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The Structural Attributes of Gombe Lineaments in relation to Baryte-Fluorite mineralization in the Gongola Sub-basin of the Northern Benue Trough, Nigeria: A Study Using Remote Sensing Data

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ABSTRACT

The study focuses on the Gombe Inlier, one of the significant geological features in Nigeria located within the Northern Benue Trough. It aims to provide comprehensive insights into microstructures, particularly examining the correlations between lineaments and faults in both Basement and adjacent sedimentary rocks using remote sensing data. Digital image processing techniques were applied to Landsat-08 OLI and SRTM data for lineament extraction. Field mapping revealed predominance of Basement Complex rocks, including Granite Gneiss and Pegmatite, alongside Cretaceous Sedimentary Formations. Notable Formations from the Gongola Sub-basin include the Bima, Yolde, Pindiga Formations, and Gombe Sandstones. Baryte and Fluorite deposits have been identified within the research region occurring inform of fracture filling deposits hosted within Granites Gneiss and Sandstones. Geological features such as Faults, Joints, and Veins exhibit structural trends in NE-SW and NW-SE directions, with the presence of the Gombe and Wuro Ladde-Wurin Dole sinistral strike-slip faults which control the mineralization. Satellite imagery analysis identified lineament trends, with NE-SW aligned lineaments denser in Basement rocks. These lineaments (Gombe lineaments) coincide with significant fault zones in Gombe Inlier, suggesting a common tectonic origin. Fracturing patterns in Gombe inlier influence mineralizing fluid movement and controls the mineralization potentials as well as groundwater infiltration in the study area, also posing a risk for engineering constructions due to potential slope failure.

Keywords: Gombe Lineaments, Northern Benue Trough, Gombe Inlier, strike-slip Faults and Satellite imagery

INTRODUCTION

The Earth's dynamic characteristics have resulted in the division of the lithosphere into blocks known as lithospheric plates. Movements of these tectonic plates, driven by convection currents in the mantle, generate stress capable of deforming rocks and giving rise to structural formations (Tsalha et al., 2015; Awoyemi et al., 2017a; Arogundade et al, 2022). Given that, structures serve as unmistakable indicators of subsurface tectonic activity, dedicated efforts have been directed toward examining the linear features beneath the Earth's surface and their implications over time. The analysis of structures yields valuable insights into tectonic trends, the identification of lineament zones, exploration of minerals and groundwater, magmatic studies, and the exploration of oil resources (Over et al., 2004; Mostafa and Bishta, 2005; Ranganai and Ebinger, 2008; Ajama et al., 2017; Olasunkanmi et al., 2020; Arogundade et al., 2022). According to Ferr e et al., 2002, Kroner and Stern, 2005, the interaction involving the West African Craton and the Nigerian shield in an oblique collision gave rise to diverse geological structures of varying magnitudes. The convergence of these lithospheric plates, occurring during the Neoproterozoic era (750 - 500 million years ago), led to regional deformation and metamorphic changes.

Gombe Inlier is one of the geological features in Nigeria; but the flat landscape in the southern parts of the Inlier have isolated hills. While the elevation of the plain is at about 3500m - 400m above sea level, and the hills reached up to 700m (Fig. 1). It is situated in North-eastern Nigeria within the Gongola Sub-basin, an arm of the Northern Benue Trough that trends from North to South and separated from an east-west trending Sub basin known as the Yola Arm by an expanse of shallow Basement rocks (Zaborski, 1998). Gombe Inlier is one of the famous sites for geoscientific studies because it displays the general stratigraphic successions and structural architectures of the Northern Benue Tough in a very small accessible area (Byemi et al.,2015).

Several studies have delved into the examination of structural features, as documented by various authors such as Auwalu et al., (2020), Rabiu et al., (2019), Byemi et al., (2015), Haruna (2007), and Zaborski (1998). Despite this wealth of literature, investigations specifically focusing on the Gombe lineaments, mineralization potentials and their interconnections with the major fault zones within the Gombe Inlier are notably absent. The current research endeavours to fill this gap by offering insights into the microstructures, particularly the relationships between lineaments and mineralization potentials in both Basement and adjoining Sedimentary rocks. These relationships are of significance as they may serve as pathways for hydrothermal fluids, subsequently leading to mineralization in the study area. The outcomes of this study are anticipated to enhance our understanding of Nigeria's structural geology especially Gongola Sub-basin of the Northern Benue Trough. Furthermore, the findings hold potential applications in advancing mineral prospecting in Gombe Inlier.

GEOLOGICAL SETTINGS

The Benue Trough in Nigeria is a rift basin spanning approximately 1000 km in length and 250 km in width, with Cretaceous–Tertiary sediments reaching up to 6,000 m in depth. Sediments predating the Mid-Santonian have undergone compression, folding, faulting, and uplift in various locations. The Mid-Santonian tectonic episode led to intense compressional folding, resulting in over 100 anticlines and synclines within the Trough (Benkhelil, 1989). The Benue Trough's origin is closely tied to the Early Cretaceous opening of the Atlantic Ocean, and various models have been proposed to explain its formation (Stoneley, 1966; Grant, 1971; Olade, 1975; Benkhelil, 1989; Guiraud and Maurin, 1992). Geographically, the trough is divided into three Sub-basins: Lower, Middle, and Upper Benue Trough. The Benue Trough's division into Lower, Middle, and Upper segments was further categorized into Southern (Lower), Central (Middle), and Northern (Upper) sections (Nwajide, 2013). The Northern (Upper) Benue Trough further comprises the Yola and Gongola Sub-basins. Cretaceous sediments in the Northern Benue Trough overlay the Precambrian Basement Complex (Fig. 2).

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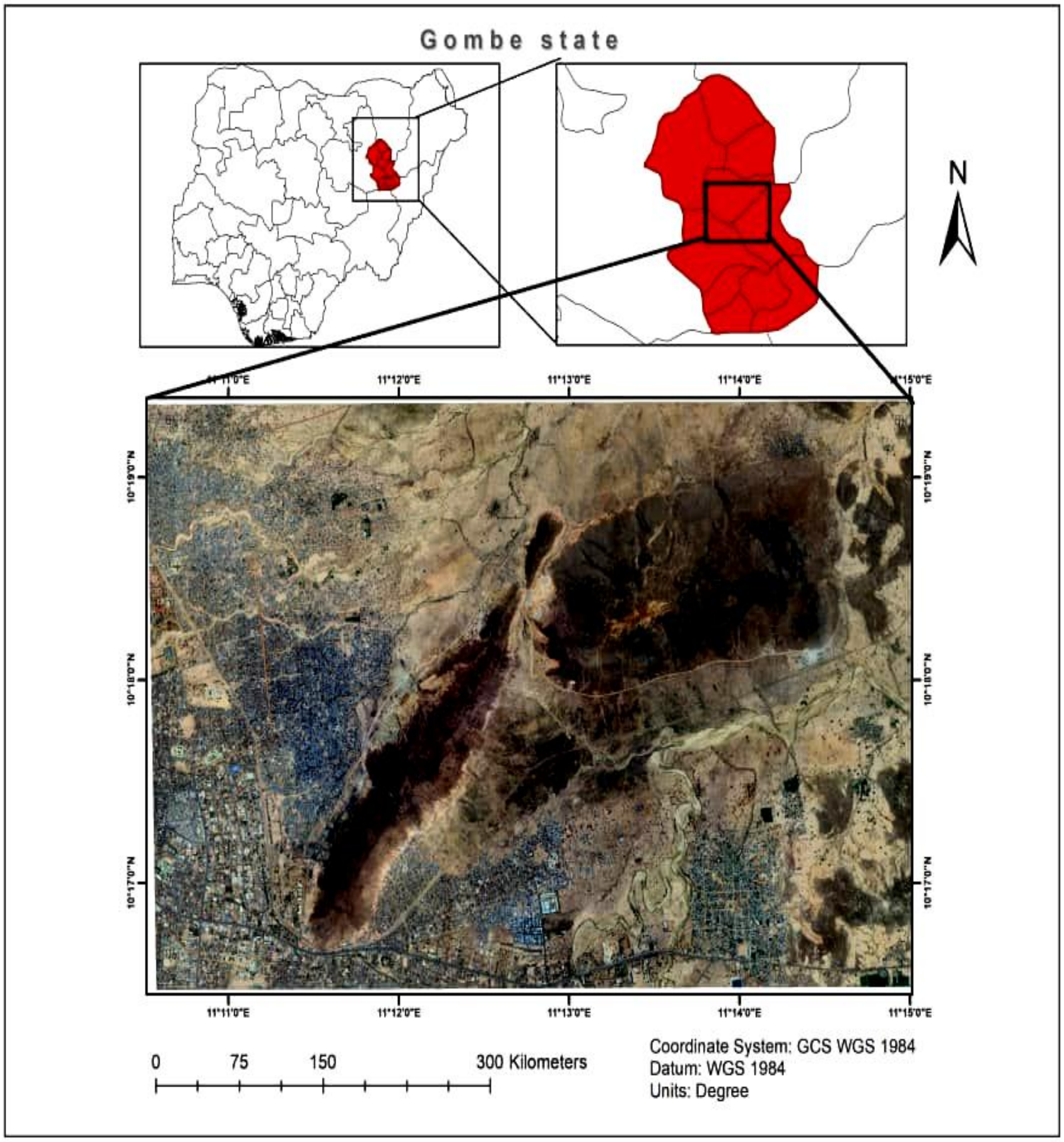

Figure 1: Location map of the study area

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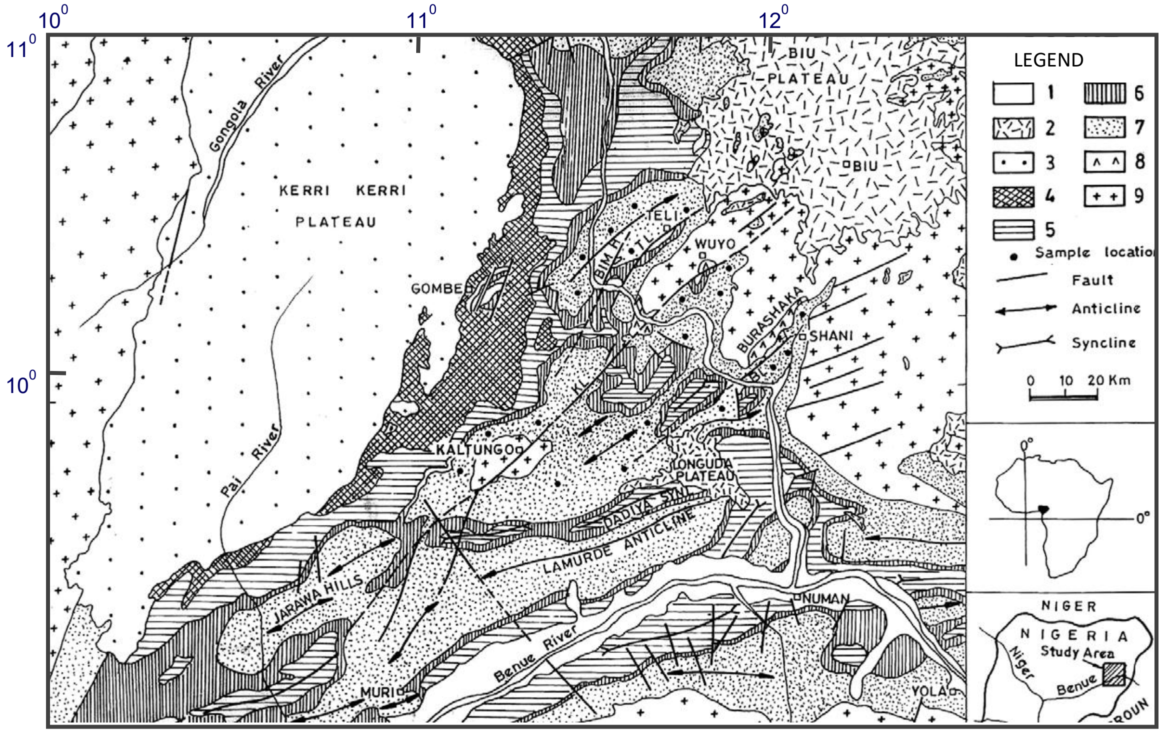

Figure 2: Simplified geological map of the Northern Benue Trough.

Quaternary alluvium; (2) Tertiary Volcanics; (3) Kerri–kerri Formation; (4) Gombe Sandstone; (5) Pindiga Formaion; (6) Yolde Formation; (7) Bima Sandstone ;(8) Burashika Complex (Mesozoic volcanism); (9) Undifferentiated Basement Complex. Main Fault zones; BL: Burashika Fault; KL: Kaltungo Fault; TL: Teli Fault (After Benkhelil, 1989).

The oldest rocks in the Northern (Upper) Benue Trough are the Bima Sandstones, situated unconformably atop the Mylonitic Granites/Orthogneisses of the Basement Complex (Fig. 3). The Bima Group, encompassing lower, middle, and upper Bima Sandstones, constitutes the most substantial sedimentary sequence in the Northern Benue Trough, reaching thicknesses of up to 1500 m (Zaborski, 2003; Zaborski et al., 1998). Representing an active rift stage in basin development, the Bima Sandstone displays pale-grey, trough cross-bedded conglomeratic Arkoses, often intermingled with Purple-colored mottled clays. This Formation is indicative of an alluvial fan braided river deposit (Guiraud, 1990a).

The Yolde Formation was deposited during a transitional period, shifting from the predominantly continental early Cretaceous to the largely marine late Cretaceous (Zarborski, 2003). Comprising fine-grained, well-bedded sandstones and braided-river sediments similar to those found in the Bima andstone, the Yolde Formation occasionally exhibits bioturbation in its sandstone layers.

Additionally, intercalated clays often display pedogenetic features, posing challenges in distinguishing between the Bima and Yolde sandstones in the field (Zaborski, 1998, 2003).

The Pindiga Formation is primarily composed of shale, with a dominant presence of Gypsum-bearing dark grey Shales that transition to a silty composition near the upper part of the unit (Fig. 3). Notably, there are layers containing yellow-grey impure calcareous nodules, often referred to as "limestone nodules," within the Shales. These nodules are indicative of genuine marine conditions that persisted from the Late-Cenomanian to the Mid-Santonian period (Zaborski et al., 1998). The deposition of the Gombe Sandstone occurred between the Mid-Santonian and the end of the Cretaceous period (Maastrichtian), with a distinct separation from the Pindiga Formation by a significant angular unconformity formed during Mid-Santonian compression (Guiraud, 1993).

The base of the Gombe Sandstone is characterized by multiple bioturbated Oolitic ironstone horizons, which transition quickly into sublittoral shale-dominated facies in the middle of the unit. Further up, the unit consists primarily of sand-dominated beach, back-beach, and fluvial facies, suggesting a return to continental conditions (Zaborski, 1998, 2003). During the terminal Cretaceous period, a compression event affected the Northern Benue Trough, resulting in the uplift, faulting, and erosion of the Gombe Sandstone (Zaborski, 1998, 2003).

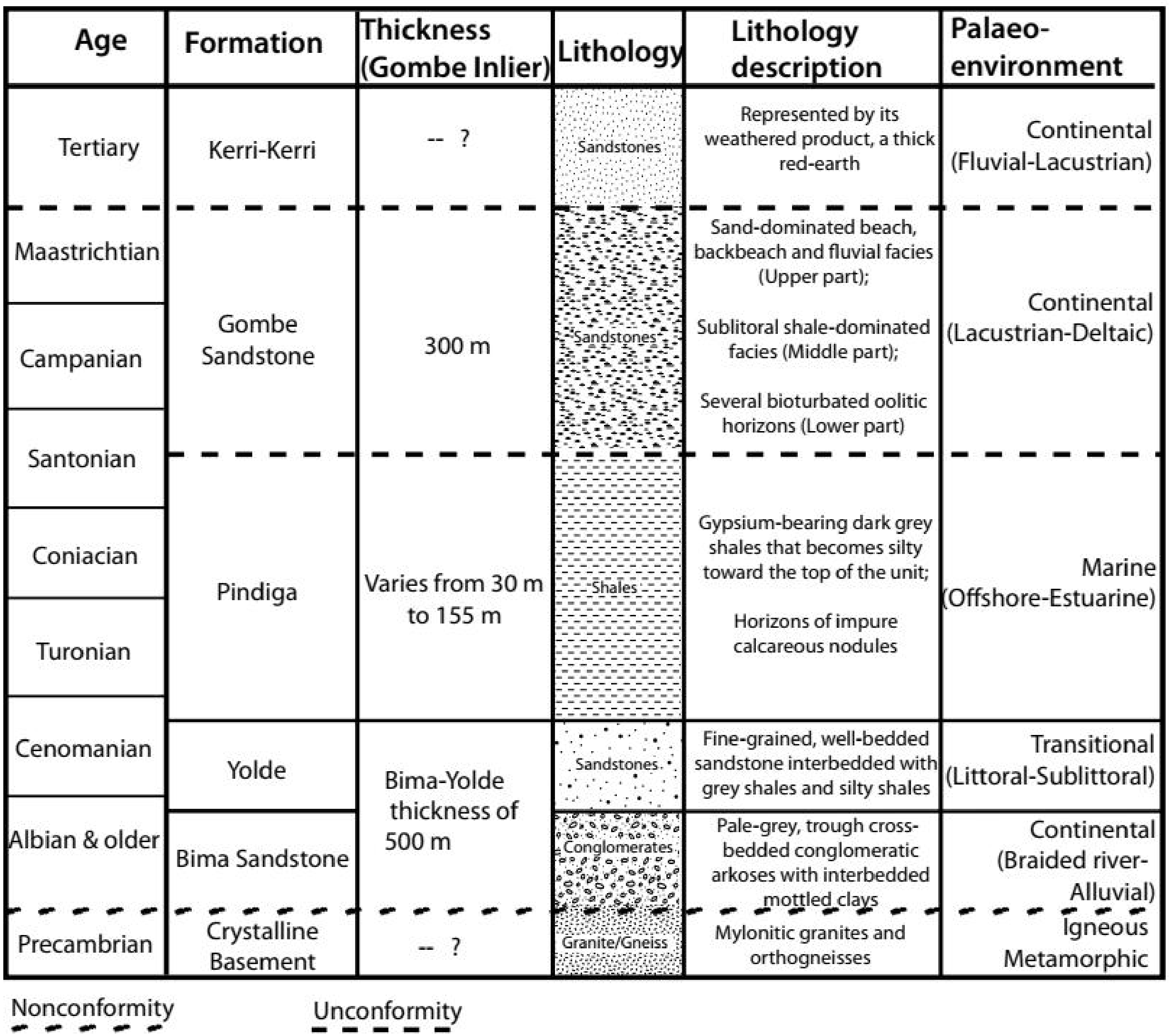

Figure 3: Stratigraphic succession of Gongola Sub-Basin of the Northern Benue Trough (Jolly et al., 2015).

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MATERIALS AND METHODS

The utilized remote sensing datasets comprise Landsat 8 Operational Land Imager (OLI) data and Shuttle Radar Topographic Mission (SRTM) data obtained from the USGS Earth Explorer website. Data from periods characterized by reduced vegetation and minimal cloud cover were selected for analysis. The Landsat -08 OLI data, and SRTM data were subjected to some digital image processing such as; Band Combination (BC), Band ratio (Br) and Principal Components Analysis (PCA) using ArcGIS Software (Fig. 4). Lineament mapping was conducted on the SRTM and Landsat-8 OLI data, employing both manual and automatic approaches. The SRTM and Landsat-8 map images were imported into Global Mapper for manual extraction of lineaments, considering tonal variation, textural differences, and other geomorphological features. The identified structures were then exported back to PCI Geomatica for the automatic extraction of lineaments. Following this, maps illustrating the distribution and density of lineaments were generated. A method of mapping involving traversing was employed to ground truth the identified lineaments, while Compass clinometer, Geological hammer, Global Positioning System (GPS), etc were utilized for detailed mapping exercise.

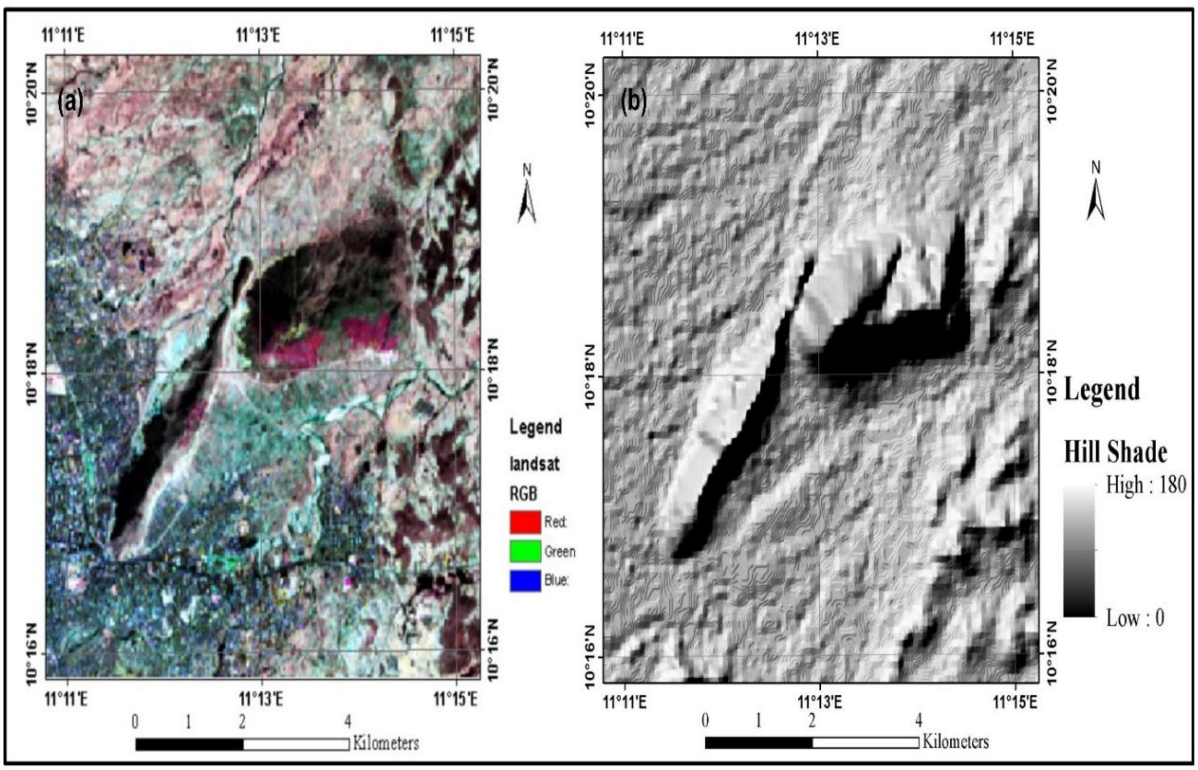

Figure 4: Satellite image of the study area **(a)** Landsat 8 OLI **(b)** SRTM-DEM

RESULTS AND DISCUSSION

General Geology of the Study Area

The geology of the study area is primarily defined by Basement Complex rocks, including Granite Gneiss, Pegmatites and Sedimentary Formations (Bima Sandstones, Yolde Formation, Pindiga Formation and Gombe Sandstones) (Fig. 5). Within the study area, the lithostratigraphic sequence has been

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influenced by a sinistral strike-slip fault located at the termination of the Gombe Inlier, situated in the north-western part of the study area, trending in the NE-SW direction (Fig. 5). This significant strike-slip fault serves as a boundary between the two major ridges, namely the Gombe ridge and Liji ridge, and is identified as the 'Gombe fault.' Additionally, there is evidence of an N-S trending Wuro Ladde - Wurin Dole fault observed in the north-eastern part of the Liji ridge.

Baryte and Fluorite mineralization have been identified within the research region occurring inform of fracture filling deposits hosted within Granites Gneiss and Sandstones, namely the Gombe-Liji Baryte field and the Liji Fluorite field. Numerous Baryte and Fluorite mining pits with varying characteristics are distributed throughout the study area. In both mineralized fields, the veins exhibit trends in the directions of E-W, NNW - SSE, and NW-SE, as well as NE-SW.

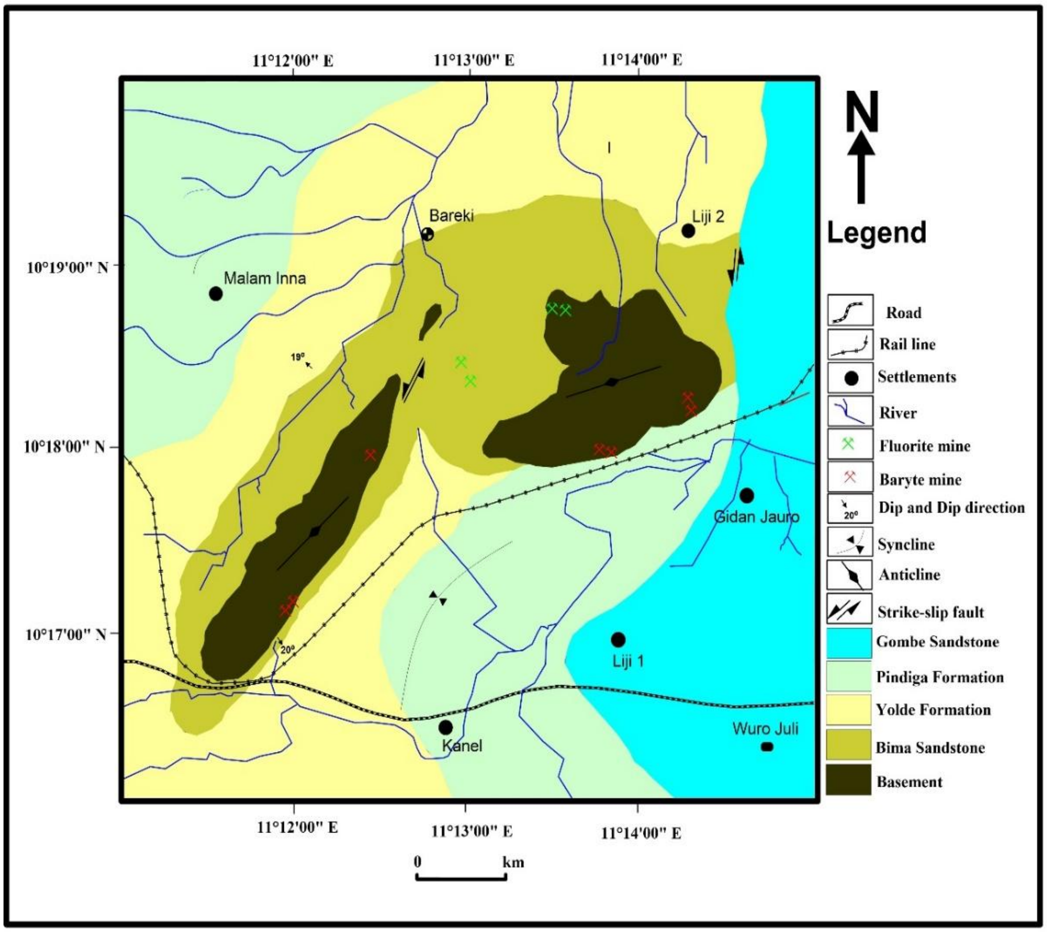

Figure 5: Geological Map of the study area.

In the southern region of the Gombe Inlier, a railway intersects the periphery of Gombe hill, revealing Quartz-Feldspar mylonites within the Basement rocks forming the core of the hill. These rocks, featuring a flower structure resulting from significant fracturing and upthrusting, offer valuable insights into the exhumation processes of the Inlier, as illustrated in Figure 6.

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Figure 6: (a) Unanalysed and **(b)** Showing analysed section of the upthrusted and fractured basement rocks in Gombe Inlier

Lineaments studies (Landsat 8 OLI and SRTM)

Lineaments were discerned through the examination of two separate datasets: Landsat

8 OLI and SRTM. A scrutiny of images obtained from these datasets indicated a non-uniform distribution of lineaments across the study area. The areas with higher lineament density were specifically concentrated within the Basement rock, primarily aligning in the NE-SW direction (Fig.7b and 8b). The Azimuth frequency diagram illustrates that various lineament trends traverse the study area. Lineaments extracted from Landsat 8 OLI imagery in the Gombe Inlier exhibit trends in NE-SW, E-W, NEE-SWW, and NW-SE directions (see Fig. 7c). On the other hand, lineaments extracted from SRTM images showcase trends in the NE-SW, NNW-SSW, N-S, NW-SE, and E-W directions (Fig. 8c).

Examination of both imagery data and a lineament density map for the study area reveals that elevated regions exhibit a pronounced prevalence of high lineament concentrations. Specifically, areas characterized by rapid slope changes within these elevated regions form the Densest clusters of lineaments, exhibiting a greater distribution in the Basement rocks as opposed to sedimentary rocks (Fig. 7a and 8a).

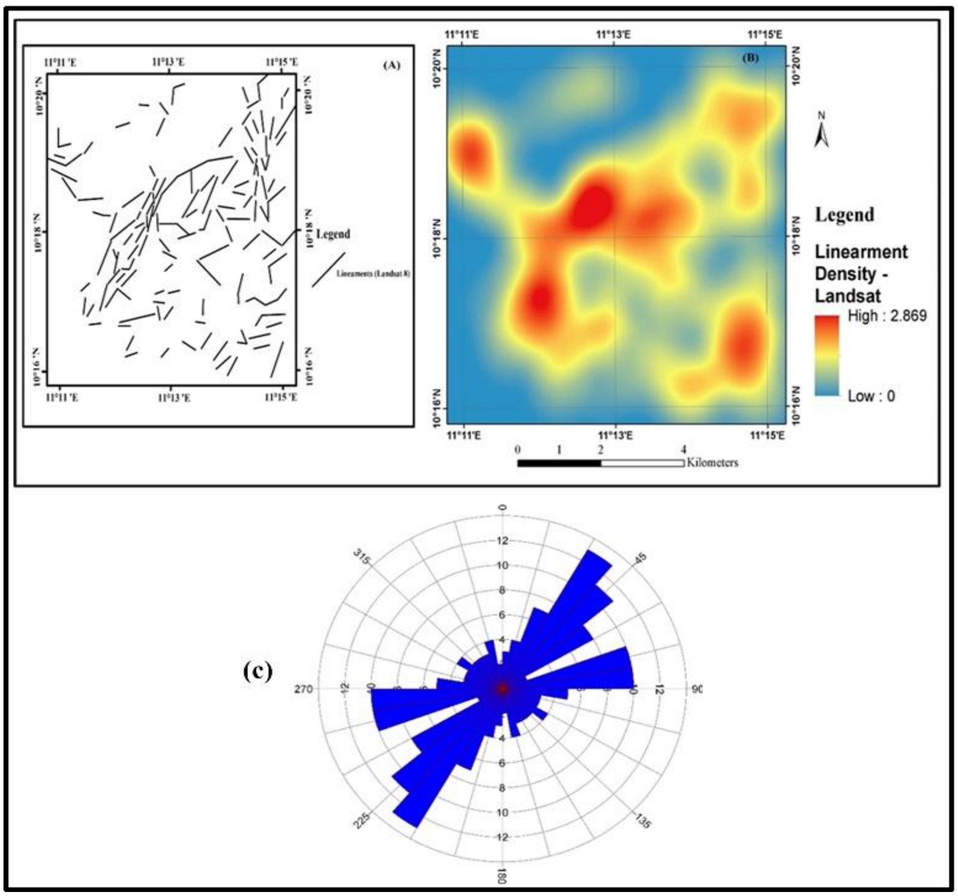

Figure 7: Lineaments from Landsat 8 OLI; **(a)** Lineaments distribution map **(b)** lineaments density map **(c)** Rose diagram

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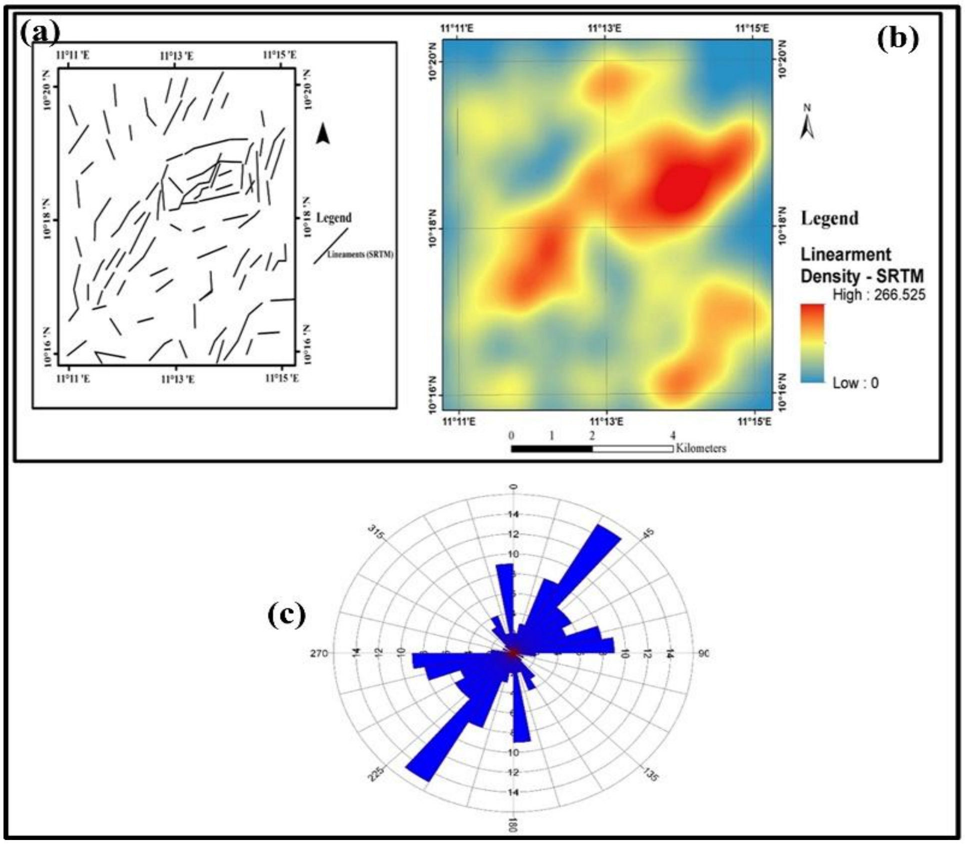

Figure 8: Lineaments from Landsat 8 OLI; **(a)** Lineaments distribution map **(b)** lineaments density map **(c)** Rose diagram

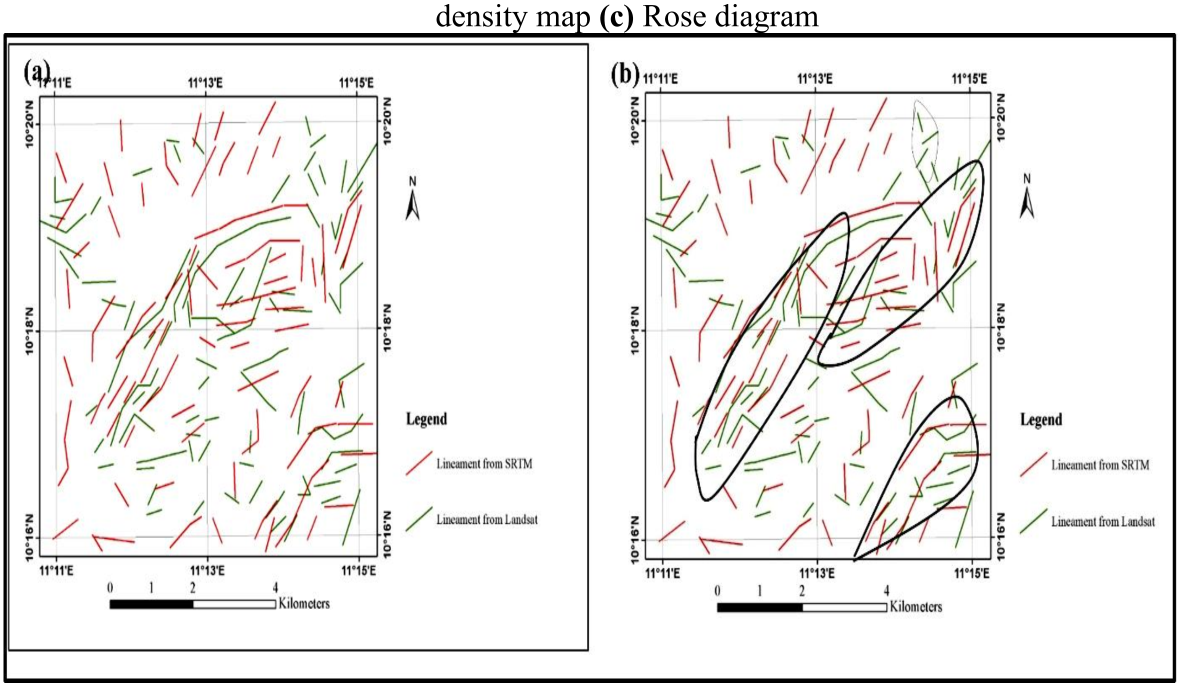

Figure 9: (a) Superimposed Lineaments map derived from Landsat 8 OLI and SRTM-DEM **(b)** showing areas with denser lineaments.

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Overlaying the lineament distribution map derived from Landsat 8 and SRTM highlights the heightened lineament densities within the Basement Complex rocks of the study area. These regions feature robust rocks exhibiting brittle behaviour under compressive forces, possibly attributed to polycyclic deformations. Notably, areas of high lineament density often coincide with significant fault zones in the vicinity (Fig. 9). The mylonite identified along these fault zones could have originated from intense shearing during faulting and folding processes. In essence, the fracturing patterns within the Gombe Inlier is termed as 'Gombe Lineaments', and are influenced by both topographical and geological factors (Fig. 10).

Upon juxtaposing the structural map of the Northern Benue Trough with our study area, a notable correlation emerges between the structural orientation of Gombe lineaments and the orientation of regional structures (Fig. 11a & b). This alignment suggests an association with the broader regional fracture system within the Benue Trough. The proximity of Gombe lineaments sharing the same orientation with the major fault zones implies a likely common tectonic origin. The fracturing observed may have ensued as a response to regional deformation propagating through the study area in an approximate NE-SW direction.

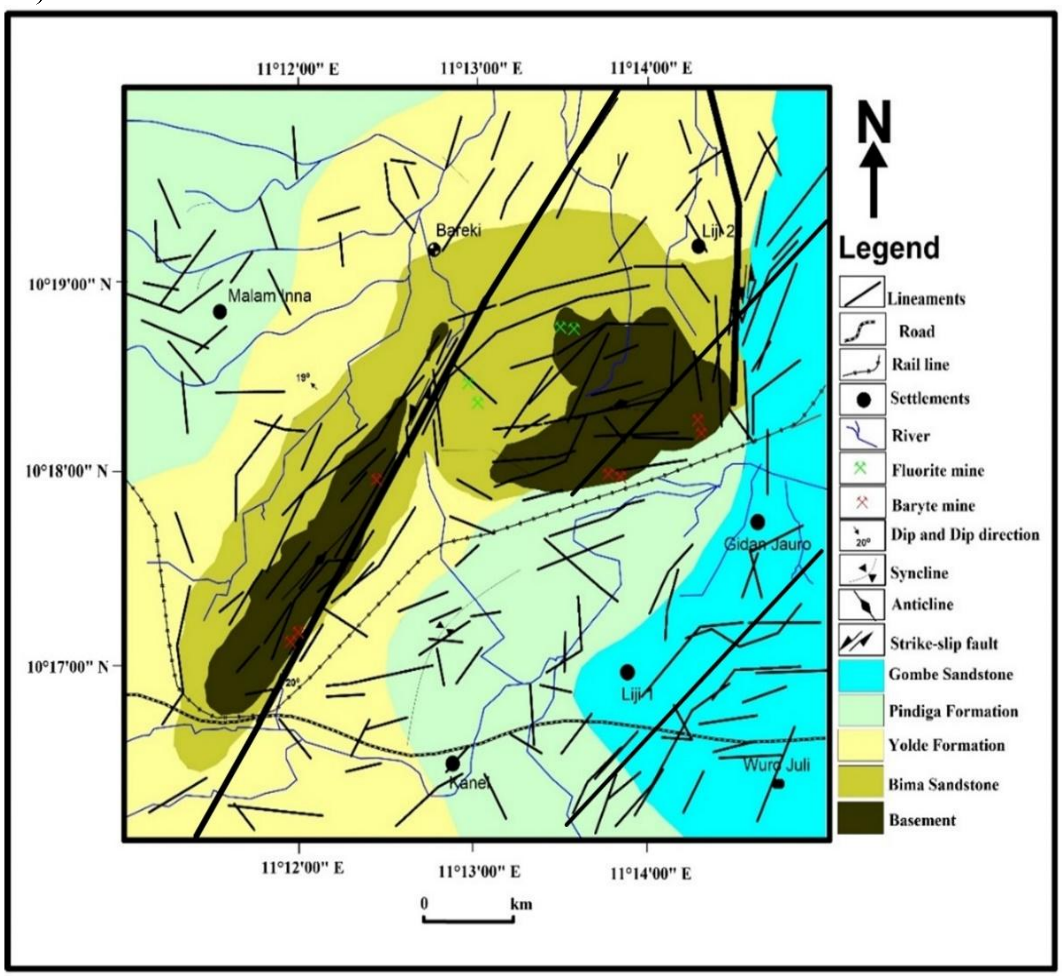

Figure 10: Inferred structural map of Gombe Lineaments

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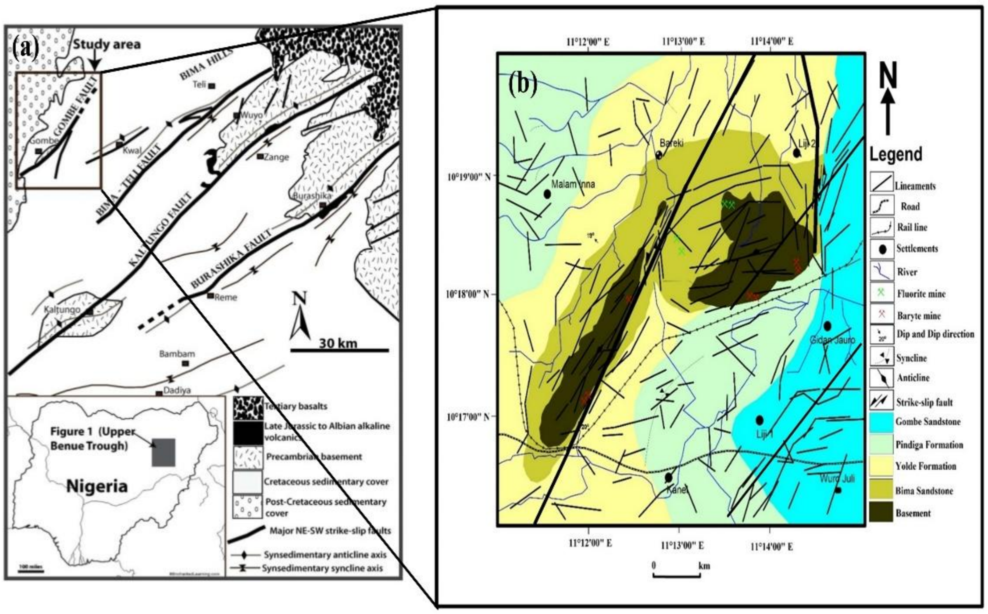

Figure 11: Comparison with; **(a)** Map of the Northern Benue Trough (Jolly et al., 2015) **(b)** Structural map of Gombe Lineaments

CONCLUSION

The research area is underlain by Basement Complex rocks, primarily consisting of Granite Gneiss and Pegmatites, along with some Cretaceous Sedimentary Formations. Notable exposed Formations from the Gongola Sub-basin in Northern Benue Trough include the Bima Sandstone, Yolde Formation, Pindiga Formation, and Gombe Sandstones. Key geological features observed in the field include faults, joints, and veins, exhibiting major structural trends in the NE-SW and NW-SE directions. Visible indications of the Gombe and Wuro Ladde-Wurin Dole sinistral strike-slip faults were noted, accompanied by the presence of their related transpressional structures. The occurrence of Baryte and Fluorite mineralization is influenced by fractures and joints aligned with the Gombe fault and Wuro Ladde-Wurin Dole sinistral strike-slip faults.

Satellite imagery analysis, using Landsat 8 OLI and SRTM data, identified trends in NE-SW, E-W, and NW-SE directions of Gombe lineaments. NE-SW aligned lineaments are denser in Basement rocks than sedimentary rocks. High lineament density coincides with significant fault zones in the area, indicating an association with the broader regional fracture system in the Benue Trough. The alignment of Gombe lineaments with major fault zones and their proximity implies a likely common tectonic origin. Fracturing patterns in the Gombe inlier are influenced by both topography and geology. Hence, these fractures serve as conduits for mineralizing fluid movement from the source to the deposition site. While they may also exhibit a higher potential for groundwater infiltration, caution is advised for engineering constructions in these areas due to the elevated risk of slope failure.

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