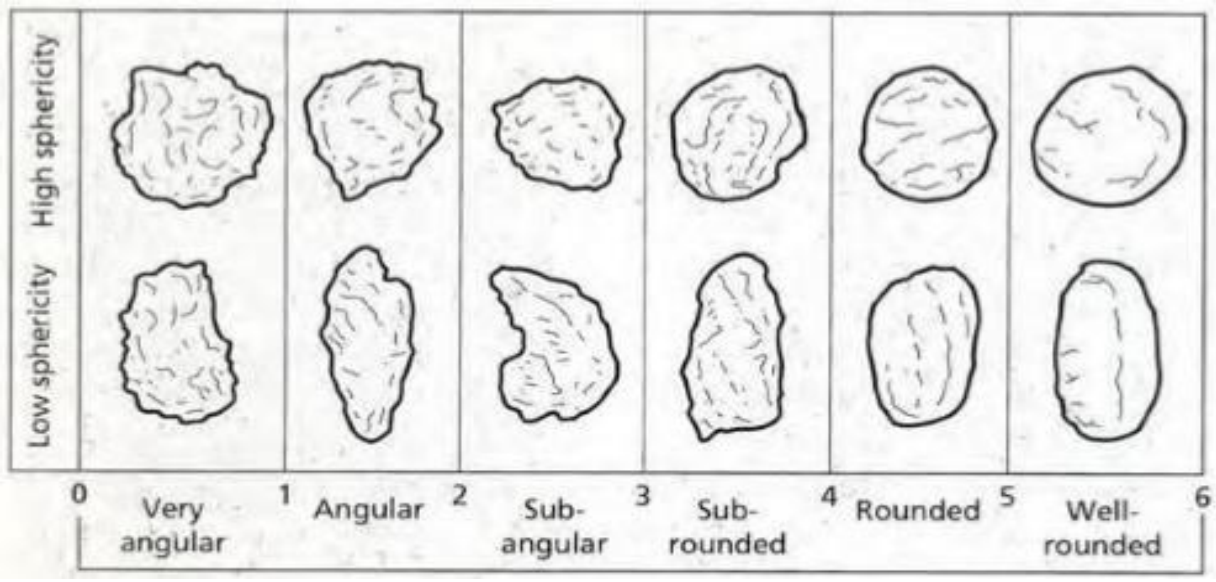


Fig 7. Degree of roundedness of sediments and their classification (After Pettijohn et al., 1987)

3.4.1.1 Parametres of granulometric analyses

a. Graphic Mean: The mean size is the arithmetic average of all the particle sizes in the sample. An approximation of the arithmetic mean can be arrived at by picking selected percentile values from the cumulative curve and averaging these values.

$$M = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

b. Graphic sorting (Standard deviation): Sorting is a description of the distribution of the clasts sizes present and it is also a function of the origin and transport history of the detritus with increased transport distance or repeated agitation of a sediment, the different sizes tend to become separated (Fig. 6). This sorting can be determined using a chart

$$I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

c. Graphic skewness: This is a measure of wether the grain-size histogram is symmetrical or is skewed to a higher percentage of coarser or finer material (Fig. 8)

$$Ski = \frac{\phi 84 + \phi 16 - 2(\phi 50)}{2(\phi 84 - \phi 16)} + \frac{\phi 95 + \phi 5 - 2(\phi 50)}{2(\phi 95 - \phi 5)}$$

d. Graphic kurtosis: This is a measure of wether the histogram has a sharp peak or a flat top

$$K_G = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

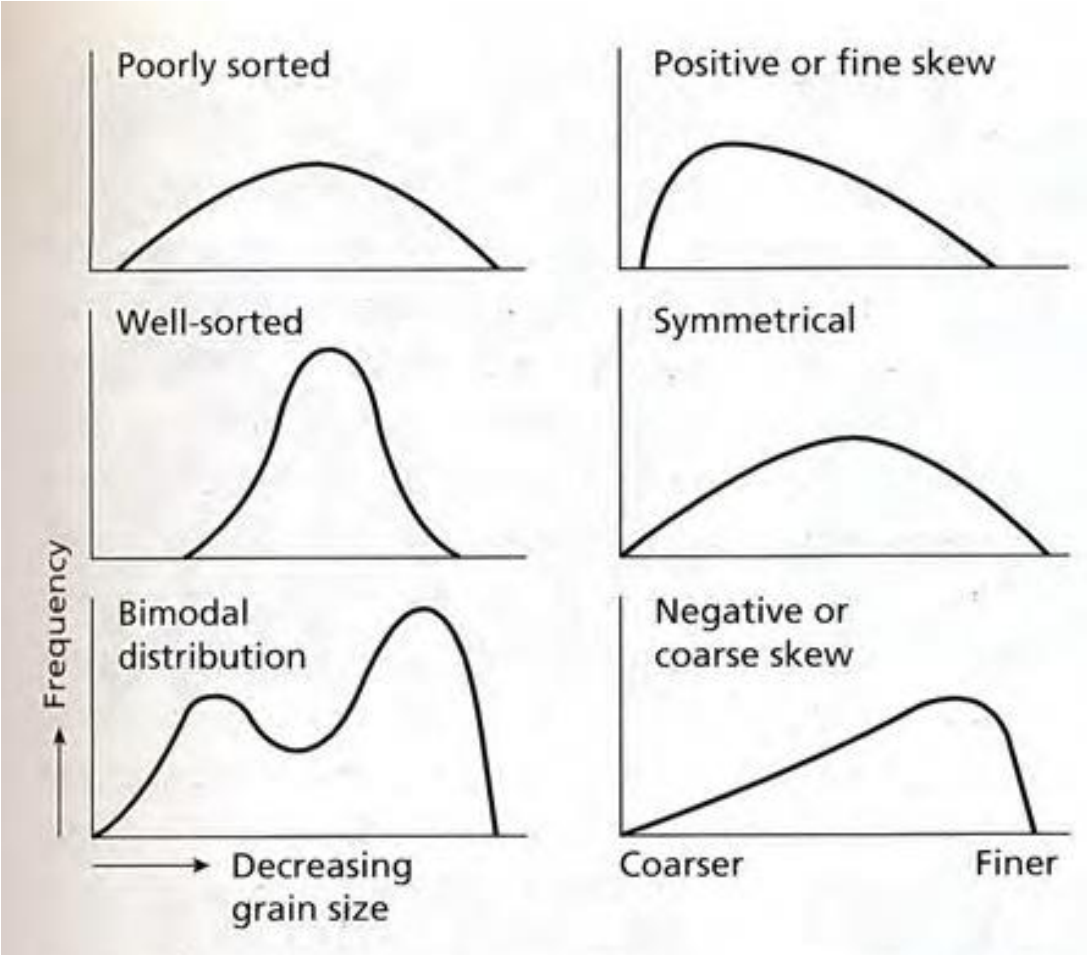


Fig.8: Smoothed frequency distribution curves showing types of sorting and skewness (Tucker, 2001)

3.4.1.2 Pettijohn sandstone classification

Pettijohn sandstone classification is a plot that classifies sandstones. It combines textural criteria, the proportion of muddy matrix and the percentages of the three commonest components of sandstone namely quartz, feldspar and lithic fragments as the basis for the classification (Gary Nichols, 2009)

When the amount of matrix is less than 15%, the rock is called an **Arenite.** (Presence of 25% feldspar in the rock, it is called feldspathic arenite (arkose); Presence of 25% lithic fragments in the rock, it is called lithic arenite: Presence of >95% quartz in the rock, it is called quartz arenite

When the amount of matrix is between 15%-75%, the rock is called **Wacke.** (Wackes can also be divided into quartz wacke, feldspathic wacke and lithic wacke)

When most of the volume of the rock is fine-grained matrix, it is called **Mudstone.** Below is figure 9, showing the classification of sandstones

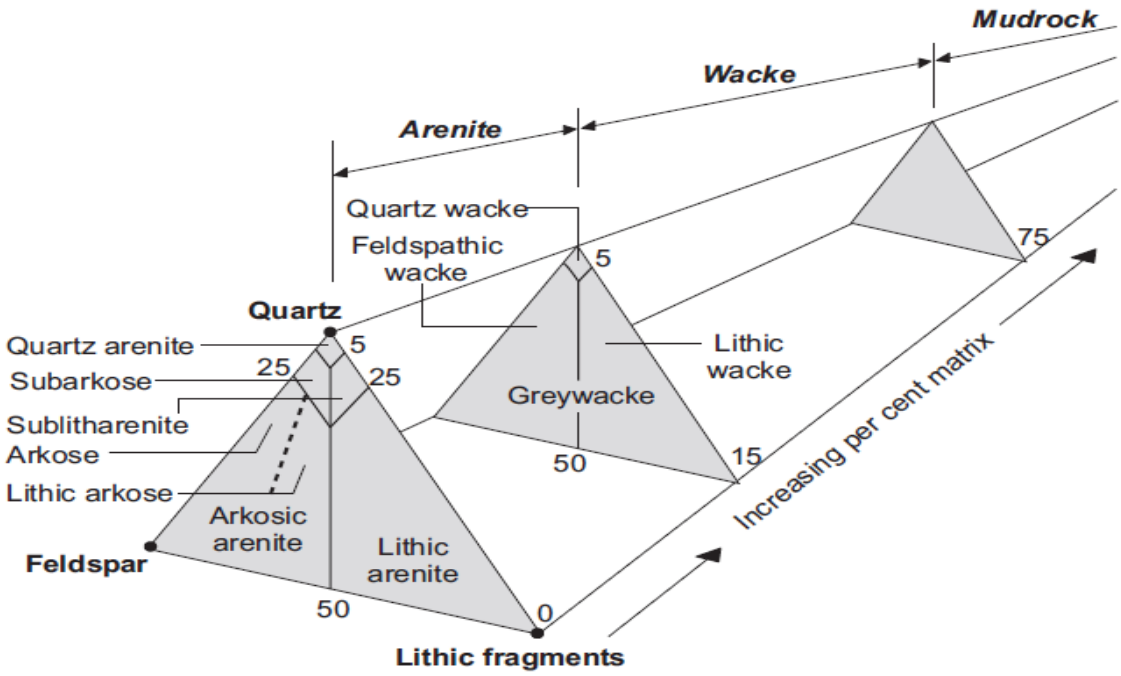


Fig.9: Classification of sandstones (After Pettijohn, 1975).

3.4.2 Petrographic Analysis

Petrographic studies involves the use of microscope to study thin sections of consolidated sediments. Petrographic analysis reveals the grains within the sandstones (shapes and sizes), the relationship between the grains, the different materials within them and their sorting or standard deviation. Thin section is a very thin (normally 30 microns) slice of rock, which can be examined under a petrological/petrographic microscope

Toward the bottom of the eyepiece tube there is a second polarising filter that is retractable. This polarizing filter is mounted perpendicular to the one below the stage, such that it only allows

through light waves that are vibrating at ninety degrees to the lower one. Fig. 3.2 is a photomicrograph of sandstone with about 80% quartz crystals. This rock can be classified as Quartz Arenite. A total of 11 samples were taken for petrographic analysis (plates I, is a basaltic flow, II, III, IV, V, VI, VII, X, and XI are sandstone photomicrograph, XII is a limestone while XIII is a shaley limestone)

CHAPTER FOUR

RESULTS

4.1 Introduction

The formations encountered in the study area includes Awe (AE), Awgu (AW) and Lafia (L) Formations. This chapter describes the stratigraphy and field observations of the study area as well as the results of the samples analysed in the laboratory. The data from the field includes lithological logs, strike, dips, and Extent/demarcation of formation boundaries. Sedimentary structures observed includes structures such as bioturbation and mudcracks. Results from sieve and thin section analyses compared with standard result as given by Folk, (1974).

Table 4.1: Results of Granulometric Analysis

	Graphic Mean	**Sorting**	**Skewness**	**Kurtosis**
L_1	1.03 Medium-grained	0.72 Moderately well sorted	-0.33 Strongly coarse skewed	1.3 Leptokurtic
L_2	1.2 Medium-grained	1.0 Moderately sorted	-0.28 Negatively skewed	1.5 Very leptokurtic
L_3	0.9 Coarse-grained sand	1.0 Poorly sorted	-0.25 Negatively skewed	1.05 Mesokurtic
L_4	1.4 Medium-grained	0.60 Moderately well sorted sorted	-0.10 Near symetrical	0.8 Mesokurtic
L_5	1.06 Medium grained sand	0.68 Moderately well sorted	-0.15 Negatively skewed	1.1 Mesokurtic
AE_1	2.2 Fine grained sand	0.88 Moderately sorted	-0.071 Near symmetrical	1.48 Leptokurtic
AE_2	2.13 Fine grained sand	1.75 Poorly sorted	-0.27 Coarse skewed	0.8045 Platykutic
AE_3	1.8 Medium grained sand	0.85 Moderately sorted	-0.25 Coarse skewed	1.1 Leptokurtic
AE_4	2.1 Fine grained sand	1.55 Poorly sorted	-0.33 Strongly coarse skewed	1.20 Leptokurtic
AW_1	1.9 Medium grained sand	2.5 Very poorly sorted	-0.533 Strongly coarse skewed	0.65 Very platykurtic
AW_2	2.2 Fine-grained sand	1.55 Poorly sorted sand	-0.38 Strongly coarse skewed	1.01 Mesokurtic
AW_3	2.45 Fine-grained sand	1.5 Poorly sorted sand	-0.26 Negatively skewed	0.99 Mesokurtic

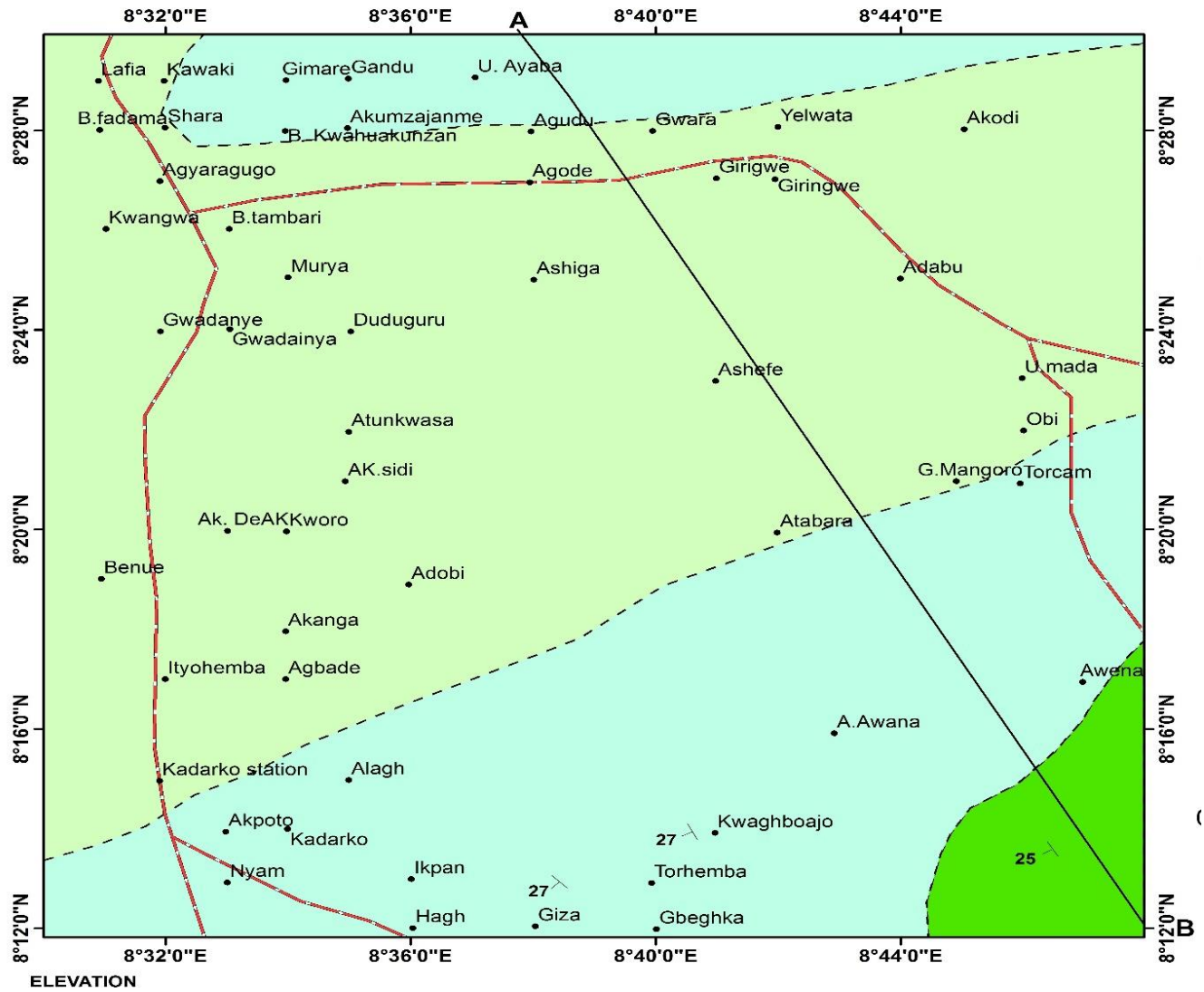


Fig. 10: Geological map of the study area showing the three different Formation

4.2 Geology and Stratigraphy of the Study Area

4.2.1 Lafia Formation

The Lafia Formation occurs mostly on the northwestern part of the map within the town of Doma and along the road from Doma to Agyaragu (Figure 10). The Lafia Formation is the youngest in the Middle-Benue Trough. It consists of ferrugenised, and thickly bedded sandstone layer at the base, sandy clay and clayey loose sands with a lateritic capping. The first section of the Lafia Formation encountered along Agyaragu-Doma road consists of (i) Sandstone at the base with a thickness of 13m, overlain by (ii) a second layer of sandy clay measuring upto 2m in thickness and overlain by (iii) a layer of clayed loosed sands at the top measuring 1m in thickness (Figure 11). The ferrugenised sandstone of this section consists of fine-grained angular grains of quartz cemented by a matrix. These quartz crystals consists of a high percentage of monocrystalline and few polycrystalline quartz grains (Plate II). The second section is composed of basaltic dyke at the base whose thickness is less than 0.02m; this is followed by ferrugenised sandstone with a thickness of 1.4m. The total thickness of this section is 1.42m and it was encountered around the town of Agyaragu. The sandstones are fine to medium grained, moderately sorted, coarse skewed to negatively skewed and range from very leptokurtic to mesokurtic (Table 4.1). The sandstone of this section was intruded by a basaltic dyke at the base (Plate Ic and III).

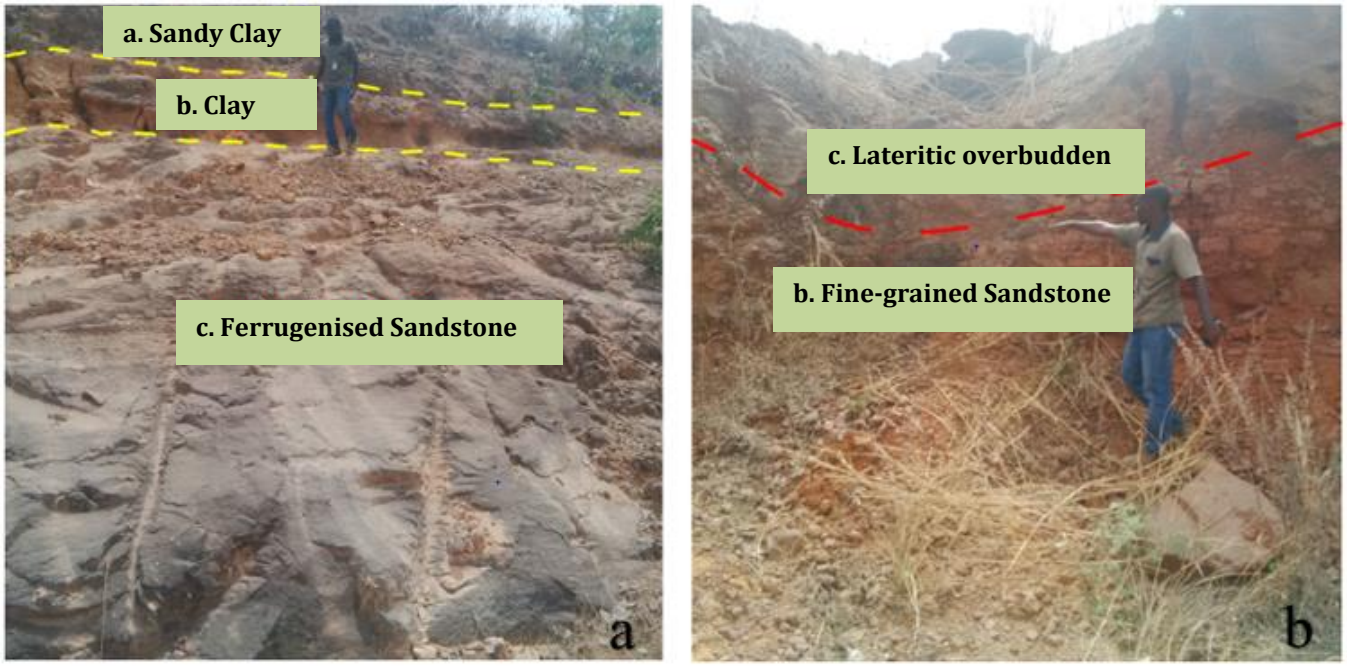


Plate I: (a) Lithologic section of Lafia Formation exposed along the road from Agyaragu to Doma. **08°22′16.4″N 08°21′03.2″E** (b) Channel fill sediments within the Lafia Formation

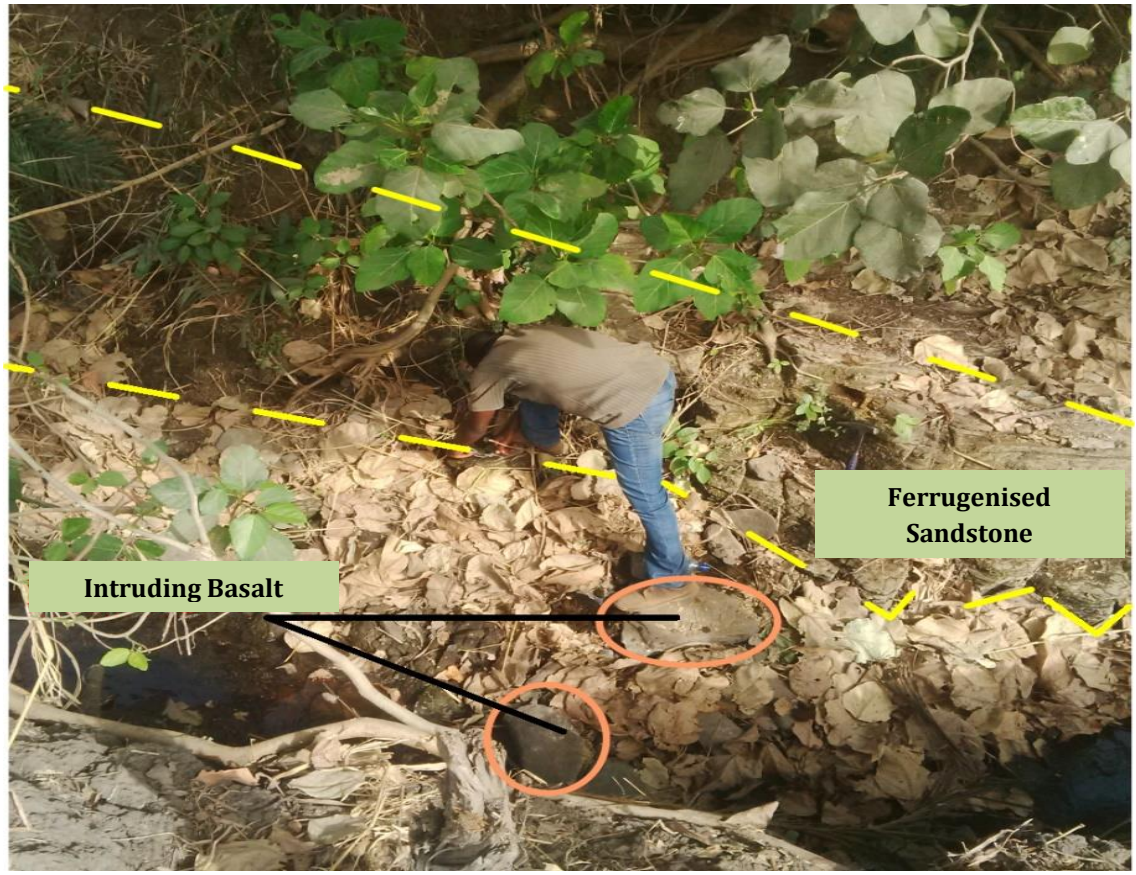


Plate Ic: A section of Lafia ferrugenised sandstone intruded by basaltic dyke

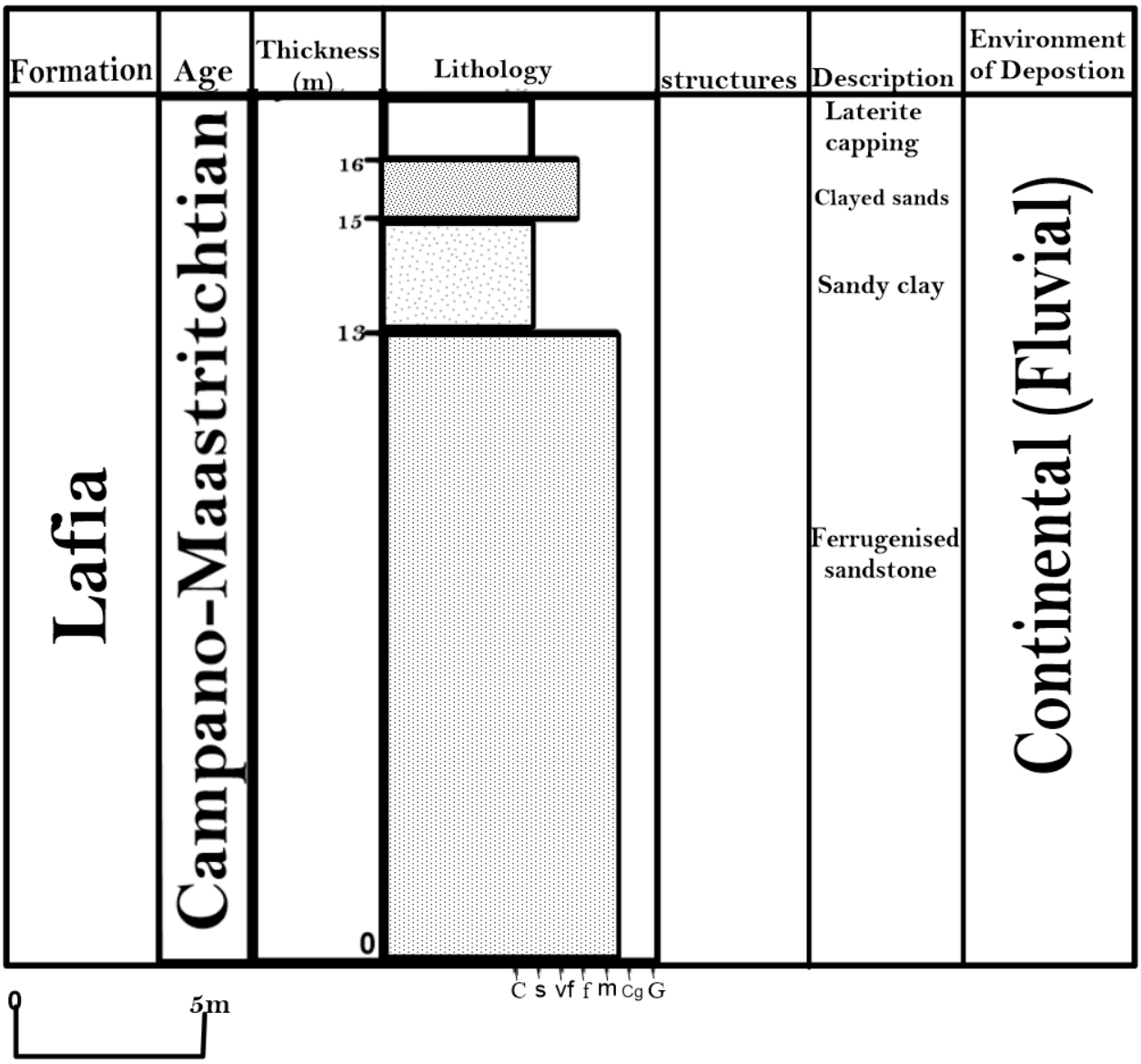


Figure 11: Lithostratigraphic log of the Lafia Formation exposed along the road from Agyaragu to Doma **08°22′16.4″N 08° 21′03.2″E**

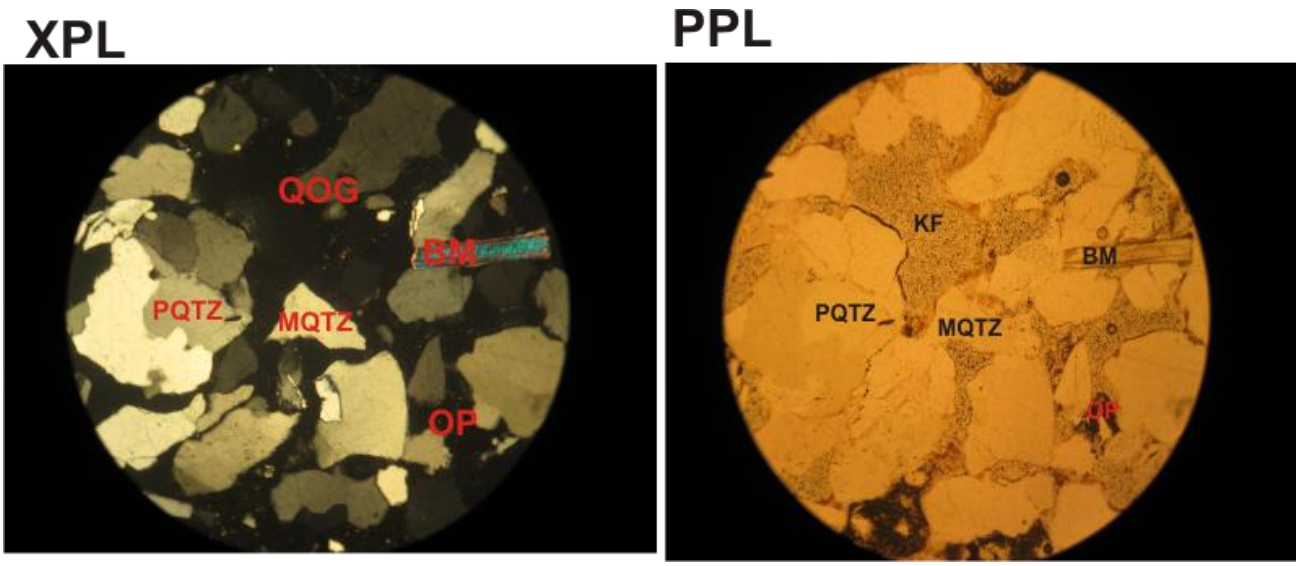


Plate II: **Sample L1-DM [Mg.x40]** Photomicrograph of sandstone of the Lafia Formation showing quartz and muscovite (Quartz Arenite) P**Qtz:** polycrystalline quartz **Mqtz**: monocrystalline quartz **Ms:** Biotite mica **Op:** Opaques **KF:** K-feldspar (Orthoclase)

Description of Lafia sandstone

The majority of the grains are quartz followed by few muscovite grains. The untwinned feldspars (K-feldspars) appears to have undergone severe alteration. Majority of the quartz grains are monocrystalline with few polycrystalline grains. The quartz grains are fine to medium grained.

The rock is mineralogically mature. The maturity is evident by the fact that there are few grains of unstable minerals like muscovite and feldpars. The grains are subangular, moderately to well sorted and therefore texturally submature.

There is also a presence of Opaques, which are Iron oxides

Diagenetic features includes Quartz overgrowth and sutured grain boundaries. The sutured grain boundaries is an indication of pressure solution and therefore deeper burial.

95% of the crystals are quartz therefore, the rock is a Quartz Arenite.

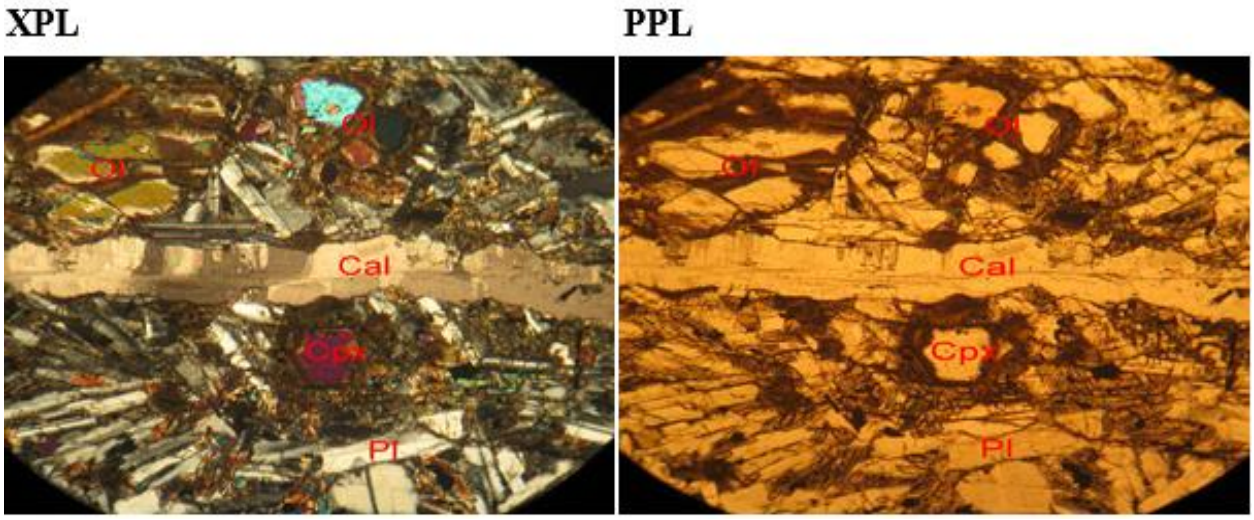


Plate III: [**MgX40]** Photomicrograph of intruding Basalt within Lafia Formation Pl**:** plagioclase feldspar, **Ol:**Olivine, **Cpx**: Clinopyroxene **Cal**: Calcite

Description

The basalt sample consists of grains of Olivine and Clinopyroxene. The groundmass consisting equigranular clinopyroxene and plagioclase forms the majority of the rock's composition**.**

The opaque minerals are platy-thread like while the clinopyroxene and plagioclase are medium grained. The plagioclase grains are euhedral while the microphenocrysts (Olivine and clinopyroxenes) are anhedral, with a very narrow vein calcite

Rock name: Basalt

4.2.2 Awe Formation

The Awe Formation covers a small portion in the southeastern part of the study area along the road from Obi to Awena (Figure 10). This formation consists of sandstones, clay, and shales. Two sections of the Awe Formation were encountered/logged along the road from Lafia to keana with thicknesses of about 3.6m and 5.08m respectively.

The first section (Plate IVa) seen along Keana to Aloshi road (i) 1.4m of clay, (ii) 1.6m of sandstone; (iii) 2.2m of sandstone intercalated with shale (Plate IV and Fig 10 and 13). This

section of the Awe Formation consists of white and very fine-grained sandstones. The sample of the sandstone reveals that 80% of the rock to be quartz grains. The majority quartz grains are present with minor compositions of feldspars and muscovites. The quartz crystals are majorly monocrystalline with few polycrystalline types. The albite twinning in the rock sample represents plagioclase feldspar. The sandstone of this section are very fine-grained, poorly sorted, coarse-skewed and platykurtic (sample AE_1 -AE_4 in Table 4.1).

The second section (Plate IVb and Fig 13) exposed at keana consists of 1.8m of sandstone at the base, followed by 1.2m of clay and 0.6m thick of shale at the top. The white and fine-grained sandstone of the formation consists of equigranular grains making up about 80% of the rock mass. Quartz grains within these equigranular grains are majorly monocrystalline with few polycrystalline types. They are also subangular. The feldspars within the grains have undergone severe alteration. The crosshatched twinning represents microcline feldspars while albite twinning are indicative of plagioclase feldspars.



Plate IV: (a) Lithologic section of the Awe Formation occurring along Lafia-Awena road. **08°11′12.9″ N 08°47′51.6″E (a)** The first exposure along the road cut showing sandstones, clay and shale **(b)** Continuation along the same road cut of the lithologic section comprising of massive sandstone overrlying a clay bed

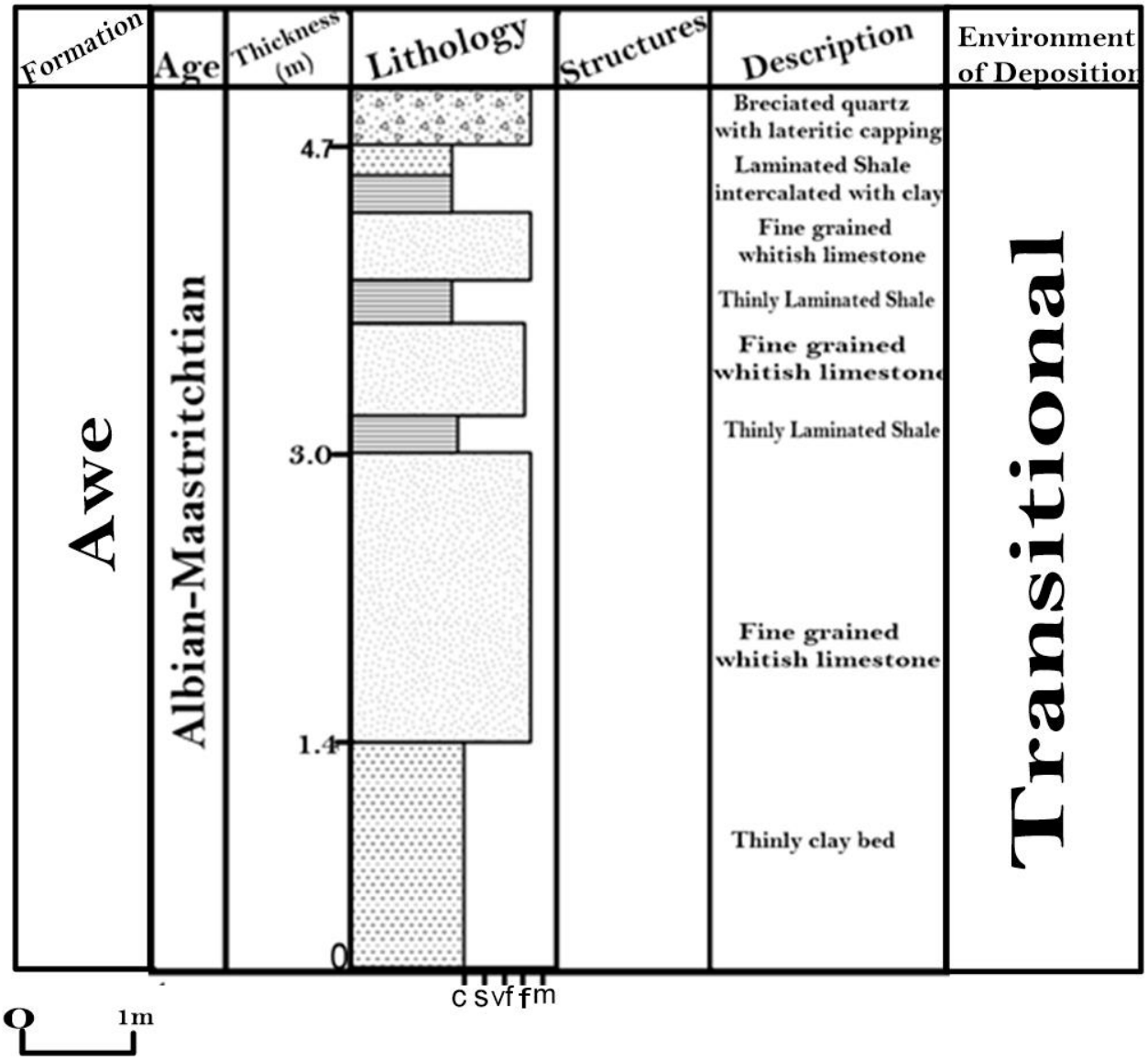


Fig 12: A lithologic section of the Awe Formation along the Keana to Giza road cut **08°14′ 50.3″ N 08°48′ 14.0″E**

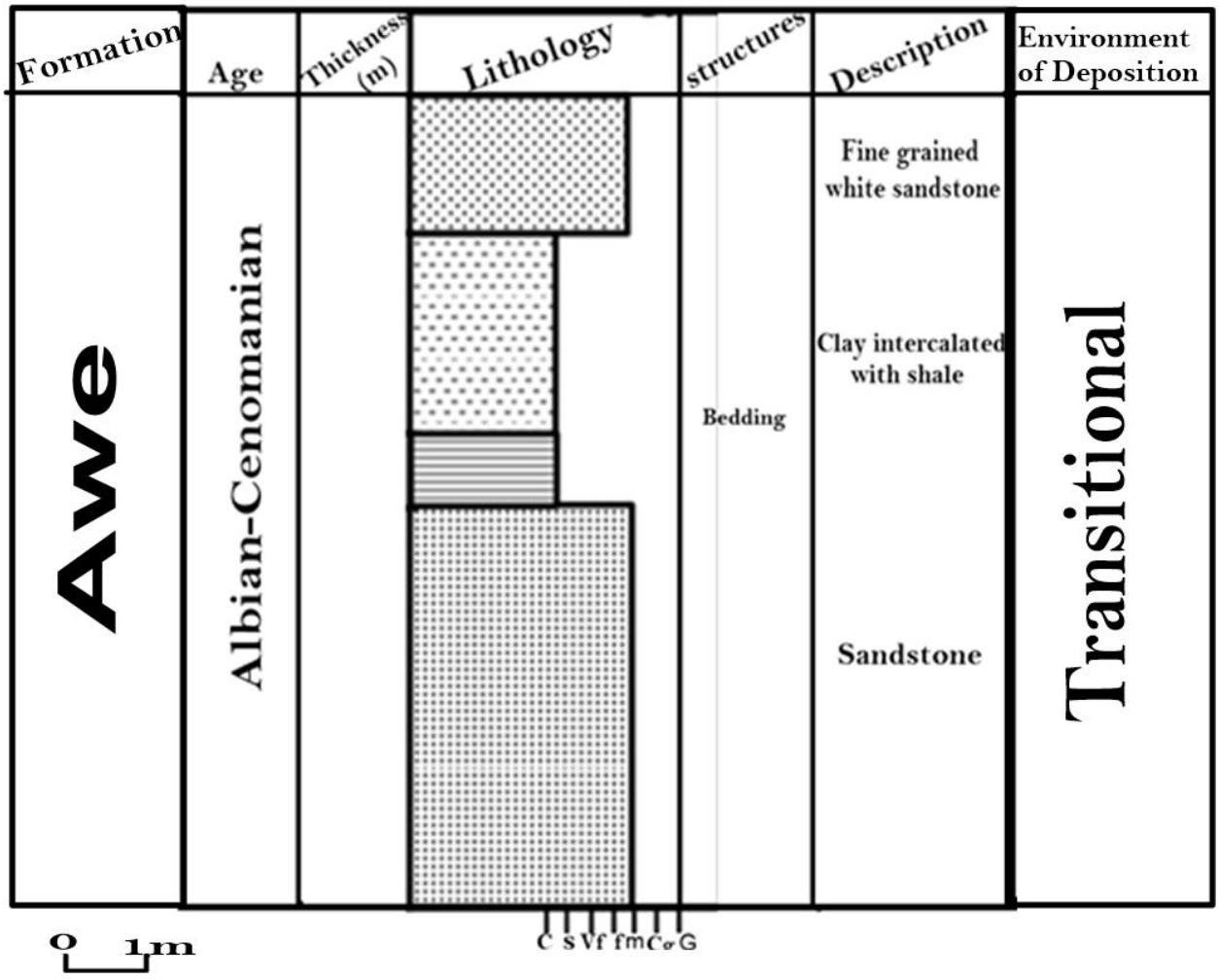


Fig 13: Lithostratigraphic log of the Awe Formation along the Keana to Aloshi road
08°14′50.3″N 08°48′14.0″E

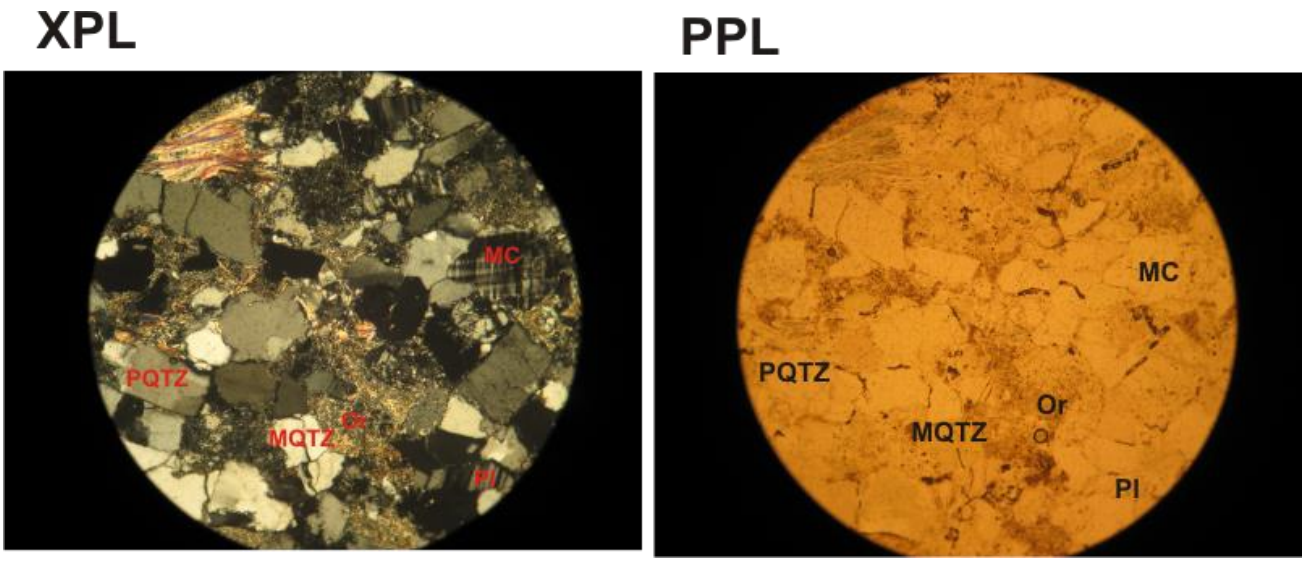


Plate V: **Sample AE-1** [**Mg.x40]** Photomicrograph of sandstone of the Awe Formation (Arkose) **NB: MQtz:** monocrystalline quartz, **PQtz**: polycrystalline quartz **Pl:**plagioclase feldspar **Mc:** microcline feldspar, **Or:** orthoclase feldspar

Description of Awe Sandstone

Majority of the grains are quartz grains, with few feldspars, and muscovite (mica flakes). The quartz grains are fine-grained and dorminantly monocrystalline, with minor polycrystalline grains. There are plagioclase feldspars represented by Albite twinning and microcline feldspars represented by cross-hatched twinning. The rock is mineralogically submature. The immaturity is evident by the fact that there are many grains of unstable minerals like muscovite and K-feldpar. The grains are angular to subangular, moderately to well sorted and therefore texturally submature. The feldspars are severely altered thereby forming sericite. There are microcline feldspars with crosshatched twinning and plagioclase feldspar with albite twinning. The orthoclase feldspar have no twinning. A few grains appear to have sutured grain boundaries, which are all diagenetic indicating intense pressure solution and therefore chemical compaction.

The rock is an arkose

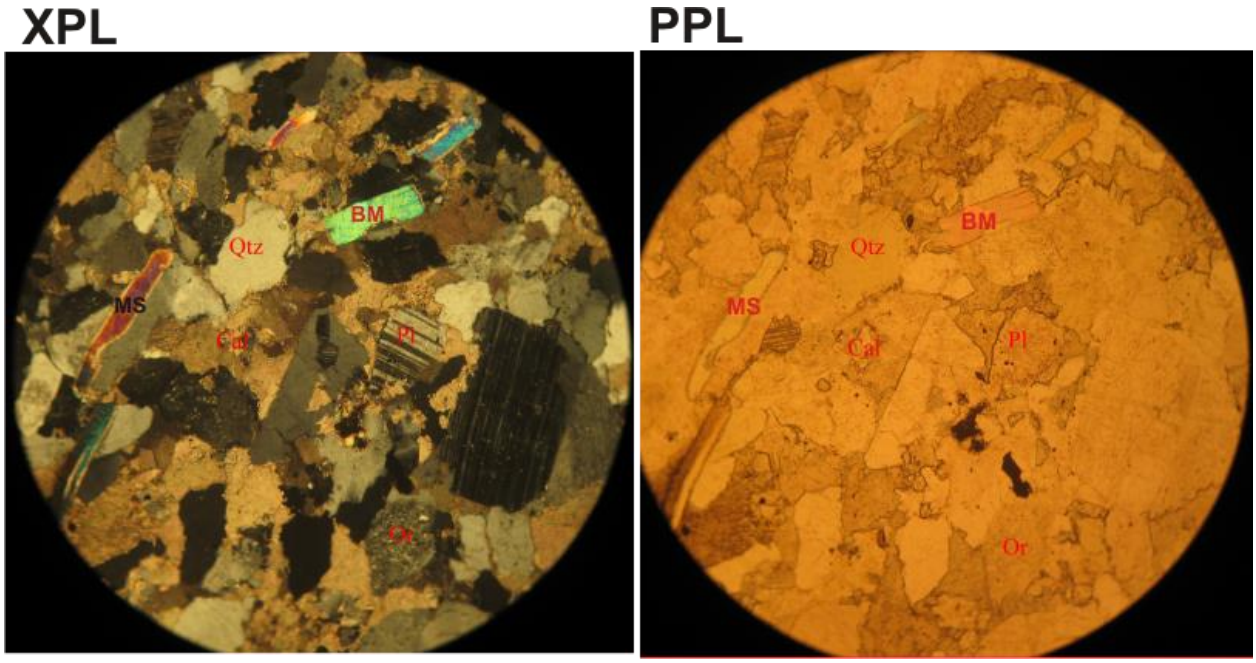


Plate VI: AE-2 [Mg. x40] Photomicrograph of the Sandstone of the Awe Formation [Subarkose] **NB: MQtz:** monocrystalline quartz, **PQtz**: polycrystalline quartz **Pl:** plagioclase feldspar, **Or:** orthoclase feldspar **Cal**: Calcite

Description Awe Sandstone

The quartz grains are quite few when compared to other samples (AE-2 and L1-DM). Majority of the quartz grains are monocrystalline with few polycrystalline types. There is also the presence of calcite in abundance. The feldspar types includes orthoclase feldspar (K-feldspar) and plagioclase feldspar showing Albite twinning. The grains of the quartz and orthoclase feldspars are fine-grained and are cemented by the calcite thereby forming a poikilotopic texture. The Micas within the rock includes biotite and muscovites. There are also opaques which are iron oxides within the rock. Below the plagioclase feldspar are few rock fragments.

The immaturity is evident by the fact that there are many grains of unstable minerals like muscovite and feldspars with little alteration. The sediments are poorly sorted, subangular and therefore texturally submature. The feldspars are severely altered thereby forming sericite. There are microcline feldspars with crosshatched twinning and plagioclase feldspar with albite twinning

Diagenetic features observed is pressure solution resulting in sutured grain boundaries. In addition, some of the feldspars have been partially lost in solution thereby creating a secondary porosity.

The rock is a calcareous sandstone

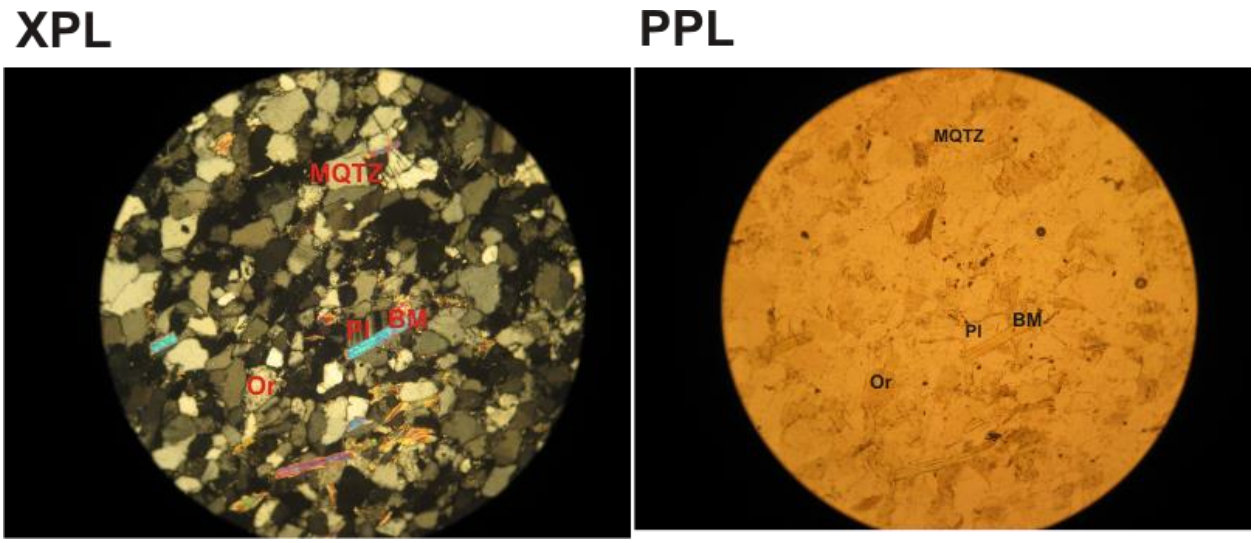


Plate VII. **Sample AE-3 [Mgx40]** Photomicrograph of sandstone from the Awe Formation (Quartz Arenite) **NB**: **MQtz:** monocrystalline quartz polycrystalline quartz, **Pl:** plagioclase feldspar **Or:** orthoclase feldspar, **Ms:** muscovite mica **BM**: Biotite Mica

Description of Awe Sandstone

The majority of the grains are quartz and few feldspars (orthoclase and Plagiocase), with some relatively low proportion of muscovite. There muscovite and biotite micas within the sandstone. The grains are very fine grained. The quartz grains are dorminantly monocrystalline with few polycrystalline type making upto 95% of the grains. The feldspars are highly altered to sericite. The grains are mineralogically submature and texturally submature as seen by its poorly sorted and subangular sediments. The sutured boundaries between some of the grains indicate pressure solution

4.2.3 Awgu Formation

The Awgu Formation has few sections at the northern part of the map around the town of Bukan Fadama and many sections at the southern part of the map around the town of Giza (Fig. 10)

This Formation consists of carbonaceous shales, shaley limestone, limestone, sandstones and coal seams; the coal seam found within a section at Bukan Fadama was seen exposed to the surface.

The first section (Fig. 14) was encountered at the southern part of the map in a village called Nyitameri with a total thickness of 2.6m while the second section was encountered at the bridge around Bukan Fadama with a thickness of 2.54m. The first section includes beds of fossilised shaley limestone with 0.8m thickness at the base, sandstone with a thickness of 0.6m, a second bed of fossilised shaley limestone with a thickness of 0.4m, a second sandstone bed with a thickness of 0.35m and a third fossilised shaley limestone bed with a thickness of 0.25m at the top (Plate VIII). The sandstones of this section are very fine-grained and consists of equigranular grains with few cementing materials (Plate X). The quartz grains within the sandstone makes up about 70% of the crystals while the orthoclase feldspars and muscovites together make up about 20%. The fine grained quartz grains are angular. The feldspars appear to be altered forming sericite. The photomicrograph of limestone within this formation shows it consists of the fossils echinoderms, ostracodes and foraminifera. The forams belong to the species *Heterophelix globulosa* while the ostracodes belong to the species *Buntonia vanmorkhoveni sp.* which corroborates earlier findings by Reyment (1965). The sieve analysis of this sandstone reveals that it is fine-grained, very poorly sorted, strongly coarse skewed, and very platykurtic. Sedimentary structures includes mudcracks, beddings, little evidence of resting trace fossils and abundant

presence of ammonites macro fossil. Nwajide (2013) named the species of the ammonite to be *Texanites sp*. This work has corroborated his earlier findings

The second section (Fig. 15) has bed of coal at base, with a thickness of 0.1m overlain by a bed of fine-grained sandstone with a thickness of 0.6m, then a bed of fissile shale with a thickness of 1.3m and finally, mudstone with a thickness of 0.54m at the top. The sandstone of this section of Awgu Formation are fine grained, consist majorly of monocrystalline quartz with few polycrystalline quartz and range from angular to subangular. It also consists of orthoclase feldspars and few grains of muscovites (Plate XI). The sandstone is fine grained, poorly sorted, stongly coarse skewed and mesokurtic (Table 4.1). Geological structures within this Formation includes bedding, and laminations within the sandstones and the shales respectively.



Plate VIII: A Lithologic section of the Awgu Formation sandstone overlain by shaley limestone at Nyimateri **08°07′45.1″N 08°42 ′ 13.4″E**



Plate IX: **(a)** Ammonite within shaley limestone of the Awgu Formation **(b)** Shaley limestone of the Awgu Formation

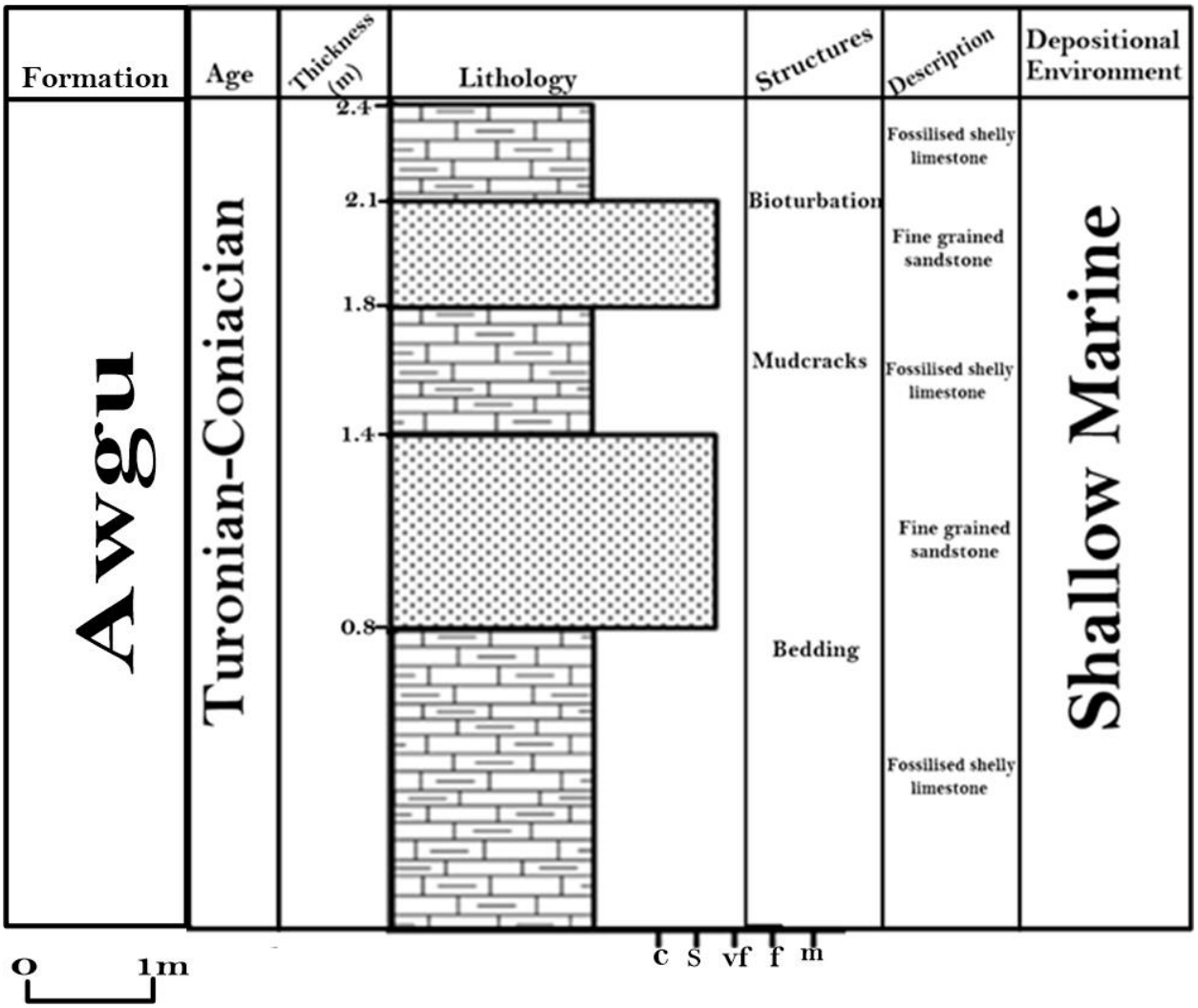


Figure 14: A Lithostratigraphic log of Awgu Formation occurring around Giza town.

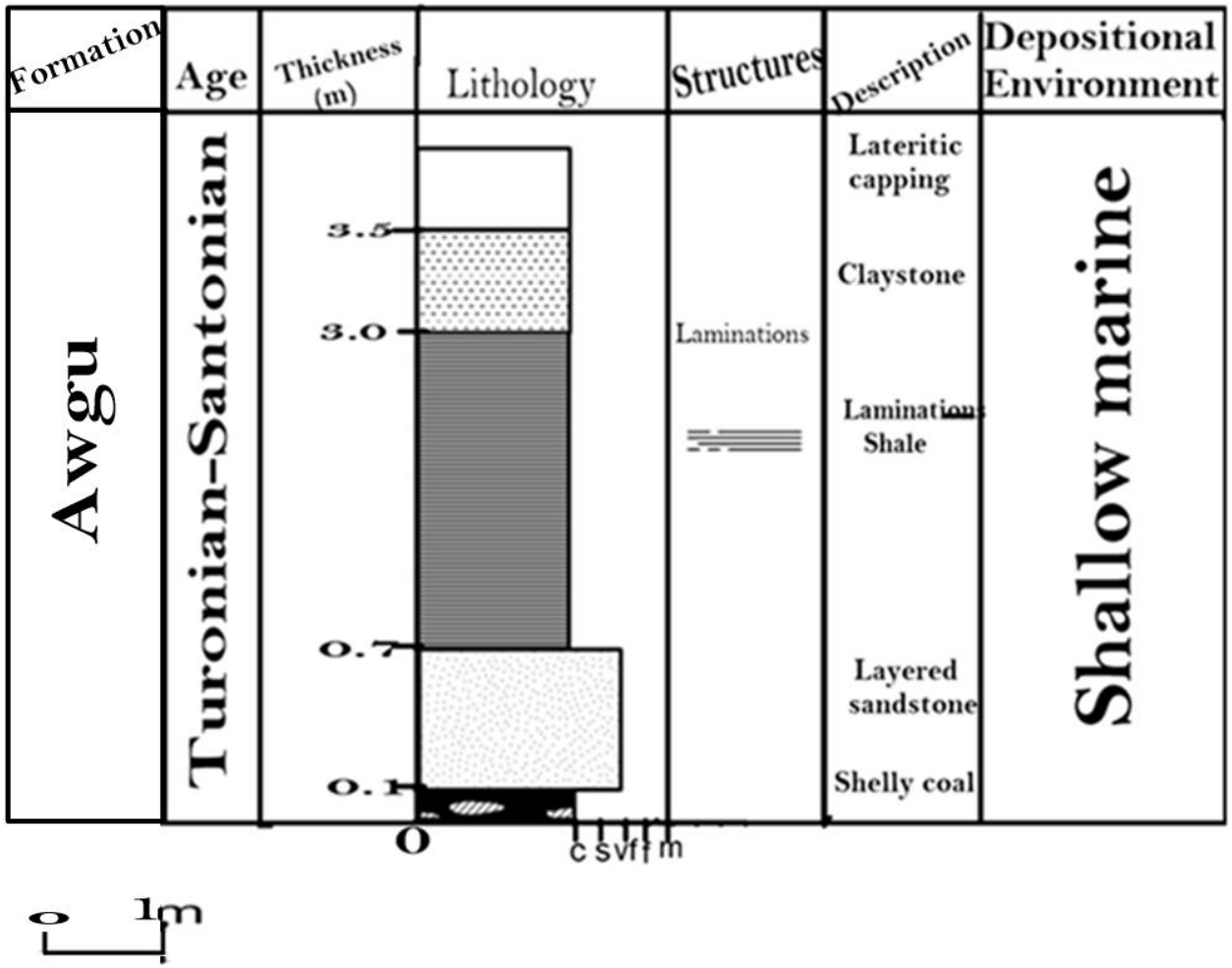


Figure 15: A section of Awgu Formation occurring between Agyaragu and Bukan Fadama. **08°11′12.9″N 08°47′ 51.6″ E**

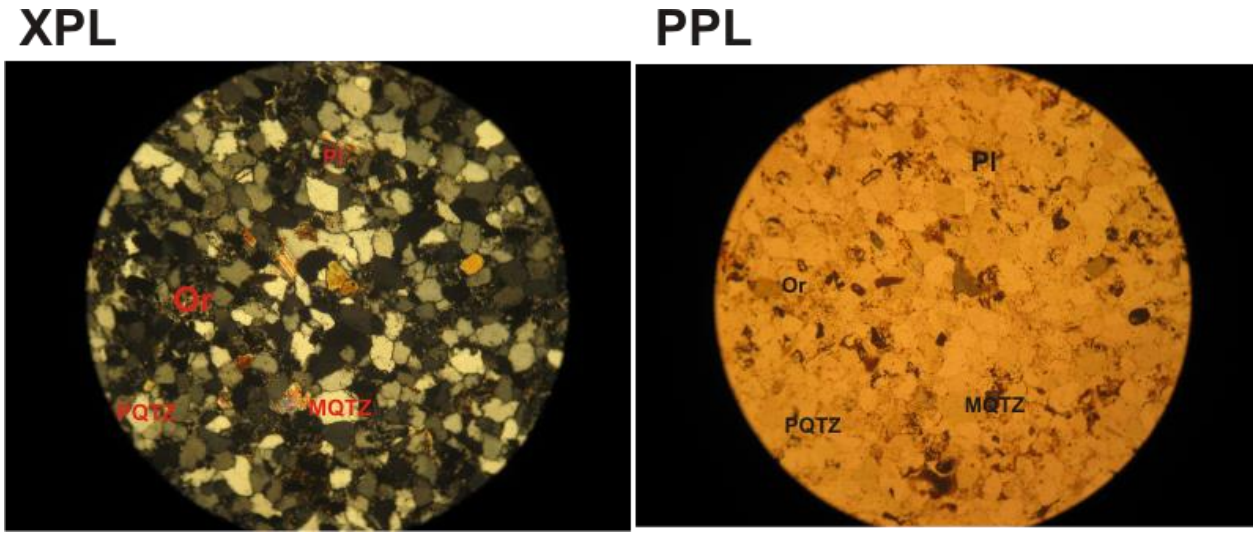


Plate X: Sample AG-1 [Mg.x40] Photomicrograph of sandstone from the Awgu Formation (Quartz arenite) **NB: MQtz:**monocrystalline quartz, **PQTZ**:polycrystalline quartz, **Pl:** plagioclase feldspar **Or:** orthoclase feldspar, **Ms:** muscovite mica

Description of sandstone of Awgu Formation

Majority of the grains here are fine-grained quartz. The quartz grains are both monocrystalline and polycrystalline in almost equal proportion. The plagioclase and orthoclase feldspars also occur in equal proportion. There is evidence of alteration of the feldspar grains. There are also muscovites within the sandstones of the Awgu Formation. The poor sorting of the grains and there subangular nature makes them submature. There is also evidence of diagenesis as seen by the sutured grain boundaries. Since the quartz grains are upto 95%, the rock is therefore a Quartz arenite

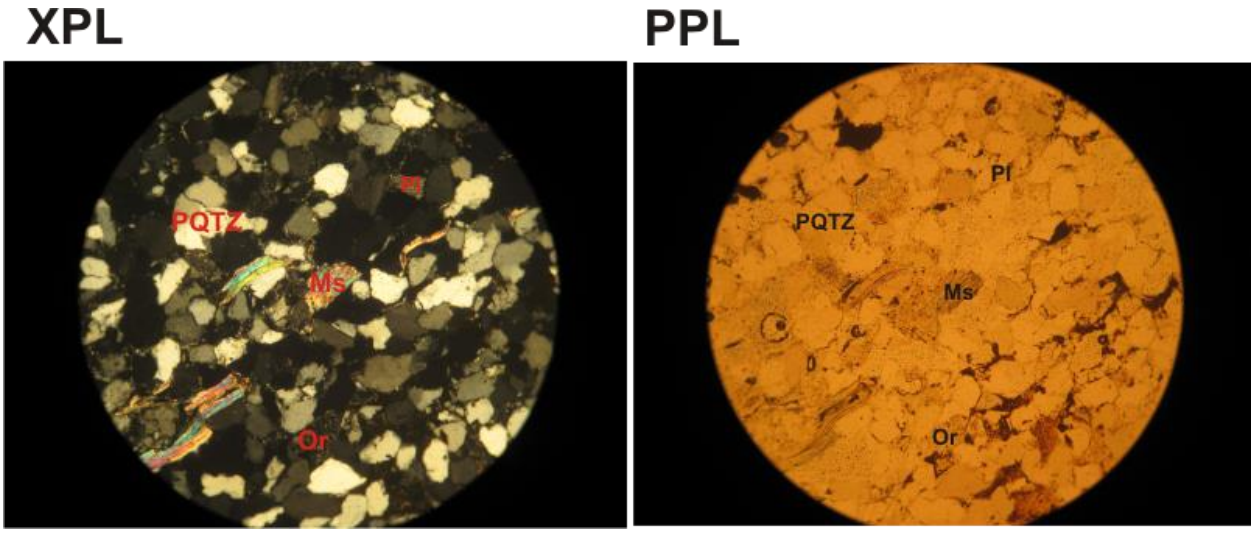


Plate XI: AG-2 [Mg.x40]. Photomicrograph of the micaceous sandstone from the Awgu Formation (Quartz Arenite) **NB: MQtz:** monocrystalline quartz, **PQtz**: polycrystalline quartz **Pl:**plagioclase feldspar **Or:** orthoclase feldspar, **Ms:** muscovite mica

Description of sandstone of Awgu Formation

Majority of the grains are quartz grains, with few feldspars and muscovite. The quartz crystals are majorly monocrystalline with some polycrystalline types. The micas within the grains are muscovites. There is also the presence of micas

There is the presence of both orthoclase and plagioclase feldspars with evidence of alteration within them. The feldspars (especially the orthoclase) are highly altered forming part of the cementing material. The bulk of the cementing material appears to be Iron oxides. The poor sorting of the grains and there subangular nature makes them submature.

There is also evidence of diagenesis as seen by the sutured grain boundaries indicating pressure solution

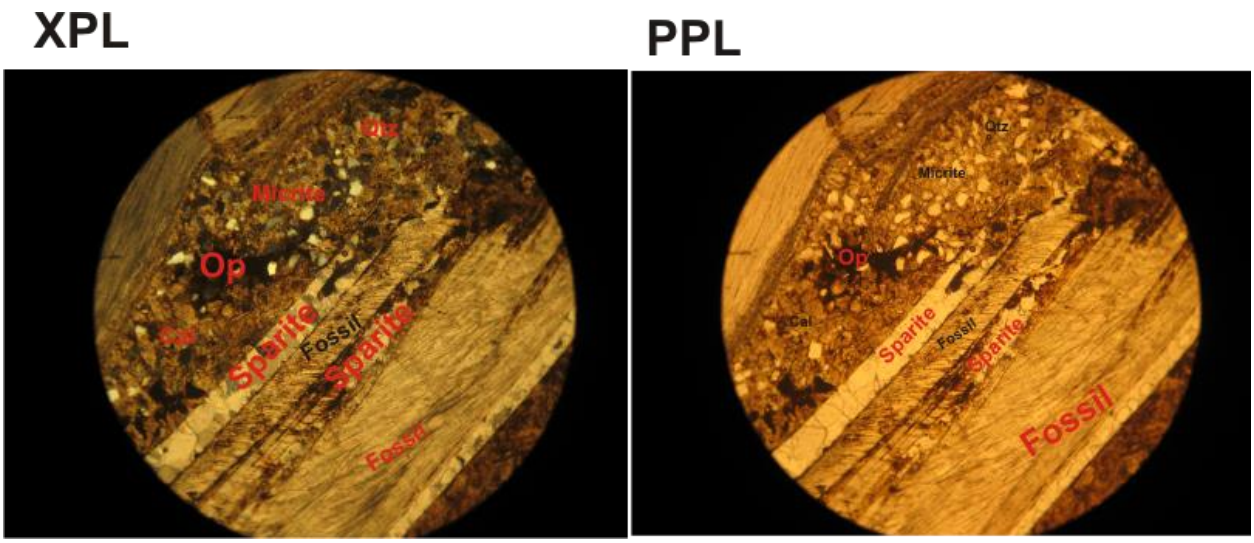


Plate XII: sample AG-L [Mg.x40]. Photomicrograph of a limestone of the Awgu Formation showing a fossil echinoderm cemented by calcite **NB: Qtz:**quartz, **Op**:Opaque mineral **Mr:** Micrite **Sp**:Sparite **Fossil**:Fossil **Cal:**calcite cement.

Description of Limestone (with fossils within calcite and quartz matrix) of the Agwu Formation

The rock sample consists of a fossil echinoderm enclosed by a sparite cement. The sparite cement are filling up the mold. The sparite cement has a drusy fabric. There are also micrite, quartz grains and calcites forming the matrix**.** The dark spaces within appearing under plane polarised light are Opaques (Iron oxides). The quartz crystals are fine-grained. There is also the presence of micrite derived from mechanical breakdown or precipitation from seawater.

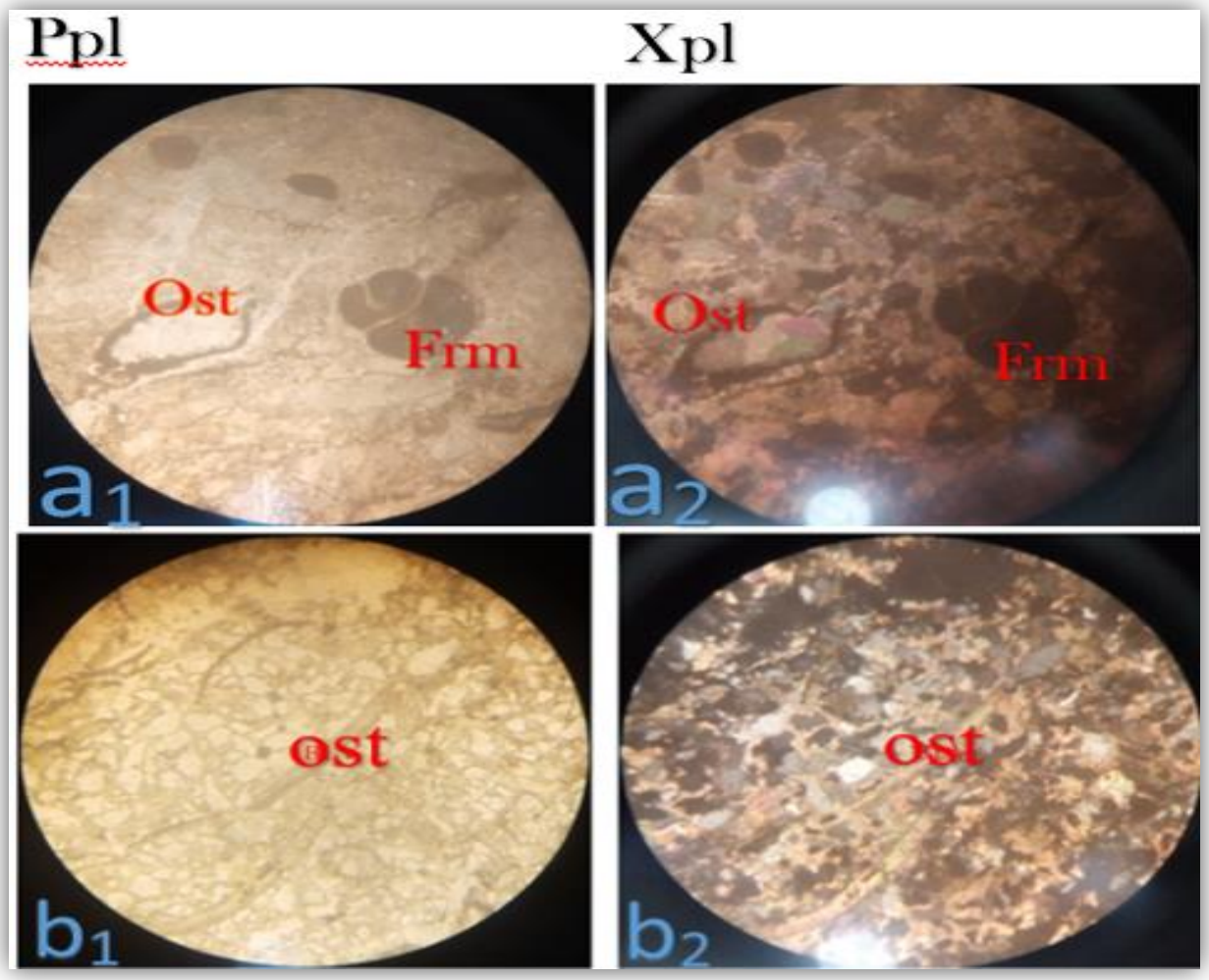


Plate XIII: **Sample AG-SL [Mg.x40]** Photomicrograph of shaley limestones showing fossils **NB: Ost:** Ostracodes **Frm:** Foraminifera **Cc:** calcite cement

Description of fossilised shaly limestones of Awgu Formation

The shaley limestone is dorminated by a calcite material, with few quartz crystals and calcite grains making up <1% of the whole rock. (Plate XIIIb) consists majorly of tostracodes and a calcitic material. Within the walls of the ostracodes of a_1 and a_2, is a sparite but a majority of the cement is micrite. The globular chamber exhibited by the foraminifera fossil indicates planktonic environment

CHAPTER FIVE

DISCUSSION

5.1 Introduction

The study area consists of three formations namely Awe, Awgu and Lafia Formations. The Awe Formation was deposited during the Late Albian-Early Cenomanian regression while the Awgu Formation was deposited during the Turonian-Santonian cycle. Finally, Lafia Formation was deposited during the Campano-Maastrichtian cycle.

5.2 Lafia Formation

This formation which consists of ferrugenised sandstones at the base, followed by a layer of sandy clay in the middle and clayed loose sands at the top. The sandstones of the Lafia Formation are fine to medium grained; they are moderately sorted, negatively skewed to near symmetrically skewed and leptokurtic.

Offodile (1976) reported that the Lafia Formation is fluviatile. The presence of a channel fill (plate 1b) in the study area within the Lafia Formation indicates fluvial environment and hence affirms his findings. The fine to medium to grained sandstones indicates transition in energy regimes. The fine-grained sandstone indicates low energy while the medium-grained sandstone indicates moderate energy condition. The Lafia Formation has a fining upward sequence that suggest a meandering river. The sediments are minerallogically mature as indicated by their lack of unstable minerals like muscovites and feldspars. The ferruginous sandstones of the Lafia Formation is indicative of the presence of iron (Fe). The iron reacted with oxygen in the presence of water thereby forming a ferric oxide (Fe_2O_3) that is responsible for the brown colour of the sandstone. The brown colour within the sandstones of the Awe Formation is indicative of deposition in an oxygen-abundant and non-marine environment. The presence of sutured boundaries between some of the crystals and quartz overgrowth is an evidence of pressure

solution and therefore chemical compaction. The dorminance of the monocrystalline quartz is an indication of igneous provenance

Facies Analysis

The sansdtone of the Lafia Formation consists of one facies as observed in the field. It is Ferrugenised Sandstone Facies

The Ferrugenised Sandstone Facies

This facies consist of sandstones that are highly ferrugenised. Its grain size ranges from fine to medium. This facies has different sub-beds suggesting breaks in deposition. This sandstone also is intruded by a basaltic dyke cutting across it at Agyaragu. This is evidenced by the enlongated calcite crystals cutting across the thin section of the basalt, which is seen, at the base of the ferrugenised sandstone (Plate III). The sandstone that hosts the dyke is highly ferrugenised indicating the presence of ferric oxide

5.3 Awe Formation

This formation consists of sandstones at the base, followed by a layer of clay, then a layer of whitish sandstone in the middle and clay intercalated with shale at the top. The white sandstone of the Awe Formation is fine-grained with sorting ranging from poorly to moderately sorted. Its skewness value range from near symmetrical to coarse-skewed and a kurtosis value from leptokurtic to platykurtic.

Different workers have suggested that the Awe Formation is fluvial with some evidence of shallow marine conditions (Offodile, 1976; Ishaya, 2015). This work corroborate their conclusion in the sense that the bivariate plot (Fig. 21) indicates fluvial conditions while the poor to sorted and calcareous sandstones associated with brine are indicators of a transitional environment. The abundance of monocrystalline quartz among other grains indicates igneous

provenance. It is a transitional environment between fluvial and shallow marine. The poorly sorted sediments indicates fluctuating depositional currents and variable current velocity. There are sutured boundaries due to calcite cement corroding crystal boundaries. This sutured grain boundaries are clearly indicating pressure solution and therefore chemical compaction

Facies analysis

The Awe Formation consists of two facies: Loosed Sandstone Facies and Compacted Sandstone Facies.

a. Loosed Sandstone Facies

This facies consists of fine-grained sandstones, which is indicative of deposition in low energy environment. This appears to be relatively loosed and exhibit white colour. The white colour is an indication of a highly reworked sediments with more quartz grains than feldspars. The feldspars have been severely altered into sericite, which is almost serving like cement to the distinct crystals of quartz and feldspars. This facies encountered around the town of Aloshi has undergone a lot of fracturing with joints and quartz veins cutting across.

b. Compacted Sandstone Facies

This facies appears to be very fine grained compared to the Loosed Sandstone Facies. The facies is moderately sorted. The grains of feldspar have also undergone intense alteration and it contains calcite cement encircling the grains and giving it a poikilotopic texture (Plate VII).

5.4 Awgu Formation

The section of the Awgu Formation consists of sandstone at the base and shaley limestones at the top (this sequence repeats itself). Another section of the Awgu Formation consists of layers of coal bed at the base, followed by a layer of fine-grained sandstone, then shaley layer and mudstone layers at the top. The sandstones of the Awgu Formation sandstone are fine grained. They are poorly sorted and strongly coarse skewed. Its skewness range from very platykurtic to

mesokurtic. The fine grained and poorly sorted sandstones of this formation is a typical characteristic of shallow marine environment.

The presence of echinoderms, mudcracks and bioturbation are pointers to deposition in shallow silliclastic marine environment. The presence of fossils within the sandstones of the Awgu Formation is accounted for by the presence of bioturbation and giving the shale a very dark colour. The lack of abundant sedimentary structures within the sandstones and the dark to grey colour of the shaly limestones of this formation are typical of deposition in quiet water, reducing/anaerobic marine environment. The environment of deposition of the Awgu Formation is shallow marine. The presence of Ammonite and echinoderm indicates Cretaceous age (Fig.22). The foraminifera species *Heterophelix globulosa* and ostracodes species *Buntonia vanmorkhoveni*. are indicators of shallow marine environment while the ammonite species Texanite *sp*. indicates Cretaceous age.

The Awgu sandstones consists of three facies namely: The Coal facies and the Shaly limestone facies

a. Coal Facies

This sandstone was found associated with a bed of coal underlying it. It is very fine-grained indicating low energy regime. It has some fissility indicating deposition in quiet water with some presence of muscovite in the thin section. The feldspars are highly altered to clay, which along with some opaques form the matrix. The presence of coal and the lack of fossils within this facies are indicators of deoxygenated or anoxic environment.

b. Limestones Facies

This sandstone is found to be occuring with the shaIe, it is micaceous and also has some fissility indicating deposition in quiet water.

The Limestones can also be classified into two facies namely; Shaly Limestone Facies and Yellow-Brown Limestone Facies.

a. Shaley Limestone Sub-Facies

These shaly limestones appear to be hardened and very dark in colour indicating anoxic environment. There is little fissility on the shaley limestone, which could be accounted for by the activities of organisms. The cementing material is a calcite and other opaque materials. Fossils within this facies includes Ostracode and Foraminifera. The presence of fossils within this limestone facies is indicative of deposition in oxygenated environment.

b. Yellow-Brown Limestone Sub-Facies

This facies appear to be hard. It is rich in calcite embedding other fossils. The fossil echinoderm appears to consist of about 30% of the fossil echinoderm.

5.5 Provenance of the Sediments

The term provenance deals with the origin or source of sediments.

The Awe Formation also consists of about 70% monocrystalline quartz as related to the few polycrystalline quartz. The feldspars contain grains with cross-hatch twinning and Albite twinning typical of microcline and plagioclase feldspars respectively. This shows that most of the sediments of the Awe Formation is of an igneous source. The microcline and plagioclases indicate that part of the sediments originated from uplifted oceanic island terranes. The presence of the Angular to subrounded quartz crystals indicates submature sediments. Alteration of the feldspars are indications of humid climates and rapid erosion, as happens in an area of high relief.

The Awgu Formation contains >60% monocrystalline quartz, which are all indicators of an igneous source. Alteration of the feldspars are indications of humid climates and rapid erosion, as happens in an area of high relief

The Lafia Formation consists of a combination of both monocrystalline and polycrystalline quartz with the monocrystalline grains dorminating. which is typical of an igneous provenance.

5.6 Cycles/History of Sedimentation in the Middle Benue Trough

The study area consists of three out of the six formations in the Middle Benue Trough. The study area reflects three out of the 4 cycles of sedimentation in the Middle Benue Trough. The unique characteristics of these formations form the basis of their sedimentatological studies (Obaje, 1994; Offodile 1976)

The first cycle of sedimentation in the study area saw the deposition of the Awe Formation, which directly overlies the Asu River Group (Arufu, Uomba and Gboko Formations). The sediments of this cycle were deposited by the regressing sea. This took place during the late Albian to early Cenomanian regression. The totality of the formation consists of clay at the bottom, layer of sandstone in the middle and laminated shale at the top. It is poorly to moderately sorted. The Awe Formation sandstones are arkosic arenites. The regression of the Albian Sea in the Middle Benue Trough during the Cenomanian period also gave rise to the process of erosion taking place in the hinterland thereby causing a large quantity of detritus to be deposited in a restricted delta. This fluviodeltaic sediments are called the Keana Formation.

The second cycle of sedimentation witnessed the deposition of the Ezeaku and the coal-bearing Awgu Formation during the Cenomanian to early Turonian transgression (Akande, 2011). The Keana and Ezeaku Formations was not found in my study area. The possible reason for this anomaly could be due to erosion. Within the study area, Awgu Formation was ecountered. This formation is made up of shaly limestone at the base, sandstones, shaly limestone and sandstone respectively. The sandstones of this formation is very pooly sorted, mature and are subarkose**.**

The mid-Santonian saw a period of folding throughout the Benue Trough.

The third cycle of sedimentation in the Middle Benue Trough saw the deposition of the Campano-Maastrichtian Lafia Formation, which formed the last cycle of sedimentation as the

sea, regressed. This was followed by the deposition of fluvial continental sediments consisting of ferrugenised sandstones at the base, sandy clay in the middle clayed loose sands at the middle at the top (Obaje, 2004). The sandstone is moderately sorted and are Quartz arenites**.** The Lafia Formation was found to be lying on the Awgu Formation paraconfomably.

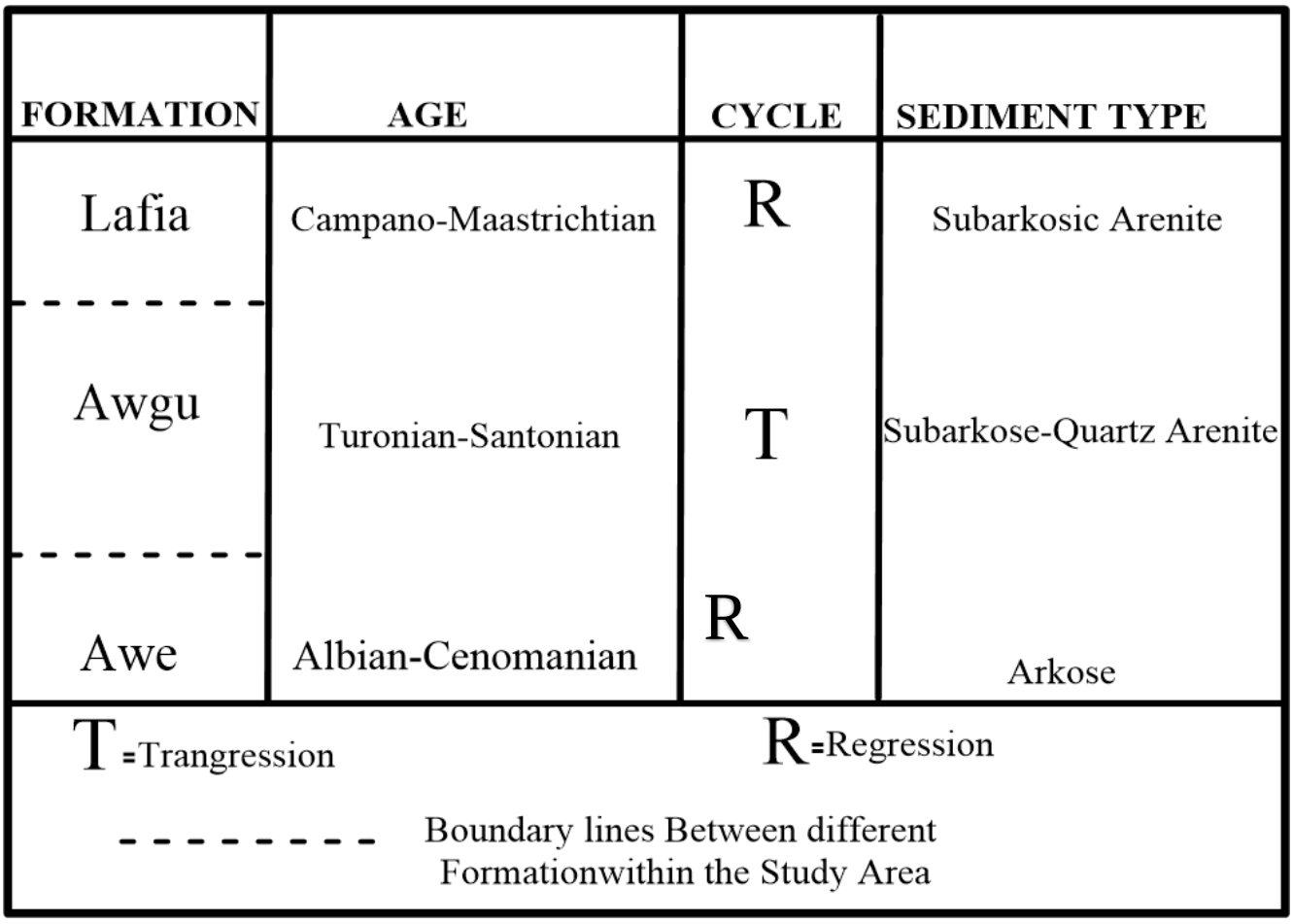


Fig. 16: A model showing the cycles of sedimentation within the study area

5.7 Geological Structures

Few geological structures were encountered within the sedimentary rocks in the study area. This includes both syn-depositional and post depositional structures.

5.7.1 Syn-depositional Structures

Bedding Planes: This is a layered feature of sedimentary rocks characterised by differences in composition, texture and structure. They are usually having a planar top and bottom surfaces that

define the units and are parallel to the surface of deposition. All the sections of the different formations encountered were having beddings.

Bioturbation: This is the disturbance of a sediment by the activities of organisms who feed by burrowing, often destroying its primary structure. Bioturbation often results in recognisable tracks, trails and burrows. Biotubation was seen within the shaley limestones of the Awgu Formation. The bioturbations seen were resting places of shallow depressions.

5.7.2 Post-depositional Structures

Faults: A fault is a fracture in earth materials along which the opposite sides have been relatively displaced parallel to the plane of movement. Two minor faults were identified within the Awe Formations. The two faults were both stike-slip and dip-slip faults which reflects the presence of a major fault. The strike of the fault was found around the town of Aloshi with a strike of N48°W. The fault found within the study area was probably created by the tectonism. This is part of 10km long calcite mineralised fault.

Veins: Within the Awe Formation, quartz-rich veins were encountered. These veins have a strike direction of NW-SE. This fractures and veins were formed by the tectonism that affected the Middle Benue Trough.

Unconformity: A paraconformity was encountered around the town of Agyaragu, **08°27′ 15.0″N 08°33′59.9″E.** At this location, the Lafia Formation was found to be lying paraconformably on the Awgu Formation. (Plate VI)



Plate XIV: Paraconformitity marking the boundary between Lafia and Awgu Formation **08°27′15.0″N 08°33′ 59.9″E**

5.8 Economic Geology

There are abundant limestones within the study area around the village of Ajor **(**8°14′30.5″N 8°40′30.5″E). The limestones in the study area can be used as building materials. They can be used in the industry to purify iron in a blast furnace and for cement making. There is also abundance of coal within the Awgu Formation around the village of Kasuwa bugau and Agyaragu. This coal has great use in electricity generation, steel making, and cement production. Around the town of Keana (about 1km out of the study area east of the village of awena), there is

an economic deposit of brine. They have a local mine where they extract the salt from the brine and use it for commercial and domestic purposes. Offodile (1976) suggested that it could be the result of the cutting-off of the Albian regressive sea thereby forming the salty lakes of the Awe Formation. He also suggested the possibility of arenaceous particles infilling these lakes. This brine is a source of Sodium chloride (NaCl)



Plate XVa: Brine associated with Awe Formation at Keana town **(08°8′45.5″N 08°47′ 27.2″E)**



Plate XVb: A coal mine associated with the Awgu Formation found at Bukan kwato **(08°27′ 10.5″N 08°34′ 18.7″E)**

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 Summary

Despite the debates about the origin and evolution of the Benue Trough, two facts are obvious. First of all, the Benue Trough was formed as a result of the separation of the African continent from the south American continent thereby creating the Atlantic Ocean. (Burke *et al*., 1972) Secondly, the evolution of the Benue Trough can be fully explained on the basis of several/combination of the theories proposed by several authors. It is best regarded as a rift structure with very strong sinistral strike-slip component (Zaborski, 1998; 2003).

The Benue Trough is subdivided into Lower, Middle and Upper Benue Trough. The Middle Benue Trough is made up of six Formations. The Asu River Group (Uomba, Gboko and Arufu Formations), Awe, Keana, Ezeaku, Awgu and the youngest Lafia Formations.

The study area consist of three of these six formations mentioned above. They are Awe, Awgu and Lafia Formations.

6.1.1 Awe Formation

The Awe Formation consists of fine-grained sandstones, which are poorly to moderately sorted. The sandstones are micaceous and calcareous and range from near symmetrical to coarse skewed. They are also leptokurtic. It consists of grey coloured shales and beds of white clay. The features above are all indicators of a transitional environment between fluvial (continental) and shallow marine (low energy conditions). The presence of monocrystalline quartz and plagioclase feldspar are all indications of igneous origin.

6.1.2 Awgu Formation

The Awgu Formation has a generally fining upward sequence with sandstones ranging from fine-grained, very poorly sorted, strongly coarse skewed and platykurtic. There is also the presence of fossils (micro and macro) such as echinoderms, ammonites, ostracodes and foraminifers. These features listed above are typical of shallow marine environment. The Awgu Formation contains quartz of which about 70% of the quartz grains are monocrystalline. This clearly indicates an igneous origin.

6.1.3 Lafia Formation

Sandstones of the Lafia Formation range from fine-medium grained, they are moderately sorted, strongly coarse skewed and leptokurtic. The formation has a fining upward sequence. The sandstones are ferrugenised, which is an indication of chemical weathering. The varying grain sizes indicates different energy regimes and all the features mentioned above are indicators of a fluvial system. Within the sandstones of the Lafia Formation, more than 60% of the grains are monocrystalline with few polycrystalline types. There are no discernible fossils within the Lafia Formation, which indicates anoxic/reducing conditions.

6.2 Conclusion

Stratigraphy and sedimentological studies remains one of the most reliable tools in basins analyses and the interpretation of past environments of deposition. This work has been able to examine sediments to look for clues such as fossils; sedimentary structures; grain shape, size, and composition in determining the source area of the sediment and their environment of deposition. Based on the stratigraphy and sedimentological studies of the sediment in this portion of Middle Benue Trough, the Awe Formation has been established to be transitional between fluvial and marine, the Lafia Formation has been established to reflect fluivial conditions while the Awgu Formation has been established to reflect shallow marine conditions

6.3 Recommendations

Other Methods of studies such as aeromagnetic studies, palynological studies and diagenetic studies should be carried out for more geological information of the study area to properly characterise the Middle Benue Trough.

Most of the exposed sections in the Middle Benue Trough are not as thick as the upper Benue Trough. Therefore, subsurface methods of study like drilling and seismic survey should be applied in the study area to have better picture of the thickness of the sediments.

Geochemical studies should be undertaken particularly on the Awe Formation to establish the origin of the brine.

6.4 Contribution to Knowledge

1. A Geological map of the study area was produced on a scale of 1:50,000. The stratigraphic sequence of the study area has been established

2. An account of the provenance of the sediments have also been provided

3. A detailed study of the stratigraphy coupled with sedimentological and provenance studies were also used to establish the environment of deposition of the sediments in the study area; The Lafia Formation sediments were deposited by a fluvial system, the Awe Formation is transitional between fluvial and marine environments while the Awgu Formation is of shallow marine environments.

6.5 Limitation

1. There were poor exposures when compared to other basins.

2. There was also a high level of insecurity (Herders/Farmers clashes).

REFERENCES

Adeleye, D.R and Fayose, E.A. (1978) Stratigraphy of the type section of Awi Formation, Odukpani area, Southeastern Nigeria. *Journal Mining and Geology* **15**, pp. 33-37.

Akade et. Al (2011) Hydrocarbon potential of Cretaceous sediments in the lower and middle Benue Trough, Nigeria: Insights from new source rock facies evaluation

Benkhelil J. (1982) Benue Trough and the Benue chain. *(Geological Magazine),* **119**: pp155-568.

Benkhelil, J. (1988) Structure et evolution geodynamique du Basin Intracontinental de la Benoue (Nigeria). *Centers Rech. Explor. Prod. Elf Aquitaine.* **12**: pp29-128.

Benkhelil, J. (1989) The Origin and evolution of Cretaceous Benue Trough (Nigeria). *Journal African Earth Sciences.*Volume **8.** pp. 251-282

Benkhelil, J., Dainellin, P., Ponsard, J.F., Popoff, M and Saugey, L. (1988) The Benue Trough wrench-fault related basin on the border of the equatorial Atlantic. In: Triassic- Jurrasic rifting, continental break-up and the origin of the Atlantic Ocean and passive margins, part B (Edited by Manspeizer, W). pp.787-819. Eslevier, Amsterdam, Netherlands.

Boggs, S. (1992) Petrology of sedimentary rocks*: New York, Macmillan Publishing Company*, pp. 353-408.

Burke, K.C. and Dewey, J.F. (1974) Two plates in Africa during the Cretaceous? Nature **249**, pp 313-316

Burke, K.C. and Whiteman A.J. (1973) Uplift, Rifting and break-up of Africa. In: Implications of continental drift to the earth sciences (Edited by Tarling, D.H. and Runcorn, S.K.), pp.735-755. Academic press,London, U.K.

Burke, K.C., and Whiteman, A.J. Dessauvagie, T.F.J. (1970) Geological history of the Benue Valley and the adjacent areas. In: T.F.J Dessauvaggie and A.J Whiteman (Edition), African Geology. Ibadan University press. pp187 - 205.

Burke, K.C., Dessauvagie, T.F.J. and Whiteman, A.J. (1971) Opening of the gulf of guinea and geological history of the Benue depression and Niger Delta. Nature **233.** pp. 51-55

Burke, K.C., Dessauvagie, T.F.J. and Whiteman, A.J. (1972) Geological history of the Benue valley and adjacent areas. In: African Geology (Edited by Dessauvagie, T.F.J. and Whiteman, A.J.), pp.187-205. Ibadan University press, Ibadan, Nigeria.

Carter, J.D., Barber, W., Tait, E.A.and Jones, G.P. (1963) The Geology of Parts of Adamawa, Bauchi, and Bornu Provinces in northeastern Nigeria. *Bulletin of Geological survey, Nigeria,* **30**: pp1 – 99

Cratchley and Jones, G.P. (1965). An interpretation of the geology and gravity anomalies of the Benue Valley, Nigeria. Overseas Geological Surveys Geophysical paper **I,** pp.1-26

Dessauvagie, T.F.J. (1969) Photogeological interpretation of 1:25000 sheet 46 Futuk (Nigeria). *Journal Mining Geology* **4** (for 1967). pp.13-27

Fairhead, J.D. and Binks, R.M. (1991). Differential opening of the Central and South Atlantic Oceans and the opening of the West African Rift System. *Tectonophysics* **187**, pp. 191-203.

Falconer, J.D. (1911): The geology and geography of Northern Nigeria. Macmillan, London, U.K

Farrington, J.L. (1952). A preliminary description of the Nigerian Lead-Zinc field. Economic geology **47**, pp.583-608.

Folk, R.L (1974). Petrology of sedimentary rocks. Hemphill, Austin, Texas

Guiraud, R. and Maurin, J.C. (1993). Early Cretaceous rifts of Western Central Africa: an overview. *Tectonophysics*, 213: pp.153-164.

Ishaya, E.D. (2015). Lithostratigraphy and sedimentological studies of the Albian to Cenomanian successions, part of the Middle Benue Trough, Nigeria.

King, L.C. (1950). Outline and disruption of Gondwanaland. *Geological magazine* **87**. pp 353-359.

Lees, G.M. (1952). Foreland folding. *Quarterly Journal of the Geological Society of London,* **108**: *pp*1-34.

Najime, T. (2010). Cretaceous stratigraphy, sequence stratigraphy and Tectono-73 Sedimentary evolution of Gboko area, Lower Benue Trough, Nigeria. pp55-93

Nichols, G.J. (2009). Sedimentary and stratigraphy.Imperial College, London. Second Edition. pp. 79-83

Nwajide, C.S. (1990). Sedimentation and palaeogeography of the central Benue Trough, Nigeria. In: C.O. Ofoegbu, (Ed.). The Benue Trough structure and evolution, view eg & Sohn, Braunschweig pp.19-38.

Nwajide, C.S. (2013). "Geology of Nigerian sedimentary basins" CSS Bookshops Ltd, Lagos.

Nwajide, C.S., Reijers, T.J.A., (1996). Geology of the southern Anambra basin. In: Reijers, T.J.A., (ed). Selected chapters on geology. Warri:SPDC, 133-148

Obaje, N.G. (1994). Coal petrology, microfossils and paleoenvironments of Cretaceous coal measures in the Middle Benue Trough of Nigeria. *Tiibinger Mikropaleontologische Mitteihengen* **11,** pp.*15-24*

Obaje, N.G. (2009). Geology and Mineral Resources of Nigeria. *Lecture notes in Earth Science 120.* DOI 10.1007/978-3-540-92685-6_5, Springer – Verlag Berlin Heidelberg.

Obaje, N.G. and Ligouis, B. (1996). Petrographic evaluation of the depositional environments of Cretaceous Obi/Lafia coal deposits in the Benue Trough of Nigeria. *Journal African Earth Sciences,* **22**: pp.159-171.

Obaje, N.G., Funtua, I.I., Ligouis, B. and Abaa, S.I. (1996). Maceral associations, organic maturation and coal-derived hydrocarbon Potential in the Cretaceous Awgu Formation, Middle Benue Trough, Nigeria. *Journal African Earth Sciences* **23**, pp 89-94

Obaje, N.G., Funtua, I.I., Ligouis, B. and Abaa, S.I. (1998). Organic maturation and coal-derived hydrocarbon potentials of Cretaceous coal measures in the Middle Benue Trough, Nigeria. *Journal of Mining and Geology*, **34**: pp.1116- 2775.

Obaje, N.G., Ligouis, B., and Abba, S.I. (1994). Petrographic composition and depositional environments of Cretaceous coals and coal measures in the Middle Benue Trough of Nigeria. International Journal Coal Geology **26**, pp.223-260

Offodile, M.E. (1976). The Geology of the Middle Benue Nigeria. *Special volume Palaeontological Institution University Uppsala* **4**, pp.1-166.

Offodile, M.E. (1984). The geology and tectonics of Awe brine field. *Journal African Earth Sciences* **2,** pp. 191-202 Offodile, M.E. and Reyment, R.A. (1976). Stratigraphy of Keana-Awe area of the Middle Benue region of Nigeria. *Bulletin of the Geological Institutions of the University of Upsala, N.S.,* **7,** pp. 37-66. Offodile, M.E. and Reyment, R.A. (1977). Stratigraphy of the Keana-Awe area of the Middle Benue Region of Nigeria. *Bulletin Geological Institutions University Uppsala (N.S.)* **7**, pp.37-66.

Offodile, M.E. and Reyment, R.A. (1977). Stratigraphy of the Keana-Awe area of the Middle Benue region of Nigeria. *Bulletin Geological institutions University Uppsala (N.S) **7**,* pp.37-66.

Ofoegbu, C.O. (1984). A model for the tectonic evolution of the Benue Trough, Nigeria. *Geologische Rundchau*, **73:** pp.1007-1018.

Olade, M.A. (1975). Evolution of Nigeria‟s Benue Trough (aulacogen); a tectonic model, *Geological magazine*, **112**: pp.575-583.

Olade, M.A. (1976). On the genesis of Lead-Zinc deposits in Nigeria‟s Benue rift (aulacogen); a re-interpretation *Journal of Mining and Geology*, **13**: pp.20-27

Pettijohn, F.J. (1975). Sedimentary Rocks: Harper and Row, New York, NY.

Raeburn. C. and Jones, B. (1934). The Chad Basin: geology and water supply. *Bulletin Geological Survey of Nigeria,* **15**: pp1-61.

Reyment, R.A. (1955). The Cretaceous Ammonoidea of southern Nigeria and southern cameroons. Bulletin. Geol. Survey. Nigeria**. V25,** pp112.

Schull, T.J. (1988). Rift basins of interior Sudan; Petroleum exploration and discovery: AAPG *Bulletin*, V.**72**, pp.1128-1142

Simpson, A. (1955). The Nigerian coalfield, the geology of part of Onitsha, Owerri and Benue provinces. *Geological survey of Nigeria Bulletin* ***2,*** 85pp

Tucker, M.E. (2001). Sedimentary Petrology. An introduction to the origin of sedimentary rocks, Department of Geological Sciences University of Durham. Third Edition. Pp 11-53

Zaborski, P.M. (1998). A Review of the Cretaceous system in Nigeria. *Afr.Geo.Rev.5: pp385-483*

Zaborski, P.M. (2000). The cretaceous and paleocene transgressions in Nigeria and Niger. *Journal of Mining and Geology,* **36(2):** pp153-173

Zaborski, P.M. (2003). Guide to the Cretaceous system in upper part of the Upper Benue Trough, North-Eastern Nigeria. *Africa Geoscience Review,* **10**: pp.13-32.

APPENDIX 1: Frequency curve and statistical parameters from sieve analysis results

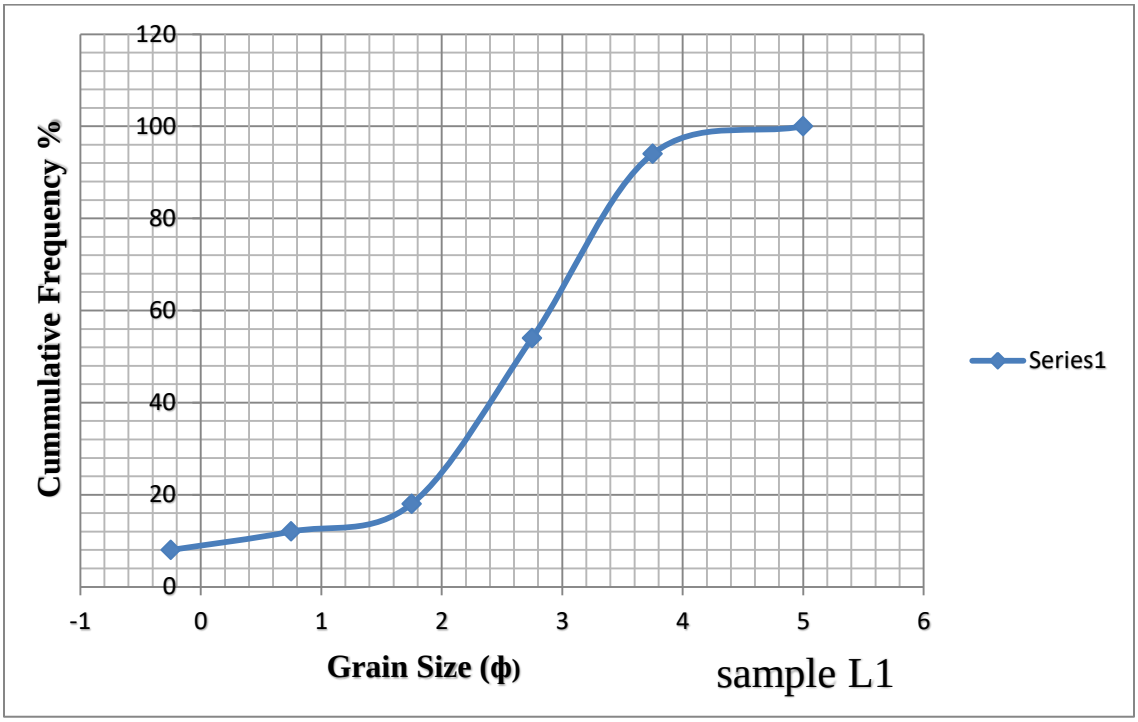


Fig. 17a: Cumulative Frequency Curve for sample L1 (Lafia Sandstone)

Table 4.2

Sieve analysis	Phi (ϕ) Value	Weight of sample (g)	Weight of sample (%)	Cummulative weight (%)
1.8	-0.25	08	7.8	7.8
0.6	0.75	04	3.9	11.7
0.3	1.75	06	5.9	17.6
0.15	2.75	35	34.3	51.9
0.075	3.75	40	39.2	91.1
pan	5.0	09	8.8	99.9

Sieve Analysis Results for Sample L1 (Lafia Sandstone)

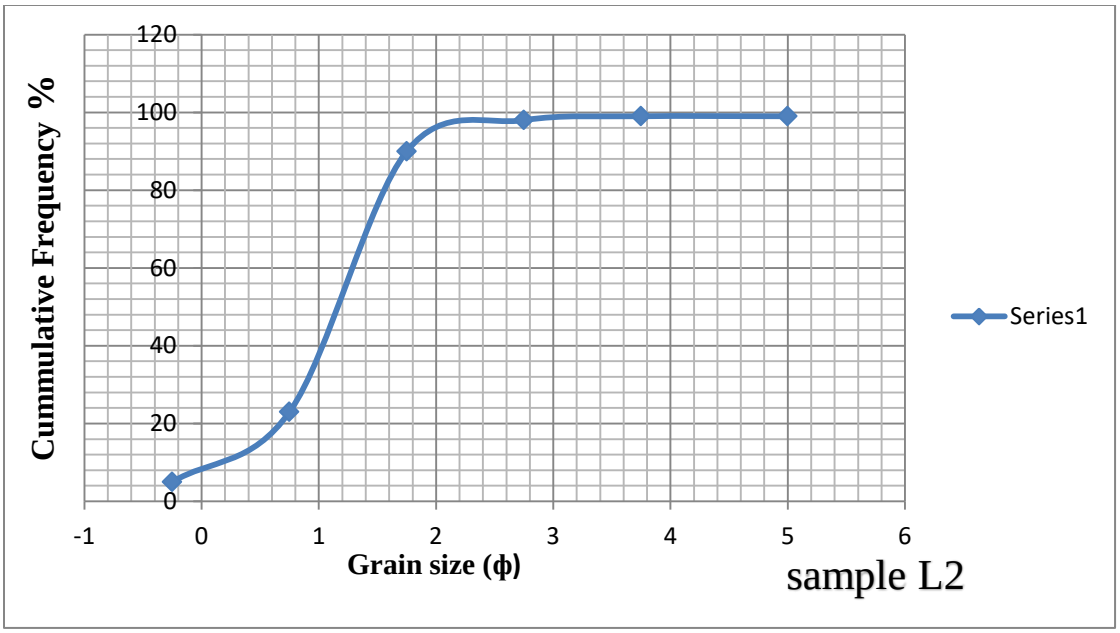


Fig. 17b: Cumulative Frequency Curve for Sample L2 (Lafia Formation)

Table 4.3

Sieve Size (mm)	Phi (ϕ) Value	Weight of sample (g)	Weight of sample (%)	Cummulative weight (%)
1.8	-0.25	05	4.9	4.9
0.6	0.75	18	17.6	22.5
0.3	1.75	67	65.7	88.2
0.15	2.75	11	10.7	98.9
0.075	3.75	1	1.0	99.9
pan	5.0	0	0	99.9

Result for Sample L2 (Lafia Sandstone)

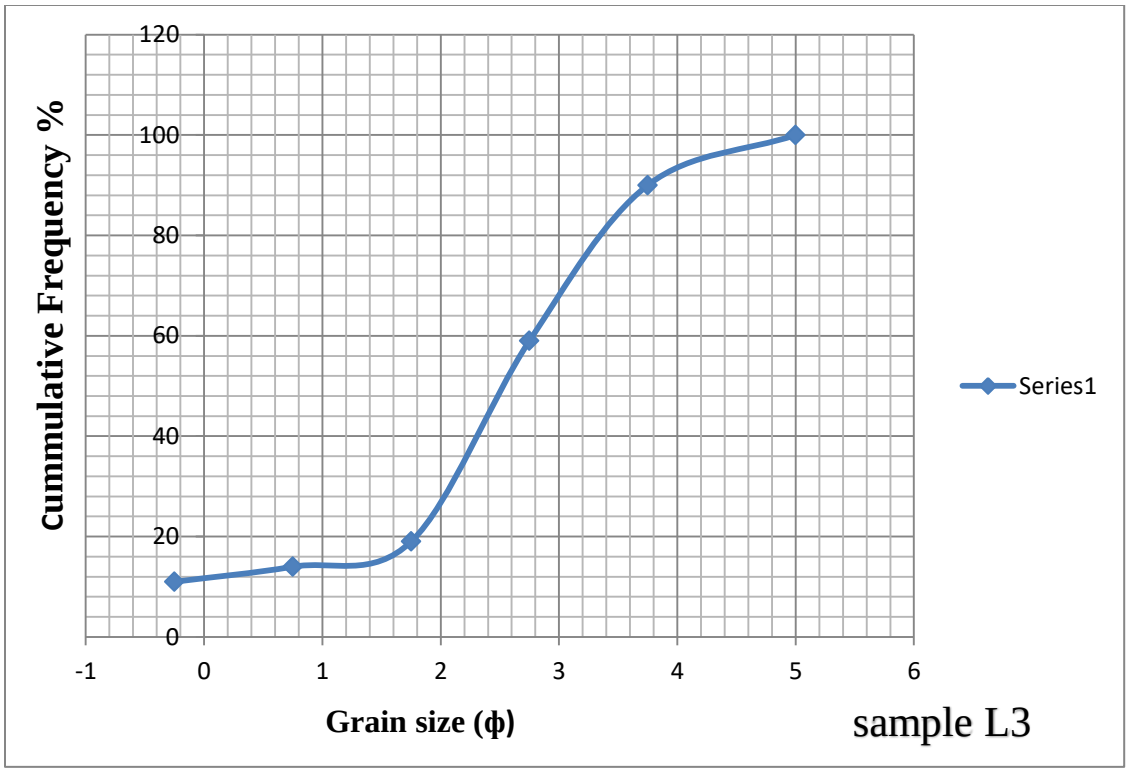


Fig.17c: Cumulative Frequency Curve for Sample L3 (Lafia Formation)

Table 4.4

Sieve Size (mm)	Phi (ϕ) Value	Weight of sample (g)	Weight of sample (%)	Cummulative weight (%)
1.8	-0.25	11	10.9	10.9
0.6	0.75	03	2.97	13.87
0.3	1.75	05	4.95	18.82
0.15	2.75	40	39.6	58.42
0.075	3.75	31	30.7	89.12
pan	5.0	11	10.8	100

Result for Sample L3 (Lafia Formation)

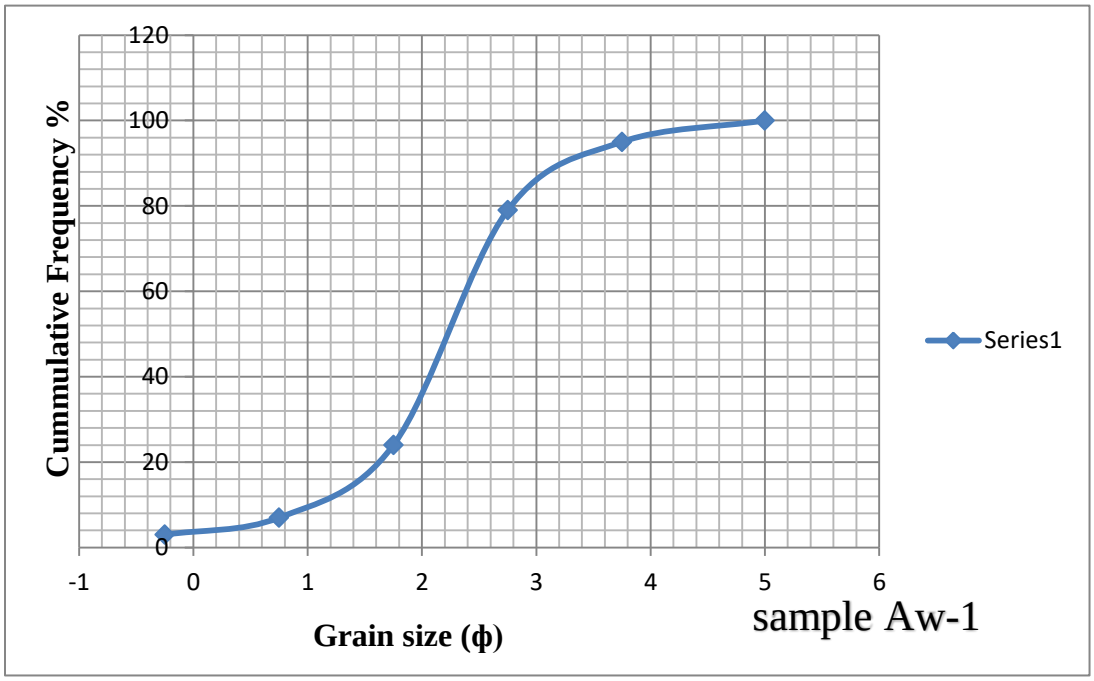


Fig. 18a: Cumulative Frequency Curve for sample Aw 1 (Awe Formation 1)

Table 4.5

Sieve Size (mm)	Phi (ϕ) Value	Weight of sample (g)	Weight of sample (%)	Cummulative weight (%)
1.8	-0.25	3	2.97	2.97
0.6	0.75	4	4.0	6.97
0.3	1.75	17	16.8	23.8
0.15	2.75	55	54.5	78.3
0.075	3.75	17	16.8	95.1
Pan	5.0	5	5.0	100

Result for sample Aw 1 (Awe Formation)

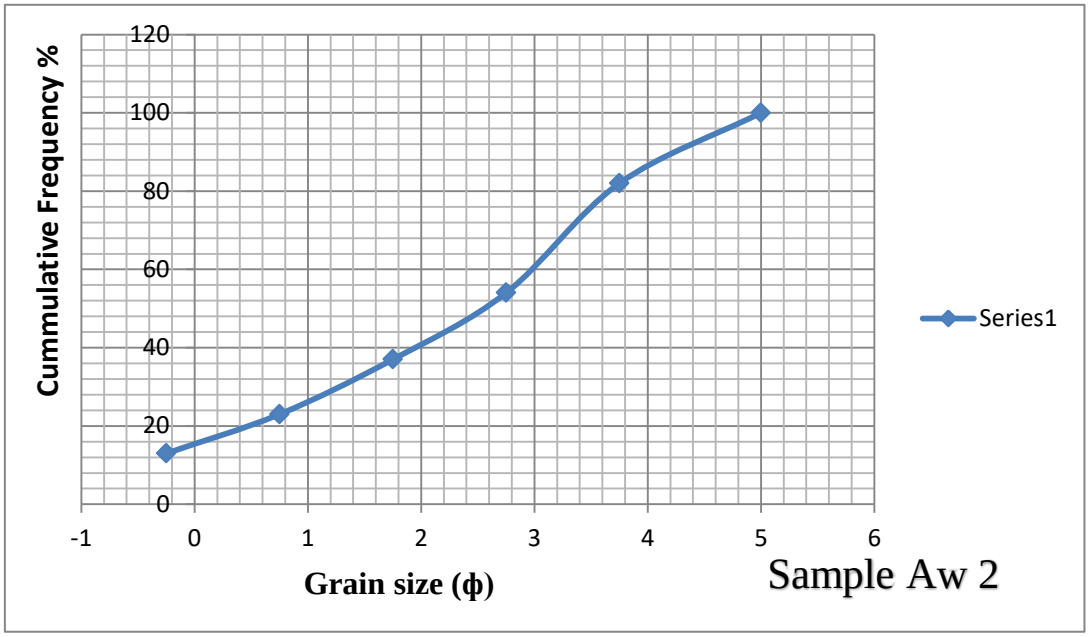


Fig. 18b: Cummulative Frequency Curve for sample Aw 2 (Awe Formation 2)

Table 4.6

Sieve Size (mm)	Phi (ϕ) Value	Weight of sample (g)	Weight of sample (%)	Cummulative weight (%)
1.8	-0.25	13	12.7	12.7
0.6	0.75	10	9.8	22.5
0.3	1.75	14	13.7	36.2
0.15	2.75	17	16.7	52.9
0.075	3.75	28	27.5	80.4
Pan	5.0	20	19.6	100

Result for Sample Aw 2 (Awe Formation)

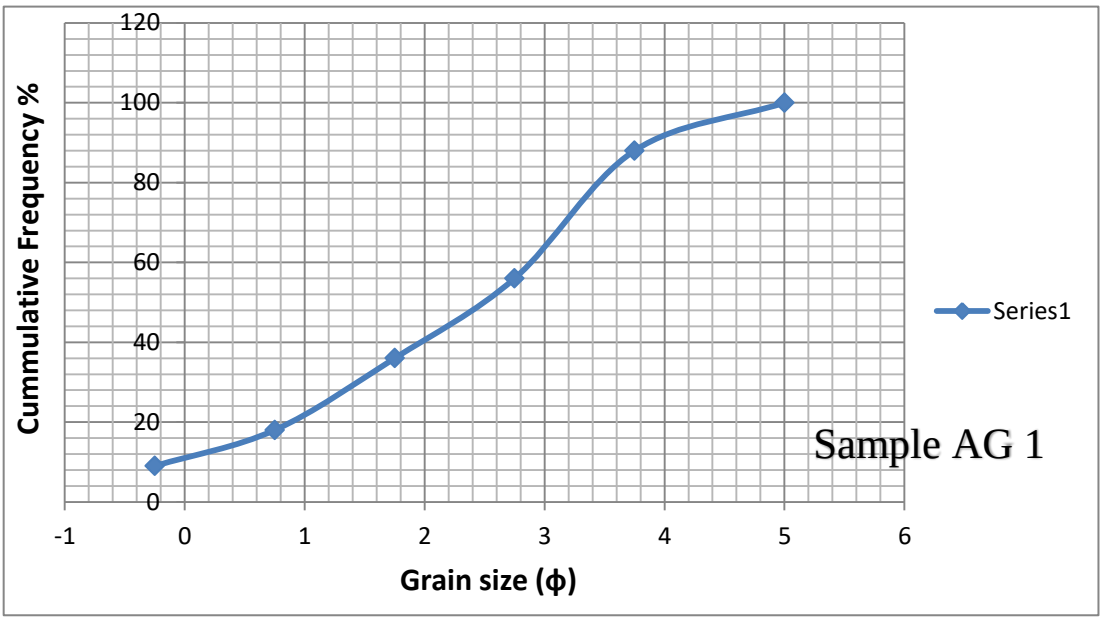


Fig. 19: Cummulative Frequency Curve for sample AG 1 (Awgu Formation 1)

Table 4.7

Sieve Size (mm)	Phi (ϕ) Value	Weight of sample (g)	Weight of sample (%)	Cummulative weight (%)
1.8	-0.25	09	8.9	8.9
0.6	0.75	09	8.9	17.8
0.3	1.75	18	17.8	35.6
0.15	2.75	20	19.8	55.4
0.075	3.75	32	31.7	87.1
Pan	5.0	13	12.9	100

Result of Sample AG 1 (Awgu Formation)

Table 4.8: Results of Sample AG 2 (Awgu Sandstone)

Sieve Size (mm)	Phi (ϕ) Value	Weight of sample (g)	Weight of sample (%)	Cummulative weight (%)
1.8	-0.25	27	27.3	27.3
0.6	0.75	9	9.1	36.4
0.3	1.75	10	10.1	46.5
0.15	2.75	5	05.1	51.6
0.075	3.75	18	18.2	69.8
Pan	5.0	30	30.3	100

APPENDIX 2: TABLES

4.9 Graphic mean standard values

Phi value of Gaphic Mean (ϕ)	**Verbal Graphic Mean**
-1.0 to 0.0	Very coarse grained
0.0 to 1.0	Coarse grained 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 8.0	Silt
8.0 to 14.0	Clay

5.0 Graphic standard deviation Values

Phi value of Sorting (ϕ)	**Verbal Sorting**
<0.35	Very well sorted
0.35 to 0.50	Well sorted
0.50 to 0.70	Moderately well sorted
0.70 to 1.00	Moderately sorted
1.00 to 2.00	Poorly sorted
2.00 to 4.00	Very poorly sorted
>4.00	Extremely poorly sorted

5.1 Graphic skewness standard values

Phi value of Graphic Skewness (ϕ)	Verbal Graphic Skewness
> +0.30	Strongly fine skewed
+0.30 to +0.10	Positively skewed
+0.10 to –0.10	Near symmetrical
–0.10 to –0.30	Negatively skewed
< −0.30	Strongly coarse skewed

5.2 Kurtosis standard values

Phi value of Graphic Kurtosis(ϕ)	Verbal Graphic Kurtosis
<0.67	Very platykurtic
0.67– 0.90	Platykurtic
0.90–1.11	Mesokurtic
1.11-1.50	Leptokurtic
1.50 -3.00	very leptokurtic

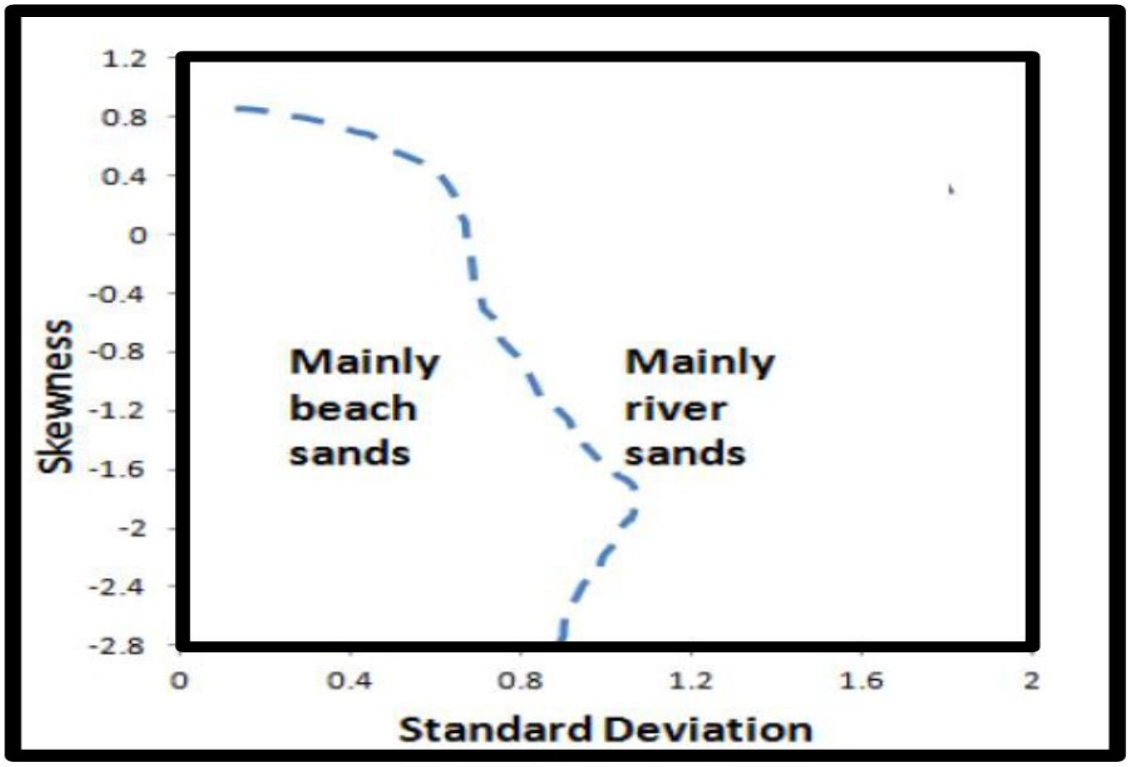


Fig. 20: Bivariate Plot of Skewness versus Standard deviation (after Friedman, 1961)

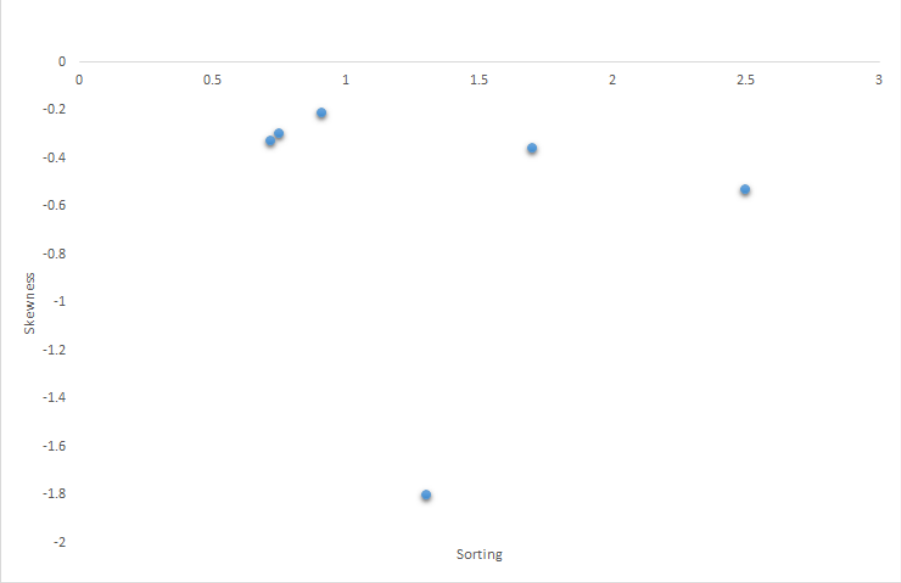


Fig. 21: Bivariate plot of Skewness versus sorting showing fluvial environment of deposition (Awe Formation)

APPENDIX 3

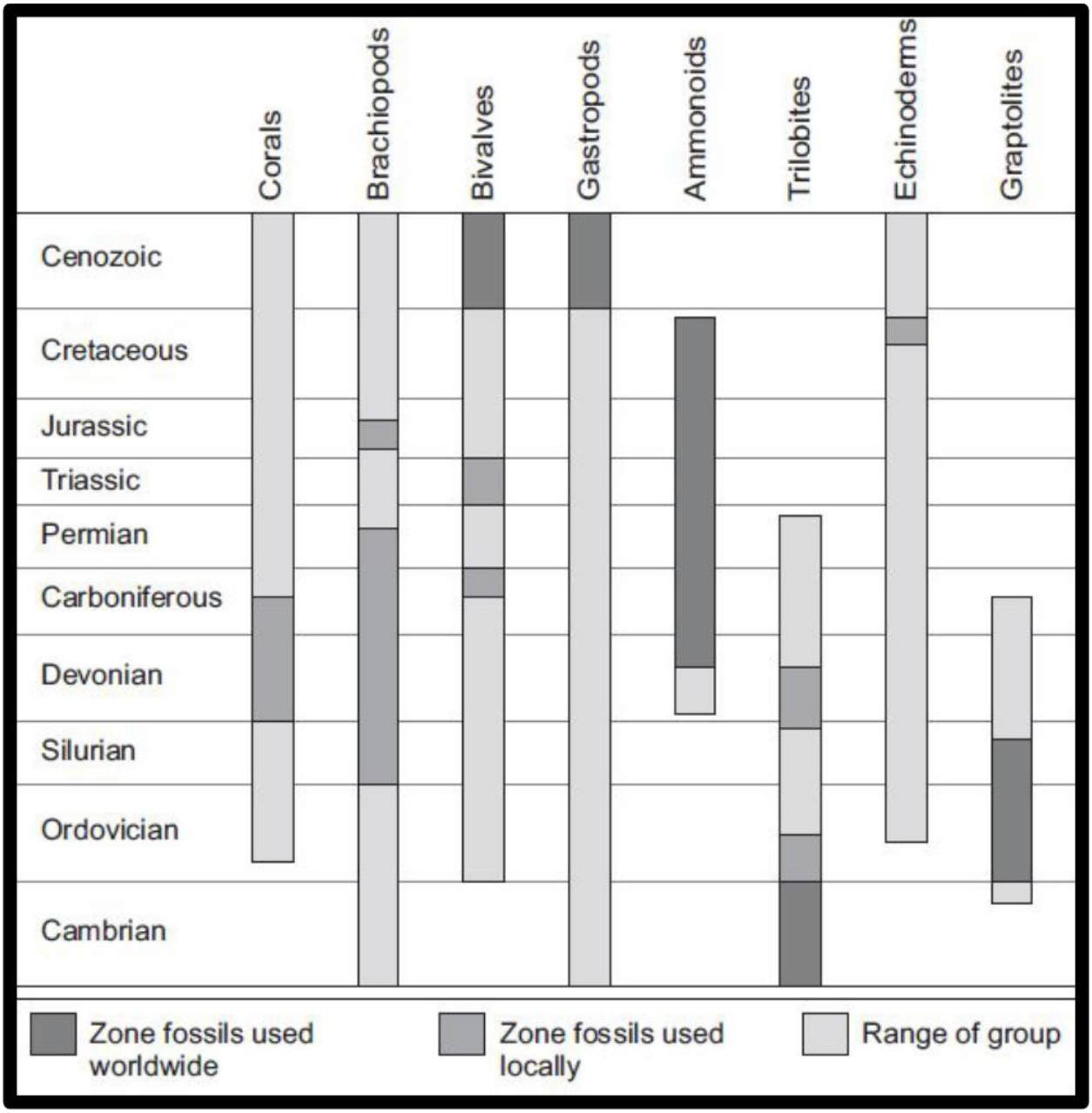
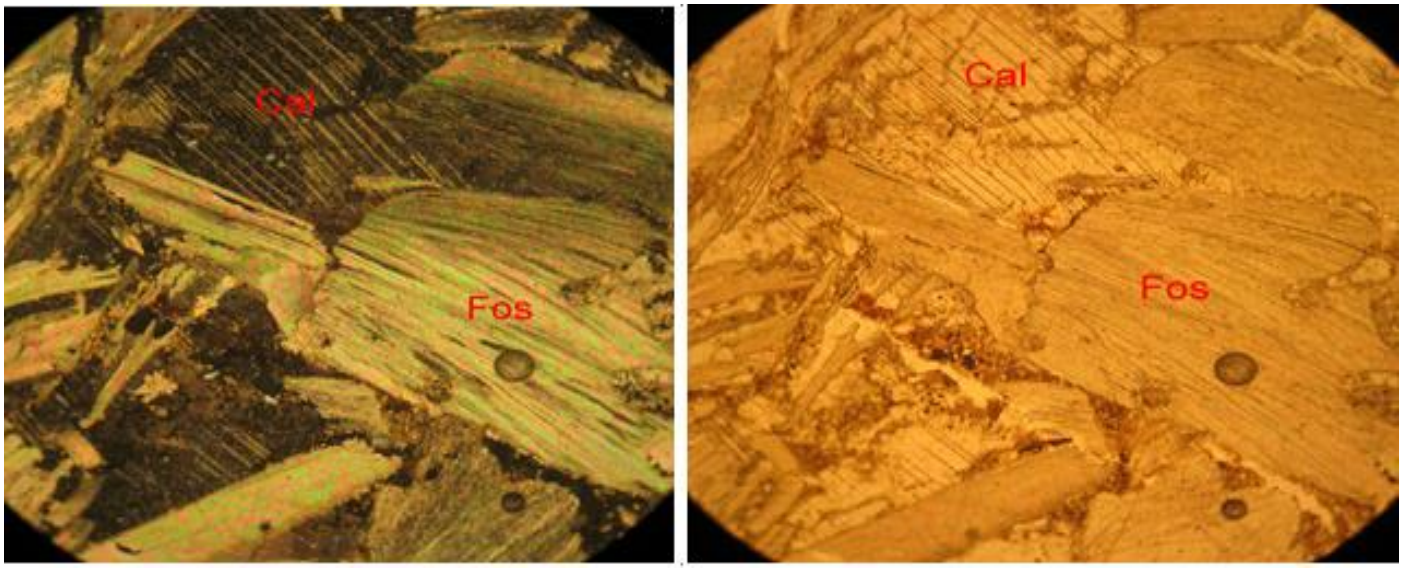
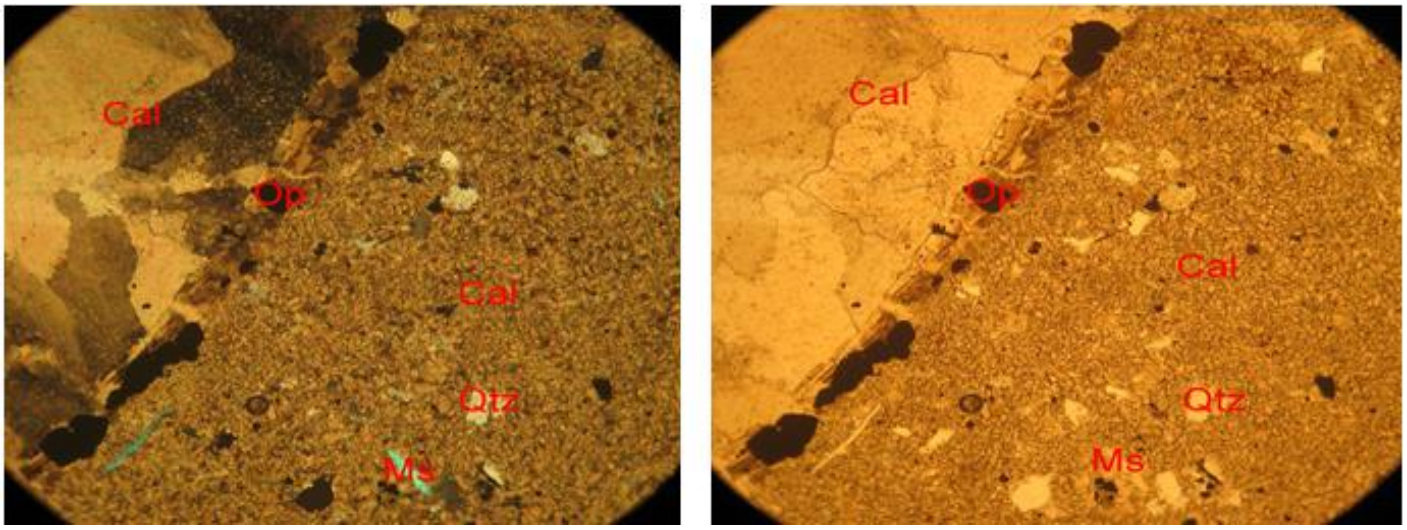


Fig. 22: Age range of macrofossils preserved in stratigraphic record (After Garry Nichols, 2009)

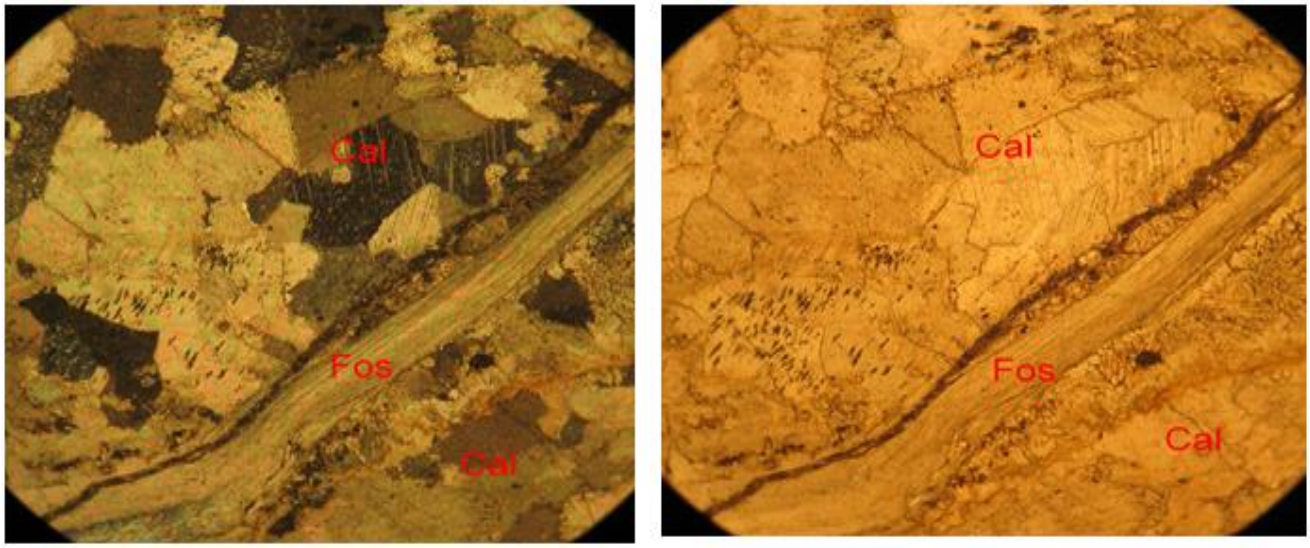
APPENDIX 4



XVIa:. Shaley limestone of Awgu Formation showing Echinoderm embedded within calcite



XVIb: Shaley limestone of Awgu Formation showing Calcites cements and opaques



XVIc: Shaley limestone of Awgu Formation Formation showing Echinoderms within calcite