LITHOFACIES ANALYSIS OF CAMPANIAN TO PALAEOCENE SUCCESSION AROUND RIBADO VILLAGE, PART OF BAJOGA SHEET 131 SE, GONGOLA BASIN NOTHEASTERN NIGERIA

BY

AHMAD, MUHAMMAD ISMAIL

DEPARTMENT OF GEOLOGY

FACULTY OF SCIENCE

AHMADU BELLO UNIVERSITY, ZARIA

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BY

MUHAMMAD AHMAD ISMAIL

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DEPARTMENT OF GEOLOGY

FACULTY OF SCIENCE

AHMADU BELLO UNIVERSITY,

ZARIA, NIGERIA

MARCH, 2016

DECLARATION

I declare that the work in this thesis entitled**"Lithofaacies analysis of Campanian to Palaeocene Succession around Ribado village, part of Bajoga sheet 131SE Gongola Basin, Northeastern Nigeria"**has been carried out by me in the Department of Geology, Faculty of Science, Ahmadu Bello University, Zaria. The information derived from the literature has been dully acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other Institution.

_____ _____

Muhammad Ahmad Ismail Date

CERTIFICATION

This thesis entitled **Lithofacies analysis of Campanian to Palaeocene Succession around Ribado village; part ofBajoga sheet 131SEGongola Basin, Northeastern Nigeria**by Muhammad Ahmad Ismail meets the regulations governing the award of the degree of Master of Science in Geology of the Ahmadu BelloUniversity, and is approved for its contribution to knowledge and literary presentation.

_____ _____

Dr. H. Hamza Date

Chairman, Supervisory Committee

_____ _____

Dr. I. Hamidu Date

Member, Supervisory Committee

_____ _____

Dr. H. Hamza Date

Head of Department

_____ _____

Prof. Kabiru Bala Date

Dean, School of Postgraduate Study

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DEDICATION

This work is passionately dedicated to IMAMUL HUJJAH (A.T.F.S)

ABSTRACT

The lithostratigraphic successions of Campanian to Palaeocene around Ribado area comprises of Upper Fika Formation, Arowa Formation and Kerri-Kerri Formation. Field work was conducted where some sections were logged, sieve analysis and micropaleontological analysis of shales and clays from the study area were carried out, and sedimentary structures were observed. The Upper Fika Formation is poorly exposed with only 7m thick section was accessed from gypsum mining pit believed to have been deposited in prodeltaic environment. The Arowa Formation is made up of coarsening upward cycles, characterized by soft sediment deformational structures and carbonaceous shalessometimes associated withcoal seams at the base. It is made up of laminated, very fine to fine grained, moderately to well sorted,negatively skewed, leptokurtic-mesokurtic, bioturbated sandstones interbedded with clay and sometimes shales. The shale predominate the base of the formation and decreases towards the top as the sandstone proportion increases and predominate.An intraformational channel filling conglomerates with clasts of ferruginous sandstone was observed in the lower part of Arowa Formation. Two lithofacies associations were observed from Arowa Fomation in the study area; the lower part is shale dominated intercalating with fine-grained sandstone varying from a few millimeters to a few centimeters in thickness. Primary sedimentary structures in these interbedded sandstones are symmetrical and asymmetrical ripple marks while the upper part is dominated by Sandstone, sometimes laminated, fine to medium grained,bioturbated, white to grey intercalating with dark grey shales or clays. The Arowa Formation was deposited under deltaic condition. The Kerri-Kerri Formation in the studyarea is continental and characterized by interbedding of clay (kaolin) with medium grained sandstones– granulestone. A NW-SE trending fault was observed in the northwestern boundary of the study area.

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CHAPTER ONE: INTRODUCTION

1.1 General introduction

The term 'facies' was first introduced into geology by Steno in 1669 (Walker, 1984) and later defined by Teichert (1958) as "entire aspect of a part of the earth's surface during a certain interval of geologic time". In its modern usage, facies (sedimentary facies) was defined by selley (1970) as "A mass of rock which can be defined and distinguished from others by its geometry, lithology, sedimentary structures, paleocurrent pattern and fossils". Lithofacies is part of the sedimentary facies that is primarily concerned and distinguishable from other facies by lithologic characteristic, geometry, sedimentary structures and paleocurrent pattern.

Therefore to know the depositional environment of sediment (palaeoenvironment), it is of paramount importance to identify the different lithofacies that characterize the sediments and to also determine how the facies are associated.

1.2. Location and Accessibility

The study area is part of Bajoga Sheet 131 SE and occurs within the Gongola Basin of Northeastern Nigeria. It lies between Longitudes 11^0 15 and 11^0 30'E and latitude 10^0 30 and 10^0 45 N mappedon a scale of 1:50,000, covering approximately 770km^2(Fig.1). The area is accessible by road and footpaths that inter link the area, though some part of the study area covered by hills lack both roads and footpaths. Tarred roads are also available linking villages with the major road from Malam Sidi to Bajoga, which passes through the area of study.

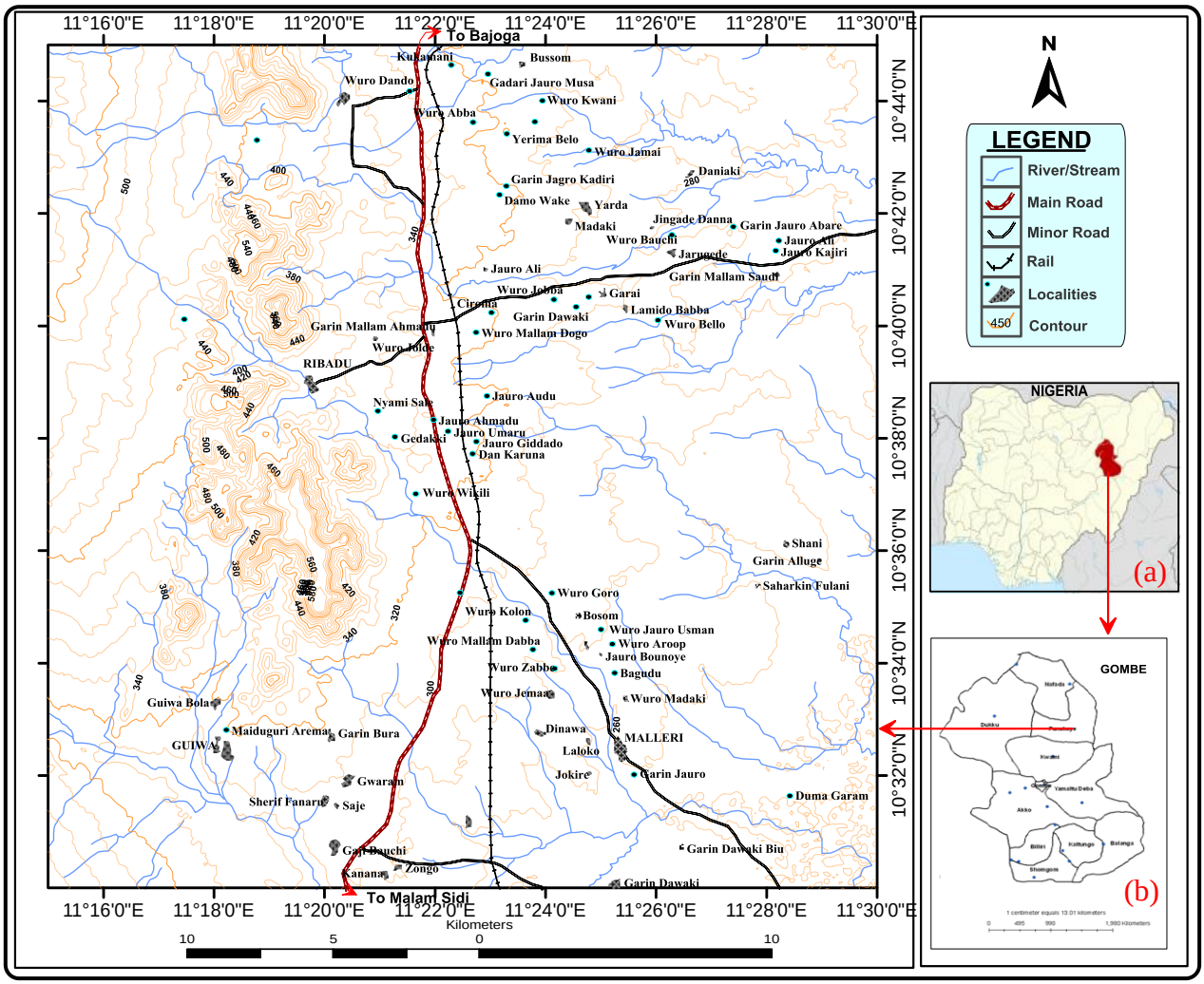


Figure1: Location map of the study area showing relief, settlements and drainage pattern with

insets: (a) map of Nigeria showing Gombe State and (a) map of Gombe state showing the location of the study area.

1.3. Statement of research problem

Several authors in the Gongola Basin and especially, Falconer (1911), Carter *et al.* (1963), Zaborski *et al.* (1998), Abubakar (2006) and Hamidu *et al.* (2013a) discussed about coal occurrence within Gombe sandstone, but with less or no details about its occurrence around Ribado area.

1.4. Justification

The lithostratigraphy around the area has not been studied in details, hence the need to carry out this research work.

1.5. Aim of the Research

This research is undertaken in order to study the lithofacies and sedimentary structures in the area with emphasis on ascertaining the stratigraphical position of coal seam in the area.

1.6.Obectives of the research

i. Producing a detailed geological map of the study area and to study the Campanian – Plaeocene lithostratigraphic succession in the area.
ii. To identify the sedimentary structures associated with the study area and to use them in interpreting the palaeoenvironment of deposition of the sediments in the area.

1.6 Climate, Vegetation and Landuse

The climate of the study area is of the tropical type. There are two distinct seasons; a dry season followed by a shorter wet season. Rain falls between April and October with an annual record varying from 625mm to 875mm. The area is characterized by Sudan Savannahtype of vegetation, with trees of few meters high and abundant shrubs. There are abundant farmlands in the relatively flat areas. Crops grown include groundnuts, millet, beans, and maize.

1.7 Topography and drainage

The Arowa Formation in Ribado area is characterized by elevated fragmented hills, the Kerri-Kerri Formation forms an elevated but relatively flat topography while the Upper Fika Formation occur as relatively flat land. The drainage pattern of the study area is dendritic mostly (Fig 1) flowing from northwest (hilly dominated region) to southeast (relatively flat region).

CHAPTER TWO: LITERATURE REVIEW

2.1. Geological setting of the Benue Trough

The Benue Trough is a Mesozoic rift basin that starts from the coast of the Gulf of Guinea and extends transversely as a deep "furrow" within the Nigerian shield. It forms part of the central West African Mesozoic bifurcating rift system, which connects with other continental rifts in the interior West African Republics of Chad and Niger (Machena 1973; Burke and Dewey, 1974). The Benue Trough, together with the Niger Delta constitute the southern segment of the "trans-African lineament" which is a deep-seated zone of crustal weakness that trends NE-SW from Nigeria through Niger into Libya and Egypt (Nagy *et al.* 1976) (Fig.2).The Benue Trough includes some pull-apart sub-basinswhere rifting and wrenching were active concurrently (Benkhelil,1988; Guiraud,1993).

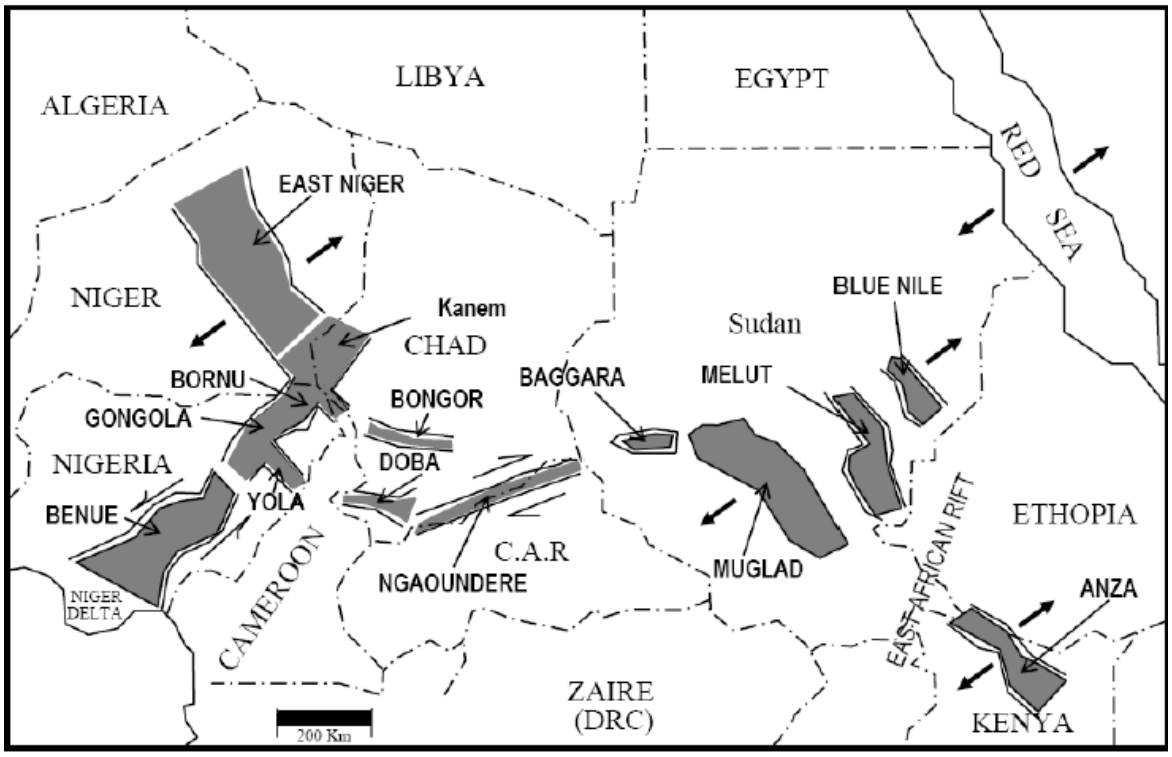


Figure2: The Central West African Rift System showing the trend of rift Basins. (Adapted from

Schull, 1988)

2.2. Origin and evolution of Benue Trough

The Benue Trough is about 1000 km in length and 300 km maximum width. Its origin, structure, and stratigraphy have been some of the most engaging and hence better understood geologic topics in West Africa. The trough forms a major re-entrant on the continental margin of West Africa and continues into the African continental plate. The Benue Trough is regarded as part of the three-armed rift system, which formed as a result ofGondwana break-up (Burke *et al.,* 1971, 1972; Burke and Whiteman, 1973; Hoffman *et al.,*1974). The Gulf of Guineaand the South Atlantic were the active arms of this triple junction along which spreading occurred, leading to the separation of Africa from South America. In the absence of crustal separation, the Benue Trough remained an abandoned rift with over 6000 m of sediments. Benkhelil (1989) also suggested that the evolution of the trough could also be as a result of tension resulting in a rift or wrench related basin. Mesozoic to Cenozoic magmatism accompanied its evolution as it is scattered all over and throughout the trough (Coulon *et al.,* 1996).

Because of its tectonic setting, rift origin, and thick sedimentary pile, the Benue Trough is regarded as an aulacogen (Hoffman *et al.,* 1974; Olade, 1975; Petters, 1978a). The stratigraphic succession in the Benue Trough comprises essentially of a thick continental and paralic sandstones, shales, and coal measures, and shallow epicontinental shales and limestones (Murat, 1972; Petters, 1978a*).* The age of the sedimentary rocks in the Benue Trough range from Aptian to Palaeocene though pre-Aptian has been suggested by some authors (Zaborski, 1998). The thicker (over 10 km) and younger deposits of the southern part of the Benue Trough belong to the Tertiary Niger aulacogen delta. Magmatic rocks ranging from the initial rift-generated alkaline basalts (Olade, 1975) to a wide variety of intrusive and extrusive suites (Wright, 1976), together with lead-zinc mineralization, are familiar features of the Benue Trough. The initial eastern axis Albian-Santonian deposit underwent inversional

movements in the Santonian because of regional compressive forces (Guiraud1990; Freeth, 1978).

The Benue Trough has been subdivided geographically into domains (the Lower, Middle and Upper Benue) (Fig.3). Each domain has recorded a separate sedimentary and structural history (Benkhelil, 1988). The present work is confined to the Upper Benue Trough alone.

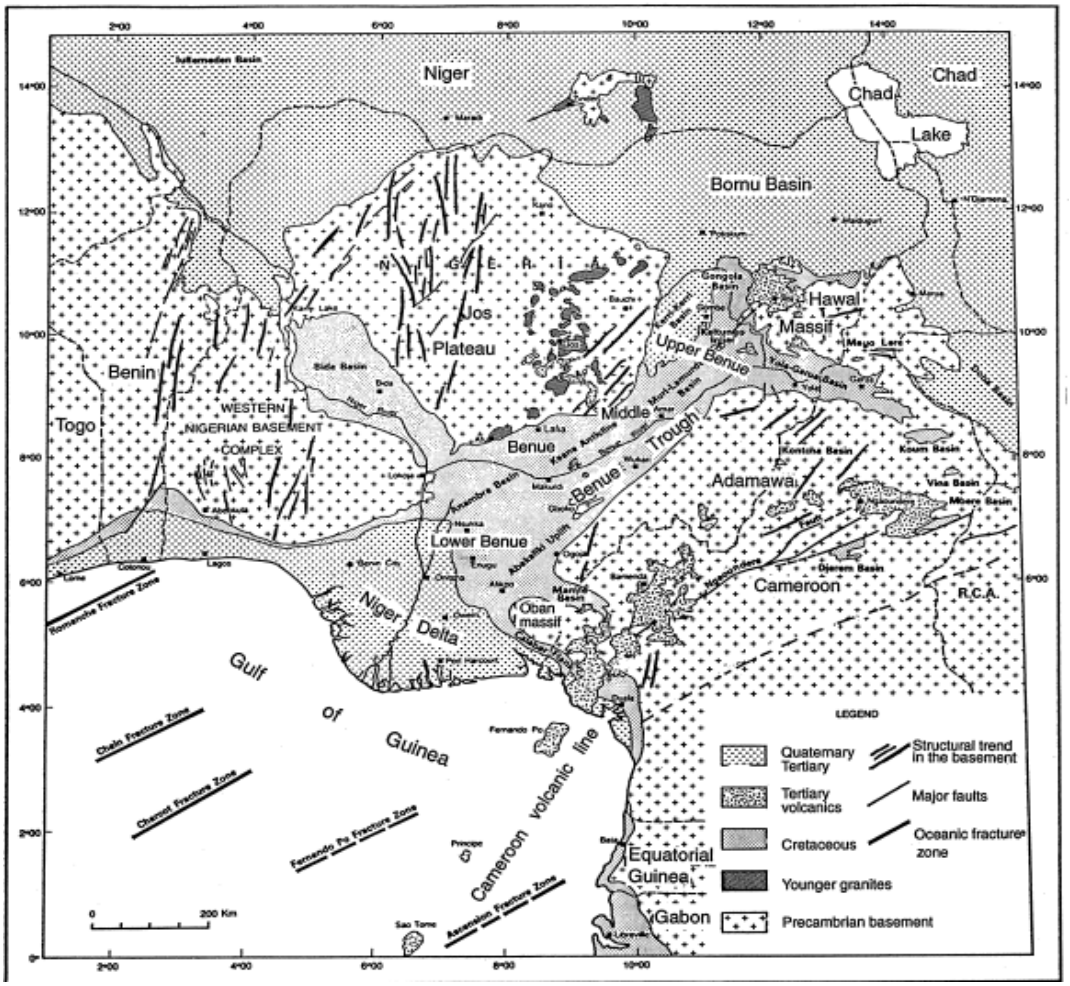


Figure3: Geologic sketch map showing Upper, Middle and Lower Benue Trough (After Benkhelil, 1988)

2.3.The Upper Benue Trough

The Upper Benue Trough comprises area extending from Bashar-Mutum Biyu line to as far north as the "Dumbulwa-Bage High" of Zaborski *et al*. (1998) a feature which separates the Upper Benue Trough from the Bornu Basin. Althogh early studies of Upper Benue Trough and southern Bornu Basin were carried out by Falconer (1911), Jones (1932), Raeburn and Jones (1934) and Barber *et al*. (1954), but the basis for all later works was provided by Carter *et al*. (1963) who undertook a regional study of the area covered by the Geological Survey of Nigeria 1:250,000 Series Map Sheet 25 (Potiskum), 36 (Gombe) and 47 (Lau). The Upper Benue Trough has since been studied in great detail and has been almost entirely re-mapped [Allix (1983), Benkhelil (1985, 1986, 1988), Popoff (1988), Guiraud (1989, 1990, 1993) and Zaborski *et al.* (1998)].

At its northeastern end the Upper Benue Trough bifurcates into an E-W trending Yola Arm and N-S trending Gongola Arm or Gongola Basin (Fig.4). Carter *et al.* (1963) referred to the general area between the Yola Arm and Gongola Basin as "Zambuk Ridge", actually a zone characterized by a number of important NE-SW trending sinistral strike-slip faults. Zaborski *et al*. (1998) proposed that the Gongola Basin is separated from Bornu (Chad) Basin to the north by anticlinal feature termed the "Dumbulwa-Bage High". concealed beneath the Cenozoic sedimentary cover of the Bornu Basin are the Cretaceous rift-like basins (Avbovbo *et al.*, 1986). This in turn form a link with those parts of the West African Rift System in Niger and Chad to the north (Fairhead and Green, 1989; Guiraud and Maurin, 1991, 1992; Genik, 1992, 1993).

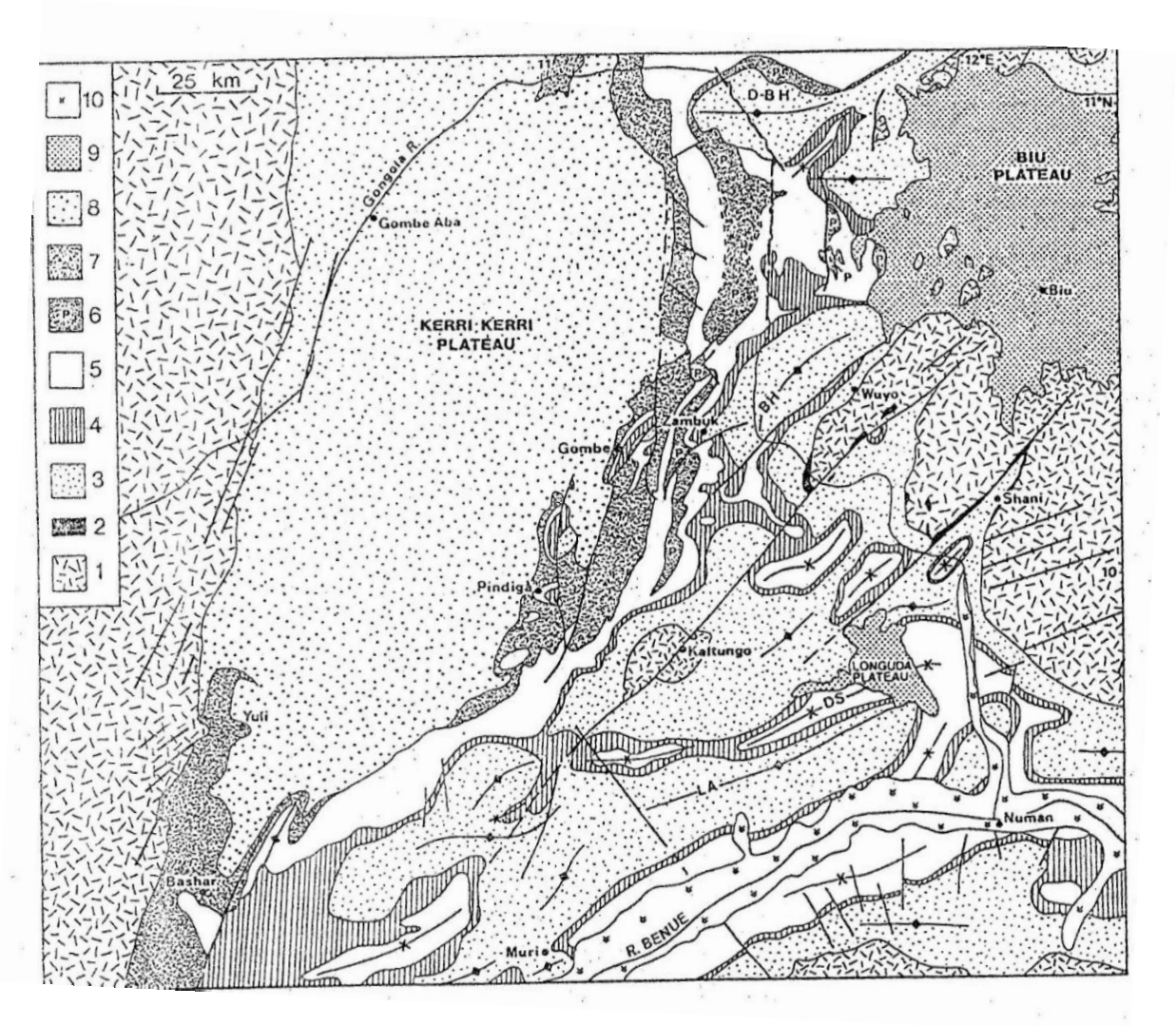


Fig. 4: Geological map of the Upper Benue Trough region (based on Benkhelil, 1985; Guiraud,

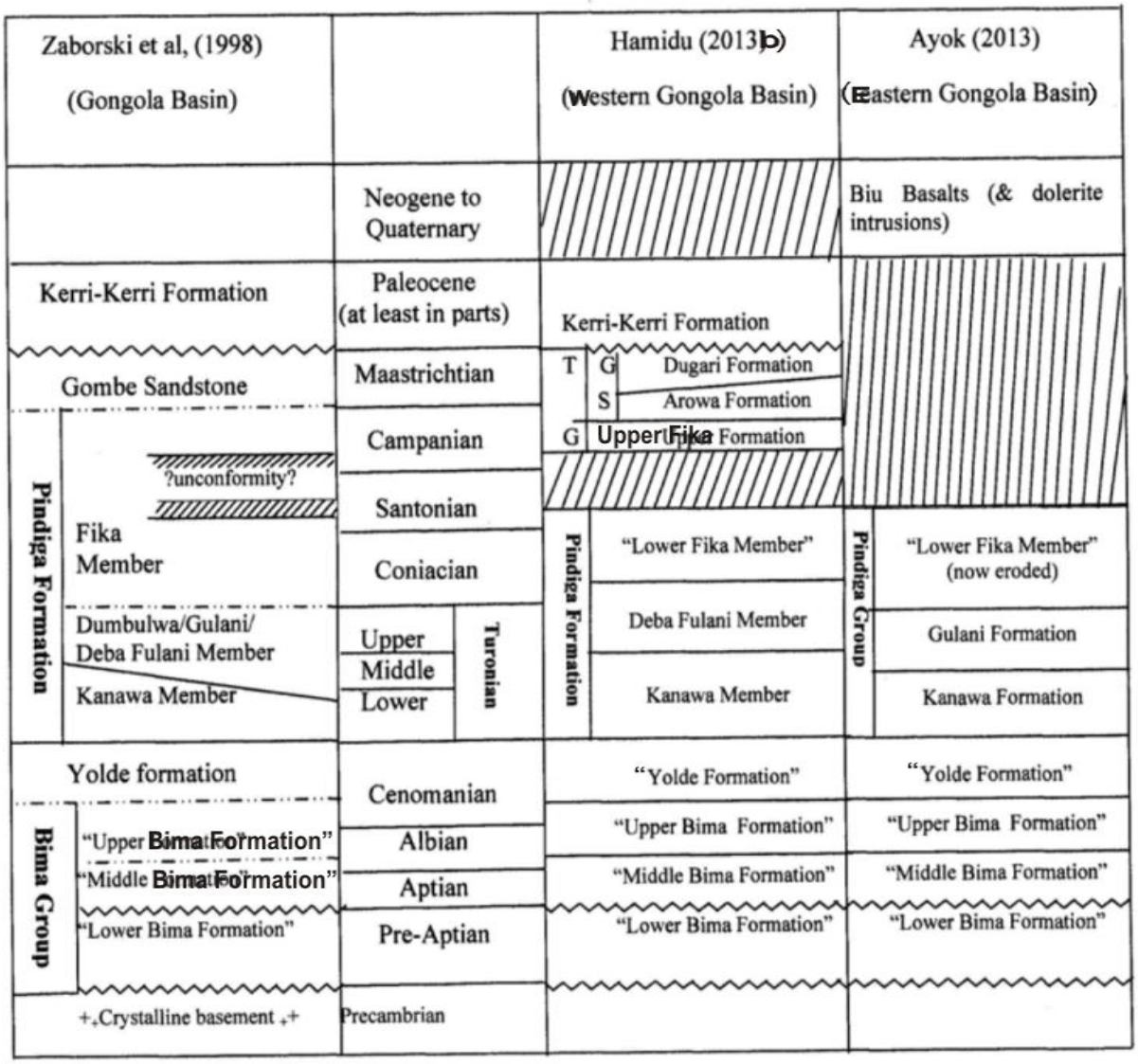
1989; Zaborski *et al*., 1998). 1. Precambrian; 2. Late Jurassic? to Early Cretaceous volcanics; 3. Bima Group; 4. Yolde Formation; 5. Pindiga Formation and lateral equivalents in the Yola arm; 6. Sandy members of the middle part of the Pindiga Formation in the Gongola Basin; 7. Gombe Sandstone; 8. Kerri Kerri Formation; 9. Neogene to Quaternary basalt; 10. Alluvium; D-B-H= Dumbulwa-Bage High; BH = Bima Hills; DS = Dadiya Syncline; LA = Lamurde Anticline (After Zaborski *et al*., 1998).

2.4. Stratigraphy of Upper Benue Trough

Chronologically, the Precambrian basement is unconformably overlain by the Aptian-Albian Bima Sandstone, which is the oldest, thickest, and most extensively outcropping formation in the trough (Carter *et al*., 1963; Guiraud, 1990; Abubakar, 2006; Mamman *et al*., 2010). Stratigraphical studies conducted by Guiraud (1990) showed that the Bima Sandstone could be divided into three siliclastic formations namely; the lower, the middle and upper Bima Formation, specifically designated as Bima 1, Bima 2, and Bima 3. The Bima

Sandstone is overlain by Yolde Formation which is a transitional interbeds of shale, siltstone and calcareous mudstone. Conformably on top of the Yolde Formation are the massive beds of limestone and thick shale of Pindiga Formation (Kanawa, Dumbulwa/Gulani/Deba Fulani; Fika Members) of Zarboski (1998)(Table 1) or (Kanawa, Dumbulwa/ Gulani/ Deba Fulani, Lower Fika Members of Hamidu *et al.* (2013b)(Table1) or Pindiga Group (Kanawa, Gulani Formations and Lower Fika Member) of Ayok (2013) (Table 1) in Gongola Basin and their lateral equivalent are the Dukul, Jessu, Sekule, Numanha and Lamja formations in the Yola Arm. The sediments overlying these formations are the poorly to moderately sorted Gombe Sandstone (Campanian – Maastritchtian) of Zarboski *et al*. (1998) or Duguri and Arowa Formations of Hamidu *et al.* (2013b)(Table1) in the Gongola Basin. The succession is capped by sandstons of the Kerri-Kerri Formation (atleast to the West of Gombe town) in the Gongola Basin.

Table 1. Stratigraphic correlation of eastern Gongola Basin (after Ayok, 2013) and western Gongola Basin(After Hamidu *et al*,. 2013b) (GS= Gombe Sandstone, TG = Tukulma Group



2.4.1. Stratigraphy of Gongola Basin

2.4.1.1. Bima Formation

The Bima Group (sensu stricto Zaborski *et al.,* 1998) reaches a thickness of several kilometres and in most places represents by far the greatest proportion of the lithostrtigraphical succession present in the Upper Benue Trough. Extensively exposed in the eastern and southern parts of the region, it has been studied in detail, notably by Carter *et al*. (1963); Allix (1983); Popoff (1988); Ojo and Pinna (1982) and Guiraud (1990, 1991). The term “Bima Sandstones” was first used by Falconer (1911) for the beds occurring at the type locality at Bima Hill, and includes the Yolde Formation of later authors. Those part of the "Upper grits and Sandstones" described by Falconer (1911) from Waja, Ture and Wuyo also belongs to Bima Group and Yolde Formation, as do the "Upper Benue Sandstones" of Longbottom (Falconer, 1911), all of which were erroneously regarded as post-Turonian. The Bima Group includes the greater part of the "Gongola Sandstones" of Jones (1932) and the "Bima Sandstone Group" of Raeburn and Jones (1934); (they also encompass the Yolde Formation) ; the "Guyuk Sandstone" and Bima Grits" of Barber *et al*. (1954) and "Bima Sandstone" of Carter *et al*. (1963). Ojo and Pinna (1982) proposed a very complex subdivision of the Bima Group. More regional workable schemes were proposed by Allix (1983) and Guiraud (1990, 1991).

Guiraud (1990, 1991) described the Bima Group in the Wuyo-Kaltungo High and adjacent areas, subdividing it into:

i. The "Upper Bima Sandstone" ("B3"), a fairly homogenous, relatively matured unit comprising coarse to fine-grained sandstones characterized by tabular cross-bedding with laterally extensive sets, a few tens of centimeters to a few meters thick. Convolute bedding and overturned cross-bedding are common. The average thickness

is about 500m with a maximum of 1200m in the Lamurde anticline; these deposits were regarded as distal braided river origin.

ii. The "Middle Bima Sandstone" ("B2"), a widely distributed, uniform unit made up of fining-upward cycles each 5 - 10 m thick. Trough and tabular cross-bedding characterizes the sandstone, in the lower part of each cycle, thin clays and palaeosols occur above. The thickness varies from 100-500 m. These deposits were regarded as proximal braided river origin. Guiraud (1991) reported fossil wood, *Metadopocarpoxylon libanoicum* (Edwards), to which a Late Aptain age was assigned.

iii. The "Lower Bima Sandstone" ("B1"), a highly variable unit ranging in thickness from 0 to over 1500 m. Lithofacies distributions were controlled by synsedimentary tectonics which created a number of fault-bounded sub-basins within which marginal alluvial fan/distal debris flow deposits pass laterally into fining-upward fluvial cycles and in places into lacustrine deposits comprising interbedded clays, fine-grained sandstones and calcareous beds. Radiometric ages from intercalated lavas suggest an age from Neocomian to Late Aptian or Early Albian.

2.4.1.2. Yolde Formation

The name "Yolde Formation" was proposed by Carter *et al*. (1963) for the "transitional beds" recognized earlier by Falconer (1911) and Barber *et al*. (1954) between the Bima Group and the Pindiga Formation. A type section was designated in the Yolde stream in the western part of Yola Arm while the most complete section of the Yolde Formation has been found northwest of Ruwan Kuka by Zaborski *et al*. (1998) in the Gongola Basin While the "Upper Bima Sandstone" may be partly of Cenomanian age, the greater parts of this stage is represented in both the Yola Arm and the Gonglola Basin by the

Yolde Formation (Carter *et al.*, 1963) [="passage beds at Bomanda" (Bomanda, 9km south of Muri) of Falconer (1911); "Transition Beds" of Barber *et al*. (1954); "Formation 4" of Allix (1983). Its thickness varies, reaching a maximum of about 200 m. It wedges out in the western part of the Dumbulwa-Bage High where syn-sedimentary uplift resulted in the attenuation of the “Middle” and ‘Upper Bima Sandstone" (Zaborski *et al*., 1998).

The Yolde Formation has been described in the Yola arm by Carter *et al*. (1963) and Allix (1983) and in the Gongola Basin by Zaborski *et al*. (1998). It consists largely of alternations of fine to coarse grained, cross-bedded or ripple-bedded sandstones and grey to greenish shales. Thin limestones or calcareous sandstones occur, especially in its upper part where oyster beds are common. The formation fines upward, channels filling coarse-grained sandstones with trough cross-bedding occur in the lower part. Thinly-bedded, fine-grained tomedium often bioturbated sandstones appear higher up. Its boundary with the "Upper Bima Sandstone" is transitional. However Carter *et al.* (1963) defined it as the first appearance of "marine" shales. Similarly, Allix (1983) used the appearance of thick, laterally continuous siltstones or silty shales or the base of a marker horizon comprising greenish fine-grained sandstone with disturbed cross-bedding found in parts of the Yola Arm as its boundary. The Yolde Formation represents fluvial and coastal plain paleoenvironments in its lower part and shallow marine conditions higher up. The foraminiferal faunas comprises entirely arenaceous forms. Dating of the formation has been carried out based on pollens by Lawal (1982). Allix (1983) and Lawal and Moullade (1986) suggested age limits between the Late Albian and the Late Cenomanian.

2.4.1.3. Pindiga Formation

Overlying the Yolde Formation in Gongola Basin is the Pindiga Formation (Carter *et al.,* 1963; Allix, 1983; Zaborski *et al.,* 1998; Hamidu *et al.,* 2013b) [= Pindiga Group of Ayok, 2013]. The Pindiga Formation of Zaborski *et al.* (1998) comprises Kanawa Member, Dumbulwa/Gulani/Deba Fulani and Fika Members. Hamidu *et al.* (2013b) proposed that the Fika Member of Zaborski *et al*. (1998) be sub-divided into: Upper Fika Formation and Lower Fika Member based on Santonian episode. The Upper Fika Formation which ispost - Santonian to be part of Tukulma Group of Hamidu *et al.* (2013a) while the Lower Fika Menber being pre - Santonian is left within the Pindiga Formation .

2.4.1.4.Kanawa Member

The Kanawa Member [= the "Kanawa Formation" of Thompson, 1958); lower "Limestone – Shale Member" of the Pindiga Formation of Carter *et al*. (1963); the lower "Limestone – Shale Member" of the Gongila Formation of Carter *et al*. (1963); Kanawa Member of Zaborki *et al*. (1998); Kanawa Member of Hamidu *et al*. (2013b) and Kanawa Formation of Ayok (2013)] are the overlying beds on Yolde Formation in Gongola Basin which are lower part of the "Turonian Limestones and Shales of the Benue valley". It consists mainly of shales, dark grey when fresh but weathered to light blue-green to grey colours. Disseminated gypsum commonly occurs in exposures, sporadic interbedded limestones are also present; most are a few centimetres to a few tens of centimetres thick but they may be superposed to produce units of up to 2m and in the Ashaka area on the southern flanks of Dumbulwa – Bage High it is nearly 10m thick. It ranges in thickness from 120m at Kumo (Lawal, 1982) to just few metres of condensed limestone – dominated beds over the Dumbulwa – Bage High (Zaborski *et al*., 1998).

The limestone beds are frequently richly fossiliferous. Dating was based on the ammonite faunas. These lithostratigraphic units constitute the upper part of the Upper Cenomanian and most or all of the Lower Turonian. Five regionally recognizable ammonite zones are present (from top to bottom)(Zaborski *et al*., 1998):

i. A zone of *Wrightoceras wallsi;*
ii. A zone of *Pseudotissotia nigeriensis* (Woods);
iii. A zone of *Vascoceras globosum* (Reyment);
iv. A zone of *Paravascoceras cauvani* (Chudeau); and
v. A zone of *Nigericeras gadeni* (Chudeau).

The Cenomanian-Turonian boundary has been variously placed but coincides approximately with the base of the *Pseudotissotia nigeriensis* Zone. The limestone-shale interval is slightly diachronous. Although it's base appears to beof approximately the same age throughout the Upper Benue Trough. The *Wallsi zone* is only known from the Wuyo-Kaltungo High area and in the Yola arm, the Dukul Formation also includes latest Early Turonian beds containing the ammonites *Hoplitoids* and *Kameruoceras turoniese* (d'Orbigny); the top of the formation approximates to the Lower-Middle Turonian boundary (Zaborski, 1990).

2.4.1.5. Dumbulwa Member/Gulani Member/Deba Fulani Member

The Middle Turonian regressive conditions affected the Upper Benue Trough. In the Gongola Basin and the Wuyo-Kaltungo High region dominantly arenaceous deposits lie above the Kanawa Member. In the eastern Gongola Basin, they make up the Gulani Formation (Ayok, 2013) or Gulani Member of the Pindinga Formation of Zaborski *et al.*(1998) [="Upper grits and Sandstones of Gulani" of Falconer 1911]. These probable fluviatile sediments include very large-scale tabular cross-bedded, coarse-grained sandstones and

granulestones, individual sets being several metres thick (Zaborski *et al*., 1998). In the Dumbulwa-Bage High the lateral equivalent is the Dumbulwa Member (Zaborski *et al*., 1998). It lies upon an erosional surface on the Kanawa Member and in places the Kanawa Member being totally eroded. The Dumbulwa Member is largely made up of fining-upward fluviatilel cycles, when complete each about 10 m thick. Localized developments of persistent tabular cross-bedded sandstones also occur. To the south the Dumbulwa Member passes laterally into the sandstones of the Deba Fulani Member of the Pindiga Formation (Zaborski *et al.*, 1998). The Deba Fulani Member represents a variety of fluvial, coastal plain and shallow sub-littoral environments. Coarse-grained, pebbly tabular cross-bedded sandstones and fining-upwards and channel-filling sandstones occurs as do more thinly bedded sandstones with fish vertebrae, phosphatic pebbles and burrows of *Ophiomorpha* type. The Deba Fulani Member wedges out to the south.

These three sandstone members have not been directly dated but have probable age limits within the range of late Early Turonian and Late Turonian. They overlie horizons in the Kanawa Member belonging to the *Nigeriensis zone* in the north and the *Wallsi zone* in the south. North of the Dumbulwa-Bage High Coniacian ammonite occur in beds overlying the Dumbulwa Member (Zaborski *et al*., 1998). The nature of age equivalent beds in the sub-surface of the western Gongola Basin is unknown. The Deba Fulani Member is not recognizable in the outcrops of the Pindiga Formation occurring in the Tukulma, Pindiga, Yelwa and Futuk Inliers.

2.4.1.6. Lower Fika Member

In the Wuyo-Kaltungo High area of the Gongola Basin, the sandy members of the Pindiga Formation are overlain by the Fika Member (Zaborski *et al*., 1998) [=upper part of the "Turonian Limestones of the Gongola valley" of Falconer (1911), "Clay-Shale Group" of

Jones (1932); upper part of the "Limestone-Shale Group" of Raeburn and Jones (1934); "Clay-Shales" of Barber *et al*. (1954); "Shale Member" of the Pindiga Formation and Fika Shales of Cater *et al.* (1963). Jones (1932) used the term "Fika Group" mainly for poorly exposed "Mudstones, muddy sandstones and shaly ironstones" in the southern Bornu Basin which appear to be, at least in large part, the lower portion of the Gombe Sandstone of later authors. The Fika Member may represent two distinct depositional phases separated by the Santonian compression event; [= Lower Fika Member and Upper Fika Formation of Hamidu *et al.* (2013a)]. Its pre-Campanian part primarily comprises shales indistinguishable from those of the Kanawa Member. From a borehole at Kumo, northwest of Kaltungo, Lawal (1982) and Lawal and Moullade (1986) described over 150m of shales with marine microfossils which they dated Coniacian to Santonian on the basis of pollen. On the northern flank of the Dumbulwa-Bage High Zaborski *etal.* (1998) reported the Coniacian ammonites *Barroisiceras* and *Foresteria* from limestones in the lower Fika Member. Barber *et al.* (1954) tentatively assigned a Coniacian age to a thin limestone in the Fika Member at Pindiga village on the basis of bivalves *Astarte nigeriensis schneeegans* and *Plicatula auressensis* Conquand.

2.4.1.7. Tukulma Group

This is the Campano-Maastrichtian succession in the Gongola Basin which is bounded by major unconformities below and above, these being of Santonian and latest Maastrichian age respectively (Hamidu *et al*., 2013a). This comprises the “Upper Fika Formation, Arowa Formation and Duguri Formation. Arowa and Duguri Formations [= the “Gombe Sandstone” of Berber *et al.* (1954); parts of the “Fika Group” and “Kerri-Kerri Group” of Jones (1932); “Upper Sandstone Group” and parts of “Kerri – Kerri Group” of Raeburn and Jones (1934). The Arowa and Duguri Formationswere used in this work instead

of the Gombe Sandstone of the previous authors; also the Tukulma Group of Hamidu *et al.* (2013a) is adopted here.

2.4.1.8. Upper Fika Formation

The Upper Fika Formation (Hamidu *et al.*, 2013a) refer to the post-Santonian part of "Fika Member" which was described by Zaborski *et al.* (1998), and comprises the "Fika Shales" of Carter *et al* (1963) and the equivalent of the Upper Shale Member recognized by those authors in Pindiga Formation. The present work upholds the use of the Upper Fika Formation.

The Upper Fika Formation is separated from Lower Fika Member by the Santonian unconformity and the Upper Fika Formation is overlain by Arowa Formation with their boundary being a hiatus (Hamidu *et al.*, 2013b). In Pindiga stream, the hiatus is probably represented by 20cm thick, brown, silty fine-grained sandstone containing rip-up shales clast and separating highly fractured gypsum rich shale below weakly fractured gypsum poor shale above. In the Pindiga stream section the Upper Fika Formation is 30m thick, its top being marked by 80cm thick bioturbated ooidal ironstone (Carter *et al.*, 1963) in the Pantami stream, in the Gombe inlier the hiatus occurs within the "Pindiga Formation" where the tectonic dips change abruptly from 20^0NW to less than 10^0NW.

The Upper Fika Formation has an overall shallowing upwards sub-littoral nature. The lower part with condensed horizon represents the deepest water conditions in the Campano – Maastrichtian sub-section, the condensed horizon themselves marking marine flooding surfaces. The shale/ooidal ironstone alternations in the upper part represented by high – frequency shallowing upwards cycles with the ooids probably of a primary kaolinitic nature and formed in agitated waters (Mucke 2000).

2.4.1.9. The Arowa Formation

The Arowa Formation (Hamidu *et al.*, 2013b) is a unit that comprises the lower and middle parts of the Gombe Sandstone. The Gombe Sandstone was proposed by Carter *et al.* (1963) and adopted by Zabroski *et al.* (1998). The name having been adopted from Falconer (1911) "Gombe silts and clays". The later unit had its "characteristic section" at Gombe Abba some 100 km to the northwest of Gombe city, which comprises beds now referred to the Kerri-Kerri Formation. The type locality of the Gombe Sandstone was designated by Carter *et al.* (1963) as the "Kware stream" about 3 km south of Gombe where 300m of sediments were described as being exposed. According to (Hamidu *et al.*, 2013b) the 1: 250,000 scale geological map (sheet 36 Gombe Lau) provided in Carter *et al*. (1963)is inadequate to determine with certainty which of the several streams in this area actually contains the type section. In any case, none of them exposes as much as 300m of Gombe Sandstone and what is exposed belongs entirely to the Arowa Formation, which is unconformably overlain by the Kerri-Kerri Formation. The Arowa Formation is adopted in this work.

The Arowa Formation outcrops from Rahama in the south, where it wedges out to the north through Pindiga to Gombe, Birri Fulani and Fika. The holostratotype of the Arowa Formation is in the Arowa stream north of Gombe town (Hamidu *et al.*, 2013b). The top and base of the type section are located at $10^0$18'29.5"N $11^0$09'24.1"E and $10^0$18'38.5"N $11^0$10'37.1"E respectively. The type section of the Arowa Formation is about 260 meters in thickness. It overlies the "Upper Fika Formation" with a transitional contact and is overlain unconfomably by the Kerri-Kerri Formation. The Arowa Formation is characterized by parasequences comprising shale and silty shale with thin intebedded sandstone showing hummocky cross-stratification passing upwards into sandstones showing low-angle cross-bedding sometimes with a feruginized sandstone layer at the top (Hamidu *et al.*, 2013b).

2.4.1.10. Duguri Formation

The Duguri Formation is a name proposed by Hamidu *et al*. (2013b) for a unit that comprises the upper part of Gombe Sandstone of previous authors and the "Red Sandstone Facies" of Zaborski *et al* (1997). Falconer(1911) used the name "Duguri Sandstones and Grits' for a reported 122 metre-thick body of strata around Duguri, which seems to be the same as that making up the type section proposed by Hamidu*et al*. (2013b). Falcorner referred it to the post-Cretaceous succession.

The Duguri Formation outcrops from north of Gaji close to the western margin of Gongola Basin south to Gudus and then northeast to Tukulma. Further isolated outcrops, earlier reported as belonging to the "bedded facies' by Zaborski *et al*. (1998), occur further to the north. The thickness of the outcropping Duguri Formation varies from place to place as consequence of both end-Maastrichtian and recent erosion. The proposed type section of Duguri Formation occurs in a roadside section and about 5km north of Gaji on the road to Dindima, it provides the best exposure of the unit especially the contact with the basement complex rocks. The top and base of the type section are located at 10^0 $10^{'}$ 45.9"N 09^0 44' 39.47"E and 09^0 44' 55.26" N 010^0 10' 54.12"E respectively. Here the Duguri Formation is about 115metres thick; it overlies the uneven surface of the basement complex rock and is overlain unconformably by the Kerri-Kerri Formation.

2.4.1.11. Kerri-Kerri Formation

The Kerri-Kerri Basin developed because of E-W extension (Benkhelil, 1986, 1988), NNE-SSW trending faults occur along its western margin and N-S trending faults to the east (Adegoke *et al.,* 1986; Zaborski *et al.,* 1998*,).* The continental Kerri-Kerri Formation reaches a thickness of over 320 m (Adegoke *et al.,* 1986; Dike, 1995). Age data is scanty but Paleocene pollens have been recovered (Adegoke *et al.,* 1978; Oloto, 1994).

The irregular topography of the unconformity surfaces that seperates the Kerri-Kerri Formation from the Tukulma Group is exposed on the nothern outskirts of Gombe town. The Tukulma Group were folded, faulted and deeply dissected prior to the deposition of Kerri-Kerri Formation. The latter shows rapid changes in thickness along the eastern margin of its outcrop due to its deposition upon an irregular topography (Zaborski *et al*.,1998).

2.5. Major structures of the Upper Benue Trough

The Upper Benue Trough includes an E-W trending Yola arm and a N-S trending Gongola arm or Gongola Basin (Fig.5). These two branches are separated by an area structurally dominated by four major NE-SW trending sinistral strike-slip faults, the Gombe, Bima-Teli, Kaltungo and Burashika faults; basement inliers, notably the Kaltungo inlier, are associated with them (Fig. 5). Benkhelil (1988, 1989) regarded this median zone as the partially exposed basement high characterizing the axis of the Benue Trough. Carter *et al*., (1963) refered to it as "Zambuk ridge". A series of N-S to NNE-SSW trending fault controls the trend of Gongola Basin (Zaborski *etal*., 1998) while deep seated E-W trending fractures appear to characterize the Yola arm (Benkhelil, 1988; Braide, 1992).

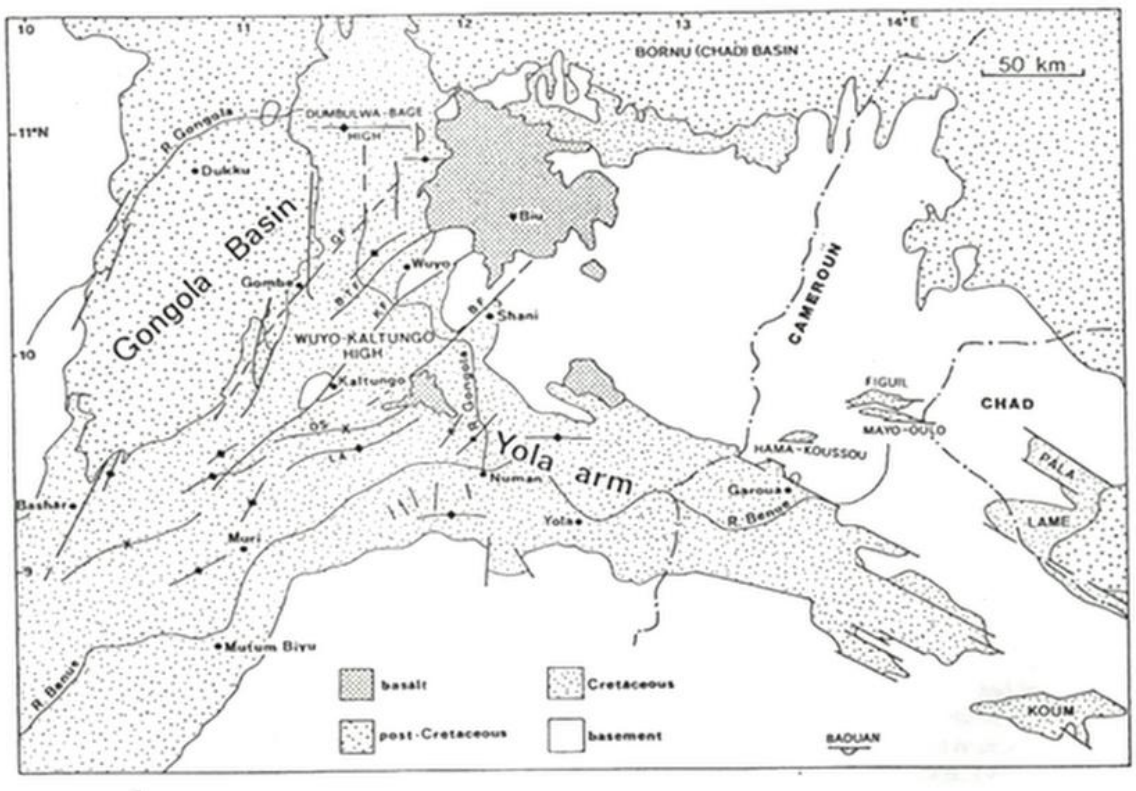


Figure 5: Outline geological map showing the main features of the Upper Benue Trough; GF, Gombe Fault; B-TF, Bima-Teli Fault; KF, Kaltungo Fault; BF, Burashika Fault; DS, Dadiya syncline; LA, Lamurde anticline (After Zaborski, 1998).

The thickest sedimentary successions occur in the western part of Gongola Basin to which Campano- Maastrichtian and Cenozoic deposits are restricted. Over 5 km of sediment occur in the "Dukku", "Akko and "Bashar" sub-basin; thinner successions occur in the "Lau" and "Numan" sub-basin of the Yola arm (Benkhelil, 1988, 1989). The Yola arm extends eastwards into Cameroun where it is known as the Garoua Basin, bounded on its eastern extremity by NW-SE trending, sinistral strike-slip faults. A number of small Barremo-Aptian, E-W trending half-grabens of transtensional origin also occur in this region (Zaborski, 1998). The Hama-Koussou, Figuil, Mayo-Oulo, Koun(Mayo Rey) and Baouan Basin, contain fluvio-lacustrine infill (Guiraud and Maurin, 1992).

CHAPTER THREE: METHODOLOGY

3.1. Field work

The fieldwork was conducted during the dry season using 1:50,000 scale topographic base map of the study area. Systematic logging technique was adopted and fourteen (14) sections were logged throughout the exercise; which involved measuring thicknesses of beds using measuring tape, studying the lithologies, and sedimentary structures associated with each bed. Boundariesof different formations within the study area were mapped and samples collected for laboratory analysis. Lithologic logs were drawn with the help of Sedlog (3.0) and Corel Photo-paint (X5) softwares.

Samples were collected systematically in order to avoid distortion of the result by weathering activities. The quantity of samples collected was about 400g on average from each lithologic unit. Information such as the sample number, the rock unit, horizon description, locality, and date of the sampling were indicated clearly on the sample bags and at the same time the relevant data was entered into the field notebook. Also, careful examinations of the nature of the surfaces separating each unit were also carried out.

The samples were collected with the aid of geological hammer and chisel. The thickness of each unit was measured using a measuring tape. The location and elevation readings were obtained using the GPS.Structures were measured with the aid of compass-clinometer. The samples were labeled and kept separately for analysis.

3.2. Laboratory sample preparation and analysis

3.2.1. Granulometric Analysis

The primary aim of sieve analysis is to determine particles size distribution and other grain size parameters like sorting, skewness, and kurtosis. A total of ten samples from Arowa Formations were selected for sieve analysis.

The samples were carefully disaggregated with the help of mortar andpestle. care was taken when disaggregating the samples to avoid crushing and grinding in order not to distort the original shape of the grains. The results from the sieve analysis are presented in tabular form.

A set of selected sieves (2.0 mm 1 mm, 500 µm, 250 µm, 125 µm, 63µm, and pan) was used for sieve analysis and 100g of each disaggregated sample was weighed usinga weighing balance. The required sieves were arranged one on top of another. The sieve with smallest opening at the bottom with an empty container (pan) below it to collects the finest grains and the top was covered with a lid.

The sieves and the bottom pan were fastened to the mechanical shaker, and 100 g of the samples poured into the upper sieve and the machine was allowed to shake for ten (10) minutes. Sediments retained by each of the sieves and the bottom pan were weighed and recorded. During the process of the sieve analysis, care was taken in the separation of the sieve to avoid the spillover of the sediments after shaking.

The cumulative frequency curves resulting from the analysis are shown in Appendix I, II, III and IV. From the cumulative frequency curves, critical percentiles (φ5, φ16, φ25, φ50 φ75 φ84 φ95) were obtained and used in the calculation of grain size parameters such as; graphic mean, sorting (graphic standard deviation), graphic skewness and graphic kurtosis; the results of these parameters for each of the samples were tabulated.

CRITICAL STATISTICAL PARAMETERS OBTAINED FROM CUMMULATIVE FREQUENCY CURVE.

$$\text{MEAN } (\mu) = \frac{\phi\,16+\phi\,50+\phi\,84}{3}$$

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

$$\text{KURTOSIS (KG)} = \frac{\phi\,95-\phi\,5}{2.44(\phi\,75-\phi\,25)}$$

$$\text{SORTING} = \frac{\phi\,84-\phi\,16}{4} + \frac{\phi\,95-\phi\,5}{6.6}$$

The statistical parameters of the grain size distribution were obtained and computed using the Krumbein and Pettijohn (1938) and Folk and Ward (1957) methods. Grain fractions were plotted against their sizes and that shows distribution range (sorting measure), symmetry parameter and least or most frequently occurring grain size range.

The bivariate plots of these parameters were plotted and compared with Friedman (1961) (Fig 6) to provide hint their depositional environment.

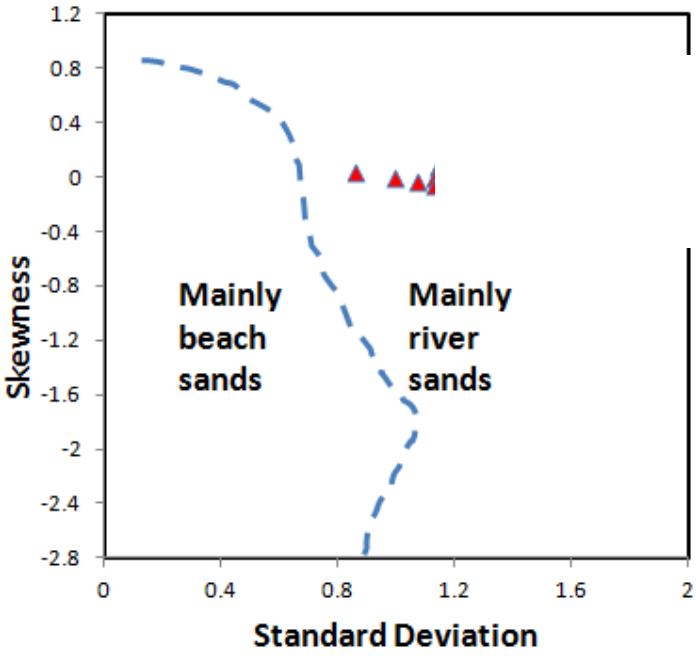


Figure 6: Bivariate Plot of Skewness versus Standard deviation (after Friedman, 1961)

3.2.2. Micropalaeontological Analysis

Micropalaeontological analysis involved washing of argillaceous samples in order to extract microfossils.

About 40g each of the samples of clays and shalesfrom Arowa and Upper Fika Formations were disaggregates using mortar and pestle and then poured into the beaker and then treated with hydrogen peroxide for about 24hours to dissolve and also to free the microfossils associated with the samples and then washed with the jet of water through a 63µm mesh sieve. After washing, the remaining residue was poured into a beaker and put in an oven to dry. The dried samples were then studied under the binocular microscope for picking and identification of the microfossils present in the samples.

CHAPTER FOUR: RESULTS

4.1. Lithostratigraphy and lithofacies

4.1.1. Lithostratigraphy

A total of 10 sections studied covered some part of Upper Fika, Arowa and lower part of the Kerri-Kerri formations (Fig.7).

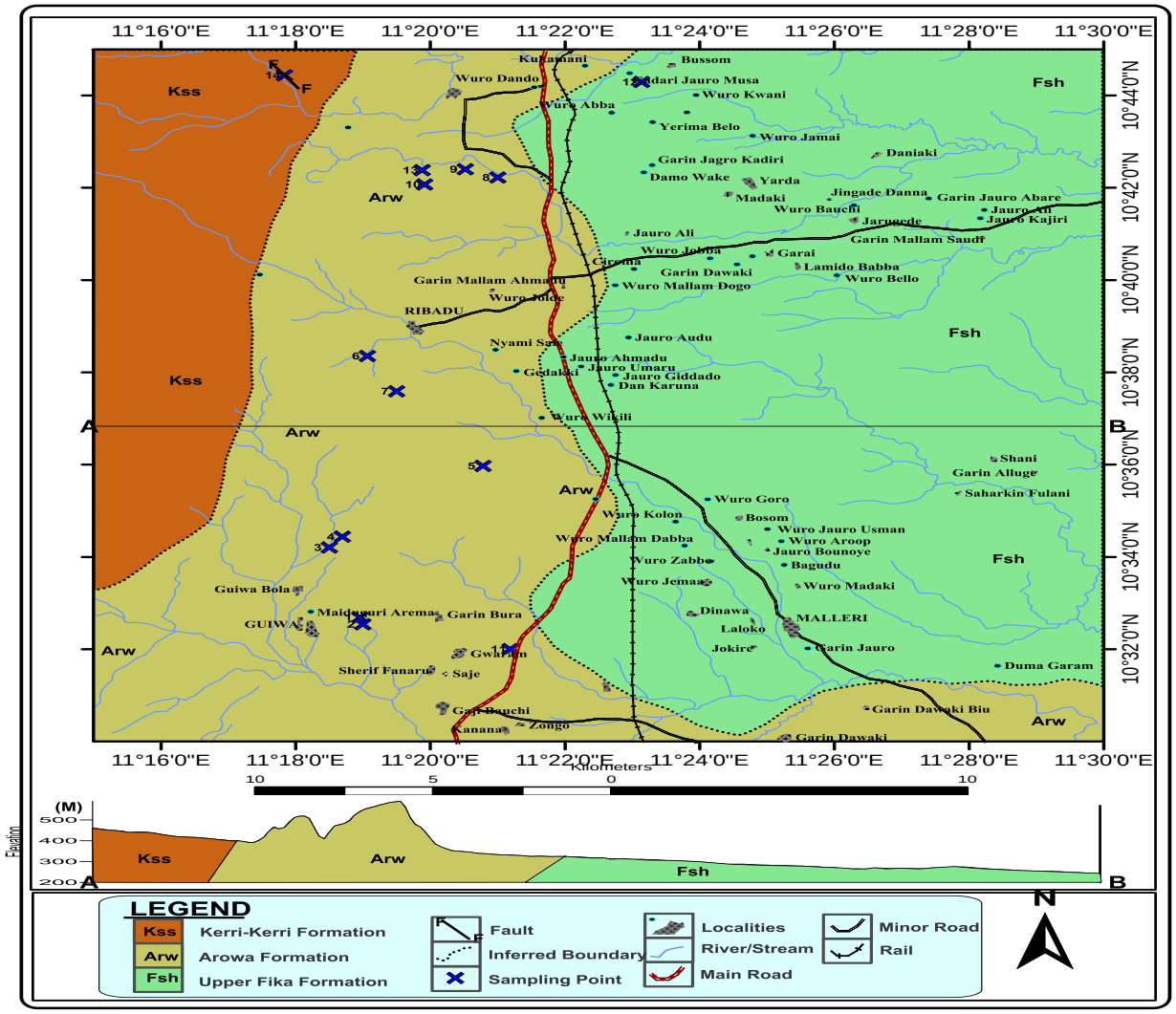


Figure 7: Geological map of the study area showing the extent and coverage of the Kerri-Kerri, Arowa and Upper Fika Formations within the study area. A cross-section A-B is also provided at the base of the map.

The upper part of the Upper Fika Formation representative section is a gypsum mining pit (about 7m) near Wuro Abba northeast of Tongo, consist of dark grey to light brown shale with some gypsum lenses at the bottom (Fig. 8).

The representative sections of the Arowa Formation in the study area occurs atGarin Bolari, Dukul, Ribado 1, Ribado 2,Tongo, Tilde, Garin Gbali, and Wuro Naraji (Figs. 9-16).

The sections are predominantly made up of fine grained sandstone varying from a few millimeters to a few centimeters in thickness associated with symmetrical and asymmetrical ripple marks, carbonaceous shale, biotubated (*Thalassinoides*) very fine grained sandstone, clays, coal seams and shales.

The Kerri-Kerri Formation in the study area is made up of massive, friable, medium grainedstone - granulestone and clay (probably Kaolin) bed sometimes associated with petrified woods (Fig. 17).

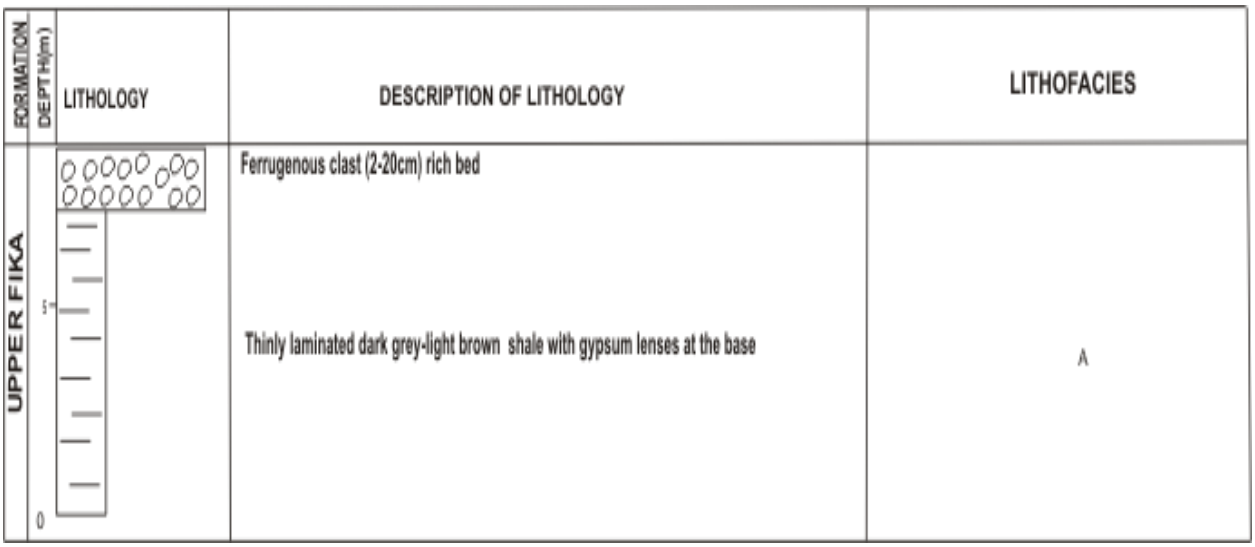


Figure 8: Lithostratigraphic section of Upper Fika Formation around Wuro Abba village. Base of

the section: (10□44□ 3.1□ □ N and11□ 24□ 17.5□ □ E)

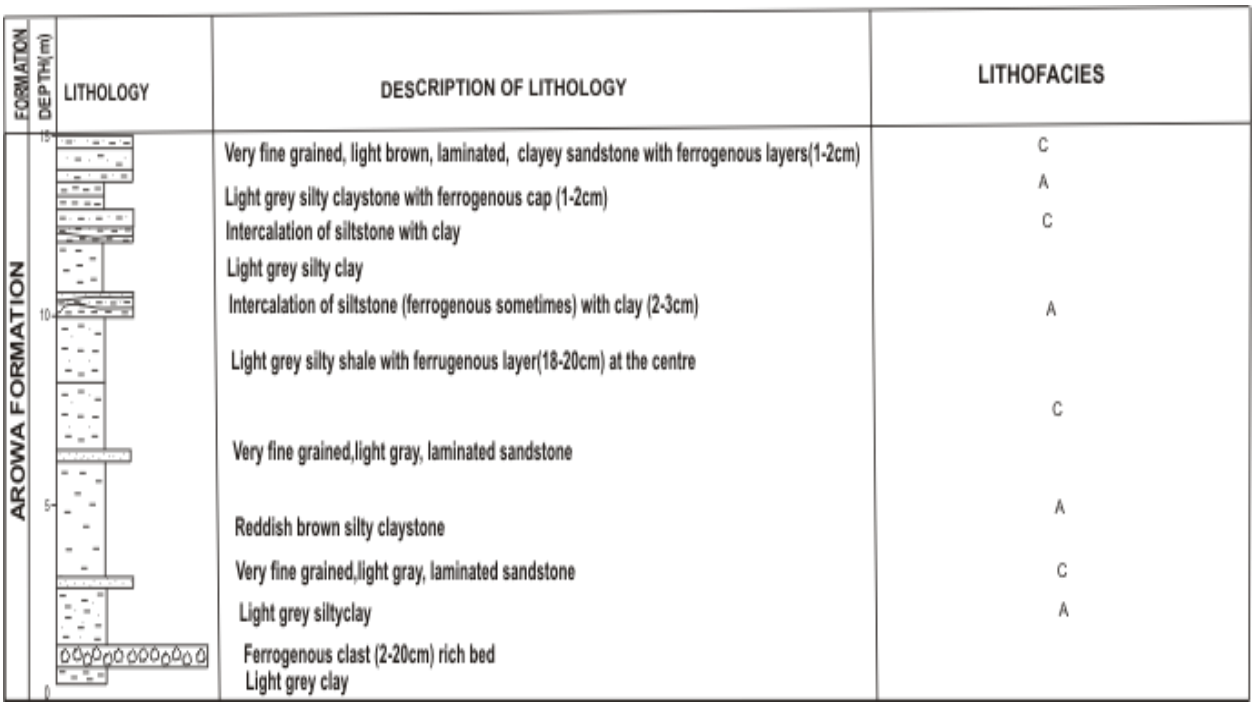


Figure 9: Lithostratigraphic section of Arowa Formations aroundGarin Bolari village. Base of the section: (10□34□ 13.2□ □N and 11□ 18□ 30.8□ □E)

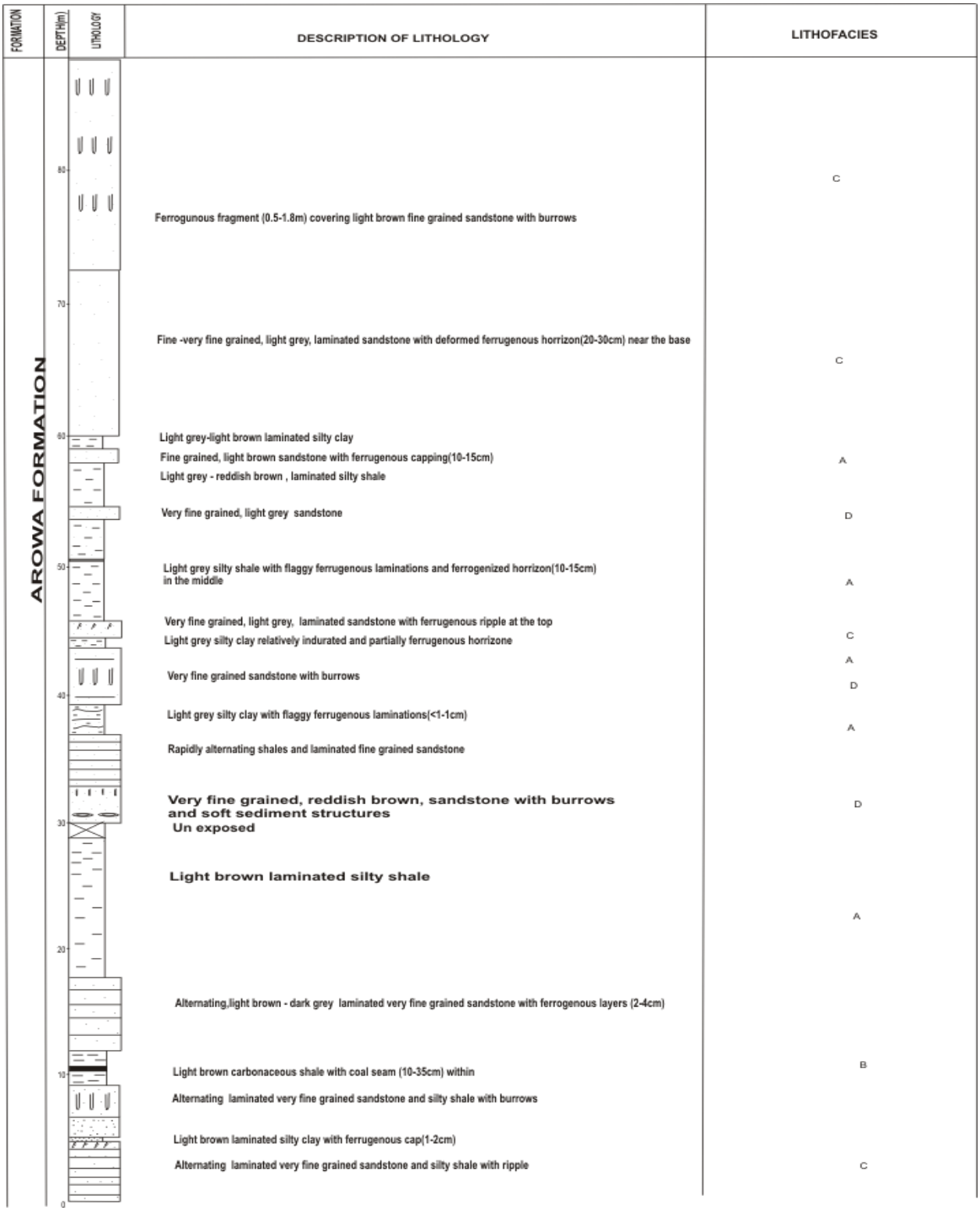


Figure 10: Lithostratigraphic section of Arowa Formation around Dukul village.Base of the section: (10□35□ 59.1□ □N and 11□ 20□ 47.8□ □E)

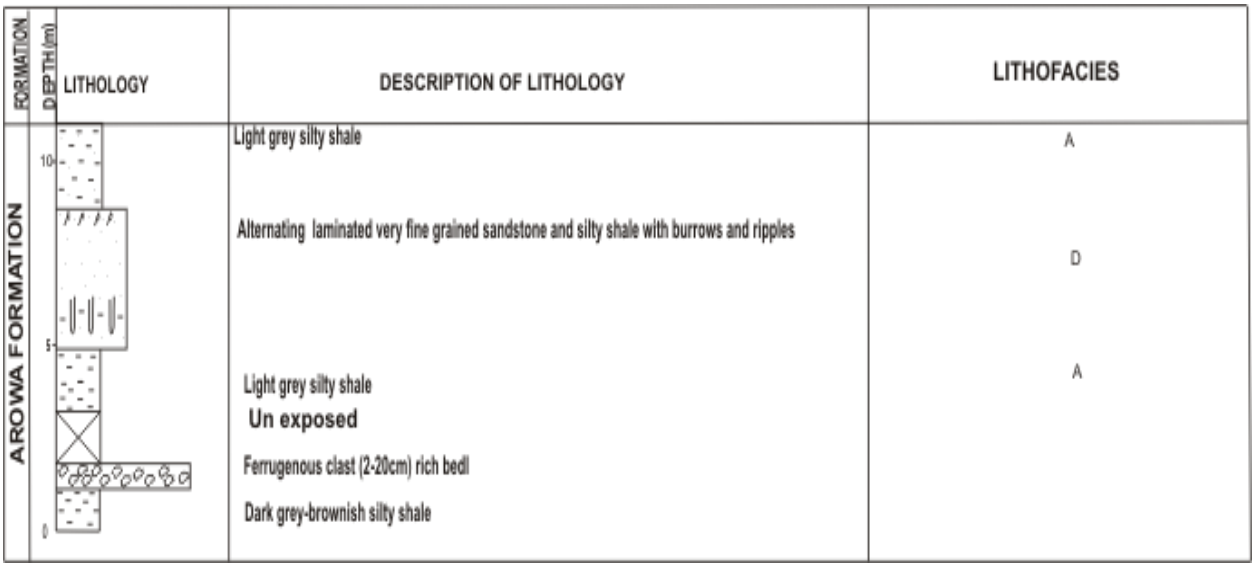


Figure 11: Lithostratigraphic section of Arowa and Upper Fika Formations aroundRibado village. Base of the section: (10□38□ 21.9□ □ N and1□ 19□ 4.7□ □E)

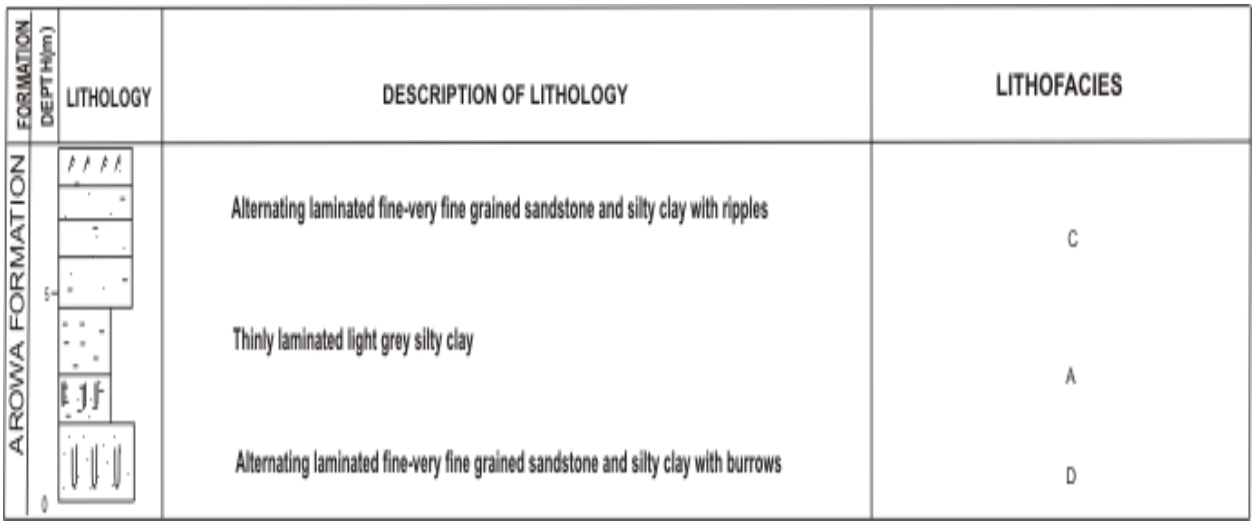


Figure 12: Lithostratigraphic section of Arowa Formation around Tongo village.Base of the section: (10□42□ 13.8□ □N and 11□ 21□ 0.98□ □E)

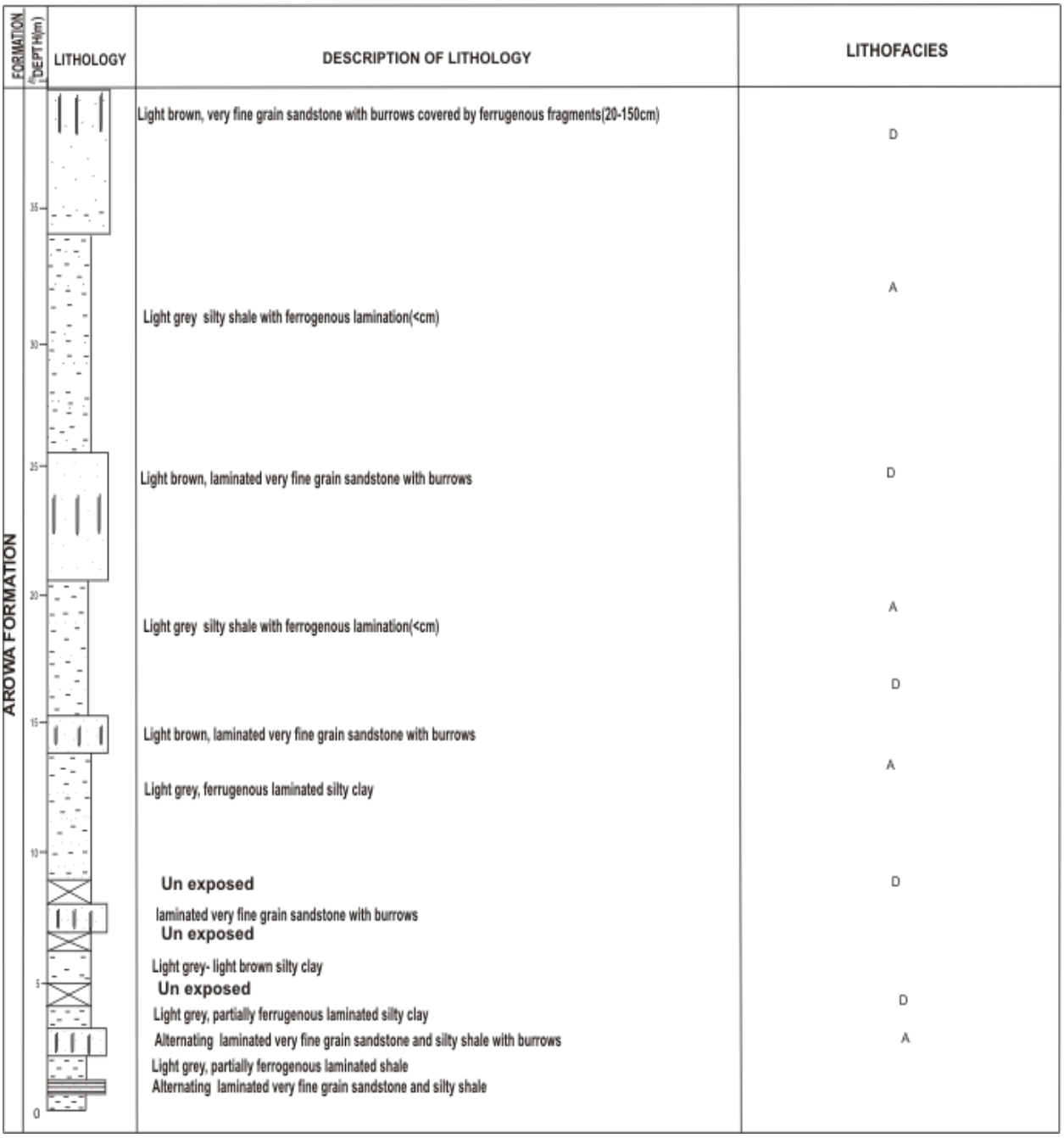


Figure13: Lithostratigraphic section of Arowa Formation around Ribado2 village.Base of the section: (10□37□ 36.1□ □N and 11□ 19□ 30.7□ □E)

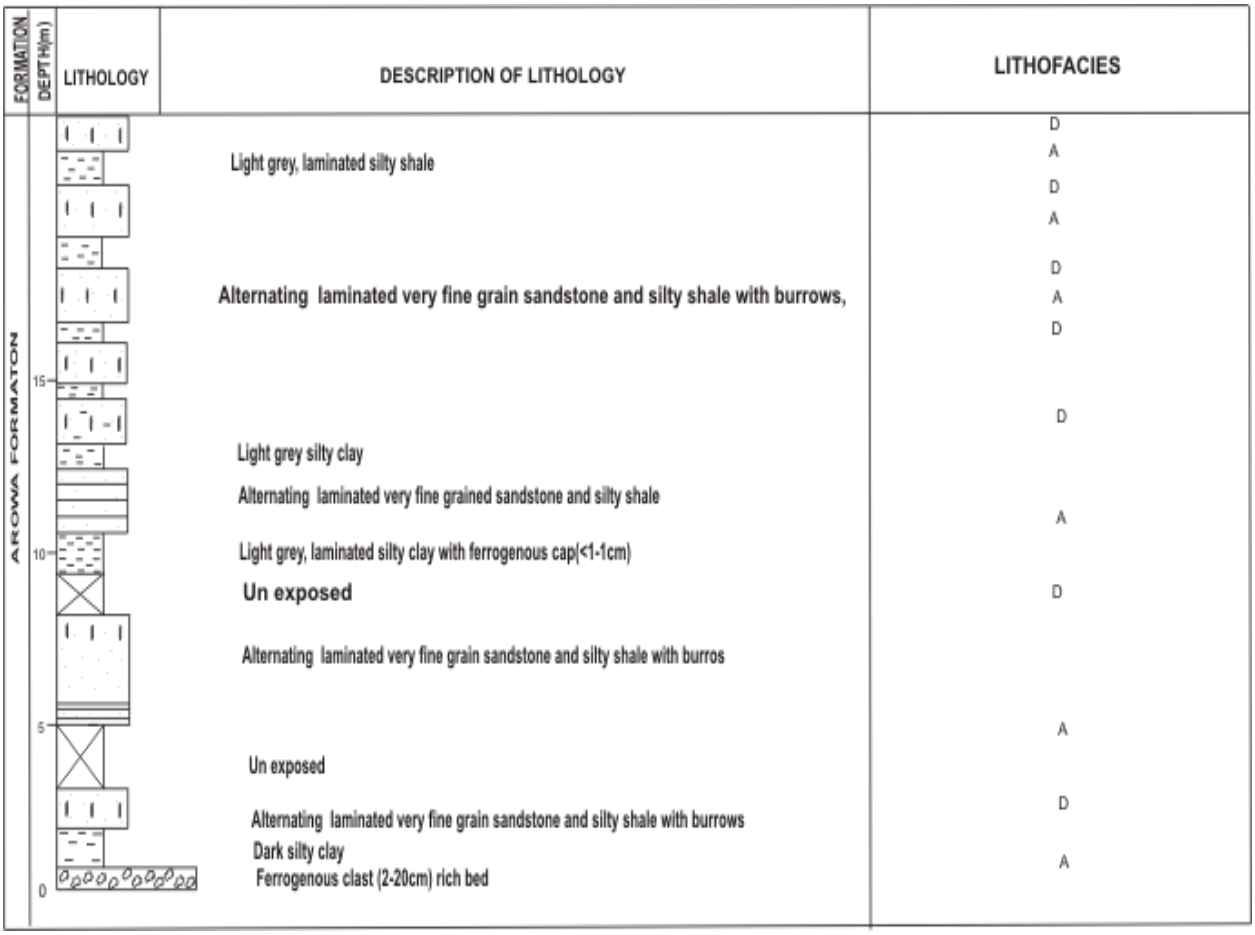


Figure14:Lithostratigraphic section of Arowa Formation around Tilde village. Base of the section: (10□42□ 24.5□ □N and 11□ 20□ 32□ □E)

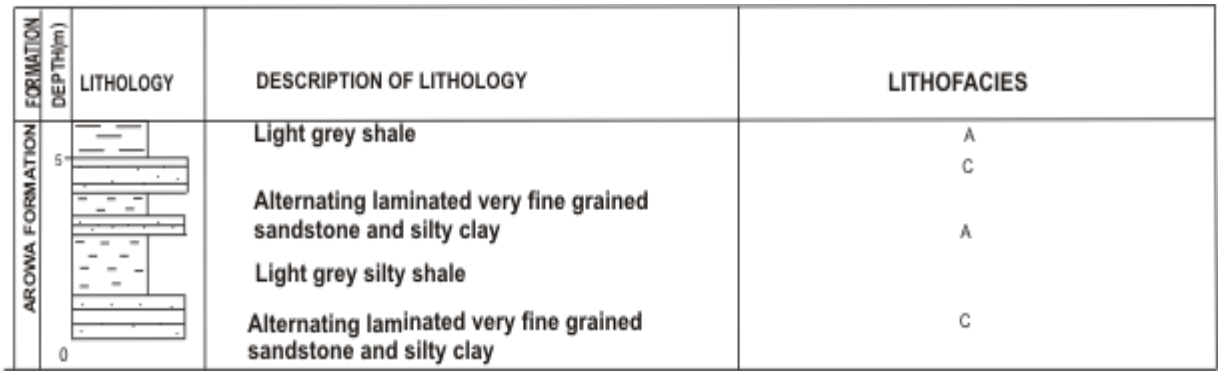


Figure15: Lithostratigraphic section of Arowa Formation around Garin Gbali village.

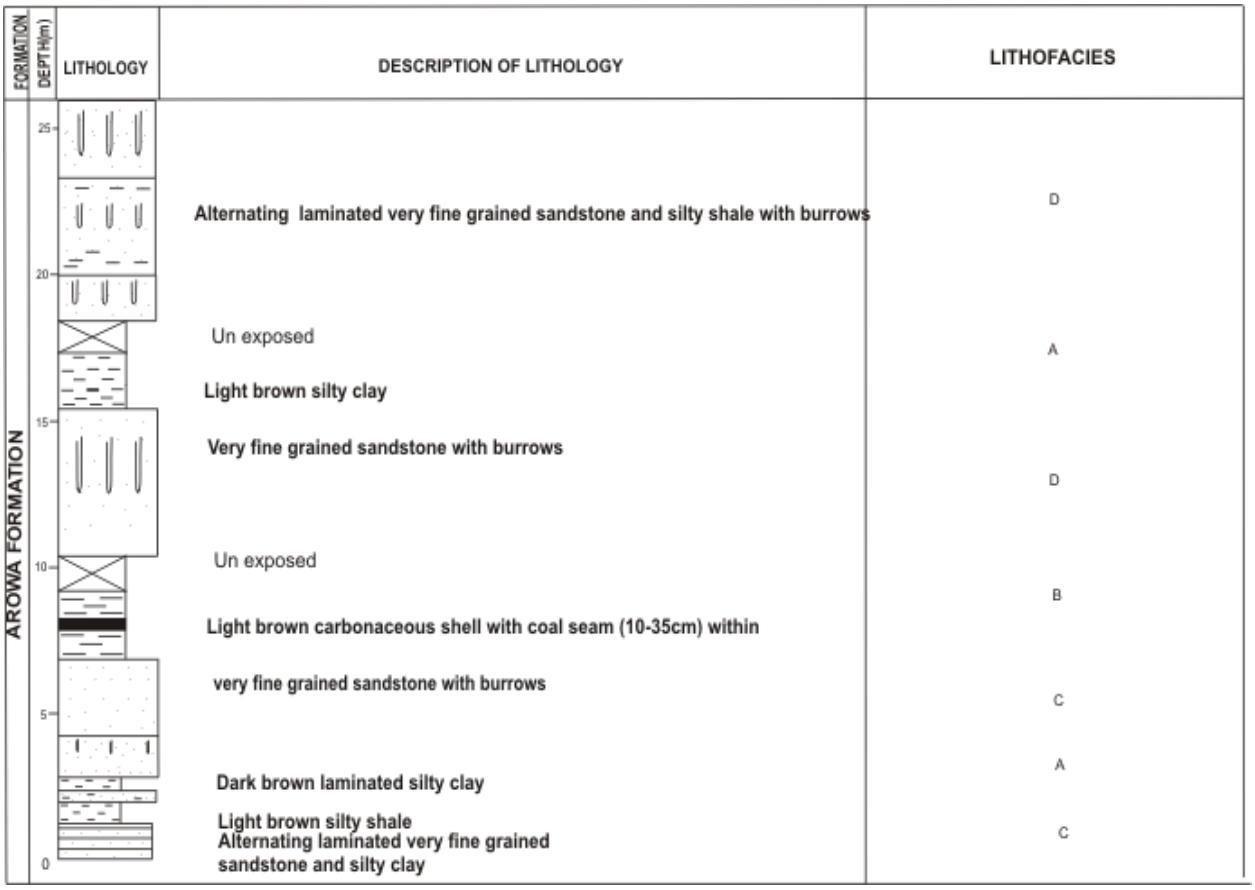


Figure16: Lithostratigraphic section of Arowa Formation around Wuro narajivillage. Base of the section: (10□42□ 4.7□ □ N and11□ 19□ 55.7□ □E)

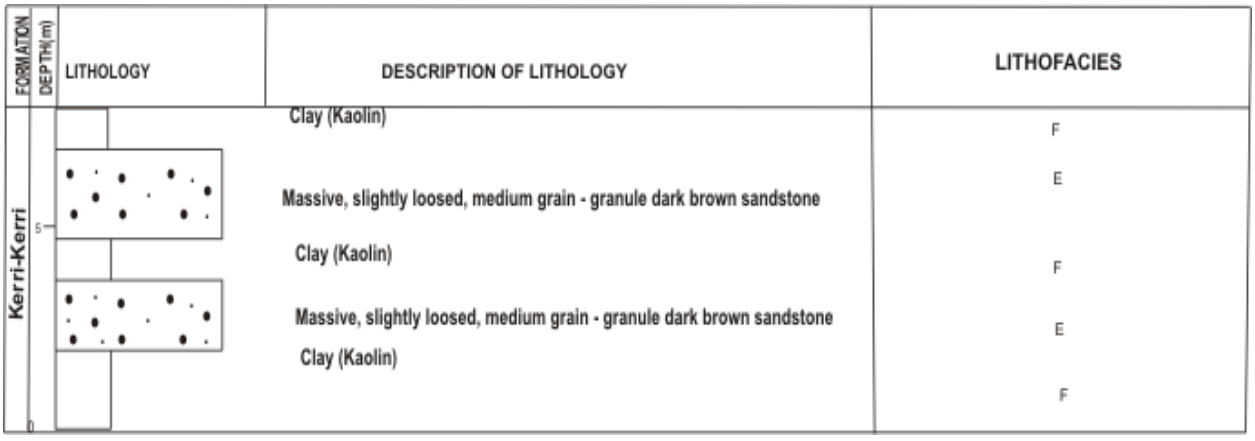


Figure17: Lithostratigraphic section of Kerri-Kerri Formations around Siddikiyo village, (N 10 □ 44□ 03.9□ □E 11□ 17□ 51.1□ □)

4.1.2. Lithofacies

A total of six lithofacies were identified with one from Upper Fika Formation, three from Arowa Formation and two from Kerri-Kerri Formation.

Lithofacies A - Massive-laminated shale range in thickness from few centimeters to few meters. It occurs both in Arowa Formation and Upper Fika Formation (plate 1a&b).



Plate 1a. “Arowa Formation” Lithofacies A around Garin Gbali village,
(N 10 □ 34□ 27.2□ □E 11□ 18□ 42.4□ □)

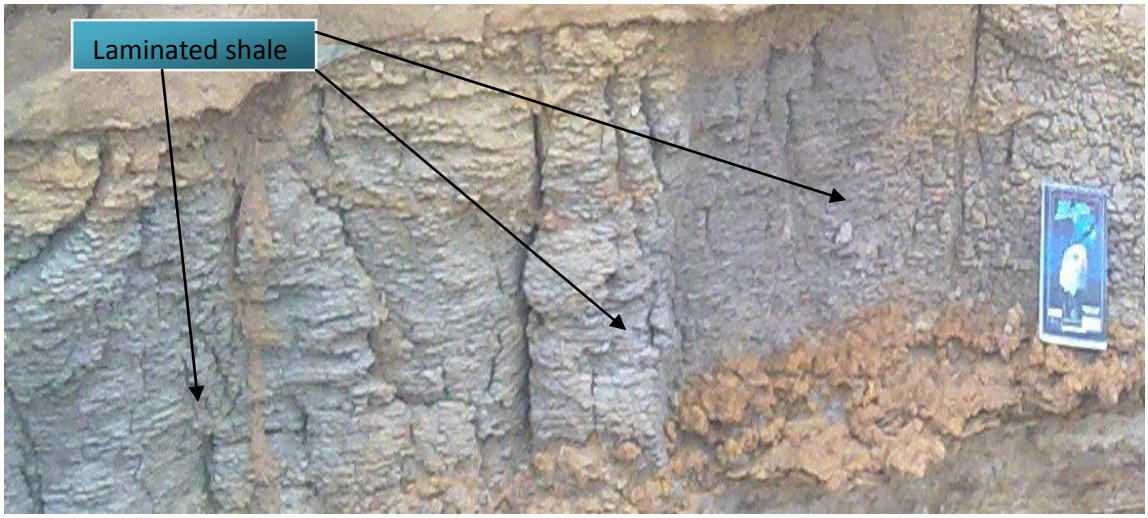


Plate 1b. “Arowa Formation” Lithofacies A around Wuro Abba village, (N 10 □ 44□ 17.8□ □

E 11□ 23□ 09.7□ □)

Lithofacies B - Carbonaceous shale, mostly with coal at the middle ranging in thickness from 0.7-1.1m while the thickness of the coal range from 0.05-0.4m. It occurs in the lower portion of Arowa Formation in the study area (plate 2).



Plate 2. “Arowa Formation” Lithofacies B around Dukul village,

(N 10 □ 35□ 59.1□ □E 11□ 20□ 47.8□ □)

Lithofacies C - Fine grained sandstone varying from few millimeters to few centimeters in thickness and associated with symmetrical and asymmetrical ripple mark. It occurs in the lower and some part of middle portion of Arowa Formation in the study area (plate 3a&b).

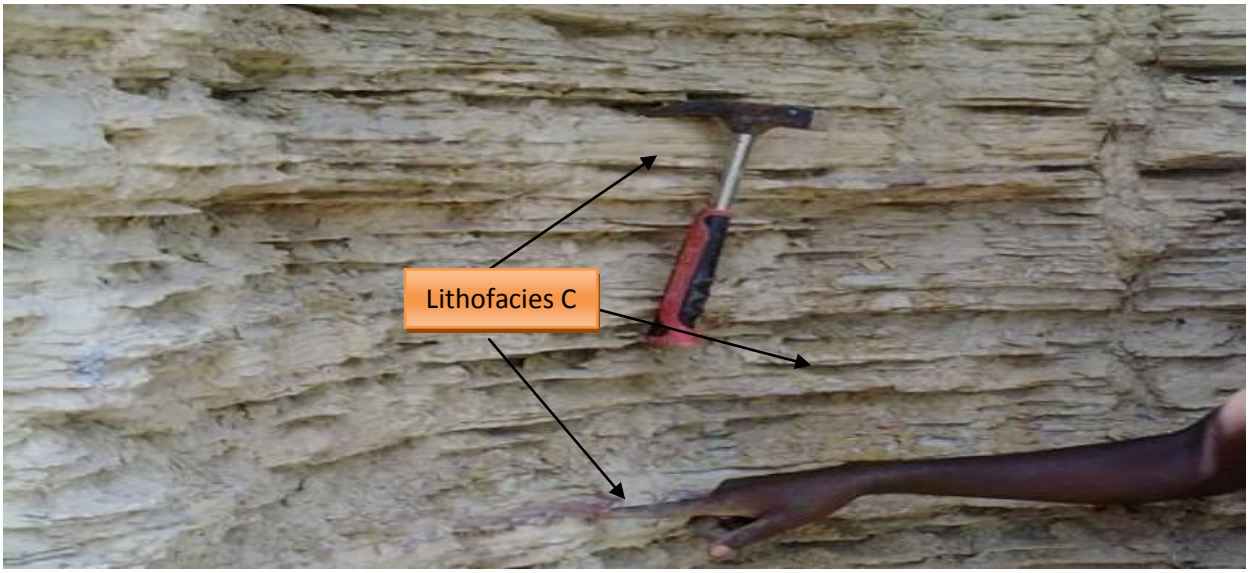


Plate 3a. "Arowa Formation" Lithofacies C around Ribado2 village, (N 10 □ 37□ 36.1□ □ E 11□ 19□ 30.7□ □)

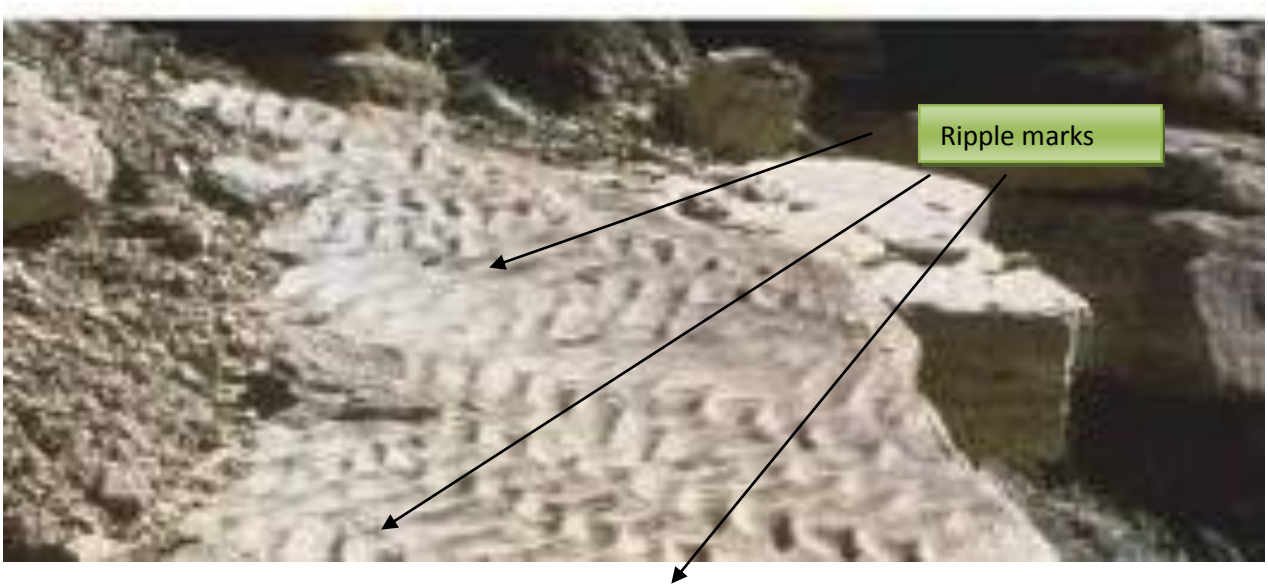


Plate 3b. "Arowa Formation" Lithofacies C around Jomari village, (N 10 □ 32□ 42.4□ □ E 11□ 18□ 58.0□ □)

Lithofacies D - Bioturbated (Thalassinoides), very fine, rarely medium grain, moderately – well sorted sandstone. It ranges in thickness from 0.4-8m. It occurs in Arowa Formation in the study area (plate 4a&b).



Plate 4a. “Arowa Formation” Lithofacies D around Guiwa village (N 10 □ 34□ 13.2□ □ E 11□ 18□30.8□ □)

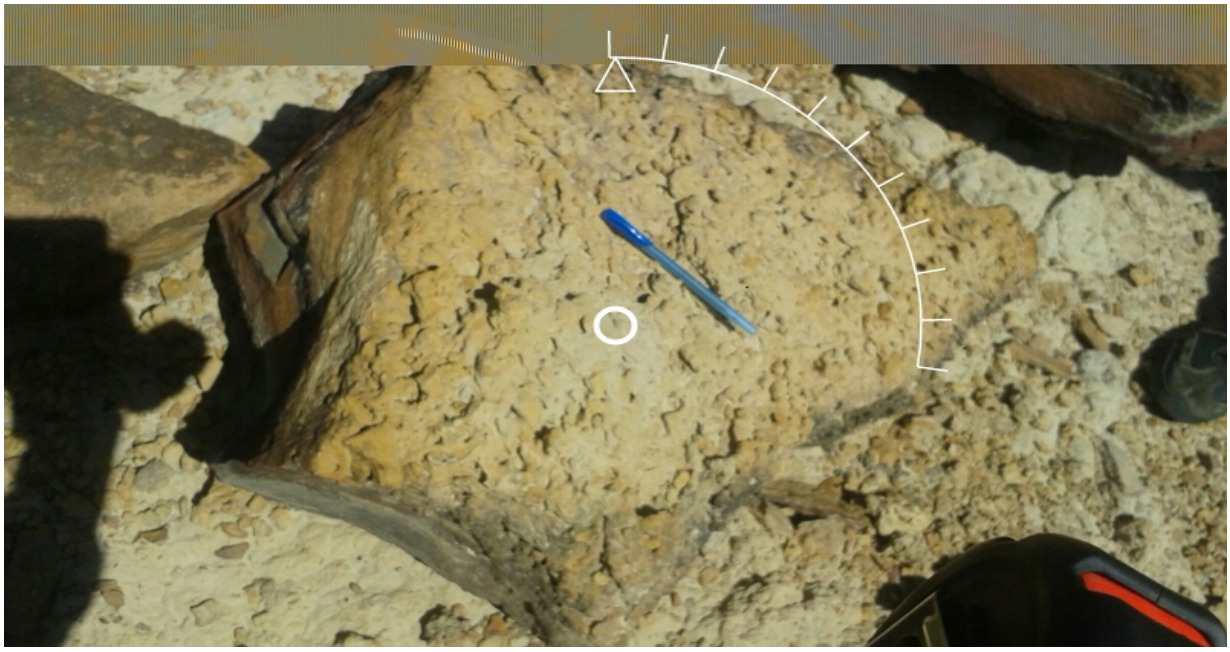


Plate 4b. “Arowa Formation” Lithofacies D around Tsakka hills (N 10 □ 42.6□ 15.2□ □ E 11□ 18□23.6□ □)

Lithofacies E - Massive, light brown, slightly loosed, medium grain – granule sandstone with bed thickness ranging from2.5m -5m. It occurs in the lower part of Kerri-Kerri Formation in the study area (plate 5a&b).



Plate 5a. “Kerri-Kerri Formation” Lithofacies E around Siddikiyo village(N 10 □ 44□ 03.9□ □

E11□ 17□ 51.1□ □)

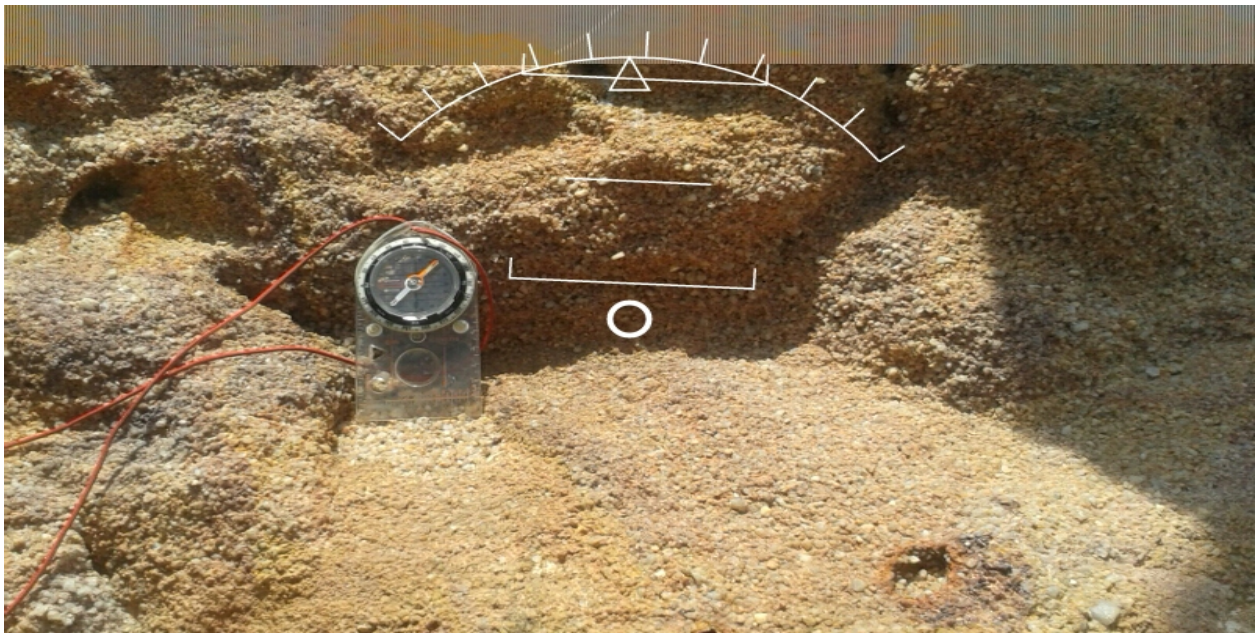


Plate 5b. “Kerri-Kerri Formation” Lithofacies E around Siddikiyo village(N 10 □ 44□ 03.9□ □

E11□ 17□ 51.1□ □)

Lithofacies F –Clay (probably kaolin) sometimes associated with petrified wood. Thickness range from 0.8-1.1m in lower part of Kerri-Kerri Formation (plate 6a&b).



Plate 6a. “Kerri-Kerri Formation” Lithofacies F around Siddikiyo village(N 10 □ 44□ 03.9□ □

E 11□ 17□ 51.1□ □)



Plate 6b. “Kerri-Kerri Formation” Lithofacies F around Siddikiyo village(N 10 □ 44□ 03.9□ □

E 11□ 17□ 51.1□ □)

4.1.3 Lithofacies associations

A total of three lithofacies associations were identified with two from Arowa Formation and one from Kerri-Kerri Formation.

Lithofacies association AC -Shale dominated interbedded fine grained sandstone varying from a few millimeters to a few centimeters in thickness with coal seamin places. Primary sedimentary structures in these interbedded sandstones are symmetrical and asymmetrical ripple marks. It occurs in lower part of Arowa Formation (plate 7).



Plate 7. “Arowa Formation” Lithofacies association AC around Tongo village

(N 10 □ 42□ 24.5□□ E11□ 20□ 32.0□ □)

Lithofacies association ABD - Bioturbated (thalassinoides), sometimes laminated very fine to fine grained, grey to light brown sandstone intercalating with dark grey shales or clay in roughly equal proportion while the sand predominate upward. There are also soft-sediment deformational features in places.It occurs in middle to upper part of Arowa Formation (plate 8).



Plate 8. “Arowa Formation”Lithofacies association ABD around Naraji village

(N 10 □ 42.6□ 15.2□ □E 11□ 18□ 23.6□ □)

Lithofacies association EF - Massive, slightly loosed, medium grain sandstone- granulestone inter-bedded with Clay (kaolin) sometimes associated with petrified wood. It occurs in Kerri-Kerri Formation (Plate 9).



Plate 9: “Kerri-Kerri Formation” Lithofacies association EF around Siddikiyo village (N 10 □ 44□ 03.9□ □E 11□ 17□ 51.1□ □)

4.2. Granulometric Studies

4.2.1. Grain size and statistical parameters

Four samples were sieved and statistical parameters of each of the sandstone samples were determined and presented in (Table.2) The cummulative curves plotted for various samples were presented in APPENDIX 1, 2 and 3. Quantitative graphical values of percentiles from various samples obtained from the cumulative frequency curve in APPENDIX 1, 2 and 3 are presented in (Table.2)

Table 2: Summary of granulometric analysis result

Parameter	Graphic mean	Graphic skewness	Graphic kurtosis	Graphic sorting
Sample L2A	3.12 Very fine grained sand	-0.14 Negatively skewed	1.52 Very leptokurtic	0.69 Moderately well sorted
Sample L4D	3.20 Very fine grained sand	-0.27 Negatively skewed	0.96 Platykurtic	0.63 Moderately well sorted
Sample L5O	3.40 Very fine grained sand	-0.17 Negatively skewed	1.59 Very leptokurtic	0.67 Moderately well sorted
Sample L6A	3.45 Very fine grained sand	-0.14 Negatively skewed	1.08 Mesokurtic	0.45 Well sorted

4.2.2. Bivariate plot

Bivariate plots were plotted for grain size parameters of the sandstone of Arowa Formation in order to determine its depositional environment. The bivariate plots of Skewness vs. Sorting (Fig.18) were compared with similar works of Friedman (1961) (Fig.6), all samples plotted fall in the beach portion.

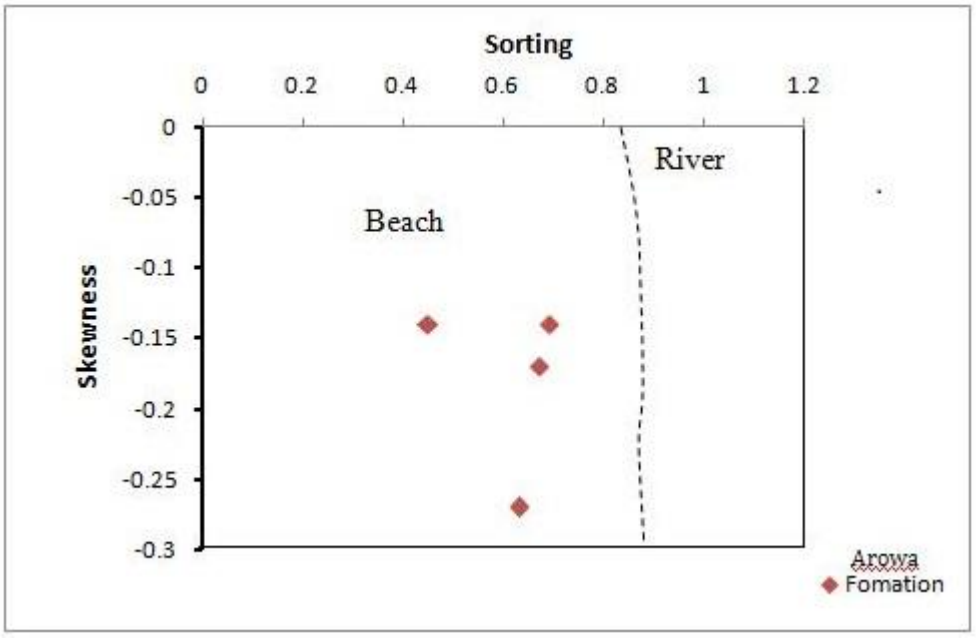


Figure 18: Bivariate plot of Skewness versus Sorting

4.3. Micropaleontology

Seven samples of shale and clay were collected from upper part of Upper Fika Formation and Arowa Formation. These samples were all washed with water and hydrogen peroxide. They were later sieved using a 63µm mesh size and dried in an oven. These samples were all subjected to thorough microscopic studies, but no microfossils were seen.

4.4. Sedimentary structures of the study area

Structures observed from Arowa Formation in the study area are mostly syn-depositional with a fault from Kerri-Kerri Formation. The syn-depositional structures are ripple marks, parallel laminations and soft sediment deformational structures.

Ripple mark: Though not too clear due to the nature of Arowa Formation in the study area, two types of ripple marks were observed (Plate 3b).

1- Symmetrical ripple mark: these were observed on some of the sandstones of Arowa Formation in the study area (Plate 3b).
2- Asymmetrical ripple marks: these were also observed on some of the sandstones of Arowa Formation in the study area (Plate 3b).

Parallel laminations: These are observed on some of the sandstones and shales of the study area (Plate 8).

Soft sediment deformational structures: these were observed in middle to upper part of Arowa Formation in the study area (Plate 12).

CHAPTER FIVE: DISCUSSION

5.1. Palaeoenvironmental Analysis

5.1.1. Facies Concept

A sedimentary facies, in this case, a lithofacies is a product of a depositional environment (Selly, 1978). Moddleton (1978) stated that, "it is understood that (facies) will ultimately be given an environmental interpretation" and the key to the interpretation of facies is to combine observations made on their spatial relations (associations) and internal characteristics (lithology and sedimentary structures) with comparative information from other well studied stratigraphic units and particularly from the studies of modern sedimentary environments (de Raaf *et al*., 1965).

Walther's law of facies succession states that "The various deposits of the same facies area and similarly the sum of the rocks of different facies areas were formed baside each other in space, but in crustal profile we see them lying on top of each other". This law therefore, suggests that in a vertical sequence, a gradational transition from one facies to another implies that the two facies represent environment that ones were adjacent laterally. Many facies defined in the field, however, have ambiguous interpretation (a cross-bedded sandstone facies could be formed in a meandering or braided river, a tidal channel, an offshore area dominated by tidal currents). The best method of interpretation, therefore, would be to analyze all of the facies communally, in context (as sequence). In other words, to properly interpret identified facies, the facies sequence (fining upward or coarsening upward) have to be identified. The sequence in which they occur, thus contributes as much information as the facies themselves.

One lithofacies was identified from Upper Fika Formation, four from Arowa and two from Kerri-Kerri Formation in the study area.

5.1.2. Lithofacies and interpretation of depositional environments in the study area

5.1.2.1. Upper Fika Formation

The Upper Fika Formation though about 7m in thickness occurs in gypsum mining pit in the study area, was confirmed by the presence of abundant gypsum. Hamidu *et al.* (2013a) described some part of the Upper Fika Formation as gypsum-rich and gypsum-rich shale has not been reported from lower part of Gombe Formation [=Arowa Formation (Hamidu *et al*., 2013b)]. The Upper Fika Formation in the study area is made up of laminateddark gray shale (facies A) with lenses of gypsum at the base of the section.

Laminated shale is a deposit of low-energy environment, and predominance of it with rare coarser-grained sedimentts suggest areas that received no or minimal sand (Kati and Piret, 2009). The gypsum layers in shale of Upper Fika Formation do not indicate restricted set-up (lagoon) where evaporites are deposited, as often interpreted, but merely reflect post-depositional diagenesis and gypsum mineralization (Abubakar, 2006). The dark gray color of the shale indicates a low oxygen environment. From its geologic context we know it was relatively deep water, quiet, marine basin thus a prodeltaic depositional environment is proposed for the Upper Fika Formation in the study area (cf. Hamidu *et al*., 2013b).

5.1.2.2. Arowa Formation

The Arowa Formation in the study area consists of massive-laminated shale (lithofacies A) carbonaceous shale sometimes associated with coal (lithofacies B), fine-grained sandstone varying from few millimeters to few centimeters in thickness (lithofacies C), and bioturbated(thalassinoides), very fine, rarely medium grained sandstone, moderately – well but occasionally poorly sorted (lithofacies D).

Coal forming environment can be either marine-connected or fresh water connected. Marine connected are persistently low areas such as lagoon or submarine inter-distributary depressions were terrestrial or marine plant debris can accumulate, and where water in circulation is restricted resulting in low dissolved oxygen content . Some deltaic environment may have high concentration of sedimentary organic matter (swamps, tidal flat, marshes, lagoons and bay fills), which create oxygen-poor pore-water environments (Harringshaw *et al*., 2010).

Interdistributary areas of delta plain are composed of (i) swamps, supporting a woody vegetation, which pass seaward into (ii) marshes supporting non-woody plants such as grasses, reeds and rushes, that can be differentiated, in humid region such as in the Mississipi delta, into fresh, brackish and saline as the shore line is approached (Gould, 1970). (iii) Enclosed or partially enclosed water bodies which are quite or even stagnant except for locally generated wind-wave. In the lower delta the water bodies include lakes, lagoons, estuaries and bays with some access to the sea. All these water bodies are shallow, yet the energy level is low and clay, silt and fine sand predominate.

The coal in the study area mostly occur associated with the carbonacous shale which are both associated with fine-very fine grained, parallel laminatedsandstone intercalated with clay or shale, sometimes bioturbated sandstone which may be interdistributary areas of delta plain.

Arowa Formation in the study area is slightly bioturbated with some few places being highly bioturbated. Bioturbation, lenticular bedding and wavy ripple suggest tidal influence (Dalrymple and Choi 2007). Bioturbation is slight because of rapid deposition but more intense when sedimentation rate decrease temporarily (Reading, 2009). Bioturbation concentrated at the bed tops suggest post storm colonization by trace makers (Pemberton *et*

al., 2001). The presence of bioturbaion in the Arowa Formation of the study area may indicate tidal influence in Arowa Formation and may be associated with interdistributary channels, a common feature of delta plain.

Planar or horizontal lamination is a structure typically interpreted by low density flow (Kneller and Buckee, 2000). Finer grained sediments are mostly deposited from suspension or by low energy medium which is also characteristic of sub-environment in lower delta plain. Arowa Formation in the study area is characterized by parallel lamination and fine grain sediments ranging from very fine grained sandstone to shale. Thus, a low energy environment of deposition can be suggested (probably lower to upper delta plain).

5.1.3. Lithofacies sequence and lithofacies associations of the Arowa Formation

The Arowa Formation in the study area is predominantly made up of repetitive coarsening-upwards cycles, each typically some 5m to 10m thickwith a general coarsening-upward sequence (cf. Hamidu *et al.*, 2013b) (Fig. 9). Small scale sequences result from differential subsidence on the delta plain, lacustrine delta formation, crevassing of distributary channels and migration of tidal channel (Tesson *et al.*, 1993). The smallest scale sequence is confine to the delta plain (Reading, 2009). Thus the presence of small scale sequence in Arowa Formation (Fig.14) of the study area may probably be indicating delta plain depositional environment for the Arowa Formation in the study area.

The lithofacies of Arowa Formation in the study area resemble delta plain deposit from Than Formation of the Early Cretaceous Saurashtra basin, Gujarat, Western India (Aslam, 1992).

The Than Formation consists of an interbedded assemblage of sandstone, claystone, carbonaceous shale, and coal facies. Small-scale crossbedded and laminated

mudstone/siltstone facies are considered to have formed by down-current migration of small-scale subaqueous bedforms and overbank deposits of distributary channels. The planar and trough crossbedded sandstone lithofacies formed by migration of sand dunes and transverse bars in distributary channels. Laminated to ripple-laminated siltstone facies with or without coaly stringers, alternate with fine clastics, are suggestive of flood deposits and abandoned interchannel plain of delta distributaries. The muddy carbonaceous shale facies represents deposition largely in low-lying interchannel plains and backswamps. Peat coal facies are interpreted as in-situ deposits in quiet-water conditions of sedimentation across a lake.

The character of Arowa Formation in the study area may reflect, to some degree, shoaling waters. The coarsening-upward cycle may be a delta cycle generated by gradual progradation of delta into shallow marine water while the Upper Fika Formation in the study area may be pro-delta shale deposited from suspension in quite water below the wave base. Periodically the pro-delta was invaded by turbidity flow descending from the delta margin area bringing in fine sand and displaced shelly debris so the pro-delta shale ultimately gave way to delta plain sand. Progressive shoaling of the water lead to change in bedding thickness from shale dominated to sandstone dominated.

The shoaling of the water may be related to regression (cf Hamidu *et al*., 2013b). Regression involves encroachment of the sea, a result of arrested or very slow subsidence accompanied by active sedimentation.

5.1.4. Channel filling sandstone within Arowa Formation

At the lower part of Arowa Formation in the study area, an intraformational conglomerate with clast of ferruginous sandstone was observed as reported by Hamidu *et al*. (2013b). In the study area, it ranges in thickness from 0.6 to 1.1m. Though not overlaying

trough and tabular cross bedded sandstone as reported by Hamidu *et al*. (2013b), in the study area it is found overlaying either silty clay or silty shale.

The channel-filling may be the result of rip-currents which comprise, narrow, high velocity, storm-generated seaward-directed currents, while the clasts of ferruginous sandstones were derived from the enclosing coarsening-upwards cycles as suggested byHamidu *et al*. (2013b). The cross bedded sandstone may have not been deposited in the study area, or was eroded during or before deposition of the intraformational conglomerate (Plate 10).



Plate 10. Picture showing channel-filling sandstone around Maiduguri village

(N 10 □ 32□42.4□□ E 11□ 18□ 58□ □)

The top of the Arowa Formation in the study area is marked by highly fragmented, very coars, trough cross bedded, ferruginous boulders of sandstone (sizes ranges from 0.4-2m) which probably is the Duguri Formation (plate 11).



Plate 11: Boulder fragments (Duguri Formation) marking top of Arowa Formation around Tongo village (N 10 □ 42□ 24.5□ □E 11□ 20□ 32.0□ □)

5.1.2.3. Kerri-Kerri Formation

Kerri-Kerri Formation occurs in the northwestern part of the study area (Fig.7). The Formation is characterized by lithofacies association EF (Plate 9) which consists of massive, friable, medium grained sandstone - granulestonebedded with clay (kaolin) sometimes the clay is associated with petrified wood.

The great range of sizes of constituents materials, poor sorting, sharp boundaries, and unstratified nature of the sandstone point to alluvial fan deposit. According to Pryer and Glass (1961), kaolin is a dominant deposit of fluvial environment. The nature of the sandstone and the presence of clay (kaolin) suggest a continental environment for Kerri-Kerri Formation in the study area (cf. Dike, 1995). A NW-SE fault occurs around Siddikiyo village which suggest continuity of tectonic instability during or after deposition of Kerri-Kerri Formation in the study area at least in this part of the basin (Plate 9).

5.2. Univariate grain size parameters

5.2.1. Graphic mean

The samples analyzed are very fine grained sand. The average size is generally controlled by the strength of the depositing current, the initial grain size and source of material (Folk andWard, 1957; Pettijohn *et al.*, 1964). That isparticles are segregated according to theirhydrodynamic behavior which depends on size,specific gravity and shape.

The value of the graphic mean from the study area shows that the samples (Table2) range from 3.12φ to 3.45 φ i.e. very fine grained sands, with an average of 3.30φ. This indicates low energy depositional environment which may be delta plain.

5.2.2. Inclusive Graphic Standard Deviation (Sorting)

The degree of sorting in sandstones generally depends on the sediment source, grain size and the depositional regime. It is indicative of hydrodynamic condition (i.e. range of velocities and degree of turbidity) operating within the transporting medium and to some extent; it is suggestive of the distance traveled (Krumbein and Sloss, 1963). The value of the standard deviation of samples from the study area show that the samples are moderately-well sorted (Table2).

5.2.3. Graphic skewness

It is the measure of the symmetry or bias in the grain size distribution towards the coarser or finer-grained end of the size range and it is a very useful descriptive term for the depositional processes of the sediments. Positively skewed samples has an excess of coarse grains, negatively skewed sample have an excess of fine grains.

The samples analyzed have skewness values ranging from -0.14 to -0.27 which are all negatively skewed (Table2). This is also suggesting a deposition under low energy condition for the sandstone in the study area.

5.2.4. Graphic kurtosis

Kurtosis is the measure of the flatness of grain size distribution as it will appear on the simple frequency curve. Flat distributions are platykurtic and peaked distributions are leptokurtic.

The various samples analyzed (Table 2) range from very platykurtic to mesokurtic. Little geological information can be derived from the value of kurtosis (Pettijohn *et al.,* 1964).

5.2.5.Bivariate plot

From the bivariate plot of Skewness vs. Sorting (Fig.18)all the samples plotted are indicative of beach deposit (cf. Hamidu *et al*., 2013b) which may also be pointing to deltaic depositional environment for sandstones of Arowa Formation of the study area.

5.3. Sedimentary structures of the study area

Syn-depositonal structures are the most observed structures from Arowa Formation in the study area. These are visible features within sedimentary rocks that are formed at the time of deposition and represent manifestations of the physical and biological processes that operated in depositional environment.

5.3.1. Soft sediment deformational structures in the study area.

Soft sediment structures include a wide range of sediment deformation under a large variety of mechanical behaviour (Allen, 1982). They may be due to gravitationally unstable conditions, fluid flows, earthquake or other factors (Allen, 1982; Owen, 1987). Water-escape

structures and soft-sediment deformation are associated with sediment instabilities (Postma, 1983; Steen and Andresen, 1997), but the issue of the triggering mechanisms for such deformation is still debated. In some cases, deformation has been interpreted to have been triggered by earthquakes (Chapron *et al*., 1999), which are widely recognized as one of the most effective triggering mechanisms for soft-sediment deformation (Leeder, 1987; Moretti *et al*., 2002; Onasch and Kahle, 2002; Montenat *et al*., 2007; Obermeier, 2009).

Estimation of the magnitude required to produce soft-sediment deformation has been attempted and a threshold Magnitude of 5.0 has been proposed (Leeder, 1987; Obermeier and Pond, 1999; Wheeler, 2002), but few examples exist of historical slide deposits and triggering earthquakes (Piper *et al*., 1999; Locat and Lee, 2002). Fluid flows have also been identified as responsible for softsediment deformation (Lowe, 1976; Mandl and Crans, 1981; Mourgues and Cobbold, 2003). However, recognition of mechanisms able to produce soft-sediment deformation remains a central issue (Moretti and Sabato, 2007; Owen and Moretti, 2008; Mc Calpin, 2009). In particular, the criteria used to distinguish seismic from nonseismic soft-sediment deformation need to be better defined (Wheeler, 2002).

North and south of Gombe major N-S and NW-SE trending faults affected the outcrop of Gombe Sandstone [Arowa Formation of Hamidu *et al.*, 2013b = part of it], the later features being associated with syn-sedimentary deformation (Zarborski *et al*., 1998).

The soft sediment deformational structure in the study area may be as a result of the tectonic activities that affected the outcrop of Gombe Sandstone. This indicate tectonically unstable environment during deposition of Arowa Formation in the study area.



Plate 12: Soft sediment deformational structure within Arowa Formation around Dukul village N 10 □ 35□ 59.1□□ E 11□ 20□ 47.8□ □

5.3.2. Planar or horizontal lamination

Planar or horizontal lamination is a structure typically interpreted by low density flow (Kneller and Buckee, 2000). Planar lamination is formed whenever there is a planar bed surface with particles raining down from above, from a fluid that is not moving fast enough to transport the particles once they land, provided only that the nature of the sediment that is raining out fluctuates in one or more ways with time. Such planar lamination is usually found in fine sediments-muds and silts for the obvious reason that it is not easy to imagine scenarios in which sediment with substantial fall velocities can be carried for long distances by near-bed currents too weak to transport that sediment as bed load (Allen, 1984).

Some parts of the study area are characterized by parallel lamination (plate 8) thus, a low energy environment of deposition may be suggested (probably a delta plain).

5.3.3. Ripple mark

Ripple marks are characteristic of shallow water deposition (Allen, 1968). They are caused by waves or winds piling up the sediment into long ridges. Symmetrical ripples form when the water moves back and forth while asymmetrical formed when wave or wind flow in one direction. The presence of ripple marks in the lower part of Arowa Formation in the study area may be pointing to shallowing of the depositional environment from prodeltaic to delta plain.

CHAPTER SIX: SUMMARY, CONCLUSIONS AND COTRIBUTIONS TO KNOWLEDGE

6.1. Summary

The study area is made up of Campanian to Palaeocene sedimentary succession. The Upper Fika Formation is made up of laminated shale with lenses of gypsum with no marine microfossil observed.

The Arowa Formation is the dominant formation in the study area and is made up of a small scale repetitive coarsening upward cycles with a coal seam at lower part below the soft sediment deformational structures. Three (3) lithofacies and two (2) lithofacies associations were observed from the Arowa Formation in the study area. The lower part is shale dominated intercalating with sandstone and the sandstone proportion increases upward to sandstone dominated upper part.

The Palaeocene Kerri-Kerri Formation in the study area is made-up of massive, slightly loosed, medium grained sandstone - granulestoneinterbedded with clay (kaolin) which is sometimes associated with petrified wood and a NW-SE trending fault.

6.2. Conclusions

The general coarsening-upwards natureof the Arowa Formation, its facies distribution, the presence of coal and the non-recovery of marine microfossils in the uppermost Upper Fika Formation in the study area point to a deltaic depositional environment and probably tidally influenced.

6.3 Contributions to knowledge

Through this research, a coal bed has been discovered and was stratigraphically positioned at lower part of Arowa Formation below the soft sediment deformational strcture, three (3) lithofacies and two (2) lithofacies associations were observed from the Arowa Formation in the study area. An updated geologic map of the area has been produced, two (2) lithofacies and one(1) lithofacies association, and a NW-SE trending fault has been discovered in Kerri-Kerri Formation.

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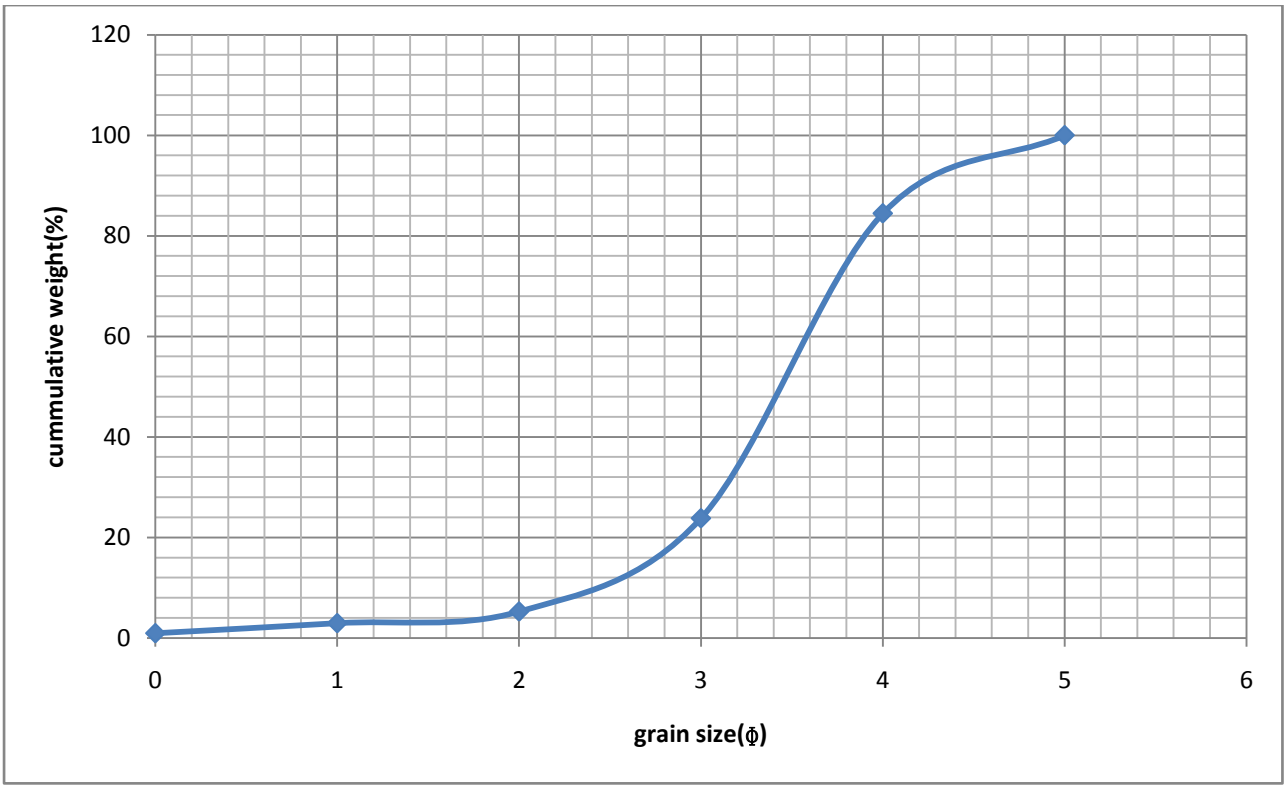
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APPENDIX I

Table 3 sample L2A

Phi(Φ) scale	Sieve size(mm)	Weight of sample (g)	% Weight of sample	Cumulative weight (%)
0	1	1.00	1.00	1.00

1	0.5	2.00	2.00	3.00
2	0.25	2.30	2.31	5.31
3	0.125	18.50	18.54	23.85
4	0.063	60.50	60.62	84.47
5	<0.063	15.5	15.53	100.00
Total		98.80	100.00	

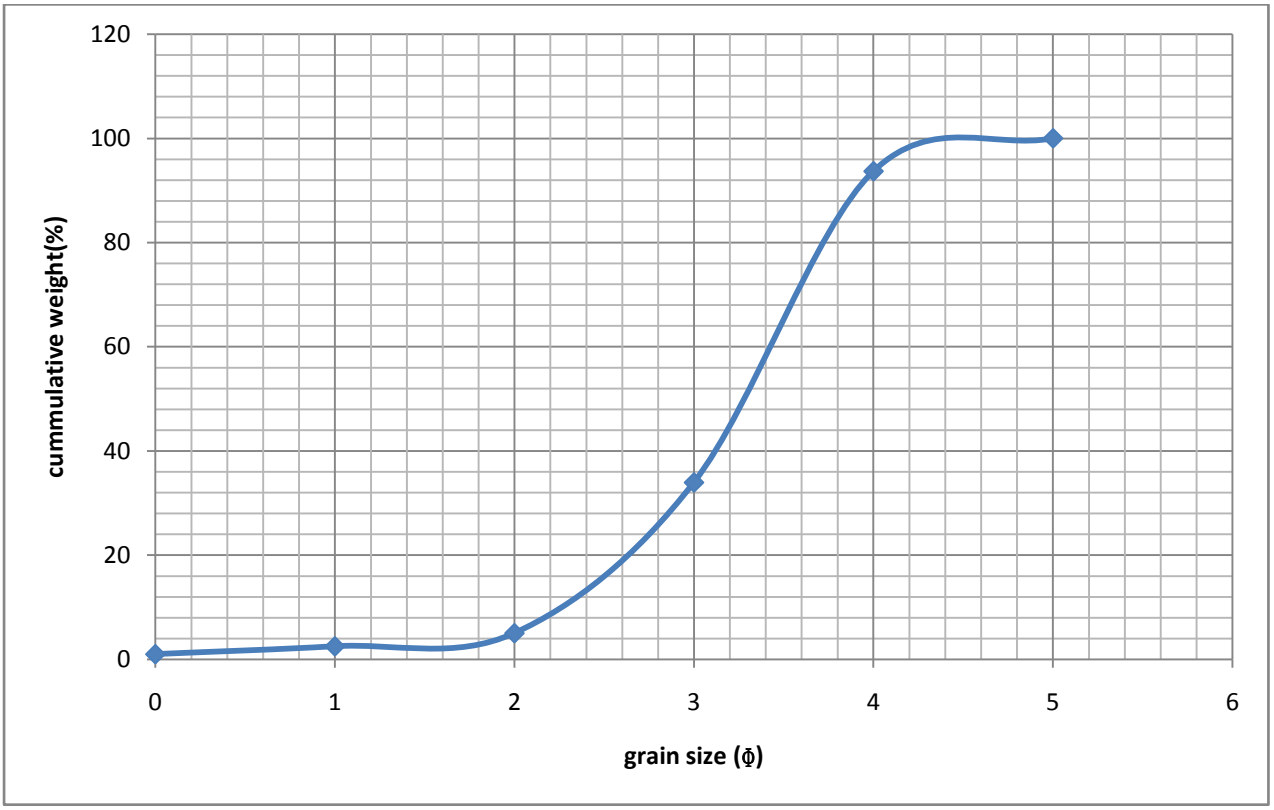


APPENDIX II

Table 4 sampleL4D

Phi(Φ) scale	Sieve size(mm)	Weight of sample (g)	% Weight of sample	Cumulative weight (%)

0	1	1.00	1.00	1.00
1	0.5	1.50	1.51	2.51
2	0.25	2.50	2.52	5.03
3	0.125	28.80	28.92	33.95
4	0.063	59.50	59.73	93.68
5	<0.063	6.30	6.32	100.00
Total		99.60		

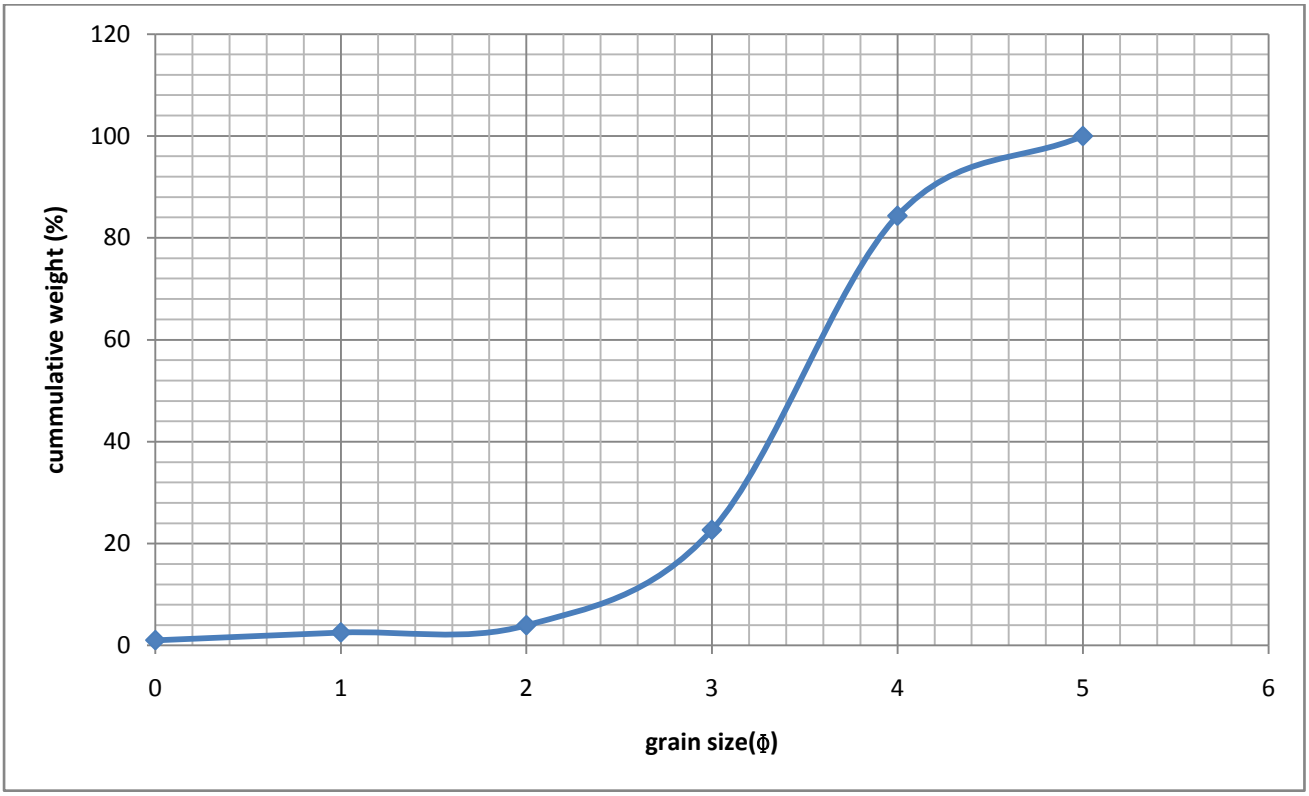


APPENDIX III

Table5 sample L5O

Phi(Φ) scale	Sieve size(mm)	Weight of sample (g)	% Weight of sample	Cumulative weight (%)

0	1	1.00	1.01	1.01
1	0.5	1.50	1.52	2.53
2	0.25	1.40	1.42	3.95
3	0.125	18.60	18.71	22.66
4	0.063	61.80	61.68	84.34
5	<0.063	15.50	15.66	100.00
Total		99.80		

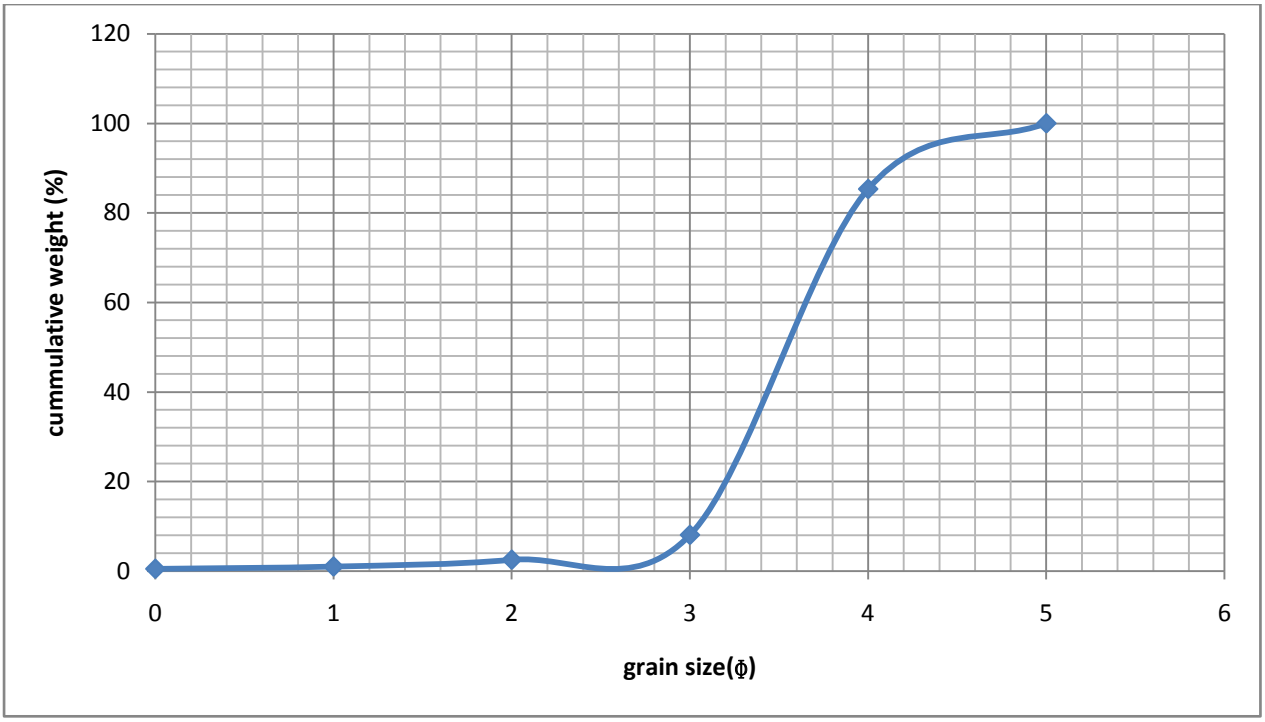


APPENDIX IV

Table 6 sample L6A

Phi(Φ) scale	Sieve size(mm)	Weight of sample (g)	% Weight of sample	Cumulative weight (%)
0	1	0.50	0.51	0.51
1	0.5	0.50	0.51	1.02

2	0.25	1.50	1.51	2.54
3	0.125	5.80	5.82	8.09
4	0.063	76.80	77.11	85.33
5	<0.063	14.50	14.56	100.00
Total		99.60		



APPENDIX V

CALCULATIONS

SAMPLE L2A

Table 7: Corresponding phi (ϕ) value of sampleL2A

SAMPLE	ϕ 5	ϕ 16	ϕ 25	ϕ 50	ϕ 75	ϕ 84	ϕ 95
L2A	1.90	2.80	3.10	3.45	3.80	4.00	4.50

Mean (μ) = $\frac{\phi 16 + \phi 50 + \phi 84}{3}$

= $\frac{1.90 + 3.45 + 4.00}{3}$

= 3.12

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

= $\frac{4.00 + 2.80 - 2(3.45)}{2(4.00 - 2.80)} + \frac{4.50 + 1.90 - 2(3.45)}{2(4.50 - 1.90}$

= -0.14

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

= $\frac{4.50 - 1.90}{2.44(3.80-3.10)}$

= 1.524

APPENDIX VI

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

= $\frac{2.86 - 0.47}{} + \frac{3.60 - 0.08}{}$

4 6.6

= 0.694

SAMPLE L4D

Table 8: Corresponding phi (ϕ) value of sampleL4D

SAMPLE	ϕ 5	ϕ 16	ϕ 25	ϕ 50	ϕ 75	ϕ 84	ϕ 95
L4D	2.00	2.50	2.80	3.30	3.65	3.80	4.00

Mean (μ) = $\frac{\phi 16 + \phi 50 + \phi 84}{3}$

= $\frac{2.50 + 3.30 + 3.80}{3}$

= 3.20

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

= $\frac{3.80+ 2.50 – 2(3.30)}{2(3.80-2.50)} + \frac{4.00 +2.00 – 2(3.30)}{2(4.00-2.00)}$

= -0.265

APPENDIX VII

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

= $\frac{4.00 – 2.00}{}$

2.44(3.65 – 2.80)

= 0.964

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

= $\frac{3.80 - 2.50}{4} + \frac{4.00 - 2.00}{6.6}$

= 0.628

SAMPLE L5O

Table 9: Corresponding phi (ϕ) value of sampleL5O

SAMPLE	ϕ 5	ϕ 16	ϕ 25	ϕ 50	ϕ 75	ϕ 84	ϕ 95
L5O	2.10	2.80	3.08	3.50	3.70	4.00	4.50

Mean (μ) = $\frac{\phi 16 + \phi 50 + \phi 84}{3}$

= $\frac{2.80 + 3.5 + 4.00}{3}$

= 3.40

APPENDIX VIII

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

= $\frac{4.00 + 2.80 - 2(3.50)}{} + \frac{4.50 + 2.10 - 2(3.50)}{}$

2(4.00– 2.80) 2(4.50– 2.10)

= -0.166

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

= $\frac{3.20 – 0.00}{2.44(1.99 – 0.50)}$

= 1.586

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

= $\frac{4.00 – 2.80}{4} + \frac{4.50 – 2.10}{6.6}$

= 0.664

SAMPLE L6A

Table 10: Corresponding phi (ϕ) value of sampleL6A

SAMPLE	ϕ 5	ϕ 16	ϕ 25	ϕ 50	ϕ 75	ϕ 84	ϕ 95
L6A	2.90	3.10	3.25	3.50	3.80	4.00	4.35

APPENDIX IX

Mean (μ) = $\frac{\phi 16 + \phi 50 + \phi 84}{3}$

= $\frac{3.10 + 3.25 + 4.00}{}$

3

= 3.45

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

= $\frac{4.00 + 3.10 - 2(3.50)}{2(4.00-3.10)} + \frac{4.35 + 2.90 - 2(3.50)}{2(4.35-2.90)}$

=0.142

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

= $\frac{4.35 - 2.90}{2.44(3.80-3.25)}$

= 1.080

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

= $\frac{4.00 - 3.10}{4} + \frac{4.35 - 2.90}{6.6}$

= 0.445

APPENDIX X

STANDARDS SCALES FOR PARAMETERS

Table 11: Verbal interpretation of graphic mean values

Phi (Φ) value	Size class (Wenworth, 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 to 7.0	Fine silt
7.0 to 8.0	Very fine silt
8.0 to 14.0	Clay

APPENDIX XI

Table 12: Verbal interpretation of sorting values

Sorting	Verbal term	Code
<0.35	very well sorted	VWS
0.35-0.50	well sorted	S
0.50-0.70	moderately well sorted	MWS
0.70-1.00	moderately sorted	M S
1.00-2.00	poorly sorted	P S
2.00-4.00	very poorly sorted	V P S
>4.00	extremely poorly sorted	EPS

APPENDIX XII

Table 13: Verbal interpretation of skewness mean values

Skewness	Verbal term	Code
-1.0 to -0.30	very negatively skewed	VNS
-3.0 to -0.10	negatively skewed	N S
-1.0 to 0.10	nearly symmetrical	N S
0.10 to 0.30	positively skewed	PS
0.30 to 1.00	very positively skewed	VPS

Table 14: Verbal interpretation of kurtosis values

Kurtosis	Verbal term	Code
<0.67	very platykurtic	VP
0.67 0.90	platykurtic	P
0.901.11	mesokurtic	M
1.11-1.50	leptokurtic	L
1.50-3.00	very leptokurtic	VL