Lithofacies Association in the Bima Sandstone of the Upper Benue Trough, Nigeria.

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ABSTRACT

The Aptian-Albian Bima Sandstone rests discomformably on the Precambrian crystalline basement in the northeastern basins of Nigeria. The formation which is widely exposed in the Upper Benue portion of the basins was investigated for lithofacies associations with a view to deducing the nature of the depositional environment. The facies geometry reflects a pull-apart origin as the facies distribution represents a basinward change in depositional environments from marginal alluvial fan to axial lacustrine system. The alluvial architecture and stacking patterns depict sedimentations mainly controlled by allogenic factors of climate and tectonism. Ten lithofacies, identified on the basis of lithology, grain size, and sedimentary structure, constitute four main lithofacies associations (FA I to FA IV) representing distinctive depositional environments.

FA I is a conglomeratic facies association representing gravity driven talus and debris flow fan deposits. FA II is a major tabular sandstone facies representing fluvial channel deposits. FA III is deformed soft sediment beds representing rapid sedimentation occasioned by hydrodynamic pressure and FA IV, composed of medium bedded lenticular sandstone which represents lacustrine and ponding environment in the basin axis. The facies associations demonstrate a trend through fluvial regime soon after the syn-rift deposition to a lacustrine regime in the inner part of the basin. A high sinuous meandering flow marked by cyclic graded bar was followed by low sinuous braided channel having isolated strips of fine grained sediment of flood plain deposits. Rejuvenation in slope gradient of the basin is inferred from the depositional style.

(Keywords: upper Benue Trough, aulacogen, Bima sandstone, alluvial deposits, lithofacies association, fluviatiles).

INTRODUCTION

The Upper Benue Trough in the northeast of Nigeria, on account of its tectono-sedimentary evolution, has a fairly complex sedimentation pattern which is reflected on Bima Sandstone. The Bima Sandstone is the most extensive earliest continental sediments deposited on the floor of the entire basins of northeast Nigeria as a basal unit of the Cretaceous series soon after crustal rifting. It lies discomformably on the basement complex (Figure 1).

The first major study on the formation was carried out by Carter, et al. (1963), based on the structural and sedimentological framework of the Lau sub-basin. Later works on the formation, especially on the structural synthesis and paleogeography in the different sections of the basin, had featured as both supplements and complements of the earlier work of Carter, et al. (1963). Prominent among them were those of Allix (1983), Genik (1992), Guiraud and Maurin (1991), Guiraud (1993), Benkhelil (1988), and Braide (1992).

These workers established that the trough developed through a geotectonic framework of both rifting and strike-slip faulting. Such geotectonic frameworks normally develop similar rapid changes in lithologic characteristics on either side of the axis of the basin. The purpose of the present study is to describe and interpret the basinward facies changes of Bima Sandstone in a trough with width less than 60km (Braide, 1992) but with accumulated continental sediments reaching up to 3,500m in thickness (Zarboski, et al., 1997). The facies is analyzed by carrying out detailed textural and structural studies of encountered beds in order to deduce the paleoenvironment of the formation.

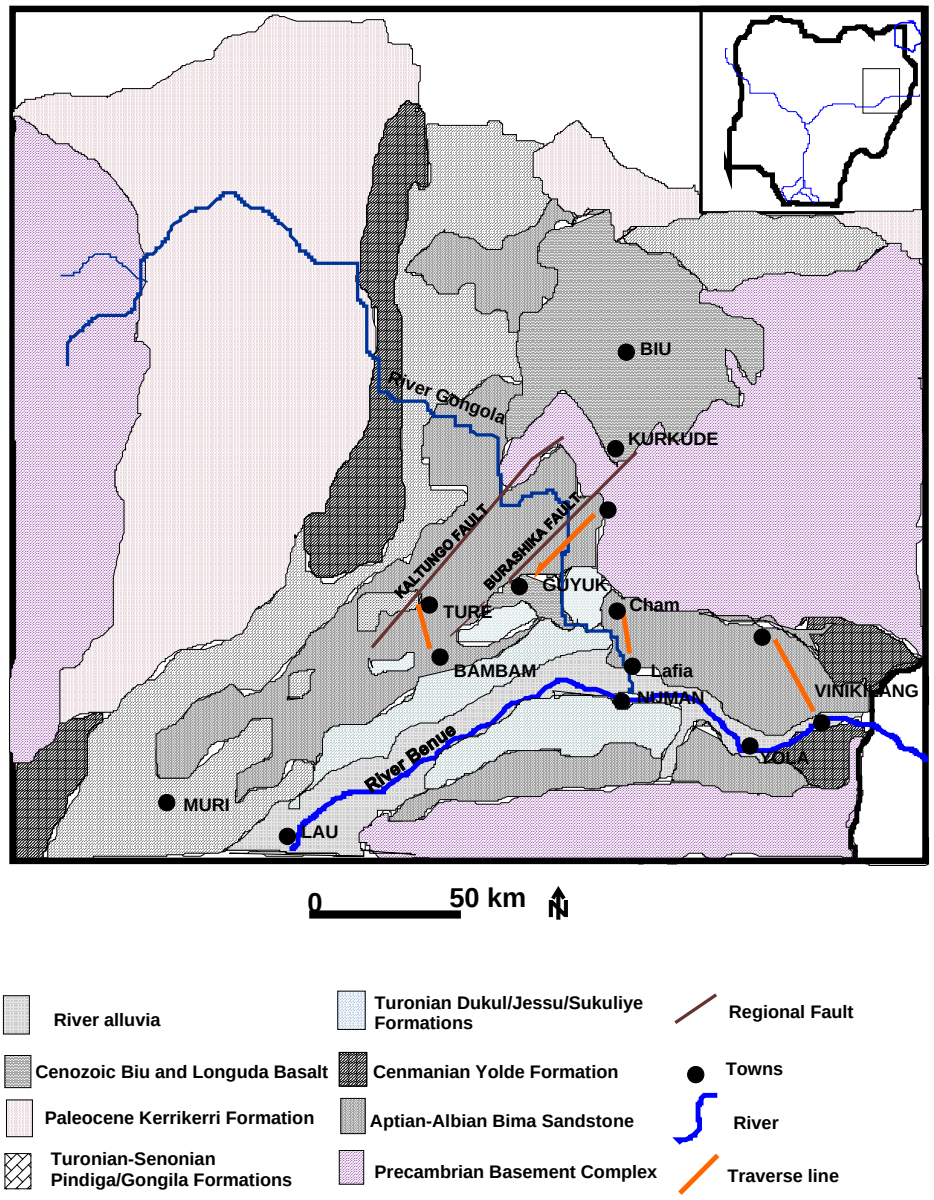

Figure 1: Map of Upper Benue Trough showing the Bima Sandstone among the Younger Cretaceous and Tertiary Series in the Basis. The Inset Indicates the Position of Upper Benue Trough in Nigeria.

UPPER BENUE TROUGH TECTONO-STRATIGRAPHIC FRAMEWORK

The opening of the Atlantic which started at the beginning of the Mesozoic triggered the crustal fragmentation of the West Central African craton into rift systems. The Benue trough was one of the major rifted basins formed from the tension generated by the separation, becoming an aulacogen which opened into the Gulf of Guinea through the Niger Delta. The Upper Benue trough is the northern section of the trough. It is bifurcated into the north trending Gongola and the east trending Yola Arms whose central axes are lined with mantle sourced alkaline-olivine basalts (Adekeye and Ntekim, 2007). The partition of the arms was related to the trilete junction (Whiteman, 1982) about a Kaltungo basement arch which forms an inlier in the sedimentary series.

Sedimentation proceeded with basement derived fanglomerates of angular boulders of gneiss and basalt resulting from the crustal rifting. In some other places, coarse clasts with mud matrix infilled the subsiding half-grabens and horst as debris flow (Guiraud, 1993). The syn-rift deposits gradually developed into fluviatiles towards the basin axis. Stages in the lithostratigraphic development of the clasts enabled division of the units into Lower, Middle and Upper Bima units. Mid-Cretaceous transgression brought about by the continental inundation of the Tethy's Sea through the Saharan Seaway and the waters of the Gulf of Guinea was responsible for the succeeding post-Albian marine carbonate and argillaceous formations in the trough (Zaborski, 2000).

Stratigraphic Units of the Bima Sandstone

The Bima Sandstone is dominantly a quartz arenite occupying the base of the Cretaceous succession in both the Upper Benue Trough and the Borno basin of Nigeria. The sediments were mainly derived from juxtaposed basement suites of older granite and gneisses which were subjected to humid conditions that accelerated the weathering processes. Despite the dominance of quartz arenite as the main lithology, the field relationships of the beds made it possible to differentiate the formation into three members; the Lower Bima (Bima – 1) the Middle Bima (Bima – 2) and the Upper Bima (Bima – 3) (Carter, et al., 1963; Allix, 1983). The three lithounits were also reflected in the seismic reflection interpretation of the depositional and structural style in the subcrop of the Nigerian sector of the Chad basin by Avbovbo, et al. (1986).

The Lower Bima was directly affected with the tectonic events (Guiraud, 1993) as large clasts with muddy matrix were straddled as sediments within the fractured horst and graben of the marginal rift structure. The unit is revealed at the exposed core of Lamurde anticline consisting of shale intercalated with feldspathic and calcareous sandstone (Carter, et al., 1963). The middle and upper Bima beds overstep the lower Bima syn-rift deposits and in some places the marginal horst of the rifted basement (Guiraud, 1990) (Figure 2). The clasts of the middle Bima are coarse to medium grained with well marked pebbly lag deposits at the base of successive beds while the upper Bima sediments are mainly of medium to fine grained clasts.

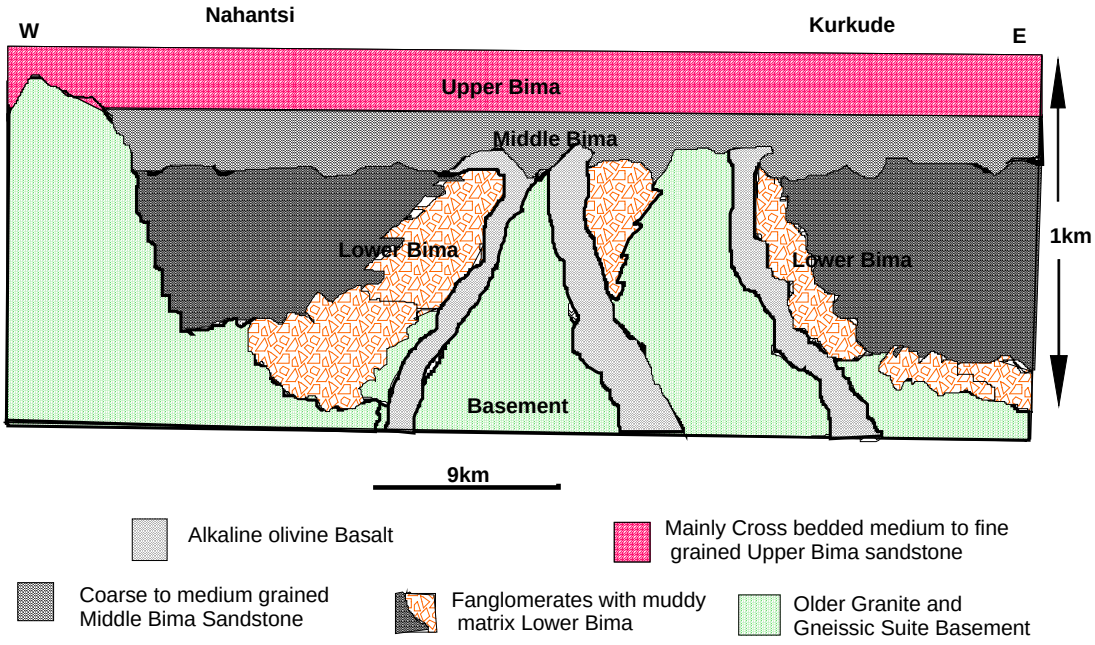

Figure 2: Schematic Diagram of Lithostratigraphic Sequences of Bima Sandstone in Relation to the Basement (Guiraud, 1990).

METHOD OF STUDY

Traverses from basin's margin towards the central axis were focused as the study areas. The traverses were made along four zones namely Kurkude-Guyuk axis, Ture-Bambam axis, Cham-Lafiya axis and Jebilamba-Vinikilang axis (Figure 1). Different textural attributes were described, stratal thicknesses measured and detailed lithological variations with emphasis on channel morphology were noted. Analysis of the various sedimentologic parameters and characterization of bedding surface hierarchy were carried out, using classification scheme of Miall (1996). The scheme facilitated identification of lithofacies and their association in each zone (Tables 1 and 2) thus aiding the interpretation of the depositional environments.

Table 1: Lithofacies Code and Descriptions of Deposits in the Zones of the Studied Area.

Lithofacies	Descriptions	Locality zones of occurrence
Gmm	Matrix supported conglomerates: clasts are poorly sorted granule to pebble size intraformational and extraformational particles. Matrix is siltstone and mud	Kurkude-Guyuk and Ture-Bambam
Gsm	Clast supported conglomerates: Dominantly extraformational poorly sorted pebble size particles with coarse sand matrix	Kurkude-Guyuk and Jebilamba-Vininkilang
Se	Crudely stratified to massive sandstone: Containing coarse to very coarse grained clasts	Kurkude-Guyuk
Sp	Planar cross bedded sandstone: Coarse to medium grained clasts	Cham-Lafiya, Kurkude-Guyuk and Jebilamba-Vininkilang
St	Trough cross bedded sandstone: Coarse to medium grained clasts	Kurkude-Guyuk
Sf	Massive and compacted sandstone: Clay draped massive to slightly laminated sandstone	Ture-Bambam
Sh	Horizontally stratified sandstone: Fine to medium grained clasts	Ture-Bambam and Cham-Lafiya
Sm	Massive sandstone: Medium grained clasts	Jebilamba-Vininkilang
Sr	Ripple cross laminated sandstone	Cham-Lafiya and Jebilamba-Vininkilang
Fl	Finely laminated sandstone	Jebilamba-Vininkilang
Cf	Soft sediment siltstone/claystone	Ture-Bambam, Cham-Lafiya and Jebilamba-Vininkilang

Table 2: Facies Associations and Interpretations of the Depositional Environments.

Facies Association	Locality zones of occurrence	Interpretations of depositional environment
Conglomeratic facies association: angular chaotic intraformational and extraformational clasts (FA1).	Kurkude-Guyuk and Jebilamba-Vinikilang	Gravity driven talus and debris flow fan deposits
Major tabular sandstone facies association: cross, massive, horizontally and trough (FA11)	Ture-Bambam, Cham-Lafiya and Jebilamba-Vininkilang	Fluvial channel deposits
Soft sediment deformed beds (FA111)	Ture-Bambam, Cham-Lafiya	Rapid sedimentation occasioned by hydrodynamic pressure
Medium bedded lenticular sandstone (FA1V)	Cham-Lafiya and Jebilamba-Vininkilang	Lacustrine and ponding in the axial portion of the trough

FACIES ASSOCIATIONS IN BIMA SANDSTONE

Kukurde – Guyuk Zone

This zone is located in the northern part of the basin and the studied axis is from Kurkude to Guyuk. At Kurkude, proximal to the basement, the deposits are mud supported conglomerates. The clasts which are mainly extraformational, range from 1m to 3m in diameter and are embedded in silty mud matrix. The clasts might have derived from nearby crystalline rocks and in-filled the faulted blocks of the gneissic basement from where they radiate towards the axis of the basin.

The beds of the sediments dip between 20^{o} and 30^{o} and gradationally become intraformational clasts towards the basin centre. They are a conglomeratic facies which bears chaotic internal fabric with reddish clay matrix. Evidence of deformation is marked by occasional sheared bands on the strata. These lithologic characteristics are also common in localities around the basement margin like Sanni and Nahantsi. East of Kurkude, close to the Hawal River as well as in Guyuk localities, the conglomeratic deposits become structured into trough cross bedding, ripple cross laminated and sometimes crudely stratified to massive sandstone bodies. Their beds and coset thicknesses range between 0.5m and 3m while the grain size is coarse to fine grained sands. The fines dominate the rippled laminated beds while coarse clasts dominate the crude stratified and massive sandstone beds.

Lithofacies Interpretation

A study of the lithologic composition of Bima Sandstone along the Kurkude-Guyuk axis reveals four major lithofacies: the matrix supported conglomerate (Gmm); crudely stratified to massive sandstone (Se); trough cross-bedded sandstone (St); and ripple laminated sandstone facies (Sp). The dominant poorly sorted and chaotic clasts of the facies indicate gravity prone turbulent form of deposition (Hossain, et al., 2002).

The basement derived clasts and the mud matrix suggest that the deposition is in form of fan related debris flow rather than being a lag deposits as there are no erosional surfaces. The gradational changes in the facies is reflected by the clastic deposits of the marginal fault scarp talus at the point of feeder channel at Kurkude area changing to crudely stratified and delta lobe deposits of the upper fan stage around Guyuk (Figure 3).

Figure 3: Alluvial Fan Lobe Deposited Distally to the Gravity Prone Marginal Fault Scrap Talus. The Crudely stratified Sandstone Body Lies on Top of Severely Eroded Cross Bedded Silty Clay of the Fan Sediments (Locality: Guyuk).

Ture-Bambam Zone

Ture-Bambam zone is within the central axis of Yola arm. The area has wide exposure of Bima Sandstone punctuated by alkaline volcanic plugs and cones. At Ture Village, close to the Kaltungo Inlier, the formation outcrops as a cliff revealing the depositional sequence. The base is horizontally bedded and arkosic with a lot of the feldspar grains. The grains are medium to coarse with a concentration of the coarse in the channel lag deposits. In each of the remaining beds of the lower section, vertical distribution of the particles reveal that they progressively decrease in size to the upper plane of the bed forming a cyclic coarse-tail graded bedding.

The upper section of the cliffy outcrop is massive with highly compacted sediments having unsorted particles that are essentially arenaceous. Other outcrop in the zone show graded bedding motif while some are conglomeratic. The conglomeratic deposits consist of pebble and granule clasts within a sandy matrix. The clasts are sub-rounded to well-rounded and fairly sorted within trough cross stratified horizons. Some horizons especially at Mbamba have syn-depositional deformed beds in form of overturned foresets (Figure 4) and convolute beddings. The deformed beds possess few dispersed coarse sands and pebbles with silty to fine grained sandstone groundmass.

Lithofacies Interpretation

Fluvial channel with normal graded bedding of decreasing grain sizes characterises each of the beddings in the encountered sections at Ture-Bambam locality. Motif of sedimentation indicates four main lithofacies, namely; horizontally bedded arkosic facies (Sh), massive and compacted sandstone facies (Sf), matrix supported conglomeratic facies (Gmm) and deformed muddy siltstone facies (Fcf). The horizontally bedded arkosic facies with its attendant bar deposit were created by a high sinuosity stream channel flow. Blair (1987) indicated that such sinuous stream deposits were ephemeral and fluctuated in discharge. The network of bar is reflected in the cyclic graded bedding indicating that no sooner was the channel continuously produced than it was continuously choked with detritus.

Figure 4: Overturned Foresets of Syndepositional Deformed Beds (Locality: Mbamba).

Rejuvenation in the competence of the flow led to deposition of chaotic stream flow of the poorly sorted massive sandstone facies. The conglomeratic trough cross bedded facies (Gmm) in the platform outcrop is interpreted as aggraded filling of frequently shifting small channels from a high sinuous stream typical of fan delta lobe (Figure 3).

The identified plastic deformations in other sections of the zone occurred where the grain sizes were observed to be drastically reduced forming muddy siltstone facies. The deformation was as a result of rapid deposition of the fine grained sediments whose low permeability increases the pore fluid pressure. The balance of rapidly increasing overburden pressure against the pore fluid pressure created a partial liquefaction of the grains towards the dominant current direction which is observed as plastic overturned / recumbent fold. It is therefore inferred that the soft sediment deformation structures are indication of rapid deposition under water saturated condition probably triggered by seismicity.

Cham-Lafiya Zone

The exposures at Cham-Lafiya zone reveal the topmost layers of Bima Sandstone and the overlying Yolde Formation as observed at the Gombe-Yola road which cut across the crest of Lamurde Anticline. The terrain is dominated by stacked sets of tabular planar cross bedding with thicknesses ranging from 0.5m to 6m (Figure 5a). Some of the beds show contrasting directions of their foresets (Figure 5b) while others have the foresets of their overlapping multi-storey channel sequences commonly dipping between N18˚E and N30˚E mainly in the southwest direction (Figure 5c). There are occasional occurrences of collapsed medium bedded sandstone draped with paleosols and containing some rip-up clasts at the erosional surfaces (Figure 5d). They are greyish to reddish in color with medium to fine grained particle size. Commonly at the topmost part of the sequence, festoon cross beddings abruptly replaced the dominating cross-beds (Figure 5a).

Figure 5: Stacked Sets of Tabular Planar Cross Beddings a) Overlapping Multistory Channel Sequences having Festoon Cross Bedding at the Top, b) Contrasting Direction of Foresets Depicting Channel Switching, c) Bedsets showing Foresets commonly dipping Southwestward, and d) Medium Bedded Sandstone Draped with Paleosol Depicting Ponding of the Stream (Locality: Lafiya).

Lithofacies Interpretations

Identified lithofacies are tabular planar cross bedded sandstone (Sp), horizontally stratified massive sandstone (Sh), and the muddy siltstone facies (Fcf). The pervading tabular planar cross bedding unequivocally represents low sinuous regime of deposition that created braided channels (Roberts, 2007). Such abundant large scale planar cross stratifications coset in multi-story sandstone sequence indicate down-current migration of transverse bars in shallow water stream channels as a result of deposition by lateral accretion.

Their occurrences in successive overlapping multi-story beddings suggest repeated re-occurrence and lateral coalescence of channels. Some of the beds however show deltaic motif of sedimentation with their isolated sets of large scale crossbeds indicating deposition by migration of large bars into a deltaic channel. The beds showing changes in current directions were as a result of channels cutting into the braided sand bars as the stream flow altered in strength and direction.

The thin to medium bedded paleosol draped sandstone beds are representative of crevasse-splay or bar top sequence associated with the flood plain. The poorly developed hydromorphic paleosol suggests a wet sub-humid alluvial system while the progressive fining upward sequences in each bed is a reflection of a declining current competency in each of the depositional episode.

Vinikilang-Jebilamba Zone

Prominent exposures in this locality zone are found in the basinward axis of Jebilamba, Girei, and Vinikilang. At Jebilamba, the exposures display a pebbly conglomerate with well-developed clast orientation and normal graded beddings. Each of the conglomeratic beds is massive and ranges from 3m to 7m in thickness (Figure 6a).

Towards Girei and Vinikilang, the beds grade imperceptibly into trough cross bedding, oblique cross laminated beddings and massive beddings with medium to coarse grained clasts. At Girei, the beds have imposing sets of oblique cross laminations with well-marked north-west oriented paleo-current direction. Each of the cross beds is bound by oblique parallel laminated siltstone (Figure 6b).

At Vinikilang, evidence of channel cutting and erosional surfaces occur along some of the bed boundaries. In some sections of the zone, lensoidal clay bodies appear between the thick sandstone beds with sole-marks identified at their underside. Other bedforms are also exposed at the surface which include furrow and rib structures, herring bone and ripple marks. Contrasting orientation of the cross lamination are also common.

Lithofacies Interpretation

Four major lithofacies present in the zone are graded and clast supported conglomeratic sandstone facies (Gcm), trough cross bedded sandstone facies (St), cross bedded sandstone facies (Sp) and massive sandstone facies (Sm). Other subordinate lithofacies are laminated and ripple siltstone (F l) and clay facies ((Fcf). The concentration of the graded conglomerate deposits in Jebilamba is a reflection of chaotic sedimentation close to the basin margin. This is another fan accumulation in response to basement fragmentation during rifting.

The beds with trough cross bedding are indicative of aggradational fillings of frequently shifting channels as the stream continue to braid (Hossain, et al., 2002). Exposures of the trough cross beddings on a plan surface are in form of ‘rib and furrow’ structure (Figure 6c).

The indication of low sinuousity stream that forms the braids is marked by the pervading presence of planar cross stratification. Braide (1992) identified the beds as crevasse splay developed mainly in the distal region of braid delta and recognised the oblique thin siltstone layers as the levee (Figure 6b).

This is in contrast with the crevasse splay formed as a result of debouching of stream load as overbank deposits. The two forms of the crevasse splay are identified in this zone between Girei and Vinikilang. The latter form of splay is often associated with desiccation cracks (Figure 6d), observed on a plan view, as a preserved structure in the muddy intervals of the massive sandstone bodies.

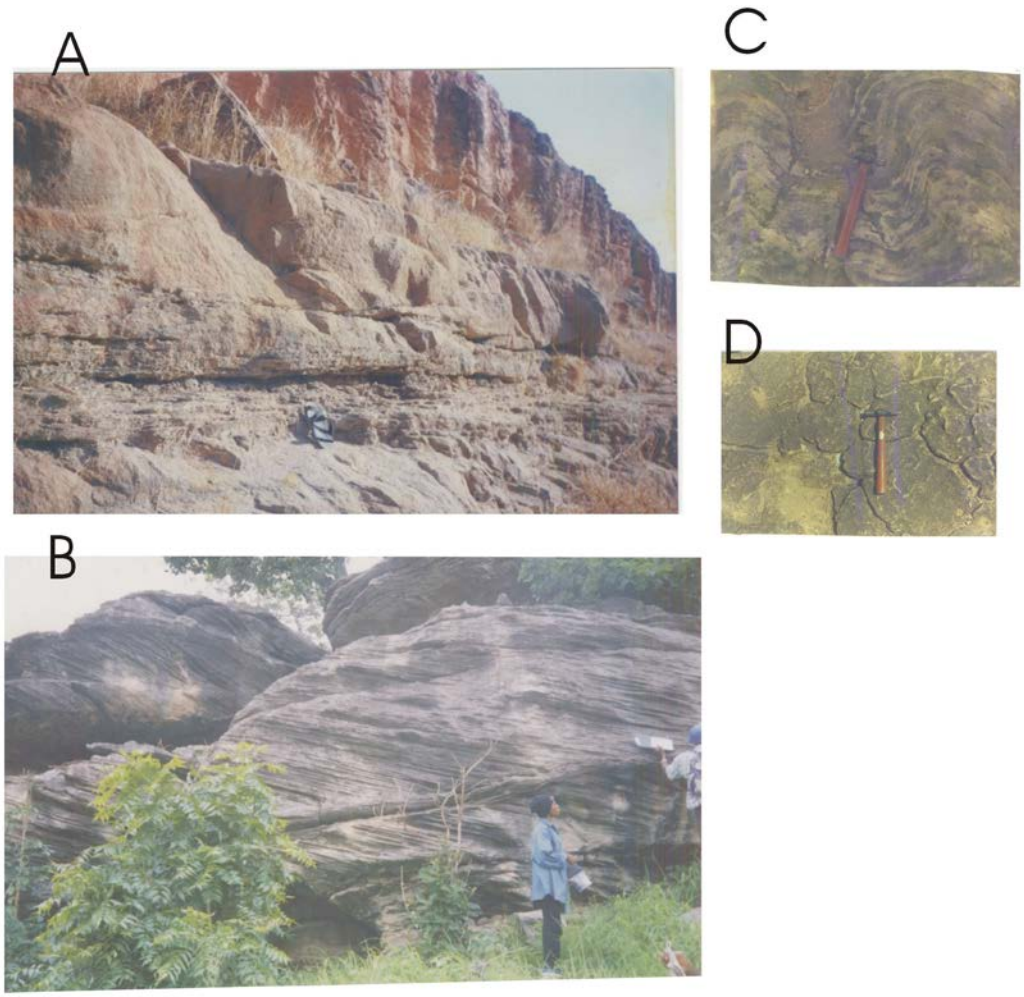

Figure 6: Massive and Cross Beddings with Structures of Overbank Deposits: a) Massive Bedded Sandstone Crevasse (splay) on top of Parallel Laminated Siltstone (levee), b) Crevasse Splay as Uni-directionally Oriented Sandstone Separated by Un-oriented Ferruginized Bedding Plain (levee), c) Trough Cross Bedded Sandstone Showing "Rib and Furrow" Structure in Plan View, and d) Desiccation Cracks in the Muddy Section of the Overbank Deposits.

DISCUSSION

Facies relationships of Bima Sandstone in local sections of Upper Benue trough, analyzed in terms of textures, internal sedimentary structures and boundary conditions provide insight into the paleo-environmental conditions that prevailed during the deposition of the formation. The analysis shows that the formation was accumulated under fully alluvial environments of both fan and channel deposition (Table 2).

Depositions started with gravity driven and mud flow sedimentations considered as syn-rift at locations closer to the basement (Kurkude and Jebilamba in this study). Although bed cross sections in this zone were not observed in the field, their surface exposures reveal exotic angular pebbles and cobbles as well as intra-formational particles in chaotic manner depicting turbulent discharges. Towards the basin axis around Guyuk and Girei, textural changes occur in facies association of trough, massive and cross bedded sandstone with clast supported conglomerate.

The deposits are recognized as Conglomeratic facies – (FA I). The association constitutes delta lobe deposits typical of the mid fan section. It is at this instance that the influence of fluvial

channel alluvial sedimentation spread towards the axis of the basin. The channel deposits are mainly marked by graded bedding cyclicity revealed in high sinuous point and transverse bar deposits. However, a large portion of the basin exhibits a low sinuous form of sedimentation typified by imposing stacking tabular cross bedded sandstone inferred as braided stream sediments whose high discharge was by lateral and vertical accretion.

The zone is recognized as Major Tabular Sandstone Facies association – (FA II). The various channels laterally pass into soft sediment facies as there is also a general trend in decreasing grain sizes basinward. The latter facies (soft sediments deformed beds – FA III) represents a series of rapid sedimentation occasioned by hydrodynamic pressures. As the channel became flooded accompanied with subsidence, overbank deposits and ponding ensued.

Crevasse splay resulting from braid delta and debouching alluvium developed as medium bedded lenticular sandstone facies association – (FA IV). The subsidence created barrier to the drainage of the fluvial system within the axial portion. Observed desiccation cracks and ferruginous sandstone bodies in this zone can be linked to the effect of climate on the stream flooding and subsequent subaerial exposure.

The trend in the depositional style corresponds to a rejuvenation of the competence of the stream which led to low sinuousity braided deposits from a high sinuous form of the point/transverse bar type. The overall depositional style therefore corresponds to an alluvial - lacustrine system. A similar system was analyzed for the Pull Apart Cretaceous Eumsung basin in South Korea by Ryan and Chough (1999).

CONCLUSION

Facies association of the Bima Sandstone in the Upper Benue Trough reflects the tectonic evolution of the basin. The concept of pull apart basin fits the rapidly changing alluvial facies from coarser grained marginal to finer grained axial deposits. The stacking patterns of the deposits are mainly of fan and fluvial channel sedimentation. While alluvial fan was deposited as gravity and debris flow, a high sinuousity stream flow leading to a low sinuous form, probably due to rejuvenation in the competence of the stream, was the basis of channel deposition of the point/transverse bar as well as braided deposits in the basin. Four major Facies association identified are: conglomeratic facies association – FA I; tabular sandstone facies association – FA II; Soft sediment deformed beds FA III and medium bedded lenticular sandstone association-FA IV.

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