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PETROLOGICAL AND STRUCTURAL EVOLUTION OF BASEMENT ROCKS AROUND GUGA, KATSINA STATE, NORTHWESTERN NIGERIA

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ABSTRACT

Lithological characterization and structural assessments of basement rocks around Guga, Katsina State was carried out to understand their geologic evolution and deformational history better. Field and petrographic studies were utilized in characterizing macrostructural, textural, and mineralogical components. Migmatite, banded and augen gneisses, schist, quartzite, and granite constitute the major lithologic units in the study area. Migmatite and the closely related banded gneiss are recognized as igneous-derived metamorphic rocks of Eburnean to early Pan African. In contrast, the augen gneisses are metamorphosed analogues of earlier banded gneiss that were intensely deformed within a ductile shear zone during the middle stages of the Pan African. Similarly, the schist and interbedded quartzite were emplaced during this period, subsequently forming part of the Malumfashi supracrustal cover, related to simple ensialic graben-like structural development. The granitic intrusions represent the youngest rock units in the mapped area, resulting from the magmatic activity of the Pan-African orogeny. Structural analysis suggests the mapped area was affected by two-phase deformation events (D1 and D2). The D1 deformation represents a regional, fabric-forming compressional event, while D2 is a localized deformational event associated with the development of a local shear zone linked to the Kalangai fault system (KFS).

Keywords: Deformation; Shear zone; Nigerian Basement Complex; Katsina; Pan-African Orogeny; Kalangai fault system.

INTRODUCTION

The southern part of Katsina State, northwest Nigeria, represents a geologically-enthralling region characterized by low-and high-grade metamorphic terrains and underlain by rocks with a complex petrological and structural setup. This basement area includes high-grade gneisses and migmatites, relicts of supracrustal metasediments and sheared rocks, bearing imprints of varying degrees of tectonism and metamorphism (McCurry, 1973; Samari, 2012; Onaji, 2014; Alaku *et al.,* 2017 a; Alaku *et al.,* 2017 b). Further, adjoining this area to the east is the Malumfashi Schist Belt, a major sequence of metasedimentary and metavolcanic rocks (McCurry, 1976; Alaku *et al.,* 2017 a). The Malumfashi Schist belt and neighbouring basement rocks are intriguingly traversed by a major NE-SW-trending transcurrent fault, the Kalangai fault system (Fig. 1). This fault zone extends about 300 km and is characterized by series of (sheared) quartzite ridges, cataclasites, and mylonites (McCurry, 1973; Ball, 1980; Danbatta, 2003; Abdulmalik *et al.,* 2018). Hence, the southern part of Katsina represents an important area for understanding the geological and structural evolution of northwest Nigeria's Basement complex. This study presents a detailed lithological characterization and structural assessment of basement rocks around Guga, southeastern Katsina. The study will contribute to a better understanding of the origin and geologic evolution of the rock units, deformational patterns, and the region's metamorphic history. The study area is located in Bakori Local Government Area of Katsina state, covering Guga village and surrounding localities. It extends over a region approximately 40 Km^2, between latitudes 11°40'35.0" and 11°45'00" N and longitudes 7°21'53.0" and 7°24'38.34" E. This area forms part of Funtua Sheet 78 topographic map (Federal Survey of Nigeria).

Geological Setting

The study area is situated within the northwestern part of the Nigerian Basement Complex (Fig. 1). The major geological domains in the Nigerian Basement Complex are; the migmatite-gneiss complex, the schist belts (metasediments and metavolcanics), older granites (Pan African Granitoids), and undeformed acid and basic dykes. Mesozoic Calc-Alkaline Ring Complexes (Younger granites) intrude into the Nigerian Basement Complex's north-central parts (Fitches *et al.,* 1985; Ajibade *et al.,* 1987; Obaje, 2009).

Structurally, the rocks of the Nigerian Basement Complex are believed to be controlled by at least four major thermo-tectonic events, corresponding to Liberian (c. 2700±200 M.a.), Eburnean (c. 2000±200 ma), Kibaran (c. 1,100 ma), and Pan African orogenic events (c. 600± 200 ma) (Grant, 1970; van Breemen *et al.,* 1977; Grant, 1978; Odeyemi, 1981; Rahaman *et al.,* 1983; Oyeagocha & Ekwueme, 1990; Obaje, 2009). However, the imprints of the earlier three cycles' have been largely overprinted by the latest and more pervasive Pan African orogenic event, which imposed a dominant N-S to NNE-SSW structural trend for the whole basement complex (Russ, 1957; McCurry, 1973; McCurry, 1976; Rahaman, 1988; Obaje, 2009).

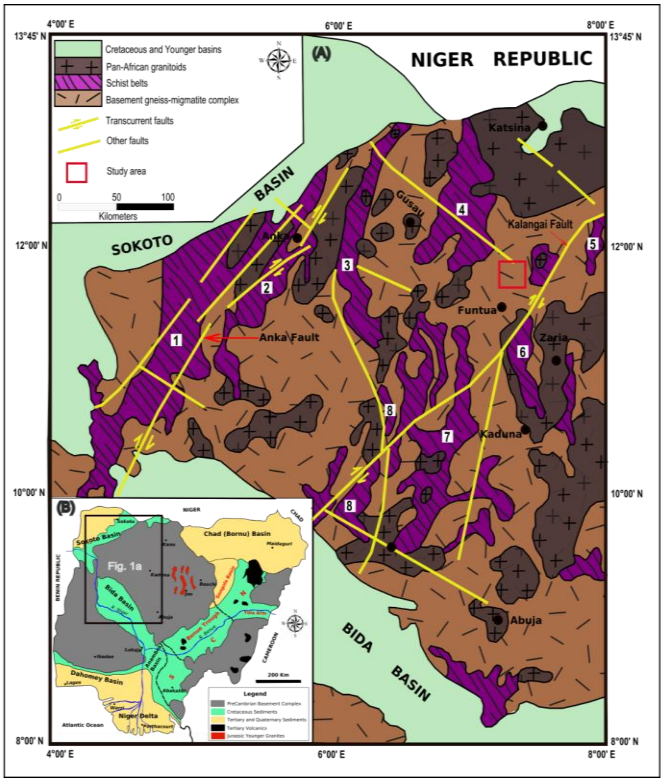

Fig. 1: (a) Simplified regional geologic and structural map of northwest Nigeria (Modified after Garba, 2002). Red square indicates current study location. Purple colour show extent of the schist belts in the region: (1) Zuru; (2) Anka; (3) Maru; (4) Wonaka; (5) Malumfashi; (6) Karaukarau; (7) Kushaka; (8) Birnin Gwari (b) Inset: Geological map of Nigeria showing major petrological units (Modified from Gebhardt *et al*., 2019):

MATERIALS AND METHOD

Field Studies and Sample Collection: A detailed field mapping of the area was conducted at a scale of 1:25,000 using the SE quadrant of Funtua Sheet 78 as a base map. Exposed rock outcrops were mapped and described using conventional field techniques and equipment. Lithological boundaries and units' contacts were carefully observed in the field and delineated on the base map to produce a geological map of the area (Fig. 2). Furthermore, associated structural features such as joints, faults, and foliations were characterized, and their orientation (strike and dip) measured using a Brunton compass with a clinometer. Additionally, fresh, representative rock samples were obtained for petrographic studies. However, fresh schist samples could not be obtained due to intense weathering and thick overburden.

Petrography: Petrographic analysis was carried out at the research laboratories of the Department of Geology, Ahmadu Bello University, Zaria. Representative samples were cut into thin slices using a diamond-edge cut-off saw, and thin sections were prepared according to the method described by Reed & Mergner (1953). The thin sections were studied with a polarizing microscope (Olympus CX31) under plane-polarized light (PPL) and cross-polarized light (XPL) to identify and characterize minerals present, their optical properties, and microstructures.

RESULTS

Field Occurrence and Description of Rock Units

The area investigated is underlain mainly by medium-to high-grade migmatites-gneisses and low-grade metasediments (schist and quartzites), which are intruded into by granitic rocks. The gneisses occur in close association with the migmatites and dominate much of the study area. In contrast, schist and quartzite occur mainly as schist ridges in the study area's central and southeastern parts, sandwiched between the gneisses with a well-defined contact (Fig. 2).

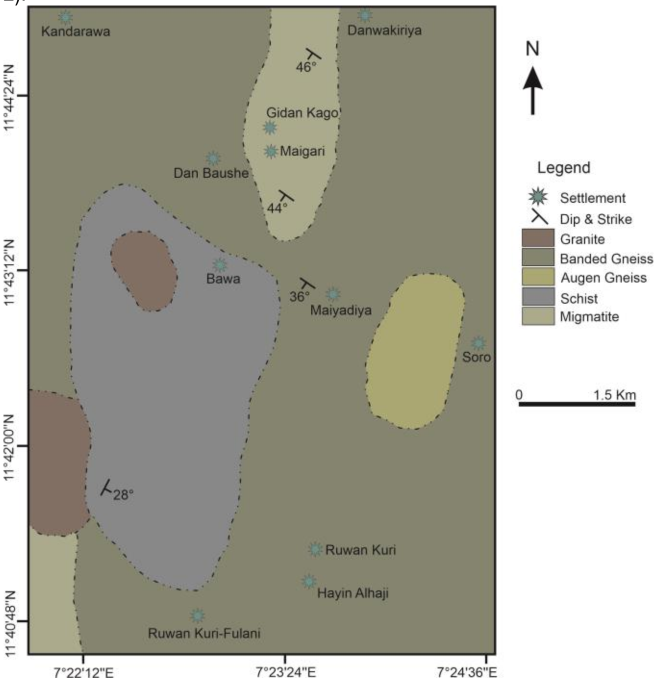

Fig. 2. Geologic map of part of Funtua Sheet 78, comprising the southern part of Katsina state around Guga locality

Gneiss: Gneisses are the most extensive rock units, covering about 65% of the study area (Fig. 2). They are exposed predominantly as low-lying ridges to moderately-rising outcrops, with a general N-S orientation. The rocks are generally leucocratic and composed mainly of felsic minerals: feldspars and quartz, together with biotite and hornblende as the most abundant mafic minerals. Two main varieties of gneiss were identified in the study area based on their texture and structural features. These are medium-grained banded gneiss and fine to medium-grained augen gneiss. The medium-grained gneiss is strongly foliated in the hand specimen. It consists of quartz and feldspar, with minor biotite and hornblende, giving it a general greyish-pink colouration with a distinct banded appearance (Fig. 3a). The banding is characterized by alternating leucocratic quartzo-feldspathic bands and dark-coloured bands containing biotite and minor amounts of hornblende. In some outcrops, the parallel bands appear to be slightly deformed, contorted, and wavy.

Non-banded, leucocratic augen gneisses dominate the eastern parts of the study area. The rocks show a reduction in grain size and a distinct augen texture, marked by large oval-shaped feldspar grains embedded in a finer groundmass (Fig. 3b). The feldspar pophyroclasts (augen) range from 0.4 to 4 cm and are oriented parallel to the foliation, although the foliation pattern is slightly deflected around the pophyroclasts. In few areas, these gneisses are well foliated and exhibit a mylonitic fabric, defined by strong foliation, well-marked traces of stretching lineation, and a further reduction in grain size (protomylonites). The feldspars are reduced in the protomylonites, with a corresponding increase in quartz content.

Thin section observation shows a predominance of orthoclase (35%), quartz (30%), and biotite (20%), with minor amounts of hornblende (10%) and plagioclase (5%) in the banded gneiss (Fig. 4a). The rock has an even texture and shows a gneissic foliation marked by the preferred orientation of minerals (parallelism of biotite and elongation of quartz and feldspar grains).

Migmatite: Migmatites constitute about 10% of the rocks in the area, outcropping mainly in parts of the northeastern and southwestern areas. These are closely associated with the banded gneiss and are composed of similar mineral assemblages. The most significant migmatite exposure is at *Maigari* in the northeastern part of the study area. It outcrops as a low-lying hill with a NE-SW orientation and a moderate dip. The rock has a medium-grained texture and a light greyish-pink colour due to felsic minerals' dominance (feldspar and quartz). The rock is highly banded, with alternating light (felsic) and dark (mafic) layers that have been distinctively contorted and folded in a tortuous manner, giving the rock surface a characteristic wavy and sinuous appearance (Fig. 3c).

The migmatite has a near-identical microstructure to the banded gneiss and is composed of orthoclase feldspar (30%), quartz (25%), microcline (5%), plagioclase (3%), biotite (25%), hornblende (10%), and other accessory minerals (2%) (Fig. 4b).

Schist and Quartzite: These rocks are relatively widespread and constitute about 20% of the rocks in the study area. They are exposed in the study area's western and central parts, forming prominent N-S trending elongate hills. The schist is brownish to light grey with a shiny appearance, medium-grained, and dominantly of mica minerals with lesser amounts of quartz and feldspar. The platy minerals (mica) have a more or less parallel arrangement, resulting in a highly developed schistosity, making the rock split into thin layers along the platy minerals' alignment direction. However, almost all schist exposures in the mapped area are intensely weathered and transformed into reddish-brown ferruginous soil, making field observation difficult. Thus, the schist's presence in the mapped area is mainly indicated by rubbles of mica flakes and large pebbles and cobbles of quartzite within reddish-brown elongate hills.

Quartzite forms a rock sub-type within the schist ridges, where it is embedded within the schist. These are mainly white to pale-coloured and consist primarily of quartz with a medium-grained, granular texture. This rock consists of about 99% quartz, which occurs as low-relief, colourless mineral grains in plane-polarized light. The crystals exhibit white to dark grey undulatory extinction in cross-polarized light, with no distinct pleochroism, cleavage, and twinning (Fig. 4c).

Granite: Granites make up approximately 5% of the mapped rocks and are confined to the western part of the study area, where they occur as discrete units (Fig. 3e). Significant exposures were observed around Bawa, where pockets of small, dome-shaped granite intrude into the schist (Fig. 3e). These are light greyish-pink, medium to coarse-grained leucocratic units, consisting of feldspars, quartz, biotite, and hornblende. Low-lying, coarse-grained outcrops of the granite occur in the south westernmost part of the study area, slightly different from the occurrence at Bawa. These outcrops have similar mineralogical and textural characteristics with the variety mentioned above, but they markedly contain angular xenolithic bodies of banded gneiss (Fig. 3f).

The granite is essentially composed of orthoclase (40%), quartz (30%), plagioclase (15%), biotite (10%), and hornblende (5%) in thin section (Fig. 4d).

Pegmatite and Aplite: These occur as minor intrusions that crosscut the whole sequence; however, abundant within the gneiss and migmatite. The pegmatites occur as near vertical to vertical, discordant intrusive bodies, with few concordant occurrences. They are leucocratic and composed of very large interlocking crystals of quartz and feldspars with accessory mica and hornblende (Fig. 3g). The pegmatites have a thickness ranging from thin units of 2-3 cm to bodies up to 60 cm wide.

Aplites occur mostly as pink, discordant dikes, with thickness ranging from 20 cm to 90 cm, and are undeformed. They are conspicuously very fine-grained and consist of orthoclase feldspar and quartz, with minor amounts of mafic minerals (Fig. 3h).

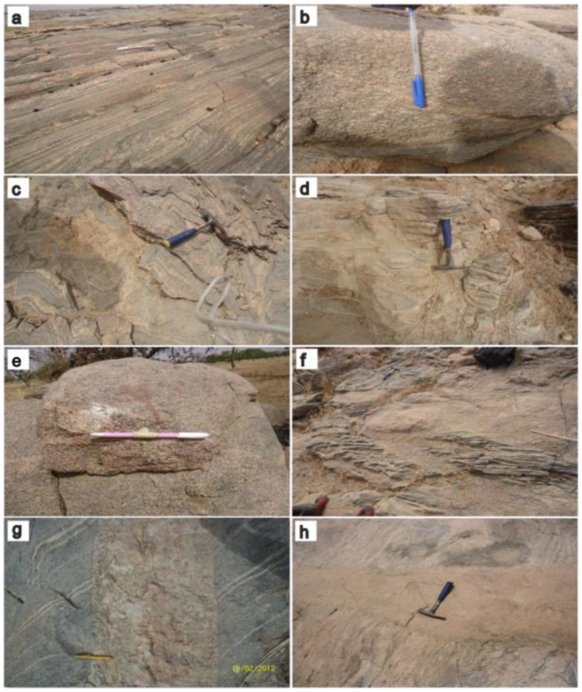

Fig. 3. Field photographs of (a) low-lying banded gneiss; (b) Augen gneiss with large, lenticular eye-shaped feldspar pophyroclats (augens); (c) Migmatite with contorted and folded bands; (d) Weathered schist exposed along a river channel; (e) Medium-grained leucocratic granite; (f) Xenoliths of banded gneiss within fine-grained granite; (g) Quartzo-feldspathic pegmatite cutting through gneiss; (h) Orthoclase feldspar-rich aplite intruding a banded gneiss.

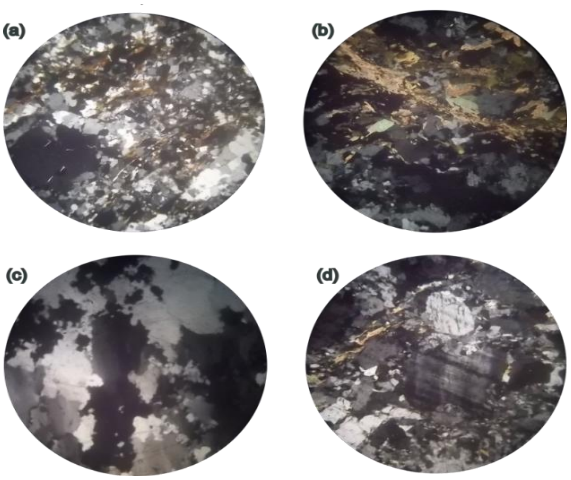

Fig. 4. Photomicrograph of thin sections of (a) gneiss; (b) migmatite; (c) quartzite; (d) granite. (All in images are in cross polarized light setting; Magnification: X40).

Structural geology

Several structural features were observed on the rocks and include those formed from brittle and ductile deformations. The brittle structures include joints, veins, and faults, while the ductile structures include; foliation, folds, boudinage, and augens.

Brittle Structures

Joints are the most common structural features observed within the rocks. Different jointing styles were observed, including conjugal (nonsystematic), parallel, cross, and vertical joints, with the spacing between them ranging from 2cm to 10 cm. Strike readings of joints were obtained and plotted on a rosette diagram (Fig. 5a), which shows a general trend in the NE-SW direction.

In some outcrops, the joints have been filled up and mineralized, resulting in the formation of veins. The veins are mainly quartzo-feldspathic, with thicknesses ranging from few millimetres to few centimeters (0.4 - 13.2cm). Two generations of veins are distinguishable in the study area: primal and late phase veins. The early veins intrude only the gneisses, migmatites, and metasediments and are relatively deformed and folded (e.g., Fig. 6a & b). Late phase veins intrude all the rocks in the area and are mostly undeformed. A plot of all vein measurements shows a dominant NNE-SSW trend (Fig. 5b).

Few faults were observed in the study area and are mainly minor faults with relatively small displacements in the order of 5-25 cm. Several quartzo-feldspathic veins are displaced and faulted as dextral strike-slip faults, while a normal dip-slip fault was observed on an outcrop of augen gneiss with a vertical displacement of 2 cm (Fig. 6c).

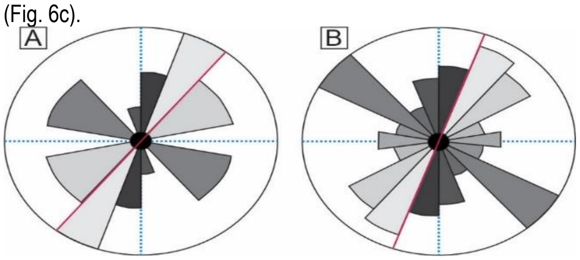

Fig. 5. Rose diagrams showing the trends of joints (a) and veins (b) in the study area. Principal joint and vein values are in the NE-SW and NNE-SSW directions, respectively

Ductile Structures

Foliation is the most conspicuous structural feature in the study area. These are defined by gneissosity in the gneisses and migmatite and by a mica-rich foliation (schistosity) in the schist. The gneissosity is marked by a strong compositional banding, characterized by alternating light and dark stripes of felsic and mafic minerals, respectively (Fig. 6d). The light-coloured bands are rich in quartz and feldspar, whereas the darker layers contain mostly biotite and some hornblende. Schistosity is discernible by the alignment and parallel orientation of planar mica minerals (muscovite and biotite). A north-south foliation trend is dominant in the rocks of the mapped area.

Folds are well developed on the migmatites, occurring as tight-isoclinal, convolute, and ptygmatic folds with general NNE-SSW oriented axes and sub-vertical axial planes. Folds were also observed in some of the gneisses, where earlier parallel bands are deformed and contorted to produce open, isoclinal asymmetrical folds (Fig. 6a). Folding is also observed in some veins and pegmatites, with their fold axes in the same direction as the gneissic bands.

Augen Structures were observed as elliptical, eye-shaped single crystals or coarse crystal aggregates embedded in a finer-grained matrix (Fig. 6d). The core of the structure is usually a hard, resilient mineral, commonly feldspar. These are particularly abundant in the augen gneisses of the study area as pophyroclasts of feldspar embedded in a finer matrix. The pophyroclasts range from small ones with a diameter of 0.4 cm to large ones measuring 10 cm.

Boudinage occurs extensively on the banded gneiss where layers of feldspar have been distended to form boudins. They occur as stretched, sausage-shaped feldspar chunks amidst the more deformable, less competent matrix (surroundings) (Fig. 6e). Some of the boudins retain the drawn layers' continuity but show variable thinning of the original layer thickness, forming pinch and swell structures (necked boudins) (Fig. 6f).

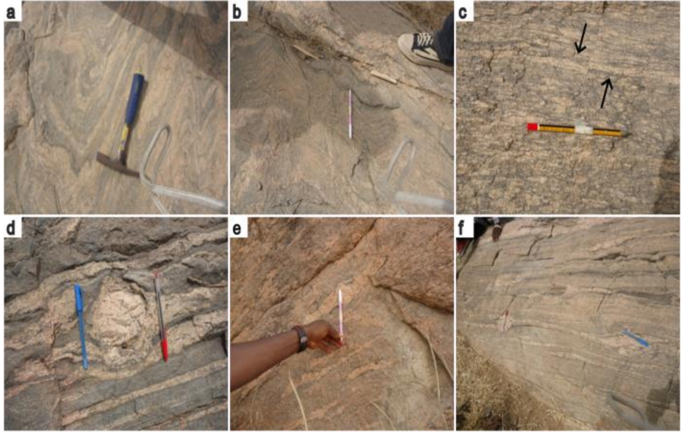

Fig. 6. Field photographs of brittle and ductile structures in the mapped area: (a) ptygmatic folding in migmatite; (b) tight-isoclinal folding in migmatite; (c) normal dip-slip fault on mylonitic augen gneiss (protomylonite); (d) Monomineralic (feldspar) augen in banded gneiss; (e) boudinage on banded gneiss; (f) pinch-swell and boudinage on banded gneiss.

DISCUSSION

Evolution of Rocks

Migmatites and closely related banded gneisses constitute the major lithologic units in the study area and form part of the ubiquitous migmatite-gneiss complex of northwestern Nigeria. From field disposition and relationships, these rocks are considered the oldest group of rocks in the mapped area and form a basement on top which the precursors of the low-grade metasediments (schist and quartzite) were deposited. The complex field relationships of the rocks and lack of geochemical analysis in the present study make it difficult to accurately define the mode of formation and protolith of the investigated migmatites and gneisses. Although Freeth (1971) and Burke *et al.* (1976) reported paragneisses in parts of the Nigerian basement complex, the migmatites and gneisses of the basement complex of Nigeria are generally interpreted as being orthogneisses of igneous origin (e.g., Grant, 1970; Onyeagocha, 1986; Ekwere & Ekwueme, 1991; Imeokparia & Emofurieta 1991; Kroner *et al.,* 2001). Furthermore, detailed studies of rocks in the southern parts of Katsina around Kafur (Elatikpo *et al.,* 2013) and Tandama (Alaku *et al.,* 2017) suggest an igneous protolith for the migmatites and gneisses in the area. Accordingly, the migmatites and banded gneisses of the present study area are recognized as igneous-derived metamorphic rocks of Eburnean to Pan African age.

However, the formation of the augen gneiss is ascribed to a different mechanism and processes. Mode of occurrence, textural features, and mineralogical characteristics suggest the augen gneiss to be deformed and metamorphosed analogues of earlier orthoclase feldspar-rich banded gneisses that have been strongly deformed within a ductile shear zone. This zone of intense deformation (shear zone) is characterized by a reduction in grain size, smoothening of gneissic banding, and development of mylonitic texture in the augen gneiss. The mechanical effects of deformation in the shear zone resulted in modifying original gneissic textures and the formation of feldspar pophyroclasts (augen). The deformation continued even after the formation of porphyroclasts, culminating in the development of protomylonites with pronounced linear fabric. The absence of visible macro-scale fracturing, discontinuity of outcrops, and lack of displacement makes it difficult to establish the extent of this ductile shear zone. However, kinematic indicators (e.g., feldspar pophyroclasts, asymmetric boudinage) suggest a north-west sense of movement along the zone (sense of shear).

Schist and associated quartzite, distinctly occurring as elongate ridges, are prominent within the mapped area and extend beyond the area. They are lithologically and structurally comparable to schistose rocks reported around Tandama (Alaku *et al.,* 2017a) and Tafoki (Onaji, 2014) few kilometres south of the study area. These schist ridges and interbedded quartzite form part of the proximal Malumfashi schist belt, primarily composed of low-grade deformed metasediments including mica schists, phyllites, and quartzites (McCurry, 1976; Danbatta, 2010; Alaku *et al.,* 2017a). The evolution of the Malumfashi schist belt, comparable to that of most other schist belts of N-W Nigeria, is generally considered to be related to ensialic graben-like structures formed during the Pan-African event (McCurry, 1973; Turner, 1983; Ajibade *et al.,* 1987; Danbatta, 2003).

Medium to coarse-grained acidic granites intrude into the metamorphic basement (migmatites, gneisses, and metasediments). These granites are recognized as granitoids of the ‘Older Granite' suite, which have been reported in most parts of the Nigeria Basement Complex (e.g., McCurry 1976; Ajibade *et al.,* 1987; Wright, 1985; Obaje, 2009) and are generally accepted as magmatic products of the Pan-African orogeny (Pan-African granitoids). Cross-cutting relationship, lack of structural features, and the presence of xenoliths (e.g., Fig. 3f) indicate the granites to be the youngest of the major rock units in the mapped area. Although minor intrusions of pegmatites and aplite cross-cutting the whole sequence mark the closing stages of the Pan-African orogeny.

Deformation and Metamorphism

The mapped area, analogous to other parts of the Nigerian Basement Complex, was affected by a series of metamorphic events and structural modification. Field and structural evidence indicate at least two episodes of deformation for the investigated rocks. Accordingly, a two-phase deformation sequence (D_1 and D_2) is proposed for the mapped area. D_1 represents a compressional event, while D_2 is associated with a shear zone.

1. The first deformation phase (D_1) is assumed to be mainly a fabric forming event, characterized by the development of a regional, N-S striking, penetrative foliation (S_1). S_1 foliation is marked by gneissosity in the migmatites and gneisses, and the development of schistosity in the schist. Asymmetrical folding of S_1 into tight-isoclinal and ptygmatic folds (F_1) is ascribed to this deformation phase. The D_1 deformational phase is pervasive and evident within most of the rocks, thus correlated to regional high-grade metamorphic events that affected the whole region. These tectono-metamorphic events are presumably pre-or syn-Pan African, characterized by ultra-metamorphism, intense folding, reactivation of pre-existing rocks, and granitization (Turner, 1983; Abaa, 1983; Okonkwo & Winchester, 2004; Obaje, 2009).
2. The second deformation phase (D_2) is a localized event associated with a zone of high strain and intense deformation in the mapped area (ductile shear zone). This later phase of deformation is responsible for the mylonitization of gneisses and the development of augen structures and boudins. Although D_2 is localized, the shear zone's development is probably not an isolated event but rather linked to the neighbouring Kalangai fault system. Large fault systems are usually characterized by intricate networks of fractures and subsidiary faults on either side of the main fault (Chester et al., 1993; Chester & Chester, 1998; Lin et al., 2007; Nishiwaki & Lin, 2019), having both brittle and ductile segments (Passchier & Trouw, 2005). The Kalangai fault typifies such large systems and is associated with numerous locally-developed subordinate faults (Abubakar, 2012). Fracture data indicate the presence of subsidiary faults of the Kalangai system within the mapped area.

Furthermore, strongly deformed and sheared rocks (ultramylonites and mesomylonites) evidencing coeval activity (deformation) of D2 have been reported a few kilometres west of the mapped area (Samari, 2012). Thus, it is posited that the identified shear zone is not a discrete feature but rather a locally-developed subsidiary shear zone, part of a lateral western component of the Kalangai fault system. This is further confirmed by the formation age of the Kalangai system in the late stages of the Pan-African orogeny (Wright, 1976; Ball, 1980; Ajibade & Wright, 1989), which coincides with the D_2 deformation phase.

Conclusion

Part of Funtua Sheet 78 comprising the southern part of Katsina state around Guga locality is underlain by rocks of the undifferentiated basement complex (migmatite and gneisses), low-grade metasediments (schist and quartzite), and Pan-African granitoids, which are characterized by ductile and brittle structures with general NE-SW and NNE-SSW structural trends. Except for the granites, the rocks in the study area are highly deformed, metamorphosed, and locally associated with ductile shearing and mylonitization.

The evolution of the rock units is associated with at least two major tectonically induced deformation episodes. The First deformation phase (D_1) is related to a pre-or syn- Pan-African high-grade tectono-metamorphic event that affected the whole region. This event is typified by reactivation of pre-existing rocks, intense deformation, granitization, and emplacement of the dominantly NE-SW structural trend. The second deformation phase (D_2) represents the final major deformation event in the area, resulting in the mylonitization of gneisses and the development of augen structures. This deformation stage is linked to the development of a shear zone associated with the regional Kalangai fault system in the late stages of the Pan-African orogeny.

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