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The Change in Fluvial System from Braided to the Meandering Streams in Shendi Formation Central Sudan: An Approach for New Lithostratigraphic Units

Abdelrhim Eltijani*

Department of Geology and Paleontology, University of Szeged, Hungary

***Corresponding author:** Abdelrhim Eltijani, Department of Geology and Paleontology, University of Szeged, Szeged, Hungary, E-mail: abdelrhimee@gmail.com

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Abstract

Detailed facies analysis of Shendi formation in the Shendi-Atbara basin displays identical assemblage of sedimentary features and; texture and structure that suggest fluvial depositional environment mainly braided and meandering rivers. Through detailed field investigation, including stratigraphic section logging, facies analysis, analysis of architectural elements and petrographic analysis. Five lithofacies associations were identified; Facies Association LFA1, Facies Association LFA2, Facies Association LFA3, Facies Association LFA4, Facies Association LFA5 and five architectural elements were also reported. These facies associations and fluvial architecture illustrate the two different fluvial environments of deposition; (multi- braided complex braided and channels in El Musawart, shifted into the meandering system at Bagrawia and Umm Ali area. Accordingly, three different lithostratigraphic units of Shendi Formation have been proposed; El Muswarat Sandstone (proximal fluvial), Um Ali-Bagrawia Sandstone (distal fluvial), and the Chert-Conglomerate unit representing the upper unit in the succession. However, the result is also supported by the spatial distribution and paleocurrent data indicate studied sediments have been derived from east and southeast to the basin.

Keywords: Fluvial; Facies; Chert-conglomerate; Shendi formation

Introduction

Shendi Formation is the formal name for the clastic sedimentary rocks covers Shendi, Atbara basins in central Sudan. The outcrops extend from the Awataib area south to Shendi town to the area south of Atbara and it is considered part of the Nubian sandstone Group. The term Nubian Sandstone was first introduced for the sedimentary rocks of the northwest part of Sudan. The outcrops along the Nile Valley Consist of pebble conglomerates, intraformational, conglomerates, mudstones, M erkhiyat sandstones and quartzose sandstones i.e. refer to the clastic rocks in the vicinity of Shendi region [1].

The Nubian Sandstone Group was subdivided into formations with the quartzose sandstone renamed Shendi Formation. Shendi Formation was studied by many authors, for instance suggested that the climate during the deposition of some part of Shendi formation was hot and dry, based on presence of Gypsum and Halite described the lithology of Shendi Formation as dipping strata of clayey sand and a ferricate mud crusts, that deposited in a Graben found Shendi formation is correlatable with the Albian-Cenomanian Omdurman and Wadi Milk Formations based on wood fossil reported at the Umm Ali region referred to warm and wet biotopes with dense vegetation conditions of deposition according to the reported freshwater vertebrate [2,3]. Abdullatif subdivided Shendi Formation into upper fluviatile and lower lacustrine deposits. Nonetheless, the previous studies of Shendi Formation have supported the idea of a fluvial depositional system. This work employs the depositional environment as a tool for the lithologic classification of Shendi Formation. Utilizing the concepts of facies to describe thelocal changes in a past environment within, and thus define the proposed stratigraphic units.

Tectonic and geological setting

Along the Central African Shear Zone (CASZ), a sequence of NW-SE trending extensional basins, formed as a consequence of intermittent reactivation of the Pre-Cambrian discontinuities. Based on the geological and geophysical study proved the presence of several deep (>2 Km) graben and half-graben structure. This structure, are located north and of the central and northern Sudan rift segments within the region of the central African Fault Zone [4]. Recommended that the Shendi-Atbara basin was developed as an isolated half-graben structure during Latest Jurassic to Earliest Cretaceous. In the beginning, it was formed during the northeastern extension to the West and Central Africa Rift System. The process was followed by thermal-sag-phase, and subsequently, the basins extended beyond the limits of the graben structure. (Figure 2) Geological sketches of the Shendi-Atbara basin and its vicinity, central Sudan. (A) The geographical location of the study area. (B) Study area, with places of prominent outcrops of the fluviatile Shendi Formation [5].

Materials and Methods

Out of the total number of the mapped outcrops, fourteen vertical and four lateral sedimentary sections of the surface part of Shendi Formation are described using lithological parameters such as mineralogical composition, texture, physical sedimentary structures. The latter two presented in graphic sedimentary logs before the

interpretations. Lithofacies are defined based on grain size and structures and are named according to Mail 1996 scheme and facies are classified into facies associations based on the distribution pattern. Moreover, the sedimentary architecture is defined from the two-dimensional representations for the profiles based on vertical and lateral geometry and variations [6]. The integration of the architecture and lithofacies is used to reconstruct the past deposition environment. Subsequently, the lithologic units are established considering the geographic transitions in the depositional medium.

Facies and facies associations

Based on facies analysis and petrographic study of the selected sedimentary profiles, the described lithofacies associations of Shendi Formation are LFA1, Facies Association LFA2, Facies Association LFA3, Facies Association LFA4, Facies Association LFA5 (Table 1). Based on these associations, three lithologic units of the Shendi Formation can be described; El Muswarat sandstone, Um Ali sandstone, and the Chert-Conglomerate unit [7].

Facies	Gm	Gt	St	Sp	Sh	Sm	Sl	Sr	Fm	Fl
Lithology	Quartz pebbles, with Chert nodules	Quartz pebbles with minor mud clasts	Medium to very coarse-grained and pebbly sandstone	Medium to coarse-grained sandstone	Fine-grained sand stone	Pebbly, Fine to coarse grained sandstones	Fine to very finely laminated sandstone, intercalated with iron oxides	Fine to very fine rippled sandstone, intercalate d with iron oxides	Silt to clay-sized Intercalated with thin layers of massive sandstone	Claystone and siltstone
Sedimentary Structures	Massive or weak gradation	Trouh cross bedding	Trouh cross bedding	Planar cross bedding, and laminatio	Horizontal bedding	Massive	Parallel thin lamination	Ripple cross lamination	Massive	parallel lamination
Geometry and lateral extension	Lens and ribbo-shaped bodies. 20-35 m	Lenticular shape. 3m	Continuous flat bedding. Tens of metes	Continuous us and discontinuous flat bedding. Tens of meters.	Laterally continuous horizontal Bedding. Tens of meters.	Discontinuous, wedge, or tabular shaped (pinching out). Few meters.	Continuous flat bedding. Tens of meters.	Continuous and discontinuous (pinching out) flatbeds. Tens of meters	Wedge, lens, and flatbed shaped bodies (20-80m).	Continuous Flatbeds 60m
Depositional setting	Low-relief longitudinal gravel bar. Bedload deposition as gravel sheets or splays by high magnitude flood flows	Channelized lag and bedform deposits, lower flow regime	Dunes or mega ripples that migrated over or across the lee faces of these bars	Migrated straight crested dunes or bars. Lower flow regime.	Plane beds under upper or lower flow regimes	Rapid deposition of sediment-laden flows during waning floods; rapid scour filling.	Waning stage of seasonal flood events and oscillatory unidirectional currents.	Migrated sinuous trains of asymmetrical ripples; lower flow regime	Suspension load in the overbank	Waning stage flood deposition chiefly in; overbank areas, abandoned flood plains.

Table 1: The characteristics of lithofacies reported in the study area.

Unit one El muswarat sandstone

The sedimentary outcrops in the area south of Shendi town cover the area of Wadi Awataib, which represents the southern periphery of the Shendi Atbra basin to the Al Muswarat and Nagaa areas. The unit represents the proximal fluvial system of the Basin and is characterized by; Lithofacies Association LFA1 and Lithofacies Association LFA2 [8].

Facies association LFA1

Varies in thickness between 10-20 m and is characterized by sharp-based, mostly trough cross-bedded lithofacies (St), coarse-to fine-grained sandstones with abundant quartz pebbles forming ploymict and monomict extraformational conglomerate at the base (Figure 1). It is poorly to moderately sorted. With common fining-upward in both forest and on a bedform scale. Horizontally bedded lithofacies (Sh) are dominant and planar cross-bedded (Sp) is relatively rare and represented in Planner cross-bedded conglomerate (Figures 1-6). Large scale inclined strata with abundant rip-up clasts occur rarely. Mudstone facies are correspondingly minor in the combined sandybodies but are more common in the isolated single storey sandy bedforms. They are massive and laminated [9].

Interpretation

The abundance of coarse to medium pebbly sandstones suggests a high-energy depositional system with a dominated bed-load mode of transportation. The trough cross-bedded sandstones indicates the deposition by migrated 3d subaqueous dunes lengthwise the channel. The trough cross-bedded non-bioturbated sandstones have usually been accompanying with in- channel deposition in the fluvial system [10].

Facies association LFA2

It is fine to medium sandstone with sharp based. Sandstones grade upwards to intercalated thin mudstone layers. Bed sets are organized in fining-upward cycles with up to 5 m thick (plate 1 Fig. 1). Sandstone bodies are single story capped by structureless and laminated mudstones. The structures change from trough cross-bedding upwards to planar and rippled, laminated, and structure less beds at the top [11].

Interpretation

The medium to fine-grained sandstones with interbedded mudstones interpreted to be transported by low energy rivers as

mixed-load, in comparison with transporting energy of LFA1. The upward shift from LFA1 to LFA2 possibly resulted from a decrease in the channel slope gradient and/or change in energy, channel pattern, and type of channel sediment load [12].

Unit two bagrawia-um ali sandstone

This unit extends from Bagrawia village near the pyramids up to UM Alli area in the area north of Shendi basin covers the regions of Bagrawia, Kabushia, and Umm Ali, which represents the distal part of the depositional system. The unit by characterized by; Lithofacies Association LFA3, Lithofacies Association LFA4, and Lithofacies Association LFA5.

Lithofacies association LFA3

Made up of medium to fine sandstones with thickness ranges between 1 to 10 m, capped by ferruginous mud stones. Beds are combined into bed sets with an undulatory erosional base and forming fining upward sequences. Texturally sandstones are moderate to well-sorted and subrounded to rounded. They show an upward gradiation shift from sandy to muddy facies tapping the uppermost part of the bodies. However, the lower sandy part is dominated by Trough and planar cross-bedded sandstones, while the upper part is characterized by horizontally and rippled laminated muddy facies [13].

Interpretation

The irregular base with fining upwards accompanied by an upward decrease in structures indicate a depositional under decreasing energy. However, the well-sorted and rounded grains may indicate intensive reworking processes during sediment transportation.

Plate 1: General lithofacies reported at the study area

Laminated mudstone is overlain by a massive conglomerate,

Massive sandstone is overlain by a massive intraformational conglomerate,

Massive extraformational conglomerate with slikin sides overlain by trough cross stratified sandstone,

Five sets of planar cross stratified sandstone with angular internal cross strata overlain by horizontally stratified sandstone, 6. Trough cross stratified sandstone overlain by planar sandstone Lithofacies.

Plate 2: General lithofacies reported at the study area

Paleosols,

Rippled sandstone

Planar cross stratified sandstone lithofacies with angular internal cross strata,

Massive mudstone lithofacies is overlain by laminated sandstone,

Soft sediment deformation structure (convolute bedding),

Massive sandstone is overlain by highly ferruginous massive mudstone.

Lithofacies association LFA4

Represented in medium to fine sandstones with interbedding of mud layers and paleosols capped by a ferruginous crust. Texturally its well to moderately sorted, rounded to subrounded grains. This Lithofacies association is characterized by the dominance of rippled-laminated planar sandstones and locally abundant massive, ripple and convolute bedded sandstones (Figures 2-5). However, small-scale trough cross-bedding occasionally occur, albeit with scour base but no lag deposits are present. This Lithofacies association is distinguishable by varying lower contacts which range from flat and gently inclined to irregular boundaries. The muddy facies are uniformly bioturbated with intensity increases in relatively finer upper beds.

The dominance of small-scale trough-cross bedding with thin mudstone and falser structure, which all of them capped with ferricrete crust, imply a low-energy environment exposed to minor current and wave activity. Although similar deposits can also form under over bank and flood plain environments . Deformation structures likely document exposure might have formed in a warm and periodically dry past climate which could be supported by the dense bioturbation [14].

Lithofacies association LFA5

Forms lenses or sheets up to 3 m thick that consist of massive mudstones and fine-grained sand stones. It overlays sandstones of LFA3 or interbedded with sediments of LFA4. The mudstones are white, grey commonly patchy, massive to crudely bedded, with occasional bioturbation. They usually form the basal and thickest part of the lithofacies association. They are overlain in many sections with sharp or gradual, irregular to horizontal contact by fine-grained sandstones and mudstones. The most prominent feature of these horizons is the high bioturbation sediments. In the lower part of these horizons, a network of burrows is locally present. The sandstones are overlain by an up to 30 cm thick horizon of iron oxide- stained ferruginous sandstones that are capped by a ferricrete crust [15].

Plate 3: General lithofacies reported at the study area

A planar cross stratified conglomerate.

Massive gravel (monomict matrix-supported extraformational conglomerate); gravels are made up of chart nodules.

Planar cross stratified sandstone with tangential internal cross strata.

Horizontally stratified sandstone.

Laminated sandstone is overlain by massive conglomerate lithofacies.

Trough cross stratified sandstone.

Interpretation

The fine-grained, massive and highly bioturbated sediments of LFA5 represent very low energy deposits. Because of the occurrence of resembling fossil root traces in the mud- and sandstones, and of the primarily irregular, gradual contacts of the lithofacies boundaries of soil horizons the facies association obviously represents palaeosols. Intense biotur bation by burrows and small fossil root traces in the basal mudstones fits an upper tidal mudflat environment. In the overlying sandstones, vertical root traces likely reflect permanent vegetation and better-drained conditions, as they exist in higher parts of intertidal salt marshes. In any case, the gradual change from massive bioturbated mudstones to deeply rooted fine-grained sandstones likely reflects increased periods of exposure to the environment.

Unit Three c hert-conglomerate

The extra-formational ferruginous monomict conglomerate in Al Eigaida region compose of chert gravels, representing the top of the succession (Figure 2 to 5); the chert gravels often occur as Alluvial fan or talus cone deposits in some outcrops in the area with gastropod fossils (Figure 5) the gravel sizes range from pebble to cobble. Bussert 1993 described similar lithology from the Al Awataib region, as Awataib conglomerate. However, both units characterized by crude trough cross-bedding, representing the typical proximal facies, probably deposited in the proximal braided channel. This facies is a product of this deposition under longitudinal gravel bar conditions of the braided rivers as shown in Figure 1.

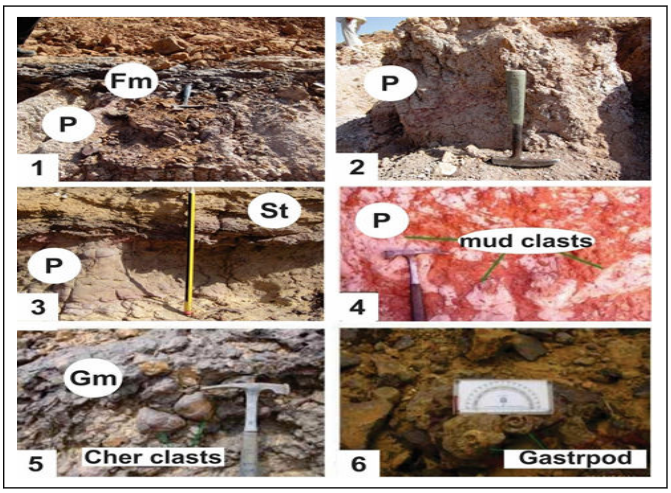

Figure 1: Longitudinal gravel bar conditions of the braided rivers.

This facies occurs as lenses and ribbon shaped bodies with is in horizontally tabular geometry of the beds, the base usually erosional and sharp, in most instance, this facies is underlain and overlain by trough cross bedded sandstones and occasionally by trough cross-bedded Gravel Gt.

Plate 4: General lithofacies reported at the study area

- Paleosols are overlain by highly ferruginous massivemudstone.
- Paleosoles.
- Paleosols are overlain by thought cross stratified.
- Massive matrix-supported to clast supported monomict extraformational conglomerate; clast is made up of chert nodules.
- Scattered chert particles consist of gastropod fossils.

Architectural elements

The studied part of Shendi Formation is characterized by five architectural elements. The identification of these elements is based on physical parameters, including the textural properties and the structures, the geometry of bodies along with lateral and vertical variations in sedimentary facies (Table 2).

Most of these elements are macroforms, produced by the collective effects of sedimentation over periods of tens to thousands of years.

Architectural element	Geometry	Lithofacies assemblage	Interpretation
Sandy channel (CH)	Lens-shaped, basal surfaces are erosional and irregular sheets 1-5 m 5-100 m	Gt, St, Sm (Sp)	Sandy channel fills
Sandy bed form Elements (SB)	Lenses, sheets 0.1-1 m thick 5-100 m width	St, Sp, Sr, Sh*l*, Sm	Secondary channel fills, subaqueous dunes, crevasse splays
Downstream accretion (DA)	Wedges, sheets 1-10 thick 10-1000 m width	Sp, St (Sh*l*, Sr)	Transverse bars
Lateral accretion (LA)	Lens resting on flat or channeled base 3-10 m thick 5-150 m width	St, Sr, Sm (Fl, P)	Sandy point bars
Floodplain Elements FF	Lenses 0.1-2 m thick 1-20 m width	Fm, Fl (P)	Floodplain deposits , deposited over a wide area that was distal to the main channel
Laminated sand sheet (LS)	Sheet, wedge- shaped, 3-7 m thick	Sh, Sl, Sr	Fine-grained point bars

Table 2: The characteristics Architectural elements encountered in the Al Muswarat and Um Ali-Bagrawia area.

Channel fill elements

The characteristics of these elements are the concave erosional base units of conglomerate, planar cross-bedded and trough cross-beddedsandstone deposited by channels incision through the laminated and massive mudstones of former floodplain deposits (Figure 2). The aggradational channel fill elements are dominant in the El Musauwarat area. This element is a product of deposition in the bars of braided alluvial channels .

Downstream accretion elements

Predominantly composed of medium to coarse planar cross-bedded and trough cross-bedded sandstones, mostly the element shows fining upward sequences with fine-grained horizontally, rippled sandstones on the top is overlain by laminated and massive mudstones. These elements indicate deposition in channel bars and point bars .

Downstream accretion elements

These elements are characterized by an irregular erosional base and occur as the lower part of the fining upward sequences. However, the characteristic facies are coarse to medium planar cross-bedded and trough cross-bedded sandstones (Figure 1). These elements indicate deposition by the river with uniform type flow. Moreover, they represent channel fill deposition by migrating transverse bars of the braided rivers.

Lateral accretion elements

They are characterized by fine to medium sandstones interbedded with mud layers in the upper parts; it generally exhibits fining upward sequences. This element is recorded in the Bagrawia area (Figure 2). The existence of inclined macro form strata indicates point bars conditions of deposition more specifically in an area where active meander channels migrate laterally resulting in point bar deposits as shown in Figure 3.

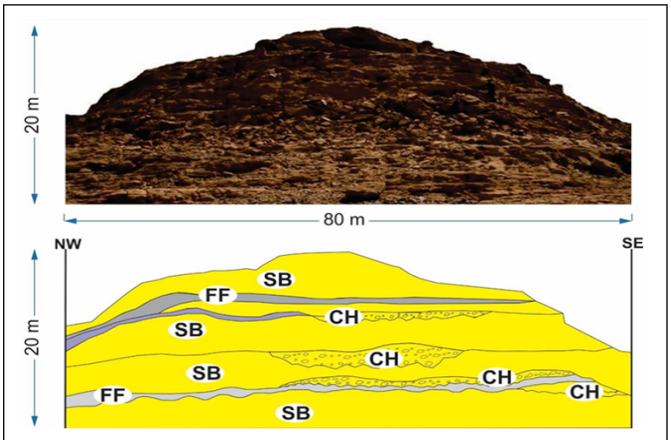

Figure 2: The characteristics of Architectural elements encountered in Al Muswarat area east Lion temple (profile viewed to the NNE).

Laminated sand sheet elements

Sandstone bodies disguised by flat lower and upper boundaries, facies are characteristically fine laminated sandstones (Figures 3 to 5). These elements tend to be a deposit of bedload under unconfined flow conditions. However, sandy grains indicate the bedload mode oftransportation was dominant over suspension mode. These elements are reported in the Umm Ali area.

Floodplain elements

Thin to thick blankets of claystone and Siltstone with fine-grained Sandstone, intercalated with paleosol and thin iron crusts. These elements generally characterized by horizontal boundaries. Additionally, the massive Mudstone facies are significantly bioturbated and more often contain root fossils. The fine grain size and the tabular geometry of these elements represent deposition in the distal part of the channel in an area with a lateral extension. The extensive development of desiccation cracks and palaeosols indicates fluctuating wet to dry surface conditions. In other words, These elements might indicate vertical aggradation of floodplains, whereas subaerial settling of wash load from open flows takes place as shown in Figure 3.

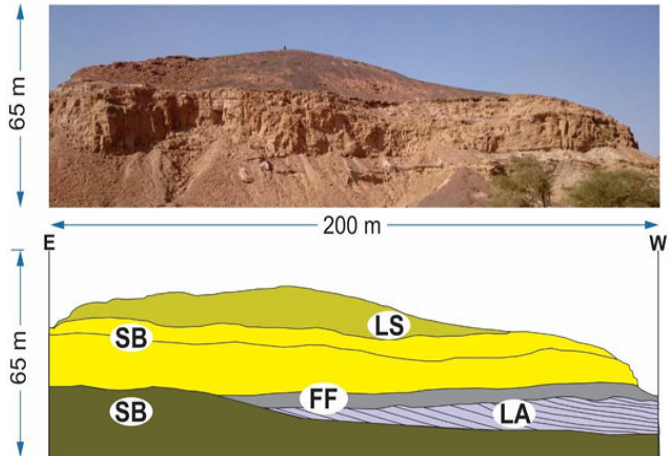

Figure 3: The characteristics of Architectural elements encountered in the Umm Ali area NNE Jebel Umm Ali (profile viewed to the N).

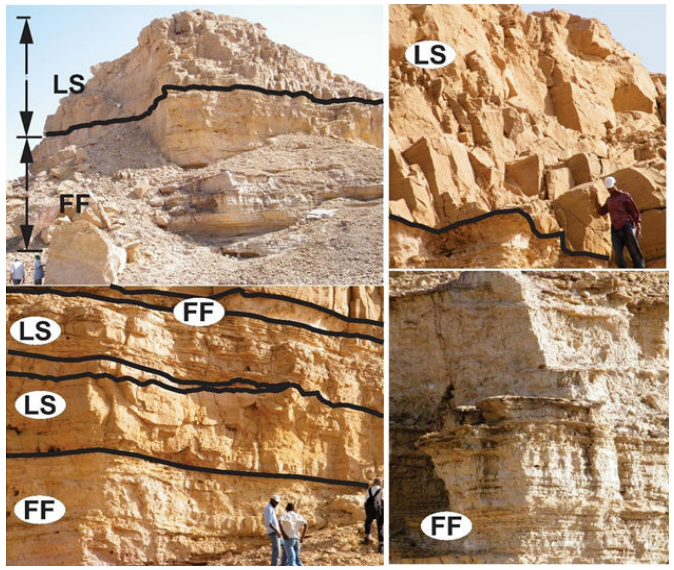

Figure 4: The characteristics Architectural elements encountered in Umm Ali area (Jebel Umm Ali), (profile viewed to the SE).

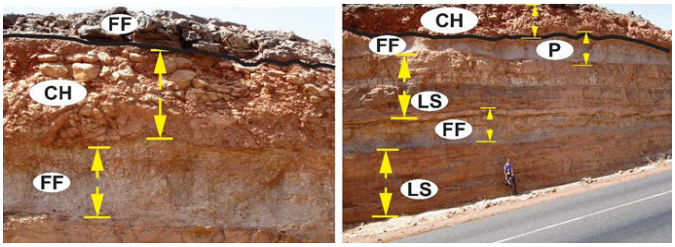

Figure 5: The characteristics of Architectural elements encountered in the Umm Ali area (Umm Ali road cut) (profile viewed to the W). The intercalation of laminated sand sheet "LS" with Overbank fines "FF" area is topped with Channel fill element "CH," which in turn overlain by Overbank fines element "FF".

Results and Discussion

Several studies have been carried out in Shendi Formation, particularly in the surface part of the formation which suggests its fluviatile origin mainly braided and meandering rivers. Nonetheless, no attempts were made to establish further lithologic units, though the classification of Shendi Formation is up to the Formation level.

The results of the current work, however, support the fluvial origin for Shendi Formation (i.e., transition from braided to meandering rivers with their environments), which is adopted and supported by the distinct fining upward sequences and the characteristic sedimentary facies, facies associations and architectural elements. Lithofacies associations dominate South and southeast (Almusawrat and Naga areas) are; LFA1 and LFA2. Both associations are products of in-channel deposition. However, the transition from LFA1 To LFA2 indicates a decrease in energy that is probably attributed to the changes in a gradient within the braided system (i.e., between proximal braided and distal braided rivers). Hence LFA2 shows variations in grain size with intercalations of mudstones. These facies associations supported by the sedimentary architectures, Sandy Bedform (SB), Downstream Accretion (DA) and Sandy Channel fill (CH) illustrate that the south and southeast areas are the proximal part of the fluvial system and therefore is suggested to be unit 1. In the northern part (Bagrawia, Umm Ali and Egaida areas), is dominated by the relatively fine-grained facies represented by lithofacies associations; LFA3, LFA4 and LFA5.

These associations indicate a low energy aquatic environment of deposition mostly meandering rivers with their subenvironments. However, the interpretation is further supported by the sedimentary architectures; Lateral Accretion (LA), Laminated Sandy sheet (LS) and Floodplain element (FF) (Tables 3 and 4). The area therefore considered the distal part of the fluvial system and regarded it as unit 2 (Figure 6).

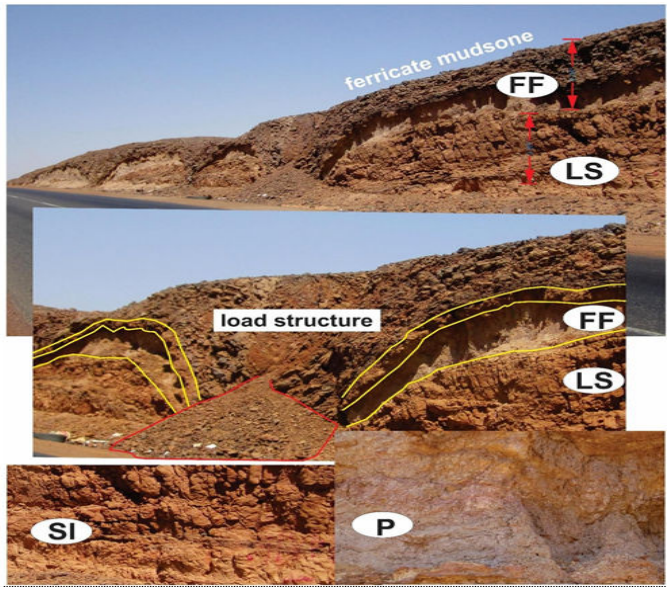

Figure 6: The characteristics of Architectural elements encountered in the Umm Ali area (Umm Ali road cut) (profile viewed to the E). Upper photo; general panoramic view of the section shows successive load structure caused by heavy ferruginous sediments resulting in the deformed architectures (I e, Overbank fines "FF" and the underlain Laminated Sand sheet "LS"). The middle photo is a magnification of one of the load structurer with talus cone deposits at the bottom. Lower the characteristic facies of the architectural elements;(laminated sandstone "Sl" representing the laminated sand sheet "LS" and Paleosole "P" representing the Overbank fines "FF").

Lithologic units	Lithofacies associations	Architecture
Unit 1 (Almuswarat-Nagar)	LFA1 (Gm, Gp, St, Sp and Sh) LFA2 (Sp, St, Sm, Sl and Fm)	SB, DA and CH
Unit 2 (Bagrawia Umm Ali Egaida)	LFA3 (St, Sp, Sh, Sl, Sr and Fm) LFA4 (St, Sm, Sr, Fl, and P)	LA, LS, and FF
Unit 3 (Awataib-Egaida)	LFA6 (Gt, Gm and Gmm)	

Table 3: Summary of the three adopted lithostratigraphic units and their charcteristics (i.g. Lithofacies, Lithofacies association, and sedimentary architectures).

Nubian Group	Shendi Formation	Surface (Fluviatile)	Unit 3 (Fans-proximal braided) Unit 1 and unit 2 (Braided and meandering)
Subsurface (Lacustrine)			

Table 4: Summary of the main stratigraphy Shendi Formation with the propsed units.

Conclusion

Additionally, the two units (i.e., unit 1 in Nagaa and Awataib areas) and unit two in (Egaida area) are overlain by Trough cross-bedded conglomerate lithofacies (Gt). It is a monomict extraformational conglomerate and the conglomerate sized grains are entirely composed of chert. In the two areas, these facies is characterized by a sharp channelized base and occasionally with faint planar cross beddings which reflects deposition by high energy currents ranges from Alluvial fans to proximal braided rivers and suggested to be unit 3.

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