Lithological Mapping and characterization of the Yolde Formation around Gombe Inlier, Gongola Sub-Basin, Northeastern Nigeria: Implication on Facies association and Paleoenvironmental Reconstruction

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Abstract

An extensive geological field survey was carried out where lithostratigraphic sections of Yolde Formation were measured. Features such as textures interpreted, physical and biogenic sedimentary structures (facies variations and associations were documented). Some selected representative samples of the sedimentary depositional facies were also subjected to grain size analysis and multivariate analysis. The Yolde Formation in the study area were lithologically made up of sandstones with dark grey to purple interbedded mottled clay and shales. The formation is structurally characterized by assymmetrical ripple, tabular and trough cross-bedding, convolute bedding as well as hummocky and herringbone cross-stratification with reactivation surfaces, channel fillings sandstone and bioturbation. The granulometric studies typified the sandstone facies to be positively near symmetrical to negatively skewed, leptokurtic to extremely leptokurtic, angular to sub angular with high spherecity, mineralogically immature, moderately to well sorted Arkose. The result of the Linear Discriminate Function (LDF) analysis scatter plot for the sandstone facies of the Yolde Formation indicate a shallow marine depositional environment. Field and textural studies of the formation suggests the sediments to be deposited in relatively high energy environment with tidal and wave influence of transport and deciphered ten (10) lithofacies grouped into four associations that is, FA-1 (subtidal), FA-2 (Intertidal), FA-3 (supratidal) and FA-4 (Shoreface). Analyses of textural, structure and statistic revealed that the sediments in the study area were deposited in shallow marine environment. Sets of the synnsedimentary faults with slickenside down thrown (0.49 – 1.41m) were classified into the NE – SW trending faults in the Gongola Sub-Basin.

Keywords: Yolde Formation, Facies association, Synsedimentary tectonics, Gombe Inlier, Gongola Sub-Basin.

INTRODUCTION

The Cretaceous succession in the Upper Benue Trough, comprises early Cretaceous continental clastic, the Bima Group, and a dominant marine late Cretaceous succession. The former include the oldest sediments known in the Benue Trough deposited during active rifting. During the late Cretaceous, thermo-tectonic sag condition prevailed and sedimentation was strongly influenced by transgressive-regressive events, the upper Cretaceous may be divisible into discrete pre-Santonian and Campano-Maastrichtian parts, the latter deposited during a renewed phase of rifting (Zaborski, 1998). Chronologically, the Precambrian basement is un-conformably overlain by the

Aptian-Albian Bima Sandstone, which is the oldest, thickest, and most extensively outcropping formation in the trough (Carter *et al*., 1963: Guiraud, 1990; Abubakar, 2006; Mamman *et al.*, 2010; Aliyu, (2015)). Stratigraphical studies conducted by Guiraud (1990) showed that the Bima Sandstone could be divided into the silicilastic formation namely; the lower, the middle and upper Bima Formation, especially designated as Bima 1. Bima 2, and Bima 3. The Bima Sandstone is overlain by transitional interbeds of shale, siltstone and calcareous mudstone of Yolde Formation (Cenomanian – Turonian), grading into massive beds of limestone and thick shale of Pindiga Formation (Kanawa, Dumbulwa/Gulani/Deba Fulani; Fika Members) of Zarboski (1998) or (Kanawa, Dumbulwa/ Gulani/ Deba Fulani, Lower Fika Members of Hamidu *et al.* (2013) or Pindiga Group (Kanawa Formation,Gulani Formation and Lower Fika Member) of Ayok (2013), in Yola Arm their lateral equivalent are the Dukul Formation, Jessu Formation, Sekule Formation, Numanha Shale and Lamja Sandstone. The sequences overlying these formations are poorly to moderately sorted sandstone of Gombe Formation (Campanian – Maastritchtian) of Zarboski *et al*. (1998) or Tukulma Group (Upper Fika Formation, Duguri Formation and Arowa Formation) of Hamidu *et al.* (2013) in the Gongola Basin. The succession is capped by sandstone of Kerri-Kerri Formation (West of Gombe town) in the Gongola Basin. The stratigraphic succession of the central part of the Gombe inlier was first documented by Thompson (1958). Geological maps of the Gombe inlier were also produced by Carter *et al.*, (1963), Guiraud (1991), and Zaborski (1997). Benkhelil (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. A terminal Cretaceous event led to the uplift, folding and fracturing of the Gombe Sandstone this event also involved strike-strip movement along the Wurroladde-Wurindole Fault (Zaborski, 1997). 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 these fault. All of the previous work were done on regional scale.

The Present research attempts to fill the gaps by employing large scale detailed field observation and updates the knowledge on the Lithostratigraphy, structure, sedimentology and paleoenvironment of the Yolde Formation in the Gombe Inlier. This research will attempt to evaluate the Lithostratigraphy of the Late Albian to Early Turonian Yolde Formation in the Study area using data obtained from detailed geological mapping and interprete the depositional environments of the sucession based on the sedimentary structures and sedimentologic studies (lithofacies analysis).

Study Area

The study area is situated within the Gongola Basin, Upper Benue Trough of Nigeria. It lies between latitudes $10^{o}\,15'$ 00'' to $10^{o}\,30'$ 00''N and longitudes 11^{o} 08' 00''E to 11^{o} 23' 00''E, on sheet 152NW and 152SE Gombe State, Nigeria and the Areal extend is two hundred and nineteen square kilometre (219km^2**).** The area is accessible via major, minor roads and footpaths linking the villages.

MATERIALS AND METHOD

The lithology, colour, macrofossils and sedimentary structures associated with the sub-facies were identified. The various facies were traced both vertically and laterally to establish the thickness/vertical continuity and the lateral continuity of the units and to determine if there is apparent truncation of the facies. Six (6) outcrop sections were logged in the field, and sketches of their stratigraphic logs produced using Surfer software 13 software and Microsoft paint. Eight samples were collected from Yolde Formation at different location for granulometric analysis following the standard procedure. The statistical parameters of the grain size frequency distribution were obtained and computed using the method of Folk and Ward (1957). Linear Discriminate Function (LDF) analysis was performed on the sandstone samples. For the standared procedure see Sahu (1964).

RESULTS AND DISCUSSION

Lithostratigraphy

Arawa Stream section

Along Arawa stream exposed 45 m thick section of this formation were mapped and logged. From the base it consists of grey shale. The bed passes into a medium to coarse grained sandstone, medium grained, trough cross-bedded sandstone with pebble lag deposits, shale, fine grained sandstone with some clay displaying a flaser bedding, fine to medium grains sandstone interbedded with thin lens of shales, fine to medium grained, light brown sandstone, fine to medium grain sandstone interbedded with thin lens of shales, trough cross bedded sandstone which tends to fines upward displaying vertical burrows towards the top, dark grey shale with sharp contact with the underlying lithology. This passes upward into fine to medium grained trough cross bedded sandstone with erosional base, sandstone and shale interbeds, trough cross bedded sandstone with erosional base, brownish clay, coarse to fine grained sandstone with lag deposits at the base displaying trough cross beddings towards the middle and ripples at the top with erosional surface, brownish clay which is in turn overlain by medium grained, light brown sandstone terminating the section (Figure 1).

Doma Liji Stream Section

Doma Liji stream exposed 100 m thick section of this formation were mapped and logged. From the base it consists of coarse to medium grained micaceous yellowish brown tabular cross-bedded sandstone with unexposed base. This is underlying fine grain-sandstone interbedded with thin lens of shales and clay, light grey to milky white clay, fine grained yellow tabular cross bedded sandstone overlain by fine to medium grained flaser bedded sandstone with ripples towards the top, fine grain trough cross bedded sandstone, fine grain yellow to brown sandstone interbedded with clay, light grey clay which underlies a bed of fine to very fine grained yellow micaceous tabular cross bedded sandstone, light grey shales. This bed passes upward into a bed of medium to very coarse grained yellow trough and tabular cross-bedded sandstone, fine to medium grained yellow sandstone interbedded with thin lens of shales, interbedded shales, clinoform with tabular cross bedding at the bottom and trough cross bedding at the top, shales interbedded with medium grained sandstone which is in turn overlain by clinoform with trough cross bedding underlying shales interbedded with sandstone overlain by interbedded shales. The interbedded shale is overlain by fine to medium grained tabular cross bedded sandstone which passes upward into interbedded shales, fine to medium grained tabular cross bedded sandstone. This is overlain by light grey shale, medium grained tabular cross bedded sandstone underlying a bed of shales interbedded with sandstone. This bed passes upward into fine grained trough cross bedded sandstone with wavy ripples, medium grained massive sandstone, gray limestone nodules underlying light grey clay, fine grained hummocky cross-bedded sandstone, light grey clay, limestone, light grey clay, very fine to fine grained massive sandstone, shales interbedded with medium grained sandstone, coarsening upward, yellow to brown hummocky and trough cross bedded sandstone underlying a bed of limestone, fine grained flaser bedded sandstone which passes upward into light grey clay terminating the stream section (Figure 2a,b,c,d and Figure 3).

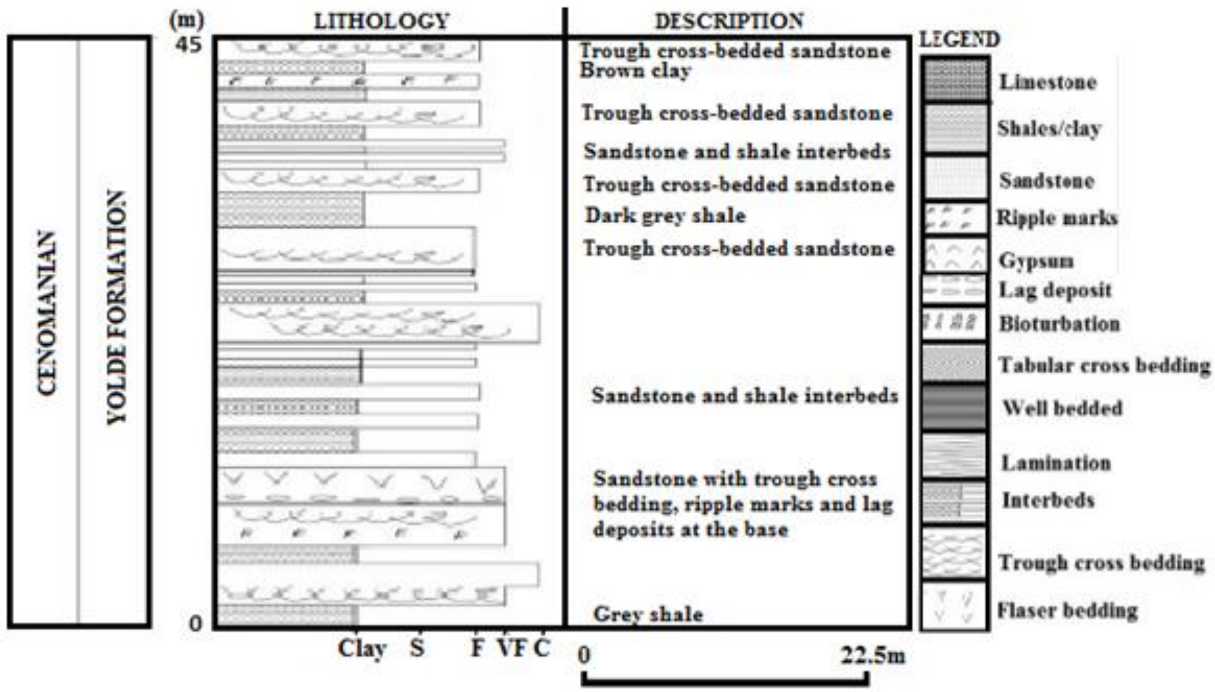


Figure 1: Lithostratigraphic log of the section exposed along Arawa stream

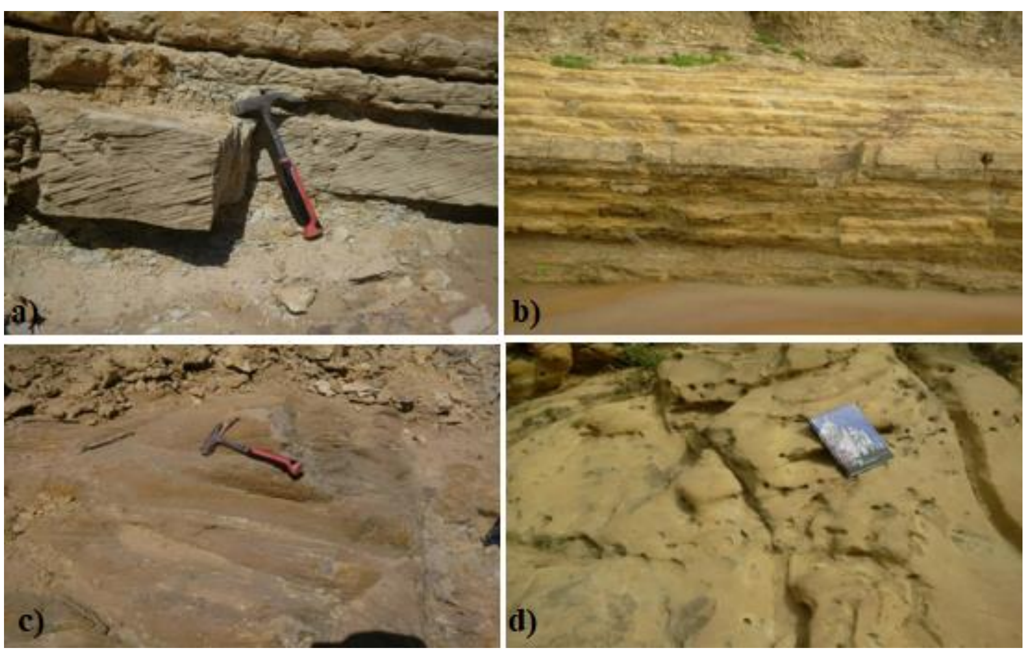


Figure 2: Yolde Formation exposed along the Doma liji stream (a) tabular cross-bedded sandstone facies (b) horizontal bedded sandstone facies (c) Hummocky cross stratification facies (d) Bioturbated Massive sandstone facies

Pantami stream section

Pantami stream exposed 100 m thick section of this formation were mapped and logged. From the base it consists of lenticular bedded grey to purple clay, medium grained massive sandstone underlying a grey to purple clay overlain by medium grained, trough cross bedded sandstone which passes upward into a bed of grey silty shales and clay underlying very coarse to pebbly grained with large scale trough cross bedded sandstone overlain by grey to purple clay. This bed passes upward into medium trough cross bedded sandstone with lag deposits at the base, grey to purple clay, medium grained trough cross bedded sandstone with parallel lamination at the base and bioturbated structure, light grey silty shales and clay, fine to medium grained trough cross bedded sandstones, light grey clay, very coarse to coarse grained tabular cross bedded sandstone with ripple marks towards the base. This bed transit into grey clay which passes upward into medium grained sandstone with small scale trough cross bedding and erosional base, grey to purple clay interbedded with medium grained sandstone, medium grained sandstone with calcareous nodules, grey clay underlying medium grained sandstone with herringbone cross bedding which passes upward into purple to grey clay terminating the section.

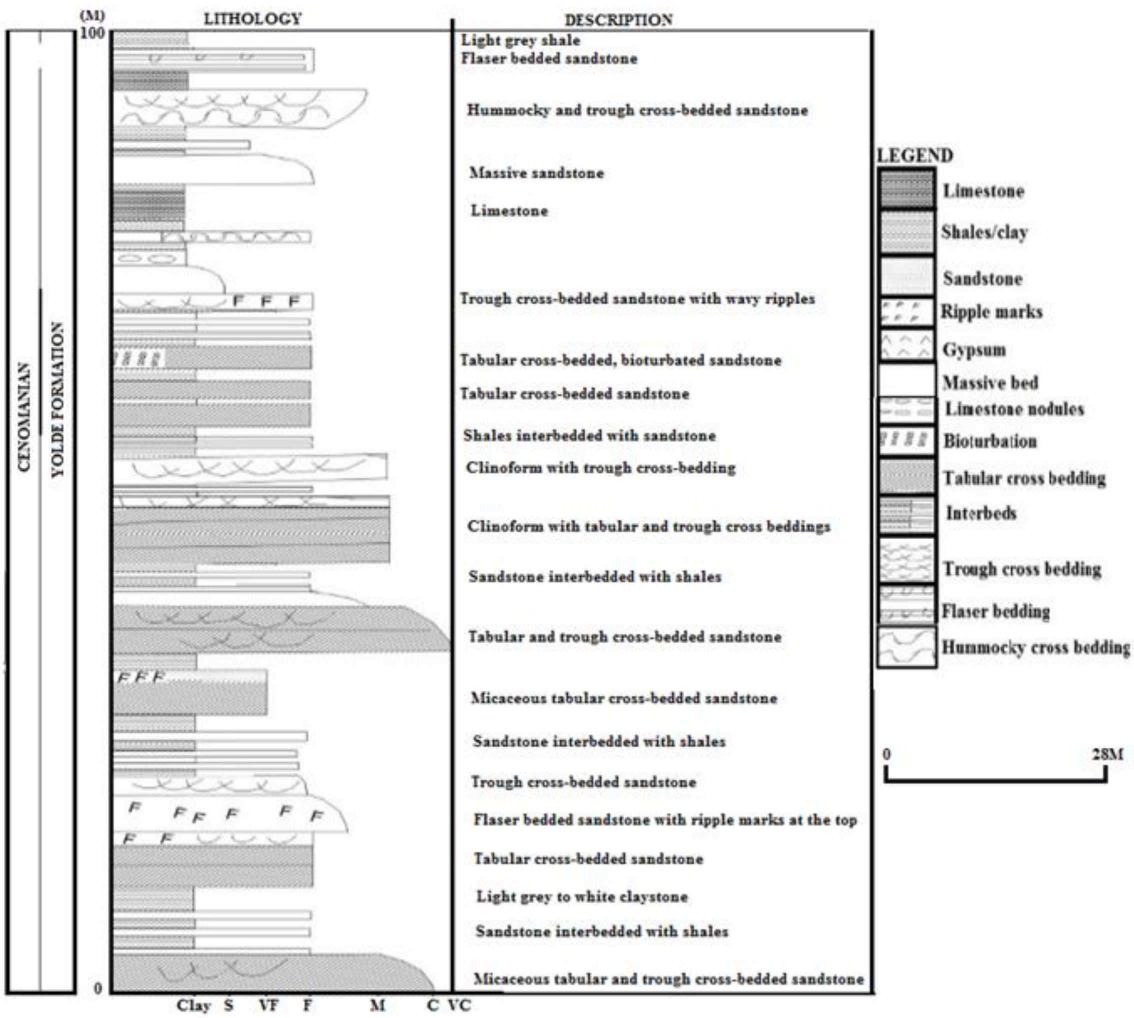


Figure 3: Lithostratigraphic log of the section Along Doma Liji stream

The upper part of the section is characterized by mainly tabular cross bedding and herringbone cross stratification (Figure 4a) and the very top of the succession is associated with massive sandstone (Figure 4b) and bioturbated stuctures. In a similar way, muds are observed to highlight the base of the sand bodies and shales are interbedded with the sandstone. However, trough cross bedding structures are observed from the lower to upper part of the succession and the fining upward sequence is not well developed. Lag deposits are seen to occur around the middle part as well (Figure 5).

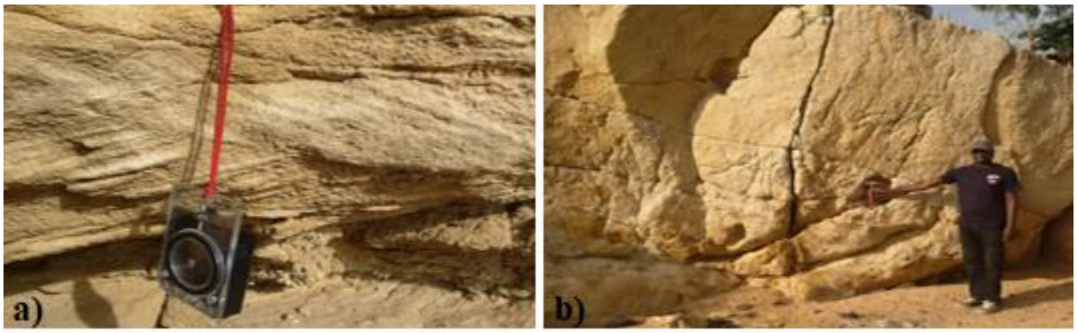


Figure 4: Yolde Formation exposed along the Pantami stream. (a) Herringbone cross-stratification with a reactivation surface (b) Massive sandstone facies

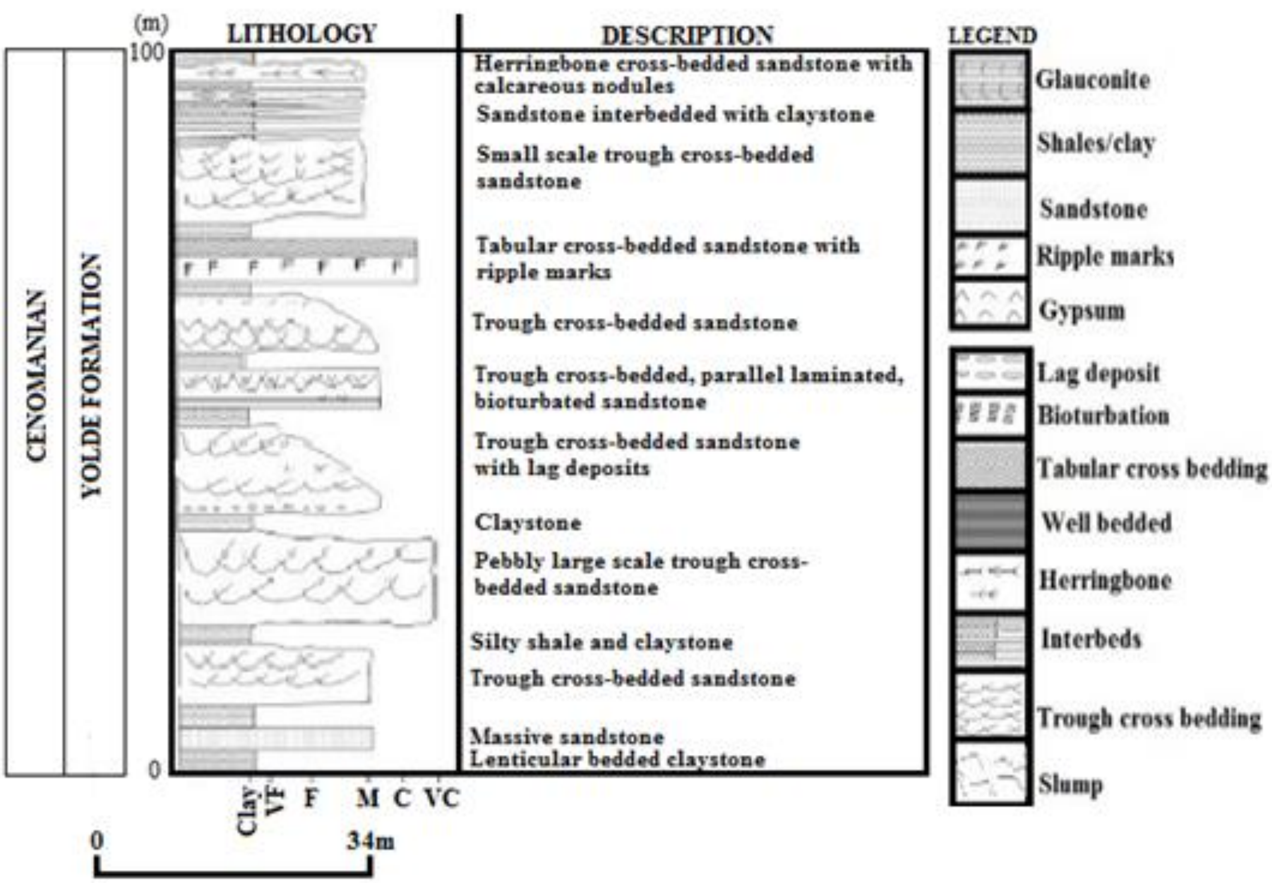


Figure 5: Lithostratigraphic section exposed along pantami stream

Wuro Biriji Stream Section

Wuro Biriji stream exposed 110 m thick section of this formation characterized by **s**tructures such as trough cross – bedding, herringborn cross stratification, tabularcross – bedding and hummoky cross bedding (Figure 6a, b, c, d) were mapped and logged. From the base it consists of grey to purple clay underlying medium grained trough cross bedded sandstone with ripples marks towards the top overlying light grey clay which transit into a bed of medium to coarse grained sandstone with trough cross bedding at the base and top with ripple marks towards the middle. This bed is overlain by light grey to purple clay underlying medium to coarse grained massive sandstone which passes upward into gray clay underlying medium to coarse grained trough cross bedded sandstone that passes upward into fine grained sandstone interbedded with thin lens of clay. This bed is overlain by fine grained trough cross bedded sandstone overlying grey shales, coarse to medium grained trough cross bedded sandstone with hummocky cross stratification towards the top of the bed, fine grained sandstone interbedded with thin lens of clays, coarse grained sandstone with ripples at the base, trough cross bedding towards the middle and herringbone cross bedding towards the top. This bed passes upward into light grey clay underlying very coarse grained tabular cross bedded sandstone overlain by light grey to purple clay, fine grained sandstone with sandstone nodules at the base, ripple marks towards the middle and tabular cross bedding towards the top. This bed passes upward into light grey to purple clay terminating the section (Figure 7).

Figure 6: Yolde Formation exposed along the Wuro Biriji stream (a) asymmetrical current ripples facies (b) trough cross bedded sandstone facies (c) shale interbeds within sandstone (d) medium grained, moderately well bedded sandstone

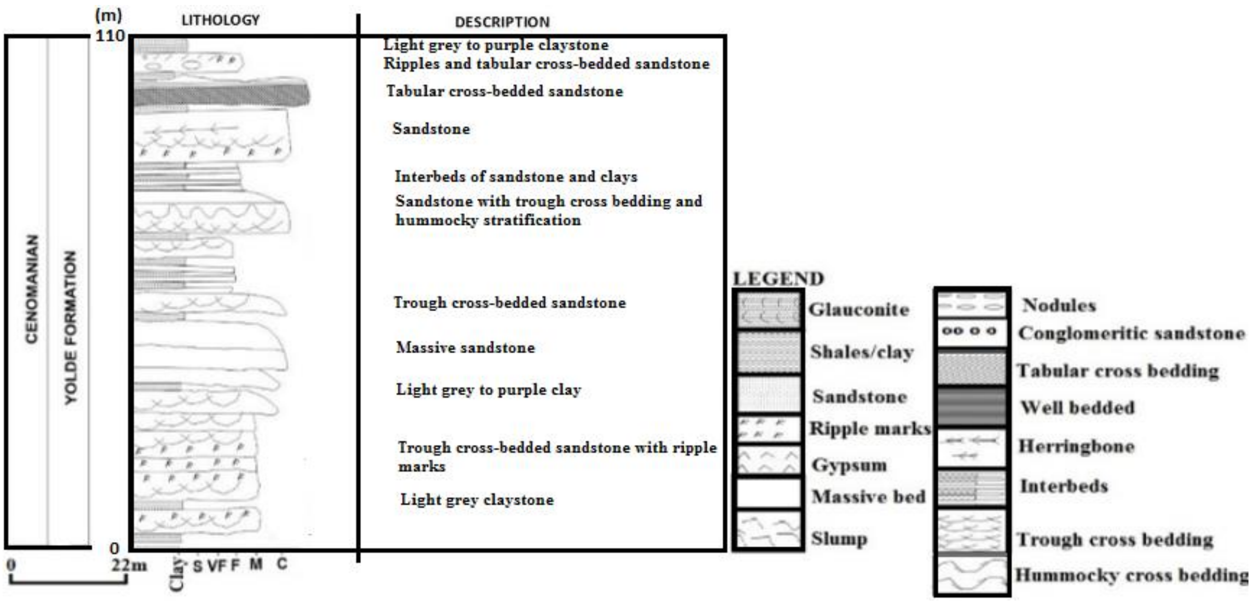


Figure 7: Lithostratigraphic section exposed along Wuro Biriji

Univariate, Bivariate and Multiveriate Analysis

The granulometric analysis results of the eight samples of the Yolde Formation analysed are presented in Table 1. The bivariate plots of standard deviation versus skewness is based on Friedman (1979) which distinguishes inland dune sand from beach sand. The plot indicates that 68.75% of the samples plotted within the river field and 31.25% of the samples plotted within the Beach sand field (Figure 8). The Linear Discrimination Functions (Y1, Y2 and Y3) of Sahu (1964) were used to characterize and delineate the depositional environment of the sandstone facies of the Yolde Formation in the study area (Table 2). Plotting of the three discriminate functions (Y1, Y2 and Y3) as bivariate scatter plots was used to improve the success rate and refinement of the discrimination of the depositional environment. A bivariate plot of Y1 versus Y2 and Y2 versus Y3 were plotted (Figure 9a and 9b).

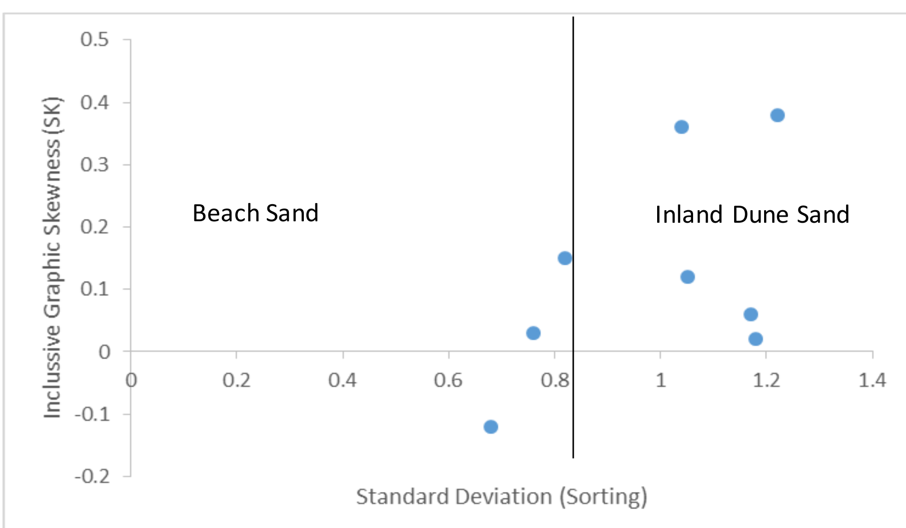


Figure 8: Bivariate Plot of Skewness Vs Standard Deviation (after Friedman, 1979).

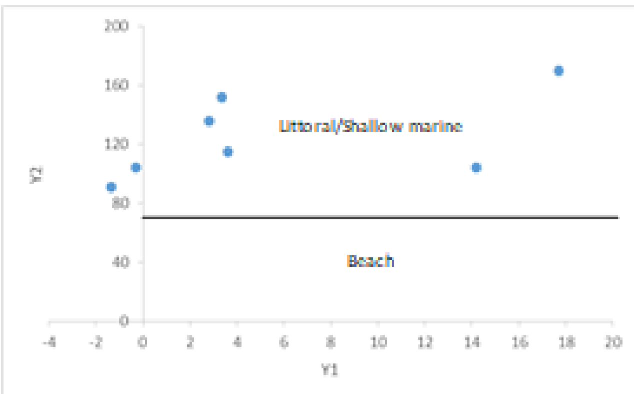
Table 1: Grain size distribution and quantitative parameters of samples of the sandstone facies of Yolde Formation in the study area.

Samples	Mean	Sorting	Skewness	Kurtosis
YTP1	1.50 medium sand	1.22 poorly sorted	0.38 Strongly positive skewed	1.28 Leptokurtic
YBS2	2.44 fine sand	0.68 moderately well sorted	-0.12 Negative skewed	2.07 very leptokurtic
YS2A	1.13 medium sand	0.76 moderately sorted	0.03 Near symmetrical	2.60 very leptokurtic
YBS12	0.74 coarse sand	1.05 poorly sorted	0.12 Positive skewed	4.52 Extremely leptokurtic
YL12	1.77 medium sand	0.82 moderately sorted	0.15 Positive skewed	0.90 Mesokurtic
YPS1K	1.56 medium sand	1.17 poorly sorted	0.06 Near symmetrical	1.11 mesokurtic
YBS10	0.95 coarse sand	1.04 poorly sorted	0.36 Strongly positive skewed	1.21 Leptokurtic
YL6	1.33 medium sand	1.18 poorly sorted	0.36 Strongly positive skewed	0.95 mesokurtic

Table 2: Shows the Discriminate Function and Depositional Environment

SAMPLE	Formation	Y1	Y2	Y3
YTP1	Yolde Formation (Pantami stream)	3.35 Beach environment is suggested	151.85 Shallow agitated marine (subtidal) environment	-14.43 fluvial deltaic deposit
YBS2	Yolde Formation (Wuro Biriji stream)	-0.30 Beach environment is suggested	104.29 Shallow agitated marine (subtidal) environment	-2.66 Shallow marine deposit
YS2A	Yolde Formation (Arawa stream)	14.20 Beach environment is suggested	104.29 Shallow agitated marine (subtidal) environment	-4.75 Shallow marine deposit
YBS12	Yolde Formation (Wuro Biriji stream)	17.69 Beach environment is suggested	169.84 Shallow agitated marine (subtidal) environment	-9.82 fluvial deltaic deposit
YL12	Yolde Formation (Doma Liji stream)	-1.34 Beach environment is suggested	91.26 Shallow agitated marine (subtidal) environment	-6.08 Shallow marine deposit

YPS1K	Yolde Formation (Pantami stream)	2.83 Beach environment is suggested	135.99 Shallow agitated marine (subtidal) environment	-11.79 fluvial deltaic deposit
YBS10	Yolde Formation (Wuro Biriji stream)	3.63 Beach environment is suggested	114.85 Shallow agitated marine (subtidal) environment	-10.91 fluvial deltaic deposit
YL6	Yolde Formation (Doma Liji stream)	3.32 Beach environment is suggested	130.25 Shallow agitated marine (subtidal)	-11.87 91 fluvial deltaic deposit



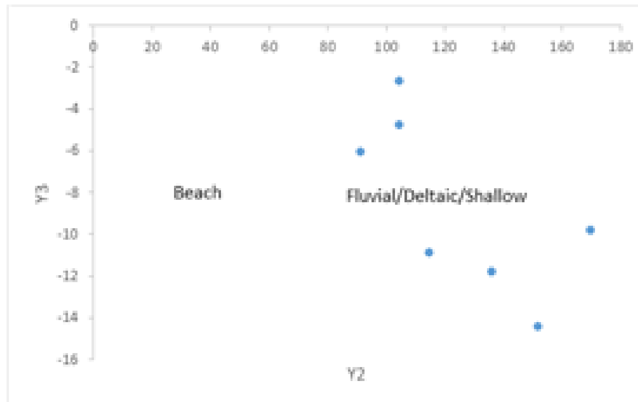


Figure 9: Bivariate Plot of (a) Y2 Vs Y1 (b) Y3 Vs Y2 (after Sahu, 1964)

Facies Analysis of Yolde Formation

Lithofacies Description/ Facies Association

Sedimentary facies is the sum of the characteristics of a sedimentary unit (Middleton and Hampton, 1973). These characteristics include depositional geometry, sedimentary structures, grain sizes and types, colour and biogenic content of the sedimentary units (Nichols, 2009). The characteristics are determined by physical and chemical processes of transportation and deposition, as well as the paleoecology during and after deposition of the sediments. On the basis of the above, ten (10) lithofacies have been recognized in the study area. The lithofacies are described below.

1. Clay/Shale Facies (C)

Description: This facies consist of the dominant lithology in the measured sections and characterized by dark grey, light brown, and white. This facies appear to be uniform in hand specimen because of their very fine grain size in nature. The fine grain nature of this facies suggested deposition in suspension due to weak current, that is low energy and off shore transition shallow marine environment.

2. Tabular Cross Bedded Sandstone Facies (PS)

Description: This facies is characterized by grey to light brown, tabular cross bedded, moderately to well sorted sandstone. The tabular cross bedded sandstone indicating flow at oblique to right angle to the direction shown by trough cross bedded sandstone facies (Figure 2a).This facie (PS) was interpreted to be deposited by migration of dunes under low energy regime flow due to wave swash process in the upper shore face (Mial 1978, Souza et al 2012).

3. Trough Cross Bedded Sandstone Facies (TS)

Description: This facies occur at several levels. This facies is characterized by brown, coarse, medium to fine grained sandstone, trough cross – bedded (both the large and small scale trough cross – beds) were observed in some major units (Figure 6b). This facies is associated with tabular cross – bedded sandstone with erosional to sharp base. The presence of trough cross beddings is indicative of tidal influence, it is formed through migration of sinous and lunate dune bedforms. (Friedman 1967)

4. Massive Sandstone Facies (MS)

Description: The sandstone are buff to brown, fine, medium to coarse grained sandstone with moderate bioturbations at the base (Figure 4b).They are mostly found in all the section studied. Massive sandstone associated with both fine and medium grain sandstone may have been formed as a result of dumping due to the weight of the sediment or similarly in high density turbidity flows in distal shelf (Nichols 2009).

5. Herringbone Cross Stratification Facies (HS)

Description: This facies is usually associated with high energy setting by more than one current trend. It consist of brownish, medium grain sandstone. They occur both in Wuro Biriji and Pantami stream (Figure 4a). This facies features is usually associated with moderately to high energy environment indicative of tidal deposits which give rise to bi-directional cross stratification (Friedman 1967).

6. Hummocky Cross Stratification Facies (HC)

Description: This facies is characterized by buff coloured, hummocky cross stratified, fine to medium grain well sorted sandstone (Figure 2b). Hummocky cross stratification is indicative of storm and wave influenced deposition, it is interpreted to represent high energy storm process with strong wave influence (Harms *et al.* 1975, Duke *et al*. 1991).The abundant of hummocky cross bedding is widely reported as the product of strong oscillatory process, often with a variable but generally subordinate superimposed unidirectional flow, which forms during intense storms the structure is commonly preserved between fair weather and storm wave base. (Harms, *et al.* 1975, 1982) suggested that this structure is formed by strong surges of varied direction that are generated by relatively large storm waves, strong storm wave action first erode the seabed into low hummocks and swales that lack any significant orientation. Duke *et al.*, (1991) suggest that hummocky cross beds originates by a combination of unidirectional and oscillatory flow related to storm activity.

7. Interbedded Sandstone and Clay Facies (ISC)

Description: This facies comprises of buff, fine to medium grain sandstone interbedded with clay. They may be produced from differential slow single episodes of sedimentation of fine grain sediments from suspension, it has been deposited in low energy environment probably at overbank to crevasse splay since the facies is associated with shale and clay (Colenman and prior 1982).

8. Parallel Laminated Sandstone Facies (PTS)

Description: This facies consist of a fine grained, well sorted sandstone. It is produced by less severe or short lived fluctuation in sedimentation condition. It is characterized by clay shale laminated. Lamination produced by alternating layers of fine and coarser grain sediment, are probably the most common kind (Boggs, 1995). This facies represent the tidal bottom current deposited during late stage of force regression in a distal slope setting (Mial, 2000 and catuneanu, 2006).

9. Symmetrical Rippled Sandstone Facies (WS)

Description: This facies is characterized by buff to brownish, very fine to fine grain, symmetrical rippled, moderately to well sorted sandstone. The rippled lamination inferred to be generated by waves. Similar facies were interpreted to represent low energy wave deposition in shallow marine setting (Walker and plint 1992).

10. Biotubated Massive Sandstone Facies (BS)

Description: This facies is characterized by buff, amalgamated moderately, bioturbated,fine to medium grain sandstone. The trace fossils include vertical burrows and planolites. It is associated with massive sandstone facies (Figure 2c). This facies is characterized by lack of physical sedimentary structures, this is due to the present of intense bioturbation which hampered interpretation of depositional processes, these may suggest a high energy deposition process within a generally low energy depositional (walker and plint, 1992, Bhattacharya *et al.* 2000 and Bhattacharya, 2006).

Facies Association

Facies association is a group of facies that is used to define aparticular sedimentary environment (Anderton, 1985; Nichols, 2009). From the description and interpretation of the facies, four facies associations were recognized; the FA-1 (subtidal), the FA-2 (Intertidal), the FA-3 (supratidal) and the FA-4 (Shoreface).

FA-1(subtidal): This facies association is composed of **PS** (planar cross bedded sandstone facies) **TS** (Trough cross bedded sandstone facies) **HS** (Herringbone cross stratification facies) **AS** (Symmetrical rippled sandstone facies) **PTS** (Parallell laminated sandstone facies) **ISC** (interbeded sandstone and clay shale facies) **BS** (Bioturbated massive sandstone facies). Due to its fining upward, the presence of the above bedforms and the degree of bioturbation, it isusually associated with high energy environment and high current velocity. This facies association is interpreted as subtidal environment (Dalrymple 2010, Boggs 1995).

FA-2 (Inter tidal): This facies is composed of **ISC** (Interbedded sandstone and clay/shale facies), **BS** (Bioturbated massive sandstone facies) and **C** (clay shale facies).This faciesis characterized with fining upward succession. This reflect decrease in energy from the lower to the upper part of the intertidal flats as recorded by texture, sedimentary structure and the transition from dominantly physical to dominantly biogenic sedimentary structure. It is interpreted as intertidal or mixed flats environment (Boggs 1995).

FA-3 (Supratidal): This facies is composed of **C** (clay shale facies), **ISC** (Interbedded sandstone and clay/shale facies) and **AS** (Symmetrical rippled sandstone facies). This facies ranges in thickness from few cm to mm and due to its prograding nature, tidal currents are very effective in transporting and depositing agent (Reading and Collinson, 1996). The thick fine grain sandstone associated with the intertidal deposit and characterized with lenticular bedding and interpreted as shallow-water environments (Archer, 1998). Dalrymple (1992) and Boggs (1995) suggest a supratidal environment.

FA-4 (Shoreface): This association composed of **HC** (Hummocky cross stratification), **AS** (Symmetrical rippled sandstone facies) and **PS** (Planar cross bedded sanstone facies). Generally, the sediments in this association are relatively coarser grained (fine to medium). The sequence depicts the energy of the depositional environment to be of the distal low energy environment to the proximal high energy deposits **g**enerated by waves in the wave-breaking and surf zones in a shoreface (Souza *et al*., 2012).

Depositional Environment

Sedimentary structures observed are massively bedded sandstone, channel filling sandstone, trough cross-bedding, tabular cross-bedding, Hummocky cross stratification, Herringbone beddings with reactivation surfaces, bioturbation and ripples. Channel filling sandstone according to (Reineck and Singh, 1980) described the channel fills as representing sedimentation in stream channels that have been abandoned by stream, because of cutoff process or due to increase rate of sedimentation and reduction in depth. So also the (Golia and Steward 1984) described the channel filling sandstone as fining upward units dominated by cross stratification mostly as a result of dune migration within shallow braided rivers in Wuro Biriji area the channel filling sandstone is about 90cm thick around and show some regular bedded sandstone, and conglomeratic base. Trough cross bedded sandstone is formed through migration of sinous and lunate dune bed forms in many situations where there are change of flow velocity or depth during bed form migration so that the dunes are modified and eroded, when deposition resumes an erosion surface formed similar to what we have here.

The presence of tabular cross bedded sandstone indicate that the grains size of the sands being moved and reworked on sea flow below the fair-weather wave base and was too large to form hummocky cross stratification under storm wave influence this forming relatively upper flow regime planar laminated sand instead. The abundant of hummocky cross bedding is widely reported as the product of strong oscillatory process, often with a variable but generally subordinate superimposed unidirectional flow, which forms during intense storms the structure is commonly preserved between fair weather and storm wave base. (Harms, *et al* 1975, 1982) suggested that this structure is formed by strong surges of varied direction that are generated by relatively large storm waves, strong storm wave action first erode the seabed into low hummocks and swales that lack any significant orientation. Duke *et al*., (1991) suggest that hummocky cross beds originates by a combination of unidirectional and oscillatory flow related to storm activity.

Herringbone cross bedded sandstone indicates deposition by tidal current i.e. bipolar cross bedding where cross beds dips adjacent set are oriented in opposite direction. It is associated with moderately to high energy environment indicative of tidal environment (Friedman 1967). Ripple lamination inferred to be generated by waves is interpreted to represent low energy wave deposition in shallow marine setting (Walker and Plint 1992). The presence of bioturbation in the sandstone indicate low sedimentation as a result of low sediment supply and where bottom waters are aerobic condition. Massive sandstone is formed as a result of dumping due to the weight of the sedimentor similarly in density turbidity flows in distal shelf (Nicholas 2009). The presence of reactivation surface suggest tidal environment as a result of lee-face modification of the bedforms by subordinate tidal currents (Ladipo 1986), (Boggs 1995) attributed them to tidal reversal during an assymetrical tidal cycle under which the ripple crest can be eroded and deposited during the next tidal cycle thereby giving rise to reactivation surfaces, they may occur in tidal sand deposits through tidal currents reversals in fluvial sediments through change in river stages suggest a lower flow regime, tranverse bars deposits.

The fluctuation in values in the sieve analysis result suggest change in energy of the depositional condition. However, poorly sorted to moderately sorted values predominate (Table 4.2) reflecting high reworking of the sediment during transport and in these respect agree with the river sand as suggested by Hamidu and Hamza, 2013. According to Friedman 1967, these properties indicate rapid deposition by fluvial processes. The values of skewness (Table 4.2) the positively skewed values predominate and this is due to the fact that much of the silts and clay were removed by marine current this indicates fluvial condition (Friedman 1967).

Very little geologic information could be derived from kurtosis (Friedman 1967) though the fluctuation in values may suggest changes in energy of the depositional medium. They are composed of fine grain angular to sub angular with high sphericity, moderately to well sorted Arkosic sandstone, consisting of poorly crystalline quartz. It is mineralogically immature due to feldspar content.With reference to Y1, Y2 and Y3 values from the linear discriminate plots of Y2 versus Y1 indicate that all the sandstone samples of Yolde Formation in the study area falls within Beach/shallow marine environment (Subtidal), (Sahu 1964) s' Y3 versus Y2 indicate that 100% of the sandstone samples are within fluvio deltaic/shallow marine agitated, the yolde sandstone in the study area is shallow marine environment (Table 4.3).

Synsedimentary Tectonics of Yolde Formation in Doma Liji Stream

Another prominent fault trend in the Gombe inlier is NW-SE. These faults show slickensides and displacements consistent with normal faults. At, location latitude N10^{o}16'04.1" and longitude E11^{o}13'34.5" faults with trends of 175/355^{o}, 176/356^{o} and 177/357^{o} were seen. This is a synsedimentary normal fault with a NE-SW extension direction. This faulting acted

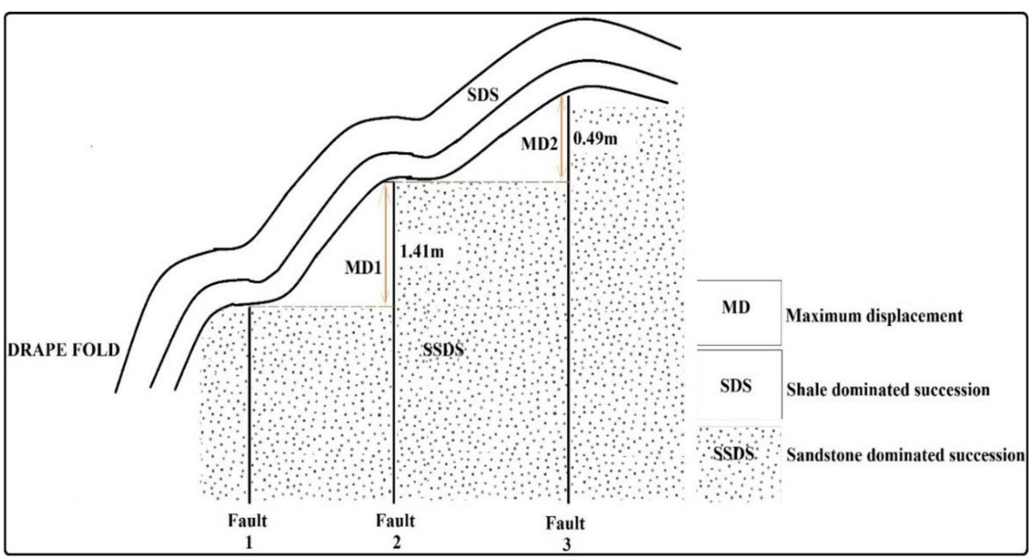


Figure 10: 2D Sketch of Yolde Formation exposed along Doma Liji stream (10^{o}16'04.1"N and 11^{o}13'34.5"E) showing sandstone dominated succession overlain by draping shale dominated succession forming a drape fold.

contemporaneously with the sedimentation of the Yolde Formation in Doma Liji Stream, with a shale dominated succession forming drape fold. The synsedimentary normal fault has a total displacement (throw) of 1.9 m occurring in two stages (Figure 10), 1.41m and 0.49 m respectively all grouped into the NW-SE trending faults.

Another important structure that signifies sysnsedimentary seismicity is the existence of convolute bedding within the Yolde Formation and small-scale synsedimentary faulting (Figure 11). This is as a result of shaking that accompanied the faulting during sedimentation in the area. These structures therefore suggest the response of incompetent lithology to stress along the Gombe fault zones and the effect of tectonic event on sedimentological processes.

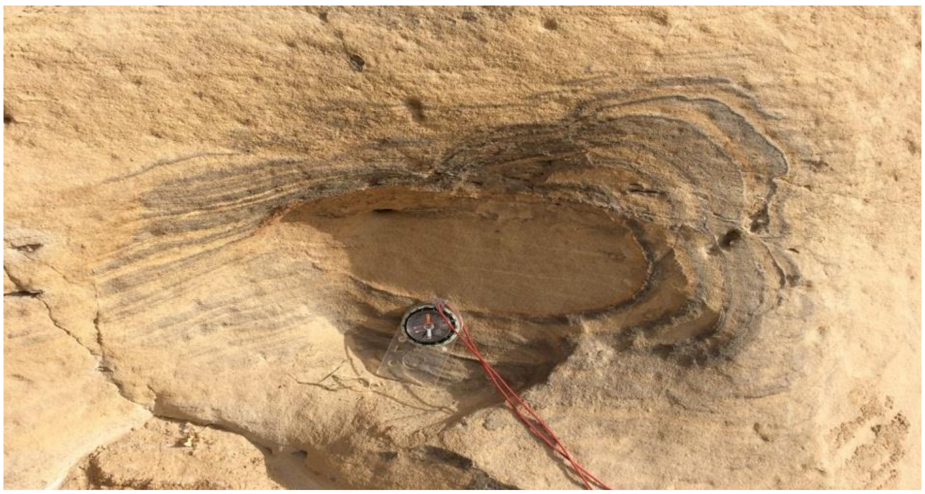


Figure 11: Yolde Formation exposed along Doma liji stream. Photograph showing convolute bedding

CONCLUSIONS

From this study the following summary and conclusion were drawn. Yolde Formation comprises of massive, bedded, dark grey to purple mottled clay and shale, coarse to medium grained, wavy, tabular, trough, hummocky, herringborne, bioturbated, channel filling , reactivation surfaces, 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 sandstone. Channel filling sandstone indicate the present of sedimentation in stream channels that have been abandoned by stream due to increase in rates of sedimentation and reduction in depth (Reineck and Singh, 1980). Trough cross bedded sandstone is formed through migration of sinuous and lunate dune in a situation where there are change of flow of velocity. The presence of tabular cross bedded sandstone suggest that the grain size of the sandstone are being moved and reworked on sea flow below the fair weather wave base and too large to form hummocky cross bedding. Hummocky stratification is normally form during intense storms (Harms *et al* 1975,1982), herringborne indicate deposition by tidal current associated with moderately to high energy environment indicative of tidal environment (friedman 1967). Ripple lamination represent low energy, wave deposition in shallow marine setting (walker and plint). The presence of bioturbation indicate low sedimentation (Romos *et al* 2006). Using the features above we have drawn conclusion that the Yolde Formation in the study area were of shallow marine deposits.

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