SEQUENCE STRATIGRAPHY OF LATE ALBIAN TO EARLY TURONIAN SUCCESSION IN THE DOMA LIJI STREAM WITHIN THE GOMBE INLIER, PART OF GONGOLA BASIN, UPPER BENUE TROUGH, NORTH EASTERN NIGERIA

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Abstract

A detailed geological fieldwork was carried out, and sections were logged. Three lithogenetic units were encountered within the Late Albian to Early Turonian succession in the Gombe Inlier. The Bima Group is about 60 meter thick and consists of brown colour, fine to coarse grained, pebbly trough cross bedded sandstone interbedded with thin clays. It overlies the basement unconformably, the Yolde Formation comprises of massive to bedded, dark grey to purple mottled clays and shales, the Fika Formation characterized by thin laminated shale, silty, fissile shale, oolitic iron stone with Thalassinoides and Skolithos burrows, and dark grey mudstone containing glauconite, gypsum bed and limestone nodules. The Yolde Formation in the Doma Liji stream shows a progradational to retrogradational stacking pattern within an overall transgressive systems tract, with the clinoform prograding into the sea while the shales above are retrograding land ward. The overall parasequences within the sequence of Yolde Formation in Doma Liji stream (clinoforms) were products of transgression that is caused when the rate of base – level rise outspaced the sedimentation rates at the coastline and normal regression that is caused when the rate of sediment supply outpaced the creation of accommodation space. The Yolde Formation in the Doma liji section is interpreted as comprising two parasequence sets (A and B). Set A is represented by thick tabular cross bedded, fine to medium grained sandstone at the base and grey coloured, medium grained trough cross bedded sandstone having a progradational parasequence stacking pattern. Set B represented by dark grey shale inter bedded with thin sandstone with thalassinoides burrows with a retrogradation stacking pattern. The maximum flooding surface is here interpreted to be the limestone deposits observed at the upper part along Doma Liji stream.

Keywords: Sequence Stratigraphy, Late Albian – Early Turonian, Gombe inlier, Gongola Basin, Yolde Formation

Introduction

The general stratigraphy and sequence stratigraphy of the various formations around the Gombe inlier (Gongola Basin) has been documented by several authors (Zaborski, 1995 and 1998, Alfarooq, 2004; Hamidu 2012, Ayok 2012, Said 2014, jolly *et al* 2015). Hamidu (2012) carried out works on the CampanoMaastrichtian on a regional scale. No work on sequence stratigraphy documented for the Late Albian to Early Turonian in the Gongola basin which form the basis for this presentation in the Study area (figure 1) using data obtained from detailed geological mapping.

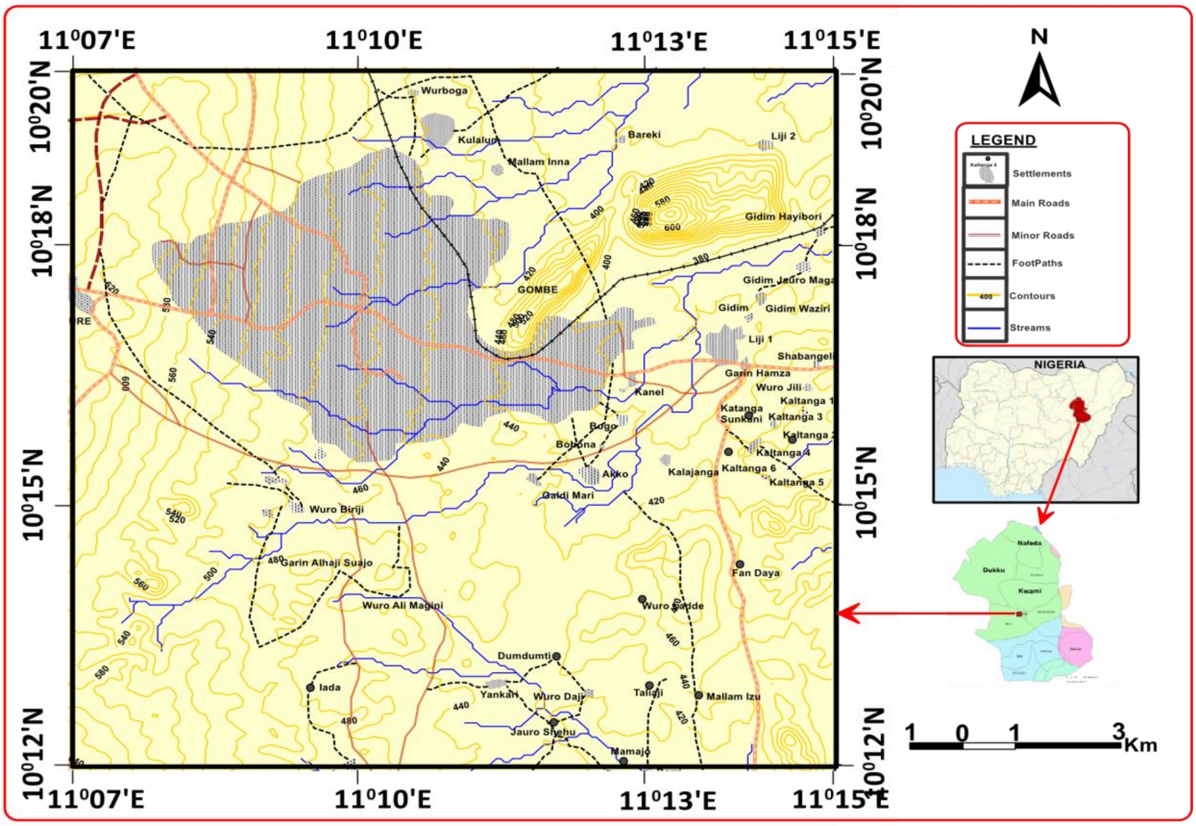

Figure 1: Location Map of the Study Area (Inset: Map of Nigeria Showing Gombe State and Map of Gombe Showing the Study Area).

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.

In the Gongola basin marine Upper Turonian to Coniacian sediments occurs 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 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, crossbedded 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.

Previous Work on the Gombe Inlier

An inlier is an area of older rocks surrounded by younger rocks. The Gombe Inlier is an outcrop of basement rocks, the Bima Group, Yolde Formation and Pindiga Formation surrounded by the Gombe Sandstone with the Gombe fault passing or cutting through it. It is trauncated to the east by the Wurro Ladde-Wurin Dole fault. The stratigraphic succession of the central part of the Gombe inlier is, according to Thompson (1958) (Table 1).

Table 1: The stratigraphic succession of the central part of the Gombe inlier (Thompson, 1958)

Formation	Age
Kerri-Kerri Formation	Paleocene
Unconformity	
Gombe Sandstone	Post-Maastrichtian
Pindiga Shales	Maastrichtian-Lower Turonian (Salmurian)
Yolde Formation	Pre-Salmurian (?)
Bima Sandstone	Cenomanian
Unconformity	
Basement Complex	Pre-Cambrian

Geological maps of the Gombe inlier were also produced by Carter *et al.,* (1963), Guiraud (1991), and Zaborski *et al*. (1997). bhatt (1988, 1989) and Guiraud (1990a, 1991a, 1991b and 1993) proposed that movement along the Gombe Fault is in places evident through deformation of the sedimentary cover. The Gombe inlier was a zone of persistent transpressional activity during the Cretaceous. The basement rocks have been upthrusted due to wrenching movement and the Cretaceous sequence, with the exception of the Gombe sandstone is markedly attenuated. Guiraud (1993) originally envisaged the wrenching movement as having persisted from 40 Ma to 70 Ma. Later, however, he suggested that an abrupt change from extensional, transtensional to transpressional stress regimes took place during the Late Cretaceous prior to the deposition of the Gombe sandstone. Benkhelil (1988) on the other hand favoured a Maastrichtian compressional episode. There is evidence that transpressional regimes persisted in the Gombe lnlier area for the greatest part of the Cretaceous and also reason to believe that a Santonian tectonic episode took place. This later event however did not mark the termination of strike-slip deformation. As mentioned above, in a number of places the Gombe Sandstone is disturbed along the line of the Gombe Fault (Zaborski *et al.,* 1997).

A terminal Cretaceous event led to the uplift, folding and fracturing of the Gombe Sandstone this event also involved strike-slip movement along the Wurroladde-Wurindole Fault (Zaborski *et al.,* 1997).

Hamidu *et al.* (2013b) upgraded the lower and middle part of the Gombe Sandstone to Arowa Formation and the upper part of the Gombe Sandstone to Duguri Formation. Jolly *et al.* (2015) worked on the field study of the positive flower structure of the Gombe inlier and considered the inlier to be a geological microcosm of the Gongola Basin. They found the inlier to be affected by a sinistral strike-slip fault, and a well-preserved transpressional structure along this fault.

Methodology

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.

Results and discussion

In the study area, three lithogenetic units were encountered namely Bima Group, Yolde Formation and Fika Formation within the Late Albian to Early Turonian succession. From this study the following conclusions were drawn:

The Bima Group is about 60 meter thick in the Gombe Inlier and consists of brown colour, fine to coarse grained, pebbly trough cross bedded sandstone interbedded with thin clays. It overlies the basement unconformably, (scour fills are made up of very coarse grained sand pebbly size quartz and feldspars, they represent short live erosion event). The presence of erosional base is indicative of break in deposition where sand and clay indicate energy changes from high to low energy. Lithofacies succession consisting of fining upward cycle. The environment of deposition of Bima in the Gombe inlier is of distal to proximal braided river origin.

Yolde Formation comprises of massive to bedded, dark grey to purple mottled clays and shales. The sandstone is coarse to medium grained, positively, near symmetrical to negatively skewed, leptokurtic, very leptokurtic to extremely leptokurtic, angular to sub angular, high spherecity mineralogically immature, moderately to well sorted Arkose with sedimentary structures such as: wavy, tabular, trough, hummocky, herringborne, bioturbated, channel filling, reactivation surfaces.

Channel filling sandstone indicates the presence of sedimentation in stream channels that have been abondorned by stream due to increase in rates of sedimentation and reduction in depth (Reineck *et al*., 1980). The features above suggest shallow marine deposits (Figure 2).

Fika Formation characterized by thin laminated fragmented shale, silty, fissile shale, oolitic iron stone with Thalassinoides and Skolithos, dark gray mudstone containing glauconite, gypsum bed and limestone nodules. Biomicsparite, bivalves are the most common bioclast with both the sparite and micrite cement in the petrographic study. It marked by bioturbated oolitic ironstone with thalassinoides and skolithos. Frey and Howard (1970) reported that thalassinoides is reliable indicator of littoral and shallow sub littoral environment. The presence of glauconite indicates stratigraphic condensation (Loutit, 1988). When shale show fissility indicates that burrowing organism was absent in the deposition environment (Friedman 1979). The variation in colour ranging from dark grey at the bottom to light grey at the top suggest a quntitative variation in organic matter content that may change from anoxic to oxic paleoenvironment condition. The features above suggest a littoral shallow sub littoral environment.

An outcrop sequence stratigraphic interpretation of the Yolde Formation was attempted for the Doma Liji section because Clinoforms are well exposed. The analysis was based on the pattern of vertical stacking of lithofacies, sedimentological characteristics of lithofacies, and identification and delineation of sequence stratigraphic surfaces (Figure 3; 4 and Plate I).

As stated above, the deposition of the Yolde Formation coincided with the major Late Albian to Early Turonian transgressive – regressive events that affected the entire Benue Trough and also Sahara regions to the north (Zaborski, 1998).

The mid-Turonian regressive conditions led to normal regression and the general progradational pattern of the Yolde Formation (Figure 3 and 4).

Systems tracts

The classification into systems tracts was based upon the parasequence types and stacking patterns. The cycles within the Yolde Formation in Doma Liji stream (Clinoforms) described earlier can be interpreted and analysed as parasequences. In this study, four basic types of parasequence were recognized (Figure 3).

i. The lower part (A) of the Yolde Formation section 1.61m away from the bottom about 3.84 m (clinoforms) has a progradational parasequence stacking pattern. The maximum flooding surface is here interpreted to be within that part of the section containing interbedded shale.

Above parasequence (A) towards the middle part of the section is parasequence (B) about 2.84 m

i. thick has a retrogradational parasequence stacking pattern suggesting that it belongs to the transgressive system tract of the sequence.

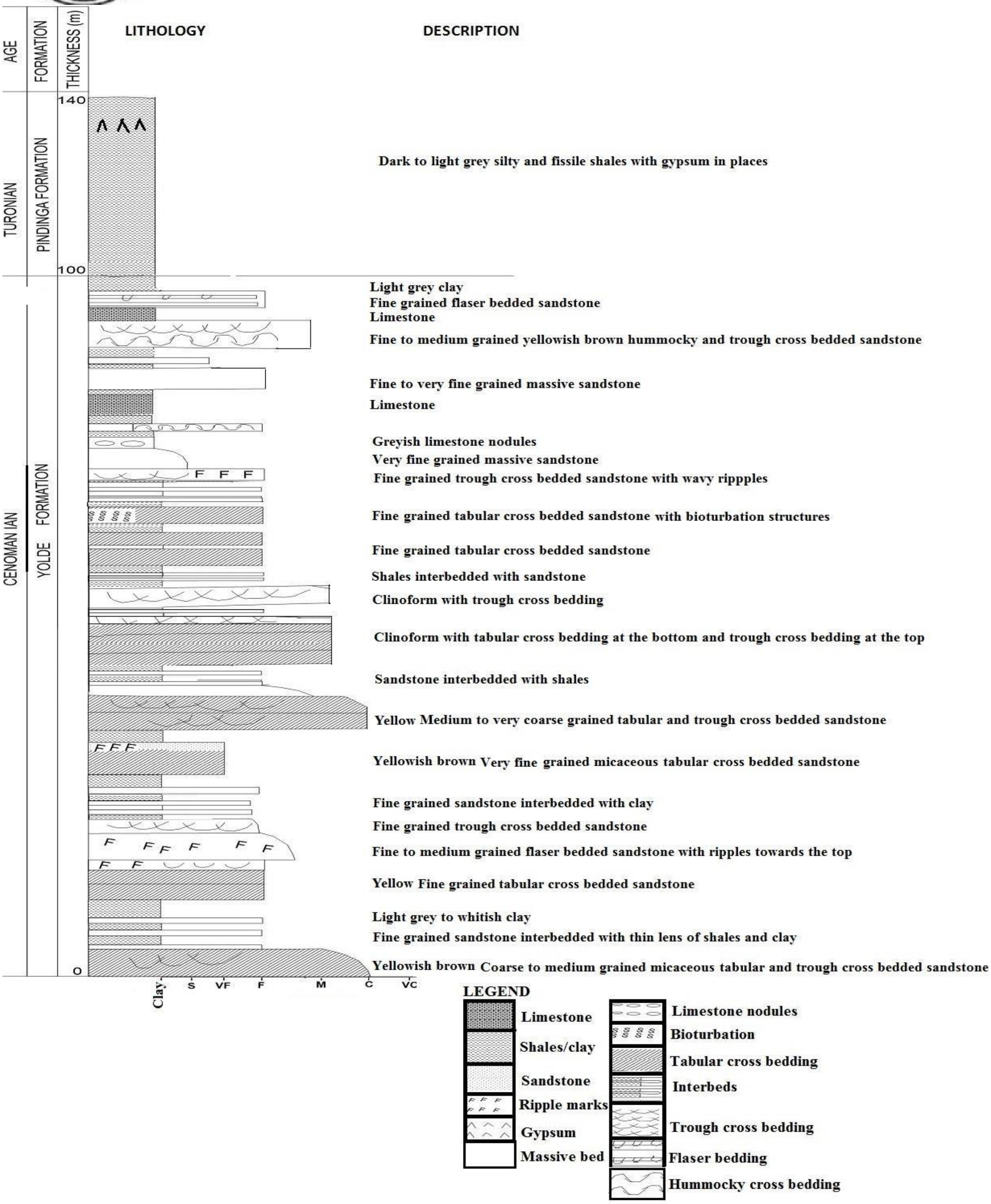

Figure 2: Lithostratigraphic log of the section Along Doma Liji stream (N 10 ^{0}15 '58.38" E 11^{0} 13' 27") Proposed Sequence Stratigraphic Interpretation of the Yolde sequence in the Doma Liji Stream in the Gombe Inlier

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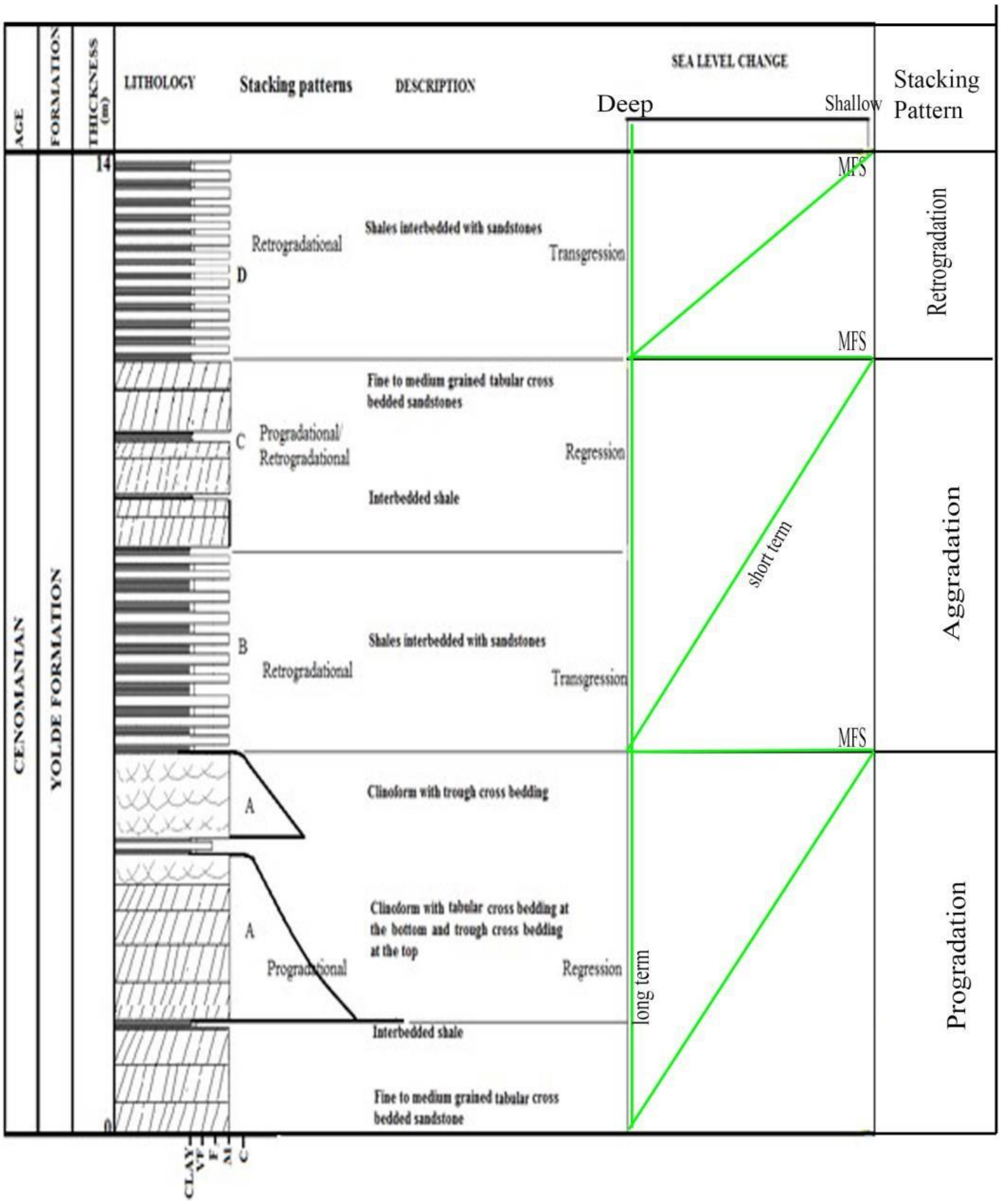

Figure 3: Lithostratigraphic log of the section exposed along Doma Liji stream indicating the clinoforms towards the base of the section (10°16'04.1''N and 11°13'34.5''E).

Plate I: Photograph of sections of Yolde Formation exposed along Doma Liji stream (10^{o}16'04.1"N and 11^{o}13'34.5"E) showing three clinoforms prograding into the sea while the shales above are retrograding land word forming a cycle

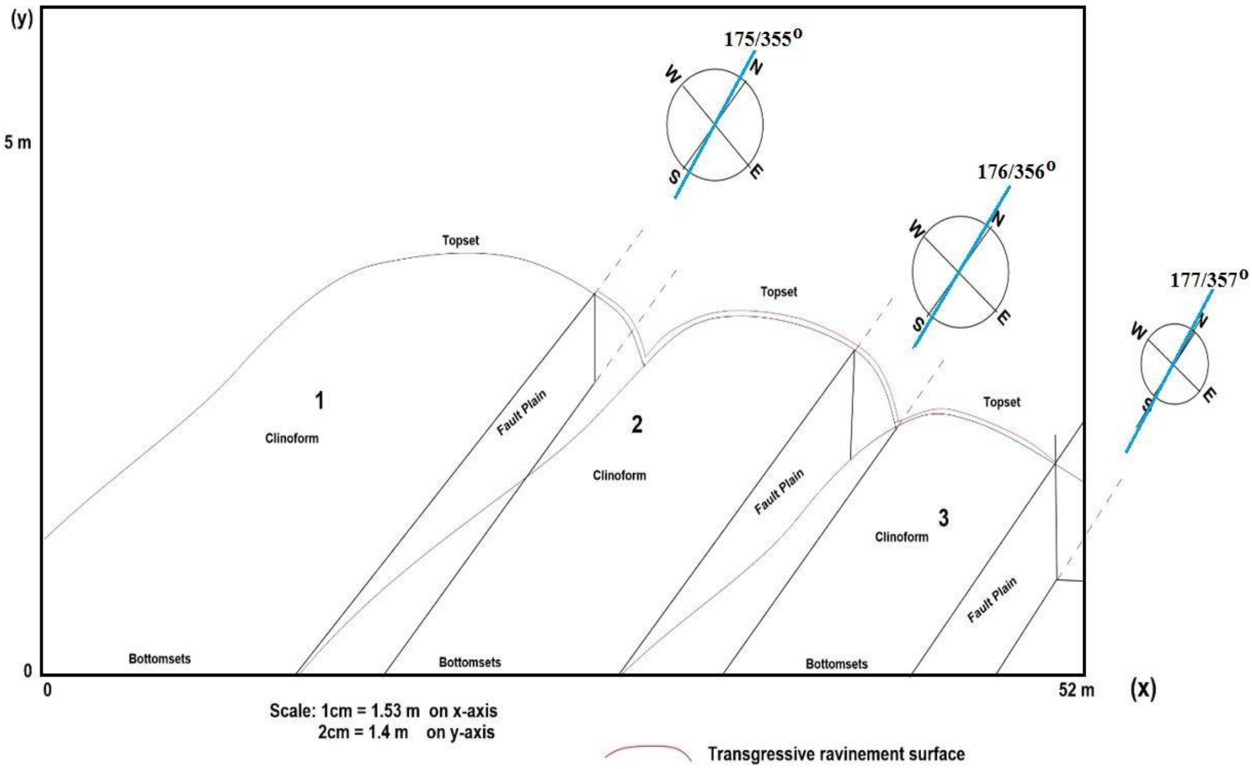

Figure 4: Sketch of sections of Yolde Formation exposed along Doma Liji stream (10^{o}16'04.1"N and 11^{o}13'34.5"E) showing three clinoform with a retrogradational becoming progradational stacking pattern

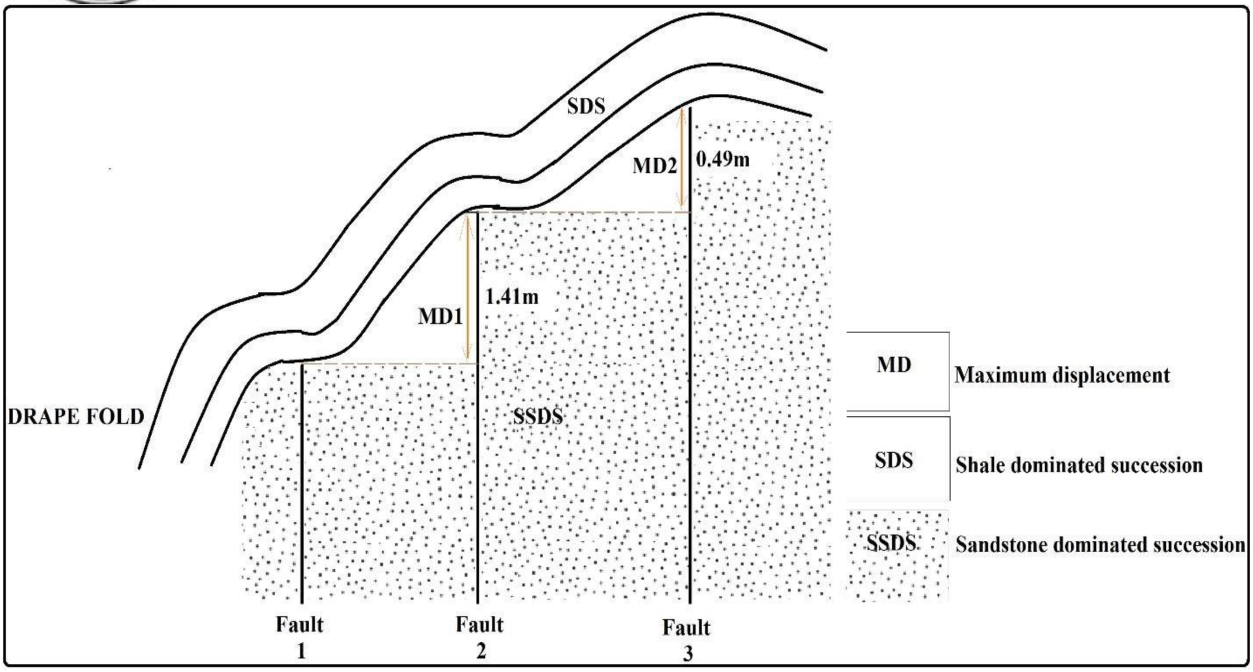

Figure 5: 2D Sketch of sections of Yolde Formation exposed along Doma Liji stream (10°16'04.1"N and 11°13'34.5"E) showing sandstone dominated succession overlain by draping shale dominated succession forming a drape fold

ii. Above parasequence (B) towards the upper part part of the section is parasequence (C) which has a progradational/retrogradational parasequence stacking pattern.

iii. At the top (upper) part of the section is a 2.97 m thick beds (D) which has a retrogradational parasequence stacking pattern. This type of stacking pattern can collectively be regarded as occurring within an overall transgressive system tract.

Since the part of Yolde sequences along the Doma Liji Stream (clinoform 3 and 2) was deposited during transgression it is expected that there will be a landward shift of facies leading to the deposition of a transgressive deposits. Clinoform 1 was deposited during normal regression therefore, it is expected that there will be a basinward shift of facies B leading to deposition of lowstand prograding wedge. The overall parasequence stacking pattern is used to determine the systems tracts, here at the base we have a prograding clinoforms belonging to the first parasequence, while towards the top is the retrogressive shales belonging to the second parasequence; therefore the parasequence stacking pattern is generally retrogradational and probably belongs to the transgressive systems tracts and the whole process occurring when the rate of sediment supply out spaced the accommodation space created. The presence of Thalassinoides in parts " ii) B)" above indicates a shallow marine environment of deposition, this trace fossil being characteristic of the Thalassinoides assemblage, indicative of the sublittoral zone on the inner shelf between depths of about 10 to 100 m (Frey, 1975), and possibly indicate a marine flooding surface.

The major parts of the Yolde sequences (Figure 3) show a generally cyclic arrangement of subfacies A, B, C and D above.

Elsewhere in the Benue Trough, the Yolde Formation in Doma Liji stream, however, differs from that of the Gulani Formation in the Dogon Zaga Hill section at eastern Gongola Basin in such that the sublittoral shale/sandstone subfacies is more thinly developed with the individual clinoforms thicker, the sand bodies consist of single sets rather than multiple sets and the sandstones have coarser grain sizes (Ayok, 2013). These differences can be explained by the rate of sediment supply being lesser in the case of the Yolde Formation in Doma Liji stream bringing about a more constant retrogradational to aggradational stacking pattern.

Conclusion

In the study area, three lithogenetic units were encountered namely Bima Group, Yolde Formation and Fika Formation within the Late Albian to Early Turonian succession. The Bima Group is about 60 meter thick in the Gombe Inlier and consist of brown colour, fine to coarse grained, pebbly trough cross bedded sandstone interbedded with thin clays. It overlies the basement unconformably, scour fills are made up of very coarse grained sand pebbly size quartz and feldspars, they present short live erosion event, the presence of erosional base is indicative of break in deposition where sand and clay indicate energy changes from high to low energy. Lithofacies succession consisting of fining upward cycle. The environment of deposition of Bima in the Gombe inlier is of distal to proximal braided river origin.

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Parasequence B represented by dark grey shale inter bedded with thin sandstone with thalassinoides burrows with a progradation stacking pattern suggesting it belong to a low system tract of a sequence. The overall parasequences within the sequence of Yolde Formation in Doma Liji stream (clinoforms) were products of transgression that is caused when the rate of base – level rise outspaced the sedimentation rates at the coastline and normal regression that is caused when the rate of sediment supply outpaced the creation of accommodation space. The presence of Thalassinoides in parts "ii" above indicates a shallow marine environment of deposition, this trace fossil being characteristic of the thalassinoides assemblage, indicative of the sublittoral zone on the inner shelf between depths of about 10 to 100 m (Frey, 1975).The section of the Yolde Formation is interpreted as comprising parts of four parasequencies from the base to the top. The lower part (A) of the Yolde Formation section 1.61 m away from the bottom about 3.84 m (clinoforms) has a progradational parasequence stacking pattern suggesting that it belongs to the regressive deposits. The maximum flooding surface is here interpreted to be the limestone deposits observed at the upper part along Doma Liji stream. Above parasequence (A) towards the middle part of the section is parasequence (B) about 2.84 m thick has a retrogradational parasequence stacking pattern suggesting that it belongs to the transgressive system tract of the sequence. Above parasequence (B) towards the upper part part of the section is parasequence (C) about 2.60 m thick has a progradational/retrogradational parasequence stacking pattern suggesting that it belongs to the regressive systems tract of the sequence. At the top (upper) part of the section is a 2.97 m thick beds (D) which has a retrogradational parasequence stacking pattern suggesting that it belongs to the transgressive system tract of the sequence. The Yolde Formation in the Doma Liji stream shows a progradational to retrogradational stacking pattern with the clinoform prograding into the sea while the shales above are retrograding land ward forming a cycle.

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