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Comparison between the stratigraphy of the eastern and western parts of the Gongola sub-basin, Northern Benue Trough, Nigeria: The role of tectonics and the Neogene Biu basalt emplacement on the resultant topography of the eastern part of the Gongola sub-basin



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ABSTRACT

Detailed field mapping exercise was carried out as well as system logging of the various outcropping lithostratigraphic units in the eastern part of the Gongola sub-basin east of Gongola River of the northern Benue Trough with the aim of establishing any similarity or otherwise with the western part of the sub-basin west of Gongola River. The study reveals that the pre-Aptian to Coniacian lithostratigraphy succession of both areas of the sub-basins are somewhat similar and comprises the following units; the Bima group (lower, middle, and upper Bima formations) followed by the Yolde formation, the Kanawa formation. The mid-Turonian sandy equivalents are directly above the Kanawa formation and are represented by the Deba-Fulani Member restricted to the southern part of the Gongola sub-basin, the Dumbulwa Member restricted to the northern part of the sub-basin and the Gulani formation confined to the eastern part of the sub-basin. The mid-Santonian tectonic event affected the pre-Santonian succession resulting in the folding, faulting, and uplifting of the various lithostratigraphic units. This subsequently led to the formation of synclines and anticlines. The pre-Santonian Fika shale presumed to have been directly above the Gulani formation is rarely observed in the eastern Gongola sub-basin compared to the western sub-basin where it is found in several places. This suggests that the denudational activities spanning from Santonian to Paleocene in the eastern Gongola sub-basin were severe before the emplacement of the Neogene Biu basalt that slowed down the activities. The Campanian–Maastrichtian and the Paleocene successions are restricted to the western Gongola sub-basin.

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1. Introduction

The Benue Trough is a northeast-southwest trending intra-continental rift basin extending from below the Anambra basin and the Niger Delta in the south, to the Chad basin in the north. This megastructure is about 1,000 km long and 120–150 km wide and lies within the

Pan African mobile belt of West Africa (Guiraud, 1990). It contains up to 6 km of Cretaceous to Tertiary sediments and associated volcanics. Different school of thoughts by several authors regarding the origin and evolution of the Benue Trough fall mainly into two major models: the rift and the pull-apart models, and these different views have been reviewed by Zaborski (1998).

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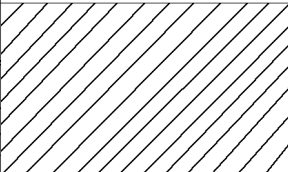
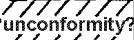
The trough is divided into the southern, central, and northern portions. The northern Benue Trough bifurcates into the N–S trending Gongola Arm (Gongola sub-basin) and the E–W trending Yola Arm. The stratigraphy of the Gongola sub-basin has been described by several authors in the past, most notably by [Carter et al. \(1963\)](#), [Popoff et al. \(1986\)](#), and [Zaborski et al. \(1998\)](#) but very recently, [Hamidu et al. \(2013\)](#) and [Ayok et al. \(2014\)](#) proposed modifications for the Upper Cretaceous lithostratigraphic successions of the western and eastern parts of the Gongola sub-basin, respectively (see [Table 1](#)). This Table shows mark variations in the Upper Cretaceous lithostratigraphic successions within these two regions of the sub-basin. This can be attributed to the tectonic history of the basin, especially the role of the Santonian and end-Cretaceous compressional events.

[Zaborski \(2003\)](#) gave a shortened version of the Cretaceous history of the Northern Benue Trough as outlined below:

- An active rifting phase mainly characterized by the Lower Bima Sandstone, this episode being followed by uplift and subaerial exposure.

- A transitional phase between the rifting and thermotectonic sag stages, represented by the Middle and Upper Bima Sandstone.
- A change from continental to marine environments during the Cenomanian, represented by the Yolde formation.
- A first major packet of largely eustatically controlled sediments; the shales and limestones of the “Kanawa Member” of the “Pindiga formation” and the Dukul formation formed during a Late Cenomanian to Early Turonian transgression; the middle sandy units of Dumbulwa, Gulani, and Deba Fulani “members” of the “Pindiga formation” and Jessu formation formed during a Middle Turonian regression; and the lower part of the “Fika Member” of the “Pindiga formation” and the Sekule/Numanha/Lamja formations representing a Late Turonian to Early Santonian interval of mainly marine conditions.
- A mid-Santonian compressional event which brought sedimentation to an end in the Yola arm and which was followed by subaerial erosion in the Gongola basin.
- Terminal Cretaceous compression leading to the uplift of the Cretaceous sediments and deep

Table 1. Upper Cretaceous and younger lithostratigraphic succession in the western and eastern parts of the Gongola basin as proposed by [Hamidu et al. \(2013\)](#) and [Ayok et al. \(2014\)](#).

Zaborski et al. (1998) (Gongola Basin)				(Hamidu et al. (2013) (western Gongola Basin)		(Ayok et al. (2014) (eastern Gongola Basin)		
		Neogene to Quaternary				Biu Basalts (& dolerite intrusions)		
Kerri-Kerri Formation		Paleocene (at least in parts)		Kerri-Kerri Formation				
Gombe Sandstone		Maastrichtian		T	G	Duguri Formation		
Pindiga Formation	 ?unconformity?	Campanian		S	G	Arowa Formation		
		Santonian		"Upper Fika Member"				
		Coniacian						
		Upper	Turonian	"Lower Fika Member"		Pindiga Formation	Pindiga Group	"lower Fika Member" (now eroded)
		Middle		Deba Fulani Member				Gulani Formation
Kanawa Member		Lower		Kanawa Member				
Yolde Formation		Cenomanian		Yolde Formation		Yolde Formation		
Bima Group	"Upper Bima Formation"	Albian		"Upper Bima Formation"		"Upper Bima Formation"		
	"Middle Bima Formation"	Aptian		"Middle Bima Formation"		"Middle Bima Formation"		
	"Lower Bima Formation"	pre-Aptian		"Lower Bima Formation"		"Lower Bima Formation"		
	+ + Crystalline basement + +		Precambrian					

E = Early; M = Middle; L = Late; DF = Deba Fulani; D = Dumbulwa; GS = Gombe Sandstone; TG = Tukulma Group.

dissection of the resultant land surface. These last sets of events (the Santonian and the terminal Cretaceous compressional events) have a marked impact on the present-day topography, and must have controlled the spatial erosivity and variation in thicknesses of the lithostratigraphic units across the Gongola sub-basin. Therefore, this study is aimed at understanding the role of these tectonic perturbations on the overall stratigraphy, and to a large extent, the paleogeography of the Gongola sub-basin during the Upper Cretaceous period. In this study, the boundary between the eastern and western parts of the Gongola sub-basin is marked by the Gongola River. The study area location is shown in [Figure 1](#).

2. Methodology

Field mapping was conducted during the dry seasons of 2007–2010 using 1:50,000 scale topographic base maps. The geological map was completed using an iterative process of satellite/air photograph interpretations and field mapping with the help of MapInfo professional 7.5 SPC and Global Mapper 8 software.

Additionally, a systematic logging technique was adopted and this included measuring thicknesses of beds with the help of a measuring tape, location of different lithofacies boundaries across/or along sections with the aid of global positioning system technology and photography using a digital camera.

3. Result (stratigraphy of the study area)

The geological map of both the western and eastern parts of the Gongola sub-basin is shown in [Figure 1](#), while the spatial variations in thicknesses of the various lithostratigraphic units of the eastern Gongola sub-basin are shown in [Figure 2a](#) and [b](#).

The following lithostratigraphic units are present in the eastern part of the Gongola sub-basin (see [Table 1](#)) and include the “Bima group” [(“Lower Bima,” “Middle Bima,” and “Upper Bima” formations of [Guiraud \(1991\)](#)], the Yolde formation of [Carter et al. \(1963\)](#), the “Kanawa Member” of [Zaborski et al. \(1998\)](#), and “Gulani Member of [Zaborski et al. \(1998\)](#) which were upgraded to formational statuses by [Ayok and Zaborski \(2014\)](#). In addition, dolerite sill intrusions were identified within the Kanawa formation. The Biu basalt caps the exposed lithostratigraphic succession towards the eastern boundary of the study area, while recent alluvium characterizes the floodplains of the Gongola River toward the western boundary of the study area.

4. Cretaceous succession

4.1. Bima group

The Bima group is generally continental and makes up the oldest sediments in the study area. It is directly underlain by the Precambrian crystalline basement and was subdivided into three components the “Lower Bima formation,” the “Middle Bima formation,” and the “Upper Bima formation” by [Guiraud \(1990; 1991\)](#). Descriptions of the various components of the Bima group observed in the study area are provided below:

4.1.1. Lower bima formation

The Lower Bima formation forms mainly flat-lying ground outcropping in the extreme south-eastern, north-western, and north-eastern parts of the study area ([Fig. 1](#)). It is made up of highly arkosic pebbly sandstones, granulestones, and microconglomerates ([Plate I](#)) with interbedded mottled clays. Generally, the sandstones show poorly defined trough cross-bedding with sets rarely exceeding 2 m in thickness. The Lower Bima formation herewith has an overall thickness of about 0.5 km corresponds to the facies 4 and 5 of [Guiraud \(1991\)](#) which he described as alluvial fan deposits.

4.1.2. Middle bima formation

The Middle Bima formation forms hills in the study area including, towards its southern part, a prominent ridge extending from the south of Fikahel to the south-east of Balbaya ([Fig. 1](#)). The average thickness of this unit in the study area is about 200 m.

The Middle Bima formation consists of medium to very coarse-grained, brownish feldspathic sandstones, displaying both tabular and trough cross-bedding in sets that range from 50 cm to about 3 m in thickness. Toward the top are fine to medium-grained, white, purple to brownish laminated, and cross-laminated feldspathic arenites ranging in thickness from 30 cm to about 100 cm. South-east of Balbaya, a streamside exposure shows beige colored clays with two interbedded calcareous units, one of which is a continuous bed while the other is nodular ([Plate II](#)). The calcareous nodules have a spherulitic microstructure ([Plate III](#)) indicating direct precipitation from a CaCO_3 -saturated gel within a probable lacustrine or perilacustrine environment. A similar sub-facies was reported 3.5 km north-west of Gwomu (N9°29'30" and E11°15'30") toward the top of the formation within “member 3 of Formation 2”

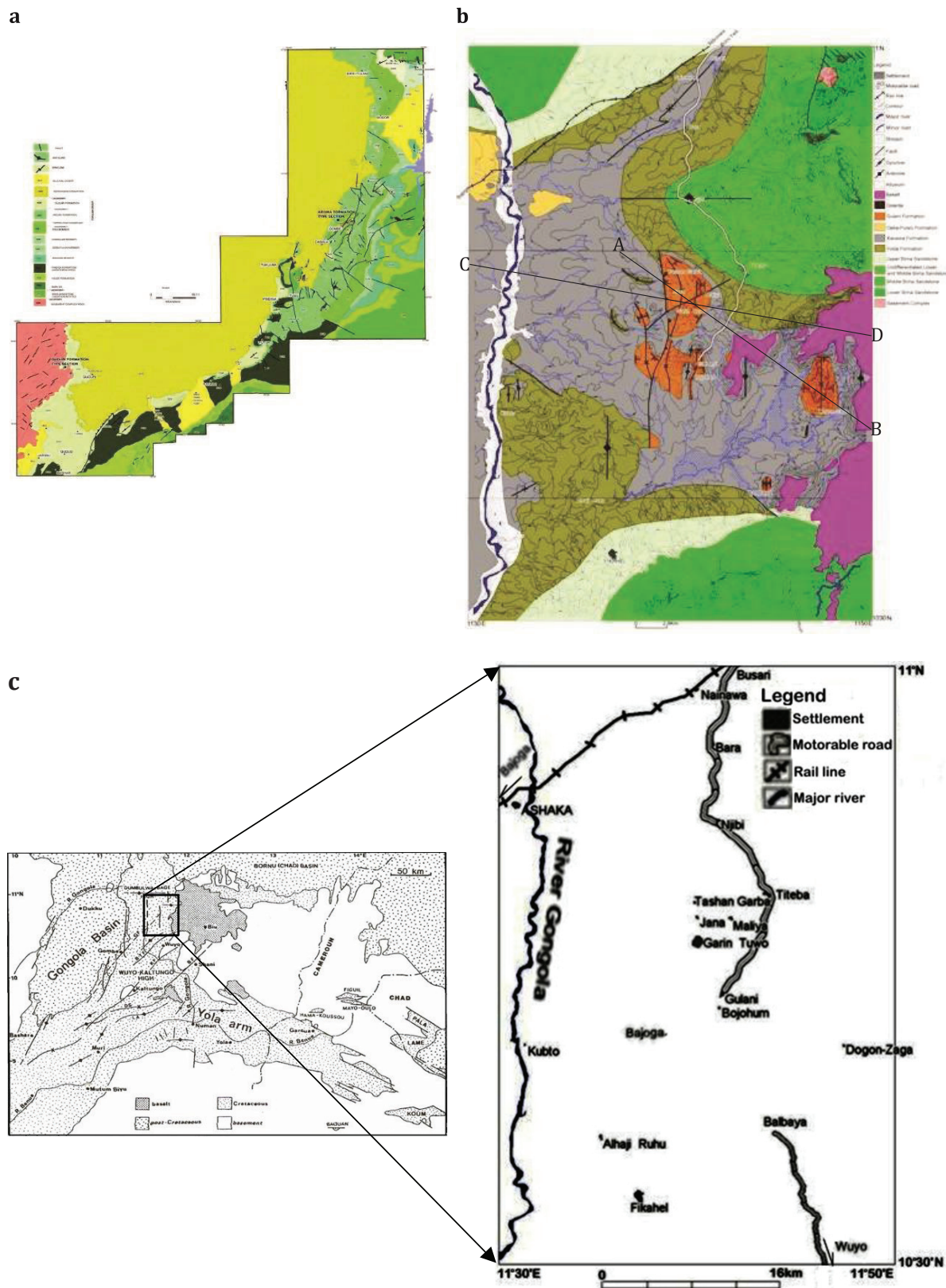


Figure 1. (a) Geological map of western Gongola sub-basin (Hamidu et al., 2013). (b) Geological map of eastern Gongola sub-basin (Ayok and Zaborski, 2014). (c) Outline geological map showing the main features of the upper Benue Trough region; GF-Gombe Fault; B-TF-Bima-Teli Fault; KF-Kaltungo Fault; BF-Burashika Fault; DS-Dadiya syncline; LA-Lamurde anticline (After Zaborski, 1998). The blocked area represents the study area.

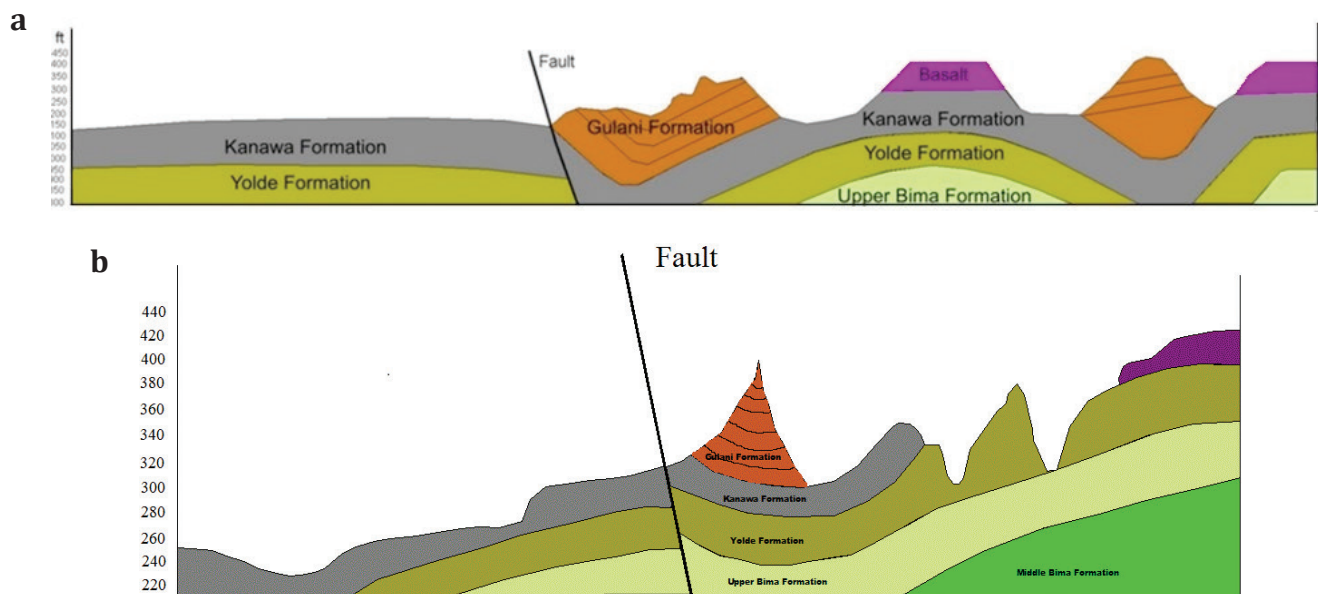


Figure 2. (a) Topographic cross-section along line A–B of Figure 1b. (b) Topographic cross-section along line C–D of Figure 1b.



Plate I. Lower Bima formation showing pebbly arkosic sandstone to microconglomerate, about 10 km south-east of Fikahel ($N10^{\circ}30'4.44''$ and $E11^{\circ}40'8.52''$).



Plate II. Middle Bima Formation showing mudstone interbedded with calcareous nodules, southeast of Balbaya; ($N10^{\circ}35'43.1''$ and $E11^{\circ}45'19.7''$).

of Allix (1983) in the core of the Lamurde anticline to the south of the present study area.

4.1.3. Upper bima formation

The boundary between the Upper Bima formation and the Middle Bima formation is often very difficult to demarcate because it is poorly exposed in the study area. In the north-eastern and north-western portions of the study area, the Upper Bima formation and the Middle Bima formation are undifferentiated on the geological map (Fig. 1). Toward the south of the study area (Fig. 1), the location of the boundary between the Upper Bima formation and the Middle Bima formation is evident because the latter forms chains of continuous hills that clearly distinguish it from the gently undulating and flat plains formed by the former. South-east of Balbaya toward the eastern boundary of the study area bordering the Biu basalt the Upper Bima formation comprises medium to coarse-grained, brownish, tabular cross-bedded

feldspathic arenites. Its total thickness is about 100 m and the description matches those of Guiraud (1991) and Zaborski et al. (1998).

4.2. Yolde formation

The Yolde formation outcrops in the south-western, north-western, eastern, and northern portions of the area. This unit is mostly characterized by gently undulating topography (Fig. 1) often with scanty vegetation. The Yolde formation is about 100 m thick in the eastern part of the area where it is overlain by the Biu basalts. Most exposures were observed along stream channels around Bara and Ruwan Kuka. Generally, the Yolde formation consists of alternating sandstones, clays, and shales. In the upper part, clays and shales generally predominate, while the lower part displays thicker sandstones (up to 5 m) and subordinate clays and shales. At the very top of the unit are oval to saucer-shaped carbonate-cemented sandstone nodules ranging in diameter from 0.5 to 2 m (Plate IV).

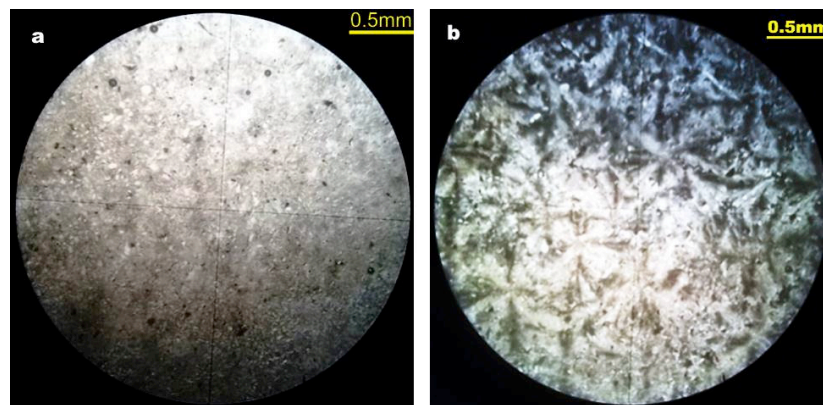


Plate III. Photomicrograph of calcareous nodules within the Middle Bima Formation showing spherulitic micro structure, a) PPL b) XPL.



Plate IV. Oval and saucer-shaped calcareous nodules at the top of Yolde Formation, southeast of Titeba; ($10^{\circ}45'54''\text{N}$ and $11^{\circ}44'44''\text{E}$)

These nodules are similar to the calcareous nodules reported at the same stratigraphic level by [Zaborski et al. \(1998\)](#). South of Ruwan-Kuka along a stream channel is an exposure of thick sandstones interbedded with thin shales with an overall thickness of about 5 m. The sandstones are coarse to very coarse-grained, moderately sorted, sub-rounded subarkoses consisting of monocrystalline quartz, polycrystalline quartz, microcline, plagioclase, untwinned feldspars, and sericite, with quartz overgrowth cement. On the North of Ruwan-Kuka, there is a ridge of highly silicified sandstone which is a coarse to very coarse-grained, moderately sorted, sub-rounded subarkose consisting of monocrystalline quartz, polycrystalline quartz, microcline, plagioclase, and perthitic feldspars, with quartz overgrowth cement. This sandstone body belonging to the Yolde formation occurs adjacent to the north-south trending Jana-Ruwan Kuka fault.

4.3. Kanawa formation

The Kanawa formation outcrops over a large part of the study area mainly forming flat featureless topography ([Fig. 1](#)). The unit is made up of gray shale interbedded with thin often fossiliferous limestones. The Kanawa formation gives rise to black to dark gray clay soils often with limestone regoliths.

The most complete section of the Kanawa formation in the study area occurs about 1.2 km north-east of Dogon Zaga between ($10^{\circ}41'11''\text{N}$ and $11^{\circ}48'5''\text{E}$; and $10^{\circ}41'9''\text{N}$ and $11^{\circ}47'14''\text{E}$) where the unit is about 80 m thick [The lithostratigraphic unit below the Gulani formation Lectostratotype; after [Ayok and Zaborski et al. \(2014\)](#)]. About 2.8 km east of Gulani town, bordering the Biu basalt is another good exposure of the Kanawa formation showing 12 m of gypsiferous gray

shale with an encrustation of a yellowish mineral (jarosite or natrojarosite?; [Plate V](#)).

4.4. Gulani formation

The Gulani formation is preserved within synclines in the Dogon-Zaga, Gulani, Jana, and Balbaya areas where it mainly forms hilly topography ([Fig. 1](#); [Plates VI–VIII](#)). East of Gulani town very close to the basalt, the sandy soil derived from this unit is characterized by a regolith comprising large blocks of ferruginized sandstone ([Plate IX](#)). The outcrop of the Gulani formation is characterized by scanty vegetation and a mostly nucleated settlement pattern.

4.4.1. The Gulani formation north-east of Balbaya

North-east of Balbaya the Gulani formation occupies the core of a symmetrical syncline. Although no good section was observed, it appears that the Gulani formation here is characterized by sandstone sub-facies displaying tabular cross-bedding with sets up to 2 m thick and foresets very evenly developed. Pebbly layers exist along the bases of sets and in places within graded foresets.

4.4.2. The Gulani formation at Jana and Ruwan Kuka

West of Jana and east of Ruwan Kuka is a north-south trending ridge of ferruginized sandstones belonging to the Gulani formation occurring within the Jana-Ruwan Kuka fault zone of [Zaborski et al. \(1998\)](#). Around Jana, the sandstones are medium to very coarse-grained, poorly to moderately sorted, subangular to subrounded quartz arenites, consisting of monocrystalline quartz and rare polycrystalline quartz. In one thin section, there is a granule-sized sedimentary rock fragment comprises quartz grains enclosing authigenic pore-filling kaolinite cement.



Plate V. Kanawa Formation about 2.8 km east of Gulani ($10^{\circ}43'10.1''\text{N}$ and $11^{\circ}42'10''\text{E}$) showing gypsiferous shale.



Plate VI. Dogon Zaga syncline, view looking north showing the Gulani Formation overlying the Kanawa Formation (flat ground and gentle slope in the foreground).



Plate VII. Gulani Formation, showing the cliffs in the eastern part of the Dogon Zaga syncline which contain the upper part of the type section.



Plate VIII. Eastern limb of the Balbaya syncline showing the Gulani formation overlying the Kanawa formation, the latter forming the flat ground in the foreground.



Plate IX. Regolith of ferruginized sandstone derived from the Gulani Formation 2.8 km east of Gulani; ($10^{\circ}43'10''\text{N}$ and $11^{\circ}42'21.6''\text{E}$).



Plate X. Dolerite sill, about 2 km southwest of Dogon Zaga; ($10^{\circ}39'41''\text{N}$ and $11^{\circ}46'54.5''$).

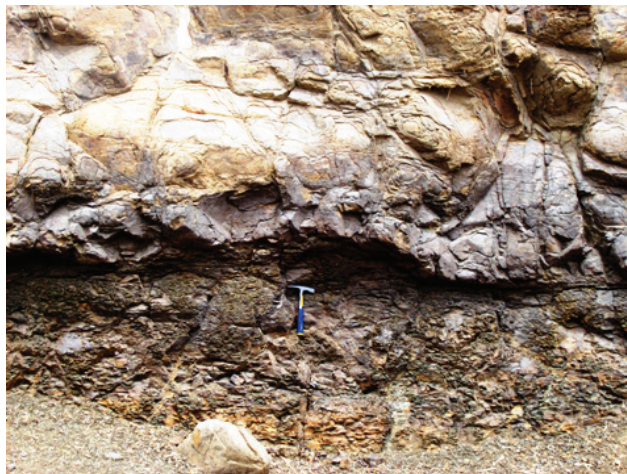


Plate XI. Dolerite sill intruding into shale of the Kanawa Formation displaying sphaeroidal weathering, about 4 km northwest of Balbaya; ($10^{\circ}46'16''\text{N}$ and $11^{\circ}40'0.3''\text{E}$).

The sandstone from Ruwan Kuka is medium to coarse-grained, moderately sorted, subangular to sub-rounded quartz arenite consisting of monocrystalline quartz and rare polycrystalline quartz, with a ferruginized kaolinite cement and remaining intergranular porosity of approximately 15%.

5. Post cretaceous rocks

5.1. Biu basalts

The Neogene Biu basalts extend into the eastern part of the study area (Fig. 1). The basalts overlie the previously eroded Cretaceous succession forming flat-topped elevated topography. They comprise vesicular and non-vesicular types.

5.2. Dolerite

Dolerite sills are exposed south of Dogon-Zaga represented by discontinuous hills/ridges that have a general north-south trend (Fig. 1; Plate X). A dolerite sill is exposed 2.8 km north-west of Balbaya intruding into shale of the Kanawa formation. The dolerite displays well-developed spheroidal weathering (Plate XI).

6. Discussion

As observed in Figure 2a and b, the variations in thicknesses amongst different exposures of the various formations in the outcropping lithostratigraphic units of the eastern part of the Gongola sub-basin, Northern Benue Trough is best understood by having a proper knowledge of the geological history of the entire Benue Trough already described in the introduction. The present topography viz-a-viz the variation in thicknesses of the various outcropping lithostratigraphic units is a product of the Santonian compressional event and emplacement of the Neogene Biu basalt.

The oldest lithostratigraphic unit in the Gongola sub-basin, Northern Benue Trough is the continental Bima group (comprising from the bottom the lower, middle, and upper Bima formations), followed by the transitional Yolde formation which is directly overlain by the marine Pindiga formation (comprising from the bottom the Kanawa Member, followed by lateral sandy equivalents the Gulani formation restricted to the east of the basin, the Deba Fulani Member restricted to south of the basin, the Dumbulwa Member restricted to north of the basin, and the pre-Santonian marine Fika shale directly overlying the sandy units). Above the Pindiga formation is the Campanian–Maastrichtian and the Paleocene successions both restricted only to the western part of the sub-basin; the former now represented by the Tukulma group of Hamidu et al. (2013)

comprising from the bottom the post-Santonian/Upper marine Fika shale, followed by the transitional Arowa formation and at the top is the continental Duguri formation and the latter represented by the youngest Kerri–Kerri formation, respectively. A period of non-deposition/hiatus spanning from the Santonian to post-Maastrichtian times persisted in the eastern part of the sub-basin until the Paleocene before the emplacement of the Biu basalt in the Neogene an attestation of the pronounced nature of the denudational activities in the eastern sub-basin than the western sub-basin; while at the same time, sediments deposition continued in the western sub-basin represented by the Tukulma group and the Kerri–Kerri formation.

The Santonian compressional event affected all the pre-Santonian succession since they were folded, faulted, and uplifted thereby creating synclines and anticlines that are now uplifted. The oldest unit in the eastern part of the Gongola sub-basin is the Bima group (see Table 1), while the youngest is the Gulani formation (see Table 1). Thus, the complete absence of the pre-Santonian Fika shale which hitherto supposed to have been directly above the Gulani formation is an indication of total removal by erosional activities, although Zaborski (1998) reported the presence of calcareous sandstone belonging to the pre-Santonian Fika shale around Bularaba part of the eastern Gongola sub-basin. The Gulani formation is preserved only within synclines as hills, suggesting that the anticlinal component of the Gulani formation has been completely eroded along with the pre-Santonian Fika shale.

It is an established fact that the effects of erosion are more on anticlines than on synclines, this is clearly manifested in the study area by the hilly nature of the synclines representing the Gulani formation. Another important point of note is the protection of the lithostratigraphic units covered by or bordering the Neogene Biu basalt from further erosion.

The anticlinal region between Bara and Titeba exposes the Yolde formation but with complete absence of the overlying Kanawa formation, the Gulani formation, and the pre-Santonian Fika shale which were also completely eroded an attestation of the severity of erosional activities on anticlines than synclines. Bordering the Biu basalt, a veneer of sediment belonging to the Kanawa formation is exposed and is directly overlying the Yolde formation.

It is also of interest to note that the thicknesses of exposed sections of Yolde, Kanawa, and Gulani formations bordering the Neogene Biu basalt, approximately doubles compared to the thicknesses observed elsewhere in the study area.

The pre-Santonian units within the eastern part of the Gongola sub-basin show higher thicknesses close to the emplaced basalt. It is therefore evident that erosional regime must have continued even after the Santonian event was over, and into the Neogene times but the emplacement of the basalt must have provided a protective cover that slowed down erosion rates of units closer to the basalt compared to areas far away leading to their complete removal.

The edge of the basalt as observed currently is not in its initial position when it was originally emplaced during the Paleogene but has been continually shifted towards the east of the study area.

7. Conclusion

The lithostratigraphy succession of both the eastern and the western parts of the Gongola sub-basins are somewhat similar from the pre-Aptian to Coniancian lithostratigraphy succession; thus comprising of the Bima group (lower, middle, and upper Bima formations) followed by the Yolde formation, the Kanawa formation. The mid-Turonian sandy equivalents are directly above the Kanawa formation; represented by the Deba-Fulani Member restricted to the southern part of the Gongola sub-basin, the Dumbulwa Member also restricted to the northern part of the sub-basin and the Gulani formation confined to the eastern part of the sub-basin. The pre-Santonian Fika shale which hitherto supposed to be directly above the Gulani formation is rarely observed in the eastern part of the Gongola sub-basin compared to the western part of the sub-basin which is widely spread. This may not be unconnected to the severity of the denudational activities spanning from Santonian to Paleocene in the eastern part of the Gongola sub-basin before emplacement of the Neogene Biu basalt. The mid-Santonian tectonic event affected the pre-Santonian succession whereby the lithostratigraphic units were folded, faulted, and uplifted, leading to the formation of synclines and anticlines. The Campanian–Maastrichtian and the Paleocene successions are restricted to the western part of the Gongola sub-basin. The eastern part of the Gongola sub-basin has shown marked variations amongst the various outcropping lithostratigraphic units which might have been as a result of the Santonian tectonic/compressional event that led to the creation of both synclines and anticlines. The synclines in the sub-basin are occurring in form of hills as typified by the mid-Turonian Gulani formation (the youngest lithostratigraphic unit in the area), while the anticlines show almost flat topography as exemplified

by other older lithostratigraphic units, e.g., the Yolde and the Kanawa formations. It is an established fact that denudational activities are more pronounced on anticlines than on synclines. Another vital important reason has to do with the emplacement of the Neogene Biu basalt toward the eastern boundary of the study area which played a vital role in slowing down the denudational activities, especially on those lithostratigraphic units (Gulani, Kanawa, and Yolde formations) bordering the basalts leading to preserved thicker sections compared to their other corresponding counterparts elsewhere.

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