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Anastomosing River Deposits: A Case Study of Enagi Siltstone, Northern Bida Basin, Central Nigeria

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Abstract

Anastomosing river system has been described as alluvial deposits having multiple coexistent interconnected channel belts enclosed by floodbasins. The present study is based on field mapping involving construction of sedimentologic graphic logs that depict the lithofacies as well as their analyses using the concept of architectural elements. This method demonstrates that the sediments of the upper part of Enagi Siltstone can be interpreted as products of an anastomosing river system. Outcrops of the Enagi Siltstone exposed near Batati, Patti-Shaba Kolo and Manigi towns revealed mainly two facies namely: Fa, characterised by (1 – 3 m thick) massive/laminated siltstones or planar cross-bedded very fine to fine-grained sandstones with sharp undulating erosional basal surfaces mantled with flat-mud-pebble conglomerate, interpreted as stable channel units; and Fb, consisting of (1 – 8 m thick) mudstones or interbedded siltstones and mudstones organised into laterally extensive thin to thick tabular beds interpreted as floodplain/overbank deposits. The facies define channel and overbank architectural elements respectively. The evidence for deposition within channels of the Fa facies is given by the possession of erosional base, coarse lag, fining-upward grain size profile as well as upward decrease in thickness of cross-bed sets which is consistent with upward decrease in energy in confined environments such as channels. Owing to the overwhelming dominance of the overbank architectural element over the channel element, the generally fine-grained nature of the deposit as well as lack of marine indicators, we then conclude that the sediments of Enagi Siltstone exemplify an anastomosing river deposit.

Keywords: Anastomosing, Bida Basin, Sandstone facies, Mudstone facies, Architectural element.

Introduction

Recognition of anastomosing river deposits has a lot of implications for interpreting the large-scale paleogeographic conditions of a sedimentary basin (Galloway and Hobday, 1983). The high sedimentation rates that occur in anastomosing river systems suggest that their deposits are abundant in the stratigraphic record (Makaske, 2001). However, not much has been documented by authors mainly because of lack of detailed facies analysis and paucity of papers that deal with description of typical features of anastomosing river sediments especially in ancient deposits.

This work presents a detailed regional lithofacies and architectural element analyses of the Enagi Siltstone Formation of northern part of Bida basin (Figure 1). The objectives include:

(1) documentation of lithofacies within the unit (2) petrographic study of representative samples (3) identification of architectural elements (4) deduction of environment of deposition.

The studies of modern anastomosing river systems is far-reaching these days due to their economic importance arising from the extensive flood plains that can be used for agricultural and other functions (Makaske, 2001).The channel facies within ancient anastomosing river deposits may perhaps serve as good reservoirs for hydrocarbons because they are usually surrounded at their tops and bases by thick floodplain mudstones. The floodplain mudstones are also potential source rocks especially when they are organic matter rich or associated with coal horizons as seen in the laterally equivalent Patti Formation in the southern part of Bida Basin.

Geological Setting

The Bida basin is a NW – SE structure oriented perpendicular to the Benue trough (Benkhelil, 1989). It is located near the central part of Nigeria (Figure 1) covering an area from around Kontagora in Niger state to Dekina in Kogi State with a distance of about 400 km and a width ranging from 75 – 150 km (Zaborski, 1998). The basin fill is up to 4 km locally but the average thickness of the succession is about 3 km (Udensi and Osazuwa, 2004).

The basin is filled with dominantly Maastritchian strata comprising four lithostratigraphic units (Adeleye, 1972) in the northern part (Figures 1 and 2). From the oldest the units are: (1) Bida Formation comprising of alluvial fans, braided and meandering river deposits (Adeleye and Desauvagie, 1972; Okosun *et al.*, 2009) its lateral equivalent is the Lokoja Formation in the southern part; (2) Sakpe Formation consisting of mainly ironstones with goethite, this unit has not beenreported from the southern part; (3) Enagi Siltstone comprising mainly siltstones and mudstones with subordinate sandstones inferred to be deposited in distal fan, floodplain and lacustrine settings, its lateral equivalent in the southern part is Patti Formation; 4) Batati Formation consisting of mainly ironstones with goethite and kaolinitic beds (Figure 3).

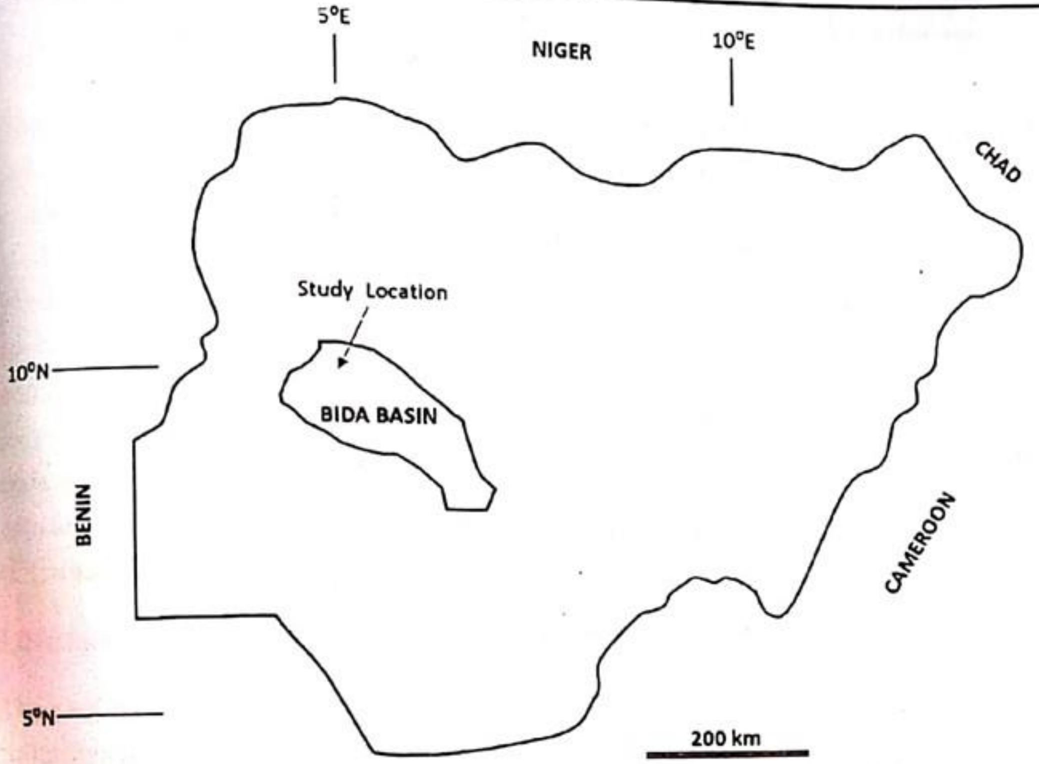

Figure 1:Map of Nigeria showing the location of the study area.

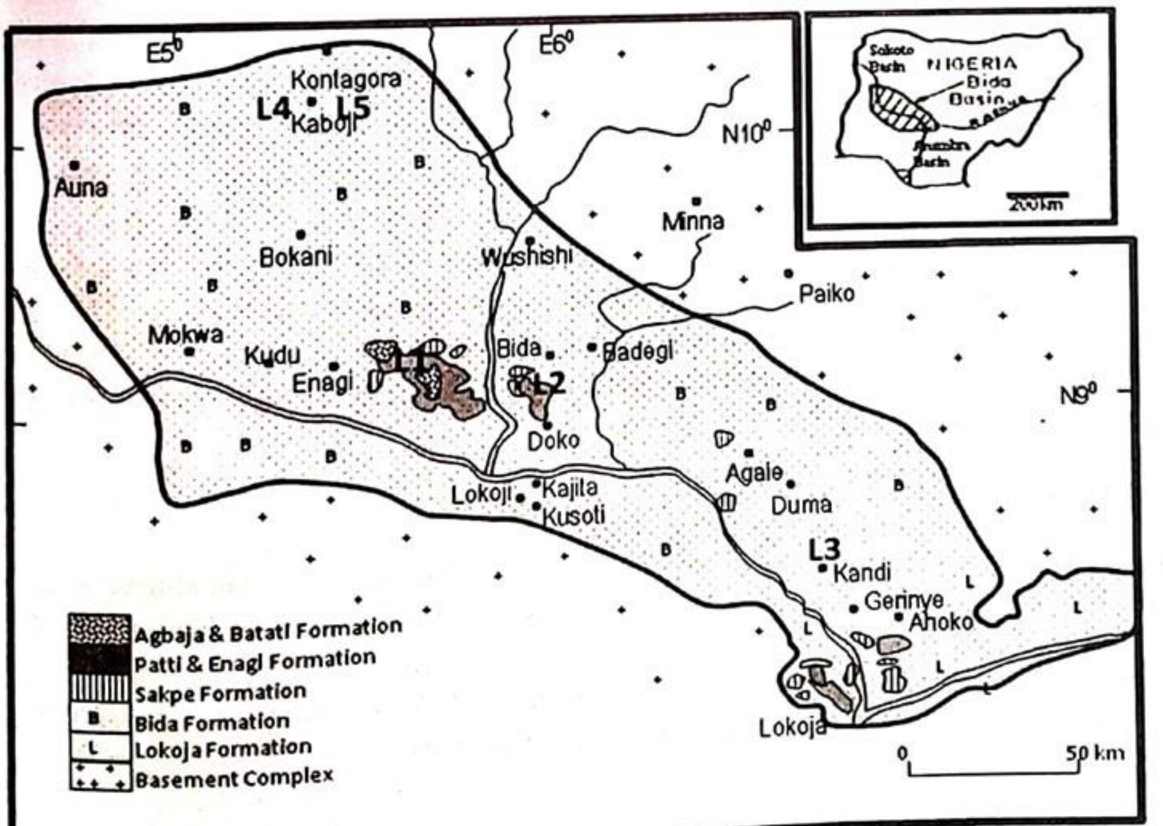

Figure 2: Simplified geological map of Bida Basin (Modified from Adeleye, 1976) showing location of logged sections (Adapted from Okosun *et al.*, 2009).

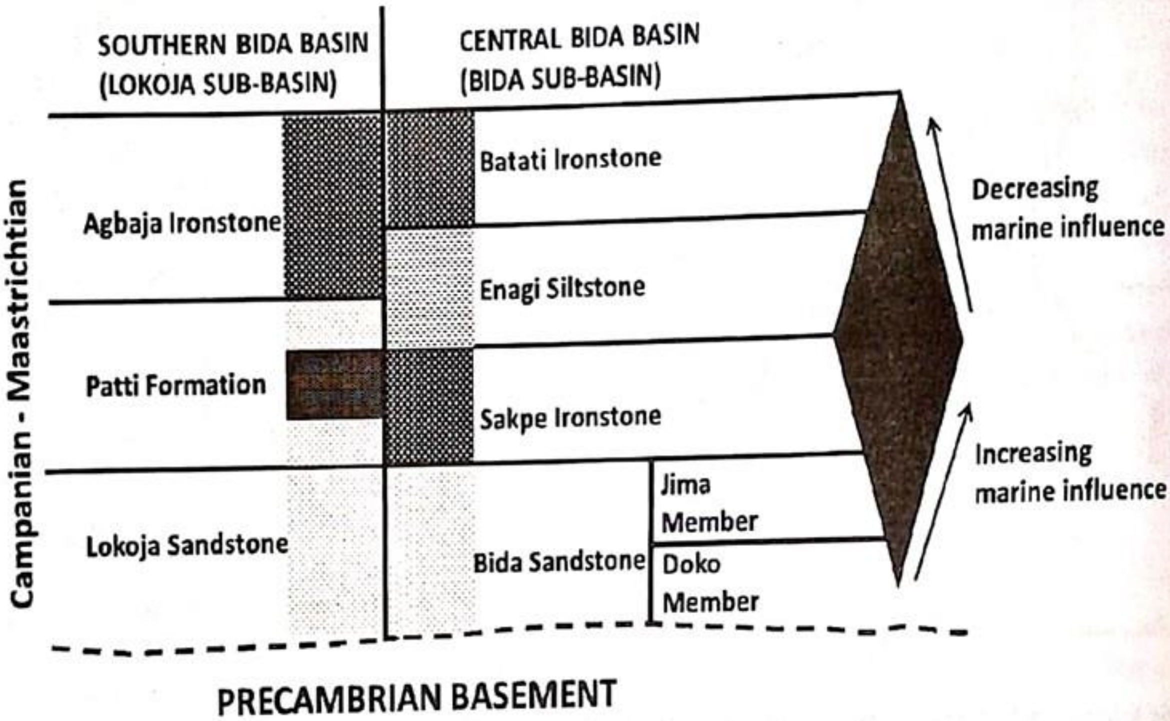

Figure 3:Stratigraphic successions in the Bida Basin (modified from Obaje, 2009).

Methodology

Field mapping of fairly well exposed parts of Enagi Siltstone sediments was conducted around Batati in the central part of the basin, Manigi in the northern part of the study area and Kandi in the eastern part (Figure 2). Representative samples were collected for thin section preparation and analysis from each location. The external and internal geometry of the lithofacies were used to define architectural elements based on Miall (1985; 1988). Interpretation of broad environment of deposition was achieved by analysis and comparison with similar units in the literature.

Results and Discussion

Two main lithofacies were identified namely: (1) sandstone facies, and (2) mudstone facies. Their field characteristics are summarized in graphic logs (Figure 4) while figures 5 and 6 show pictures of the main features that differentiate the facies despite their generally fine grained nature. The two lithofacies broadly define two architectural elements represented by channel and overbank architectural elements (Mial, 1985; 1988).

Lithofacies

Lithofacies (Fa) - Sandstone Facies

This facies consist of 1-3 m thick units comprising mainly fine grained sandstones with subordinate very. fine-grained sandstones and siltstones (Figures 4 and 7). They are characterized by sharp, erosional bases overlain directly by coarser sands and mud rip-up clast conglomerates (Figure 5D). Sedimentary structures include fining upwards of grain size, planar cross bedding, upward decrease in size of the cross bed sets (Figure 5A), ripple lamination especially towards top of units (Figure 5A). Cross bed sets range from 5 - 45 cm and display unidirectional paleocurrent direction mainly to the northwest around the northern part of the study area. Other sedimentary structures include mud drapes on foresets of cross beds as well as reactivation surfaces (Figures 5F, G) and sand balls (Figure 5F). Some units appear massive or horizontally laminated especially when they are very fine grained sands (Figure 5E).

Lithofacies (Fb) - Mudstone Facies

The sedimentary units belonging to this facies are mainly mudstones and siltstones with subordinate very fine to fine grained sandstone beds (Figure 4). They occur as thin laterally extensive interbedded tabular beds (7-25 cm or 40 - >100cm) of mudstones and siltstones (Figures 6A, B, D, E). Internally, the beds are either parallel laminated (Figure 6C) or massive and mottled (Figure 7D). Wave ripples are seen at the top of some siltstone beds (Figure 6E). On outcrops, the siltstones mostly form ridges while the mudstone beds make up the recess formers due to their vulnerability to erosion. This facies is also characterised by concretions that occur at certain intervals and can be traced for several hundred meters laterally (Figure 6F). The concretions are mostly siltstones that are ferruginised and assume mainly circular to elliptical shapes, although some are irregular in shape. Some siltstone beds are thick (1 – 3 m) with sharp, concave-up erosional basal boundaries directly overlain by thin flat-mud pebble conglomerates similar to Fa units.

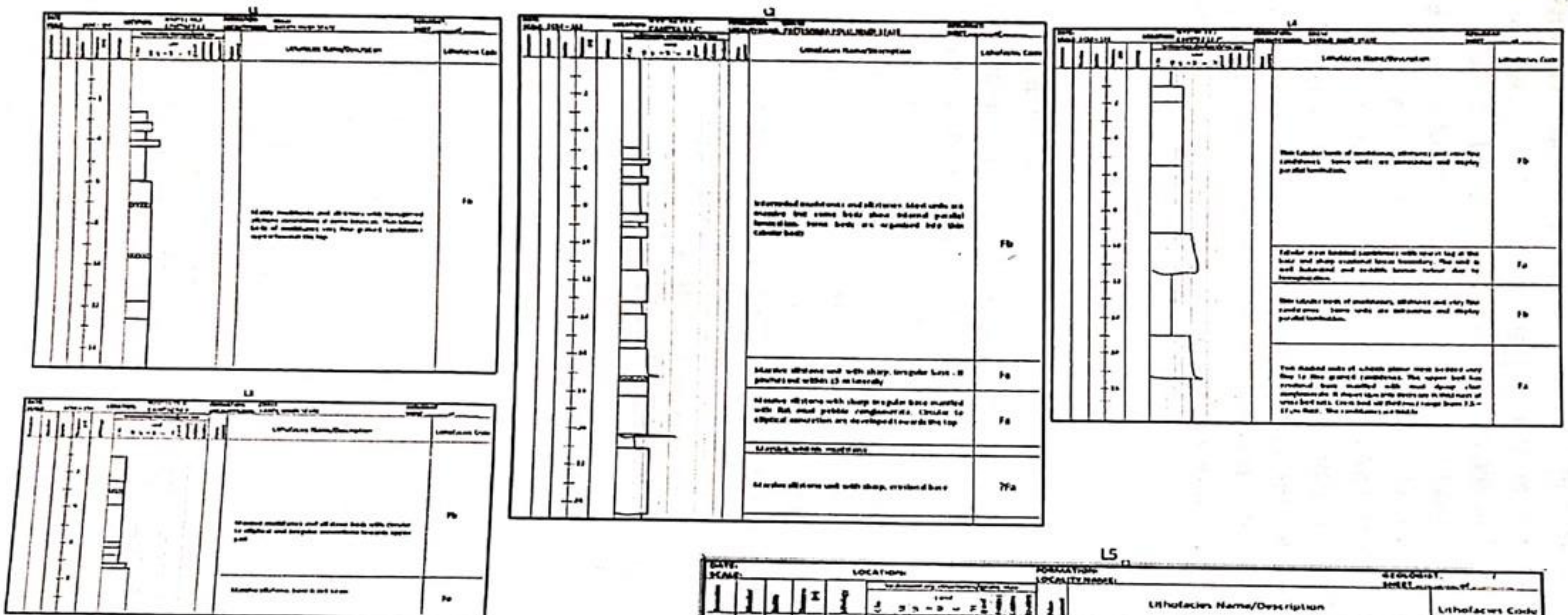

Figure 2. Graphic logs summarizing typical features of the uppermost part of Enagi Siltstone, Northern Bida basin, Nigeria: L1, Batati; L2, Patti-Shaba Kolo; L3 Kandi; L4 ...

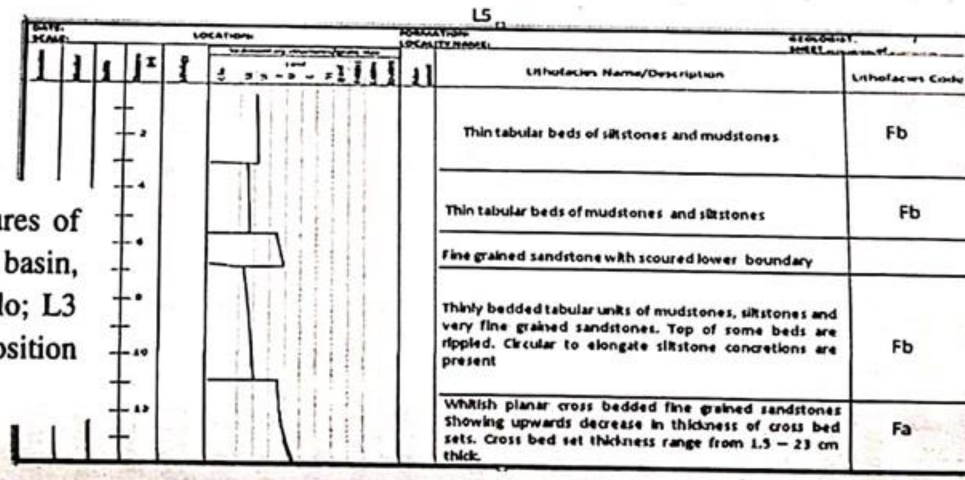

Figure 4: Graphic logs illustrating typical features of the upper part of Enagi Siltstone, northern Bida basin, Nigeria. Note: L1, Batati; L2, Patti-Shaba Kolo; L3 Kandi; L4 & L5, Manigi. See Figure 2 for the position of the logged areas.

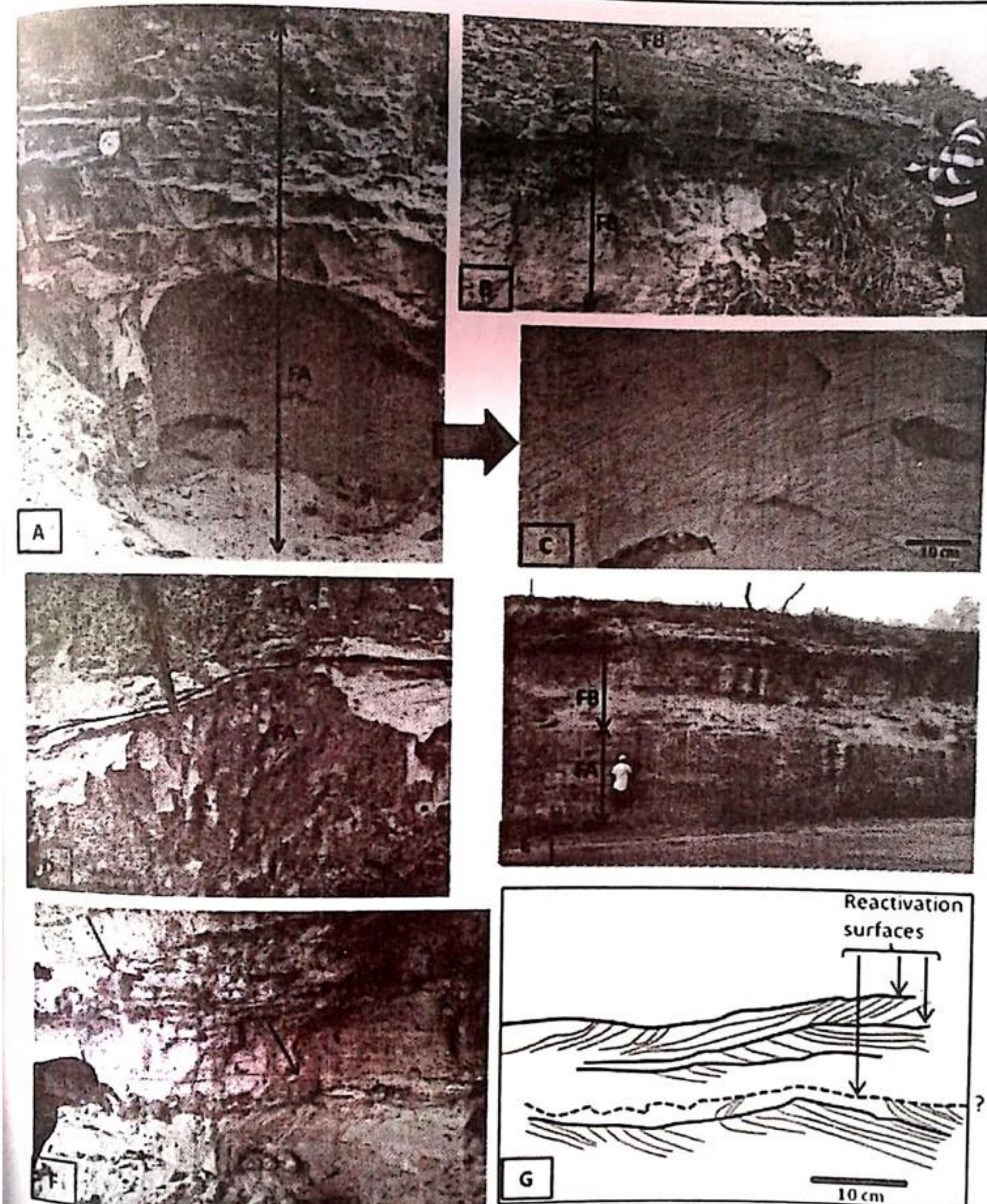

Figure 5: Outcrop photos of Fa units showing: (A) trough cross-bedding, upwards decrease in cross bed set thickness in fine-grained sandstone unit from L5 (B) sharp, undulating boundary between Fb and Fa; and gradational boundary between Fa and Fb towards the top, from L4 (C) enlarged photo of the lower part of (A) as indicated by an arrow, showing the trough cross-bedding and mud drapes on foresets of the cross beds, from L4 (D) erosional surface separating two Fa units; the surface is, L4 overlain by thin mud rip-up clast conglomerates (intercepted by the lower end of biro used as a scale) (E) massive very fine grained sandstone Fa facies, L3 (F) small-scale trough cross and planar cross beds towards top of an Fa unit and reactivation surfaces as well as sand balls (indicated by the red arrows), L5 (G) interpreted sketch of (F) picture showing details of the reactivation surfaces.

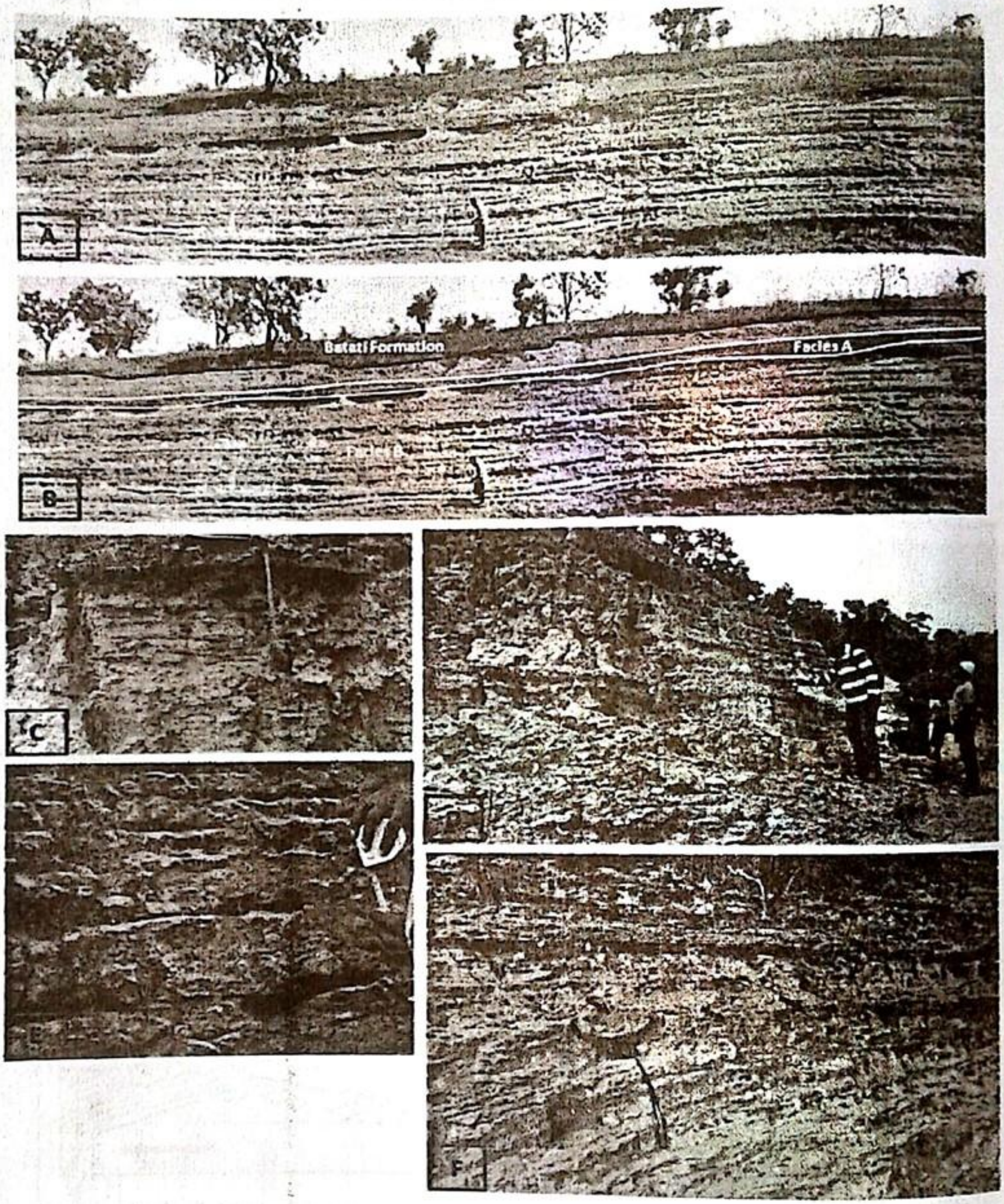

Figure 6: Outcrop pictures showing typical features of Fb sediments:

A. Picture illustrating the proportion of Fb to Fa; Fb is usually thicker than Fa (unannotated).

B. annotated picture of (A) showing thickness disparity between FA and Fb; the Fa is demarcated with yellow lines and the red line shows the boundary between Enagi Formation and Batati Formation.

C. Horizontal lamination within Fb facies sediment.

D. Fb sediments showing laterally extensive thin tabular beds

E. Close-up view of thin tabular beds within FB, note the ripples at the top in some beds.

F. Concretions along a horizon within Fb, black arrows point at the concretions.

Thin Section Petrography

The results of the petrographic analyses further discriminate the various grain sizes observed in the two identified lithofacies (Figure 7). Photomicrographs (Figure 7A and B) display the grain sizes of coarse lag sediment and fine-grained cross-bedded sandstones of Fa respectively. The thin-section micrograph of erosively based siltstone unit of Fa is shown in Figure 7C while the siltstone and mudstone units of Fb a location in Kandi are displayed in Figure 7D and F. Figure 7E shows a micrograph of bioturbated mudstone unit. The thin-sections results are fairly consistent with the observations made at an outcrop scale. Diagenetic features were not assessed due to the weathered nature of the sample; however, the mostly floating contacts observed in the units indicate minimal compaction of the sediments.

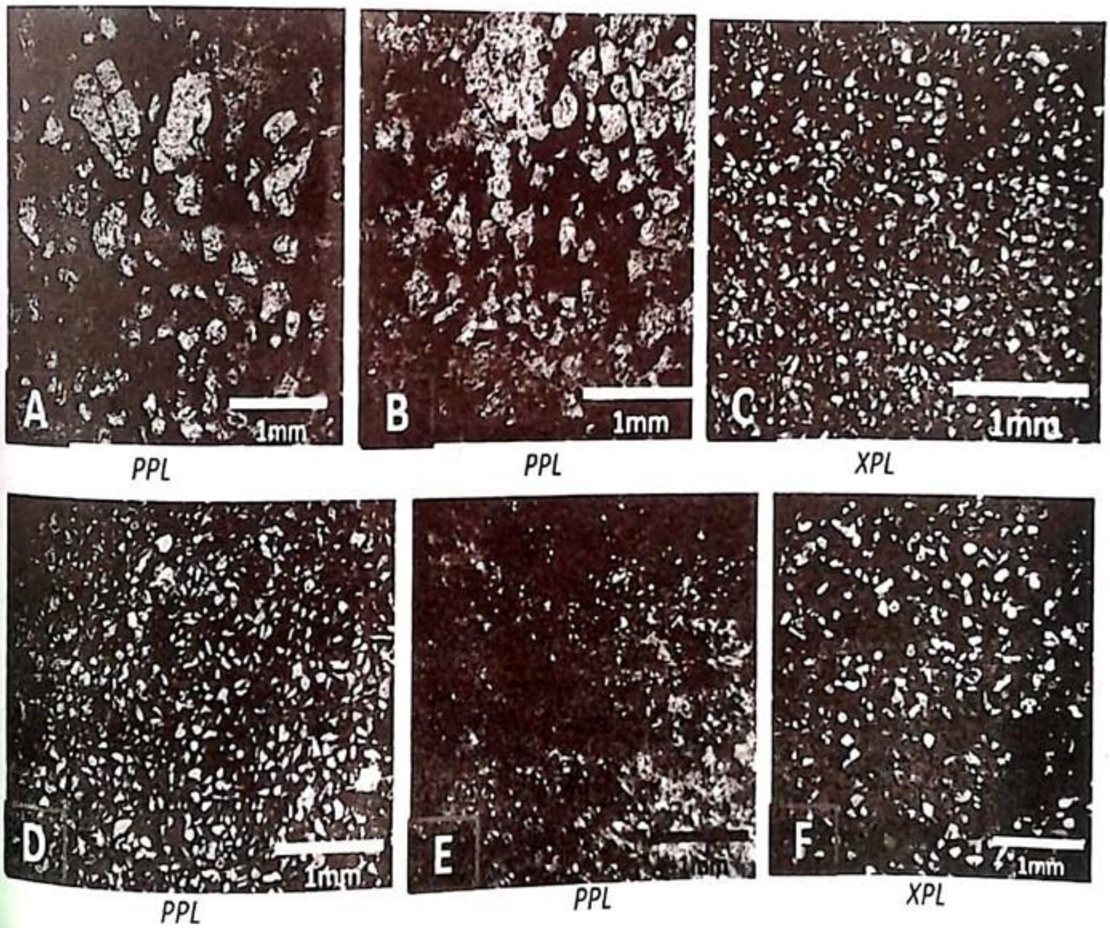

Figure 7: Photomicrographs of representative samples showing:

A. Coarse-lag sediment at the base of Fa; from Manigi (L4)
B. Fine-grained, cross-bedded sandstone of Fa; at Manigi (L5)
C. Siltstone with channel-fill geometry (Fb); at Kandi (L3)
D. Unbioturbated siltstone of Fb (L2)
E. Bioturbated mudstone of Fb (L1)
F. Unbioturbated siltstone of Fb (L4)
(*PPL*, in Plane Polarized Light; *XPL*, in Cross Polarized Light)

Architectural Elements

Channel Architectural Element

Channel architectural element (Mial, 1985; 1988) is defined by the sandstone facies (Fa) of this work. They occur as vertically isolated units within the dominantly finer grained sediments of Fb. They are laterally not as extensive as the Fb units based on the observed pinch out seen within few meters (less than 50 m) in some outcrops. They are however more than 50 m laterally in some places. Lines of evidence underpinning the interpretation of these sediments as channelized deposits are the presence of sedimentary structures such as erosional base mantled with mud rip-up clasts conglomerates, fining upward of grain size, progressive upwards decrease in size of cross bed sets and unidirectional paleoflow trend. Cross bedding record migration of subaqueous 2D and 3D dunes. Presence of reactivation surfaces and mud drapes on foresets of cross beds may indicate tidal effects on the channels (Reineck and Singh, 1980). Changes in river stages and fluctuating energies are responsible for the formation of these structures (Tucker, 2003). Formation of sand balls are related to sediment gravity loading of more competent intervals in the midst of less competent ones at upper reaches of channels units where energies are lesser allowing heteroliths to develop.

Overbank Architectural Element

The sediments of Fb show the usual characteristics of overbank architectural element (Mial, 1985; 1988). They pre-dominate the succession with a proportion of at least 70%. They have tabular geometries with sharp upper and lower boundaries. The interbedded thin tabular siltstones and mudstones occurring close to the top of Fa units may be interpreted as levee deposits while the laterally extensive interbedded mudstones and siltstones with wave ripples can be interpreted as lacustrine deposits (Nadon, 1994). The mottled, massive mudstone intervals are assumed to be marsh deposits (Smith, 1983). The channelized siltstone units are interpreted as abandoned channel deposits based on the geometry of the units (Makaske, 2001).

Earlier works (Adeleye, 1972; Braide, 1992; Okosun *et al.*, 2009) on the sediments of Enagi Siltstone described the sediments as mainly siltstones with minor amount of sandstones and interpreted them as flood basin sediments of distal portion of alluvial basin without considering detail of the geometry of the sandstones within the flood basin sediments. However, more recent understanding of floodplain geomorphology shows that flood basins are flat, shallow depressions that are usually poorly drained and overlie natural levees of active or abandoned channels (Makaske, 2001). This definition clearly shows that the interpretation of these sediments as flood basin deposits is inadequate.

Owing to the overwhelming dominance of the overbank architectural element (floodplain, abandoned channell and shallow lacustrine sediments) over the channel element, the generally fine-grained nature of the deposits as well as lack of typical marine indicators, it is concluded that the sediments of the upper part of Enagi Siltstone were deposited in an anastomosing river system. The isolated channel elements within the overbank elements record aggradation in fixed channels as a result of stable banks during low discharge periods (Friend *et al*., 1979; Gibling, 2006). At high discharge periods, the channel suffers avulsion and shifts to another isolated position within the flood plain. These rapid flood plain aggradations contemporaneous with repeated avulsion have been inferred to build up the sedimentary succession of anastomosing river deposits (Makaske, 2001). Rapid base level rise in an alluvial system, especially if close to a marine basin provides favourable conditions for development of anastomosing river systems (Smith and Smith, 1980). The studied sediments display mud drapes on foresets of cross beds as well as reactivation surfaces which may indicate tidal effects suggesting proximity to a marine basin. Changes from arid to humid climate have been attributed by some researchers as possible causes of anastomosis (Garner, 1967; Baker, 1978).

This unit is laterally correlatable with the better studied Patti Formation in the southern part of the basin. Ojo and Akande (2006; 2009) interpreted the upper part of Patti Formation as non-marine swamp/floodplain deposits based on detailed facies and palynological analyses of the sedimentary succession. This is similar to the interpretations made herein. The occurrence of swamp and marsh deposits within overbank architectural elements of anastomosing river deposits have been highlighted by researchers such as Miall (1985) and Collinson (1996) which further strengthens the interpretations made in this work.

Conclusions and Recommendation

The architectural element analysis of the upper part of Enagi Siltstone in the northern part of Bida basin suggests deposition in anastomosing river setting based on punctuation of the floodplains by channelized units at some intervals.

Two architectural elements were identified including: (1) channel element characterized by very fine to medium-grained erosionally based cross bedded sandstones showing fining up grain size profile and upwards decrease in size of cross beds; (2) overbank element consisting of tabular siltstones, mudstones and subordinate very fine to fine-grained sandstone recording floodplain, marsh as well as abandoned channels. Tidal effects are suggested by mud drapes on foresets of cross beds in channel elements indicating possible proximity of the rivers to a marine basin.

This work also shows that detailed architectural element analysis of the Enagi Siltstone may yield useful results that may perhaps change or modify earlier interpretations of the unit.

These interpretations are similar to those for the laterally correlatable upper parts of Patti Formation; yet more detailed analysis using especially palynology and clay mineral analysis is suggested.

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