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# The Primary Depositional Structures of The Upper Bima Member from Fufore and Environs, Yola Arm of The Upper Benue Trough, Northeastern Nigeria: Implications for Paleoenvironment

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**Abstract**

*Primary depositional structures are important parameters that can provide the means of unraveling the processes and process responses in sedimentary depositional settings. This paper is aimed at determining the paleoenvironment of the Upper Bima Member in Fufore and environs using the primary depositional structures. This research was carried out in two phases which involved fieldwork that dealt with logging the outcrops sections and desk work whereby the logged sections and other field data are digitized, remodeled and analyzed using relevant computer programs. The result of the study shows that the Upper Bima Member is composed of five lithofacies succession; trough cross-bedded sandstone facies (St), planar cross-bedded sandstone facies (Sp), horizontal bedded sandstone facies (Sh), ripple cross-laminated sandstone facies (Sr), and mudstone facies (Fm). These lithofacies gave rise to two facies associations; sand dominated and fine-grained facies dominated facies association. The cross-stratified facies show an overall paleocurrent trend in the NW direction. These facies succession represent both shallow perennial and ephemeral sand-bed in a braided river depositional environment.*

**Keywords: Facies, paleocurrent, Bima Formation, Upper Benue Trough, Braided River.**

## INTRODUCTION

The Benue trough of Nigeria is a contiguous intracontinental basin in the Central and West African Rift System; it trends in NE-SW. The sedimentary deposit of the trough is about 500 to probably 1000 km in length and it is roughly more than 150 km in width. The trough is segmented into 3 major regional basins based on geographical localities, these are; Southern, Central, and Northern Benue Trough Abubakar et al., (2014). The Benue Trough is an extension of the reported Mega-Rift system that is known as the West and Central African Rift system (WCARS). The WCARS is composed of the Doba Dosea Basin of southern Chad, the Termit Basin of Niger and Western Chad, the Muglad Basin of Sudan, and the Salamat Basin of Central Africa Republic. The Benue Trough has its southern boundary with the Niger-delta basin and its northern boundary with Chad Basin Abubakar, et al., (2014). The Bima

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Formation is the oldest, thickest, and widely most exposed Cretaceous sediments in the Upper Benue Trough. The sedimentology, stratigraphy, and geochemistry of this formation have been documented in several papers e.g. (Carter, 1963; Guiraud and Maurin, 1992; Zaborski et al., 1997; Samaila et al., 2006; Samaila, 2007; Sarki Yandoka et al., 2014, 2015a, 2015b; Tukur et al., 2015; Shettima et al., 2018; Aliyuda et al., 2019; Shettima et al., 2020a, 2020b; Finthan and Mamman, 2020; Valdon et al., 2021; Finthan et al., 2022), these previous papers have improved the understanding of the Bima Formation. The Bima Formation is the target reservoir rock as well as a member source rock linked to its fluvio-lacustrine facies (Sarki Yandoka et al., 2015a; Shettima et al., 2018). The depositional facies from the study area (Fufore and environs) have not been reported despite having extensive outcrop exposures, therefore, this paper is looking at the primary depositional structures of the Bima Sandstone from the outcrops sections in the study area; and its implications for the paleoenvironment which will help both government and industries during oil exploration, since sandstone facies are the target reservoir rocks.

**Geologic setting**

The Benue trough as stated earlier is a contiguous intracontinental basin that is an extension of the Mega west and Central African rift system (WCARS). This basin is trending in NE-SW. The basin has a sedimentary infill with a minimum thickness of 500 km and thickness of 1000 km in length and it is at least 150 km in width. However, the E-W oriented Yola arm is one of the two sub-basin that made up the Upper Benue Trough (Fig. 1), it is bounded in the Northeastern part of the sub-basin by Kaltungo inlier while in the southeast by Hawal Masiff, and in the southwest by Adamawa Masiff (Fig. 1). The origin and the evolution of the Benue Trough which one of its arms is the Yola sub-basin as reported by earlier workers resulted from two different proposed tectonic mechanisms namely; tensional forces that lead to episodic rifting of the basin (King, 1950; Cratchley and Jones, 1965; Cratchley, 1984). The rifting model of the tectonic events was interpreted from the gravity data, and this drawn conclusion was objected by (Benkhelil, 1989; Popoff et al., 1983). The other tectonic mechanism is said to be that of pull apart model that is associated with strike-slip and the transcurrent fault with strikes angle of 60° E. The tectonic event sprang up from the reactivation episode of continental drift related to south America and African plates respectively (Benkhelil, 1989; and Guiraud, 1990). The sedimentary infills of the Yola Arm are stratigraphically composed of seven geologic formations (Fig.2) and these are; Bima Sandstone (Continental deposit), Yolde Formation (Transitional deposit), Dukul, Jessu, Sekuliye, Numanha, and Lamja Formations are all marine in origin (Carter et al., 1963 and Guiraud, 1990).

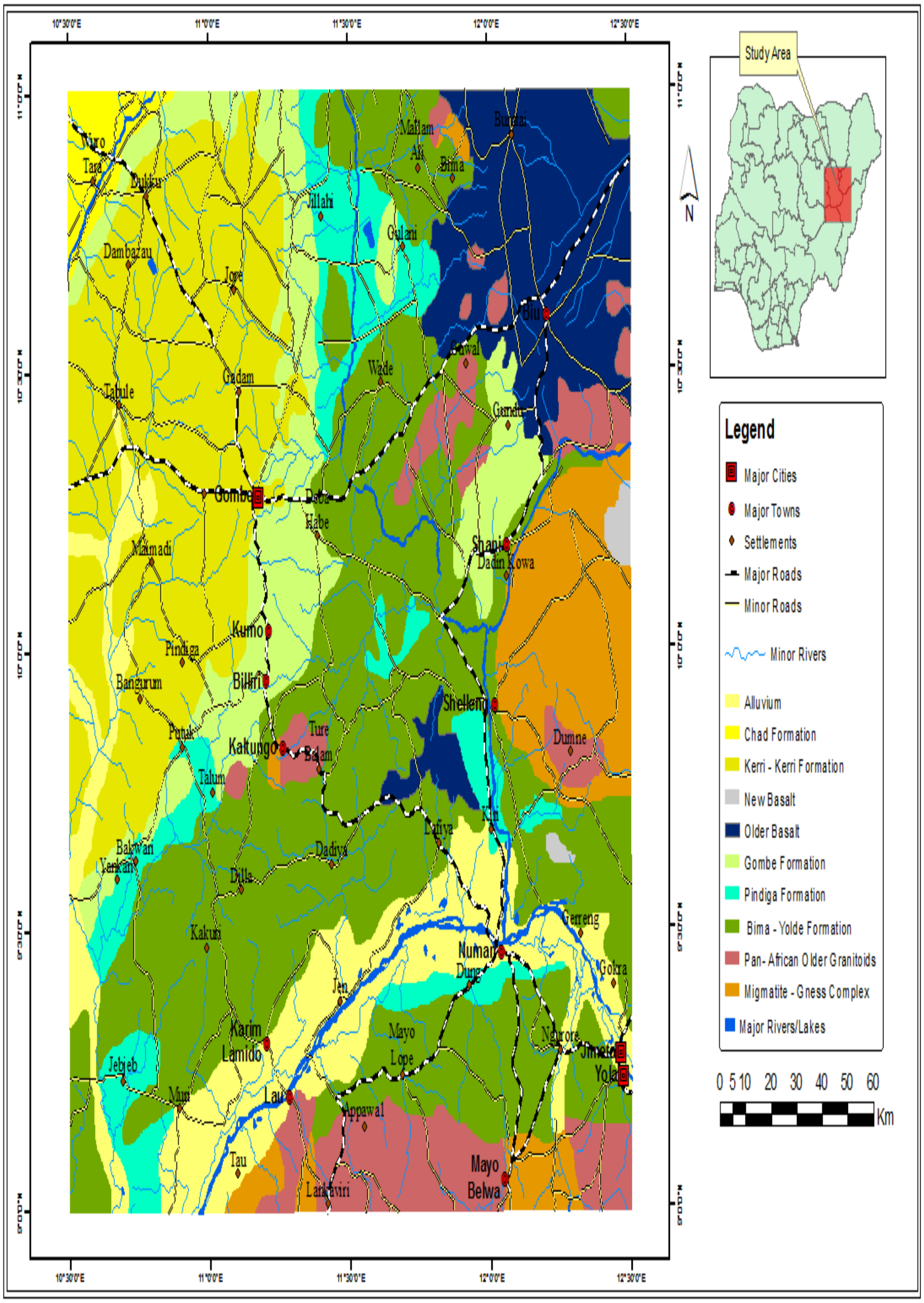


Figure 1: The geologic map of the Upper Benue Trough (Modified after Guiraud, 1990).

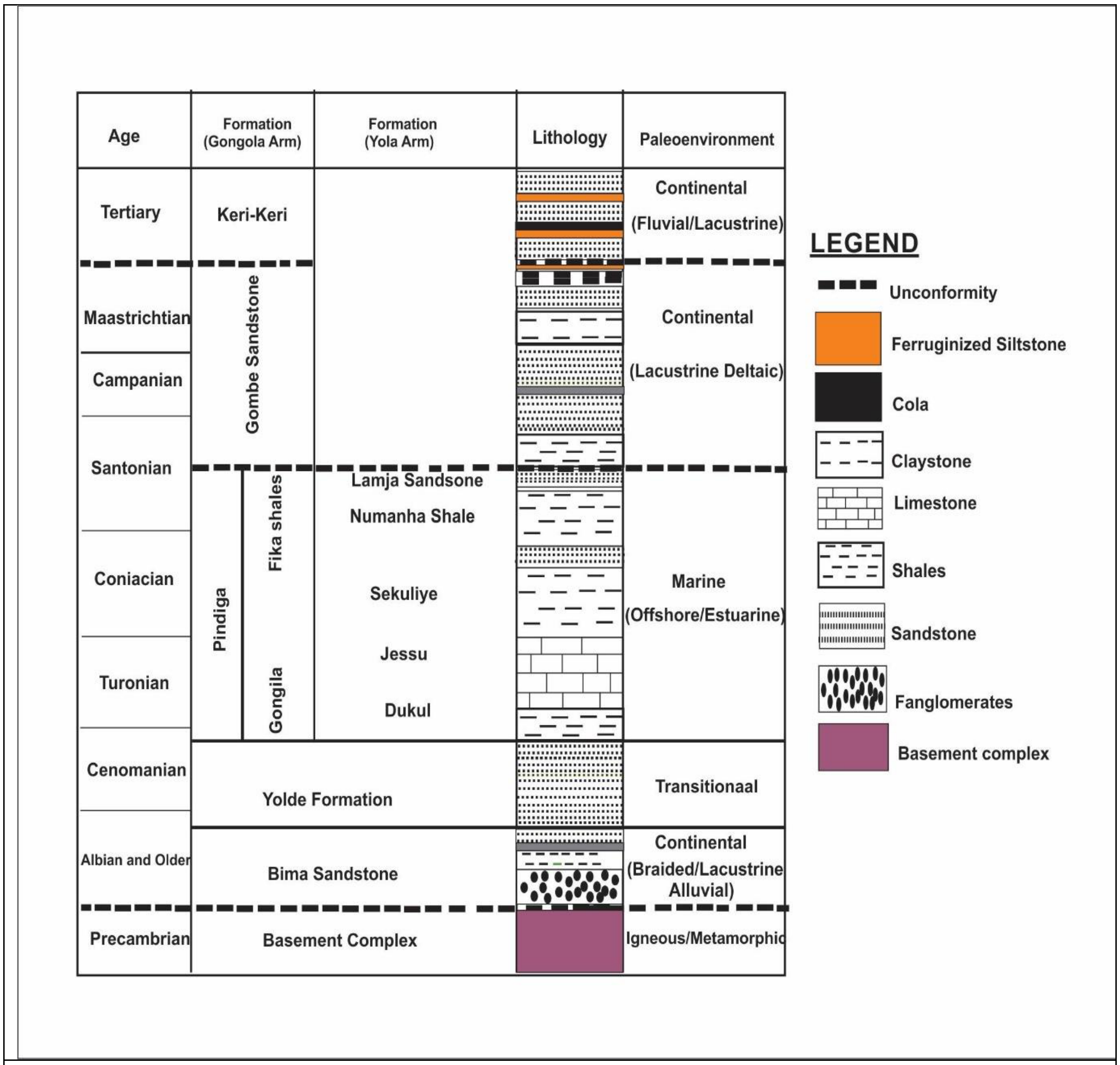


Figure 2: The stratigraphic Table of the Upper Benue Trough (modified from Zaborski et al., 1997 and adopted from Finthan and Mamman, 2020).

## METHODOLOGY

The research work was carried out in two phases, and these involved both field and desk work analysis. From the fieldwork, mapping of key locations and distributions of the exposed Bima Formation was carried out with the aid of a topographic map, Global Positioning System, the azimuths of the cross-beds (foreset) which are primary depositional structures were measured using compass and clinometer, and about 120 readings of the dips and strikes were taken from the surfaces of low angle cross-bedded sandstone and ripple cross-stratification facies. Measurements were made regarding determining the thickness of individual bedding units using tape both vertically and laterally, the sections were carefully logged, and the lithology, facies sequences, and their various architectural frameworks were noted, and relevant field photos were snapped. The facies analysis was carried out following (Miall 1977, 1996; Rust, 1977), the facies model and the facies code were adopted from Miall, (1977). The deskwork which includes plotting of the field data using software e.g., the lithostratigraphic sections were built using the 2019 model of the Corel draw, and the rose diagram for paleocurrent flow patterns were plotted using software known as StereoPro.

## RESULTS

### Facie and Facies Association

Six lithofacies were identified from the Bima Formation in the study area and these are; trough cross-bedded sandstone (St), planar cross-bedded sandstone (Sp), massive sandstone (Sm), parallel-bedded sandstone (Sh), ripple cross-laminated sandstone (Sr) and mudstone facies (Fm), and these lithofacies gave rise to facies association as presented below:

### Facies Description

### Trough cross-bedded sandstone (St)

The trough cross-bedded sandstone facie in the study area is composed of sub-angular to sub-rounded that gave rise to poorly sorted coarse to very coarse-grained sandstone facies, the individual beds of these facies are 1.5 and 2 to 3 m as an amalgamated unit (Fig. 3 and 4 a and d). these facies are commonly overlain by ripple cross-laminated sandstone (Sr) or mudstone facies (Fm). According to (Miall, 2010, 1978, 1977; Rust, 1977) these lithofacies form due to migrating sinuous 3-3 dunes that stack up to create bar forms in the channel. The details of these facies descriptions can also be obtained in (Sarki Yandoka et al., 2014; Shettima et al., 2018; Finthan and Mamman, 2020)

### Planar cross-bedded sandstone (Sp)

The planar cross-bedded sandstone facies (Sp) is made up of sub-rounded, medium to coarse-grained poorly sorted sandstone. The Sp facies is commonly overlying the trough cross-bedded sandstone facies (St), and the individual forset's thickness varies between 1-3 cm and 35 cm to 1.2 m as coset (Fig. 3 and 4 b, f and h). The sandstone units of these facies are commonly overlain by horizontally bedded sandstone (Sh) and/or ripple cross-laminated sandstone (Sr) or mudstone facies (Fm). The Sp facies occasionally exhibit wedge-shape foreset at some horizons in almost 7-10 m thick amalgamated facies sequences, similar facies was reported by Shettima et al., (2018). According to (Miall, 1977, 1978, 1996, 2010; Rust, 1977) such lithofacies are transverse bars formed due to a low flow regime. (Sarki Yandoka et al., 2014; Shettima et al., 2018; Finthan and Mamman, 2020) for the descriptions related to these facies.

### Horizontal-bedded sandstone (Sh)

The lithofacies (Sh) is composed of sub-angular to sub-rounded poorly sorted fine, medium to coarse-grained sandstone facies. The thickness of the individual beds ranges from 60 cm to 2 m but the laminated units are less than 1 cm thick (Fig. 3 and 4 b, e and g). This lithofacies is commonly underlain or overlying trough sandstone (St) and planar sandstone (Sp) cross-bedded sandstone facies respectively. The formation of these facies may be from the upper plane-bed phase and/or from the lower plane-bed phase Hentz and Ruppel, (2010). The bedded configuration of the lithofacies may be due to fluctuation of the depositional conditions which lead to variation in the grain sizes and clay material. The Sh facies was probably formed under plane-bed flow or better still supercritical flow (Miall, 1977, 1978, 1996, 2010; Rust, 1977). Finthan and Mamman, (2020) reported similar facies from Girei and environs.

### Ripple Cross-laminated Sandstone (Sr)

The Upper Bima Member is commonly characterized by these lithofacies as it frequently overlies the trough or planar cross-bedded sandstone facie (St & Sp). The facies are sub-rounded and moderately sorted with fine to medium-grained shape and textures. The facies has a thickness that ranges from 50 cm to 1.1 m. The ripple cross-laminated sandstone (Sr) is commonly underlain by a trough and/or planar cross-bedded sandstone facies and also overlain by mudstone facies (Fm) (Fig. 3 and 4 c). The depositional conditions of these sandstone facies may be linked to migrating current ripples which are controlled by a lower flow regime (Miall, 1978, 1996), however, Rust (1977) defined this depositional facies as a product of wanning flow sheet flood. These facies were reported from the Girei area by Finthan and Mamman, (2020).

**Mudstone Facies (Fm)**
The mudstone facies (Fm) commonly overlie the ripple cross-laminated sandstone (Sr) and occasionally the planar cross-bedded sandstone facies (Sp) (Fig. 3 and 4 a and g). The facies is light-dark grey, it has a thickness that varies between 20 cm to 1 m, it lacks any form of ichnofacies, the Fm facies is deposited in water with extremely low energy condition where the suspended sediments of fine silt and clays settle down (Miall, 1978, 1996), however, Rust, (1977) defined this facies as most distal floodplain deposit.

**Facies Association**

**Sand Dominated Facies Association**
The sand-dominated facies association is composed of coarse to very coarse-grained sandstone facies. It is made up of four lithofacies namely; trough cross-bedded sandstone facies (St), planar cross-bedded sandstone facies (Sp), horizontal bedded sandstone facies (Sh), and ripple cross-laminated sandstone facies (Sr) see (Fig. 3) for the facies model, and each of these lithofacies has been described above.

**Fine-grained dominated facies association**
This facies association is composed of three lithofacies; the fine-grained ripples cross-laminated sandstone, fine-grained horizontal bedded sandstone (Sh), and mudstone facies (Fm). Each of these facies is described above.

**Facies Succession**

**Braided River system facies succession**
This facies succession is made up of two facies association and each is composed of the following facies; St, Sp, Sh, Sr, and Fm (Fig. 3 a-h). The architectural framework of this succession is generally fining upward.

The braided river facies succession in this study area is probably developed in a shallow fluvial channel. The shallow channel speaks volume of continuous fall in paleogeographic profile related to Upper Bima Member (BIII). The facies are dominantly composed of multi-storey planar cross-bedded sandstone facies (Sp) with an average thickness of 16 m, it is commonly underlain by trough cross-bedded sandstone facies (St) which suggest processes of aggrading to form bar complexes known as linguiod bars Withkack et al., (2002) see (Fig.3 ), and these facies succession is overlying Middle Bima Member elsewhere in the Upper Benue Trough. The facies succession reflects shallow perennial sand bed in a braided river system e.g. (Miall, 1977, 1996, 2006; Rust, 1977). The amalgamated planar cross-stratified facies are often overlain by horizontally bedded sandstone (Sh), ripple cross-bedded sandstone (Sr), and mudstone (Fm) facies, these facies successions are generally regarded as products of flashy ephemeral sheet flood sand-bed in a fluvial depositional system (Miall, 1977, 1996, 2006; Rust, 1977).

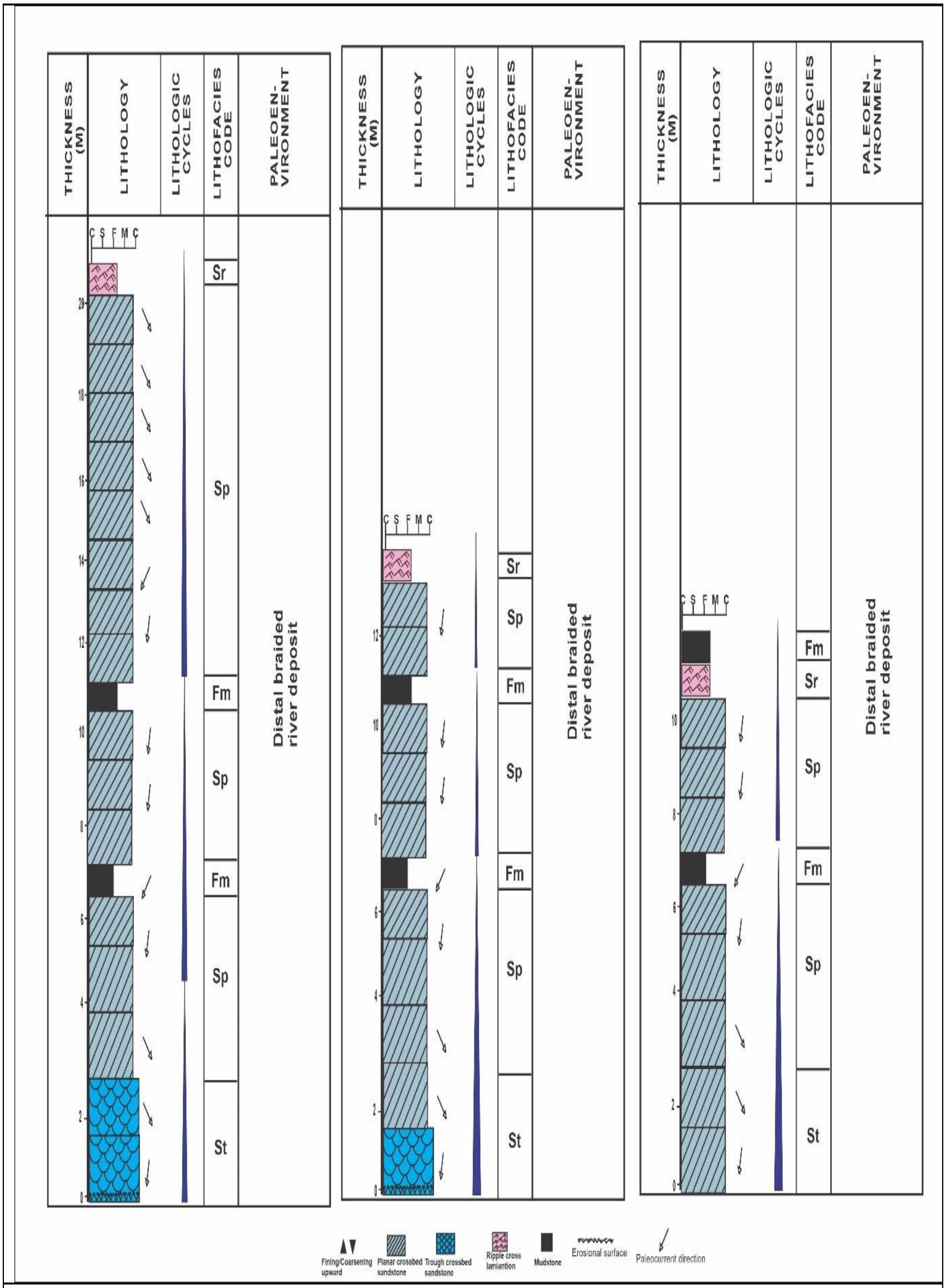


Figure 3: Facies model of the braided river succession for the Upper Bima Member from the study area

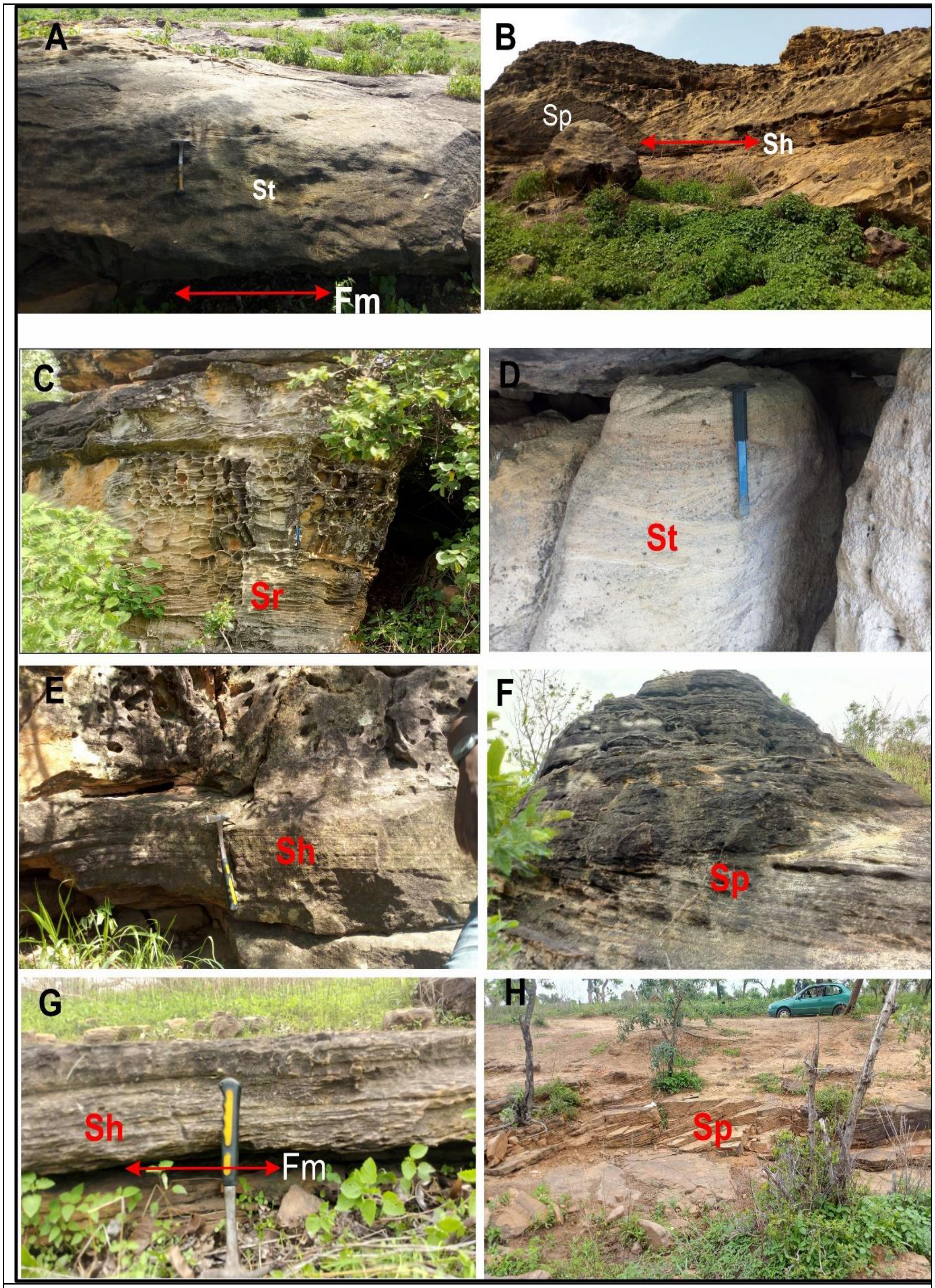


Figure 4: (a and d) Small scale trough cross-bedded sandstone facie (b, f, and h) Planar cross-bedded sandstone facie (Sp) (c) ripple cross-bedded sandstone facie (Sr) (b, e, and g) horizontal bedded sandstone facies (a and g) mudstone facies; see red arrows.

**Paleocurrent**

One hundred and Twenty-eight azimuth readings were taken from the primary depositional structures e.g., trough cross-bedded sandstone (St), planar cross-bedded sandstone (Sp), and ripple cross-laminated sandstone. The plotted azimuth data generally show the trend of paleoslope that is pointing in the northwestern direction (NW) (Fig. 5)

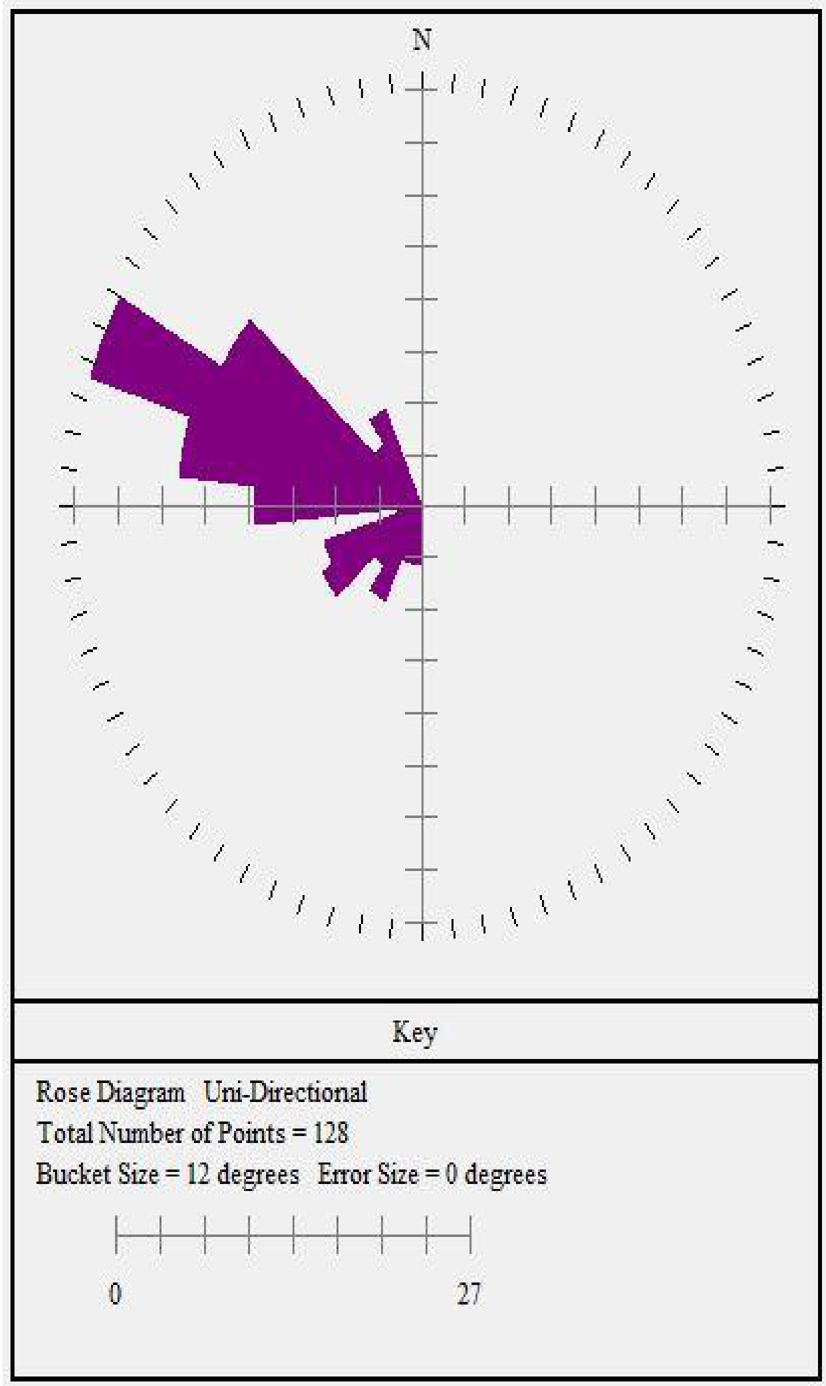


Figure 5: Rose diagram of paleocurrent trend for the cross-beds within Upper Bima Member (BIII) indicating paleoslope in northwestern direction.

## DISCUSSION

The analysis of the primary depositional structures of the Upper Bima Member (BIII) provides a means of understanding the paleoenvironment and depositional conditions of the formation in the study area. Climate and tectonics are the principal factors that control the sedimentation processes, deposition, and architectural framework of the facies and facies association within a sedimentary basin (Shanley and McCabe, 1991; Plint et al., 2001; Posamentier, 2001; Catuneanu, 2006; Catuneanu et al., 2009, 2011). The braided river deposits of the Upper Bima Member are commonly formed in a shallow fluvial channel which is a product of shallow perennial sand-bed braided river Miall, (2006). Further, this also represents flashy ephemeral sheet flood sand-bed in a fluvial depositional system (Miall, 1977, Miall, 1985, 1996, 2006; Rust, 1977). Syn-depositional tectonic is a principal force that controls the topography of any given sedimentary basin whereby it leads to alteration of paleocurrent directions which further serves as a pointer to the paleoslope (Arche and López-Gómez, 1999). The Upper Bima Member characterized by linguiod bars in the study area is deposited in a shallow fluvial river system reflecting low gradient paleoslope Cant and Walker, (1978). The topographic differentiation in the studied sections developed linguiod bars perhaps at a high stage which may be transverse to flow. The preserved flood plain facies such as Sr and especially the Fm facies are commonly inundated at the high stage as tabular cross bars were driven on to them.This description project the Upper Bima Member to fit into Platte-type facies model of Miall, (1977). The large-scale cross-bedded sandstone facies with thicknesses ranging from 1 m to 3 m may represent fluvial channel deposits that were formed due to reduced velocity and channel expansion, such depositional settings are termed sand flat Cant And Walker, (1978).

## CONCLUSION

The Upper Bima Member (BIII) which is part of the Bima Formation from the Upper Benue Trough is exclusively formed in a shallow braided river setting. This is akin to the succession pattern that is characterized by amalgamated planar cross-stratified sandstone facies. The amalgamated Sp facies are commonly a product of shallow perennial sand-bed that transit into shallower ephemeral sheet flood sand-bed within a braided river depositional environment. The uniform paleocurrent trend in the NW direction speaks volumes of a regular topographic landscape, unlike the underlying Lower and Middle Bima Members that were formed in a dynamic setting characterized by irregular topography.

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