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Nature of the Campano-Maastrichtian Sub-Basins in the Gongola Basin, Nigeria

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ABSTRACT: Geological mapping was carried out and outcrop sections were examined alongside palaeocurrent directions from the greater part of the Campano-Maastrichtian outcrops in the Gongola Basin in Nigeria. Palaeocurrent measurements were obtained from asymmetrical ripples, cross bedding and dune bedforms within the channel-filling sub-facies of the Arowa Formation, and the foresets of the tabular cross bedding displayed in the Duguri formation. A north-westerly to a northerly paleocurrent direction was determined for the Arowa formation, indicating that the open sea was located to north-north-west, while a unimodal palaeocurrent directions characterize the Duguri Formation. These currents transported sediment into the Dukku, Akko and Bashar sub-basins with an overall centripetal pattern. The main structural features of the western part of Gongola Basin from E-W, are the N-S, NE-SW and NW-SE trending faults. These series of faults controll the basin subsidence and deposition of the Campano-Maastrichtian succession in the Dukku, Akko and Bashar sub-basins.The lateral and vertical facies variation within the Campano-Maastrichtian succession are in consistence with the northerly retreat of the sea.
Keywords: Campano-Maastrichtian, sub-basin, palaeocurrent, rip-currents**.**

INTRODUCTION

The Benue trough, east Niger rift basins and Sudanese rift basins are major elements of the West and Central African Rift System (WCARS). The Benue trough is a Cretaceous sedimentary Basin in Nigeria, formed as a consequence of both rift and strike-slip episodes. At its northeastern end, is an area commonly known as the Upper Benue trough. It bifurcates into an E-W trending Yola Arm and a N-S trending Gongola Arm or Gongola Basin (Figure 1) (After Zaborski, 1998).

Major parts of the Upper Benue trough have been studied and re-mapped (Allix, 1983; Benkhelil, 1985, 1986, 1988; Popoff, 1988; Guiraud, 1989, 1990a, 1990b, 1991a, 1993 and Zaborski *et al*., 1997, Zaborski, 1998). Ayoola (1981) worked on the Paleocurrent and sedimentological studies in the Benue trough. However, Ayoola (1981) and Benkhelil (1989) misinterpreted the beds around Bashar as Kerri-Kerri formation and Bima Sandstone respectively. The present work is aimed at determining the nature of the Campano-Maastrichtian basin in the Gongola basin, and is achieved through extensive geological mapping covering the entire Campano-Maastrichtian succession, assessing the palaeocurrent directions as deduced from sedimentary structures and comparison of grain sizes from place to place and their relationship to basin structure and determination of the variation in facies both vertical and lateral and interpreting their relationships.

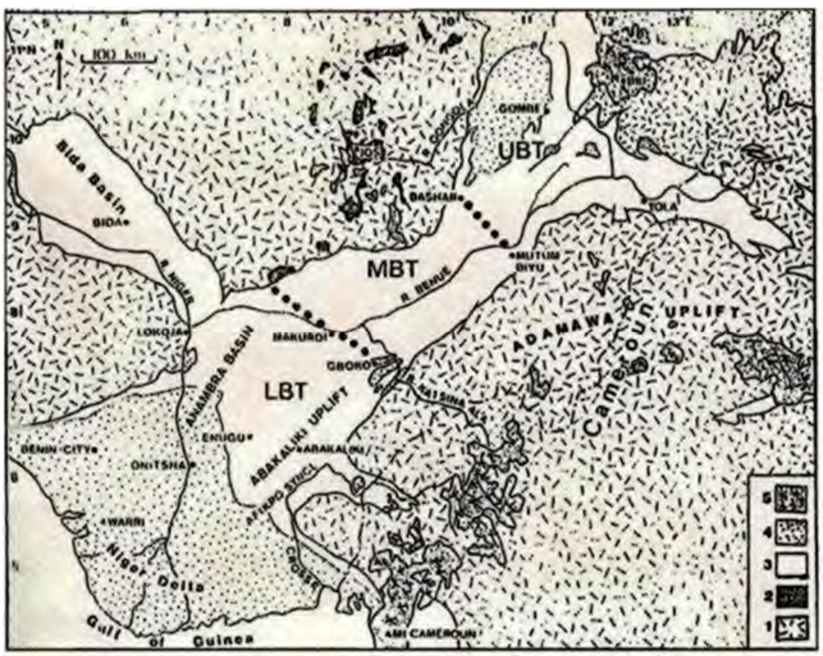
THE GEOLOGY OF THE GONGOLA BASIN

The N-S aligned Gongola basin contains a largely Cretaceous infill comprising Early Cretaceous continental clastics, the Bima Group, and a dominantly marine Late Cretaceous succession (Table 1).

In the Gongola basin marine Upper Turonian to Coniacian sediments occur in the lower part of the Fika, a member of the Pindiga Formation (Allix, 1983; Zaborski *et al*., 1997). Zaborski *et al*. (1997) reported the Upper turonian ammonites *Coilopoceras* and *Placenticeras* in glauconitic calcareous sandstones belonging to lower part of Fika Member north of Bularaba and the Coniacian ammonites *Barroisiceras* and *Forresteria* were reported in limestone regolith 1 km north east of Sollare on the northern flank of the Dumbulwa–Bage High. Evidence of a major Santonian compressional event is found throughout the northern half of Africa (Guiraud and Bosworth, 1997). Zaborski *et al.* (1997) reviewed the structural and stratigraphic evidence for the existence of a Santonian-Campanian unconformity in the Upper Benue Trough region, comparable to that which is well known in the Lower Benue Trough. He concluded that it is possible that the "Fika Member" of the Pindiga Formation as proposed by Zaborski *et al.* (1997) [= the "Fika Shale" and upper "Shale Member" of the Pindiga Formation of Carter *et al*. (1963)] is divisible into a discrete pre-Santonian portion (herein the "lower Fika Member") and an upper Campanian-Maastrichtian portion (herein the "upper

Fika Formation”). The “upper Fika Formation” is conformably overlain by the “Gombe Sandstone” of previous authors.

Zaborski *et al*. (1997) recognized three lithofacies within the Gombe Sandstone. Above, the “red sandstone facies” composed of brick red coloured, cross-bedded sandstones with coarse to very coarse-grained, cross-bedded channel-filling sandstones; a middle “bedded facies” consisting of extremely regularly bedded, fine to medium-grained white and grey quartz arenites with interbedded silts, silty clays flaggy and vesicular ironstones and channel-filling sandstones; and at the base a“transitional portion” consisting of rapidly alternating thin beds of silty shales with plant remains and fine to medium-grained sandstones with thin flaggy ironstones. Hamidu (2012) proposed that the Campano-Maastrichtian succession makes up the Tukulma Group which comprises the “upper Fika Formation” the post-Santonian part of the Pindiga formation of previous authors below and the “Gombe Sandstone” of previous authors above. The name “Gombe Sandstone” is abandoned in favour of the Arowa Formation below and the Duguri formation above. During the course of the present study field-mapping was carried-out and lithologic sections have been examined alongside palaeocurrent directions from the greater part of the Campano-Maastrichtian outcrop in the Gongola basin, extending from the Duguri and Bashar area in the south-west to the Birri Fulani area in the north-east (Figures 2 and 3).



Key:
LBT Lower Benue Trough;
MBT Middle Benue Trough;
UBT Upper Benue Trough.
1. Precambrian;
2. Jurassic “Younger Granite”;
3. Createaceous;
4. Post Cretaceous;
5. Cenozoic to Recent Basalt

Figure 1: Outline geological map of the Benue Trough and adjacent areas. [**Source:** Zaborski (1998)]

Table 1: Lithostratigraphical subdivision for the Gongola Basin proposed herein and compared with Zaborski *et al*. (1997).

		Zaborski et al., (1997)		Hamidu (2012)	
PLEISTOCENE					
PALEOCENE (At least in part)		KERRI KERRI FORMATION		Kerri-Kerri Formation	
MAASTRICHTIAN		GOMBE SANDSTONE		Tukulma Group	Duguri Formation / Arowa Formation
CAMPANIAN		PINDIGA FORMATION	FIKA MEMBER ?UNCONFORMITY		"upper Fika Formation"
SANTONIAN				Unconformity	
CONIACIAN				Pindiga Formation	"lower Fika Member"
UPPER	TURONIAN		DUMBULWA/GULANI DEBA FULANI MEMBERS		Dumbulwa/Gulani/Deba Fulani Member
MIDDLE					
LOWER			KANAWA MEMBER		Kanawa Member
CENOMANIAN		YOLDE FROMATION		Yolde Formation	
ALBIAN		BIMA GROUP	"UPPER BIMA FORMATION"	Bima Group	"upper Bima Formation"
APTIAN			"MIDDLE BIMA FORMATION"		"Middle Bima Formation"
pre-APTIAN			"LOWER BIMA FORMATION"		"Lower Bima Formation"
PRECAMBRIAN		CRYSTALLINE BASEMENT		Crystalline basement	

Note the modifications of the Campano-Maastrichtian succession.

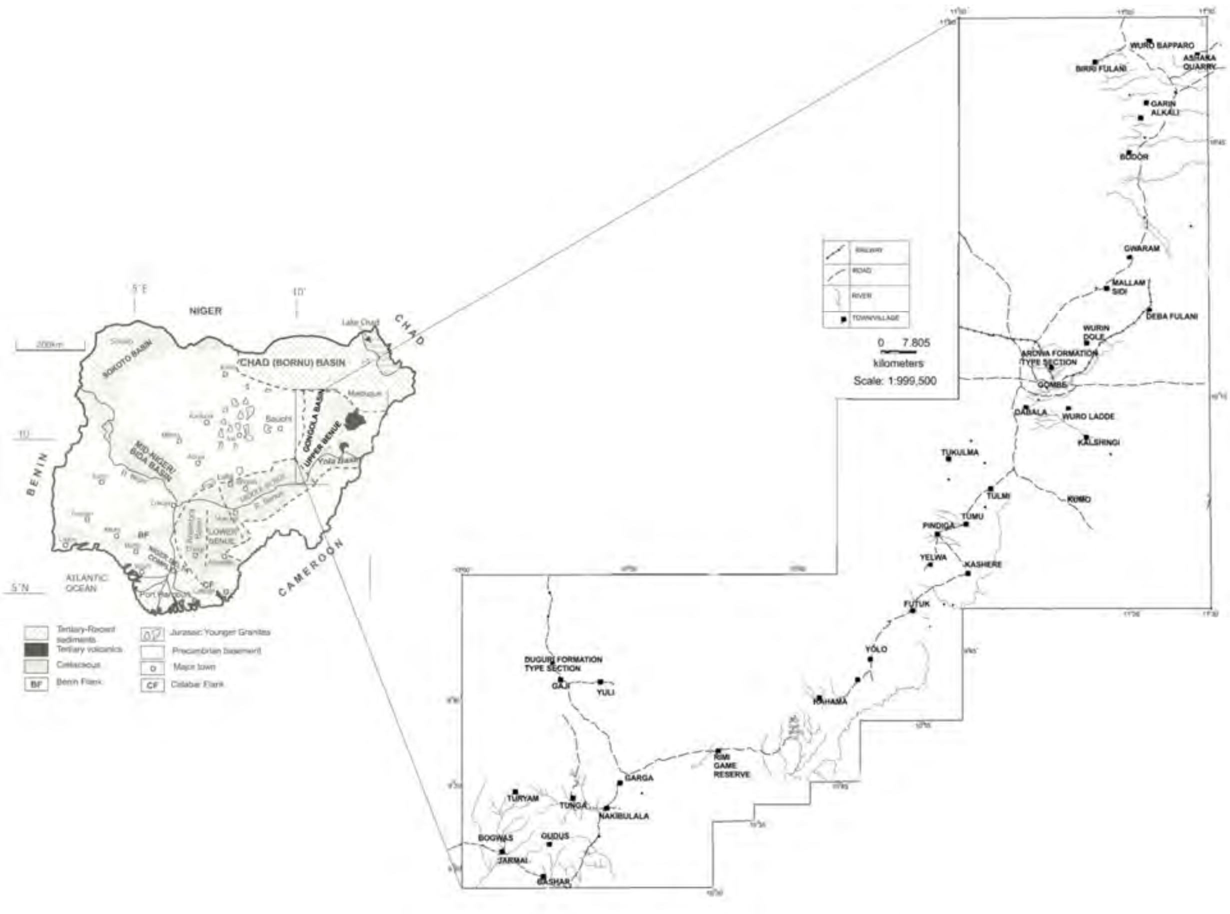


Figure 2: Outline map of Nigeria. Inset shows the study area

METHODS OF STUDY

Remote Sensing Methods

At the preliminary stage, interpretation of aerial photographs dating from 1964 on a scale of 1:40,000 was conducted and integrated with digital satellite imagery. The satellite images Landsat ETM+ (Enhanced Thematic Mapper) scene Path 187/ Row 53, dated 2003 and a single Landsat ETM scene (Path 186/ Row 53, dated 1986) were downloaded and processed using Envi 4.6.1software. Digital processing of the ETM+ images for the study area generated several products ranging from single band images to false colour composite images; 732 in RGB was found to be suitable for this study. Other processing were done using Global Mapper 8 software, while the geological map of the study area was produced using MapInfo 7.5 software1.2 (MapInfo, 2010).

Field Methods

Detailed field mapping involved description of exposed sections mainly along river channels and road cuts, outcrop samples collection, and photography of relevant features were under-taken. Delineation of geological boundaries was done so as to update the geological map of the study area and as ground trotting to the previously conducted remote sensing data.

Sieve Analysis Method

A generalized form of mechanical analysis to determine grain size was done by sieving (Wentworth, 1982). Most commonly sieving is used for size determination in the pebble and sand ranges (particles coarser than 0.063mm). The coarsest sieve required was placed at the top of a nest of sieves in which the screen openings becomes progressively smaller downwards (4mm - <0.045mm). A pan was placed beneath the lowest sieve to retain the 'fines', which pass through the entire column. The retaining lid closed and the nest of sieves arranged in a mechanical shaker, the nest was agitated by the shaker for about 10 minutes; finally each sieve was weighed and the result recorded and interpreted.

RESULTS AND DISCUSSION

Palaeocurrent Directions and Paleogeography of the Campano-Maastrichtian succession

Palaeocurrent patterns may be of four types: unimodal, bimodal, polymodal or random. In the present study palaeocurrent measurements were obtained from asymmetrical ripples, cross bedding and dune bedforms within the channel-filling sub-facies of the Arowa Formation. The channel-filling sandstones occurs cutting through the more shale-rich portions of the lower Arowa Formation. Channels are formed by erosion and are commonly filled with sediment that is texturally different from the beds they truncate. Arowa Formation channel-filling sandstones may be the result of rip-currents which comprise, narrow, high velocity, storm-generated seaward-directed currents that start in the surf zone (Gruszczynski *et al*., 1993). The currents that produced the channel-fillings flowed intermittently. A north-westerly to northerly directed paleocurrent was determined for the Arowa Formation, indicating that the open sea was located to north-north-west, while in the Duguri Formation palaeocurrent measurements were taken on the foresets of the tabular cross bedding. Tabular cross bedding is formed by the down current migration of dunes bed forms, the current erodes grains from the crests and deposit them on the down current or the lee face. The results are shown in (Figure 4), along with the numbers of measurements, mean grain sizes (mm) of the sediments and the basement isobaths. In summary:

a. Around Yuli unimodal easterly-flowing paleocurrents was determined.
b. At Tunga and Gudus bimodal to variable paleocurrents occurs.
c. From Rimi to Birri Fulani the paleocurrents are generally unimodal, and westerly flowing.
d. At Gombe and Kalshingi there are north-westerly and south-westerly directed paleocurrent respectively.

Generally unimodal palaeocurrent directions characterize the Duguri formation. They transport sediment into the Dukku, Akko and Bashar sub-basins (which are concealed below the Kerri-Kerri Formation) with an overall centripetal pattern. The bimodal patterns at Bashar and Gudus area are inconsistent with the trend around Yuli. In the former areas, the palaeocurrent and sediment transport pathways may have been controlled by pre-existing basement lineaments particularly the NW-SE trending structures (Figure 3). The absence of marine indicators, the relatively mature sediment texture and broadly unimodal palaeocurrents suggest an alluvial environment of deposition. The sandstones are dominantly negatively skewed and moderately to poorly sorted reflecting high reworking of the sediment during transport and in these respects agree with river sands.

The grain size variation shows coarser mean grain sizes in the west and south-west, and in the area between Dagudi and Gudus, suggesting a greater proximity to the source area. The paucity of argillaceous horizons suggests deposition in braided rivers, similar to those proposed for the Upper Bima Sandstone by Guiraud (1991).

Available data on palaeocurrents for Cretaceous units in the Gongola basin are summarized below (Figure 5).

a. For the Duguri Formation, centripetal flows into the Bashar, Akko and Dukku sub-basins.
b. For the Arowa Formation (from channel-filling sandstones), north-north-westerly flowing palaeocurrent direction occurs.
c. For the mid-Turonian Deba-Fulani Member of the Pindiga Formation, there is little evidence, but east of Gombe a north-westerly flowing palaeocurrent direction occurs.
d. For the upper Bima Sandstone south-westerly flowing palaeocurrents direction occurs.

These patterns indicate separate depocentres for the upper Bima Sandstone and the younger successions.
The Deba Fulani Member, Arowa and Duguri formations were channelled towards the same depocentres (Bashar, Akko and Dukku sub-basins). These sub-basins became active during the deposition of the Deba-Fulani Member and became the main depocentres during the remainder of Cretaceous time.

The marine part of the Arowa formation is dissected by channel-filling sandstones that are seaward directed rip-channels. The sea that deposited the Arowa Formation was coming from a south-easterly direction, while the sea that deposited the Duguri formation was coming from both east and west as the sea retreated to the north.

Basin Structure

The main structural features of the western part of Gongola Basin from east to west are the N-S trending

Wuro Ladde-Wurin Dole fault, the NE-SW trending Gombe fault, the N-S trending Kashere fault and the NE-SW trending faults at Garga and west of Yuli (see Figure 3). These series of faults controlled basin subsidence and the deposition of the Campano-Maastrichtian succession. Benkhelil (1982, 1988, 1989) believed that the Gongola basin was mainly controlled by N15° trending faults close to its western margin. The major structural feature that separates the Dukku, Akko and Bashar sub-basins from the area to the east, where the older Bima-Yolde depocentres occur, is the N-S trending Wuro Ladde-Wurin Dole fault (Figure 3). To the west of the Yuli area major basement fractures trend parallel to the western margin of the Duguri Formation outcrop and controlled its deposition in the E-W extension basin (Figure 3). The Duguri Formation outcrop (Plate 1) can be inferred to have originally had a lateral extent of a minimum of 8 km further to the west, with subsidence of at least 240 m taking place during the Campano-Maastrichtian (Figure 6). West of Wuro Ladde-Wurin Dole fault the upper part of Pindiga Formation a few kilometres west of Gombe is about 460 m (Allix, 1983). Further west the thickness increases to about 885 m, this indicates rapid thickening of this part of the succession toward the centre of the Akko/Dukku sub-basins.

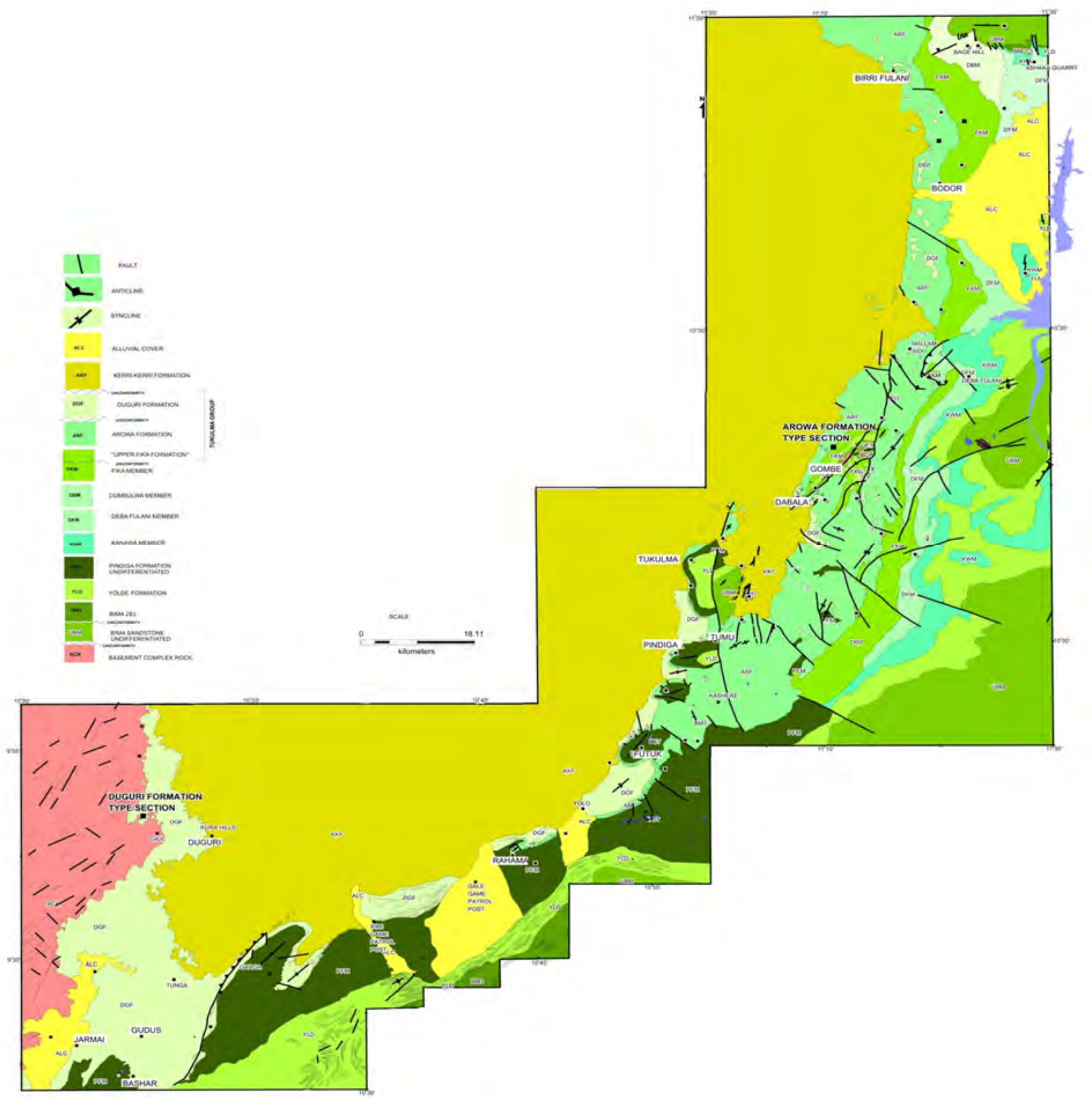


Figure 3: Geological map of the western part of the Gongola Basin

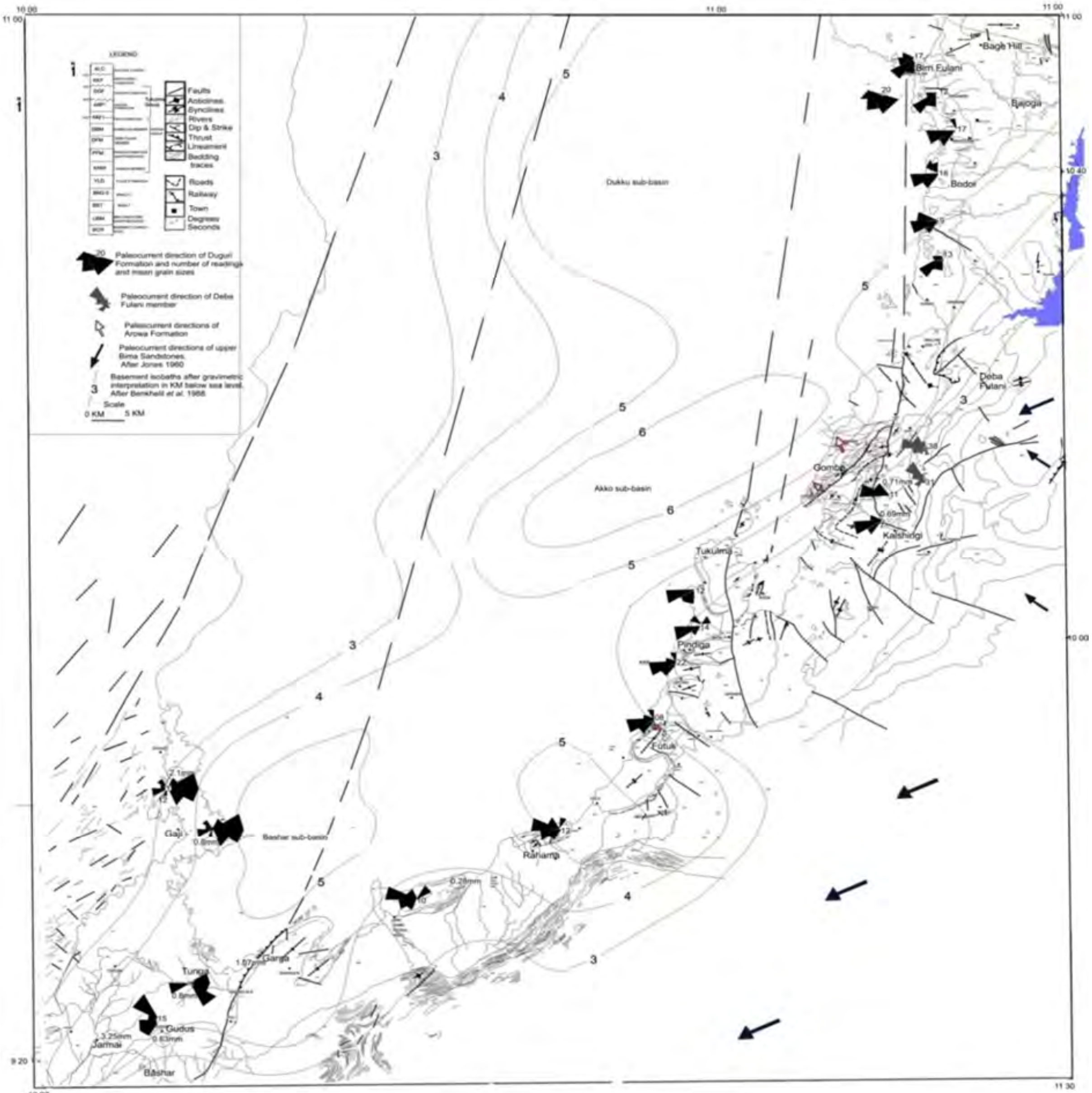


Figure 4: Paleocurrent map of the Cretaceous succession in the western part of the Gongola Basin and superimposed with basement isobath.

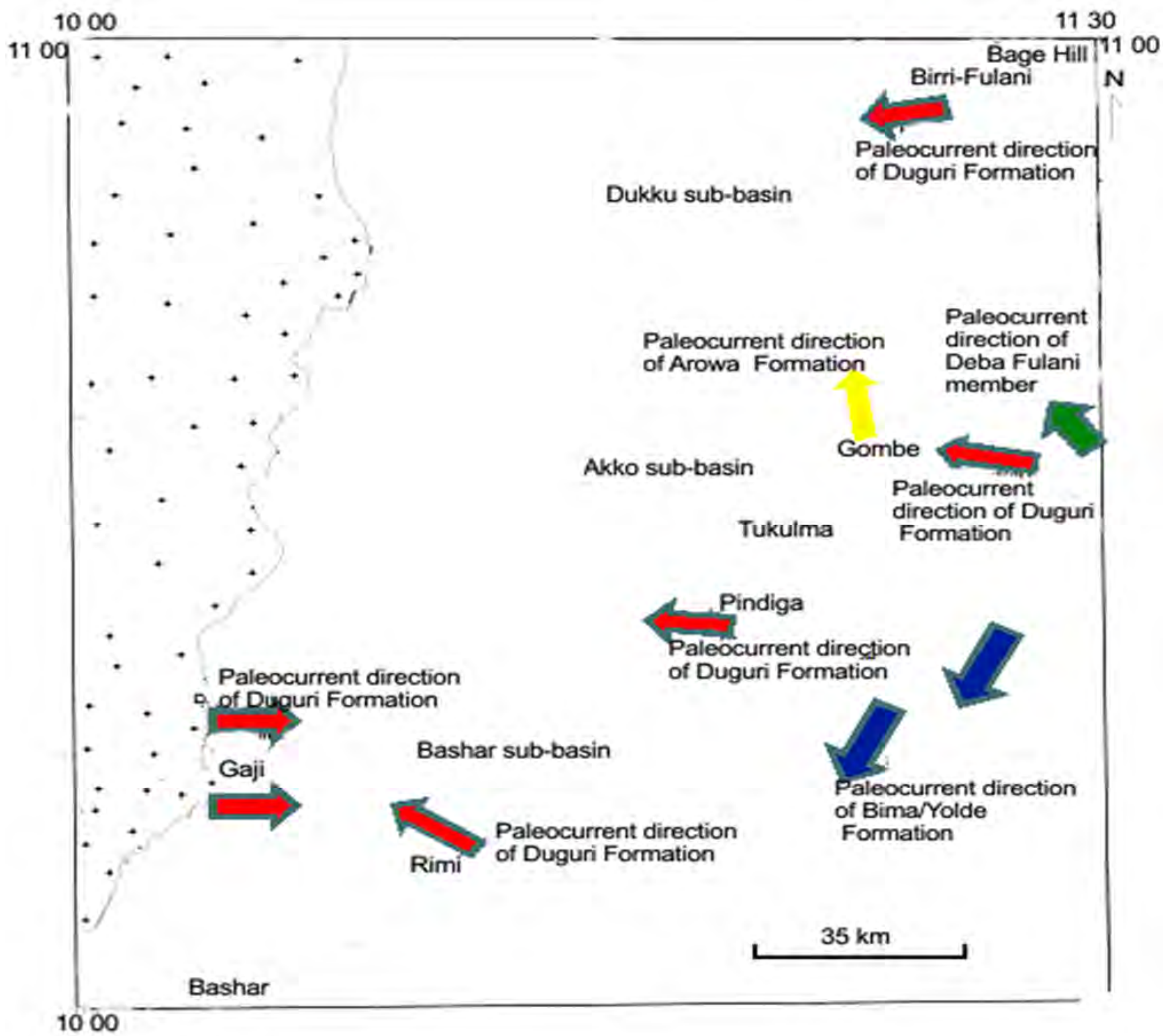


Figure 5: Map showing Cretaceous palaeocurrent directions in the Gongola basin.

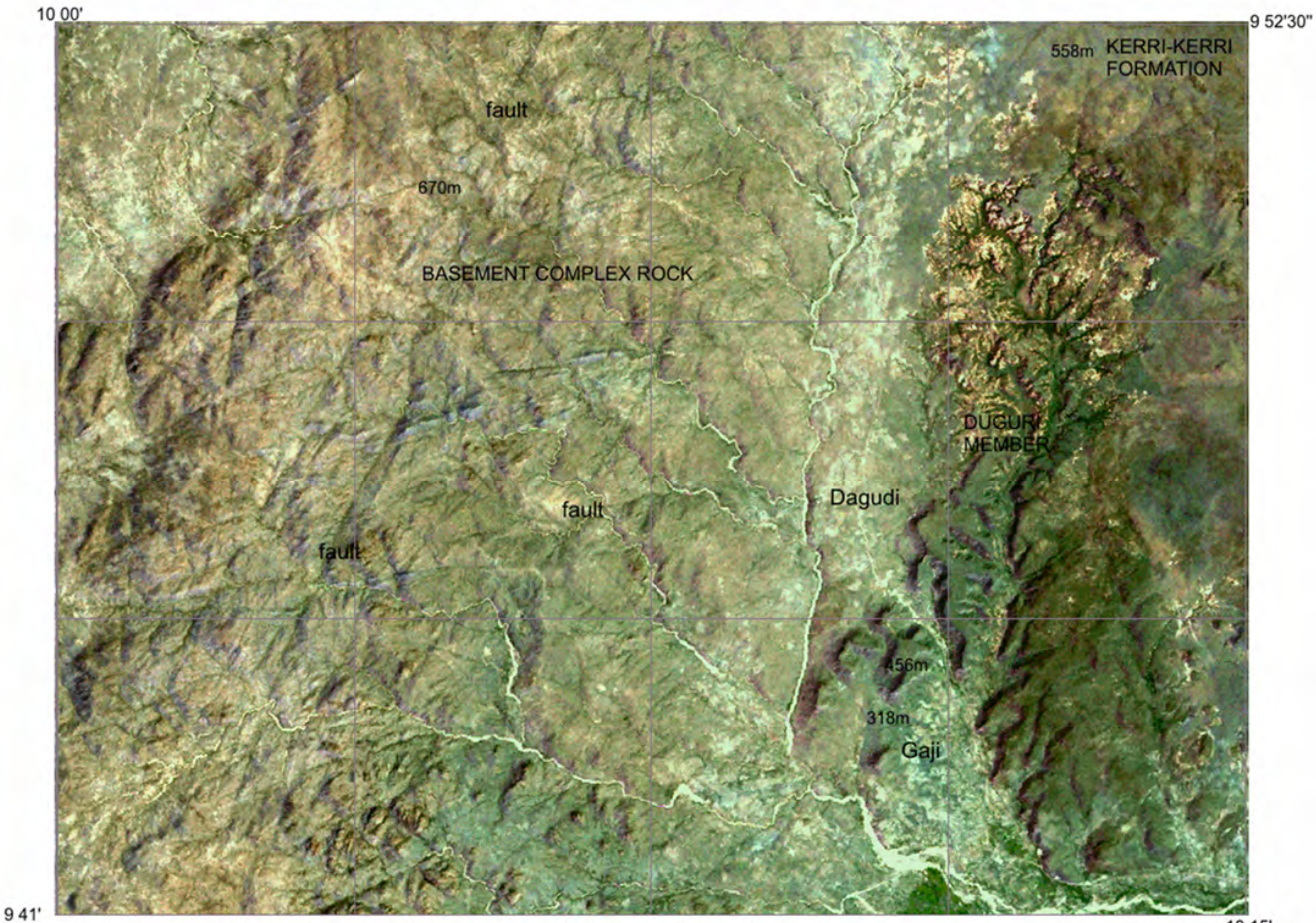


Plate 1: A landsat ETM+ draped on DEM Showing the NE-SW trending faults that control the deposition of Duguri Formation and Kerri-Kerri Formation at the western portion of the Gongola Basin.

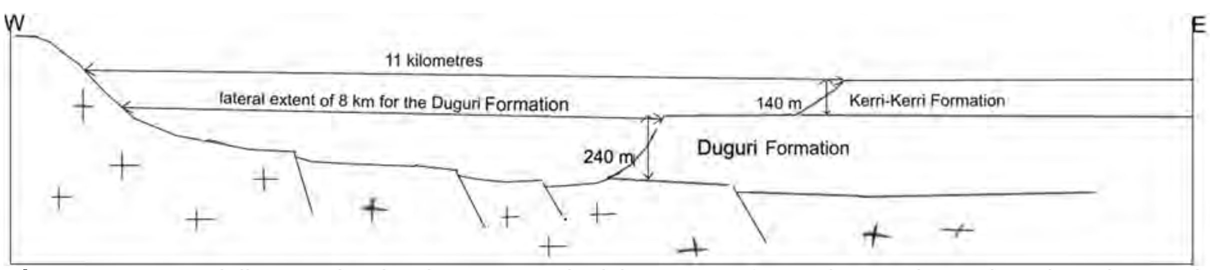


Figure 6: Annotated diagram showing the lateral and original extent of Duguri Formation and Kerri-Kerri Formation in relation to the NE-SW trending faults that controlled the deposition of sediments along the western margin of Gongola Basin at Yuli area.

Facies Relationship Within The Campano-Maastrichtian Depositional Systems

The lateral and vertical facies relationships within the Campano-Maastrichtian succession are shown in (Figures 7 and 8). The marine basin contains the upper Fika Formation and the Arowa Formation. The lithofacies distribution conforms with the previous authors on the direction of retreat of the sea. The Campano-Maastrichtian in most of the Nigerian part of the Chad Basin is shaly throughout (Carter *et al*., 1963) which conforms with the proposal of a sea retreating to the north. The Duguri Formation is younger than the Arowa Formation in places but probably in part an age-equivalent especially where the contact between them is transitional (Figures 7 and 8). Lack of precise dating within the Campano-Maastrichtian succession however, makes this conclusion provisional.

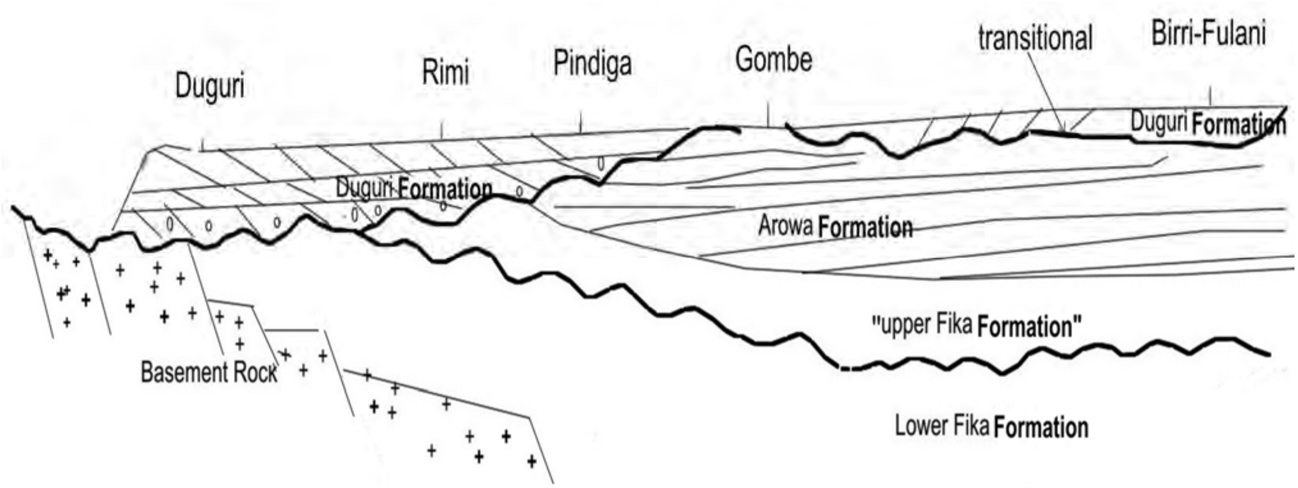


Figure 7: Inferred lateral and vertical facies relationship within the Campano-Maastrichtian depositional systems.

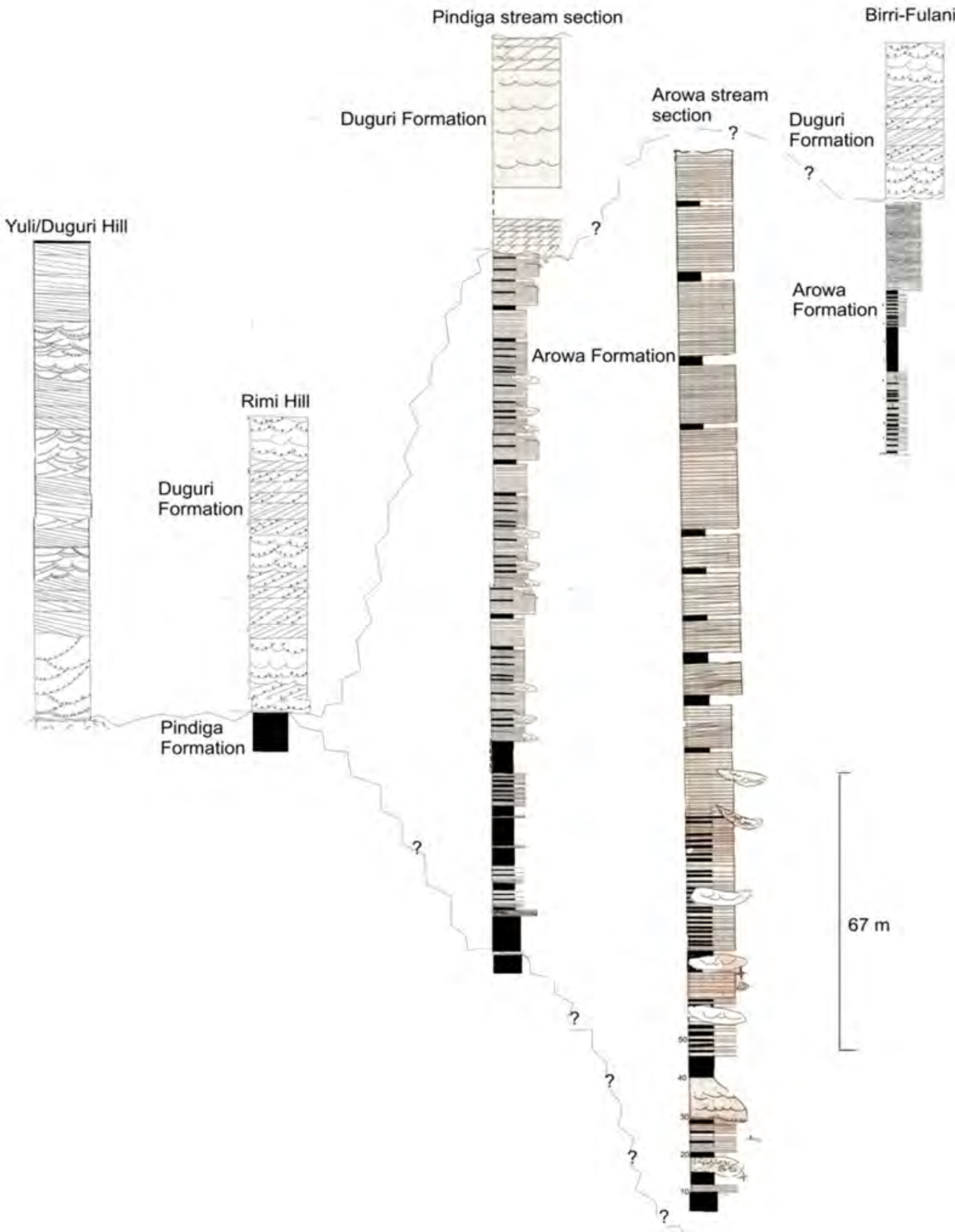


Figure 8: Diagram showing the inferred lateral and vertical facies relationship within the Campano-Maastrichtian depositional systems.

CONCLUSION

The palaeocurrent analysis inferred that the Campano-Maastrichtian successions in the Gongola Basin in Nigeria, are deposited in an open sea located to north-north-west. These currents transported sediment into the Dukku, Akko and Bashar sub-basins with an overall centripetal pattern. The main structural features of the successions at the western part of Gongola Basin from E-W, are the N-S, NE-SW and NW-SE trending faults. These series of faults controls the basin subsidence and deposition of the Campano-Maastrichtian succession in the Dukku, Akko and Bashar sub-basins. The lithofacies distribution indicates a northernly retreat of the sea.

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