FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 10 No. 5, March, 2026, pp 15 – 22
DOI: https://doi.org/10.33003/fjs-2026-1005-4950

LITHOFACIES STUDY OF BIMA SANDSTONE IN GURIN AND ITS ENVIRONS, YOLA SUB-BASIN, NORTHERN BENUE TROUGH, NIGERIA

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ABSTRACT

Understanding the distribution of various lithological units, along with the environmental conditions and depositional settings, is essential for building a geological understanding of an area. This study focuses on the lithofacies in Gurin and its environs to enhance geological and paleoenvironmental understanding. The study involved field mapping and laboratory analysis. The mapping involved the identification of rocks, their lithological contacts and sampling while petrographic analysis was performed on the fifteen (15) representative sampled rocks. The rocks in the area are predominantly composed of sandstone and a few volcanic plugs. The study identified five (5) lithofacies within the Bima sandstone: trough cross-bedded sandstone (St), planar cross-bedded sandstone (Sp), ripple cross-laminated sandstone (Sr), parallel laminated sandstone (Sh), and mudstone facies (Fm) in which the planar cross-bedded (Sp) dominated the area. These lithofacies indicate a fluvial depositional setting, specifically a braided river environment, based on the fining upward sequence and primary structures identified. Petrographic analysis revealed that the Bima sandstone is predominantly composed of quartz (70-99%), with minor amounts of feldspars (1-28%) and rock fragments (1-5%). Based on their composition, the sandstones are predominantly quartz arenite with minor subarkosic and arkosic sandstone. Petrographic studies show that the sandstone is predominantly composed of monocrystalline quartz grains with intercrystalline boundaries; the abundance of monocrystalline quartz grains with intercrystalline boundaries suggests derivation from plutonic source rocks. This study provides valuable insights into the lithofacies, depositional environments, and petrographic characteristics of the Bima Sandstone, contributing to the geological understanding of the area.

Keywords: Lithofacies, Petrography, Braided Setting, Depositional Environment, Fining Upward

INTRODUCTION

Understanding the distribution of various lithological units, environmental conditions and depositional settings is essential for building a geological understanding of an area. Bima sandstone is the most exposed and widespread Cretaceous sediment in the Northern Benue Trough, and its attributes reflect a pointer towards a good petroleum system element, coupled with the fact that Nigerian Government has intensified exploration towards the inland basins to increase hydrocarbon exploration in the country (Abubakar, 2014; Finthan et al., 2023). This study is aimed to understand the lithofacies, facies association and petrographic study of the Bima sandstone in this part of the Yola sub-basin. The Yola sub-basin, part of the Northern Benue Trough in Nigeria, is an intracratonic basin that extends from the Mega-Rift system, known as the West and Central Rift System (WCARS). This system is a significant geological feature in Africa, stretching 4000 km from the Gao Basin in Mali to the Anza Basin in Kenya (Lenhardt et al., 2025), as shown in Figure 1. The petroleum systems found in the West and Central African Rift basins are laterally equivalent to the Cretaceous formations in the Northern Benue Trough (Akande et al., 1998). Hydrocarbons have been identified in the Gongola sub-basin of the Northern Benue Trough within the clastic reservoirs of Cretaceous petroleum systems (Abubakar, 2014). The Bima Formation serves as both the target reservoir rock and source rock, associated with its fluvio-lacustrine facies (Sarki Yandoka et al., 2017; Shettima et al., 2018).

Consequently, this study will concentrate on the lithofacies and facies associations in Gurin and its surrounding areas, which are part of a comprehensive set of tools used to enhance geological and paleoenvironmental understanding. The study area, located within the Yola arm of the Upper Benue Trough, is bounded by latitudes 9° 03' 00" N – 9° 15' 00" N and longitudes 12° 39' 00" E – 12°54' 00" E (Fig. 2). The selection of Gurin and its environs was based on the excellent exposures of Bima Sandstone and the desire to understand the lithofacies and paleodeposition. The depositional history of this area is characterized by the unconformable deposition of Bima sandstone on the Precambrian Basement during the Aptian/Albian (Allix and Popoff, 1983). The Bima Sandstone is divided into three units: Bima1 (B1), Bima2 (B2), and Bima3 (B3), arranged from the oldest to the youngest (Carter, et al. 1963; Guiraud 1990), although research by Tukur et al. (2015) has reclassified the Bima into two units: lower and upper Bima. Understanding the geological setting of the Northern Benue Trough is crucial for interpreting the lithofacies of the Bima Sandstone and the depositional environment in Gurin and its environs.

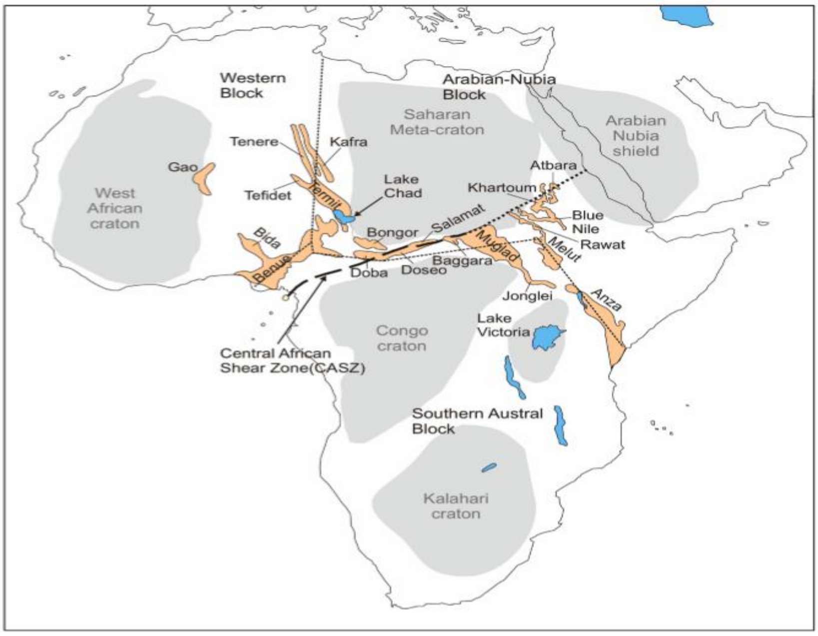
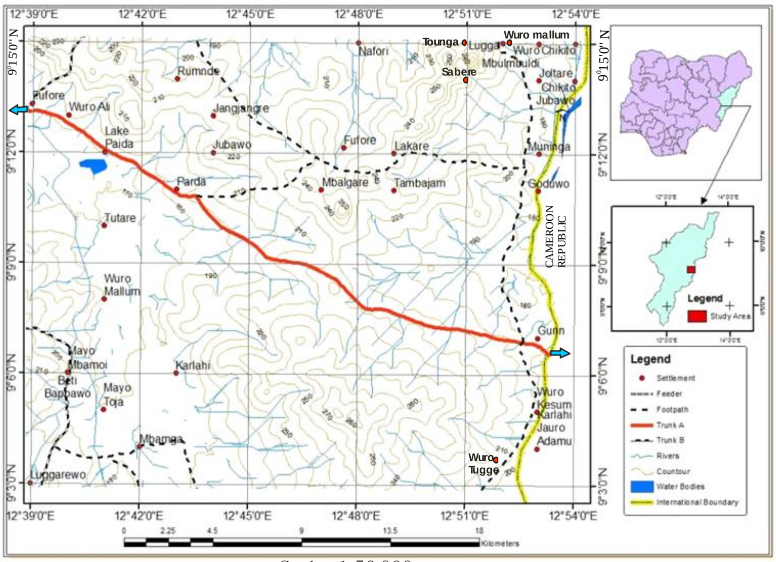


Figure 1: Map showing the Location of the WCARS Basins between the Major Cratonic Areas in Africa (Lenhardt et al., 2025)



Scale: 1:50,000

Figure 2: Topographic Map of the Study Area

Geological Settings

The Benue Trough is a 1,000 km long, 150 to 250 km wide intracontinental NE – SW trending rift depression in Nigeria and it is filled with continental and marine sediments (Nwajide, 2013). The Benue Trough is a prominent tectonic feature in WARS (Fig. 1). It is a polyhistory NE-SW trending collection of several minibasins demarcated into three major segments: The Southern, Central, and Northern Benue troughs (Nwajide, 2013). The Northern part of the Benue Trough bifurcated into the N–S-trending Gongola sub-basin and the E–W-trending Yola sub-basin (Fig. 3). The study area is located within the Yola sub-basin; the stratigraphy of the Yola sub-basin is composed of Cretaceous sequences that overlies the Precambrian basement complex (Fig. 4). This is unconformably overlain by Aptian-Albian continental Bima Sandstone (Carter et al., 1963; Guiraud, 1990). The non-marine Bima Sandstone is overlain by the Yolde Formation which is transitional in nature, the formation is composed of shale sandstone intercalation from the bottom and it pass into siltstone and carbonate rock, the Yolde Formation is overlain by the transgressive Dukul Formation which is purely marine deposit characterised by thick grey shales that pass up into thin silty bed of shale and limestone intercalation, in an upward sequence, the formation is overlain by transitional Jessu Formation, marine Sekuliye, Numanha Formation and finally capped by the Lamja Formation (Opeloye, 2012; Finthan and Mamman, 2020).

MATERIALS AND METHODS

The work is limited to field mapping and petrographic analysis. The study involved identifying the rock formations, their lithological boundaries and collecting samples of all rocks encountered using various geological tools. These rocks were located around hill escarpments, local quarries and stream cuts. Lithologic sections were studied using descriptive and lithological attributes based on texture, color, thickness, grain size, shape, and sedimentary structures. Lithofacies were recognized based on these attributes. All lithofacies and facies codes were applied following Miall (1977) standards. Field observations of five well exposed stratigraphic sections (latitudes 9^0 06' 45''N – 9^0 15' 00''N and longitudes 12^0 48' 00''E – 12^0 54' 00''E) were noted, photographs were taken, and fresh samples were collected and labeled properly. 37 samples were collected from the field in a systematic way (2m spacing) after which 15 representative samples were subjected to petrographic analysis. Fifteen thin sections from different Bima Sandstone samples were analyzed and examined under a polarizing microscope to identify the mineral components. Various optical properties were observed under plane-polarized light (PPL) and cross-polarized light (XPL). The point-count method (Compton, 1962; Ingersoll et al., 1984) was used to assess the relative abundance of the mineral components. This technique involves identifying and counting several hundred points on a thin section, usually in a grid pattern, to determine the volumetric percentages of constituent minerals.

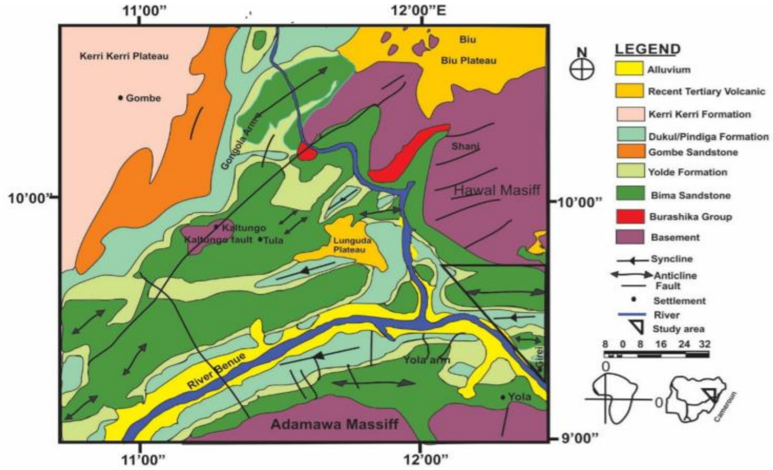


Figure 3: Geological Map of the Northern Benue Trough (After Maurin et al., 1985)

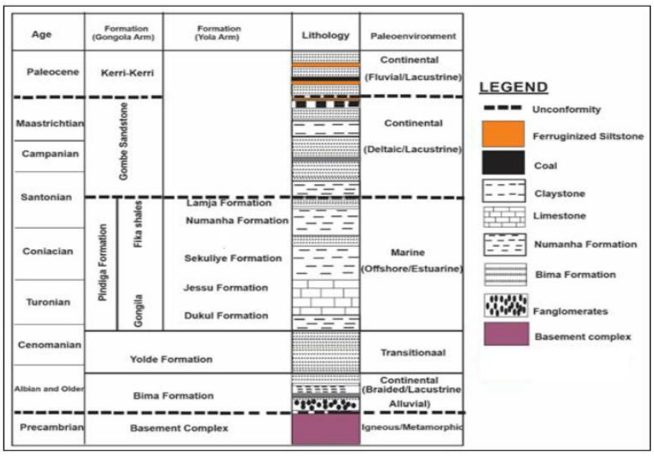


Figure 4: Stratigraphic Succession of the Northern Benue Trough (Finthan and Mamman, 2020).

RESULTS AND DISCUSSION

Facies Analysis and Description

The study area is predominantly composed of Bima Sandstone. The study area is characterized by primary sedimentary structures such as planar trough beds, symmetrical ripple mark which is highly bioturbated. The lithofacies sequence are defined by light brown, planar cross-bed and coarse to medium to fine grained sandstone. Lithostratigraphic descriptions of the study area identified five lithofacies within the Bima Sandstone: trough cross-bedded sandstone (St), planar cross-bedded sandstone (Sp), ripple cross-laminated sandstone (Sr), parallel-laminated sandstone (Sh), and mudstone facies (Fm). The lithofacies and facies associations of the Bima Sandstone indicate its deposition in a fluvial setting. A composite single facies model summarizes the progradational facies sequence of a braided river system, representing a distal fluvial fan. This progradational sequence aligns with the Bijou Creek and/or Platte-type facies models (Miall, 1977).

Sand Dominated Facies Association

Facies St

Trough cross-bedded sandstone sets are uncommon in the study area. This facies consists of fine to medium grained, poorly sorted sandstone often associated with planar cross-bedded sandstone (Pla. I and fig. 5). Trough cross-bedded sandstone is interpreted as the deposit of 3-D sinuous-crested subaqueous dunes, formed by the infilling of trough-like scours as the flow power

Plate I: (a)Planar Cross Bed (b) Strike Slip Fault (c) Small Trough Cross Bed with fine Grained Ripple Cross Lamination and Erosional Surfaces (d) Load Cast (e) Small Scale Trough-cross Bed (f) Highly Bioturbated Bima Sandstone with Planar Cross Bed

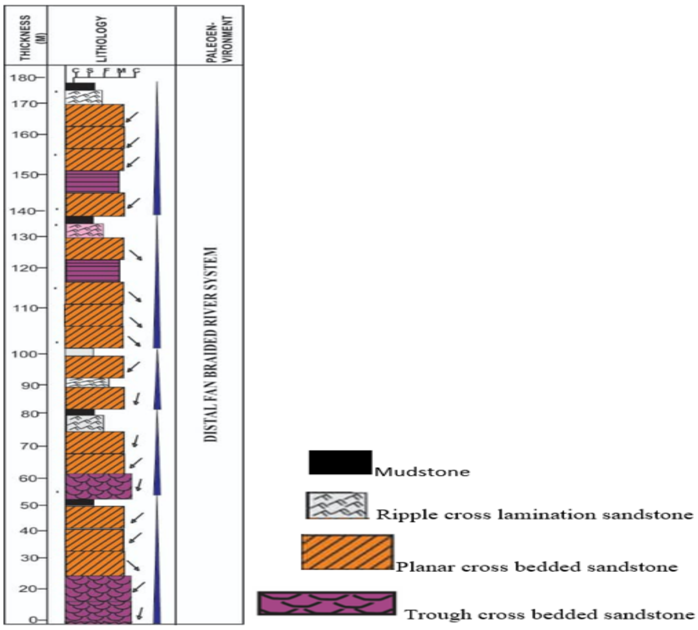


Figure 5: Composite Lithostratigraphic Section of the Bima Sandstone in the Study Area

decreased. These dunes typically form in water deeper than 2-D dunes (Miall, 1985) and are often associated with Gm, Gp, and Sp lithofacies, likely forming during periods of bankfull discharge of the river.

Facies Sp

Planar cross-bedded sandstone is one of the most abundant lithofacies in the study area, occurring at scales ranging from 8 cm to 95 cm in thickness and tens of meters in length. This facies is characterized by medium- to fine-grained, poorly sorted sandstone (Pla. I a-d and fig. 5). The Sp lithofacies represents deposits of 2-D (Ashley, 1990) straight-crested dunes (Miall, 1985). As described by Cant and Walker (1976), planar cross-bedding is widespread in braided river deposits. The Sp lithofacies was likely produced by the migration of straight-crested sand sheets and generally exhibited a fining-upward sequence.

Facies Sr

This lithofacies occurs as fine-grained sandstone lenses in overbank areas. The fine-grained sandstone, up to 50 cm thick was moderately to poorly sorted (Pla. Ic and fig. 5). Ripple cross- laminated sandstones are formed by relatively low-velocity currents and/or moderate wave action in nearshore environments (Miall, 2000).

Facies Sh

This lithofacies consists of fine to medium grained, poorly sorted sandstone characterized by laminated siltstone (fig. 5). It forms as a result of high-density/energy flow and tidal bottom currents deposited during the late stage of forced regression in a distal slope/submarine canyon setting (Miall, 2000; Catuneanu, 2006).

Mud-Dominated Facies Association

Facies Fm

Mudstone lithofacies (Fm) are rare in this area, suggesting that fine-grained deposits were mostly deposited in the proximal parts of the floodplain, which are only reached by very fine-grained suspended sediment. The overlying units of the Bima Sandstone are composed of mudstone lithofacies (Fig. 5) and represent the distal floodplain facies of the Bima Sandstone.

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Lithofacies analysis provides a comprehensive understanding of the depositional environment of the Bima Sandstone, indicating a dynamic fluvial system with varying energy conditions and depositional subenvironments within the broader braided river setting. This interpretation is supported by the finning-upward sequence of the sandstone and the presence of specific primary sedimentary structures.

Petrographic Analysis

Thin-section photomicrographs and their corresponding mineral compositions are displayed in Plates II and III. Microscopic examination of thin sections (Pla. II & III) revealed that the framework grain shape contact was characterized by floating grain and long contact, with grains ranging from poorly to moderately sorted. These characteristics align with the lithofacies interpretation of a braided river system, where varying flow energies can result in poor to moderate sorting. The petrographic observations are consistent with the identified lithofacies; the predominance of quartz and the grain characteristics support the interpretation of various sandstone facies (St, Sp, Sr and Sh). Petrographic studies revealed that the mineral composition of the Bima Sandstone in the study area consisted of Quartz (70-99%), Feldspars (1-28%), and Rock fragments (1-5%), as shown in Table 1. The high quartz content supports the interpretation of a fluvial depositional environment. Petrographic studies indicate that the sandstone is predominantly composed of monocrystalline quartz grains with intercrystalline boundaries. The abundance of monocrystalline quartz grains with intercrystalline boundaries suggests a derivation from plutonic

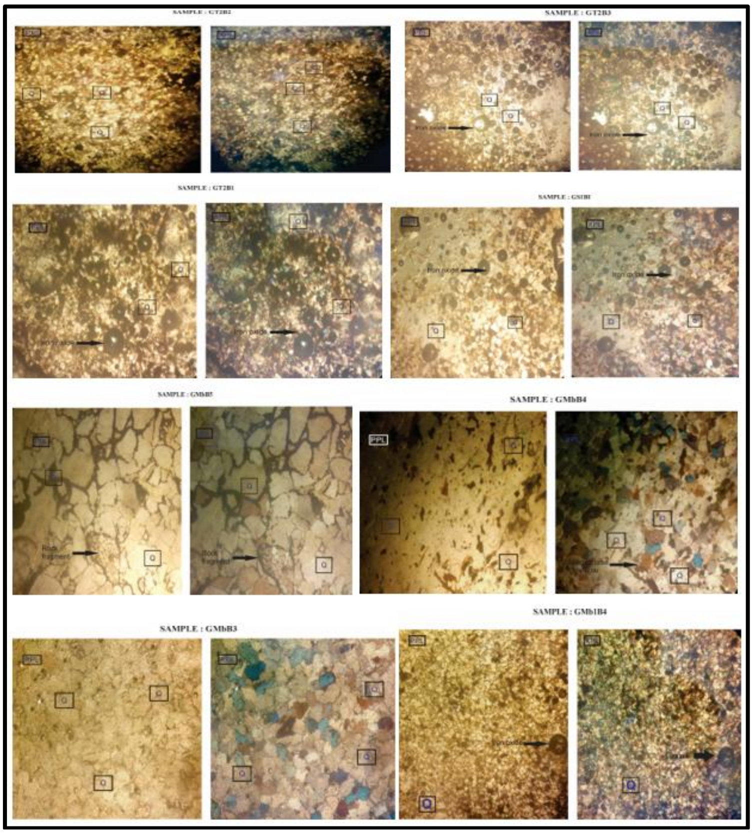

Plate II: Microphotographs of Bima Sandstone of 8 Samples Viewed under Plane and Cross Polar Respectively. L= Rock Fragment, Q= Quartz, F=Feldspar, I.O=Iron Oxid

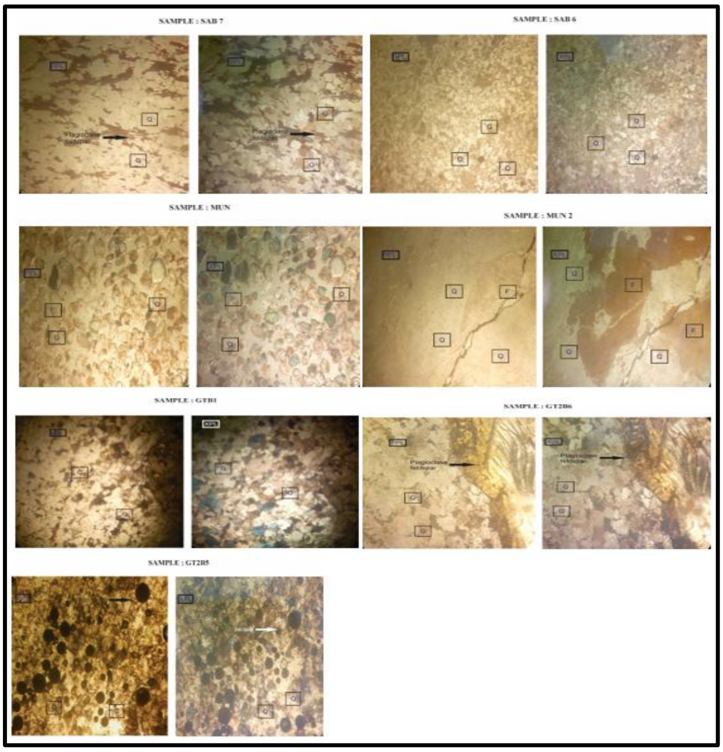

Plate III: Microphotographs of Bima Sandstone of 7 Samples Viewed Under Plane and Cross Polar Respectively. L= Rock Fragment, Q= Quartz, F=Feldspar, I.O=Iron Oxide

Table 1: Modal Composition of Bima Sandstone of The Study Area

Sample I.D	Q(%)	F(%)	RF(%)
GMb1B4	95	3	2
GMbB3	99	1	0
GMbB4	99	1	0
GMbB5	95	3	2
GS1B1	94	4	2
GT2B1	90	7	3
GT2B2	94	6	0
GT2B3	96	3	0
GTB5	70	28	2
GT2B6	85	13	2
GTB1	81	14	5
SAB7	99	1	0
MUN2	74	25	1
MUN	98	2	0
SAB6	97	2	1

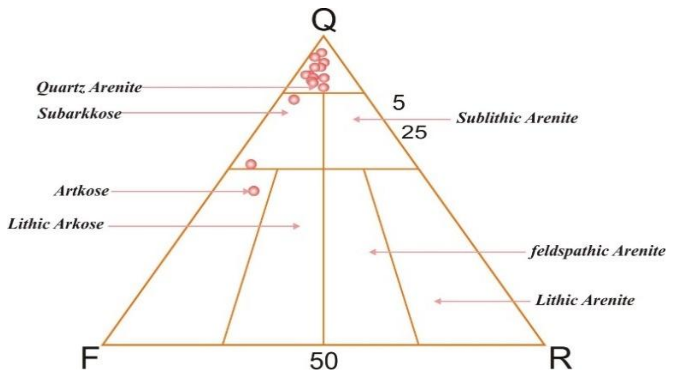

Figure 6: The QRF Ternary Plot showing the Classification of the Bima Sandstone in the Study Area (After Folk, 1980) Source Rocks

The QRF ternary diagrams (Fig. 6), plotted using the modal compositions of quartz, feldspar, and rock fragments, show that the analyzed sandstone is predominantly quartz arenite with two samples classified as subarkose and one as arkose. Therefore, the Bima Sandstone in the study area is classified as Quartz Arenite.

CONCLUSION

The Bima Sandstone was deposited in a braided river within fluvial sub-environmental settings. The identification of diverse lithofacies, including planar cross-bedded sandstone, trough cross-bedded sandstone, ripple cross-laminated sandstone, parallel bedded sandstone, and mudstone, points to a dynamic fluvial system characterized by varying energy conditions within a braided river setting. Petrographic findings reinforce this interpretation, as the poorly to moderately sorted grains and long grain contacts align with the fluctuating flow regimes of a braided system. Petrographic studies show that the sandstone is predominantly composed of monocrystalline quartz grains with intercrystalline boundaries; the abundance of monocrystalline quartz grains with intercrystalline boundaries suggests derivation from plutonic source rocks. Petrographic studies reveal that the microphotographic samples of the Bima Sandstone are predominantly composed of quartz, feldspars, iron oxide, and rock fragments. Based on Folk (1980) sandstone classification, the sandstone is predominantly quartz arenite with minor subarkosic and arkosic sandstone. The petrographic analysis provides crucial microscopic evidence that supports and refines the macroscopic lithofacies interpretation, offering a more comprehensive understanding of the Bima sandstone's depositional environment and sediment source. The study offers valuable insights into the lithofacies, depositional environments and petrographic characteristics of the Bima Sandstone, contributing to the geological understanding of the Gurin and its environs. The study is primarily limited to surface field mapping and petrographic analysis of fifteen (15) representative thin sections. The scope was restricted to outcrops at hill escarpments, quarries, and stream cuts, which may not fully capture the lateral and vertical heterogeneity of the Bima Sandstone across the entire Yola sub-basin. Additionally, the lack of subsurface data, such as well logs or seismic sections, limits the ability to correlate these surface findings with deeper basin architecture. To build upon these findings and support the ongoing national push for inland basin exploration, the future research should focus to increase the sampling density beyond the current fifteen (15) representative samples to provide a higher-resolution understanding of facies transitions across the sub-basin and integrate outcrop data with available seismic and well-log data to develop a three-dimensional stratigraphic model of the Northern Benue Trough.

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