Original Research Article

Sub-environments of Deposition and FaciesCharacteristicsof the Nyaba River in Enugu Metropolis Southeastern Nigeria

Abstract

A field study undertaken on the various sub- environments of deposition and sedimentary facies attributes of the Nyaba River in Enugu Metropolis was for a better understanding and interpretation of modern river processes and their sedimentary facies characteristics. A unique attribute of thisriver is its meanderingcharacteristics at the upper reaches and minor braiding at its lower reaches. TheMeandering river sub- environments and their faciesare distinguished into the main meander channels/lag deposits, well -developed point bar deposits, the levees and the flood plain deposits. Abandoned channel deposits (meander cut off) is also a common characteristic of the river. Braided channel and longitudinal braid bars constitute the depositional sites of the braided river.Clasts are dominated by sandy fractions with sub-angular to sub-rounded grains. Sorting varies from poorly sorted to well sorted. Pebbles and muddy fractions also occur. Sedimentary structures consist of cross beddings on point bar sands, horizontal laminations, small current ripples, mudcracksand burrows of terrestrial organisms. Nyaba River is classified as a mixed load river.

KEY WORD: Nyaba, Enugu, Abandoned channel, Meander, Braid bar, Linguoid ripples

1.0 Introduction

A depositional environment is a geographically restricted part of the earth's surface which is characterized by the complex of physical, chemical and biologic conditions, influences or forces under which a sediment accumulates. This complex which distinguishes it from the adjacent areas also determines the properties of the sediments deposited within it (Krumbein and Sloss, 1963; Potter, 1967; Pettijohn, 1975; Selley, 1978; Blatt et al., 1980; Reineck and Singh, 1980; Slumberger, 1989). Miall (2018) defined a depositional environment as a particular location on the earth surface where a limited range of physical, chemical, and biological processes take place, resulting in the generation of a limited range of sedimentary deposits. Rivers are one of

such geomorphic settings on the continents where sediments are influenced by the physical, chemical and biologic processes resulting to a sedimentary facies of the environment.

Ancient river sediments or sedimentary rocks are widely distributed on the surface and subsurface parts of the earth. The importance of these ancient rocks cannot be overemphasized. Understanding and interpretation of the modern river environments and facies will provide clues to the delineation of the depositional settings of their ancient counterpart from their sedimentary facies attributes. One of the fundamental principles in geology referred to as "the principle of uniformiterianism" is simply interpreted as "the present is the key to the past" According to Miall (2018), identification of the characteristics of sediments in the modern settings enables the interpretation of depositional environments of the ancient sedimentary deposits. Such sediment characteristics include; the nature of lithology, texture (grain size, grain shape, roundness and sorting) and sedimentary structures.

This paper is aimed at identification of the various sub-environments of the Nyaba River and their facies attributes.

1.1 The Study Area

Enugu Metropolis is an industrialized and commercial city known mostly for its coal deposits and coal mining. It is located in southeastern Nigeria (Fig.1). The city is accessible through the east- west running Enugu- Onitsha and north- south trending Enugu- Port Harcourt expressways. There are also road networks which connect different parts of the metropolis. Major settlements in the town include Coal Camp, Uwani, Ogui, New Heaven, Emene, Abakpa Nike, Awkunanwu, Akwuke, Ugwuaji, Agbani, Independent layout, Trans Ekulu etc.

Enugu is situated at the foot of a Cuesta and underlain by the Campanian to Maastrichtian sediments of the Anambra Basin. The underlying lithostratigraphic units include the Enugu Formation overlain by the Mamu, followed upward by the Ajali and the Nsukka formations. The lowlands are underlain by the Enugu Formation whereas the sandstones of the Mamu, Ajali and Nsukka formations underlie the highlands.

Enugu Metropolis is drained by the Ekulu, Nyaba, Ogbete and Asata Rivers, which are the distributaries of the Cross River drainage system.

Enugu is located within the humid tropical rain forest zone of Nigeria with a derived savanna (Sanni*et al.*, 2007). Its annual rainfall has been estimated to vary from 1,600 to 2000 mm (Ofomata, 1965; Inyan, 1978; Egboka*et al.*, 1989). Warm day temperature ranges from 27°C to 32°C and moderately cool nights of between 17°C and 28°C.

Two main seasons characterize the area; the rainy and the dry seasons. Rainy season commences from March to October, with an August break. Most of the rainfalls are heavy and often accompanied by thunderstorms, which results in heavy flooding and soil loss. Relative humidity is between 65 to 80% and highest during the rainy season. Dry season begins from early November till February and is characterized by cold and dusty weather (harmattan) caused by the northeast trade winds.

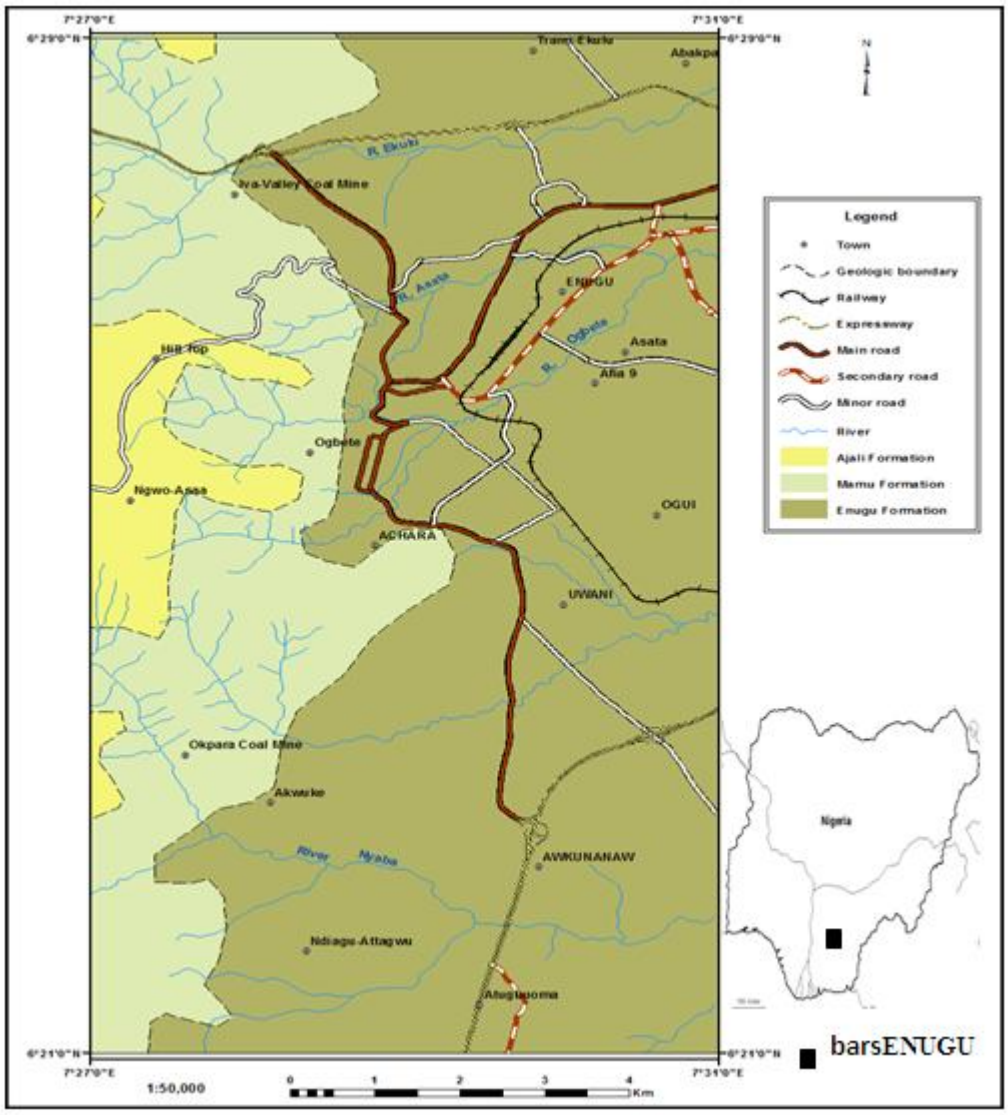

Fig. 1: Geologic Map of the Study Area

2.0 Methodology

The Geological and geomorphological mapping of the river and its deposits were carried out as well as the geo- referencing of the sample locations with the GPS(Table 1). Flow direction of the river, orientation of the braid and point bars were taken with the aid of a compass/clinometer.

Textural characteristics of the sediments were studied in the field with the aid of hand lens and grain size comparator.

Table 1: Sample location points

S/N	Locality	Coordinate	Elevation (m)
1.	Attakwu Town	N06°22′ 30.7″ E007°28′ 11.3″	183
2.	NdiaguAmagu	N06°22′ 05.9″ E007°29′ 19.4″	168
3.	Below Gariki Bridge (west of Enugu- Onitsha expressway)	N06°21′59.2″ E007°29′40.2″	170
4.	Below Gariki Bridge (east of Enugu- Onitsha expressway)	N06°21′58.5″ E007°29′44.3″	159

3.0 Results and Discussion

3.1 Channel Types and Sub- environments of the Nyaba River

Two distinct types of channel patterns were identified in the river; the meandering and braided channels. In some localities such as Attakwu town and Gariki, both channels occur within a stretch of length with the Enugu Formation being the underlying lithostratigraphic unit. The two channel types were identified and distinguished based on the degree of sinuosity of the channels as well as the occurrence of network of channels separated by bar(s). The meandering river is confined within a single channel with high sinuosity (Figs. 2) whereas the braided river is characterized by channels separated by bars (braid bars) and low sinuosity. Leopold et al. (1964) distinguished meandering rivers from the braided rivers on the basis of sinuosity of the channel which is defined as a ratio of channel length to down- valley distance. They classified rivers with

sinuosity of 1.5 or greater as meandering and those below 1.5 as braided rivers. Meandering rivers are noted for their great sinuosity.

Reineck and Singh (1980) noted a continuous gradation between one channel pattern and another because river channel patterns are strongly controlled by the amount of sediment load and its characteristics, and the amount and nature of discharge. High sediment transport and low threshold of bank erosion favour braiding of rivers, whereas the essential conditions for meandering rivers include low slope, high suspension load/ bedload ratio, cohesive bank material and relatively steady discharge. However, according to Boggs (2006) many meandering rivers are downstream continuation of braided rivers, formed as stream slope and coarseness of bedload decrease and large-scale fluctuations in discharge become less marked. Fluctuation in discharge is suggested as the major cause of the co- occurrence of both channel types at a closer intervals within the Nyaba River.

3.1.1 The Meandering River System

Meandering channels are common characteristic feature of the Nyaba River (Fig. 2) and consist principally of the main meander channel with its channel lag deposits and the point bars. The overbank deposits represented by natural levee and flood basin/flood plain deposits, and the abandoned channel fill or meander cut- off deposits also occur. There are also a lot of old channel fills which represent the older terraces of the river on both sides of the river.

Fig. 2: Meandering channel of the Nyaba River showing the main meander channel and point bars as exposed at (a) Attakwu (b) NdiaguAmagu (c) below Gariki Bridge, east of Enugu-Onitsha expressway, Enugu

The Channel Lag Deposits

The channel lag deposits consist of very coarse to coarse sand, pebbles, boulders, mud and woody particles laid down at the floor of the main meander channel, beneath the water surface. Clasts are poorly sorted and is dominated by quartz. Clay pebbles also occur. Quartz grains are commonly sub- angular to sub- rounded.Figure 3 shows an exposed section of the channel lag deposit and the overlying point bar sands.

The Point Bars

Point bars are the major depositional sites of the Nyaba meandering river and are located on the convex sides of the meander loop (Fig. 2&3). Deposits consist predominantly of very fine to medium grained sands but coarsest at the base. Cross bedding is noticeable at the basal part of the point bar. Sorting varies from moderately well sorted to poorly sorted with quartz being the dominant mineral in the sand. Quartz grains are commonly sub-angular to sub-rounded.

Point bar deposits result from lateral accretion owing to lateral migration of the meandering river during flooding. Helical circulation has been considered by many workers as the most dominant factor in sedimentation processes in meander. The helicoidal flow is generated by heaping up of water against outside shores of the meander, the mechanism which results to lateral accretion of point bars (Reineck and Singh, 1980; Slumberger, 1989).

Abandoned Channel Fill or Meander Cut- off Deposits

The abandoned channel fills were exposed at Attakwu area and consistpredominantly of very fine to medium grained sand that is moderately to poorly sorted. The deposit results from sudden abandonment of channel course due to cut- off process. Chute cut- off is the attribute of the river

in which the river course was shortened at the meander loop by cutting new channel along the swale of the point bar.

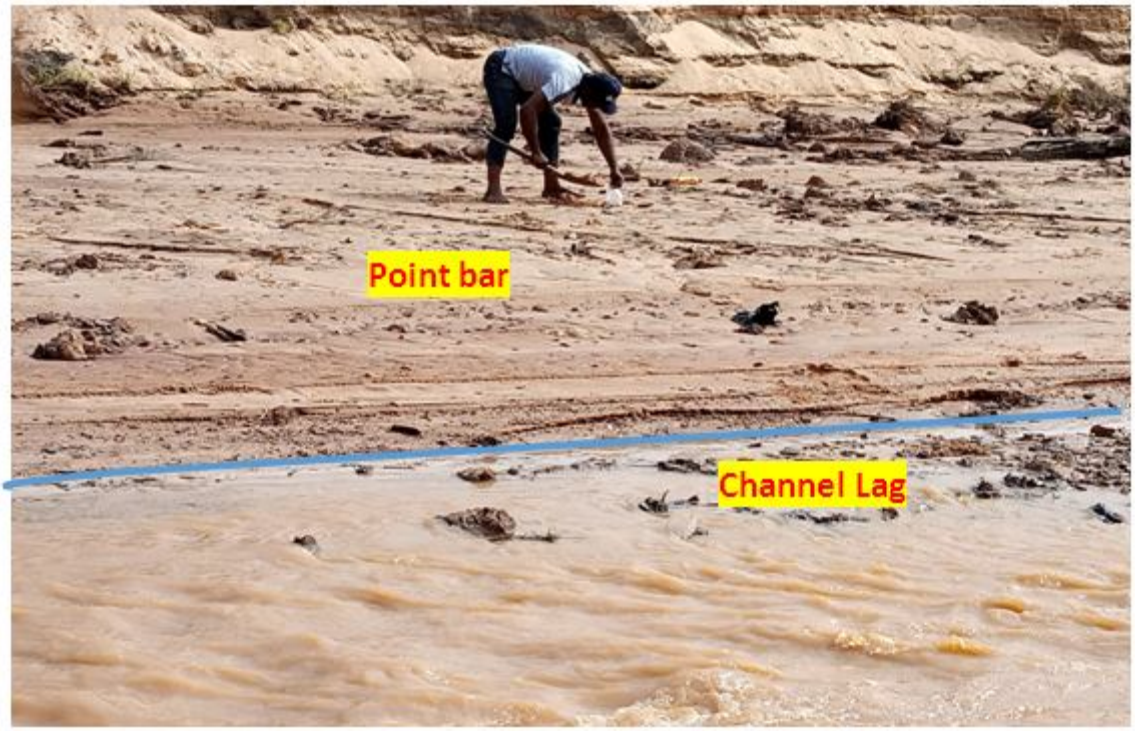

Fig. 3: Channel lag and Point bar deposit of Nyaba River exposed at Attakwu area. Blue line shows the stratigraphic boundary

Natural Levee Deposits

The levees consist of fine to very fine sand and overlying thin muddy units deposited at the concave (steep) side of meander (i.ebehind the meander bend) and adjacent to the meander channel. Both the sand and mud are ripple laminated and bioturbated (Fig. 4a). The small current ripples consist of straight crested, undulatory (sinuous) and linguoid types. Branched horizontal burrows of terrestrial organisms are common. Mudcrack is also associated with the muddy unit.

Natural levee deposits form as a result of sudden loss of competence of streams as they overtop their banks and coarsest sand is deposited closer to the channel and grain size decreases away from the channel edge (Reineck and Singh, 1980; Boggs, 2006). This is the case of Nyaba River.

The Flood Basin/ Flood Plain Deposits

The flood plain deposits at Attakwu area consist of silt and whitish clay deposited at lower areas close to the river channel (Fig. 4b). Sediments of the flood basin are deposited during heavy floods when the river overflows its bank. Flood basins act as settling basins, in which suspended fine- grained sediment settles down from overbank flows after the coarser sediments have been deposited on levees (Reineck and Singh, 1980).

The depositional model for the Nyaba meandering river system is presented as Figure 5.

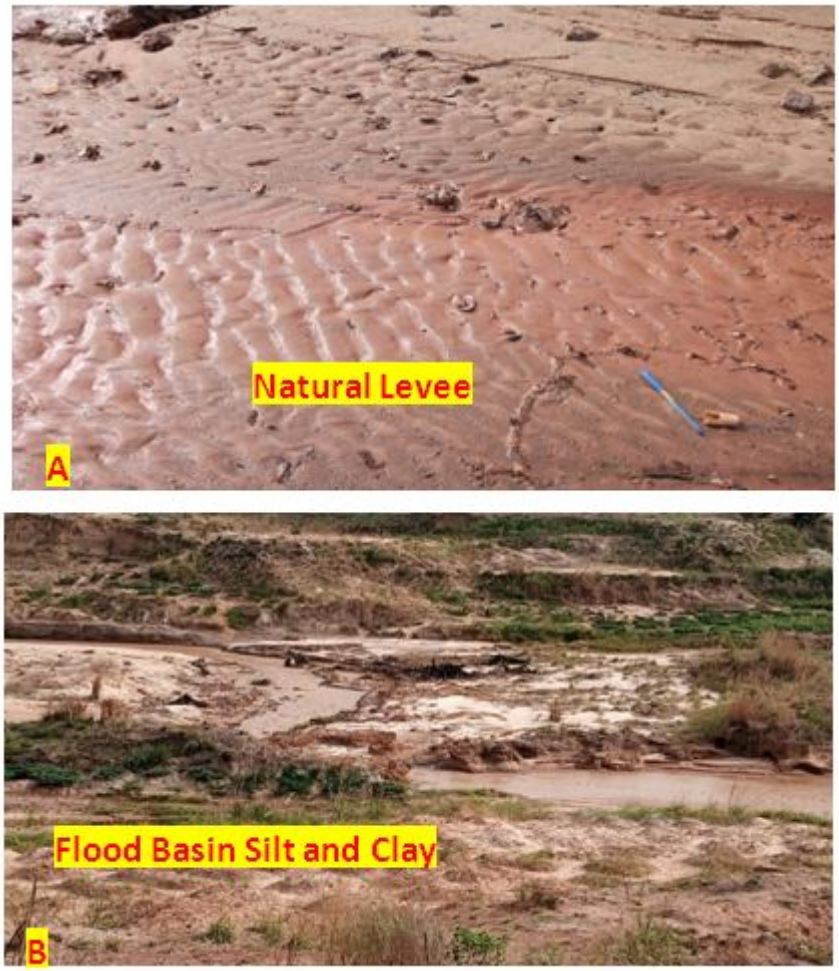

Fig. 4a: Natural levee (b) Flood basin fine sand and mud

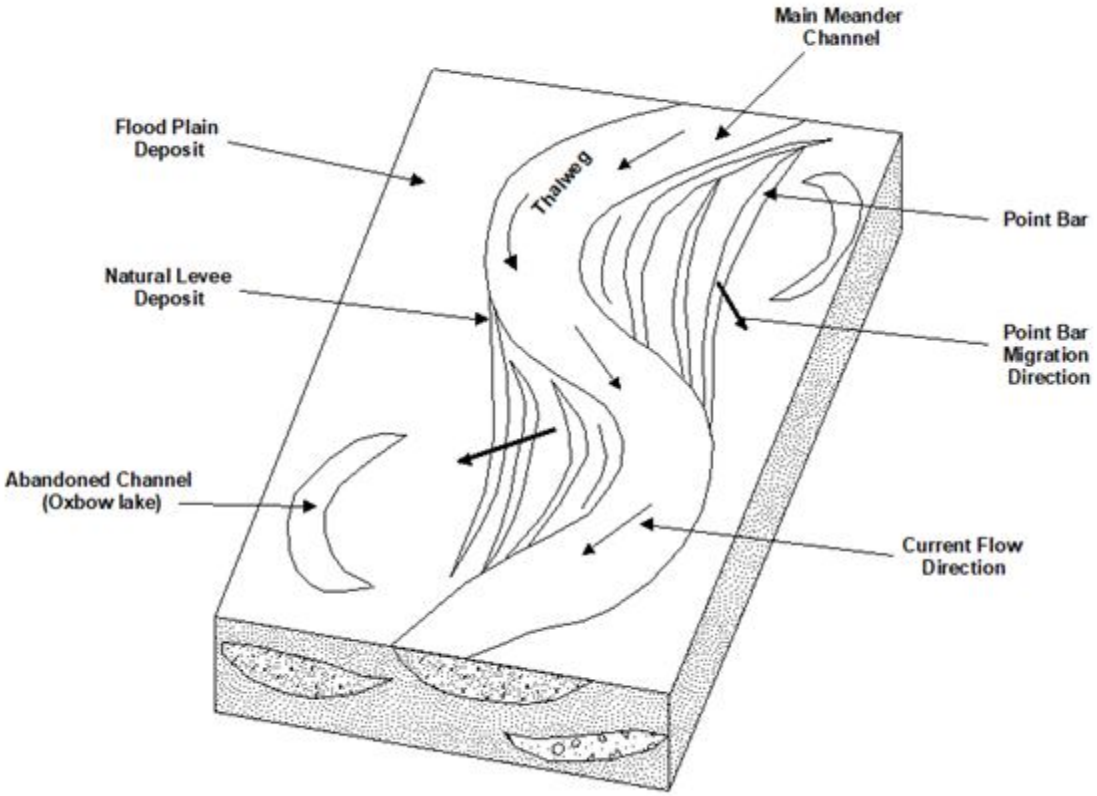

Fig. 5: Depositional model of the Nyaba Meandering River

One of the notable attribute of the Nyaba River is meandering at its upper reaches as exposed at Attakwu and NdiaguAmagu areas. Meandering characteristic is a typical attribute of a river in its lower reaches usually caused by decreased sediment load, low discharge, low slope and cohesive bank. At upper reaches in mountainous areas, rivers are usually braided. However, this meandering characteristic exhibited by the river at it upper reaches can be attributed to the following which are typical attributes of a mixed load rivers based on Collinson (1996);

1. Significant bedload which is predominantly sandy being transported with fine, suspended sediments. Pebbles and boulders also occur but are minimal. According to

Gustavson(1978) and Forbes (1983), accumulation of these kind of sediments with sufficient fine- grained particles enhance bank stability. Thus meandering of the river occurs.

2. The Nyabameandering river occurred on alluvial plain and between terraces in its upper reaches. Intensive sand mining for commercial purposes are on- going on the alluvial plains and old terraces of the river. .

Based on Schumm's (1972) classification scheme for river channels, NyabaRiver can be classified as a mixed load river. This grouping is based on the two attributes of the riverwhich have been stated above, together with other characteristics exhibited by the river such as; the development of point bars on the insides of meander bends and lateral accretion in these bars as meander bend migrates. The river also have braided reaches though not well developed.

3.2 Expected Facies Succession of the Nyaba Meandering River

According to Walter's law, 'facies that occur in conformable vertical successions of strata also occurred in laterally adjacent environments (Boggs, 2006). Relating this to the facies of Nyaba meandering river, each of the facies formed in these various sub- environments of the river as seen in the depositional model (Fig. 5) are laterally adjacent. Therefore, it is expected that a lateral shifting of these sub- environments as a result of the meandering of the river will cause their deposits to become superimposed or vertically stacked. If they are eventually preserved in the future, the channel lag will be at the base and followed upward by the point bar, then the levees and the flood plain deposits at the uppermost part of the succession. This will generate a fining- upward succession (Fig. 6) typical of meandering river environment.

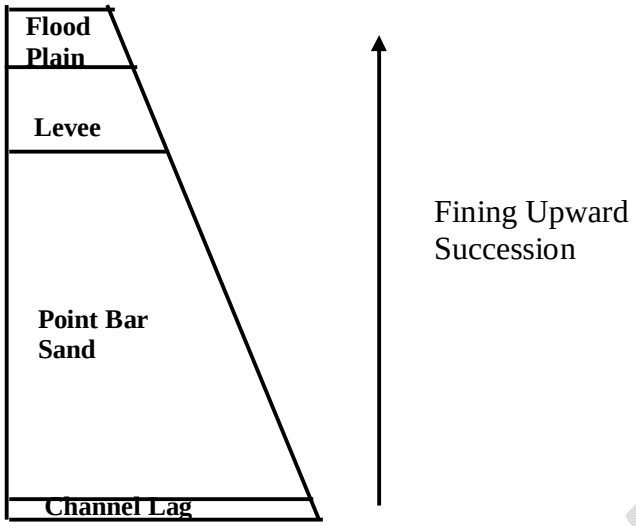

Fig. 6: Expected Facies succession of the Nyaba Meandering River

3.1.2 The Braided River System

Braid channels and bars are depositional areas of the braided rivers. Longitudinal braid bar is the only braid bar type in the Nyaba River. The mid channel bars have their long axis oriented parallel to the flow direction (Fig.7). Grain size varies from very fine to medium grained sands but predominantly fine grainedand are moderately to poorly sorted.

Another typical characteristic of the Nyaba River is braiding at its lower reaches at Gariki area (below Gariki Bridge, west of the Enugu- Onitsha expressway). This is recorded at close proximity to the point where the river receives very fine to fine grained sands and muds from one of its tributaries. According to Reineck and Singh (1980), braid bars of fine grained materials develop in rivers with large seasonal discharge and sediment load in the lower reaches of the river.

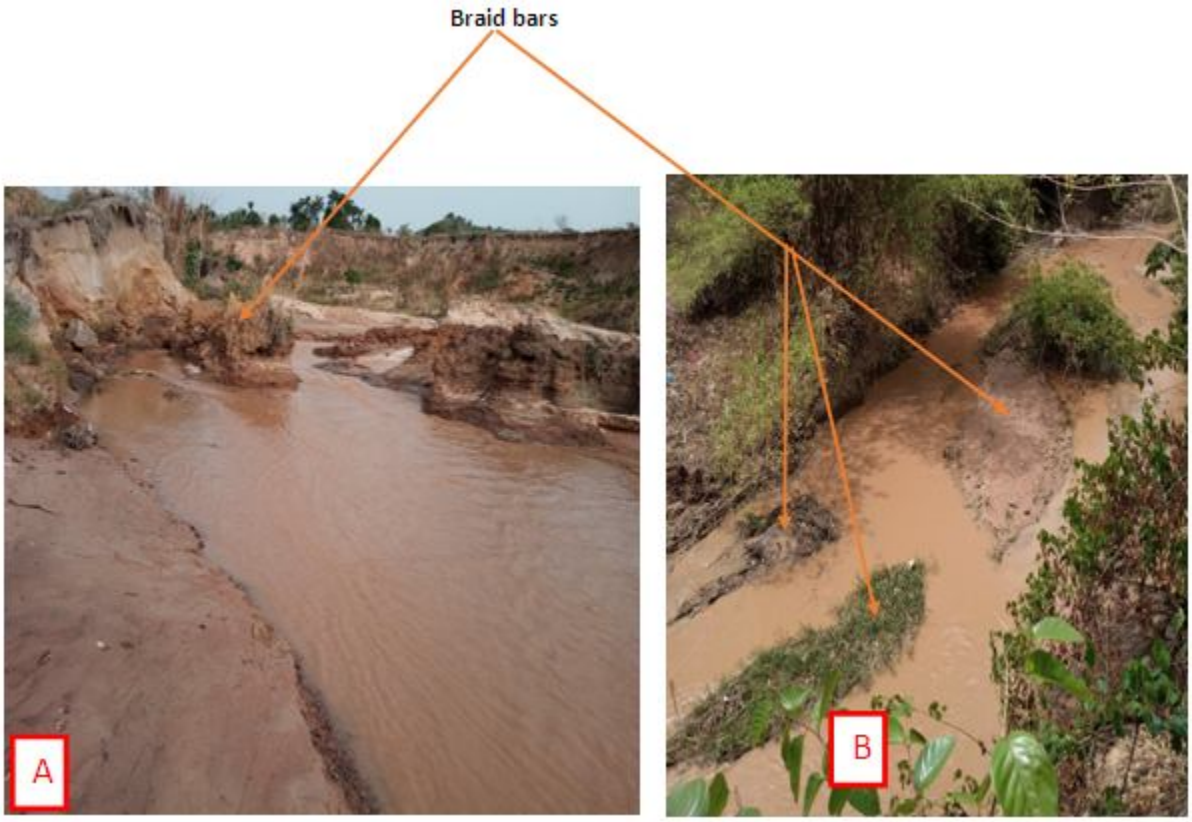

Fig. 7: Braided channel of the Nyaba River showing the longitudinal braid bars as exposed at (a) Attakwu area (b) below Gariki Bridge, west of Enugu- Onitsha expressway, Enugu

3.2 Sedimentary Structures

Sedimentary structures which occur on the surfaces of fine grained sands and muddy units of the natural levees of the river consist of bioturbation and small current ripples (Figs. 8 &9).

Bioturbation: The fine sands and the overlying thin muddy units were bioturbated. Horizontal branching burrows of terrestrial organisms were documented on these lithologic units (Fig. 8).The burrows are suggestive of low energy condition of the environment.

Small Current Ripples

These are good indicators of the types and strengths of currents that moved and deposited sediments. They form mostly on fine sands and are small asymmetrical undulations on a bed surface produced by a unidirectional current flowing over it. Small current ripples on the fine sand and muddy units of the Nyaba River consist of straight crested, lunate and linguoid ripple types (Fig. 9). According to Collinson et al. (2006), such ripples are useful in interpreting conditions of deposition. The straight crested ones are the earliest to be formed at lower flow energy but with gradually increasing flow strength, the ripples become undulatory (sinuous) and then into more three dimensional pattern leading to linguoid current ripples. The lunate and linguoid ripples in the study area have steeper concave- upwards lee faces and more gentle sloping convex- upwards stoss side. The co- occurrence of these current ripples parallel and adjacent to each other on the sand and muddy surfaces in a place reflect fluctuation in the strength of the flow.

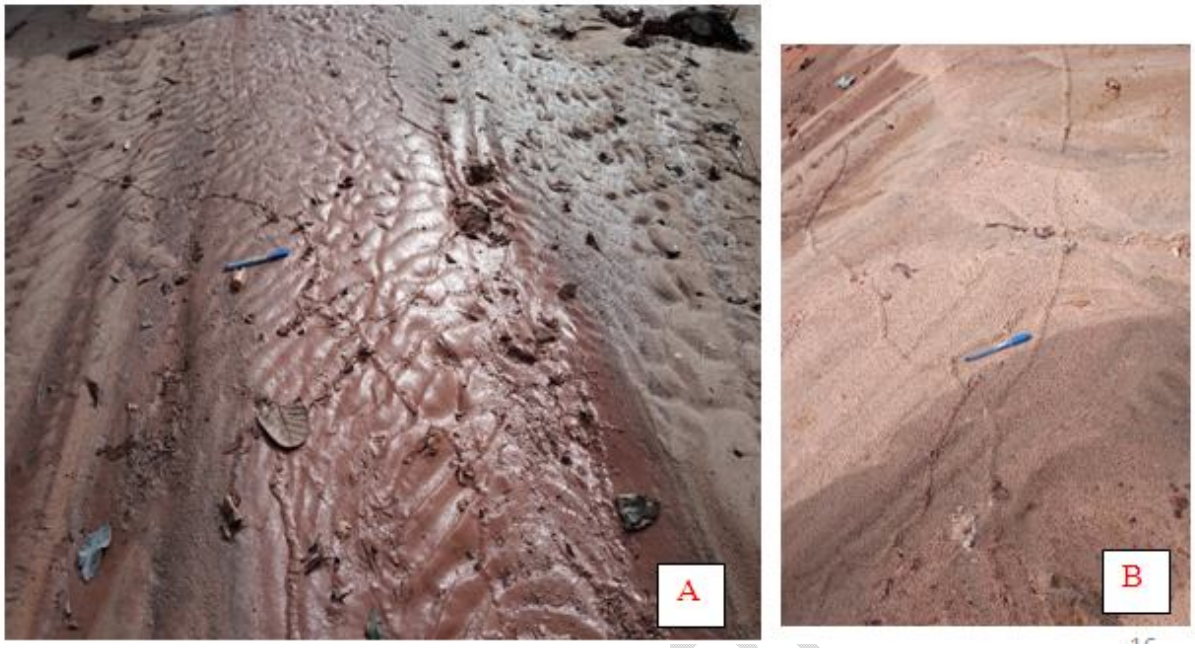

Fig. 8: (a) Small current ripples and bioturbation on the fine sand and the overlying thin muddy unit of natural levee. The current ripple varies from straight crested type at the left to more sinuous form at the centre and linguoid type at the right. Pen is pointing at the branched burrows on the muddy unit (b) Branched horizontal burrows on the fine grained sand

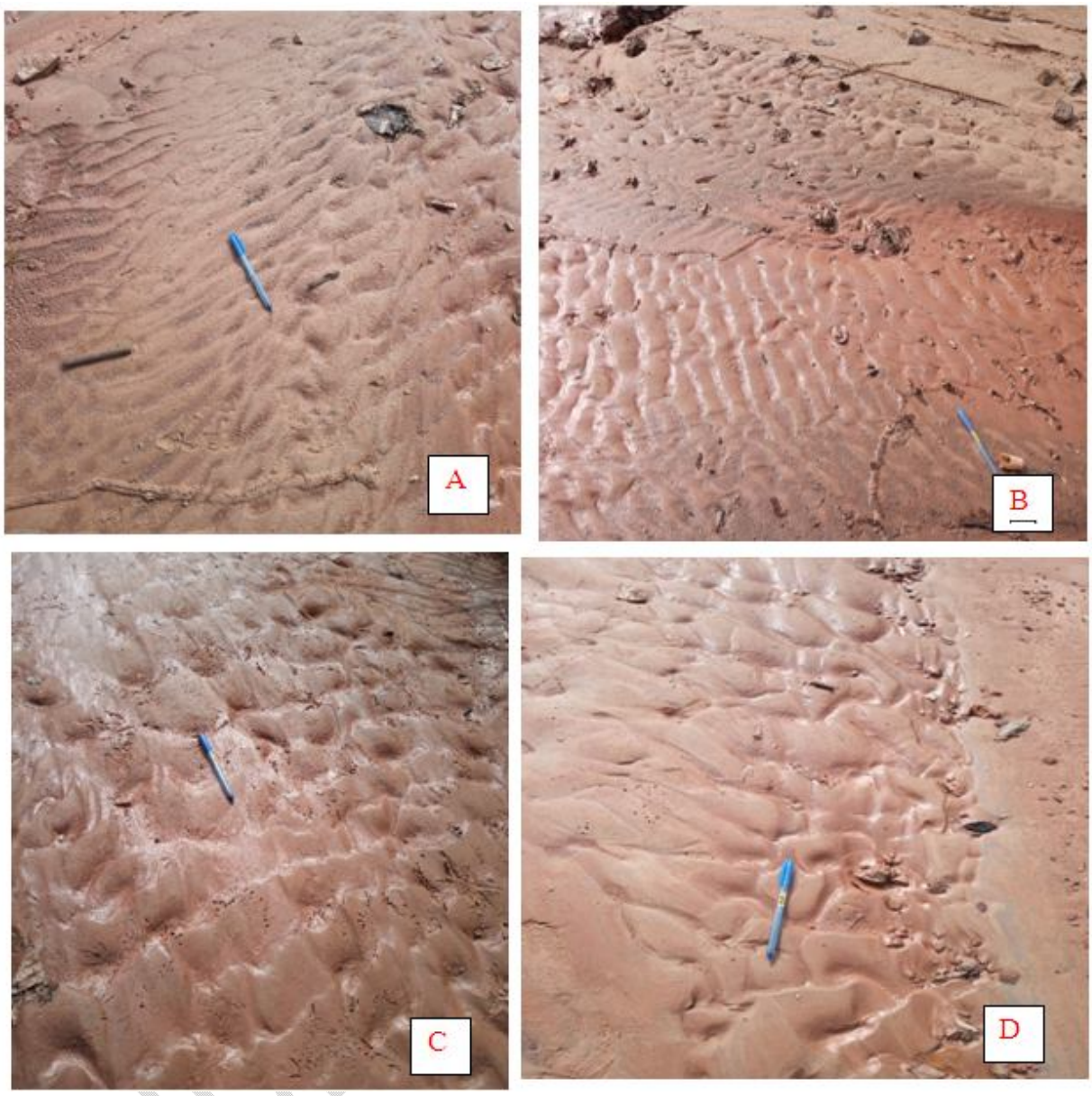

Fig. 9: Small current ripples (a) Straight crested (b) Lunate ripples (c & d) Linguoid ripples

Conclusion

Nyaba River is a mixed load river characterized by meandering at its upper reaches owing to the transport of significant sandy sediments, sufficient fine grained particles and minimal pebbly fractions. The meandering river channel which is surrounded by the alluvial plains and terraces is distinguished into main meander channel, well developed point bar, levee and the floodplain sub-environments and facies. Minor braiding of the river also occur especially at its lower reaches where the longitudinal bars are the main depositional sites.

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