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New insights into tectonostratigraphy and structural style of the Late Cretaceous sediments of Gongola Basin, Northern Benue Trough, NE Nigeria

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ABSTRACT
Tectonostratigraphy of the Gongola Basin is still least understood. This study aims to present a new insight into tectonic evolution and structure of Gongola Basin based on field geology. The study revealed that sedimentation processes commenced in the depression created by tectonic subsidence as a result of Early Cretaceous tectonic events, which affected the basin and subsequently, reactivated the Santonian/Maastrichtian compression. The sediments were affected by Santonian and Maastrichtian compressions resulting in syn-sedimentary deformation and post-depositional faulting and folding. The imprints of dextral strike-slip faults and reverse faults on pre-Maastrichtian and Maastritchtian sediments formed as a result of reactivation of the pre-Santonian and Santonian faults. Active rifting phase followed by uplift and subaerial exposure as in Gombe inlier, and adjacent areas such as Teli Fault, Kaltungo, Burashika inliers followed by subsidence allowing for initial deposit of continental sediments and later, marine ingression which causes a change from continental to marine environments during Cenomanian. Eustatic adjustment in Late-Cenomanian to Early-Turonian led to first major transgression and short-regressive phase in middle Turonian-early Santonian. Mid-Santonian compression folded the sediments and was followed by subaerial erosion of parts of the folded sediments. Another eustatic adjustment in Late-Santonian-Campanian led to a short-lived transgression. A gradual retreat of the sea in the Maastrichtian resulted in progradation of Gombe Sandstone. Late Maastrichtian compression in end-Cretaceous tectonic event folded and tilted Gombe Sandstone, responsible for the angular unconformity that existed between Gombe Formation and overlying Paleocene sediments of Kerri-Kerri Formation, mostly restricted to NW of the basin.

Keywords:
Tectonostratigraphy,
Structure,
Cretaceous,
Gongola Basin.

INTRODUCTION

The structure and stratigraphy of coastal and intracontinental basins of West Africa are broadly similar in tectonic style and succession of facies as all the basins originated in response to basement fragmentation, block faulting, subsidence and rifting accompanying the separation of the South America and Africa plates consequent upon the early Cretaceous opening of the South Atlantic Ocean and the Gulf of Guinea (Benkhelil, 1989). This had led to the deposition and accumulation of sediments ranging in thickness between 5km in the northeast to over 12km in the southwest (Hoque and Nwajide, 1985). The Benue Trough is a sedimentary basin of about 1000km long, and 100-150km wide with a NE-SW tectonic trend and is filled with 5-6km thick mainly fluvial to marine Cretaceous sediments overlying the inherited Pan-African faulted basement rocks (Maurin, 1986).

At the south-western end, the Niger Delta has built a wedge of fluvial, deltaic and submarine fan deposits into the Atlantic Ocean (Fig. 1). Consequent upon the opening of the South Atlantic, the third arm of the tripartite tectonic stresses created as a result of the failure of the third arm to open into the Nigerian sector constitutes a part of the West and Central Africa Rift System comprising of Niger, Chad, Cameroon and Sudan (Fig. 1). This failed arm extended up to the north eastern Nigeria where it is characterized by a Y-shape. The Gombe-Pindiga area in the Gongola Sub-basin forms part of the Northern Benue Trough structural framework. Therefore, the origin and tectonic setting of the Northern Benue Trough is best discussed in relation to the structural and tectonic framework of the Benue Trough as a whole. In the Gongola Sub-basin of the Northern Benue Trough, interactive tectonic forces and climatic changes are the major driving forces responsible for the basin evolution. The unique position and appearance of the trough within Nigeria and the West African structural framework tends to suggest a kind of structural control for the deposited sediments, and these have led to series of postulations for its origin.

This study aims to present new insight into tectonostratigraphy and structuration of Gongola Basin based on detail field evidences. The study of the Late Cretaceous sediments was extended on a regional basis to include the synthesis of the geology of Gongola Sub-basin with particular interest paid to the stratigraphy as well as the tectonic and structural evolution of the basin. Integration of the tectonic, sedimentological and stratigraphic data assisted to deduce the stratigraphy, depositional environment and the reconstruction of the paleogeography. The study covers detail investigation of the Late Cretaceous sediments of the Gongola Sub-basin in Pindiga-Gombe area which forms part of the Federal survey of Nigerian 1:50,000 topographic sheet 172 (Gombe NW and SW). The investigation encompasses reconnaissance as well as detail geological mapping to identify and make detailed description of outcrop sections of the formations in relation to tectonic structures that defines the order of stratigraphic successions and delineate lithological boundaries.

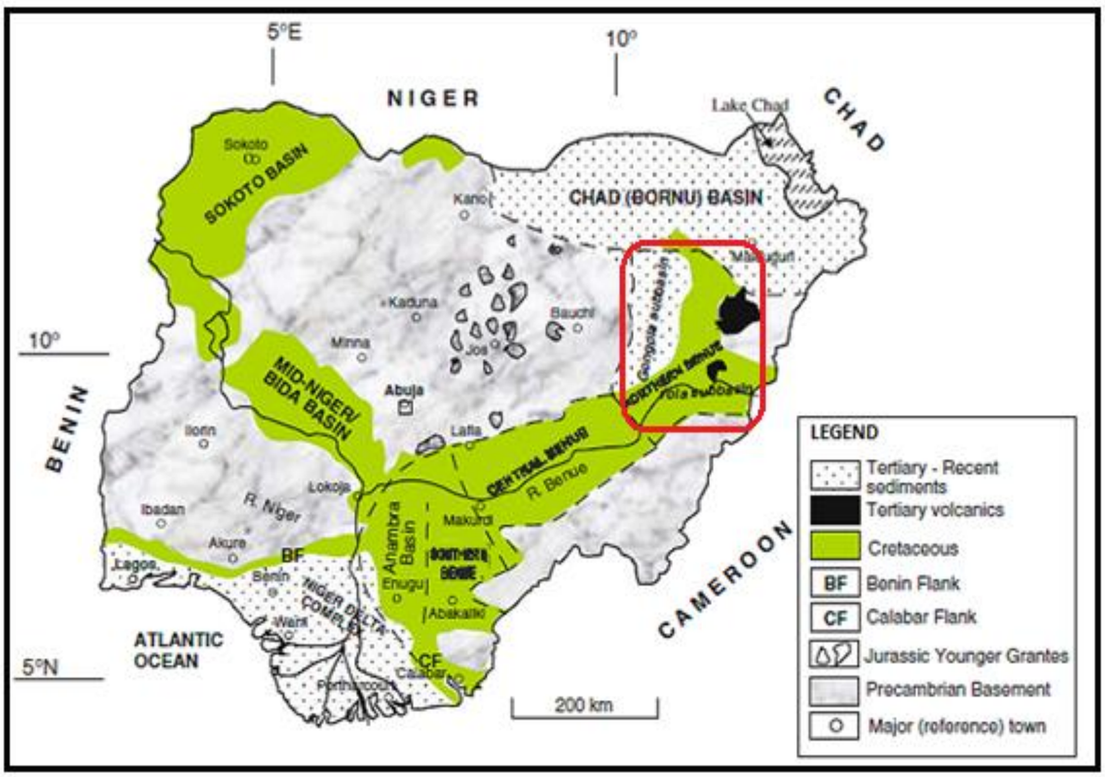


Figure 1: Generalized geological map of Nigeria and position of the Northern Benue Trough (after Obaje, 2009)

Geologic setting

Several studies of the Benue Trough are available in the areas of its origin (Carter *et al*., 1963; Grant, 1971; Benkhelil and Robineau, 1983), stratigraphy (Allix and Poppof, 1983; Zaborski *et al*., 1997; Obaje and Hamza, 2000; Abubakar, 2006), tectonic and structures (Ajakaiye,1981; Benkhelil, 1986, 1989; Maurin, 1986), mineralization and gravity and aeromagnetism (Ajakaiye, 1986). King (1950) proposed a rift origin for the Benue Trough. In his opinion the rift was in response to the breakup of Gondwanaland. This model assumes a tensional regime for the fault-bounded basin. Stoneley (1966) and Wright (1968) based on the plate tectonic theory proposed a graben origin related to the readjustment of African plate after the Cretaceous opening of the Gulf of Guinea. This model assumed an axial network of strike-slip faults acting in a sinistral way. A sea floor spreading model was proposed by Burke *et al*. (1970) for the Southern Benue Trough, and that the spreading terminated by Late Cretaceous. Grant (1971) and Thiessen *et al*. (1979) put forward a three-armed rift model in which the Benue Trough is believed to be an aulacogen where there are two true rift systems -one toward the North America and another towards South

Africa and the third which would have opened the African continent through Nigeria but failed and left a trough which was subsequently filled with sediments. This model invoked a stretching on a continent scale for the opening of the trough comparable to the East African Rift System (Guiraud, 1990, 1993).

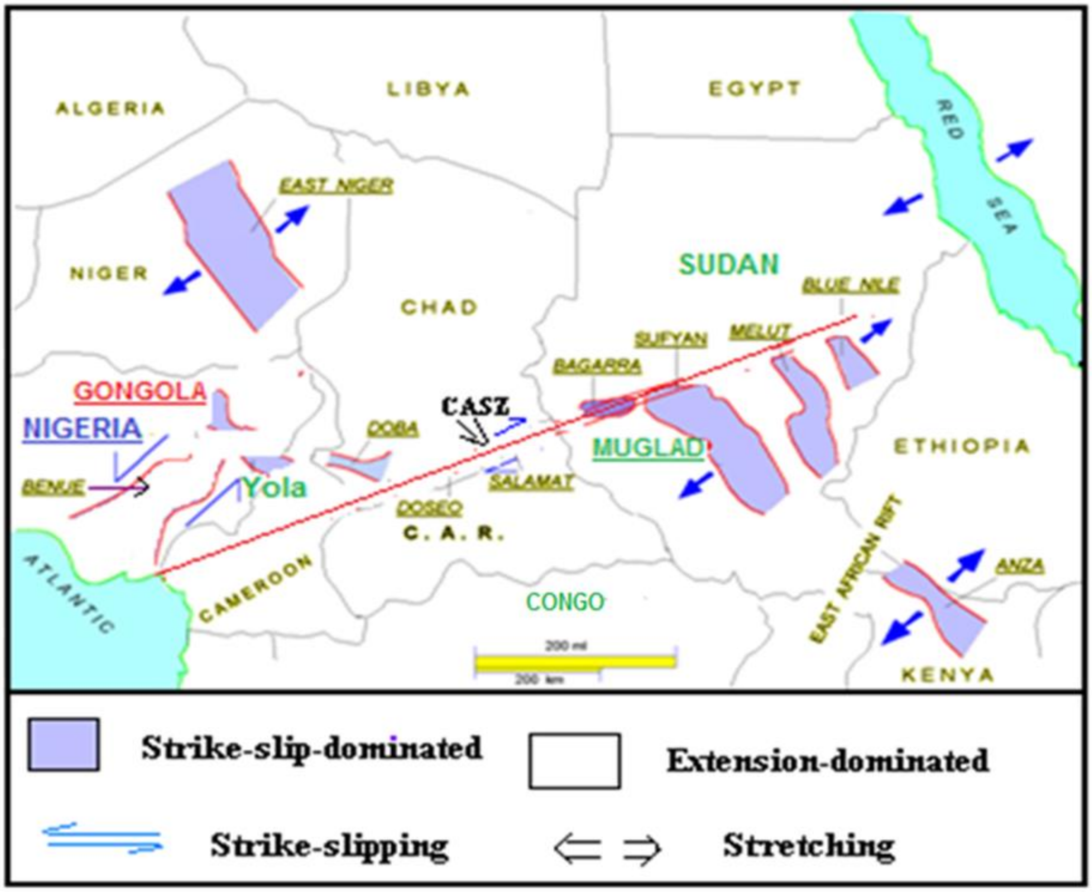


Figure 2: Map showing the origin of Gongola Sub-basin in the Benue Trough as part of the West and Central African Rift System (modified from Fairhead and Green, 1989)

The model of Benkhelil (1982) and Benkhelil and Robineau (1983) comprises of a transcurrent movement initiated on a continental extension of the Equatorial transform faults, the Benue Trough being the result of the juxtaposition of pull-apart basins along strike-slip faults. Benkhelil (1983), Benkhelil and Robineau (1983), Benkhelil (1986), Maurin (1985) and Rebelle (1990) described the Cretaceous Benue Trough as a set of juxtaposed pull-apart basins initiated and formed by sinistral strike-slip fault along N60-145E inherited transcurrent faults all within the major trough. This showed that sinistral wrenching was the dominant tectonic process during the trough evolution (Benkhelil 1983). This kind of model was based upon the existence, below the Benue Trough axis of the central positive gravity anomaly interpreted as basement highs (Cratchley and Jones 1965: Benkhelil *et al.*, 1989). Field evidences and gravity, magnetic and SLAR imagery data interpretation of Benkhelil *et al.* (1989) indicated that transcurrent motion initiated by a set of deep seated faults was superimposed on the axial high which played a significant role and controlled the tectonic evolution of the Benue Trough. This view was consistent with the assumption of Einsele (1991) that many extensional tectonics and rift zones express a significant strike-slip component. On these bases, the two models comprising rift tectonics and pull-apart basin related to wrench faulting with a directional NE-SW trend among other postulations were major mechanisms considered for the origin of the trough. It has been generally believed that the Benue Trough is controlled by mega-rift structures due to complex faults along the basin geometry (Carter *et al*., 1963).

Tectonic structure of Gongola Basin

The Northern Benue Trough (Fig. 1) has been discussed by many authors (*Carter et al*., 1963; Cratchley and Jones, 1965; Zaborski *et al.*,1997; Benkhelil *et al*., 1989; Guiraud, 1990, Sarki Yandoka *et al*., 2014). The Trough comprises of the Gongola Sub-basin and the Yola Sub-basin (Fig. 1) and the (Lau-Lamurde Sub-baisn) (Guiraud, 1990; Akande *et al*., 1998; Dike, 2002). The area is separated from the Chad Basin in the north by Zambuk ridge or Dumbulwa-Bage high (Zaborski, 1998) which run roughly northeastward. It is roughly bounded by the Adamawa highland to the east and the Nigerian Central Basement rocks to the west and northwest. This part of the trough is traversed by four NE trending sinistral strike-slip faults comprising the Gombe, Bima-Teli, Kaltungo and Shani faults tectonically related to the oceanic transform fault zones (Maurin *et al.*, 1986). The geology of this area was first described by Carter *et al*., 1963 which was a precursor to the strike-slip tectonic studies demonstrated on the Cretaceous rocks by Benkhelil (1989) and Guiraud (1993).

The geology of the Northern Benue Trough comprises of tectonically controlled sedimentary rocks of the Gongola and the Yola Sub-basins (Fig. 2). The Cretaceous sediments in this area are mainly composed of five sedimentary formations namely, Bima, Yolde, Pindiga, and Gombe Formations. The stratigraphic succession in the Gongola Sub-basin include: Bima Formation which which is the oldest formation overlies the basement complex unconformably. The Bima Formation is of Late Jurasic to Albian in age. The Yolde Formation conformably overlies the Bima Formation and is considered a transition between the Bima Formation and the overlying Pindig Formation. The Yolde Formation ranges in age from Lower Cenomanian to Upper Cenomanian. The Pindiga consists of limestone-shale beds overlying the Yolde Formation. The Pindiga Formation represents a shallow marine environment is considered as an upper Cenomanian to Turonian age. The dominantly shales of Fika is considered as the upper part of Pindiga Formation and deposited in the mid-Santonian to Campanian (Zaborski *et al*., 1997). The Gombe Formation is the youngest Cretaceous sediments in the stratigraphic successions of the Gongola Sub-basin. The Fomation overlies the Pindiga Formation and is considered as continental deposits of Maastrichtian age that marks the end of the Cretaceous deposit in the Gongola Sub-basin.

The northern part of the Benue Trough has similar structural and tectonic characteristics with the Termit Basin of Niger and western Chad, the Bongor, Dossa, Doba and Doseo Basins of Southern Chad, the Salamat Basin of Central African Republic and Muglad Basin of Sudan (Fairhead and Green 1989). These basins including those of Northern Benue Trough constitute the extensive West and Central African Rift Systems (WCARS) in a single tectono-structural domain (Fig. 2). This tectonic structure was reactivated by a set of sinistral strike-slip transcurrent faults which generated pull-apart sub-basins along inherited NE-SW trend (Bumby and Guiraud, 2005). In Northern Benue Trough, these basins are represented by the Y-shaped tectonic trend, each controlled by reactivated inherited Pan-African fractures, that is the N120ºE or WNW-ESE trending Yola Sub-basin, the N50ºE trending Lamurde domain, and N180ºE or N-S trending Gongola Sub-basin. The structural geology of the area can as well be related to the tectonic events which occurred in the Jurassic period when anorogenic Younger Granites were emplaced in around Jos Plateau area (Ajakaiye, 1981). The work of Ajakaiye *et al*. (1986) has shown that the concentration of alkaline Younger Granite along the NE-SW narrow magnetic lineaments corresponds to pre-existing zones of weakness in the African Crust which may have influenced the rifting of the African continental margin during the Jurassic. Two major tectonic events affected the Northern Benue Trough .

The Mid-Cretaceous Sinistral Wrenching Tectonic Events

The m-Cretaceous sinistral wrenching tectonic events are genetically related to the evolution of the Northern Benue Trough because of the similarity and timing of the structural framework of the trough which is well delineated by and coincided with the numerous NE- SW trending transform fault zones (Maurin *et al.*, 1986). Guiraud (1990) based on evidences from microtectonics and microfault analyses supported a mid-Cretaceous wrenching as responsible for the numerous NE-SW trending transcurrent fault zones. That all these structural trends were formed in the late Pan-African and were reactivated as sinistral strike-slip faults in the mid- to Late-Cretaceous times. These structural trends sum up to four major zones of NE-SW trending faults. From North to South, they include the N45ºE Gombe fault, the N50ºE Teli-Bima, the N55ºE Kaltungo fault and N60ºE Burashika fault (Fig. 3). These faults/lineaments bear the imprints of the Chain and Charcot transform fault lines initiated in the Jurassic tectono-dynamic events (Guiraud, 1983). These fracture zones emanate from the Mid-Atlantic Ridge cutting through the Gulf of Guinea and are thought to be strike-slip or transcurrent faults. They are generally assumed to be the surface effects of fracture zones of tensional or shear zones. In the Northern Benue Trough several NE-SW lineaments (including Gombe and Kaltungo Inliers) are essential components in the structure of both Pan-African Basement and Cretaceous sediments. According to Guiraud (1990), these strike-slip faults cut across the Cretaceous deposits and are extended into the basement.

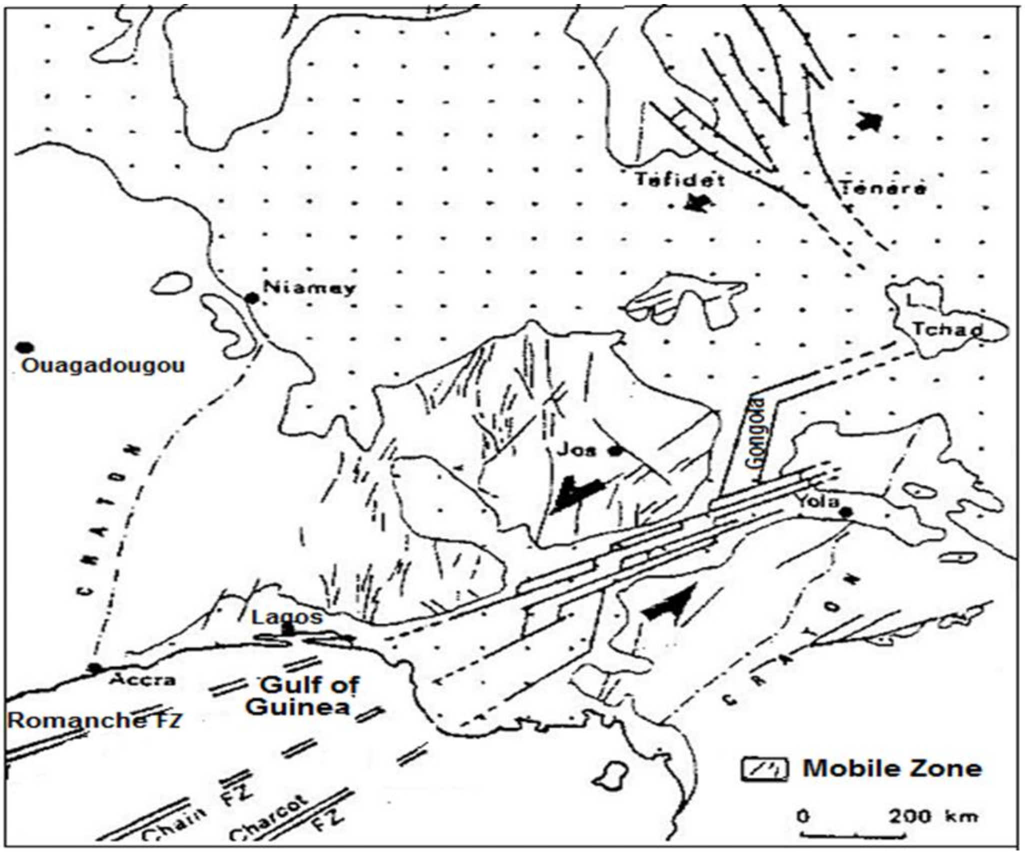


Figure 3: Connection between the Gombe/ Kaltungo Faults in Northern Benue Trough and the fracture zones in the Atlantic Ocean initiated by the Younger Granite intrusions (after Guiraud, 1990)

According to Maurin *et al*. (1986) the Kaltungo lineament and other similar ones are related to the Benue tectonics by exhibiting both ductile shear zones which are expressed by mylonitic bands generated by the Pan-African dextral wrenching and brittle shear zones and are represented by fault rocks of cataclastic series related to a sinistral wrenching occurring during the Mesozoic. In the Gombe inlier, these brittle faults are superimposed to dextral Pan-African NE-SW mylonites where they are represented by cataclasites and the Cretaceous deposits by the Megaslices of (crushed) Bima Sandstone (Maurin *et al*., 1986). As earlier indicated, these inherited faults seemed to correspond with the weak zones initiated by the anorogenic intrusions of the alkaline granites. The mid-Cretaceous events are precursors to the Late Cretaceous events which actually affects primarily the sediments of the Pindiga-Gombe area.

The Late Cretaceous Tectonic Events

The Late Cretaceous tectonic events (Benkhelil, 1982) comprise the Santonian and Maastrichtian events where the whole Cretaceous deposits/sediments were subjected to folding associated with intense fracturation. The mega-structures of the tectonic events are represented by N60°E striking Lamurde anticline and Dadiya syncline and the associated fracturation and shear zones as expressed in the basement by fault breccias (Maurin, 1986) where cataclasites are aligned on a sinistral NE-SW strike-slip fault (Maurin 1986). The later- or end-Cretaceous (Maastrichtian) event is characterized by transpressional tectonics represented by folded beds of the Maastrichtian Gombe Formation which subsequently were eroded and overlain unconformably by Paleocene continental Kerri-Kerri Formation displaying a well exposed angular unconformity. This deformation corresponding to the Maastrichtian compression is dominated by folding and reverse/thrust faulting. On the Gombe Inlier, NE-SW sinistral strike-slip Gombe faults displayed intense deformation of the Albian Bima deposits. In view of this, is assumed that lineaments played a significant role in the origin of the trough.

MATERIALS AND METHODS

The field equipment used for the geological mapping include hammer and chisel, compass and clinometer, pocket still tape, a hand lens, Global Positional System (GPS), camera and mobile phone, topographic base maps and map cases, acid bottle, hard cover field Field studies involved reconnaissance surveys and systematic geological mapping via selected traverses. Most traverses were taken along the stream sections, road cuts and footpaths across the study area. Detailed information such as bed thickness, lithology, sampling points, facies descriptions taking from the base to the top of the section, strikes and dips and attitude of planar sedimentary structures from within the various formations were recorded. The Thickness of the beds were measured and lithologically described. The nature of the bed contacts was examined and genetically-related lithologies were grouped into facies. Strikes and dips of such planar structure as folds and linear structures such as plunge of folds, joints, joint directions and dips, faults and directions of displacement are measured. The spatial distribution of sedimentary assemblages combined and evidences from the tectonic structures, allowed the palaeoenvironment and tectono-stratigraphic framework of this sub- basin to be reconstructed.

RESULTS AND DISCUSSIONS

Tectonics and structures

In the Late Cretaceous time, two major tectonic events affected the sediments of the Pindiga-Gombe area in the Gongola Sub-basin. These are the Santonian and the Maastrichtian tectonic events. The Santonian tectonic event affected the pre-Santonian to Santonian sediments while the Maastrichtian tectonic events affected the pre-Maastrichian to Maastrichtian sediments.

The Santonian Tectonic Events

Tectonic events recognized in the sediments in the Pindiga-Gombe area are dominantly sinistral strike-slip faults.

(i) Sinistral strike-slip faults

The sinistral strike-slip faults in this area are represented by the NW-SE strike-slip faults on the rocks of Yolde Formtion and the NE-SE sinistral strike-slip faults on the Gombe inlier and related sediments.

(ii) The NW-SE sinistral strike-slip faults

The NW-SE trending sinistral strike-slip faults on the sandstone of the Yolde Formation was generated as a result of displacement caused by NW-SE trending fracture that faulted the pre-existing NE-SW trending fracture. The main evidence of this tectonic event is the sense of displacement on the rock.

(iii) The NNE-SSW to NE-SW strike-slip faults

Two sets of strike-slip faults affected the Late Cretaceous sediments, for example, the NE-SW (N40ºE) trending Gombe Hill (Inlier) and the overlying Late Cretaceous lithostratigraphic succession of the Ceomanian-Santonian sediments of the Yolde and Pindiga Formations were affected by sets of NNE-SSE to NE-SE sinistral strike-slip faults in the Santonian tectonic event. These overlying rocks were affected by the earlier Gombe lineament which displaced (faulted) the rocks sinistrally. The effect of this fault is conspicuously noticeable on the map of the Gombe inlier. The mode of formation is related to the late Pan African fault of Gombe lineaments which were reactivated in the Santonian by sinistral strike-slip faults. Field evidences include brecciated bands, cataclasite (crush conglomerate) which penetrate the basement and crushed zones in the sediments of Yolde Formation represented by horizontal slickesides and the sense of displacement. This intense deformation shows evidence of a sinistral displacement along the visible NE-SW Gombe fault zone (Fig. 4).

The Maastrichtian Tectonic Events

The Maastrichtian event in Late-Cretaceous sediments comprises of compressional and extensional tectonics. The results of these events include sinistral and dextral strike-slip faults; soft-sediment and gravity related deformations that affected both the Maastrichtian and the pre-Maastrichtian sediments in the Gongola Sub-basin.

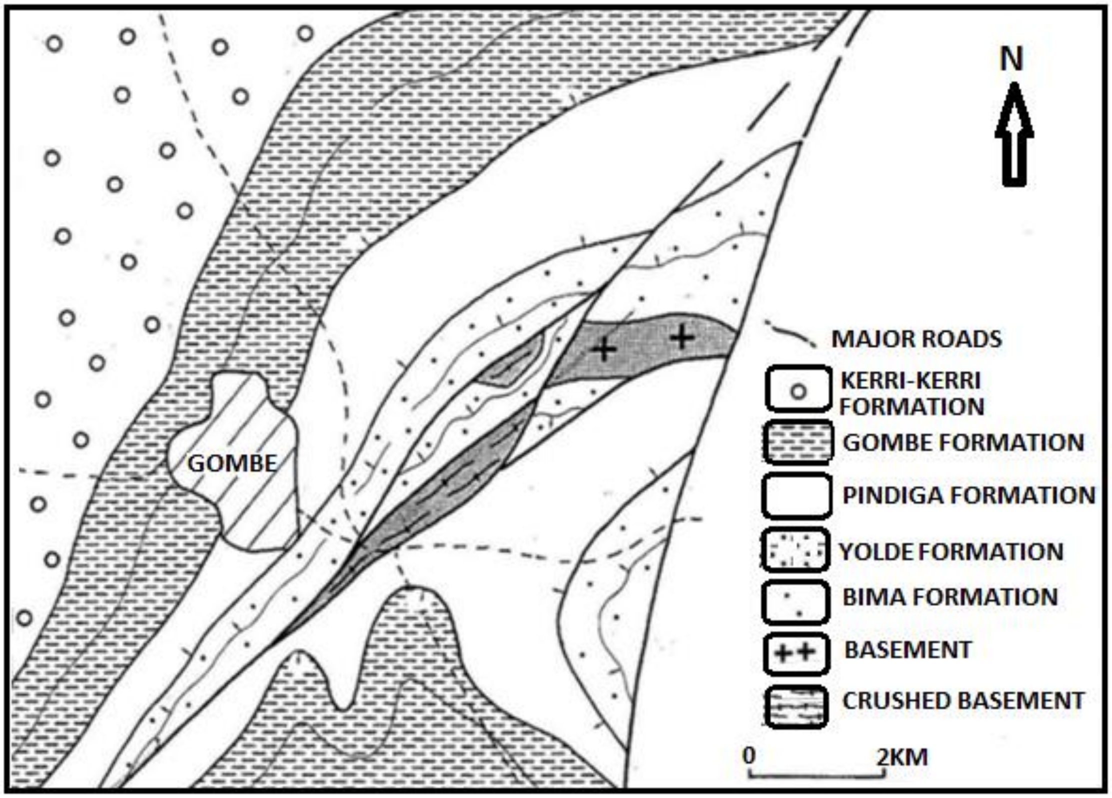


Figure 4: Geological map of Gombe Inlier showing sinistral strike-slip faulting in the pre-Santonian sediments in the Gombe Fault zone

(i) Sinistral strike-slip faults

An example of these faults is the flower structure in Fan-Daya and Wuro-Biriji areas in the Maastrichtian Gombe Formation. The mode of formation of the flower structure is related to a displacement that is dominantly reverse with overall transpression and small component of shortening. As the faults tend to join downwards onto a single strand in the basement, the geometry has led to these being termed flower structure. At the surface, the strike-slip faults consists of en- chelon and braided segments probably inherited or reactivated from the NE-SW sinistral strike-slip faults that affected the Cenomanian-Santonian sediments. The flower structure in the Gongola Sub-basin is related to two generations of sinistral strike-slip faults. For example, the lithostratigraphic succession of the Gombe Inlier has been affected by the earlier Gombe lineament (fault) and the later Wuro Ladde-Wurin Dole faults. The movement of the older Gombe fault started in the Santonian causing a basement thrust which initiated the first Santonian N-S (N174E) compression, while the younger Wuro Ladde-Wuro Dole fault which sinistrally truncates the Liji Hills anticlines at the northeast portion of the Gombe inlier resulted in a NEE-SWW trends which developped during the Maastrichtian compression. Wuro Ladde-Wurin Dole compressional faults resulted in the positive flower structures in the Fandaya area in the Gongola Sub-basin.

(ii) Dextral strike-slip faults

In the Wuro-Biriji stream section, the NW-SE dextral strike-slip fault which is the result of the Maastrichtian tectonic event in the Maastrichtian Gombe Formation is related to the Maastrichtian compression. The dextral displacement of the NE-SW trending sediments of Gombe Formation is related to the transpressional process associated with the reactivation of the earlier NE-SW sinistral strike-slip faults in the Santonian. In the upper part of the Gombe Sandstone Formation in Gabukka stream section, the structural elements of Maastrichtian tectonic event is related first to transcurrent processes associated with the reactivation of the Santonian NW-SE sinistral strike-slip fault as NW-SE trending dextral strike-slip faults and the extension processes is related to the reactivation of the Santonian NE-SW fracture as normal fault. Evidences of the strike-slip and the extensional movements are the presence of intersection of strae. The wall on which the black back stands seemed to have moved northwest as indicated by the horizontal slickensides and downward as indicated by the second set of the strae which indicate vertical movement downward cross-cutting the horizontal strae.

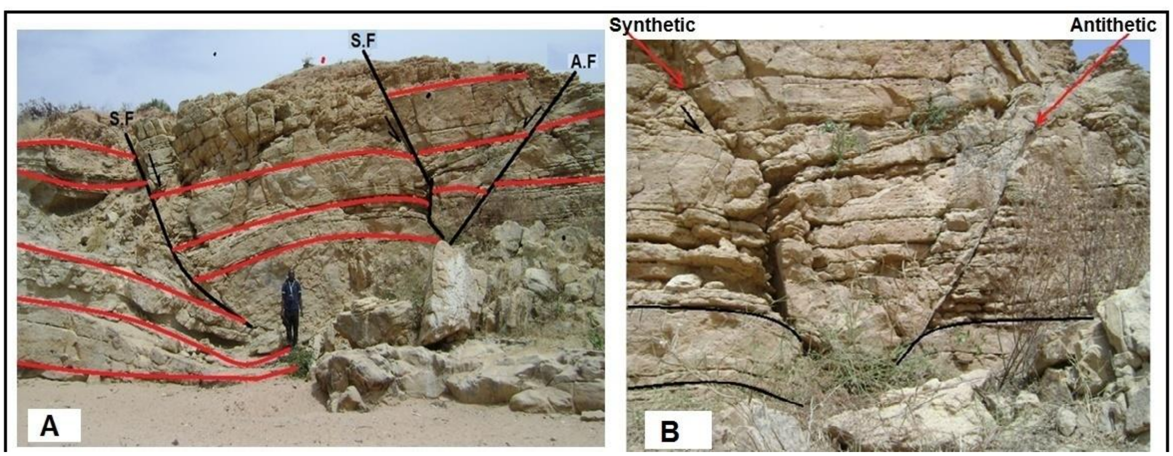
(iii) Folding and faulting

During the end Cretaceous time, Cretaceous sediments of the Gombe Formation were affected by a folding phase which was conjugate to intense fracturation. In the basal part of Gombe Formation in the Gabukka section, folding and faulting occurred contemporaneously. During the late Maastrichtian transpressional tectonic event, some of the Santonian sinistral strike-slip faults were reactivated as reverse faults with parasitic folds in ductile parts of the rocks.

(iv) Unconformity and growth faults

In the upper part of the Gombe Formation, the folded Maastrichtian sediments are abnormally overlain by mudrocks displaying a well expressed angular unconformity. Maastrichtian tectonic event is responsible for the formation of rollover anticline on growth faults in the Gombe Formation in Dabala area. The growth faults occur as a result of the development of normal faults during sedimentation as sediment accumulation on the downthrown block exceeds that on the up thrown block (Fig. 5). The faulting occurs by rotational sliding of the overlying sediments of the Gombe Formation, usually triggered by the movements of overpressured ductile shaly facies of Fika Formation and/or Pindiga Formation during delta progradation. These growth faults are listric in nature near the top of the over pressured shales which slide due to gravity as the mudrocks move under their own weight. The formation of rollover anticlines and growth faults is independent of the underlying basement structural frame. Just as the tectonics and structures is mainly syn-sedimentary/syn-depositional and have been developed as faulted rollover on growth faults.

The contemporaneous deformation of the underlying Fika Shale (Campanian) can be attributed to rapid sedimentation of the overlying Gombe Formation over the uncompacted mobile shale. Growth fault originated due to the development of shale waves in shaly Formation. Local overloading of the delta slope causes free gravitational sliding. The growth fault has a curve concave-upward plane. Movement along such a curved fault plane leads to the warping of sediment in the downthrown block, creating a drag down on axis parallel to the fault. This creates a reversal of dip of strata adjacent to the fault plane and produces a dip into the fault as rollover. Rollover is responsible for the slip on listric normal faults in predominantly deltaic related formation as in Gombe Formation. Growth faults are composed of synthetic fault which dip basinward. In the Gongola Sub-basin especially in the Gombe Formation, growth fault is one of the contemporaneous structural features. The dip at the base of Dabala's growth fault is relatively gentle (30-40^{o}) which corresponds to a high tension rate, and at the top, the dips (50-70^{o}) are steep which means the subsidence rate is compensated by sedimentation. In the Dabala growth faults, the normal faults comprise step fault (half graben) and antithetic rotational normal faults assemblages and rollover anticline which are related to gravity slumping along growth fault planes.



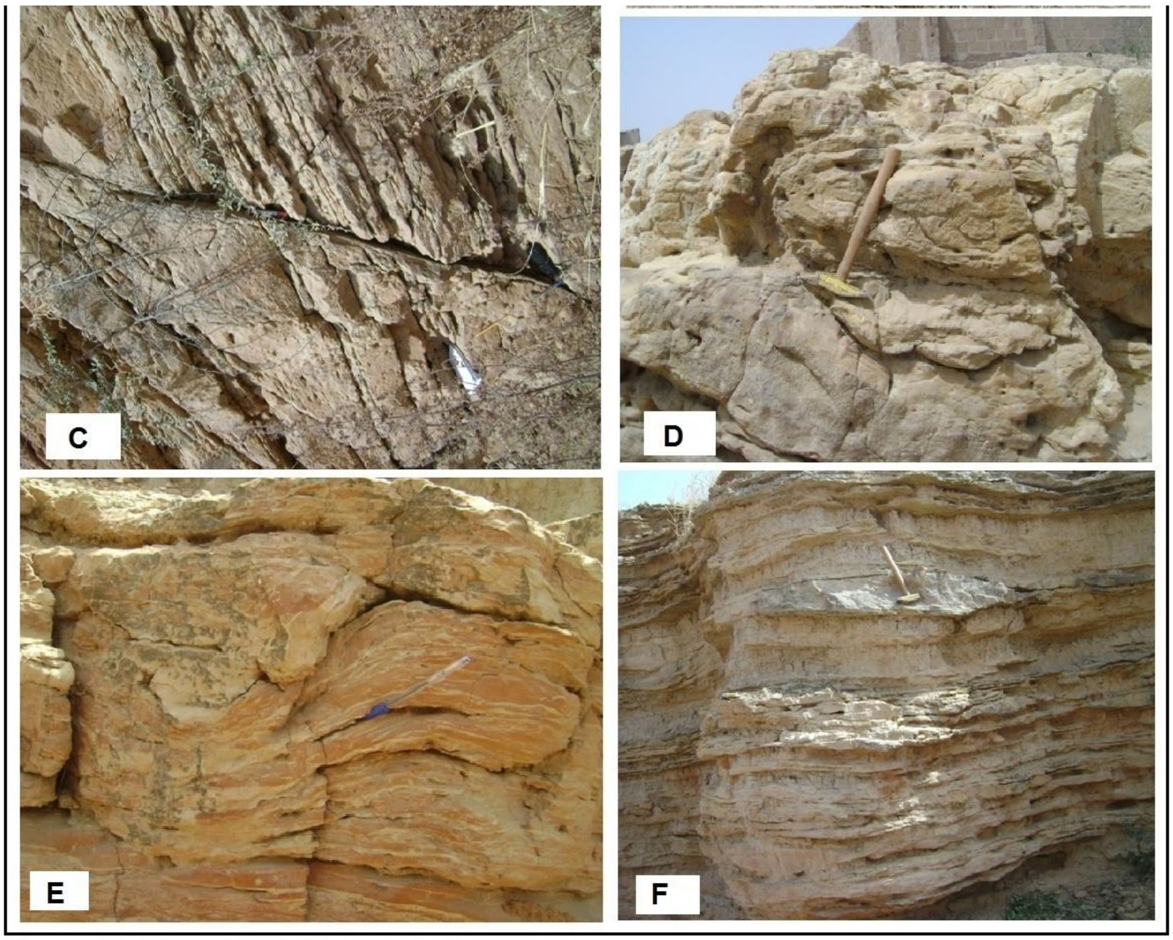


Figure 5: Field photographs showing the folded growth fault around the Gongola Basin

Tectonostratigraphy

The Gongola Sub-basin experienced phases of tectonic events which resulted in subsidence, uplift and accumulation of various types of sediments from Early Cretaceous to the Late Cretaceous. The structural trends resulting from the tectonic events controlled the structuration of the Northern Benue Trough in alternating highs (inliers) and lows (basins) along the general trends. In the Gongola Arm, the high represented by the Gombe Inliers and the low represented by the Pindiga-Gombe basin fills. This corresponds to the pull-apart basin recognized by Benkhelil (1982) of sinistral wrench tectonics some of which are compressional and restricted to the inliers and others extensional which are restricted to the the Pindiga- Gombe basin fill. Subsidence of basin margin concomitant with sedimentation allows a thick pile of sediments in the basin. Thick sediments accumulated in the depression created by the extensional tectonics consisting of continental to marine deposits generated as a result of transgression and regression cycles. The Late Cretaceous succession in the sub-basin (Fig. 6) is composed of four major sedimentary formations. The basal formation of the Late Cretaceous sequences which corresponds to the coastal sedimentary environments of sandstone, mudstone and occasionally sandy clay of Yolde Formation (Carter *et al.,* 1963).

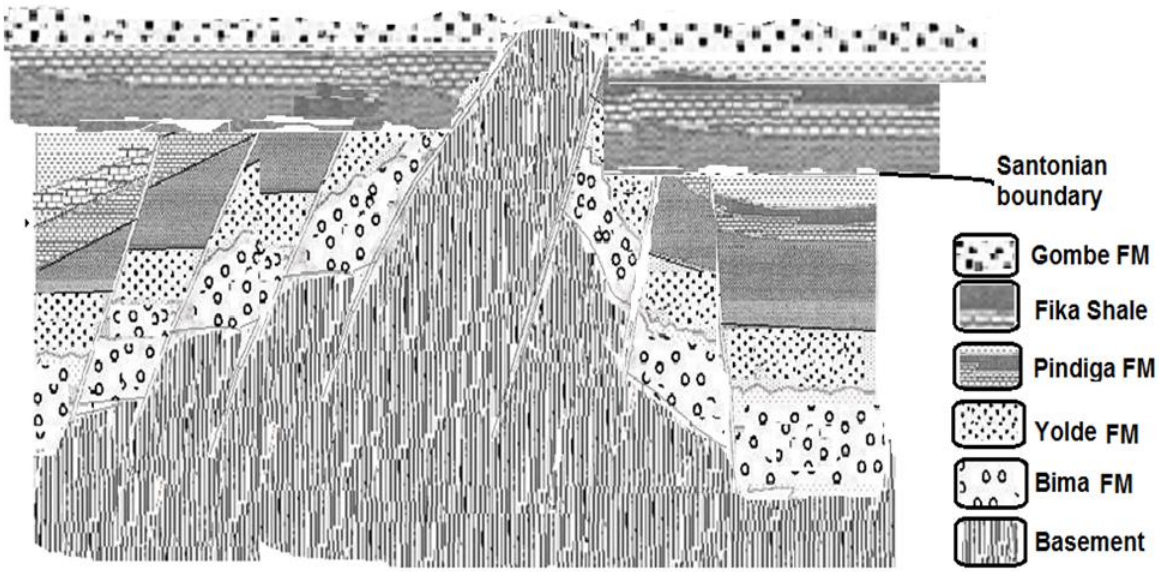


Figure 6: The present-day lithostratigraphic successions in the Gombe-Pindiga area based on tectonic and structures.

The Yolde Formation represents the transition between the underlying Upper Aptian to Upper Albian continental sedimentation and the top marine deposition of the Cretaceous sequence (Pindiga Formation) and considered to have been deposited in a barrier island/deltaic setting (Abubakar *et al.*, 2006). The deposits of Yolde Formation are more of trangressive going into the basin forming fining-upward succession. The succession comprises of basal pebbly sandstone which display crude cross-bedding and trough cross-bedded coarse-grained sandstone filling erosive base of estuary to tidal channel, overlain by the bay-head delta facies which consists of medium grained, bioturbated sandstone and ripple laminated sandstone successions. The cross-beds are biomodal-unipolar to polymodal-bipolar.

CONCLUSION

The study of the new insights into tectonostratigraphy of the Gongola Basin of the Northern Benue Trough revealed that the sedimentation processes commenced in the depression created by tectonic subsidence as the result of the Early Cretaceous tectonic events which affected this part of the trough and were subsequently reactivated in the Santonian/Maastrichtian compression. The sediments have been affected by more than one tectonic events involving Santonian and Maastrichtian compressions resulting in syn-sedimentary (contemporaneous) deformation and post-depositional faulting and folding. The imprints of dextral strike-slip faults and reverse faults on the pre-Maastrichtian and Maastritchtian sediments formed as a result of the reactivation of the pre-Santonian and Santonian faults. Active rifting phase followed by uplift and subaerial exposure as in Gombe inlier, and adjacent areas such as Teli Fault, Kaltungo, Burashika inliers followed by subsidence allowing for initial deposit of continental sediments and later marine ingression causes a change from continental to marine environments during Cenomanian. Eustatic adjustment in the Late-Cenomanian to Early-Turonian led to the first major transgression depositing first the shales and limestones and short regressive phase in the middle Turonian-early Santonian depositing the sandstone (lithic arenite) of the of Pindiga Formation. The limestone-shale is a lagoonal to shallow marine deposits of carbonate ramp depositional system as indicated by the carbonate microfacies. Mid-Santonian compression folded the deposited sediments and was followed by subaerial erosion of parts of the folded sediments. Another eustatic adjustment in the Late-Santonian-Campanian led to a short-lived transgression that resulted in the deposition of the dominantly shaly sediments. A gradual retreat of the sea in the Maastrichtian resulted in the progradation of the Gombe Sandstone depositional system and Late Maastrichtian compression in the end-Cretaceous tectonic event folded and tilted the Gombe Sandstone which was responsible for the angular unconformity that existed between the Gombe Formation and the overlying Paleocene sediments of the Kerri-Kerri Formation mostly restricted to the NW of the basin.

REFERENCES

Abubakar, M.B. (2006). Biostratigraphy, Paleoenvironment and Organic Geochemistry of the Cretaceous Sequences of the Gongola Basin, Upper Benue Trough, Nigeria. Unpublished Ph.D Thesis, Abubakar Tafawa Balewa University, Bauchi, Nigeria.

Abubakar, M.B., Dike, E.F.C., Bukar, S., and Tukur, A. (2006). Lithostratigraphy and paleoenvironments of deposition of Yolde Formation of the Gongola Basin, Upper Benue Trough, Nigeria. Nig. Min. Geosci. Soc. 42nd Annual International Conference, Kaduna, Abstract Vol, pp. 48.

Ajakaiye, D.E (1981) A gravity interpretation of the Benue Trough, Nigeria. Tectonophysics, v. 79, p. 109 - 128. *Doi.org/10.1016/50899-5362(85)80089*

Ajakaiye, D.E.(1986) Aeromagnetic anomalies in and around the Benue Trough, Nigeria. Nature; vol.319, No.6054, pp. 582-584.

Allix, P. (1983). Enviroments Mesozoiques de la partie nord-oreintale du fosse de la Benoue (Nigeria): stratigraphie, sedimentologie, evolution geodynamique. In: Popoff, M., Wiedmann, J. and Klasz, I. (1986). The Upper Cretaceous Gongila and Pindiga Formations, Northern Nigeria: subdivisions, age, stratigraphic correlation and paleogeographic implications. Eclogae Geol. Helv., 79, 343-363. **DOI:** 10.12691/jgg-1-1-3

Benkhelil, J. (1986) Structure et Evolution geodynamique du basin intracontinental de la Benoue (Nigeria). These de Doctorat d'Etat. University of Nice, 226p.

Benkhelil, J. (1989). The origin and evolution of the Cretaceous Benue Trough, Nigeria. Journ. Afr. Earth Sci. 8, 251 – 282 https://doi.org/10.1016/S0899-5362(89)80028-4

Benkhelil J. and Robineau, B. (1989)" Le Fosse de la Benoue Est-il un Rift?" In: J. Benhkelil, M.Guiraud, J.F.Posard and I. Saugy, Eds.*The Bornu-Benue Trough, the Niger Delta and its offshore: tectono-sedimentary reconstruction during the Cretaceous and Tertiary from geophysical data and geology*. In: Kogbe, C.A (2nd Ed.). Geology of Nigeria. Rock View Nig. Ltd. (publ), Jos, Nigeria, 277-310

Burke, K.C., Dessauvagie, T.F.J. and Whiteman, A. J. (1970) Geological History of the Benue Valley and Adjacent Areas. Ibadan. University Press, Ibadan, Pp. 187 – 205 https://doi.org/10.1016/B978-0-444-41549-3.50011-6

Carter, J.D., Barber, W.and Tait, E.A, (1963) Geology of Parts of Adamawa, Bauchi and Borno Provinces in the Northeastern Nigeria. Geological Survey of Nigeria. Bulletin **30**: Pp. 1-109.

Cratchley,C.R. and Jones, J.P. (1965) An Interpretation of the geology and gravity anomalies of the Benue valley, Nigeria. Overseas Geol. Surveys Geophysical Paper, 1, 1-26

Einsele,G.(1991) Submarine mass flow deposits and turbidites. In: cycles and events in Stratigraphy (Ed. by G. Einsele, W.Ricken and A. Seilacher), pp. 313-339. Springer-Verlag, Berlin. 10.2.3.

Ekwo, E.O. (2017). Tectonostratigraphy, facies distribution and depositional environments of Late Cretaceous sediments of Gongola Basin, Northern Benue Trough, northeastern Nigeria. PhD unpublished Thesis, Abubakar Tafawa Balewa University, Bauchi, 201p.

Fairhead J.D. and Green, C.M. (1989) Controls on rifting in Africa and the regional tectonic model for the Nigeria and East Niger rift basins. J. Afr. Earth. Sci., v.8, p. 231-249. https://doi.org/10.1016/0040-1951(88)90265-X

Grant, N.K. (1971). The South Atlantic Benue Trough and Gulf of Guinea Cretaceous Triple Junction. Geol. Soc. Amer. Bull., 82, 2259 - 2298. https://doi.org/10.1130/0016-7606(1971)82[2295:SABTAG]2.0.CO;2

Guiraud,R.M. (1990) Tectono-sedimentary framework of the Early Cretaceous continental Bima Formation (Upper Benue Trough, NE Nigeria). Jour. Afr. Earth Sci. 10, 341 -353. https://doi.org/10.1016/0899-5362(90)90065-M

Guiraud, R.M. (1993) Late Jurassic rifting - Early Cretaceous Rifts of Western and Central Africa: an Overview. Tectonophysics, 213, 153 - 168 https://doi.org/10.1007/978-3-030-11295-0_5

Hoque, M. and Nwajide, C.S. (1985) Application of Markov chain and entropy analysis to lithologic succession: an example from the Cretaceous of the Benue Trough (Nigeria). Geolog. Rundschau, v.74, p. 165-172. https://doi.org/10.1007/BF01764578

King, L.C. (1950) Outline and Distribution of Gondwanaland. Geol. Mag., 87, 353 -359.

Maurin J.C. (1985) Occurrence of Alkaline granite in the granitic uplift block of Kaltungo area, Upper Benue (Nigeria). J. African Earth Sci. Abstract, **3**, 276.

Maurin, J.C.(1986) Analyse de sones decrochantes dans le fosse de la Benoue (Nigeria) et systematiques U-Pb et Pb-Pb appliqués aux mineralisations uraniferes et Pb-Zn associees. These Univ. Montepellier II, 211 pp. https://doi.org/10.1016/0040-1951(92)90256-6

Obaje, N.G,.and Hamza, H. (2000) Liquid hydrocarbon source-rock potential of mid-Cretaceous coals and coal measures in the Middle Benue Trough of Nigeria. Int. Jour. Earth. Sci., 89, 130 - 139. https://doi.org/10.1007/s005310050321

Rebelle M. (1990) The marine transgression in the Benue Trough (NE Nigeria): a paleogeographic interpretation of the Gongila Formation. Journal of African Earth Sciences, 10(4): 643-655. doi:10.1016/0899-5362(90)90031-9

Sarki Yandoka, B.M., Abubakar, M.B., Abdullah, W.H., Amir Hassan, M.H., Adamu, B.U., Jitong, J.S., Aliyu, A.H. and Adegoke, A.A. (2014) Facies analysis, paleoenvironmental reconstruction and stratigraphic development of the Early Cretaceous sediments (Lower Bima Member) in the Yola Sub-basin, Northern Benue Trough, NE Nigeria. Journal of African Earth Science. **96**, pp 168-179. https://doi.org/10.1016/j.jafrearsci.2014.04.007

Stoneley R. (1966), The Niger Delta Region in the Light of hte Theory of the Continental Drift. Geol. Mag., 103, 385 - 397.

Thiessen, R., Burke, K. and Kidd, W.S.F. (1979) African hotspots and their relation to the underlying mantle. Geology 7, 263-266.

Wright, J.B. (1976) Origin of the Benue Trough: a Critical Review. In: Kogbe, C.A. (ed.) Geology of Nigeria. Elisabethan Publ.Co., Lagos, pp. 309 – 317. Doi.org/10.1016/0040-1951(76)90093-7

Zaborski, P.M. (1998) An Introduction to the petroleum potential of Niger. *Jour. Petrol. Geol.*, 21(1), 83-103. DOI: 10.4236/ojg.2021.119021

Zaborski, P.M, Ugodulunwa, F., Idornigie, A., Nnabo, P. and Ibe, K. (1997) Stratigraphy and structure of the Cretaceous Gongola Basin, Northeast Nigeria. Bull. Centre Rech.Epl. Prod.,21(1) , 153 – 185 **DOI:** 10.12691/jgg-2-3-2

Zaborski, P.M. (1998) A review of the Cretaceous system in Nigeria. *African Geoscience Rev*., 5, 385 – 483. DOI: 10.4236/ojg.2021.119021