LITHOSTRATIGRAPHY AND SEDIMENTOLOGICAL STUDIES OF THE ALBIAN TO CENOMANIAN SUCCESSIONS, PART OF MIDDLE BENUE TROUGH, NIGERIA.

BY

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Declaration

I declare that the work in the thesis entitled **" Lithostratigraphy and Sedimentological studies of the Albian to Cenomanian successions, part of Middle Benue Trough, Nigeria"** has been performed by me under the supervision of Dr. H. Hamza and Dr. T. Najime. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any other university.

_____ _____

Ishaya Ephraim Dauda Date

Certification

This thesis entitled LITHOSTRATIGRAPHY AND SEDIMENTOLOGICAL STUDIES OF THE ALBIAN TO CENOMANIAN SUCCESSIONS, PART OF MIDDLE BENUE TROUGH; NIGERIA by Ishaya Ephraim Dauda meets the regulations governing the award of the degree of Masters of Geology of Ahmadu Bello University Zaria, and is approved for its contribution to knowledge and literary presentation.

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Dedication

I dedicate this work to God Almighty and to my God give parents Mr. and Mrs. Ishaya Dauda.

Acknowledgement

I will forever give glory, honour and adoration to God for the enablement, knowledge and inspiration that led to the success of this work.

I want to express my gratitude to my able supervisors Dr. H. Hamza and Dr. T. Najime for using their precious time to correct, suggest and gave constructive criticisms which have helped in sharpening the work and made it presentable. May God reward you richly.

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Abstract

The stratigraphy of the Albian to Cenomanian successions in the Middle Benue Trough comprises of the marine Asu River Group, the transitional Awe Formation and the continental Keana Formation. Previous authors regarded the Asu River Group to consist of the Arufu, Uomba and Gboko Formations which are lateral equivalent facies depending on the locality.

Lithostratigraphic studies describes the marine Uomba Formation of the Asu River Group in the study area to comprise of fineto medium grained regularly bedded sandstones overlying massive shaly mudstones and dark grey to black fissile shales, no fossils observed due to the anoxic/reducing conditions at the time of deposition with low supply of nutrients. The heavy mineral suite is of moderate diversity comprising of euhedral zircon, tourmaline and magnetite suggesting an igneous source with few rounded grains indicating some degree of transport before deposition.

The transitional Awe Formation comprises of grey to black shales, calcareous and micaceous shales, calcareous sandstones some occurring as nodules towards the top, fine to medium grained white sandstones and clays deposited in a shallow marine environment associated with tidal currents. Petrographic studies following the classification scheme, classify the sediments in this formation to comprise of quartz arenite and subarkoses. Current ripples are the major sedimentary structures observed; trace fossils thalassinoides also occur in the micaceous silty shales, bioclastic remains (bivalve) were seen especially in the calcareous sandstones suggesting deposition in oxidized nutrient rich environment. The heavy minerals suite is of low diversity dominant of euhedral light and colourless zircon with few rounded ones, brownish tourmaline and magnetite suggesting an igneous provenance while the rounded grains are of sedimentary (reworked sediment) provenance. This formation is cut by several mineralised veins rich in quartz and barite in some places.

The continental Keana Formation occurs towards the northern part of the study area. Lithostratigraphic studies shows coarse grained massive sandstone occurring as parallel beds and in some places as boulders which indicate deposition in a deltaic environment under a high to moderate energy conditions (delta mouth bar). The heavy mineral suite comprises mainly of dominantly light and colourless euhedral zircon, brownish tourmaline and opaque minerals (magnetite) suggesting an igneous provenance while the rounded grains indicate a sedimentary source (reworked sediments).

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CHAPTER ONE

INTRODUCTION

1.1 General Introduction

The sediment filled elongated NE-SW trending depression in Nigeria is referred to as the Benue Trough (Cratchley and Jones, 1965; Burke *et al*., 1970) and it has been divided into the Lower, Middle and Upper Benue Trough by Cratchley and Jones (1965) (Fig. 1). 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). However, the lithostratigraphy, petrography and sedimentological studies of the sediments of the study area in the Middle Benue Trough are poorly known.

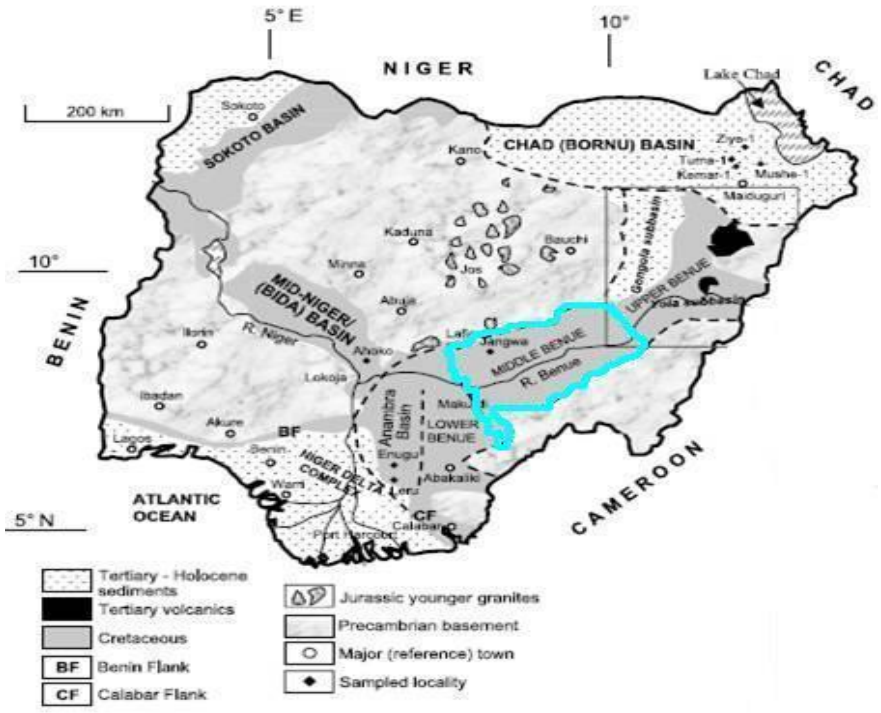


Figure 1: Geological map of Nigeria showing the location of Middle Benue Trough (Obaje, 2009).

1.2 The Aim of the Study

The aim and objectives of the present study are to update the existing knowledge with regards to the lithostratigraphy, sedimentology as well as sedimentary structures and to deduce the provenance of the sediments in the study area.

1.3 Location, Extent and Accessibility of the Study Area

The study area is part of Lafia Sheet 231 NE (Scale 1:50,000). This area lies within the Middle Benue Trough of Nigeria bounded by latitudes **8° 45□ 00□ □** to **8° 56□ 00□ □ N** and longitudes **8° 00□** to **8° 15□ 00□ □ E** (Fig. 2). This area is situated between Aloshi, Keana (Fig. 3) and some part of Chikinye in Benue State. The area is very accessible by roads and footpaths linking the area.

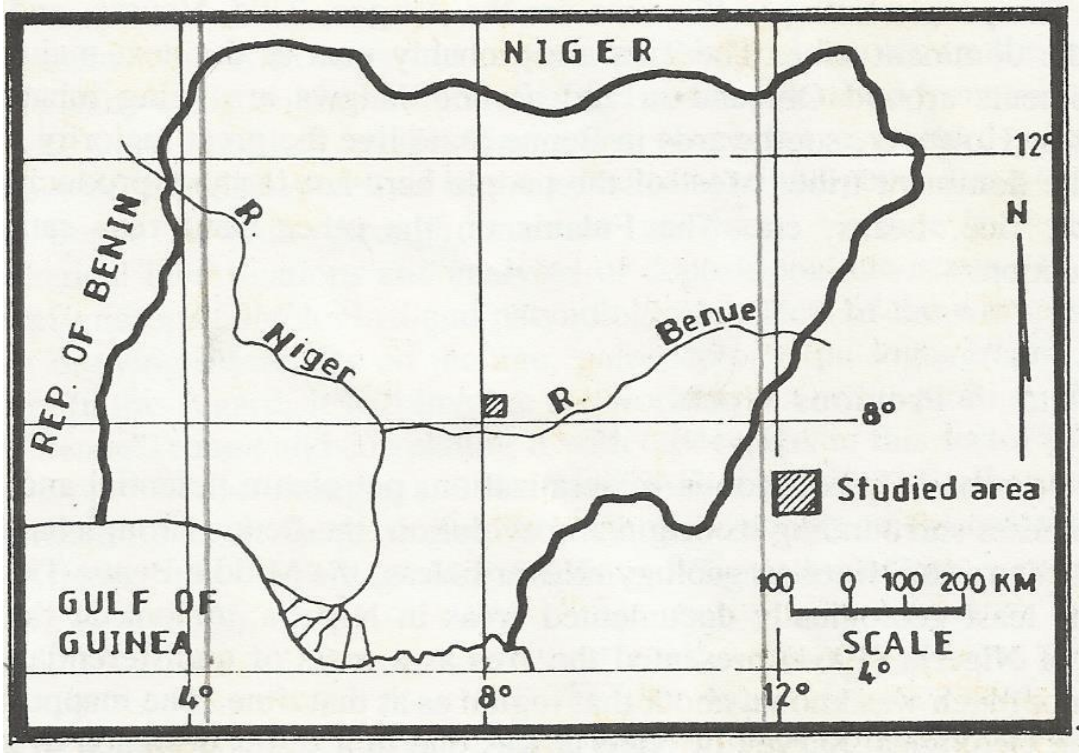


Figure 2: Map of Nigeria showing location of the study area

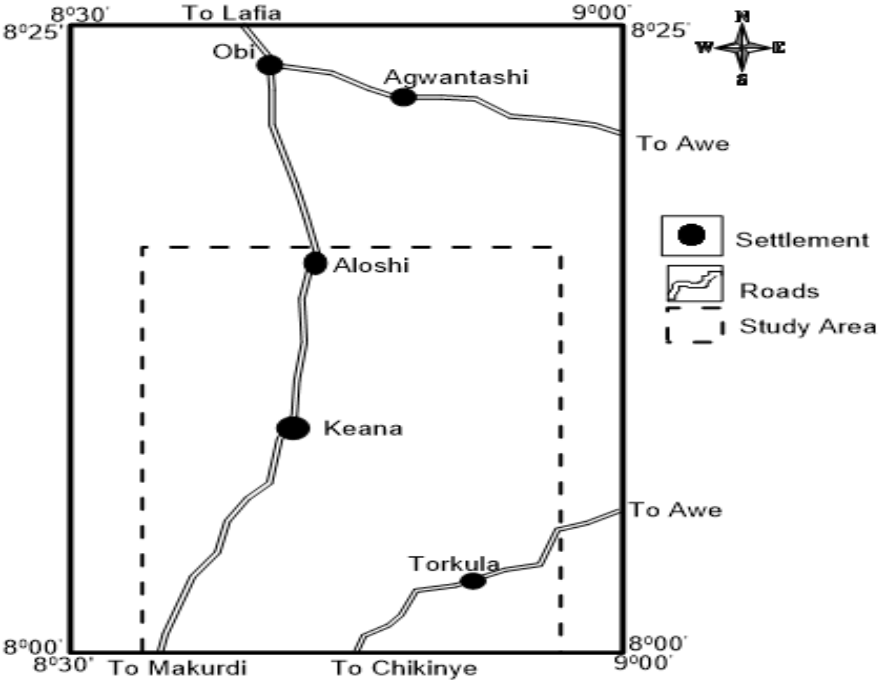


Figure 3: Location and Accessibility map of the study area

1.4 Relief and Drainage

The area is generally an undulating land with a few isolated hills. The highest point is 246.0 m and the lowest point is 131.0 m above mean sea level. The drainage pattern in the area is dentritic. The area is well drained with major rivers such as Ome, Ugir, Okumase and Okpalaga among others and streams occupying rather wide valleys. The rivers eventually drain into the River Benue. The tributaries are mostly seasonal having their sources mainly within the area.

1.5 Climate and Vegetation

The climate of the study area falls within the tropical climatic zone. Two main seasons are recognized, a long rainy or wet season normally accompanied by heavy down-pours from April to October with maximal rainfall in June to September and a shorter dry season from November to March. This area enjoys a mean annual rainfall range of 112 cm-150 cm. The mean annual temperature range from 26^{o}c to 30^{o}c and varies with elevation (Offodile, 1976). The relative humidity range from 60% to 80%,

during the wet season, the area is under the influence of moisture-laden southeast trade winds, which give way to the dry and sometimes dusty northeast winds (the harmattan) during the dry season.

Vegetation is typically that of the Guinea Savannah forest characterized by shrubs and grasses. There are tall trees along the river valleys. However, the original vegetation has been, in most cases, tempered with by human activities.

1.6 Human Geography

The main inhabitants in this area are the Arogos, Tivs, Hausas and Fulanis. The Arogos are the dominant tribe. The Tivs are probably the next major tribe, as many of the settlements around Aloshi and part of Keana are being inhabited by the Tiv speaking natives. However, towards the southern part of Keana to Chikinye in Benue State live the great majority of the Tivs where they are the dominant tribe. Most of the people here are farmers producing yams, guinea corn, maize, rice, etc. the Fulani on the other hand rear cattle for milk and beef production.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The linear NE-SW trending Benue Trough (Fig. 1) has a length of approximately 800km and opens into the Gulf of Guinea where the Cenozoic Niger Delta has built out upon oceanic crust (Avbovbo, 1980). The Trough is filled with Cretaceous rocks whose ages range from Aptian to Maastrichtian and bounded on either side by granite and gneisses which make up the crystalline basement (Cratchley and Jones, 1965). The stratigraphical and structural features are essentially continuous from the Lower to Upper Benue Trough.

The Middle Benue Trough corresponds to the median rectilinear NE-SW trending Benue Trough. It extends north-eastwards from as far as a line joining Bashar and Mutum Biyu (Fig. 4). 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) coincides with its main surface structural feature, the NE-SW trending Keana anticline. On the southeastern flank are a "Wukari" and a "Mutum Biyu Sub-Basins" 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). The Middle Benue Trough is relatively poorly known, especially in its northeastern parts, no detailed geological maps of this sector is available but the area immediately south of Bashar (Fig. 4) was included in a photogeological map prepared by Dessauvagie (1969). Maps of

Lafia-Keana-Awe region were presented by Offodile (1976) and Offodile and Reyment (1977).

In the Middle Benue Trough, source rock facies are represented by the shale of the Asu River Group and are overlain by the regressive shale, siltstones and sandstones of the Awe and Keana Formations, although no exploratory well has penetrated successions of rocks in the Middle Benue Basin except for the shallow coal core holes.

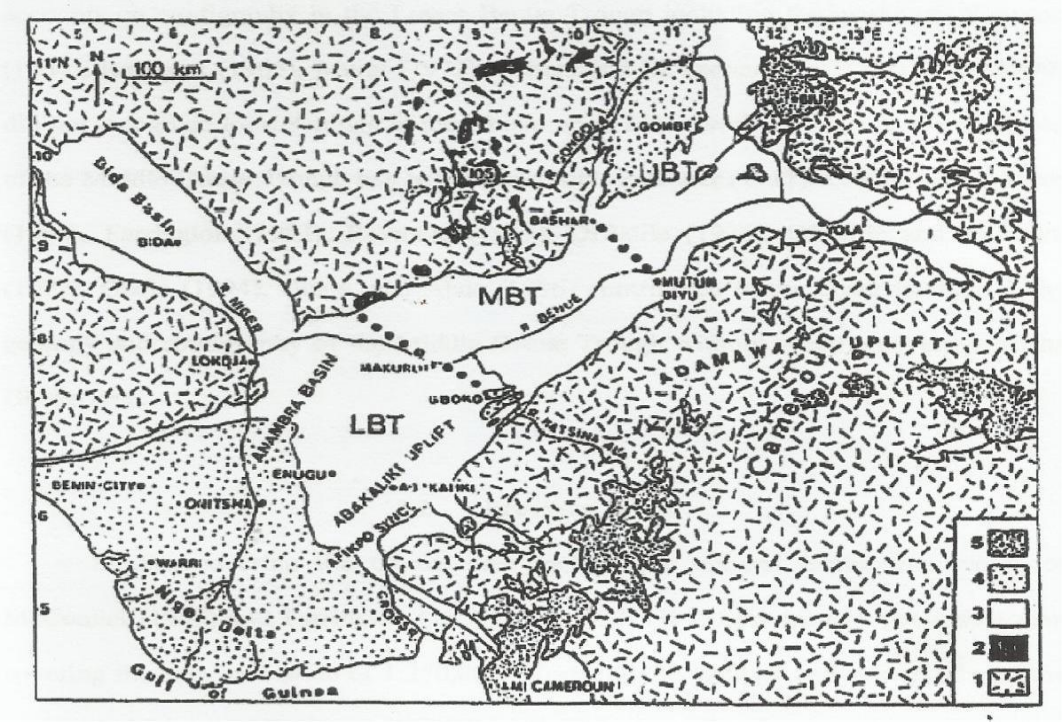


Figure 4: Outline geological map of the Benue Trough and adjacent areas. LBT, lower Benue Trough; MBT, middle Benue Trough; UBT, upper Benue Trough. 1, Precambrian; 2, Jurassic "Younger Granites"; 3, Cretaceous; 4, post- Cretaceous sediments; 5, Cenozoic-Recent basalts (including those of the Cameroun line) (After Zaborski, 1998).

2.2 Origin and Evolution of the Benue Trough

The origin and tectonic history of the Benue Trough is linked with the separation of the African and South American continents during the Early Cretaceous (Stoneley, 1966; Benkhelil, 1989) (Fig. 5). This separation was followed by the

drifting apart of these continents, the opening of the South Atlantic Ocean and the development of the mid- Atlantic ridge (Benkhelil, 1989).

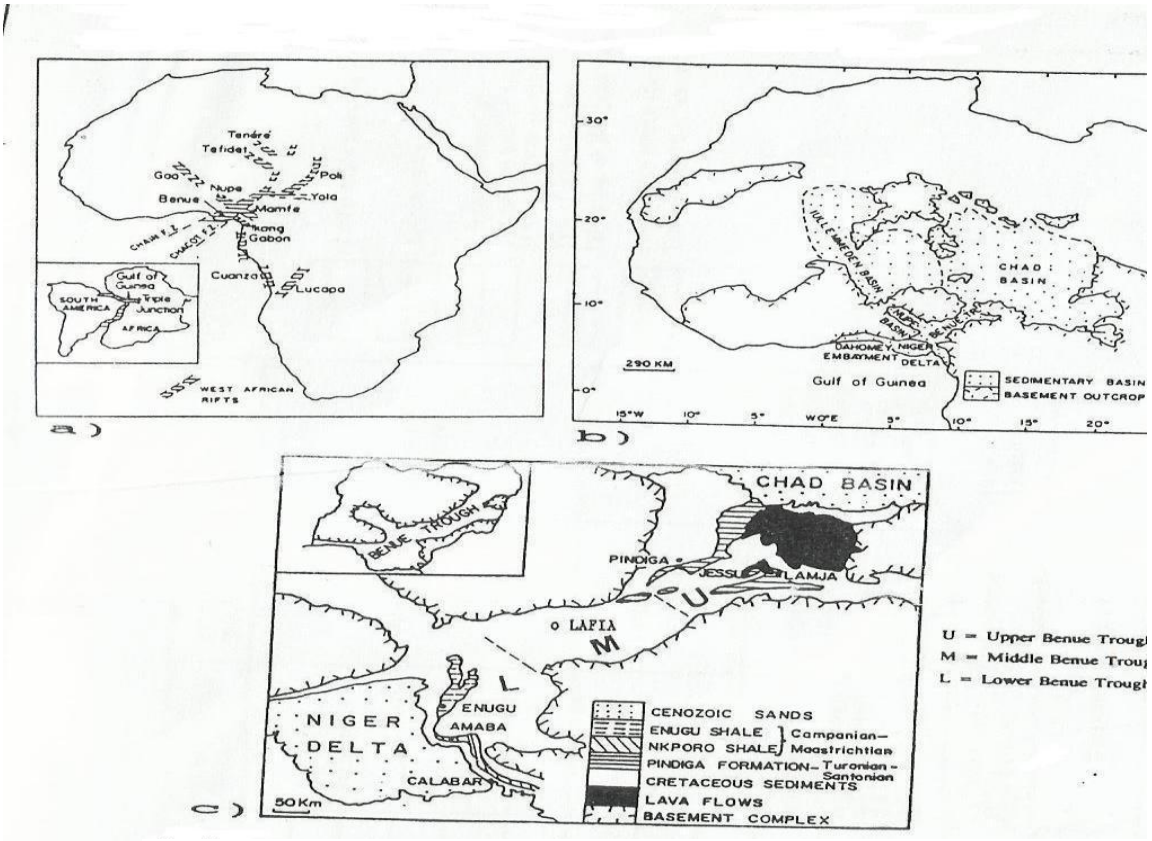


Figure 5: The Origin/Formation of Benue Trough (After Peters, 1982)

a) Separation of the continents of Africa and South America and initiation of the Benue Trough.
b) The Benue Trough in relation to other major sedimentary basins in Central West Africa
c) Geographic location of the Benue Trough in Nigeria

However, there are essentially two models: namely the rift and the pull-apart models.

Several early models were proposed based on a rifted origin beginning with King (1950). Cratchley and Jones (1965) interpreted a regional axial positive gravity anomaly as being typical of a rift valley configuration with crustal thinning and elevation of crust-mantle boundary beneath the central part of the rift.

Lees (1952) considered the Benue Trough to be a compressional downwarp structure, with folding created by deep seated basement contraction. Burke *et al*. (1971,

1972), Burke and Whiteman (1973) and Burke and Dewey (1974) proposed a model regarding the trough as the failed arm of a Rift-Rift-Rift triple junction. The trough was seen as direct product of the South Atlantic Ocean opening, initiated by early Cretaceous mantle upwelling created by a hot spot beneath the present Niger Delta. The other two arms progressed by active seafloor spreading and continental separation to form the Equatorial and South Atlantic Oceans respectively. They regarded the Benue Trough as the site of active spreading with a strip of oceanic crust generated below the Lower Benue Trough from Albian to Santonian times and later removed by subduction.

Grant (1971) proposed a failed arm model for the trough but considered the Niger Delta triple junction as a rift –rift-fault junction, with transform fault making up the Gulf of Guinea segment. Wright (1976) compared the Benue Trough to the Afar region and dismissed the spreading ridge hypothesis of Burke *et al*. (1971) as untenable but suggested that shallow inclined basement faults existed beneath the Lower Benue Trough, while a normal rift valley configuration was proposed for its upper part where crustal thinning was less pronounced.

Mascle (1977) also considered the Benue Trough to be a continental rift. Olade (1975, 1976) regarded the Benue Trough as an aulacogen related to intermittent mantle upwelling, updoming, crustal attenuation and rifting. The mantle plume was dormant during the Cenomanian, giving rise to minor folding but was reactivated during Turonian times. Eventually its activity ceased or it shifted elsewhere during the Santonian resulting into the collapse of the trough.

Ofoegbu (1984) and Ofoegbu *et al.* (1990) proposed a model similar to that of Olade(1975, 1976) except that protruded dyke-like bodies were postulated within the zone of weakness resulting from updoming. They were believed to have contributed to

the stretching and thinning of the crust.

Whiteman (1982) proposed that an Early Cretaceous, mantle plume-related to Rift-Rift-Rift triple junction existed below the present day Niger Delta, and suggested that the Santonian folding was as a result of compressional stress. He considered the Benue Trough to have formed as a result of incipient rifting during the breakaway of the South America from Africa and also the opening of the South Atlantic in the early Cretaceous.

Benkhelil (1982, 1989); Guiraud (1990) and Guiraud and Maurin (1992) described the Benue Trough as a set of juxtaposed pull-apart basins genera ted along pre-existing N60^{o}E strike-slip faults during the early Cretaceous. The transcurrent (strike-slip) faults were believed to have been connected to the oceanic fracture zones (Romanche, Chain and Charcot) and reactivated during the separation of the South American and African Plates.

Benkhelil (1986, 1988, and 1989) and Benkhelil *et al*. (1988, 1989) were of the opinion that the Benue Trough was always floored by continental crust. Early versions of the strike-slip model (Benkhelil, 1982; Benkhelil and Robineau, 1983) proposed that the Romanche Chain and Charcot fractures extended from the Atlantic Ocean below the Niger Delta. This model is based on geological and geophysical studies in the Benue Trough, which indicated that most of the major faults are transcurent faults rather than normal faults. Though the identified normal faults mostly trending N120^{o}E in the Upper Benue Trough control the graben structures, they are always connected to major sinistral N60^{o}E strike-slip faults.

Benkhelil (1986, 1988) indicated that only the Chain and Charcot fracture systems extended into the Benue Trough. Geophysical data revealed more clearly the disposition of the sub-basins flanking the trough axis; these are arranged in enchelon

and were also interpreted as a pull-apart origin.

According to Benkhelil and Robineau (1983); Popoff *et al.* (1983) and Maurin *et al.* (1986) the problem with the rift model is the lack of conspicuous faults at the margin of the trough and a generalized folding of the Cretaceous sediments. An additional problem according to them is the scarcity of Cretaceous magmatic activity associated with rift structures which is only observed close to, or along major faults. Cratchley and Jones, 1965 however, argued that the main boundary rift faults are now concealed by the Cretaceous sediments overlying the margins of the trough.

The pull-apart model which is the manifestation of strike-slip faulting can be integrated into a more regional view of the West and Central African Rift System (WCARS). According to Fairhead (1988a,1988b); Fairhead and Green (1989); Fairhead and Binks (1991); Binks and Fairhead (1992) and Genik (1993), the resultant effects of the separation of Africa and South America on the African continent led to the development of a closely linked rift system in the West and Central African regions. This system is subdivided into the West African Rift Sub-system (WARS) and the Central African Rift Sub-system (CARS). Both were developed within the Pan-African lines of lithospheric weakness (Maurin and Guiraud, 1993).

According to Fairhead (1988a) and Fairhead and Green (1989), the equatorial Atlantic in the Early Cretaceous was considered to be a transform boundary, and not a constructive plate boundary as proposed by Burke *et al.* (1971, 1972). This assertion was also made by one proponent of the rift model, Grant (1971) who proposed that the triple junction at the southern end of the Benue Trough was a Rift-Rift-Fault-triple junction, with the faulted segment represented by the Equatorial Atlantic. The two major strike-slip zones were the Benue Trough and the Central African Shear Zone which, according to Guiraud and Maurin (1991, 1992) are ancient shear zones

reactivated during the Cretaceous.

Wilson (1992) and Wilson and Guiraud (1992, 1998) believed that passive extension alone may not fully account for the opening of the Benue Trough. The St.Helena hotspots were located below the present day Niger-Delta at 120-130 Ma (Morgan, 1983; O'Connor and Duncan, 1990; O'Connor and le Roex, 1992); [cf. Burke and Whiteman (1973)]; Burke and Dewey (1973, 1974). It may have served to weaken the lithosphere in this region by conduction of heat and transport of volatiles from the underlying mantle plume head. Zaborski (2003) suggested rifting processes that are strongly modified by strike-slip faulting to be the main control on the Early Cretaceous history of the Upper Benue Trough.

The Middle Benue Trough is the mid-geographical subdivision of the Trough and shares the same tectonic origin as the Benue Trough. Therefore, from the models proposed by several authors, the origin of the Benue Trough is best regarded as a result of combination of rifting and sinistral strike-slip faulting.

2.3 Stratigraphy of the Middle Benue Trough

Stratigraphic descriptions of sediments in the Benue Trough have been presented by Reyment (1965); Offodile (1976); Adeleye and Fayose (1978); Peters (1982); Peters and Ekweozor (1982); Benkhelil (1989); Nwajide (1990); Akande *et al*. (1992); Idowu and Ekweozor (1993) and Obaje *et al*. (1994) among others.

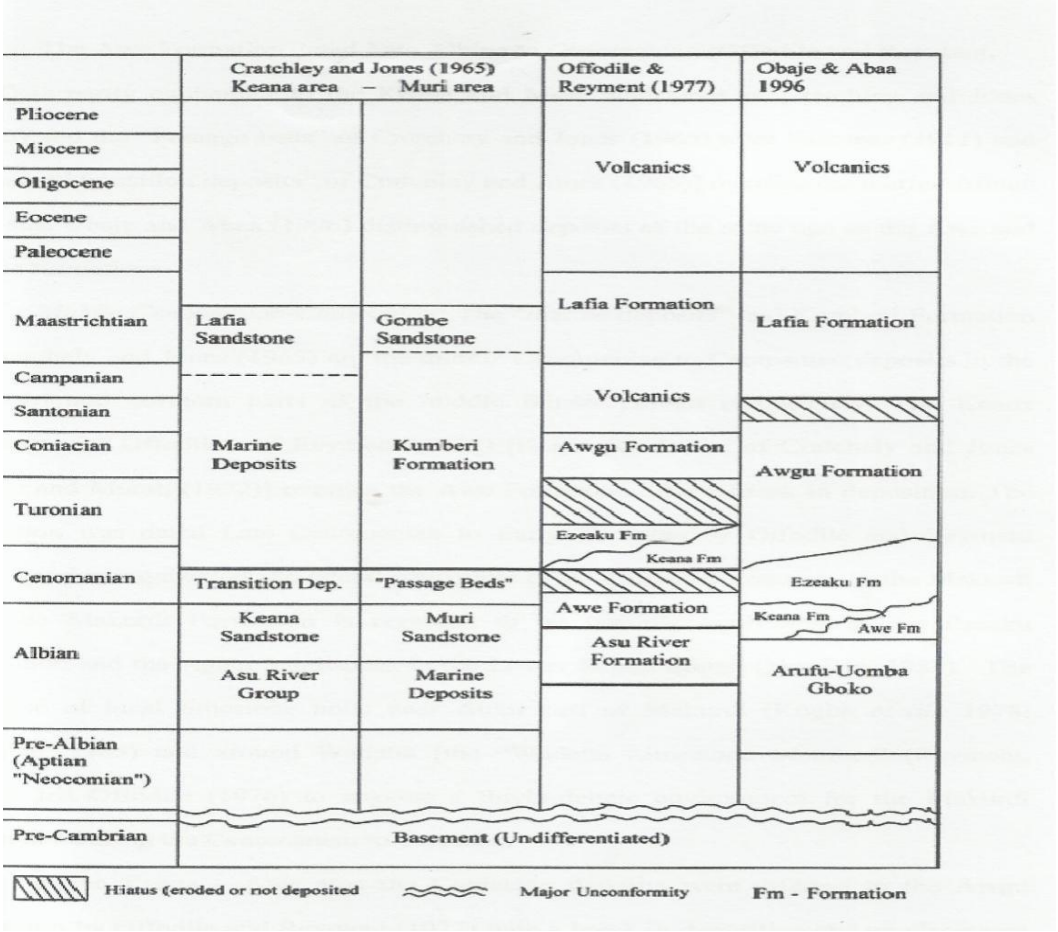
In the Middle Benue Trough, the sediment thickness is about 4,000m (Obaje *et al*., 1996). The stratigraphic succession in this part of the Trough begins with the basal Albian Arufu, Uomba, Gboko Formations, belonging to the Asu River Group. They are overlain by the Cenomanian Keana and Awe Formations and the Cenomanian-Early Turonian Eze-Aku Formation. The late Turonian-Early Santonian Awgu Formation lies conformably on the Eze-Aku Formation (Table 1). The post

folding Campanian- Maastrichtian Lafia Formation ended the sedimentation in the Middle Benue Trough, after which widespread volcanic activities took over in the Tertiary (Obaje *et al.,* 1998).

2.3.1 The Asu River Group

The Asu River Group is referred to as a group comprising of three formations- the Arufu, Uomba and Gboko Formations (Petters, 1982). It is noted that the Arufu, Uomba and Gboko are lateral equivalent facies referable to any one name of the three depending on the locality (Obaje, 1994). The Asu River Group is the oldest marine deposit in this area. This group was deposited during the Mid-Albian marine transgression of the South Atlantic-Gulf of Guinea. The lithologic composition of this group/formation comprises mainly limestones, shales and calcareous shales, micaceous siltstones, mudstones, clays and fine grained sandstones (Cratchley and Jones, 1965 and Offodile, 1976). The Asu River Group outcrops mainly in the Keana anticline east of Keana town and south of Azara; and in the area around Gboko as was observed in the quarry of the Benue Cement Company near Yandev-Gboko (Petters, 1982). This formation is very fossiliferous. Numerous ammonites have been described from the formation by Offodile and Reyment (1976) while Petters (1982) identified and described mainly agglutinated and some calcareous foraminiferal taxa attributed to the Asu River Group outcropping in the quarry of the Benue Cement Company. However, Najime (2010) described a 120 m 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, he places the Gboko Formation in the Lower Benue Trough.

Table 1: Lithostratigraphic sub-divisions for Cretaceous and Tertiary rocks of the Middle Benue Trough region as suggested by the authors `indicated (Adopted from Najime, 2010).



2.3.2 The Awe Formation

The Awe Formation was deposited as passage (transitional) beds during the Late Albian-Early Cenomanian regression. This formation overlies the Asu River Group. The type locality is around the town of Awe where Offodile (1976) estimated the thickness of the formation to be about 100 m. The formation consists of flaggy, whitish, and medium to coarse grained calcareous sandstones, carbonaceous shales and clays. The sandstones become finer grained and more micaceous towards the base with fine current beddings (Ariyo, 1987).

2.3.3 The Keana Formation

This unit overlies the Awe Formation, the contact between the two being variously described as gradational and unconformable (Offodile, 1976, 1984; Offodile and Reyment 1977) . The Keana Formation consist mainly of thickly cross bedded, fine to very coarse-grained to conglomeratic, gritty arkosic sandstones of inferred fluvial or deltaic origin (Murat, 1972; Offodile, 1976). Offodile (1976) and Offodile and Reyment (1977) described the Keana Formation as grading downwards into the Awe Formation and laterally, in part, into the marine Eze- Aku Formation towards the south. Outcrops of the Keana Formation flank the east and west sides of the Keana anticline around Keana, (at Chikinye, Jangerigeri, Azara and Daudo). Although not directly dated, the Keana Formation has generally been regarded as Late Albian to Cenomanian and representing the southern part of a fluvio-deltaic system discharging into the receding sea. Its lateral equivalent to the north is the "Muri Sandstones" (Cratchley and Jones, 1965; Murat, 1972; Whiteman, 1982; Benkhelil *et al*., 1988). Offodile (1976) suggested that this fluvio-deltaic system was diachronous, Late Albian to Cenomanian in the Upper Benue Trough, the Keana Formation being Cenomanian and the Makurdi Formation Cenomanian to Turonian.

2.3.4 Eze-Aku Formation

The Eze-Aku Formation consist mainly of grey to black shales with clay horizons, fine to medium-grained sandstones and limestone beds (Offodile, 1976; Offodile and Reyment, 1977). Its basal part includes shelly limestones containing the bivalve *Costagyra olisiponensis* (Sharpe) and a marly horizon has yielded the Late Cenomanian ammonite *Euomphaloceras septemseriatum*. West and south of Keana black shales, marls, limestones and micaceous sandstones occur in the Eze-Aku Formation, with fine to coarse-grained felspathic sandstones appearing in its upper part

(Obaje, 1994). In the region around Makurdi the Makurdi Formation (Reyment, 1964) outcrops over a large area. Nwajide (1985) regarded it as a facies equivalent of the Eze-Aku Formation and laterally continuous with the Agala Sandstone to the south. Around Makurdi the formation is 400-500m thick, dominantly arenaceous and including planar or trough cross bedded, coarse-grained pebbly sandstones and fine-grained, micaceous ripple-bedded sandstones showing mud cracks (Nwajide, 1985).

2.3.5 Awgu Formation

In the Keana- Awe area the beds overlying the Eze-Aku Formation were referred to the Awgu Formation by Offodile (1976) and Offodile and Reyment (1977) (Fig. 6b) who by comparison with Nkalagu area in the Lower Benue Trough, suspected that the boundary between the two may be unconformable, the upper part of the Turonian being missing. Obaje (1994) believed the contact to be conformable and dated the Awgu Formation as Turonian to Coniacian (or Early Santonian). Numerous sections obtained from outcrops and boreholes drilled in the course of exploration for coal were described by Obaje (1994). Offodile (1976) suggested that the Awgu Formation recorded numerous oscillations between continental and shallow marine conditions with marine marls or shales enclosing coals and associated non-marine beds. The coals which are of bituminous rank were subdivided into three facies types by Obaje (1994); Obaje and Ligouis (1996) and Obaje *et al*. (1994, 1996) as follows:

1. A vitrinite-fusinite facies believed to have formed in telmatic wet forest swamps along and within lagoons.
2. A trimaceratic facies, dominated by vitrinite with subordinate liptinite and inertinite, believed to have formed within deltaic plain, limno-telmatic clastic marsh environments.

3. A shaly coal facies, containing more than 25% mineral matter, mostly clay minerals and pyrite, believed to have formed under greater marine influence.

The environment of deposition of the coal- bearing sequences were thought to range from shallow marine through lagoonal to delta plain. Most or all of the Santonian and Campanian stages are generally believed to be missing in the Middle Benue Trough. Offodile (1976); Offodile and Reyment (1977) and Obaje (1994) related this hiatus to the Santonian compression which they believed produced the main NE-SW trending fold structures including the Keana anticline.

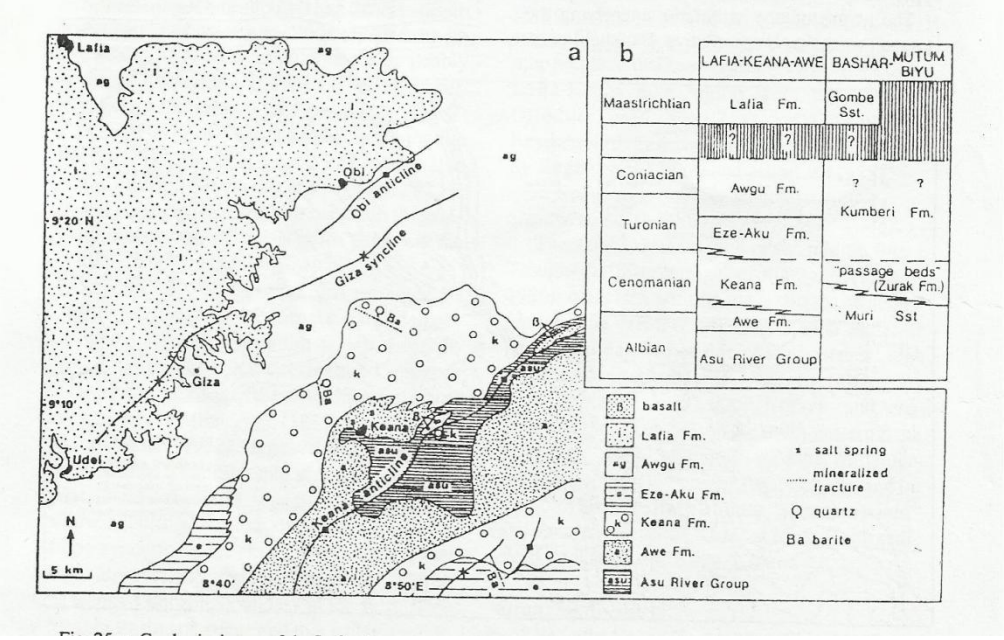


Figure 6: **a.** Geological map of the Lafia-Keana area in the Middle Benue Trough (After Offodile, 1976; Offodile and Reyment, 1977).
b. Lithostratigraphical subdivisions proposed for parts of the Middle Benue Trough (After Zaborski, 1998).

2.3.6 The Lafia Formation

Lafia Formation (Offodile, 1976) [the "Lafia Sandstaone" of Cratchley and Jones (1965)] comprises the youngest sediments in the southern part of the Middle Benue Trough. It is confined to the Kadarko sub-basin. A thickness of 500-1500 m was quoted by Offodile (1976) though only about 50 m was reported east of Lafia where wedging out is apparent. It consists of red, poorly consolidated, commonly cross-

bedded frequently ferruginous sandstones, flaggy mudstones and clays with a palaeosol horizon identified just south of Lafia (Offodile, 1976). Carbonized plant remains are the only known fossils. Although not precisely dated, the formation is generally regarded as Maastrichtian.

2.3.7 The Post-Cretaceous Rocks

No post Cretaceous sediments, apart from superficial deposits occur in the Middle Benue Trough. Volcanic activity was relatively minor in scale, a notable occurrence is the phonolitic trachyte of Wase Rock (Wright, 1989), dated as 14.4±0.4Ma by Grant *et al*. (1972). Basaltic flows occur around Awe and dolerite sills of presumed Cenozoic age have been encountered within the Lafia Formation (Offodile, 1976; Obaje, 1994). Offodile (1976) reported that intrusives in the Lafia-Awe area are restricted to anticlinal structures.

2.4 Structural Features of the Middle Benue Trough

The Keana Anticline is the major structural element in this part of the Trough (Fig. 6a). This structure stretches for over 120 km in a mean N50E direction (Benkhelil, 1986). To the north of Makurdi at the passage between Lower and Middle Benue, the anticlinal axis deviates toward a N30E direction following the structural trend of the Anambra Basin. To the northeast, the anticline is relayed by parallel folds which form a continuous step up to the Upper Benue Trough. The Cretaceous rocks have been subjected to several folding episodes and, as a result, their dips tend to be variable. In the Asu River Group, dips vary from 0^{o} on the crest of the Keana anticline to 25^{o} on the flanks of this fold. The Asu River Group and Eze-Aku Formations are more intensely folded than the younger sediments and they are characterized by drag folds. There is evidence for three folding episodes. Nwachukwu

(1972) suggested the existence of a post-Albian and pre-Turonian folding phase, basing his inference on inter alia the "greater intensity of folding of the Albian sediments". It is generally accepted that there was a folding episode in Santonian or Early Campanian time and the effects of this can be identified in all the formations of the area with the exception of the Lafia Formation (Offodile and Reyment 1976). The resultant uplift and subsequent erosion has left remnants of the Makurdi and Awgu Formations dotting the volcanic hills around Keana. Finally, there is the post-Maastrichtian folding episode (Wright, 1975) which touched all formations, including the Lafia Formation.

The Keana anticline, like the Abakaliki structure, is cut by a set of mineralized veins. They form perfectly straight ridges running over a maximum of 10 km and consisting of quartz, calcite and barite (Benkhelil, 1986).

CHAPTER THREE

METHODOLOGY

3.1 Introduction

Field mapping techniques were employed in order to delineate the various stratigraphic sections; it was carried out within the period of March and April, 2014. Various stratigraphic sections were studied and samples collected from each section for sieve analysis, petrographic, micropalaeontological and heavy minerals analyses.

3.2 Field Methods

Traverses were taken with the aid of compass clinometer along major roads and minor paths while sampling of rock units was carried out concurrently where there are exposures of surface outcrops. However, much attention was devoted to locating stratigraphic outcrop sections which are mainly exposed along river banks and road cuts. Along these river banks, it is easier to locate and describe geological contacts or boundaries. Because of the large area involved it was necessary to use motor cycle between some outcrop locations.

Fresh samples were carefully collected from each section in order to avoid distortion of the result due to weathering. Vital information such as location, sample number, horizon descriptions such as; lithologies, colours, sedimentary structures from each unit and date of the sampling were clearly indicated on the sample bags and all the relevant data entered into the field note book.

Ten sections were logged and careful examination of the nature of surfaces separating each unit noted in order to determine if there are variations in their lithologies and their fossil contents.

Samples of the various lithologic units were collected with the aid of geologic hammer and chisel.The thickness of each unit measured using measuring tape. Location and elevation readings obtained using the GPS (Global Positioning System), the strike and dip of beds were measured with the aid of compass-clinometer. The samples were well labeled and kept separately in sample bags for analysis in other to avoid contamination. Graphic lithologic logs were drawn for each section measured with the help of MapInfo professional 11.0 software. The paleoenvironmental interpretation was attempted based on facies association, sedimentary structures, textures, petrography and heavy minerals analysis.

3.3 Laboratory Method

3.3.1 Petrographic analysis

This involves the identification of the optical properties of the most frequently observed minerals in rocks, the way they appear and interact with the light going through them, using petrographic microscope. It also aid in the identification of the various forms of cements, matrix and the determination of grain size, sorting, roundness, nature of contacts of grains and the preserved porosities in rocks.

Samples collected from the field were prepared at the thin section laboratory of the Department of Geology, Ahmadu Bello University Zaria. Each sample was cut using the cutting machine and mounted on a glass slide using canada balsam. The rock slice which has been glued to a glass slide was grinded until 30 microns thickness was reached. At this thickness most minerals become more or less transparent and can therefore be studied by a microscope using transmitted light. Sorting of grains were estimated under the microscope using the visual comparators for sorting in thin- sections based on three dimensional distributions of spheres that are long-normal by volume frequency (Jerram, 2001; Fig.

7), while rounding of grains was estimated under the microscope using the roundness chart of Pettijohn *et al.* (1987; Fig. 8)

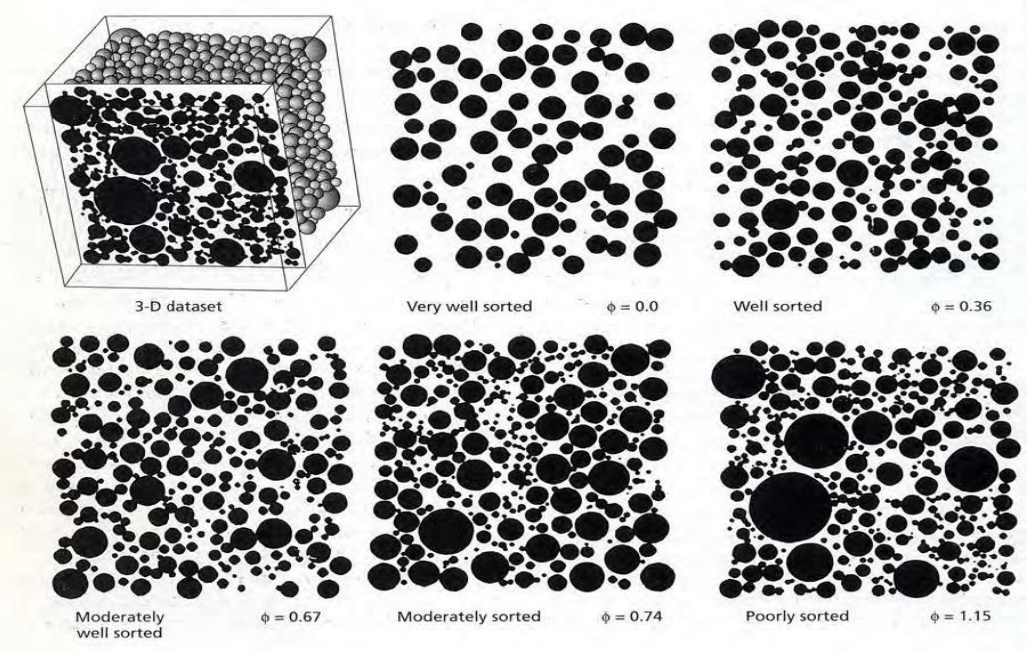


Figure 7: Visual comparators for sorting for thin-sections based on three-dimensional distributions of spheres that are log-normal by volume frequency (After Jerram, 2001)

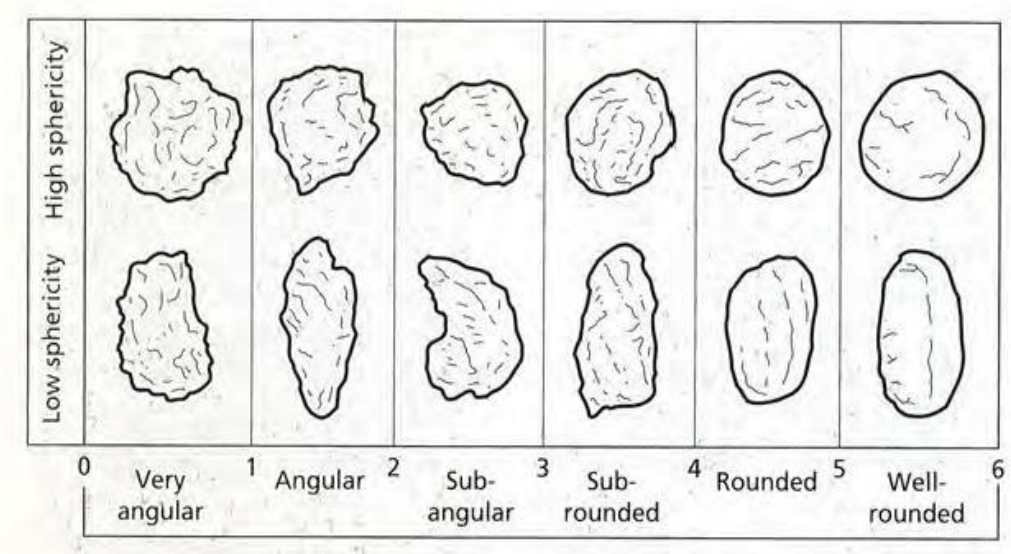


Figure 8: Categories of roundness for sediment grains for each category a grain of low and high sphericity is shown (After Pettijohn *et al.*, 1987)

Classification of the sandstone facies was done using the Pettijohn *et al.*(1987) classification chart or scheme (Fig. 9). A sandstone with at least 95% of quartz grains is called quartz arenite, a rock is generally accepted as an arkose when it consist of 25% or more of feldspars and sub-arkose when it consist of 5%-25% feldspars while a rock is referred to as a greywacke when it consist of >15% clay matrix and a lithic arenite when the proportion of rock fragments is >25% in the rock, this would be achieved using percentage estimation comparison charts (Fig. 10).

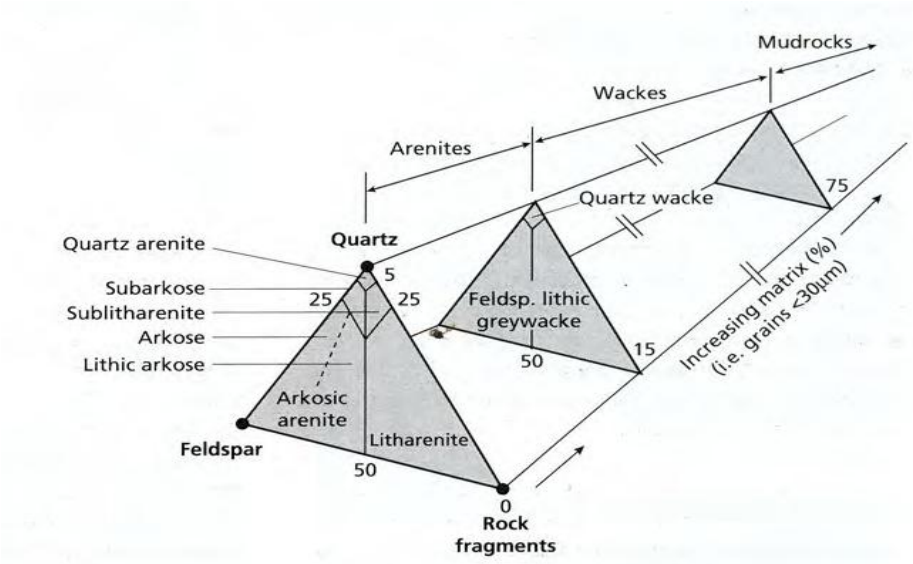


Figure 9: Classification of sandstones (After Pettijohn *et al.*, 1987)

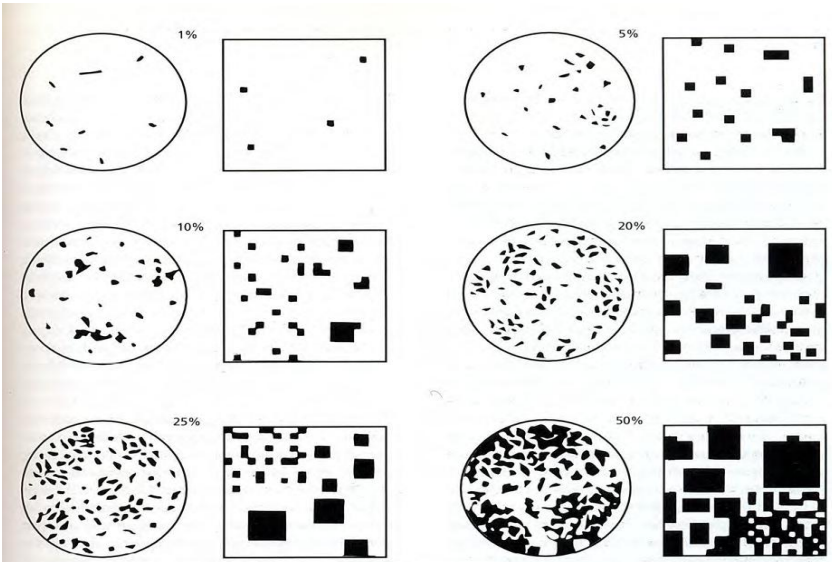


Figure 10: Percentage estimation comparison charts, conventional and computer generated. Reproduced from Terry and Chillinger (1955) and Folk *et al.* (1970)

3.3.2 Sieve analysis

Sieve analysis also known as granulometric analysis was employed to determine the grain size distribution of the sediments from the study area. Five samples were collected from Uomba Formation (Asu River Group), Awe Formation and Keana Formation in the field for this purpose. For each of the sample, the procedures below were followed:

The selected samples were first carefully disaggregated with the aid of a porcelain mortar and a pestle. 100 g from each disaggregated sample was measured with a weighing balance. Empty sieves with mesh sizes of 1000 µm, 500 µm, 250 µm, 125 µm, 63 µm and sieve pan were individually measured with a weighing balance and the results recorded.

The sieves were stacked together in decreasing mesh sizes order i.e. 1000 µm sieve at the top and 63µm sieve at the base on the sieve pan. The 100 g sample was poured into the stacked sieves and placed on an electric shaker set to run for 10minutes to aid the separation of sediments according to their mesh sizes. This process was repeated for each of the five samples. The grains retained from each sieve and the sieves were weighed individually on a weighing balance and the result recorded in each case.

To get the weight of the grains retained in each sieve, the weight of empty sieve was subtracted from the weight of the sieve plus sample and the result recorded. During the course of the sieve analysis, care was taken in the separation of the sieves after shaking to avoid spillover of the retained sediments. When disaggregating the samples, care was also taken to avoid crushing and grinding in order not to distort the original shape of the grains.

The raw results from the sieve analysis are presented in appendix I. The

cumulative frequency curves were also plotted in Appendix II and critical percentiles ϕ 5, ϕ 16, ϕ 25, ϕ 50, ϕ 75 ϕ 84 and ϕ 95 were obtained (Appendix III) from the graphic cumulative frequency curve plots and used in the calculation of grain size parameters such as; graphic mean, sorting (graphic standard deviation) (Fig. 11), graphic skewness and graphic kurtosis; the results of these parameters for each of the samples were tabulated. The statistical parameters of the grain size distribution were computed by the method of Krumbein and Pettijohn (1938); Folk and Ward (1957).

3.3.2.1 Grain size distribution and statistical parameters

Study of sediment texture involves considerations of grain size and grain size parameters, grain morphology, grain surface texture and sediment fabric. These parameters are used as an aid to the interpretation of the sedimentary rocks. The texture of clastic rocks is a reflection largely of the depositional process (es).

Natural siliciclastic particles range in size from clay to boulders. Because of this wide range of sizes, the most useful grade scales for expressing particle size are logarithmic or geometric scales that have a fixed ratio between successive elements of the series. The grade scale most widely used by sedimentologists is the Udden–Wentworth scale (Wentworth, 1922).

The formulae for the calculation of grain size parameters from Folk and Ward (1957) are shown below:

1 Graphic mean $(M) = \frac{\phi 16 + \phi 50 + \phi 84}{3}$

2. Graphic Standard Deviation (sorting) $(I) = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$

3. Inclusive Graphic Skewness $(Ski) = \frac{\phi 84 + \phi 16 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 95 + \phi 5 - 2\phi 50}{2(\phi 95 - \phi 5)}$

4. Graphic Kurtosis $(K_G) = \frac{\phi 95 - \phi 5}{}$

$2.44(\phi 75-\phi 25)$

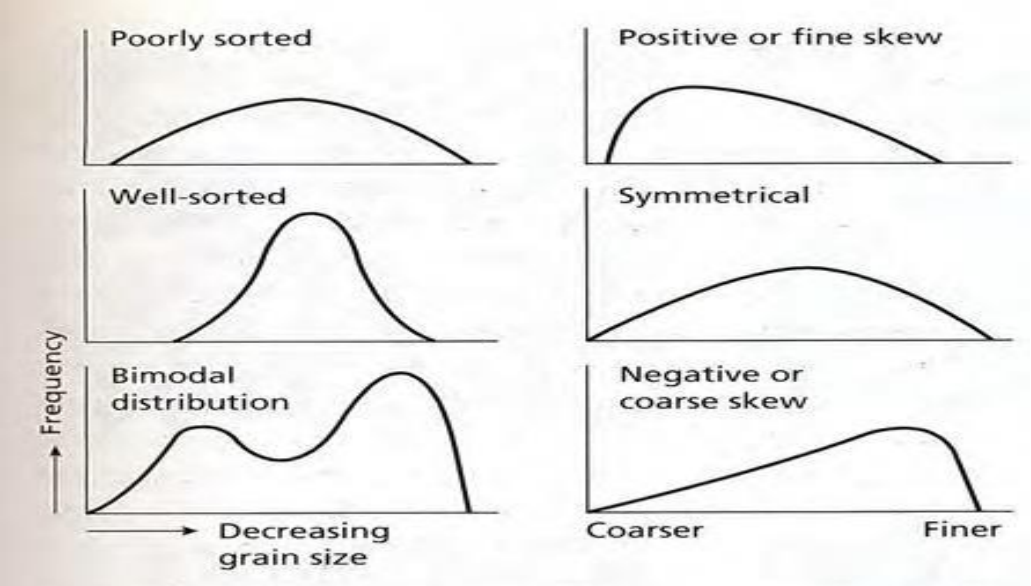


Figure 11: Smoothed frequency distribution curves showing types of sorting and skewness (Tucker, 2001).

3.3.3 Micropalaeontological Study

This is the study of the remains of ancient organisms preserved in rocks (usually hard parts) using microscope. Usually, microfossils occurs in sedimentary rocks such as shale, limestone and clays but are rarely or not well preserved in sandstones and coal due to the porosity in sandstones and intense heat in coal.

Six samples of shale and mudstone dominated facies from Uomba Formation (Asu River Group) and Awe Formation collected from the field were soaked in water and hydrogen peroxide solution added and then left to stand for 24hrs so as to enable the complete disaggregation of the samples into individual grains. They were washed under running water through a 63µm sieve mesh so as to remove the mud. The residues were later filtered using filter paper and transferred to the oven to dry up for easy picking of microfossils using a binocular microscope.

3.3.4 Heavy minerals analysis

A total of five samples from the three formations (Uomba Formation of the Asu

River Group, Awe Formation and Keana Formation) from the sandstone dominated facies were subjected to heavy mineral analysis in the Sedimentology Laboratory of the Department of Geology, Ahmadu Bello University Zaria.The sandstones were sieved to obtain the very fine to fine sand fractions (4phi preferred) which are commonly analyzed because it is the size fraction likely to contain the highest percentage of heavy minerals. In addition, this size is most easily identified with the petrographic microscope. Two grammes from each of the samples was weighed and poured into the centrifuge tubes containing 10mls of the heavy liquid (bromoform). The centrifuge tubes were inserted in their respective holes in the centrifuge and the cover closed before running the machine for 10 minutes. This was followed by standard methods for separation of heavy minerals from lighter ones. The heavy minerals were finally identified with the help of a binocular microscope.

It has been found that certain heavy minerals are very good indicators of the origin of the sand (Figs.12 and 13). Provenance studies in sandstones are therefore often carried out by separating the heavy minerals from the bulk of the grains (mostly light minerals) and identifying them individually (Mange and Maurer, 1992).

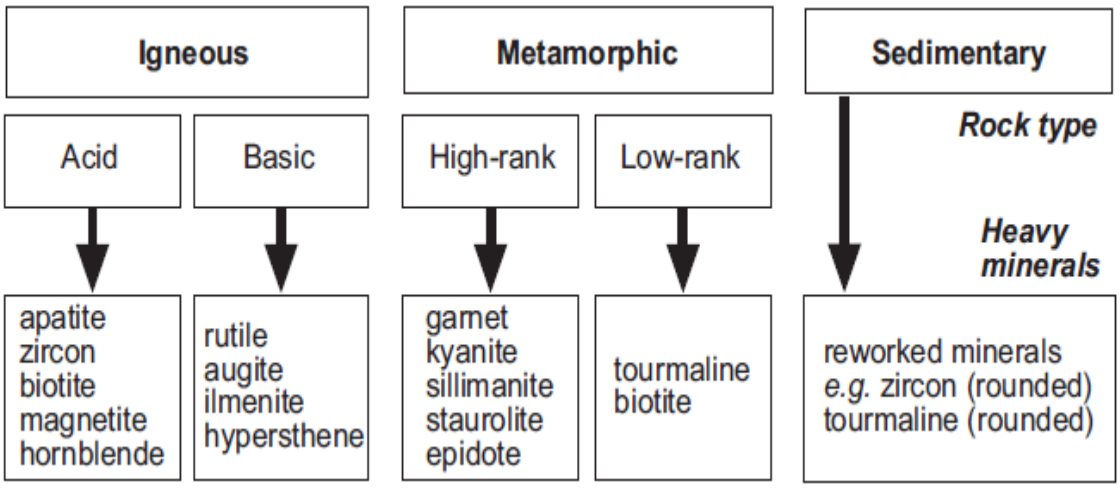


Figure 12: Some of the heavy minerals that can be used as provenance indicators (After Nichols, 2009).

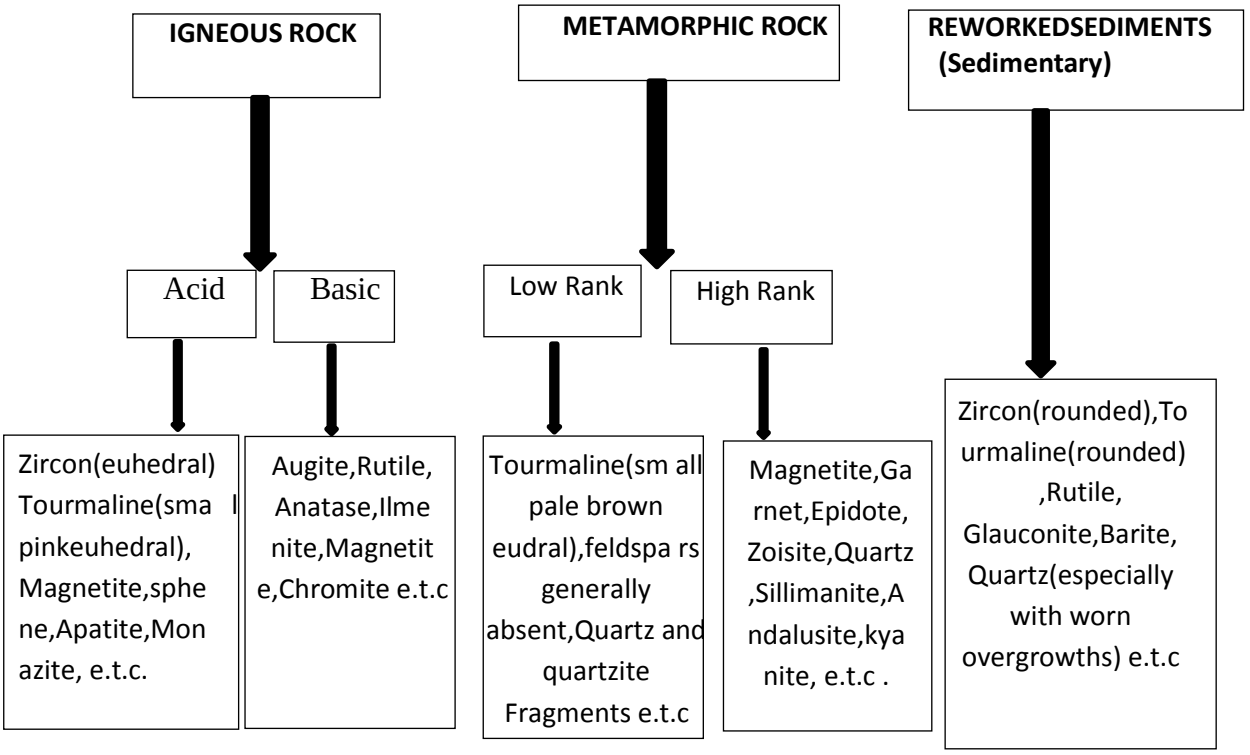


Figure 13: Detrital mineral suites characteristic of source rock types (After Pettijohn, 2002).

CHAPTER FOUR

RESULTS

4.1 Introduction

Sediments from each sedimentary environment exhibit uniquely different characteristics and properties that distinguish them from sediments of different environment.

Stratigraphy is defined by Whittaker *et al.* (1991) as the description, defining and naming of rock units while Hedberg (1976), defined lithostratigraphy as a tool of stratigraphy that deals with the lithology of strata and with their organization into units based on lithological characteristics. In the study area, three formations which are: the Uomba Formation (Asu River Group), Awe Formation and the continental Keana Formation were studied (Fig. 14).

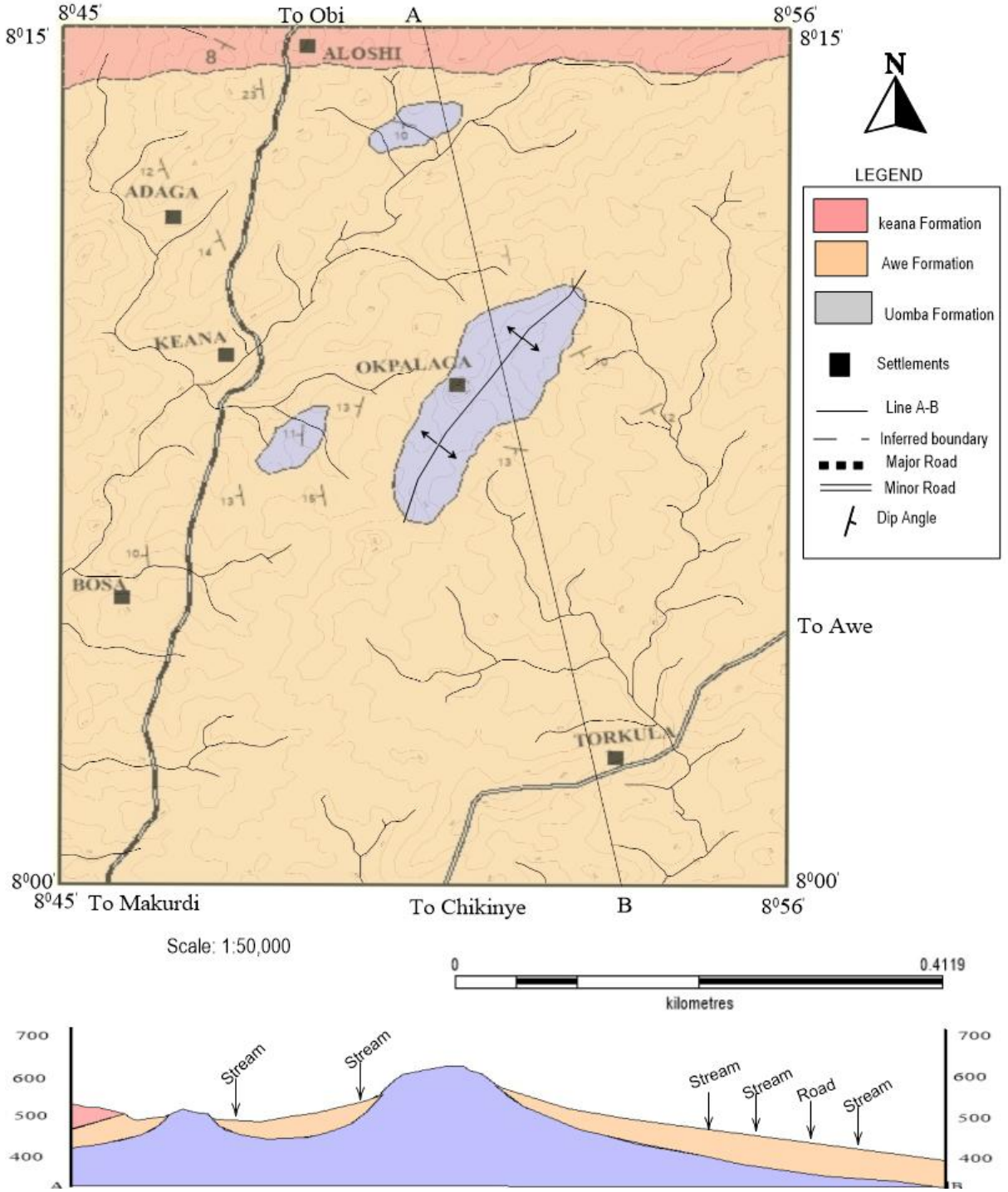


Figure 14: Geological map of the study area and a cross sectional profile through line

A-B

4.2 Lithostratigraphy of the Study Area

4.2.1 The Uomba Formation (Asu River Group): This formation is the oldest marine deposit in this area. Reyment (1965), Offodile (1976) and Peters (1982) described the marine sediments that made up the Asu River Group. Three sections of the Uomba Formation (Asu River Group) were studied and logged. Plates I, II and III and Figures 15,16 and 17 show exposures of this formation encountered along a stream southeast of Keana Local Government Secretariat and along a stream near Aloshi with thicknesses of 2.7m and 3.0m respectively (Fig. 14). They comprises of medium grained sandstones with regular beddings overlying a shaly mudstone with no traces of activities of organisms (trace fossils). Another exposure of 2.2 m thick was studied north eastern part of the study area and consists of dark grey to black fissile shales (Plate III) no trace fossils observed.

Lithostratigraphic descriptions of Uomba Formation (Asu River Group) section **(E5)** exposed in the southeastern part of Keana town, comprises of a 2.2 m thick reddish brown medium grained sandstone beds overlying a 0.5 m thick whitish shaly mudstone with a sharp contact and no fossils observed from the section.



Plate I: Uomba Formation exposed southeast of Keana Local Government secretariat**.**

Photograph showing medium grained sandstone overlying a shaly mudstone bed **$08^0 08' 12.8'' N$, $08^0 47' 9.1''$ E**.

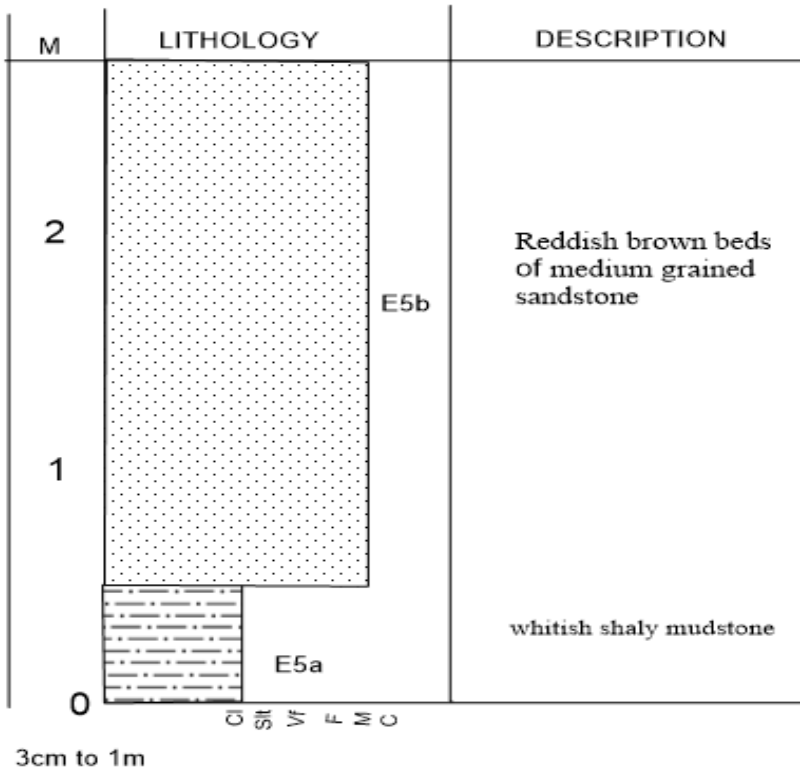


Figure15. Lithostratigraphical log of Uomba Formation southeast of Keana town **08^o $08' 12.8''$ N, 08^o $47' 9.1''$ E.**

Lithostratigraphic descriptions of the Uomba Formation (Asu River Group) section **(E10)** exposed along a stream near Aloshi town comprises of a 0.3 m thick whitish shaly mudstone with no fossil content having a sharp contact with an overlaid 1.2 m thick beds of medium grained sandstone



Plate II: Uomba Formation along a stream near Aloshi town Photograph showing thinly bedded sandstone overlying a bed of shaly mudstone **8^o $14' 33.1''$ N**

08^{o} 49□27.1□E .

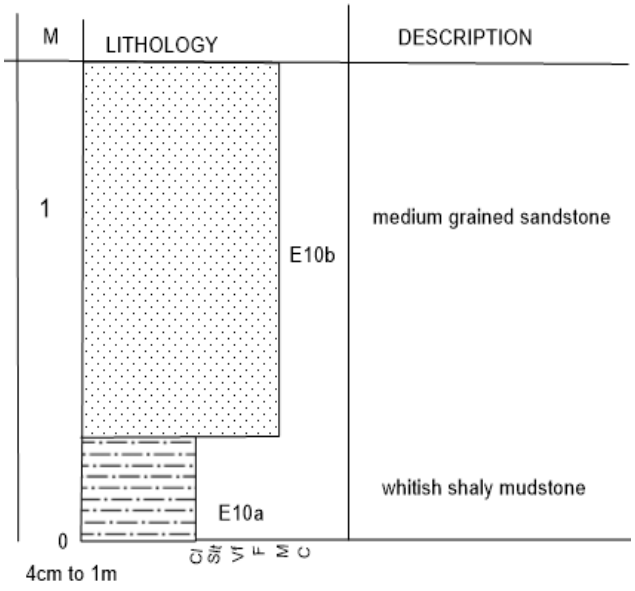


Figure 16. Lithostratigraphical log of Uomba Formation exposed along a stream near Aloshi town **8^{o}14□33.1□ N 08^{o}49□27.1□ E**

Lithostratigraphic descriptions of **Section (Es)** of the Uomba Formation (Asu River Group) exposed northeast of Okpala village comprises of a 2.4 m thick (Es) dark grey to black fissile shales with no fossils and fissility being the sedimentary structure observed (Plate III)



Plate III: Shales of the Uomba Formation showing fissility **08^{o} 09□9.3□ N 08^{o} 51□ 44.7□ E**

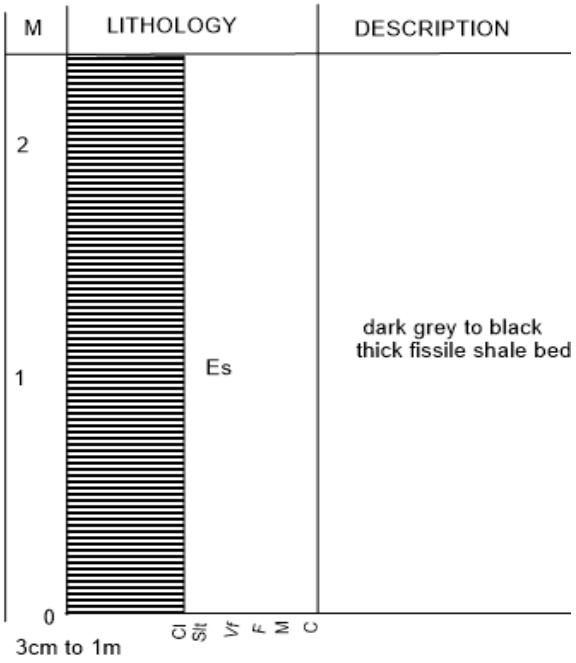


Figure17. Lithostratigraphic log of shales of the Uomba Formation exposed northeast of Okpalaga village **08^{o} 09□9.3□ N 08^{o} 51□ 44.7□ E**

4.2.2 The Awe Formation: This formation is transitional between marine Uomba Formation of the Asu River Group and continental Keana Formation. Seven sections of the Awe Formation were studied and logged and comprises of grey to black shales, calcareous and micaceous shales and calcareous sandstone ocuuring as calcareous nodules towards the top of the sections (Plates IV-IX). The formation is fossiliferous in some places and rich in clay and heavy minerals such as glauconite, haematite (Plates XI-XXI). Offodile (1976) described this formation as a passage bed. Sedimentary structures such as current ripples were observed and trace fossils thalassinoides due to the activities of organisms were also observed in some sections (Fig. 18, Plate IV). Along the road from Keana to Aloshi a section was studied to compose of numerous mineralized veins rich in quartz and barite with sizes ranging from 1cm to 30 cm thick cutting across the whole section causing the sandstone to become highly silicified (Plate VII). Boulders of varying sizes rich in quartz and barite ranges from 10 cm to a meter were observed at the top of the section. Below are the descriptions of sections of the

Awe Formation in the study area.

Lithologic description of section **(E2)** of Awe Formation exposed near Bosa village comprises of a 2.5 m thick (E2a) grey to black shale bed having a gradational contact with an overlaid 2.7 m thick (E2b) intercalation of grey to black shale and micaceous silty shale beds which are becoming more calcareous towards the top dipping at 10^{o} w consisting of trace fossils (thalassinoides burrows) and current ripples with bidirectional waves. Towards the top occurs a 0.8 m (E2c) thick bed of calcareous sandstone occurring as nodules.



a.





b c

Plate IV: Awe Formation exposed along a stream near Bosa (a) the complete exposure of the section (b) thalassinoides burrows (c) current ripples. **$08^{o}05\square\ 59.1\square$ N$08^{o}46\square\ 39.7\square$ E**

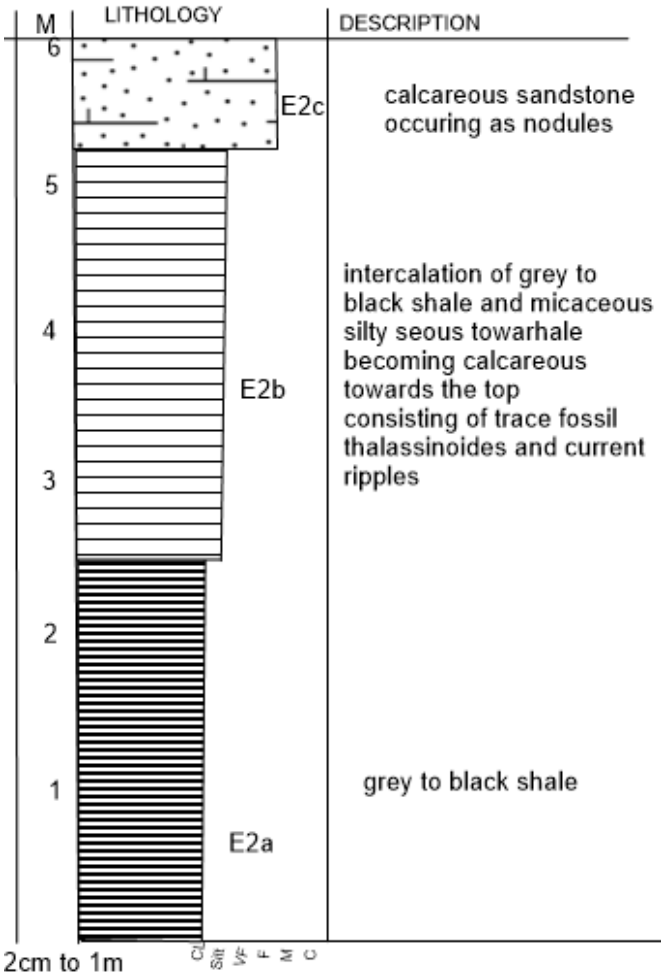


Figure 18: lithostratigraphical log of the Awe Formation exposed in a stream near Bosa village **08° 05□ 59.1□ □N 08° 46□ 39.7□ E**

Lithologic description of section **(E3)** Awe Formation exposed at the eastern part of Bosa village comprises of a 2.1 m thick (E3a) grey to black shale becoming micaceous towards the top overlaid by a 0.5 m thick (E3b) bed of fine to medium grained calcareous sandstone occurring as nodule having a sharp contact with no trace fossils observed (Plate V Fig. 19)



Plate V: Awe Formation showing grey to black shale, calcareous sanstone (nodules) towards the top **08^{o}07′33.1″ N 08^{o}48′27.1″E**.

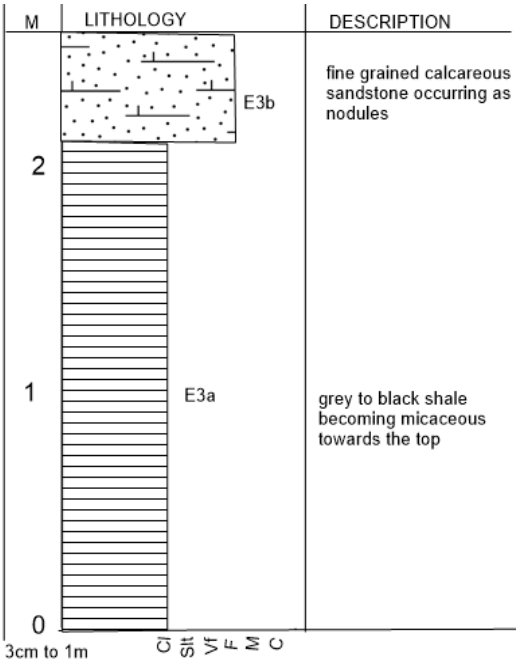


Figure 19: Lithostratigraphic log of the Awe Formation exposed in the eastern part of Bosa Village **08^{o}07′33.1″ N 08^{o}48′27.1″ E**

Lithologic description of section **(E6)** of Awe Formation exposed northwest of Adaga village **08^{0}10′57.7″ N 08^{0}46′31.3″ E** comprises of a 7.5 m thick intercalation of fine grained brownish indurated micaceous sandstone, micaceous shale and clay thin beds with gradational contacts and thicknesses ranging from 2 cm to 30 cm having a general dip of 12^{o} w with no any trace fossil nor sedimentary structurse observed (Fig. 20)



Plate VI: An exposure of Awe Formation near Adaga village. Photograph of micaceous sandstone beds intercalated with thin beds of micaceous shale and clay **08º 10□ 57.7□N 08º 46□ 31.3□E**

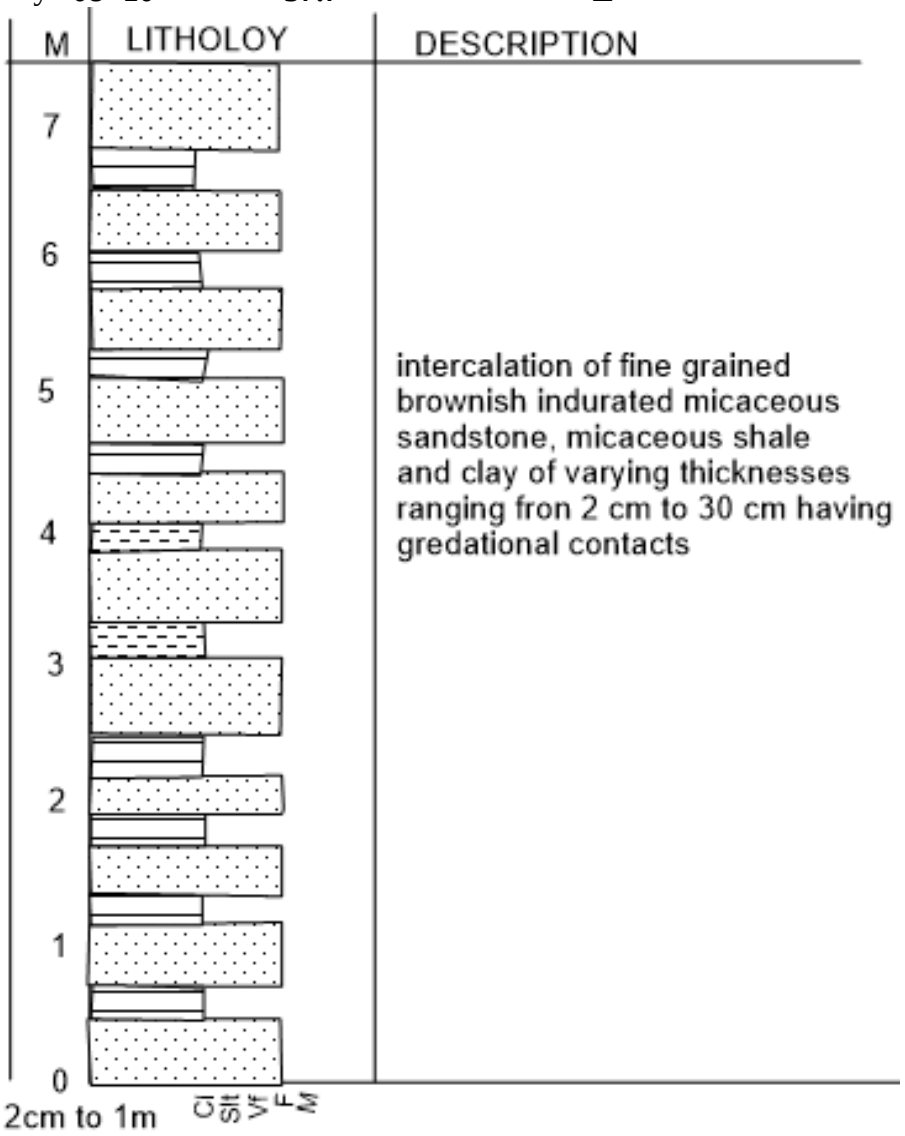


Figure 20: Lithostratigraphic log of the Awe Formation exposed along a stream northeast of Adaga villge **08º 11□ 57.7□N 08º 46□ 31.3□E**

Lithologic description of Section (**E7)** along Keana-Aloshi road **08°14′49.10″N 08°48′16.5″E** comprises of fine to medium grained white sandstone intercalating with beds of clay in a regular pattern at 23° w having sharp contacts with quartz, barite rich veins of varying sizes ranging from 1cm to 30cm cross cutting the section perpendicularly (Plate VII, Fig. 21).

i. E7e, 2.0m fine to medium grained white sandstone cross cut by mineralized veins

ii. E7d, 0.5m clay bed crosscut by mineralized veins (quartz, barite rich)

iii. E7c, 1.4m fine to medium grained white sandstone bed crosscut by mineralized veins (quartz, barite rich)

iv. E7b, 1.8m clay bed crosscut by mineralized veins (quartz, barite rich)

v. E7a, 0.8m fine to medium grained white sandstone bed crosscut by mineralized veins (quartz, barite rich)



a



b.

Plate VII: Photograph showing Awe Formation along Keana-Aloshi road
(a) entire section exposing clay intercalated with sandstones (b**)** Veins cross cutting the section (quartz, barite rich) **08°14□49.10□N 08°48□16.5□E**

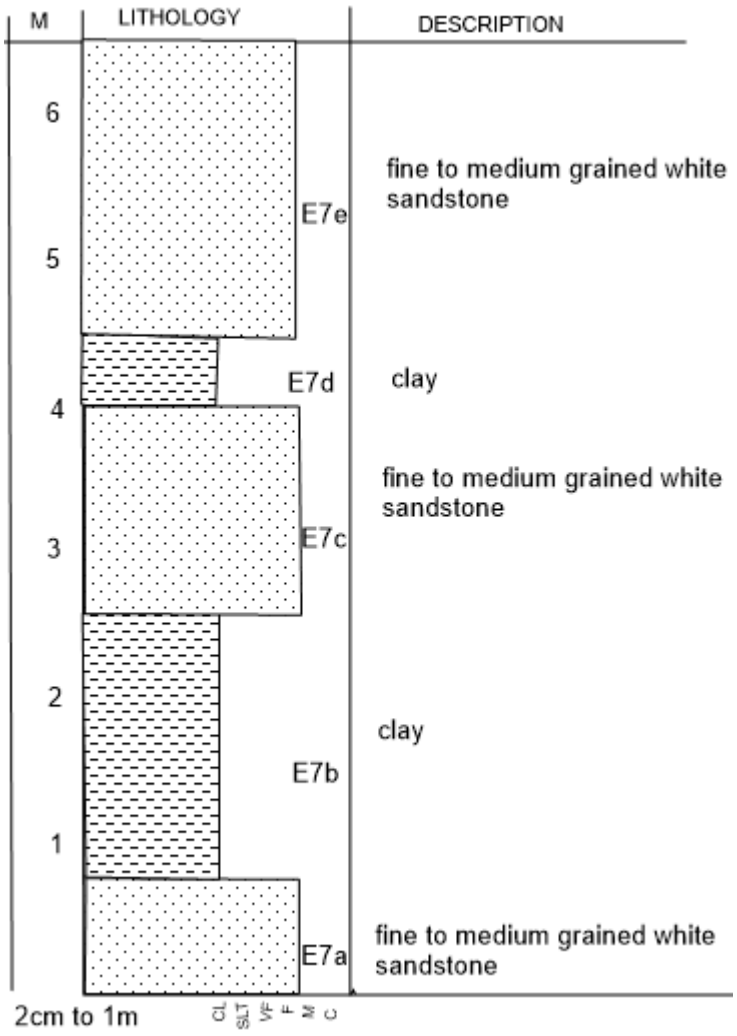


Figure 21: Lithostratigraphic log of Awe Formation along Keana-Aloshi road, north of Keana town **08°14□49.10□N 08°48□16.5□E**

Lithostratigraphic description of section **(E11)** of Awe Formation comprising of alternation of grey shale and sandstone having a sharp contact and a general dip of 13^{o} S with no fossil content, has the following sequence:

i. E11f, 0.12m grey shale

ii. E11e, 0.2m fine to medium grained sandstone

iii. E11d, 0.25m grey shale

iv. E11c, 0.11m fine to medium grained sandstone

v. E11b, 0.28m sandy grey shale (Fig.22)

vi. E11a, 0.1m fine to medium grained sandstone



Plate VIII: Awe Formation. Photograph showing sandstones and shales intercalated **$08^{o}07^{\square}7.74^{\square}$ N $08^{o}48^{\square}07.2^{\square}$ E**

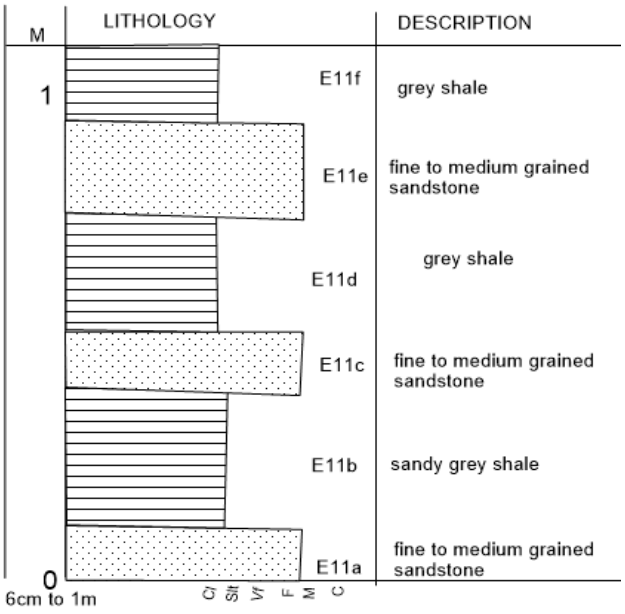


Figure 22: Lithostratigraphic log of Awe Formation **08°07□7.74□N 08°48□07.2□E**

Lithostratigraphic description of section **(E14)** of Awe Formation exposed about 1km north of Keana town comprises of a 3.1 m thick beds of reddish brown fine grained micaceous sandstone intercalating with very thin beds of clay and mudstone (Fig. 23) with no any sedimentary structures and fossil content observed having gradational contacts.



Plate IX: Sandstone of Awe Formation north of Keana town. Photograph showing fine grained sandstones intercalating with clay and mudstone **08°11□21.5□N 08°47□8.59□ E**

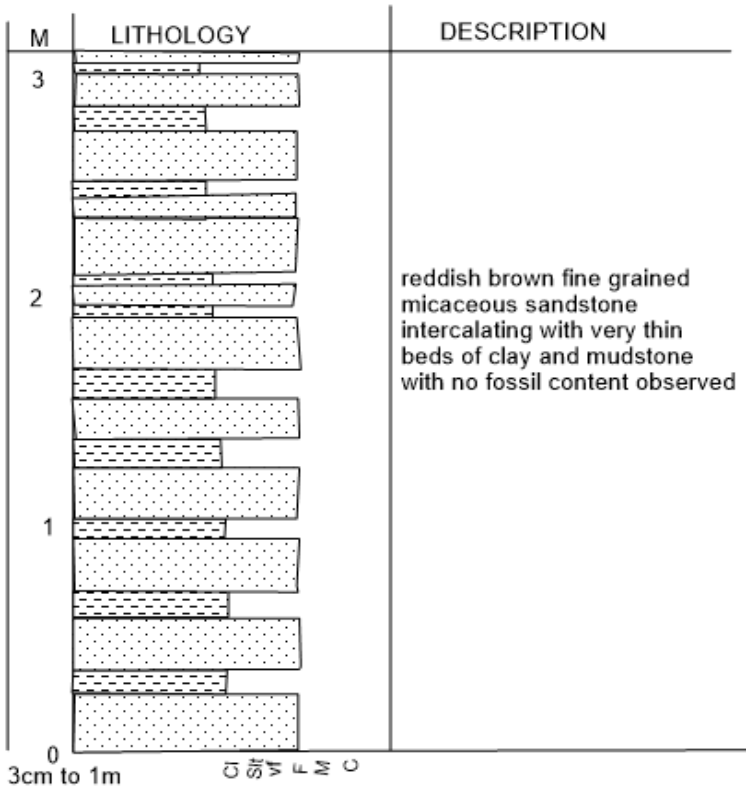


Figure 23: Lithostratigraphic log of sandstone of Awe Formation exposed along a road cut from Keana to Aloshi **08°11′21.5″N 08°47′8.59″ E**

4.2.3 Keana Formation: Outcrops of Keana Formation were studied in the northern part of the study area towards Aloshi from Keana main town (Fig. 24). They occur as parallel beds with indistinct tabular cross bedding and in some places as boulders of varying sizes (Plate X). A section was studied south of Aloshi and found to comprise of a 2.5 m thick coarse grained, sub-rounded to sub-angular brownish sandstone with some muscovite mica noticed from hand specimen.



Plate X: Sandstone of Keana Formation exposed south of Aloshi Village **08°14□52□N 08°48□5.1□ E**

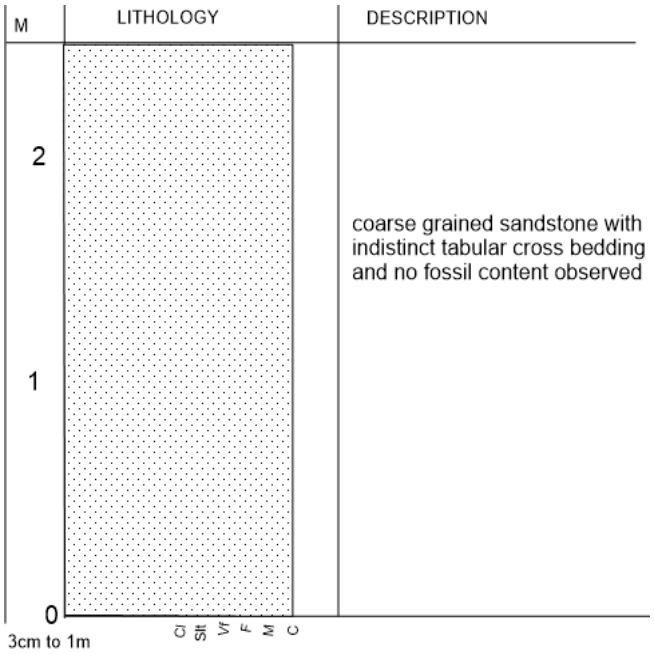


Figure 24: Lithostratigraphic log of a section of Keana Formation **08°14□52□N 08°48□5.1□ E**

4.3 Petrographic Studies

Eleven samples were collected for thin section and were studied using petrological microscope. The petrographic descriptions are presented below:

Petrographic description of **Sample (E2a)** of Awe Formation near Bosa Village**.**

a. XPL b. PPL



Plate XI: Photomicrograph of calcareous sandstone of Awe formation, **Mg. X40.** showing: Medium to coarse grained, subrounded, moderately well sorted subarkose as the feldspar content is >15% but <25% consisting of monocrystalline quartz and few polycrystalline quartz, plagioclase, orthoclase, cross hatched twinned microcline feldspars, sericite mica and reddish brown haematite with quartz overgrowth, calcite, clay and kaolinitic cement. Sutured boundaries of quartz grains and presence of stylolite due to grain to grain pressure solution are the major diagenetic features observed.
MQ: monocrystalline quartz, **PQ:** polycrystalline quartz, **PF:** plagioclase feldspar, **CC:** calcite cement, **OP:** opaque (iron oxides)

Petrographic description of calcareous sandstone (nodule) **Sample (E3b)**Awe Formation **a. XPL** **b. PPL**

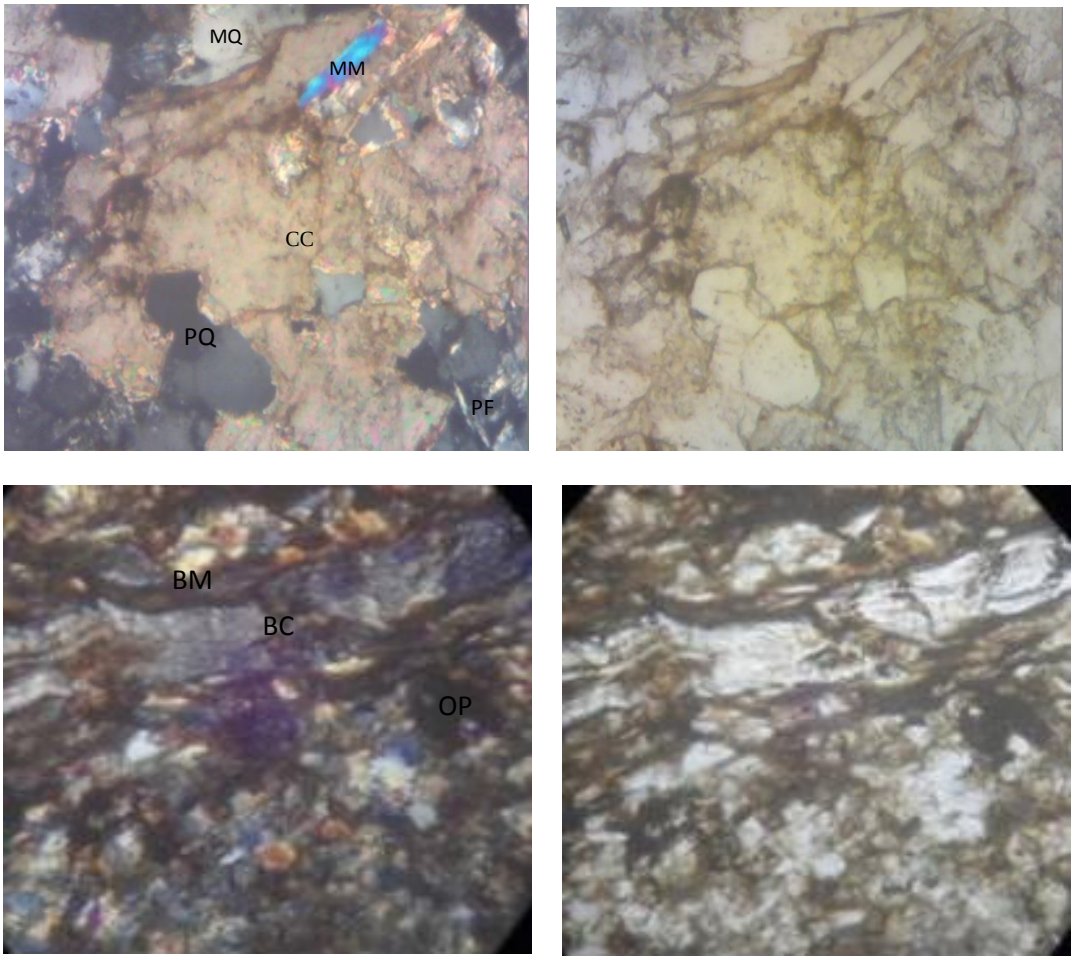


Plate XII: Photomicrograph of calcareous sandstone occurring as nodules of the Awe Formation, **Mg.x40.** Showing fine grained moderately well sorted, poikilotopic calcite cemented fossiliferous quartz arenite because 95% of rock is quartz, consisting of monocrystalline and polycrystalline quartz, few plagioclase and orthoclase (untwinned) feldspars almost entirely altered, muscovite, sericite, biotite more dominant most of which are aligned in a preferred direction. The heavy minerals observed are the reddish brown haematite (iron oxides), bioclast (bivalve) observed and calcite cement with a poikilotopic texture, cement of haematite rims around grains. The diagenetic features are mainly the corrosion and replacement of quartz and feldspar grains by calcite, mechanical compaction as seen from the breakage of the bioclast.

MQ: monocrystalline quartz, **PQ:** polycrystalline quartz, **PF:** plagioclase feldspar, **MM:** muscovite, **BM:** biotite, **CC:** calcite cement, **OP:** opaque, **BC:** bioclast.

Petrographic description of sandstone **sample (E6a)** Awe Formation

a. XPL **b. PPL**

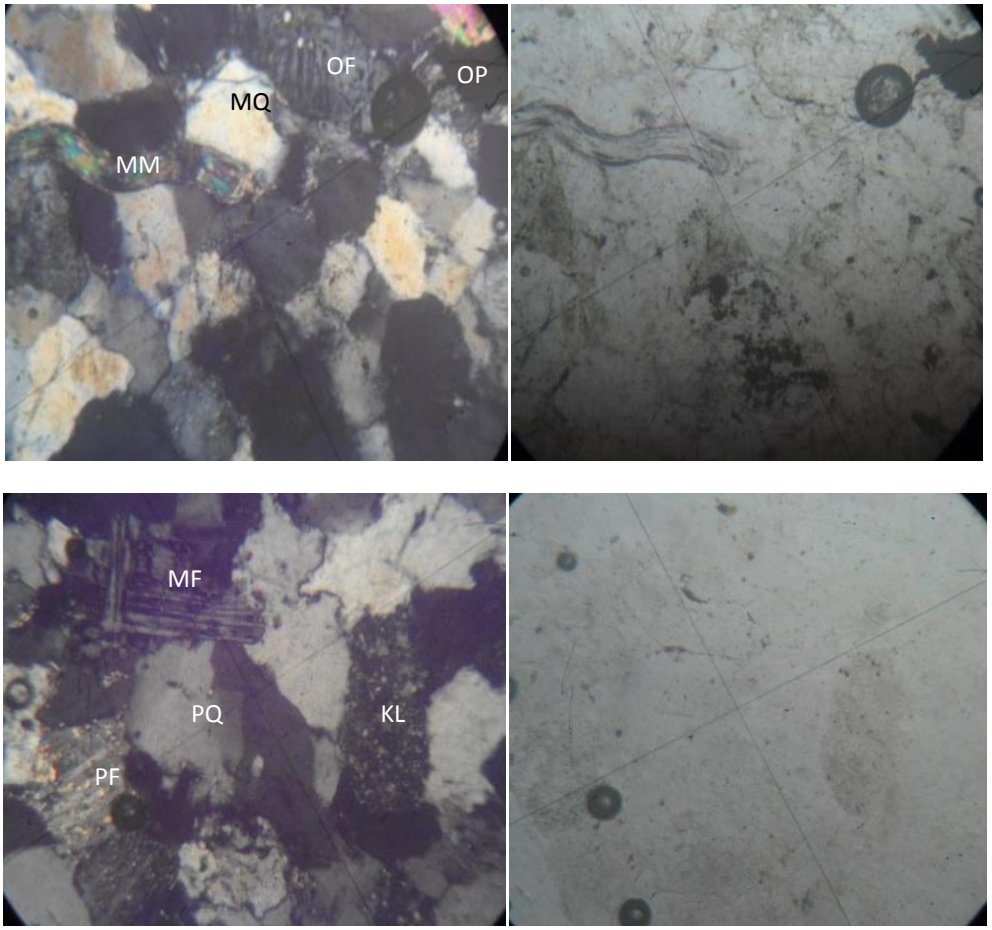
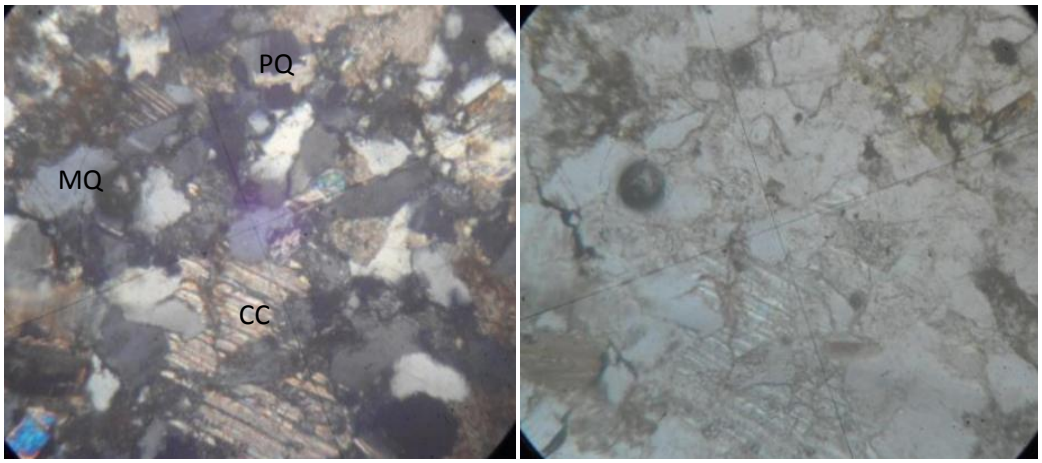


Plate XIII: Photomicrograph of a micaceous sandstone of the Awe Formation **Mg.x10** showing a fine grained, very well sorted, sub-rounded subarkose as feldspar in the rock is greater >15%, consisting of monocrystalline quartz dominantly with few polycrystalline quartz, plagioclase, orthoclase and microcline feldspars both fresh and altered, muscovite, biotite and sericite, opaque heavy minerals (iron oxides), cement of quartz overgrowth illite and kaolinitic cements. Mechanical compaction, grain to grain pressure solution resulting to sutured grain boundaries and the alteration of feldspars are the diagenetic features.

MQ: monocrystalline quartz, **PQ:** polycrystalline quartz, **PF:** plagioclase feldspar, **MF:** microcline feldspar, **OF:** orthoclase feldspar, **MM:** muscovite, **BM:** biotite, **KL:**kaolinite, **OP:** opaque,

Petrographic description of sandstone **sample (E6b)** Awe Formation

a. XPL **b. PPL**



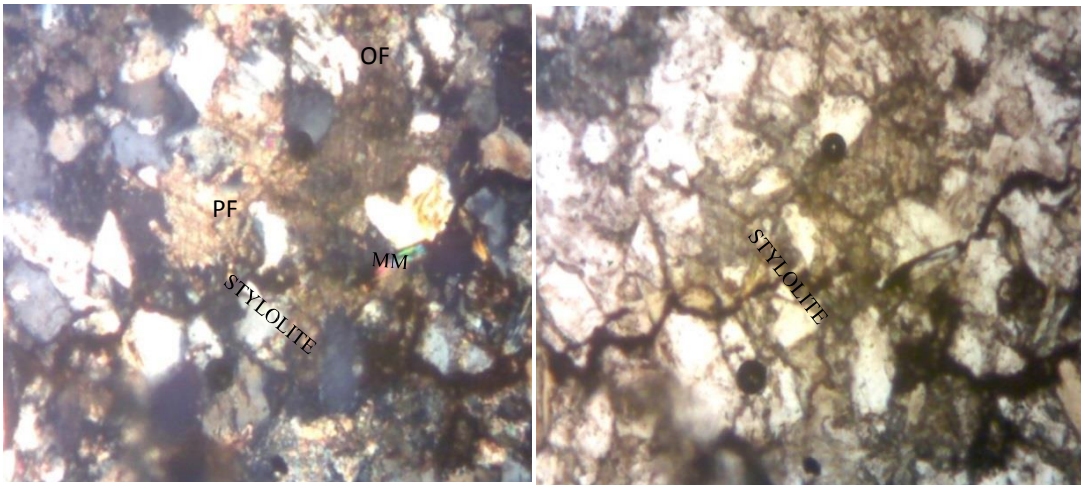


Plate XIV: Photomicrograph of sandstone of Awe Formation **Mg.x10** and **x40** showing fine grained, well sorted sub-rounded clay rich quartz arenite as the quartz content is about 95% of the rock, consisting of monocrystalline quartz and few polycrystalline quartz, plagioclase and orthoclase feldspars undergoing partial and complete alteration, biotite, muscovite and sericite, reddish brown (haematite), cement of calcite (ferroan looking rusty), quartz overgrowth, rims of iron oxides and clay. Diagenetic features are the grain to grain pressure solution forming stylolites, dissolution and replacement of grains by calcite, alteration of feldspars to sericite mica and clay.

MQ: monocrystalline quartz, **PQ:** polycrystalline quartz, **PF:** plagioclase feldspar, **OF:** orthoclase feldspar, **MM:** muscovite, **CC:** calcite cement

Petrographic description of a silicified sandstone **sample (EQV)** section **(E7)** Awe Formation

a. XPL **b. PPL**

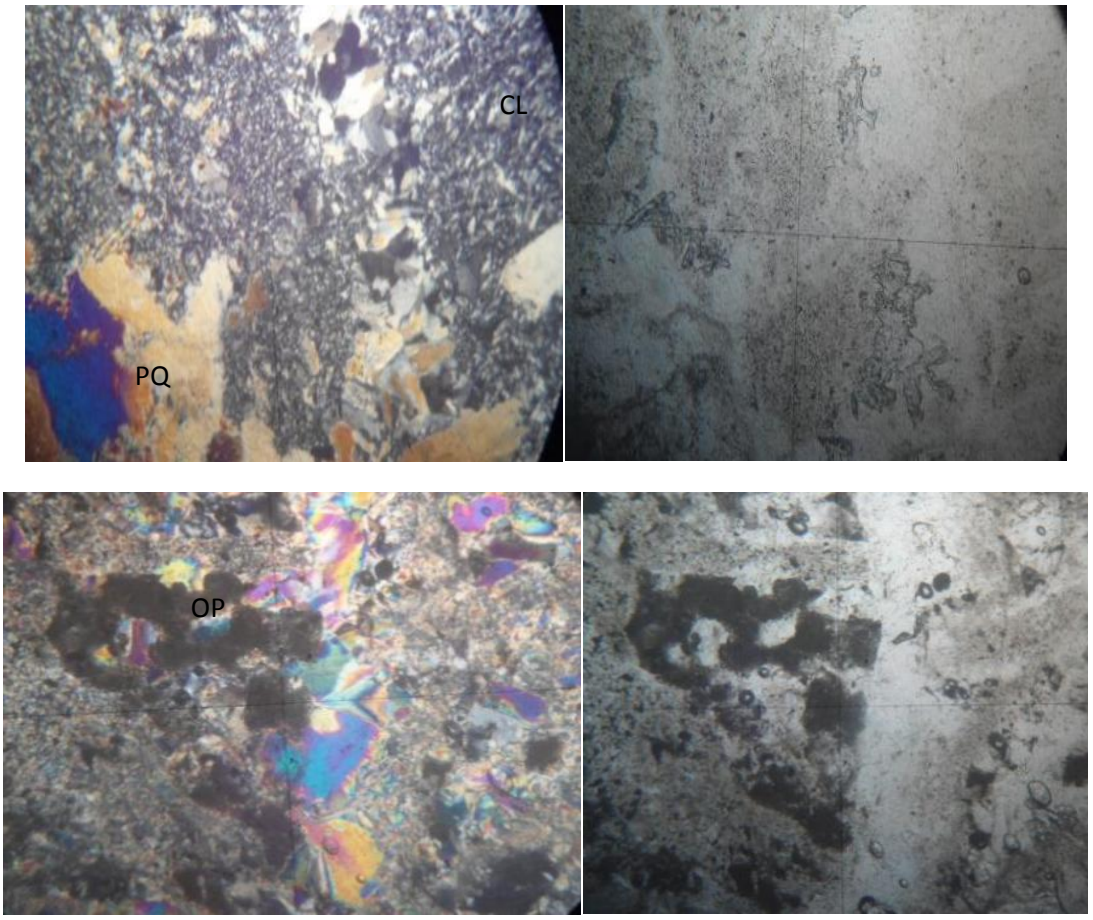


Plate XV: Photomicrograph of a silicified sandstone of Awe Formation **Mg.x40** a fine to medium grained, angular, poorly sorted quartz wacke this is because the rock is made up of dominantly quartz grains and >15% matrix, consisting of dominantly polycrystalline quartz with little monocrystalline grains, opaque heavy minerals widely distributed with little reddish brown haematite, cement of quartz overgrowth and matrix of clay minerals. Diagenetic feature observed is chemical compaction resulting in sutured grain boundaries

MQ: monocrystalline quartz, **PQ:** polycrystalline quartz, **OP:** opaque minerals (iron oxides), **CL:** clay

Petrographic description of a sandstone **sample (E9a)** Awe Formation

a. XPL **b. PPL**

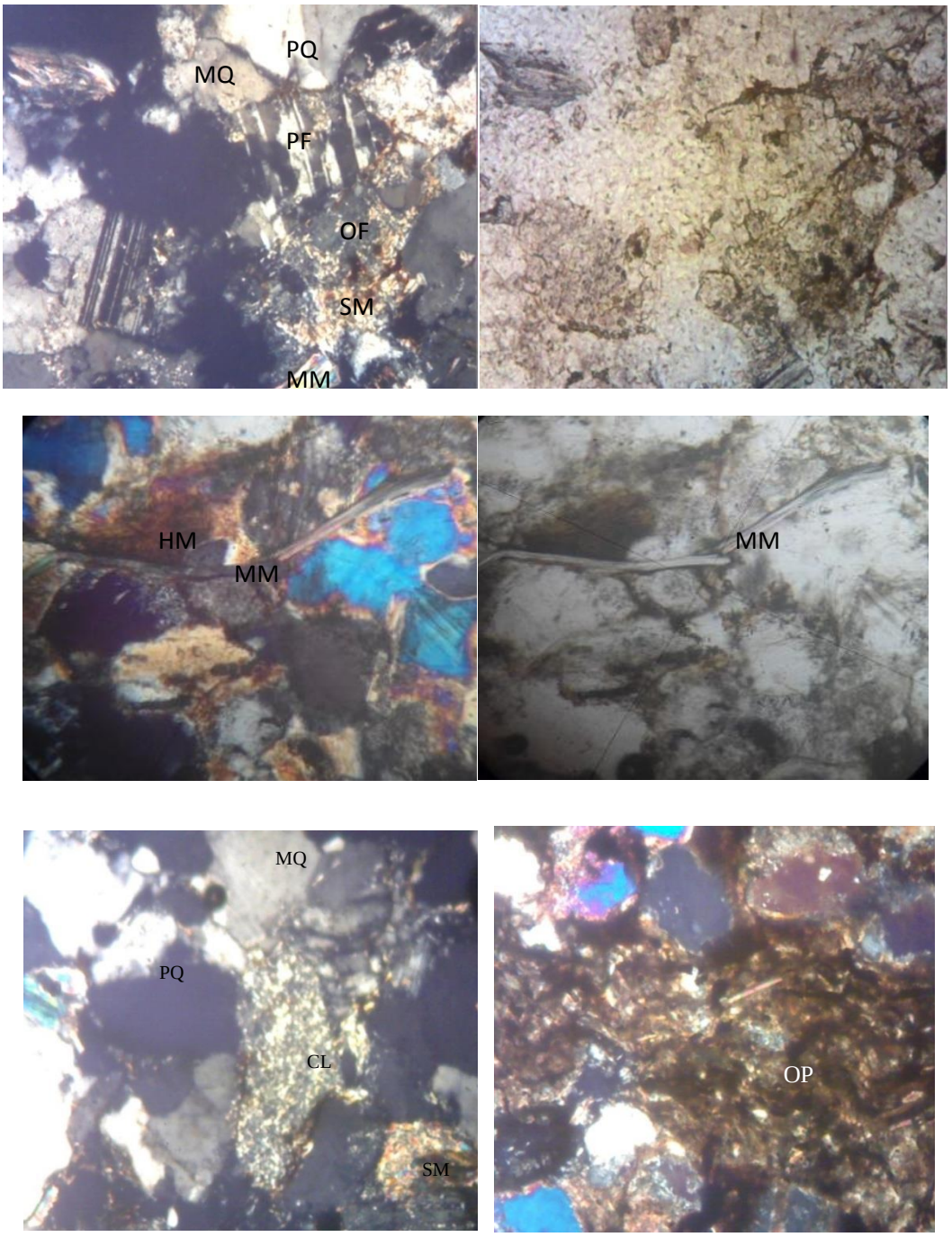


Plate XVI: Photomicrograph of a sandstone of Awe Formation **Mg.x40 and x10 for the middle slides,** showing medium to fine grained, sub-rounded very well sorted quartz arenite as the quartz content of the rock is about 95%, consisting of dominantly monocrystalline quartz and few polycrystalline quartz, plagioclase and orthoclase feldspars altered due to their cloudy appearance with few unaltered, sericite dominates, muscovite and biotite mica and reddish brown iron oxides spread in the rock, major cements are quartz overgrowth, kaolinite cement, clay (illite) and iron oxide rims. Diagenetic features observed are partial and complete alteration/decomposition of feldspars to clay minerals, mechanical compaction from breakage of mica as seen from the plate above and chemical compaction (pressure solution) resulting to sutured grain

boundaries.

MQ: monocrystalline quartz, **PQ:** polycrystalline quartz, **PF:** plagioclase feldspar, **OF:** orthoclase feldspar, **MM:** muscovite, **SM:** sericite, **OP:** opaque, **MC:** mechanical compaction, **HM:** haematite, **CL:** clay

Petrographic description of a sandstone **sample (E9b)** Awe Formation

a. XPL **b. PPL**

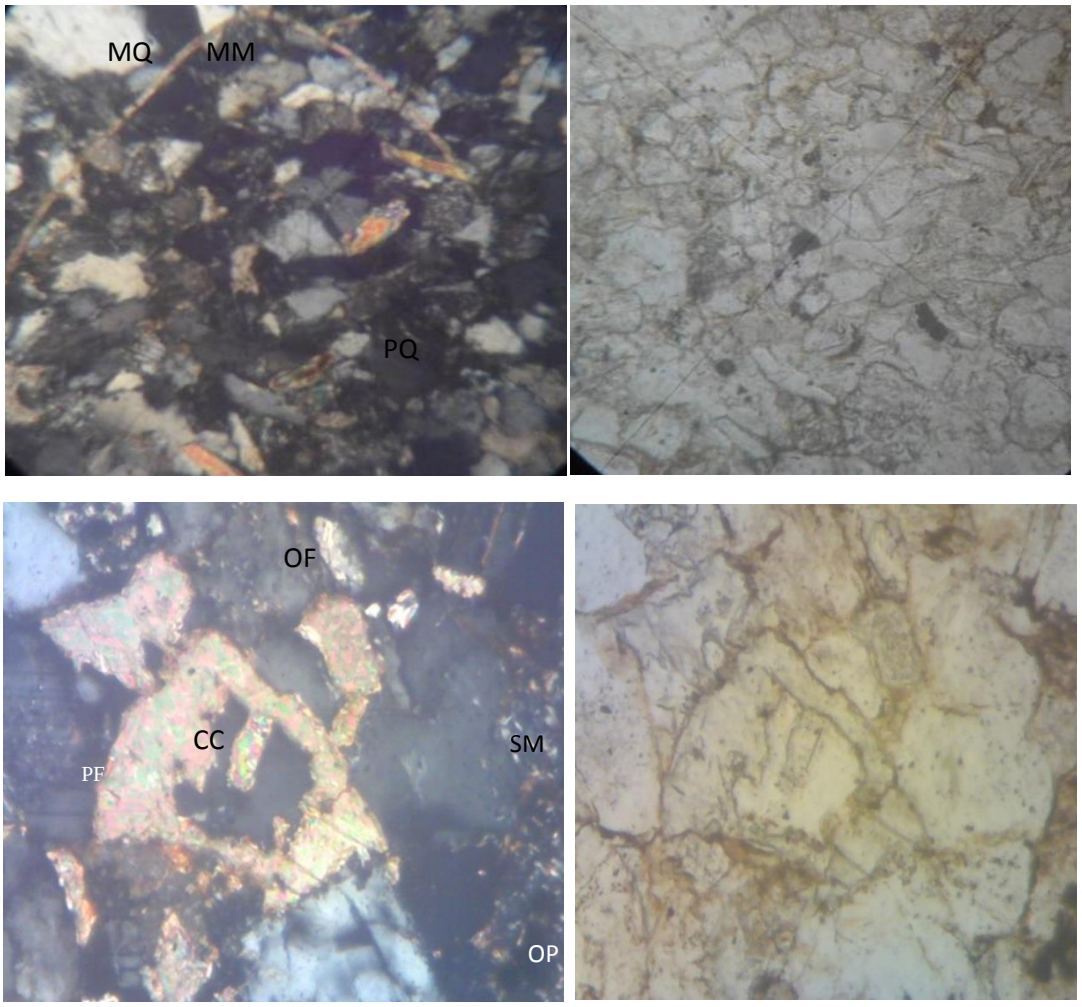


Plate XVII: Photomicrograph of a sandstone of Awe Formation **Mg.x40** showing very well sorted subangular coarse grained subarkose because the feldspar content is between 10% to 25% of the rock, consisting of monocrystalline with few polycrystalline quartz, plagioclase and orthoclase feldspars both fresh and altered, biotite, muscovite and sericite , the heavy minerals are the reddish brown haematite. Quartz overgrowth, calcite cement, rims of haematite and clay minerals around grains are the major cements. Mechanical compaction from bending of micas, edges of quartz and feldspar grain corroded by calcite, alteration of feldspars to clay minerals.

MQ: monocrystalline quartz, **PQ:** polycrystalline quartz, **PF:** plagioclase feldspar, **OF:** orthoclase feldspar, **MM:** muscovite, **SM:** sericite, **CC:** calcite cement **OP:** opaque (iron oxides).

Petrographic description of a sandstone **Sample (E11a)** Awe Formation

a. XPL **b. PPL**

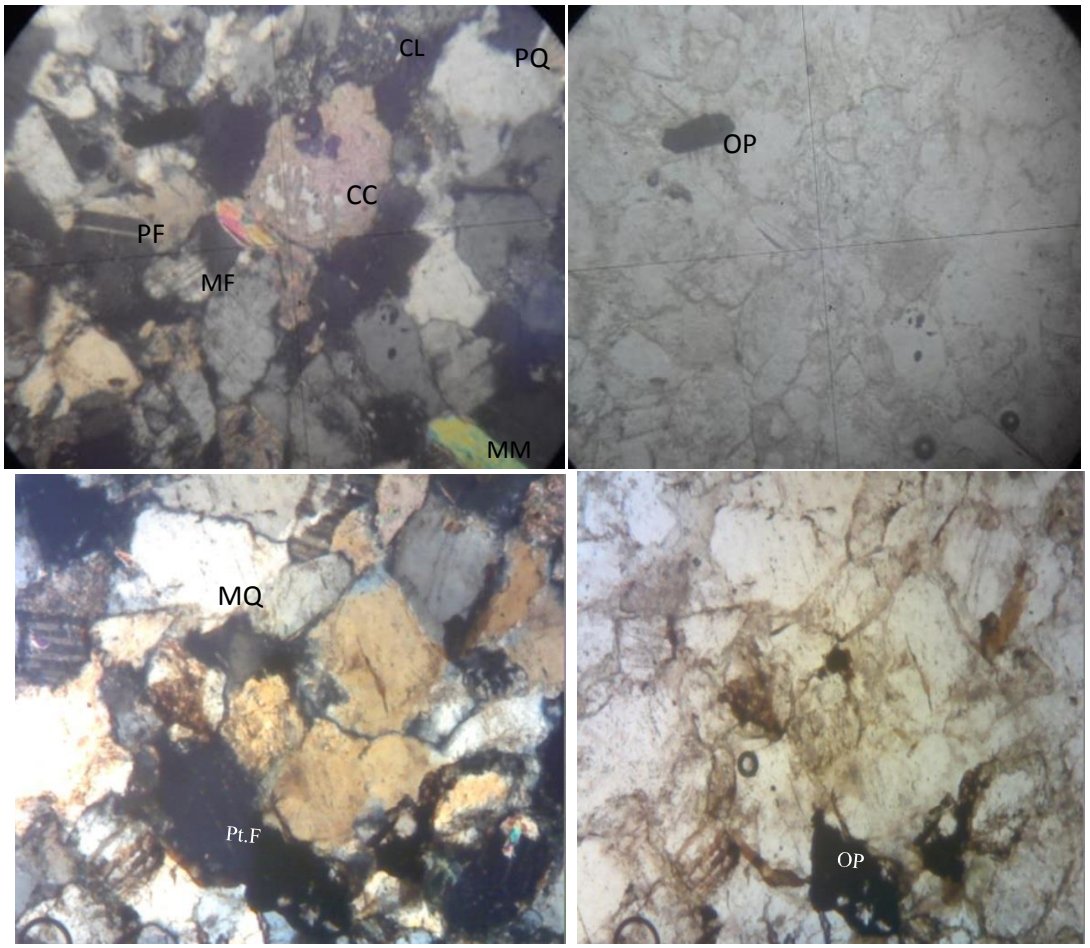


Plate XVIII: Photomicrograph of a sandstone of Awe Formation **Mg.x40** showing a coarse grained, sub-angular to sub-rounded, well sorted subarkose as the feldspar content is less than 25%, consisting of dominantly monocrystalline quartz with rare polycrystalline quartz, fresh and altered plagioclase, orthoclase and perthite feldspars, muscovite, sericite and a few biotite, haematite (iron oxide) are the heavy minerals with cements of clay (kaolinite) filling voids, calcite and rims of iron oxides around grains. The diagenetic features of grain to grain pressure solution, dissolution and replacement of grains by calcite, decomposition and alteration of feldspars to sericite and clay minerals were observed.

MQ: monocrystalline quartz, **PQ:** polycrystalline quartz, **PF:** plagioclase feldspar, **MF:** microcline feldspar, **OF:** orthoclase feldspar, **MM:** muscovite, **CC:** calcite cement, **PtF:** perthite, **OP:** opaque, **CL:** clay

Petrographic description of a sandy shale **Sample (E11b)** Awe Formation

a. XPL **b. PPL**

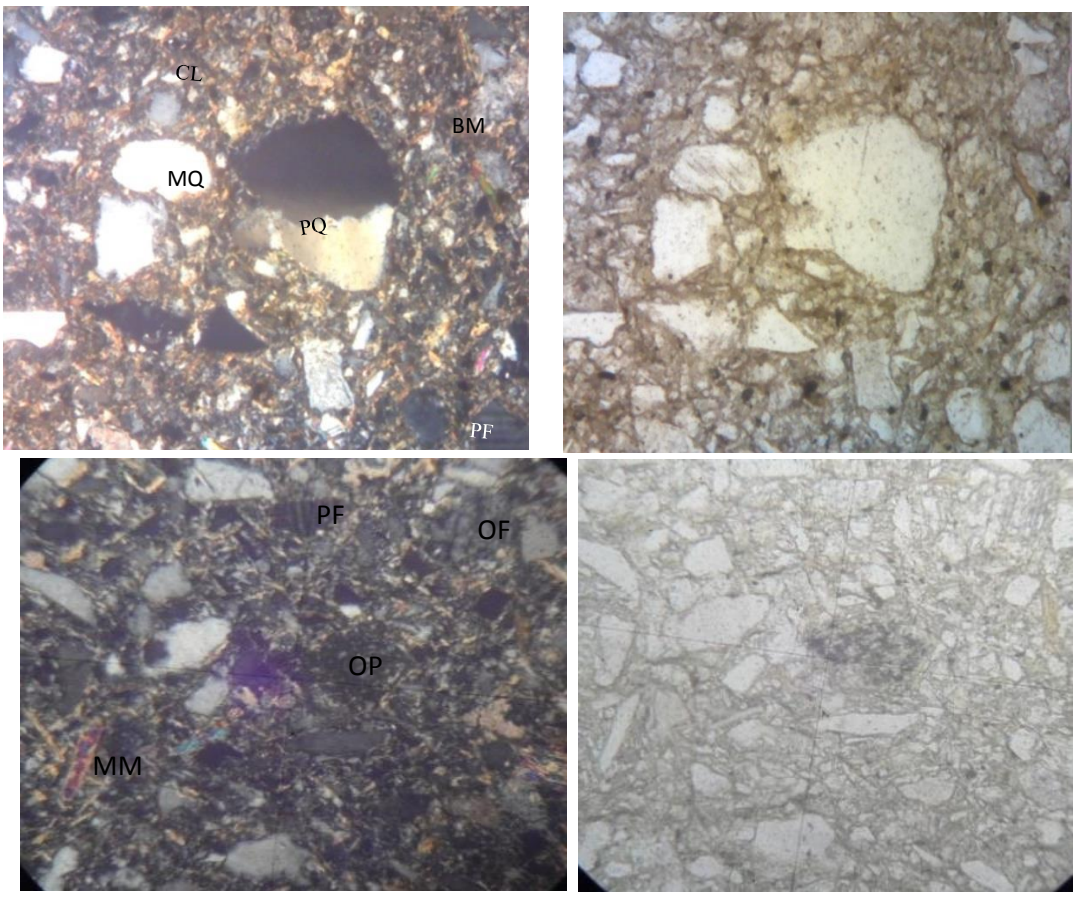
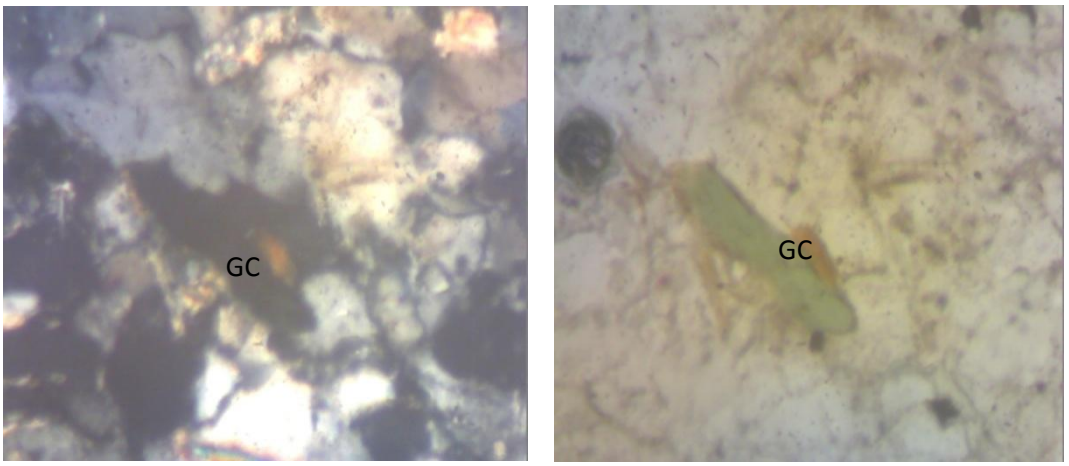


Plate XIX: Photomicrograph of grey sandy shale of Awe Formation **Mg.x10** showing fine grained sub-rounded, poorly sorted greywacke because the rock contains morethan 15% clay matrix, consisting of polycrystalline and monocrystalline quartz, orthoclase and plagioclase feldspars altered with few fresh ones, muscovite, biotite with a little sericite, reddish brown haematite and cement of carbonate matrix and clay. The dissolution and replacement of detrital grains by calcite and corroding the edges of quartz grains are the major diagenetic features.

MQ: monocrystalline quartz, **PQ:** polycrystalline quartz, **PF:** plagioclase feldspar, **OF:** orthoclase feldspar, **MM:** muscovite, **BM:** biotite, **SM:** sericite, **OP:** opaque, **CL:** clay

Petrographic description of sandstone **Sample (E14)** Awe Formation

a. XPL **b. PPL**



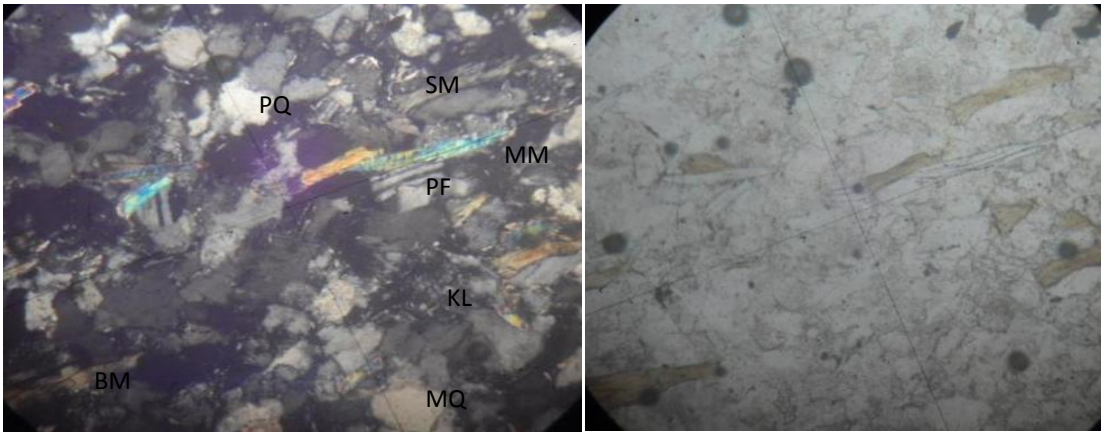


Plate XX: Photomicrograph of micaceous sandstone of Awe Formation **Mg.x40** showing a fine grained, very well sorted, sub-rounded to sub-angular glauconitic subarkose because >15% of the grains are feldspars, consisting of monocrystalline quartz with little polycrystalline quartz, plagioclase and orthoclase feldspars most of which are altered,biotite mica dominant, muscovite and sericite, iron oxides (haematite) and glouconite heavy minerals with cements of quartz overgrowth, clay (kaolinite and illite), iron oxides in form of rims around grains. The decomposition and alteration of feldspars to clay and sericite mica are the diagenetic features.

MQ: monocrystalline quartz, **PQ:** polycrystalline quartz, **PF:** plagioclase feldspar, **MM:** muscovite mica, **BM:** biotite, **SM:** sericite, cement, **KL:**kaolinite, **GC:** glauconite,

Petrographic description of sandstone **Sample (E1),** Keana Formation

a. XPL **b. PPL**

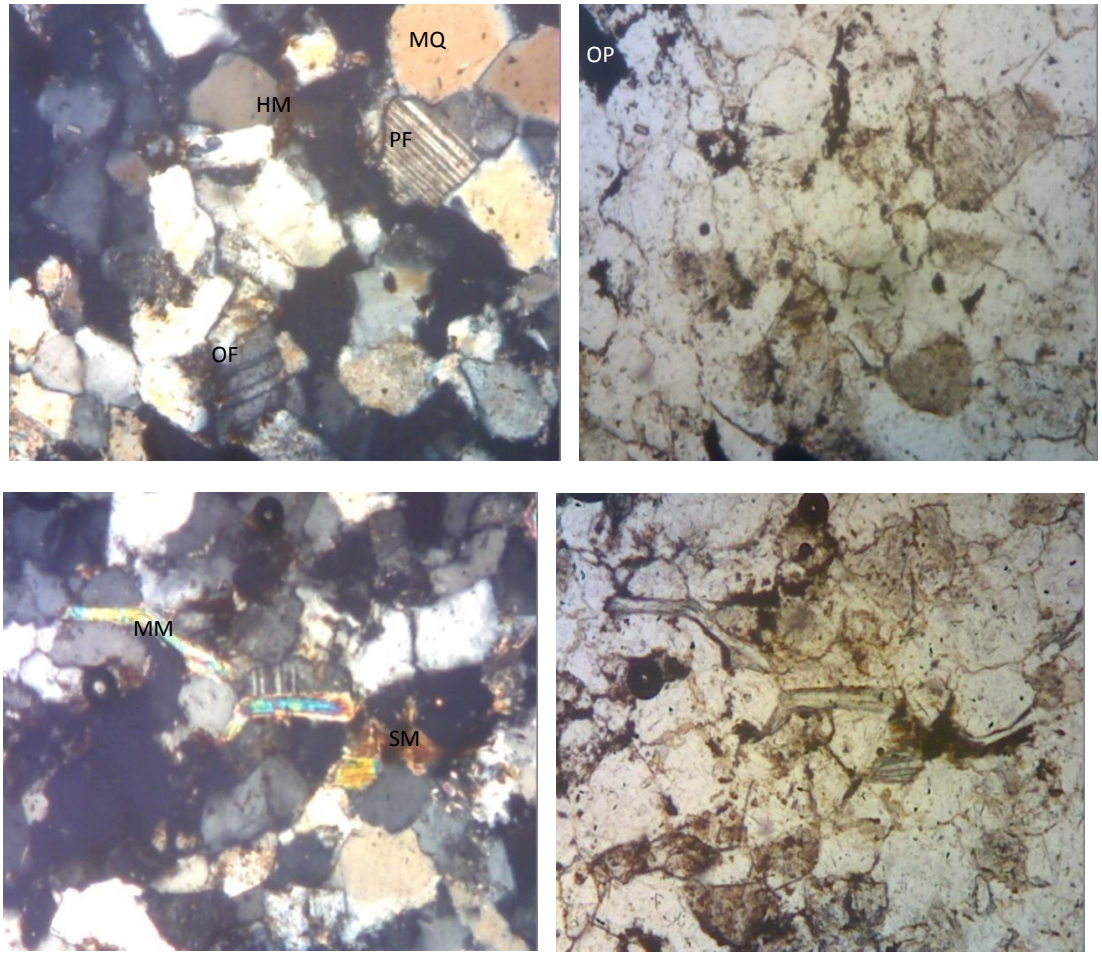


Plate XXI. Photomicrograph of a sandstone of Keana Formation **Mg.x10**, showing a coarse grained, sub-rounded to sub-angular, moderately well sorted arkose this is because about 25% or more of the grains are feldspars, consisting of dominantly monocrystalline quartz, very rare polycrystalline quartz, plagioclase and orthoclase feldspars with both fresh and altered, muscovite, little sericite, iron oxides and quartz overgrowth as the major cement. Diagenesis of the alteration of feldspars, grain to grain pressure solution and compaction as seen from bending of micas observed.

MQ: monocrystalline quartz, **PQ:** polycrystalline quartz, **PF:** plagioclase feldspar, **OF:** orthoclase feldspar, **MM:** muscovite, **SM:** sericite, **OP:** opaque (magnetite), **HM:** heamatite.

4.4 Granulometric Studies

Geologists have assumed that grain-size characteristics reflect depositional conditions and processes and thus depositional environments. Sediments from each sedimentary environment allegedly exhibit uniquely different grain-size properties that distinguish them from sediments of different environments.

Five samples were sieve analyzed and the raw sieve analysis results for each of the analyzed samples are presented in (Appendix I).

The cumulative frequency plots are presented as appendix II and the various percentiles of the distributions obtained from the cumulative frequency curves are presented as appendix III.

4.4.1. Univariate grain size parameters

Although graphical plots provide a convenient visual method for evaluating the grain- size distribution of a given sample, comparison of large numbers of such plots can be very cumbersome. Parameters that describe grain-size distributions mathematically, includes:

a. The graphic mean:

The mean size is the arithmetic average of all the particle sizes in a sample. The graphic mean size (Table 3) is obtained by calculating the average of the 16th, 50th, and 84th percentile diameters determined from the cumulative curve (Table 3).

For the samples analysed, the graphic mean values for samples E5b, E7a, E7c and E10 (Table 3) range from 1.29 to 1.90 which shows that they are medium grained sands. While sample E8 with a mean value of 0.31 shows that it is coarse grained.

b. Graphic sorting (standard deviation).

Sorting is a measure of the standard deviation, i.e. spread of the grain-size

distribution. It is one of the most useful parameters because it gives an indication of the effectiveness of the depositional medium in separating grains of different classes.

From the analysis carried out, samples E5b, E7a, E7c and E10 have calculated sorting values ranging from 1.02 to 1.30 which show that they are poorly sorted, while sample E8 with a value of 0.66 is moderately well sorted (Table 2).

Table 2. Grain size distribution and quantitative parameters for the samples analysed.

Parameter	Graphic mean	Graphic Skewness	Graphic kurtosis	Graphic sorting
Sample E5b	1.90 Medium grained sand	0.003 Nearly symmetrical	1.05 Mesokurtic	1.30 Poorly sorted
Sample E7a	1.64 Medium grained sand	0.11 Fine skewed	0.86 Platykurtic	1.13 Poorly sorted
Sample E7c	1.29 Medium grained sand	0.19 Fine skewed	0.89 Platykurtic	1.02 Poorly sorted
Sample E8	0.31 Coarse grained sand	0.99 Strongly fine skewed	2.87 Very leptokurtic	0.66 Moderately well sorted
Sample E10b	1.87 Medium grained sand	0.25 Fine skewed	1.15 leptokurtic	1.15 Poorly sorted

a. Graphic skewness

Skewness is an additional measure of grain-size sorting that reflects sorting in the tails of the distribution. When plotted as a frequency curve, the grain-size distributions of most natural sediments do not yield a perfect bell-shaped curve instead; they display an asymmetrical or skewed distribution (Fig. 11).

For the present study, samples E7a, E7c and E10 are fine skewed with skewness values ranging from 0.11 to 0.25. Sample E5b have skewness of 0.003 which

is nearly symmetrical, sample E8 is strongly fine skewed with skewness value of 0.99.

b. Graphic kurtosis

The sharpness or peakedness of a grain-size frequency curve is referred to as **kurtosis**. Sharp-peaked curves are said to be leptokurtic; flat-peaked curves are platykurtic.

The samples analysed displays various forms of kurtosis. Samples E7a and E7c are platykurtic i.e they are flat-peaked curves which indicate poor sorting, E5b is mesokurtic, sample E10 is leptokurtic (sharp peaked curve) while E8 is very leptokurtic (sharp peaked curve) indicating better sorting.

4.5 Heavy Minerals

Five samples collected for heavy minerals analysis from the three formations in the study area comprising of the Uomba Formation of the Asu River group (samples E5b and E10b), the Awe Formation (samples E7a and E7c) and the Keana Formation (sample E8).

Heavy minerals suite from the Uomba Formation showed a moderate diversity comprising of the brown to reddish brown varieties of zircon, the black and brown varieties of tourmaline and magnetite.

The heavy mineral suite from Awe Formation is of low diversity consisting of dominantly the white and colourless varieties of zircon and tourmaline grains which are slightly elongated and are euhedral, while some show some degree of rounding, few crystals of magnetite.

Heavy minerals from Keana Formation comprise mainly of the white, light brown and colourless zircon and little brownish tourmaline variety most of them are euhedaral while few are rounded.

CHAPTER FIVE

DISCUSSION

5.1 Sedimentology, Facies Description and Depositional Environments

5.1.1 Uomba Formation (Asu River Group)

This is the oldest known marine sedimentary formation in Nigeria dated to be Albian in age as recorded by Reyment (1965). The deposition of the Nigerian Albian sediments is associated with the first influx of the sea (transgression) following the rifting of the Benue Trough. The transgression is thought to have been caused by the changes in the sea level resulting from the initial growth of the mid- Atlantic ridge which was tectonically controlled. The sea was generally shallow and more or less influenced by tropical climatic factors over most of its extent. There was apparently an abundant supply of argillaceous material from the continent, under a very low gradient and low energy conditions. The presence of mudstones and shales in a stratigraphic section suggest deposition in quiet water palaeoenvironment. Where shales show fissility it indicates that burrowing organisms were absent in the depositional environment (Friedman, 1979).

In the study area, the Uomba Formation (Asu River Group) is made up of thin parallel beds of poorly sorted, fine to medium grained, fine skewed, leptokurtic micaceous sandstone facies which indicate deposition under a moderate energy condition overlying a bed of mudstone facies (Plate I) indicating deposition in a low energy condition marine environment. The shale facies is generally dark grey to black and fissile (Plate II) indicating very low energy marine environment, this feature corresponds to that of Cratchley and Jones, (1965) and Offodile (1976). Poor circulation reduces oxygen in the waters and the conditions becomes anoxic, organic

matter accumulates under these anoxic conditions. The dark grey to black colour in the shales of the Uomba Formation in the study area is partly due to the presence of the organic matter and the finely disseminated pyrite (iron sulphide) which also forms under reducing conditions. No distinctive sedimentary structures were observed from the sediments except for the fissility of the shales and no fossils encountered. This could be as a result of the rapid changes in salinity, temperature, nutrient supply, to environmental extremes appear to have occurred occasionally, in isolated localities, and resulting in the massive migration of organisms as also reported by Offodile (1976). He reported the occurrence of fossils in some restricted areas in the Middle Benue Trough such as Akiri-Wuse area where ammonites abound, but in most of the Keana and Akanje areas, no fossils were found. Currents that transport and deposit sand may also carry nutrients for organisms living in the sand and so therefore, many organisms prefer to live on and within oxygenated nutrient rich sandy substrate in a low/quiet water conditions. This part of the study area may have been devoid of the conditions highlighted above especially in the grey to black shales which were deposited under reduced/anoxic conditions and are not favourable to attract the activities of marine life in this part of the area.

5.1.2 Awe Formation

It was first recognized by Falconner (1911) under the name "passage beds" and proposed as a formal lithostratigraphical unit by Offodile and Reyment (1976). The Awe Formation by its stratigraphical position appears to have been deposited towards the end of the Albian marine episode, in a transitional environment between the predominantly marine and the fluviatile conditions (Offodile, 1976). The Albian transgression probably terminated at the northernmost section of the Middle Benue Trough after which it regressed, accompanied by tidal currents. These

oscillations of the coastline due to tidal currents resulted in an interplay of shallow marine and transitional marine conditions with deposition of rapidly alternating fine to medium grained sandstones, shales and clays (Plate VI). The traces of the activities of marine life in form of bioturbations, the presence of current ripples (Plate IV) are more commonly seen in shallow marine sediments, the occurrence of calcareous sandstones in form of calcareous nodules shows deposition in shallow marine environment with low latitudes and where the climate is relatively warm with less supply of terrigenous materials. The presence of glauconite (Plate XX) indicates marine to relatively shallow marine depositional environment with low sedimentation and the presence of some organic matter. Glauconite forms from the alteration of mica, volcanic glass, biogenic pellets, and feldspar at the sediment water interface during very early diagenesis (Wilson and Pittman, 1977; Boggs, 1992). In the study area, the Awe Formation consists of sandstone facies, shale facies and clay facies.

Sandstone facies comprises of;

a. Micaceous sandstone subfacies: they are made up of fine, medium to coarse grained, poorly to moderately well sorted and are found intercalating with micaceous shales commonly seen towards the base and at the middle of the section. This features suggests deposition in low and moderate energy conditions.

b. Calcareous sandstone subfacies: consists of fine to medium grained, poorly to moderately well sorted, rich in heavy minerals dominantly the opaques (iron oxides and pyrite), glauconite and are fossiliferous due to the presence of bioclast as seen in (Plate XII). The thin calcareous sandstone beds commonly occur as nodules towards the top (Plate V). The presence of fossils (bioclast) suggests deposition in shallow, quiet waters/low energy conditions, relatively warm climate rich in nutrients which favours the activities of the marine organisms with less supply of terrigenous clastic sediments.

c. White sandstone subfacies: consists of fine to medium grained, poorly sorted beds rich in zircon, brownish tourmaline and opaque minerals as observed from heavy minerals analysis, intercalating with thin and thick beds of clay and cross cut by numerous mineralized veins rich in quartz and barite as seen in (Plate VII). The facies features suggest a shallow marine environment. The alternation with clay beds shows fluctuations/changes in energy levels from quiet or low to moderate conditions.

Shale facies comprises of;

a. Grey to black shale subfacies: it is made up of grey to black shales occurring in intercalation with micaceous shales (Plate IV). Their occurrence indicates deposition in reducing/relatively anoxic conditions with the presence of some organic matter

b. Micaceous silty shales subfacies: occur intercalated with micaceous sandstones. The beds are laminated with bright specks of muscovite, plant roots, trace fossils thalassinoides burrows and current ripples (Plate IV).The characteristics of this facies show deposition under quiet water /low energy and relatively moderate energy shallow marine oxic environment.

Clay facies;

The clay in the study area found to occur in alternation with white sandstones (Plate VII) and are cross cut by mineralized veins almost perpendicular to the orientation of the beds. They also occur in alternation with thin beds of micaceous shale and micaceous sandstone (Plate VI). Their occurrence shows a very low energy/ quiet water depositional environment.

5.1.3 Keana Formation

Dated to be Cenomanian (Offodile, 1976) and thought to be the southern extension of the Bima Sandstone which apparently moved down with the retreating Albian Sea (regression). The post Albian folding episode probably gave rise to the

fluvial systems of erosion, sediment transport in the hinterland and deposition. The formation is continental, whereby large quantities of detritus or terrigenous materials transported by fluvial systems appear to have been deposited in the restricted delta which according to (Offodile, 1976) having broken through levees, moved southward with time to form the Keana and Makurdi Formation.

In the study area, the outcrops are massive (Plate X) and contain no fossils. The sandstone facies occur in the northern part of the study area towards Aloshi and consists of coarse grained, moderately well sorted, subrounded to subangular, very leptokurtic feldspar rich sandstone beds (an arkose) with indistinct tabular cross bedding. These features of the Keana sandstone suggest deposition in a deltaic environment (delta mouth bar) of high to moderate energy conditions.

5.3 Provenance Studies

The term provenance is derived from the French word provenir, meaning to originate or come forth (Pettijohn *et al*., 1987). Information about the source of sediment, or provenance of the material, may be obtained from an examination of the clast types present (Pettijohn, 1975; Basu, 2003). If a clast present can be recognized as being characteristic of a particular source area by its petrology or chemistry, then its provenance can be established. In sedimentary petrology, provenance has been used to encompass all factors related to the generation of sediment, with specific reference to the composition of the parent rocks as well as the physiography and climate of the source area from which the sediment is derived (Weltje and Von Eynatten, 2004).

Among the minerals of the parent rock surviving destruction during transport are the heavy minerals. These minor accessory minerals form less than 1% and are marked by higher specific gravities (greater than that of a bromoform, 2.85). If the heavy minerals are newly derived from the crystalline rock, they are little worn and the

crystals are more or less euhedral, but if however, the heavy minerals are derived from earlier sediments, the less stable ones tend to be absent and the more stable survivors show notable rounding.

From the present study of the heavy minerals in Uomba, Awe and Keana Formations, zircon and tourmaline where the principal heavy minerals identified and are the most chemically inert and stable heavy minerals with little of iron oxides (magnetite).

5.3.1 The Uomba Formation (Asu River Group)

The provenance of the Uomba Formation for the sandstone facies was determined using heavy minerals separation technique. A binocular microscope was used to identify and study the various heavy minerals. The sandstone facies within the Uomba Formation (Asu River Group) shows the following characteristics:

a. They are fine to medium grained, poorly sorted nearly symmetrical to positively skewed sands reflecting newly derived sediments from crystalline rocks with few grains that were reworked during transport

b. The heavy minerals suite is of moderate diversity comprising of zircon, tourmaline (brown to reddish brown varieties) and opaque minerals. The heavy mineral crystals like in the tourmaline and zircon are commonly euhedral while some show some varying degrees of rounding. The characteristic features suggest an igneous provenance while the rounded grains were as a result of some distance transport before deposition.

5.3.2 The Awe Formation

Heavy minerals analysis, petrographic and granulometric analysis of the sandstone facies of the Awe Formation were significant in deducing its provenance. The sandstones within the Awe Formation show the following

characteristics:

a. The quartz grains are dominantly monocrystalline with few polycrystalline (Plates XI-XXI).

b. They are dominantly subarkose, even though some show the tendency of being quartz arenite and quartzwacke (Plates XIV and XV).

c. They are fine to medium grained, subrounded to subangular, medium to poorly sorted.

d. Both fresh and altered feldspars are present

e. The heavy minerals suite is of low diversity comprising of white and colourless zircon dominated and few crystals of brownish tourmaline variety. The zircons are slightly elongated and are mostly euhedral while some show some degree of rounding.

This formation is shallow marine and transitional between the marine Uomba Formation (Asu River Group) and the continental Keana Formation. Therefore, based on their characteristics as stated above, the sandstones are mainly of igneous provenance, the rounded grains may have passed through erosion and abrasion during transport and therefore are of reworked sediment (sedimentary) provenance.

5.3.3 The Keana Formation

The provenance for the sandstone of Keana Formation was established with the aid of heavy mineral, granulometric analyses and petrographic studies. Based on the analyses carried out, the Keana Formation shows the following charateristics:

a. Consists of coarse grained, sub-rounded to sub-angular moderately well sorted sandstone with some reworked grains as noticed from their rounding indicative of abrasion and long distance transport before deosition.

b. Monocrystalline quartz dominate with few polycrystalline

c. More of fresh feldspars with few altered

e. The heavy minerals are dominantly the light, colourless zircon and very few of the brownish tourmaline variety, reddish brown haematite and opaques especially seen in petrographic studies (Plate XXI). The crystals are slightly elongated, euhedral with few rounded. The rounding is an indication of erosion and abrasion and processes of turbulence during transport. The characteristic is an indication of igneous provenance while the few rounded grains are of reworked sediment (sedimentary) provenance.

CHAPTER SIX

SUMMARY AND CONCLUSION

The Benue Trough is subdivided into Lower, Middle and Upper Benue Trough. The Middle Benue Trough stratigraphically, comprises of six lithologic formations: the older Asu River Group, Awe Formation, Keana Formation, Eze-Aku Formation, Awgu Formation and the youngest Lafia Formation.

The Keana Anticline is the main structural element in this part of the trough and is cut by a set of mineralized veins rich in quartz and barite. In the study area, three formations were encountered namely; the Uomba Formation (Asu River Group), Awe Formation and the Keana Formation. From this study, the following summary and conclusions are drawn.

- The Uomba Formation (Asu River Group) comprises of thin beds of poorly sorted fine to medium grained, positively skewed, leptokurtic micaceous sandstone, dark grey to fissile shales and non-laminated beds of shaly mudstone without any distinctive sedimentary structures.
- The absence of sedimentary structures in the mudstone, the fissility and the dark grey to black colour of the shales of the Uomba Formation, indicates deposition in a quiet water reducing or anoxic marine environment.
- Heavy minerals analysis of the sandstone of the Uomba Formation indicates that the euhedral zircon, tourmaline and opaque mineral grains are of igneous provenance, while the rounded grains may have been transported for a certain distance before deposition.
- The Awe Formation of the study area comprises of fine, medium to coarse grained, poorly to moderately well sorted micaceous sandstone, calcareous

sandstone in form of calcareous nodules, micaceous shale, grey shale and clay.

- The calcareous sandstones in form of calcareous nodules occur towards the top. Petrographic studies indicate the presence of poikilotopic calcite cement, opaques (iron oxides and pyrite) and bioclast.
- Most of the sandstones of Awe Formation are sub-arkose (Fig. 9).
- The presence thalassinoides burrows in the siltyshale facies of the Awe Formation indicates the activities of marine organisms in an environment that was rich in nutrients and oxygenated.
- The heavy mineral analysis and petrographic studies of the Awe Formation shows the occurrence of elongated euhedral and rounded zircon and tourmaline grains, subangular to subrounded and rounded quartz grains, hematite coatings around grains and within biotite cleavages in some places. The euhedral zircon, tourmaline and quartz grains indicate an igneous provenance while the rounded grains are of reworked sediment (sedimentary) source. The haematite coatings around grains are an ndication of an oxidizing environment commonly in shallow marine environments.
- The Keana Formation of the study area consists of massive coarse grained, moderately well sorted, and very positively skewed, leptokurtic, feldspathic sandstone without any distinctive sedimentary structures and contain no fossils.
- The heavy minerals analysis of the sandstone of Keana Formation shows the presence of both euhedral and rounded to subrounded zircon and tourmaline grains. The euhedral grains indicates igneous provenance while the

rounded to subrounded indicates a sedimentary (reworked) source.

- Most of the sandstones of the Keana Formation are arkoses (Fig. 9)

Contribution to Knowledge

The following contributions to knowledge were achieved:

a. The Geologic map, Lithostratigraphy and Sedimentological studies (through granulometric, lithologic logs and petrographic studies) of the sediments in the study area were updated.

b. Knowledge on the provenance of the sediments in the study area was highlighted.

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APPENDICES

Appendix I: Statistical Parameters of the Analyzed Samples

Sample E5b

Sieve size (mm)	ϕ Value	Sieve size (mm)	Sample weight (g)	Weight (%)	Cumulative weight (%)
1mm	0	1.000	3.55	3.55	3.55
500µm	1	0.500	20.66	20.67	24.22
250µm	2	0.250	29.49	29.51	53.73
125µm	3	0.125	25.92	25.93	79.66
63mic	4	0.063	11.44	11.45	91.11
Pan	5	<0.063	8.89	8.90	100
	Total		99.95	100	

Sample E7a

Sieve size (mm)	ϕ Value	Sieve size (mm)	Sample weight (g)	Weight (%)	Cumulative weight (%)
1mm	0	1.000	3.93	3.94	3.94
500µm	1	0.500	27.61	27.65	31.59
250µm	2	0.250	31.30	31.34	62.93
125µm	3	0.125	23.89	23.92	86.85
63mic	4	0.063	10.38	10.40	97.25
Pan	5	<0.063	2.82	2.82	100
	Total		99.86		

Sample E7c

Sieve size (mm)	ϕ Value	Sieve size (mm)	Sample weight (g)	Weight (%)	Cumulative weight (%)
1mm	0	1.000	7.28	7.29	7.29
500µm	1	0.500	35.24	35.27	42.56
250µm	2	0.250	33.46	33.49	76.05
125µm	3	0.125	17.17	17.19	93.24
63mic	4	0.063	6.12	6.13	99.37
Pan	5	<0.063	0.64	0.64	100
	Total		99.91		

Sample E8

Sieve size (mm)	ϕ Value	Sieve size (mm)	Sample weight (g)	Weight (%)	Cumulative weight (%)
1mm	0	1.000	65.60	65.76	65.76
500µm	1	0.500	19.17	19.22	84.98
250µm	2	0.250	6.24	6.26	91.24
125µm	3	0.125	4.01	4.02	95.26
63mic	4	0.063	2.30	2.31	97.57
Pan	5	<0.063	2.43	2.44	100
	Total		99.75		

Sample E10b

Sieve size (mm)	ϕ Value	Sieve size (mm)	Sample weight (g)	Weight (%)	Cumulative weight (%)
1mm	0	1.000	1.25	1.25	1.25
500µm	1	0.500	19.05	19.05	20.30
250µm	2	0.250	36.76	36.77	57.07
125µm	3	0.125	27.87	27.88	84.95
63mic	4	0.063	8.58	8.58	93.53
Pan	5	<0.063	6.47	6.47	100
Sieve size (mm)	Total		99.98		

APPENDIX II: Grade Scale for Grain Size Parameters

M: Graphic mean standard values

Phi (ϕ) value	**Size class (Wentworth, 1922)**
-1.0 to 0.0	Very coarse grained sand
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 5.0	Coarse silt
5.0 to 6.0	Medium silt
6.0 to7.0	Fine silt
7.0 to 8.0	Very fine silt
8.0 to 14.0	Clay

I: values Graphic phi standard deviation

Phi standard deviation	**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

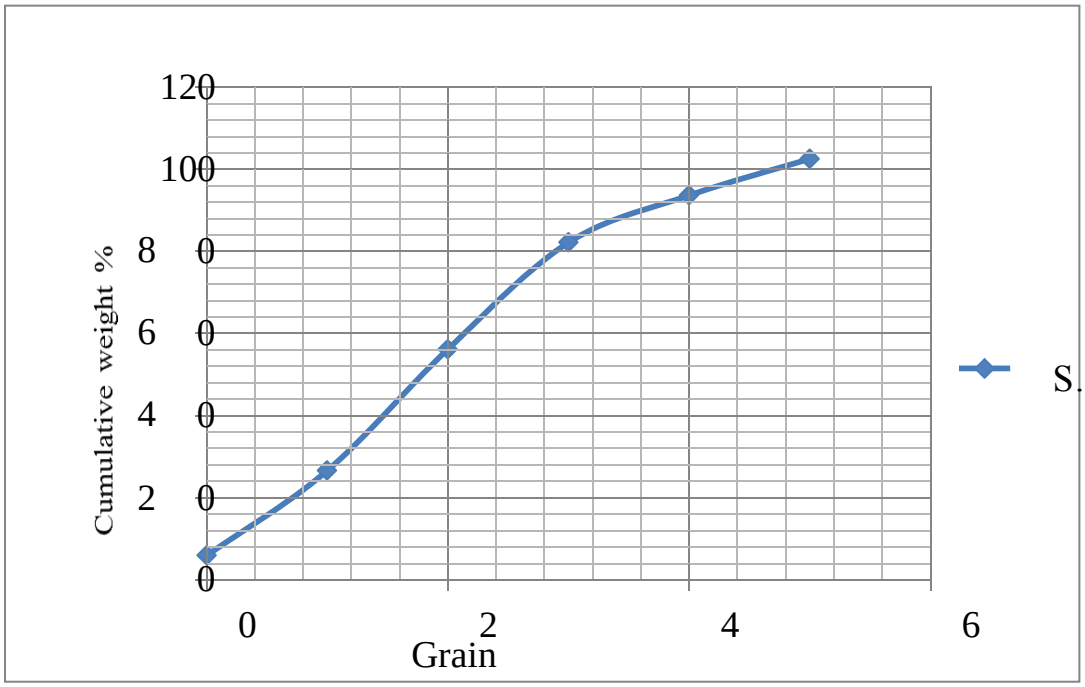
Ski: Graphic skewness standard values

Calculated skewness	**Verbal skewness (Fig.11)**
> +0.30	Strongly fine skewed
+ 0.30 to +0.10	Fine skewed
+0.10 to –0.10	Near symmetrical
–0.10 to –0.30	Coarse skewed
< −0.30	Strongly coarse skewed

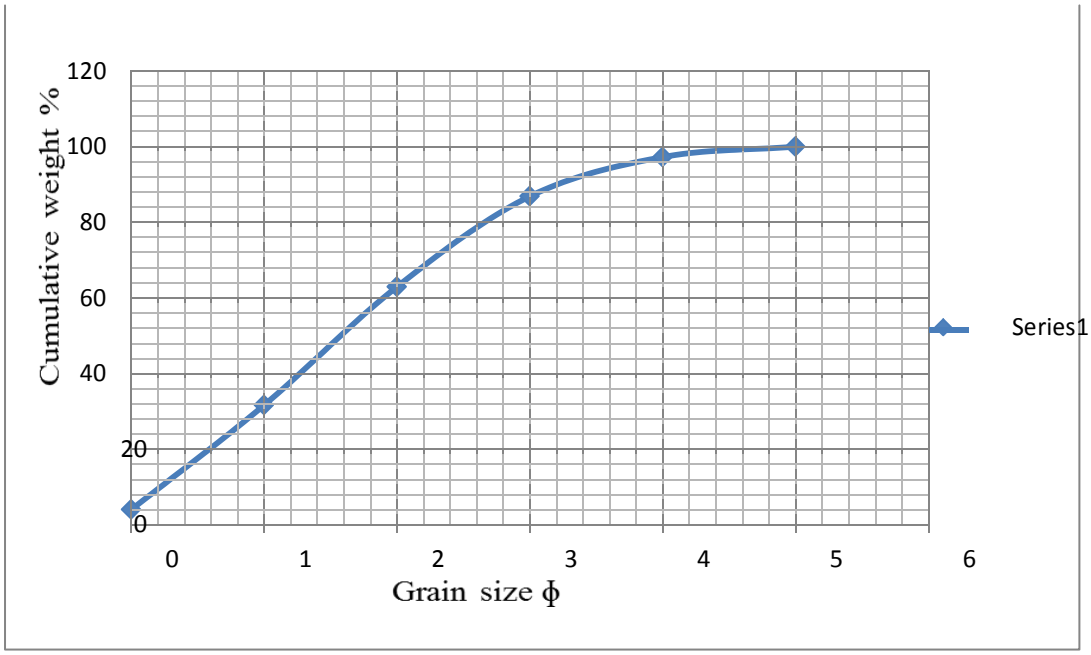
K_G: Graphic kurtosis standard values

Calculated Kurtosis	**Verbal 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

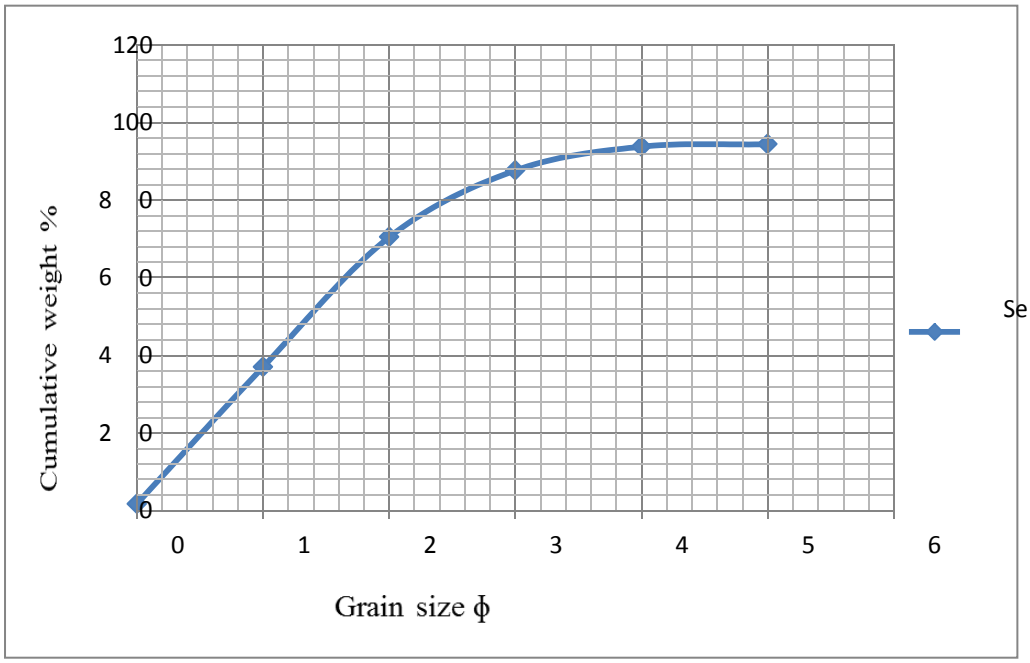
Appendix III: Cumulative Frequency Curves of the Analyzed Samples



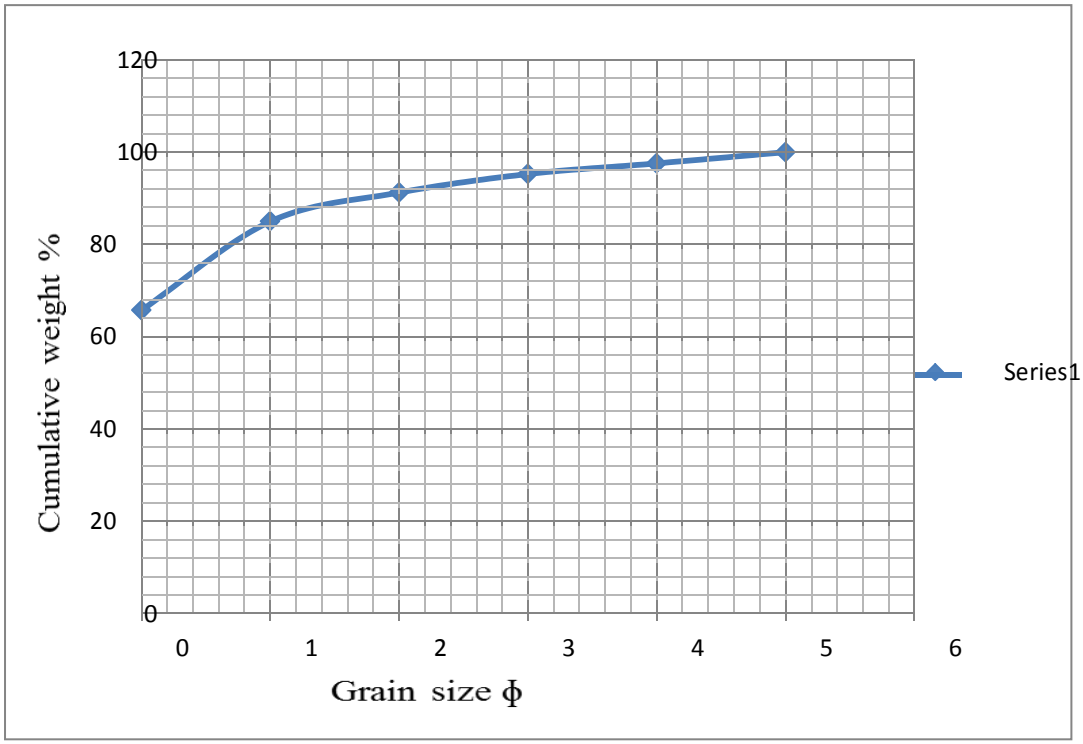
Cumulative frequency curve for sample E5b



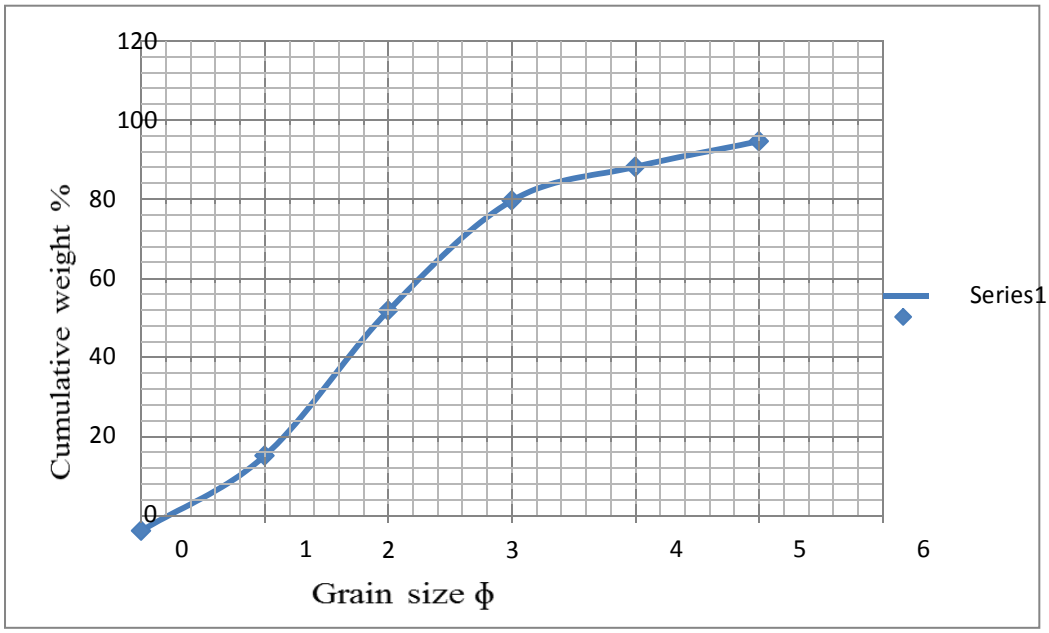
Cumulative frequency curve for sample E7a



Cumulative frequency curve for sample E7c



Cumulative frequency curve for sample E8



Cumulative frequency curve for sample E10b

Table 2: Percentile values from cumulative frequency curve plots for the samples analyzed

SAMPLE	ϕ 5	ϕ 16	ϕ 25	ϕ 50	ϕ 73	ϕ 75	ϕ 84	ϕ 95
E5b	0.10	0.60	1.10	1.90	2.67	2.78	3.20	4.40
E7a	0.08	0.47	0.75	1.58	2.38	2.43	2.86	3.60
E7c	0.00	0.27	0.50	1.20	1.88	1.99	2.40	3.20
E8	0.00	0.00	0.00	0.00	0.35	0.40	0.94	2.80
E10b	0.20	0.82	1.18	1.80	2.50	2.60	2.98	4.20