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Lithological characteristics and structural analysis of basement complex rocks of Danko, Zuru Schist Belt, Northwestern Nigeria: Implication for structural evolution

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ABSTRACT

The lithological and structural characteristics of Danko northwestern part of Zuru Schist Belt have been investigated and analyzed with the aim of unraveling the structural evolution of this part of the basement complex. The area comprises of muscovite schist, quartzites, quartz schist, and late post-tectonic granite (fine to medium grained), as well as pegmatite and aplite veins and dykes. Field investigation reveal that the basement was subjected to three phases of tectonic deformation denoted as D1, D2, and D3. The first phase of deformation (D1) was associated with the development of a regional foliation S1 on an S0 bedding plane and a flat lying partially obliterated minor asymmetrical fold F1. The second phase of deformation (D2) is the main deformation phase, and involved a heterogeneous deformation that gave rise to large-scale upright tight to isoclinal folds F2 with a NNE–SSW trend of axial plane and an S2 crenulation foliation. D3 deformation phase is a late stage phase, which involved brittle deformation marked by late subvertical fractures which gave rise to granitic veins, pegmatite, faults, and joints. These extensional fractures show a bimodal orientation mainly in WNW–ESE and NW–SE directions that are nearly perpendicular to the regional metamorphic foliation.

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1. Introduction

The Nigerian Basement Complex is part of the Benin-Nigeria shield (Fig. 1) situated within a Pan-African mobile zone extending between the West African Craton in the west and the Gabon Congo Craton in the southeast (Kröner et al., 2001). The basement complex has undergone polyphase deformation and polycyclic metamorphism during the Proterozoic and early Phanerozoic periods (Odeyemi, 1977; Onyeagocha and Ekwueme, 1990). It has been well established that the basement complex witnessed a major tectonic event about 600 ± 100 Ma ago (Grant, 1978; Van Breemen et al., 1977). Available isotopic data have shown that intermittent tectonic and thermal activities took place between the late Proterozoic

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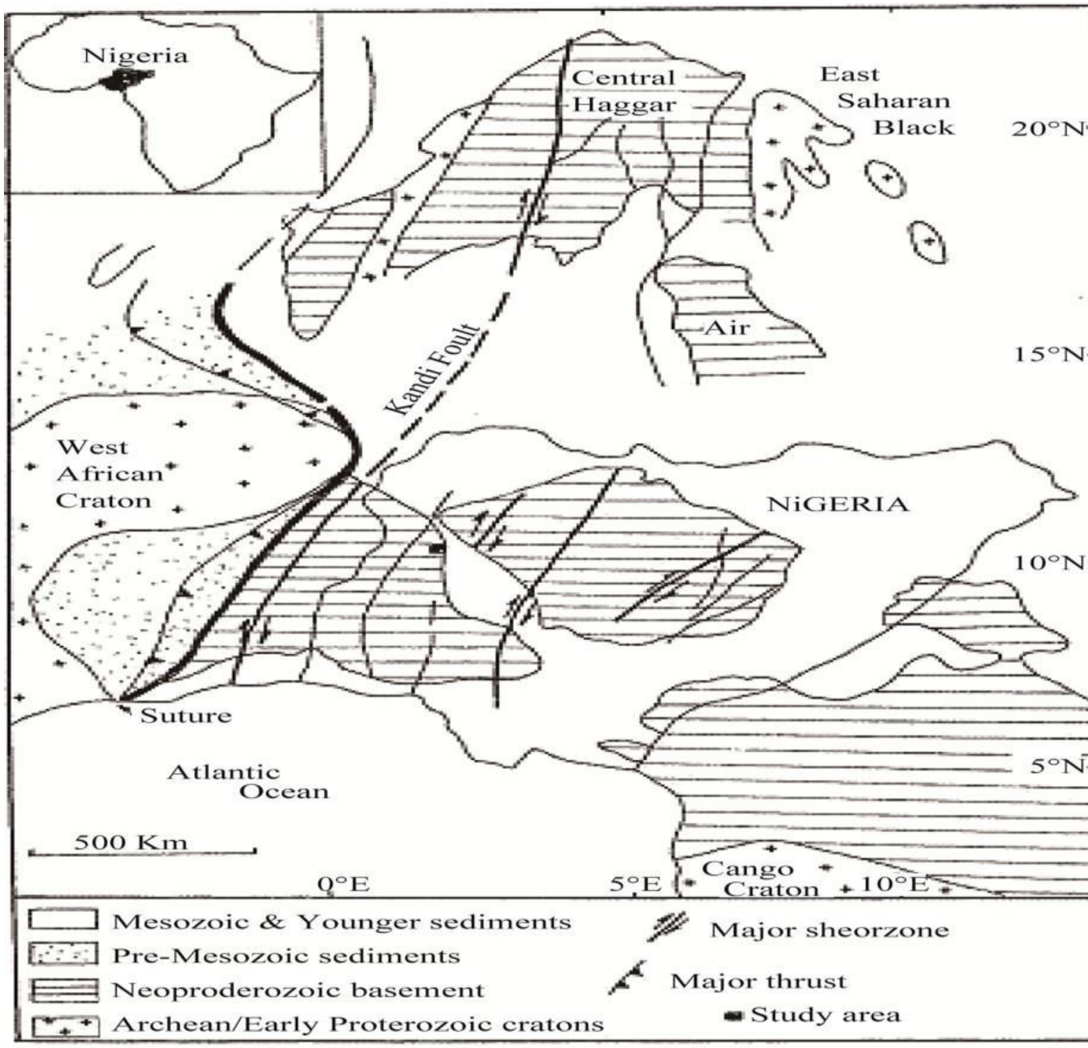

Figure 1. Index map showing the location of Nigeria within the Neoproterozoic Trans-Saharan mobile belt (after Ferre et al., 2002).

to early Paleozoic periods (Grant, 1970, 1978). The basement complex rocks comprise Archean and Proterozoic rocks which have been subjected to Liberian (2,700 ± 200 Ma), Eburnian (2,000 ± 200 Ma), Kibaran (1,100 ± 200 Ma), and Pan-African (600 ± 150 Ma) events (Ajibade et al., 1987; Dada, 2008; Grant, 1970). The Liberian and Kibaran events are largely disputed, and Cahen et al. (1984) pointed out after assessment of the then-available geochronological data that the Pan-African Orogeny is the only undisputable event that affected the Nigerian basement.

The Nigerian Basement Complex is well endowed with metasediments (schist belts). The metasediments are classified as younger and older (ancient) metasediments (Rahaman, 1976, 1988; Rahaman & Ocan, 1978; McCurry, 1976). The ancient metasediments occur in the northwestern parts of the country and consist of calc-silicate rocks, arkosic quartzites, and high-grade schists that occur as relicts on gneisses and migmatite and are the oldest rocks in the basement. The younger metasediments occur in the southwestern parts of the country as discontinuous N-S trending schist belts within the basement. They have been variously termed as newer metasediments (McCurry, 1976; Oyawoye, 1964; Rahaman, 1976). About twelve (12) schist belts have been identified and include Zungeru-Birnin Gwari, Kusshaka, Malumfashi, Kazaure, Wonaka, Maru, Anka, Zuru, Toto, Iseyin–Oyan River, Ife-Illesha, and Igarra–Kabba–Lokoja belts (Ajibade, 1976; Danbatta, 1999; Turner, 1983). The polyphase nature of the Nigerian basement complex has been studied in great detail by some workers (see Ajibade, 1980; Danbatta,

Table 1. Deformation and structural histories established for the schist belts in northwestern Nigeria (Danbatta, 2008).

Belt/Source of Information / Deformation events	Kazaure Belt (Danbatta, 2002)	Malumfashi Belt (McCury, 1973)	Anka Belt (Holt, 1982)	SW of Zuru Belt (Danbatta, 1991)	Kushaka Belt (Grant, 1978)	Birnin Gwari (Ajibade, 1980)	Maru Belt (Egbuniwe, 1982)
D4					Rare and relict minor folds. Local development of strain-slip cleavage	Steeply dipping folds and kinks. Axial planes strike N-S/E-W.	Steeply dipping kinks with E-W strike
D3				Open folds with smooth profiles and sleep NNE-SSW axial planes dip	Open folds with NNE-SSW axial planes. Axes plunge north and south.	Open folds NE-SW axial dip and rounded or angular crest.	Open to tight Chevron folds and tight to isoclinal folds
D2	Upright isoclinals folds with NNE-SSW axial planes. Cleavages developed	Tight to isoclinals D_L fold with N-S axial planes strike. Cleavages developed	Steeply dipping, E-w striking bands.	Tight to isoclinals folds with moderate plunging axes, N-S cleavages developed.	Tight to isoclinals disharmonic folds with steep axes. Axial planes strike N-S	Co-plnar with D1. Open to isoclinals large scale folds of S, schistocity. Axial planes strike NE-SW.	Open to isoclinals folds. Steeply dipping N-S striking cleavage.
D1	Relict recumbent isoclinals folds with N-S trending axial planes. Mostly obliterated.	Early ENE-WSW foliation mated to D_E folds. Largely obliterated.	Open to isoclinals upright folds with NNE-SSW axial planes and Axes.	Rare and obliterated minor folds with shallowly dipping E-W to ENE-WSW trends. S1 axial plane cleavage.	Rare minor folds with E-W axial planes.	Folding of cover rocks on NE-SW trending axial planes. Cataclastic deformation of basement cover contact. Cleavage well developed.	Relicts flatlying folds with N-S axes and S_1 cleavage. Folds obliterated by transposition

1991, 2002; Egbuniwe, 1982; Grant, 1978; Holt, 1982; McCurry, 1973) (Table 1).

The study area Danko is located in the northwestern part of the Zuru Schist Belt. Which is the least investigated part of the schist belt, probably due to its geologically complex nature and inaccessibility. As a result, its geology is not well studied but the main rock type are quartzites (locally feldspathic that are interbedded) with quartz–muscovite schist (McCurry, 1976; 1978). The geological structures within the Zuru Schist Belt are very complex, varying widely in dips and strikes. Recent studies (Danbatta, 2008) in the southwestern part have demonstrated the polyphase nature of deformation of the basement. In this paper, we described field relationships around Danko outlining the structural relationships between successive thermo-tectonic episodes.

2. The Study Area

The present study area is in the northwestern parts of the schist belt and bounded by latitude N11° 30' 00" to N11° 45' 00" and longitude E5° 00' 00" to E5° 20' 00" (Fig. 2). The area is characterized by an undulating topography with the highest peak in Kokanawa with an elevation of about about 432 m above mean sea level and Dago with elevation of about 410 m in the southeastern parts of the study area. The lowest point is at Masama with an elevation of about 260 m in the northwestern parts of the study area. In a broader term, the general relief of the area is defined by low-lying ridges, hills, and minor domes which rise above the surrounding areas. The study seeks to describe the structures and lithologies so as to document the polydeformational nature of this part of the basement complex.

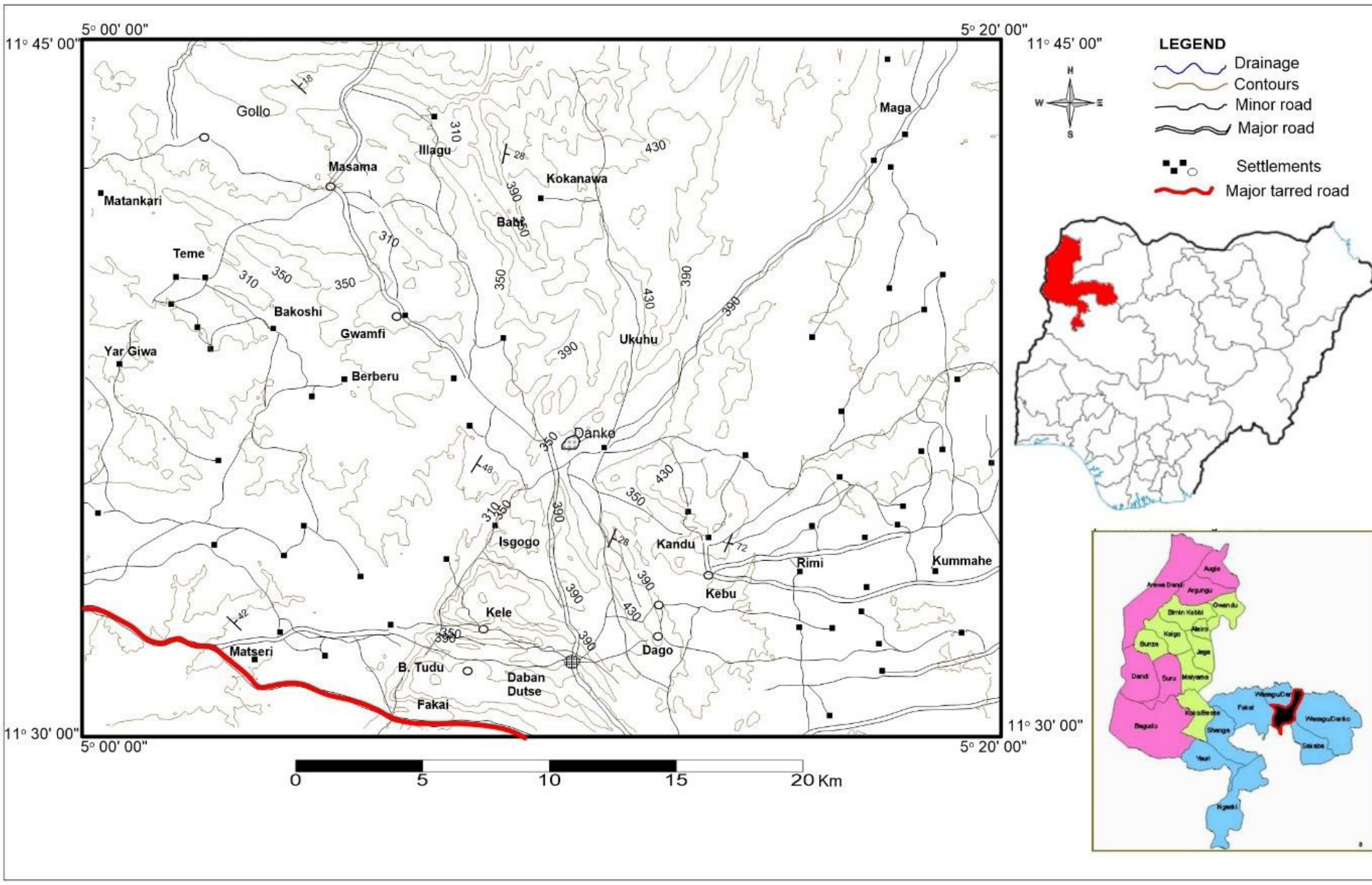

Figure 2. (I) Map of Nigeria showing Kebbi State. (II) Map of Kebbi State showing the Zuru area. (III) Location map of the study area.

3. Lithological Characteristics

The northwestern part of the Zuru Schist Belt is composed of metasedimentary rocks (quartzites and muscovite schists) which have been intruded by late to post-tectonic granitic rocks (medium-grained granite) of probably Pan-African age (Fig. 3). The distribution, mode of occurrence and relationships are discussed.

4. Quartzites

Quartzites occur as ridges with broken fragments in the vicinity of the study area the vicinity of the area. Two different varieties of quartzite were distinguished based on textural and compositional relationships. A gray variety that contains a considerable amount of mica minerals (Plate 2) and a brownish white variety poor in mica minerals or completely has none (Plate 1). In the eastern part, quartzite occurs intercalated with schists and are intensively fractured and jointed. as well as folded in other parts of study area. Hand specimen observation of the quartzite show that it is massive, medium-grained, and have interlocking crystals of quartz grains.

Plate 1. Outcrop of brownish white quartzite

5. Muscovite Schist

Muscovite schist occurs as low-lying outcrops around river channels and road cut exposures (Plate 3). In the northwestern and southwestern parts of the study area

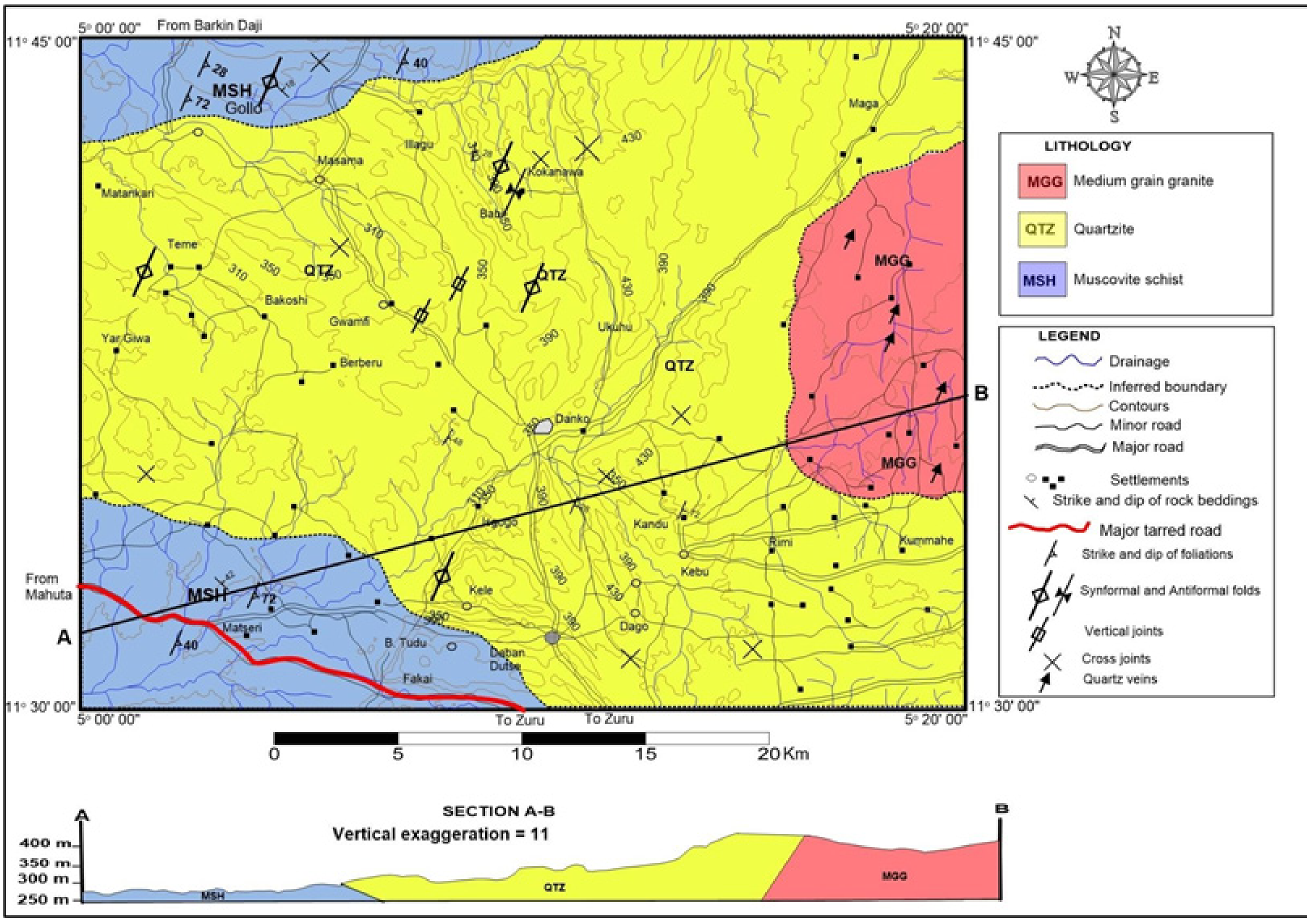

Figure 3. Geological map and cross-section A–B of the study area.

Plate 2. Outcrop of gray quartzite.

Plate 3. Photograph of muscovite schist along a river channel at Masama.

with intercalation of quartz stringers (Plate 4). They are fractured, strongly foliated (schistosity) defined by the alignment of muscovite minerals in the NE-SW. Hand specimen observation shows that it has, it has a silky shinny appearance due to the abundance and the reflective nature of muscovites. The shiny flakes of mica were conspicuous enough to allow megascopic

Plate 4. Photograph of muscovite schist with quartzite intercalation.

Plate 6. Photograph of quartzofeldspathic pegmatite.

Plate 5. Whale back shape outcrop of medium-coarse grained granite.

Plate 7. Photograph of an antiform (isoclinal) fold at Kokanawa. Note the person standing at the curvature of the fold.

determination. It is generally medium grained and dark gray in color.

6. Medium-Grained Granite

This rock unit outcrops as whalebacks and domes occupying entirely the eastern parts of the study area. It is leucocratic, with a medium- to coarse-grained texture. Phenocryst of feldspar minerals on this rock range in thickness from about 1.0 cm to 1.5 cm. The rock contains quartzo-felspathic pegmatite veins and dykes with a major NE-SW strike direction suggesting a Pan-African trend (Plates 5 and 6).

7. Structural Characteristics

7.1. Folds

Megascopic and mesoscopic folds were observed and recorded in the study area. Large-scale folds were mostly associated with quartzites around Kokanawa where as fold train of antiforms and synforms (Plates 7 and 8). One prominent antiform (Kokanawa antiform)

Plate 8. Photograph of a synform fold at Kokanawa.

Plate 10. Photograph of an antiform and synform fold train at Kokanawa.

Plate 9. Photograph of an asymmetrical meso scale fold on muscovite.

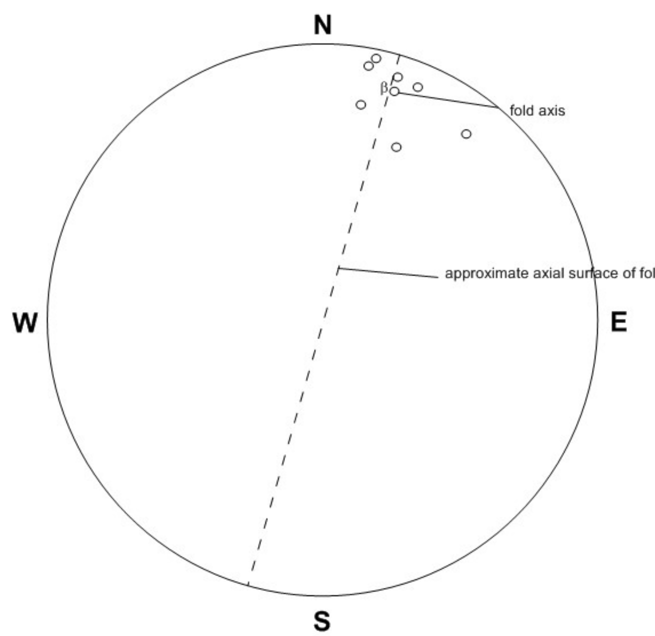

Figure 4. Lower hemisphere equal area projection of fold axis showing concentrations in the NE and approximate axial surface of folds.

about 200 m northwest of Kokanawa has an approximate amplitude of about 10 m and an NE-SW trend of fold axis. Most mesoscopic folds are associated with muscovite schist as asymmetrical and recumbent folds (Plate 9). The attitudes of the fold axis (trend and plunge) of these folds were measured and plotted stereographically (poles to great circle) (Fig. 4). The results show that the trend and plunge (Table 2) of the folds occupied the NE axis of the stereoplot with an approximate axial surface of NNE–SSW.

Table 2. Trend and plunge reading of fold axis.

S/N	Trend (degrees)	Plunge (degrees)
1.	010	004
2.	008	006
3.	010	022
4.	016	008
5.	017	014
6.	022	034
7.	020	009
8.	038	016

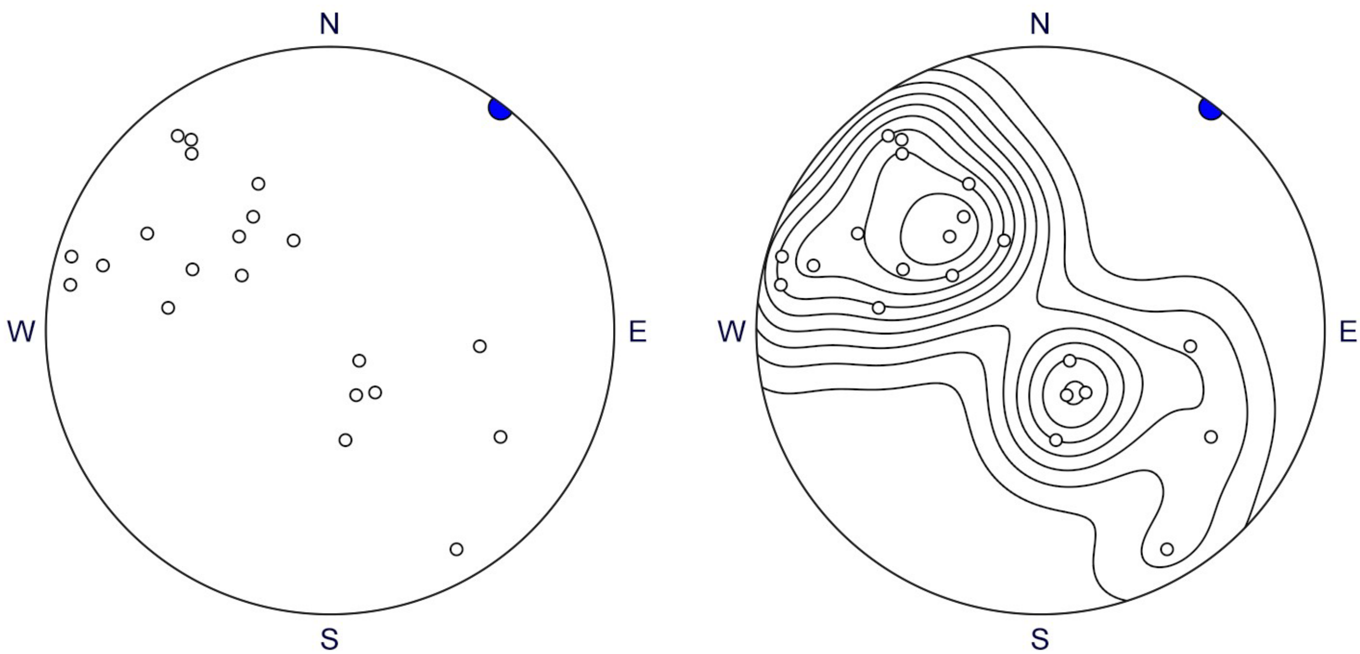

Figure 5. (A) Equal area lower hemisphere stereographic projection of poles to foliation and (B) density stereoplots (Schmidt lower hemisphere projection) for 21 points showing concentration in the NW-SE portions (NE-SW trends). Contours are 2, 4, 6, 8, 10, and 12% per %area, maximum 16%.

8. Foliation and Related Features

The dominant foliation type was a schistosity, which was associated with muscovite schist where it is defined by the planar alignment of mica minerals (muscovites) that gave the rocks a shiny luster. Crenulation cleavage was very distinct because it cuts the host rock that possesses a preexisting continuous cleavage (schistosity) into microfolds. The foliation is typically a zonal crenulation cleavage because the cleavage domains coincide with tight limbs of microfolds in the pre-existing continuous cleavage (schistosity). A total of about 21 foliation surfaces were measured. The foliation surfaces had low to high dips (10–82) predominantly toward the southeast. Foliation data (strike and dip of foliation planes) plotted on stereonets (beta and pie diagrams) shows that the foliation planes have a NE-SW trend. In other to get an overall orientation of the foliations, the poles of these planes were plotted and contoured using the conventional technique of Ragan (1973). These density stereoplots show that the poles of the foliations are concentrated in the NW and SE portions of the net (Fig. 5A), thus confirming the dominant NE-SW trends. In order to determine the specific orientation of the foliations, cumulative rose diagrams for the entire locations from which measurements were taken was plotted. The rose diagrams define the dominant direction for the foliations as NE-SW (Fig. 6).

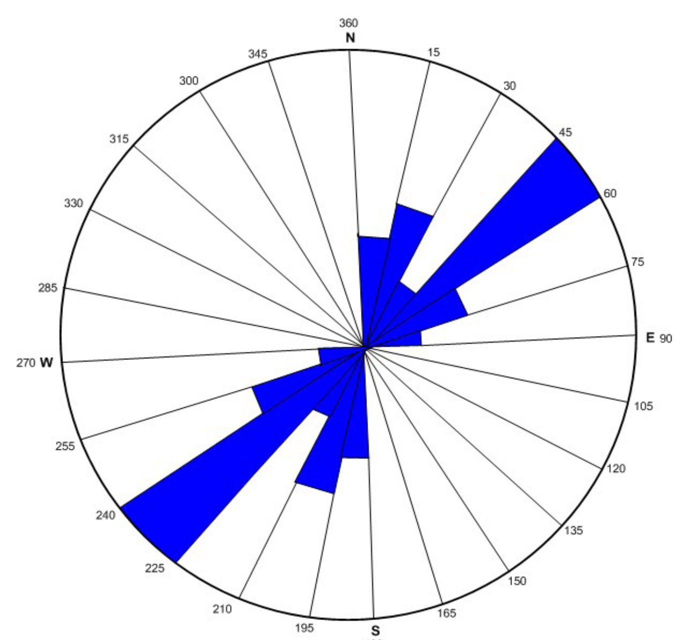

Figure 6. Cumulative rose diagram of foliation planes showing a NE-SW trend

9. Faults

Faults occur as strike-slip with a dextral (right) sense of shear with an average displacements of about 20 cm and fault plane trend The fault planes trend in a NE-SW direction satellite imageries of the study area reveal a major dextral fault which is the Bin Yauri-Zuru fault

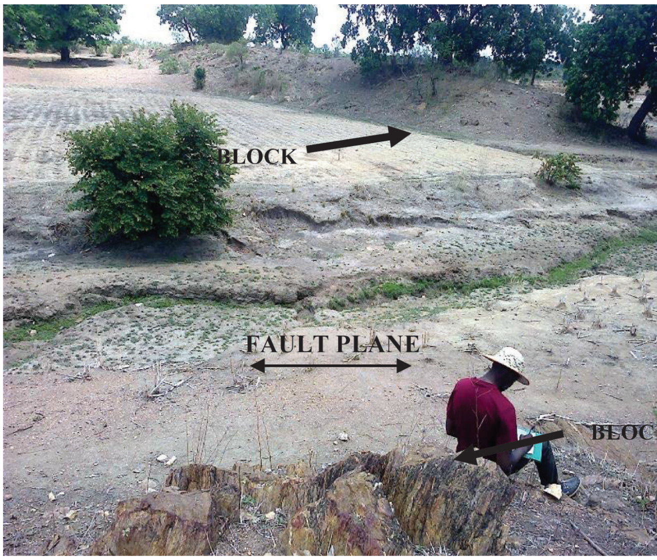

Plate 11. Bin Yauri fault zone that cuts through the study area at Barkin Tudu.

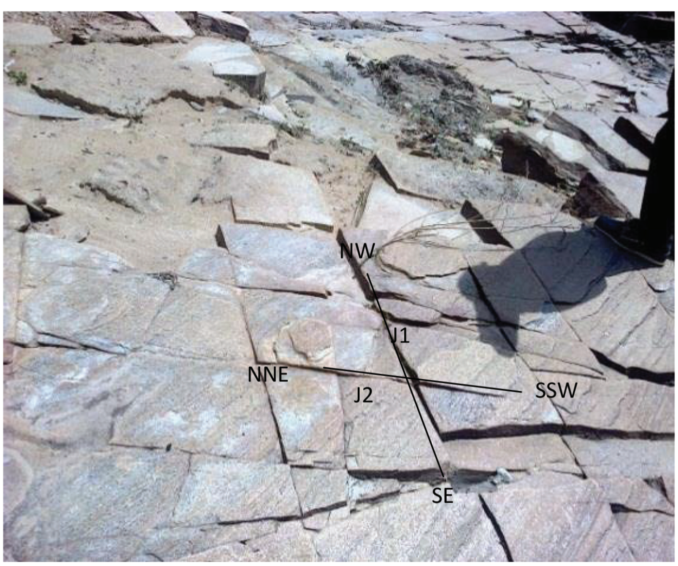

Plate 12. Cross joints on muscovite schist outcrop at Gollo with T-geometry.

Plate 13. Cross joints on a quartzite outcrop at Kokanawa with X-geometry.

Plate 14. Vertical (parallel) joints on quartzite

zone (Danbatta, 1991) that cuts through the study area with a NE-SW trending of fault plane (Plate 11). The rocks within the fault region in the field were characterized by deep fractures, abundant folded quartzite veins, and strong penetrative cleavages.

10. Joints

The joint pattern as observed in the field further support the polydeformed nature of the terrain. Most of the joints identified were cross joints and vertical joints (Plates 12–14). A total of 382 joints were recorded and analyzed for paleostress directions. The result show orientations in the E-W, NW-SE, NE-SW, and N-S directions. Rose diagrams were also plotted for individual rock types; granite showed a dominant NNE-SSW trend (Fig. 7), quartzite showed NE-SW and NW-SE trends (Fig. 8), while schist had NNE-SSW and NNW-SSE trends (Fig. 9). The joint set includes non-systematic and systematic sets with average aperture of about 10–25 mm. The nonsystematic joints have inconsistent average perpendicular spacing. In general, the surfaces of joints appear irregular and haphazard. Common intersection geometry of joints includes T-geometries where the individual joint trace meets at right angle and X-intersection geometries where the individual joint sets meets at acute angles. Tip geometries include gradual die out, branch out, and *Y* tips.

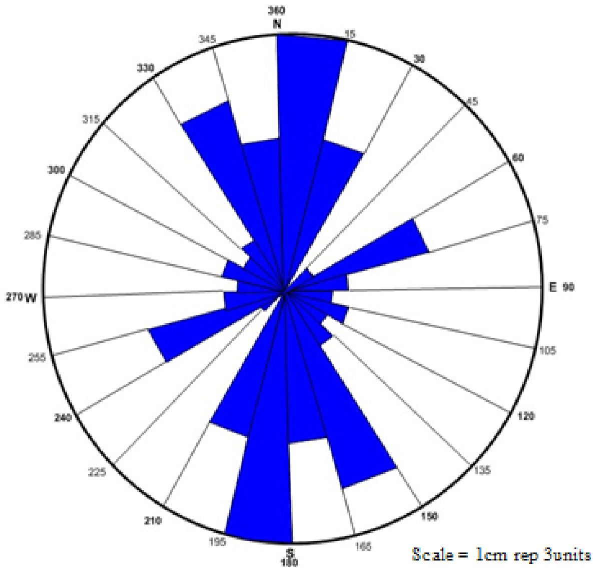

Figure 7. Rose diagram for medium-grained granite with orientations in the NNE-SSW directions.

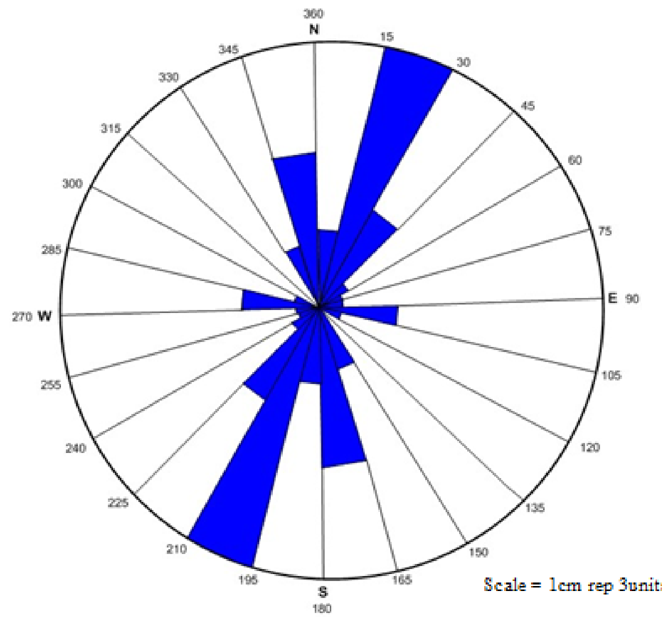

Figure 9. Rose diagram for muscovite schist with orientation in the NE-SW direction and NNW-SSE directions.

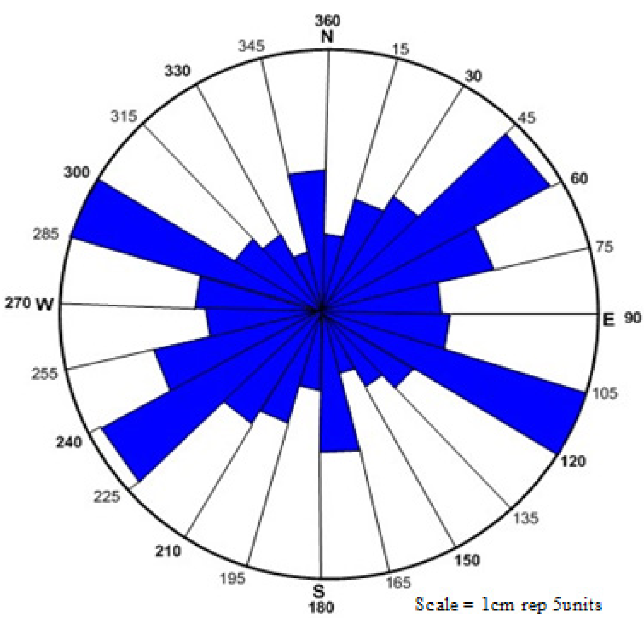

Figure 8. Rose diagram for quartzites with orientation in the NE-SW and NW-SE directions.

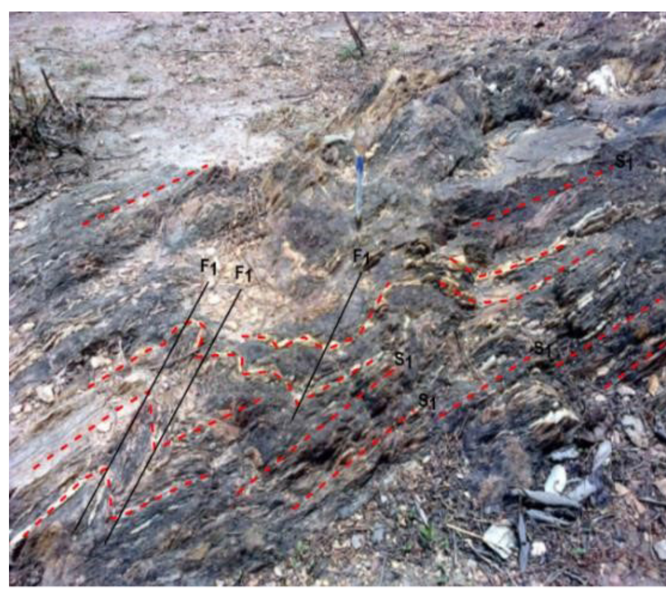

Plate 15. Quartzite veinlet invading schist showing F1 folding and S1 schistosity.

11. Structural Development

Three phases of tectonic deformation denoted as D1, D2 and D3 have been identified in the study area and are described below.

12. First Phase of Tectonic Deformation (D1)

The first deformation event was associated with the development of S1 schistosity and F1 folding from S0 bedding (Plate 15). The earlier planar structure S1 is generally parallel to the bedding surface S0 and is defined by the preferred alignment of muscovite and platy quartz on the S0 surface. S1 schistosity foliation is defined by a grain-shaped alignment of muscovite and platy quartz (Plate 16). A total of 21 measurements of strikes and dips of S1 surfaces were taking. The foliation surfaces have low to high dips (10°–82°) mainly to the southeast and secondarily to the northwest. The poles to S1 surface lie on

Plate 16. S1 schistosity on S0 surface of a muscovite schist.

Plate 17. S2 crenulation cleavage.

the NW-SE axis of the stereographic projection confirming the dominant NE-SW trends.

F1 folds are rarely seen as they occurred as flat lying and obliterated minor folds on the muscovite schist; they had an ENE-WSW trend of axial plane. The dominant foliation S1 occurs as axial planar cleavages to this folds. No major folds of this generation were identified.

13. Second Phase of Tectonic Deformation (D2)

This tectonic phase is well developed in both the muscovite schist and the quartzites. It is characterized by a

Plate 18. F2 tight to isoclinal fold Fabric

heterogeneous deformation of the previous D1 fabric. D2 deformation is associated with the development of an S2 crenulation cleavage and F2 major folds. The S2 cleavage cross cuts the S1 cleavage into small regular crinkle folds that has an asymmetric form called the crenulation cleavage (Plate 17). F2 folds occur as large scale upright tight to isoclinal folds with a NNE-SSW trend of axial plane (Plate 18). In other places, they occur as open to isoclinal folds where they form a continuous series of antiforms and synforms.

14. Late Stages of Tectonic Deformations (D3)

Late stages of deformation can be attributed to brittle tectonics marked by late subvertical fractures which are transcurrent faults with a dextral shear sense, granitic veins, pegmatites, and joints (cross and longitudinal joints). These veins are generally filled with quartz materials and trend in a NE-SW direction; the joints displayed two main orientations NE-SW and NWSE with a minor E-W trends.

15. Discussion

The schist belts of Nigeria are complexly deformed with earlier folds being refolded by later ones (Burke et al., 1976). The rocks of the study area are polydeformed. Field studies (attitude of planar and linear structures, orientation of fold axial planes, styles of folding, and over printing of one fabric by another) of these rocks showed that they have been affected by three episodes of deformation denoted as D1, D2, and D3, respectively.

D1 is the earliest deformation episode and D2 is the late deformation episode. Olabanyi (1997) ascribed D1

Table 3. Chronological order of events of the structures within the study area

Stages of deformation	Structural imprints	Trends	Types of structures
Late tectonic stage	Brittle deformation that produced fractures	E-W, NW-SE, NESW, NNE-SSW, N-S	Joints, faults
Second deformation (D2)	Ductile and brittle deformations events that produces second generation structures.	NE-SW, NNE-SSW, N-S	S2 crenulation cleavage F2 major isoclinal folding
First deformation event (D1)	Ductile deformation that produced the first generation of structures.	ENE-WSW, NE-SW	F1 minor obliterated asymmetrical folds S1 schistosity

to the Eburnean event and D2 to the Pan-African event in the metasediments of the Egbe-Isanlu area. It is suggested that the Eburnean closure along an easterly dipping Beniof zone led to D1 deformation and metamorphism in the schist belts (Dada et al., 2008). D1 was a major ductile deformational event which was identified on the muscovite schist. It was characterized by an early S0 bedding that is parallel with the earliest NE-SW trending schistosity S1. F1 folds of this deformation episode were rarely seen as they have been largely overprinted by subsequent D2 deformations. They occurred as flat lying and obliterated minor asymmetrical folds with an ENE-WSW trend of axial plane. Mullan (1978) was of the opinion that the E-W structures were probably pre-Pan African (Eburnean) in age.

Subsequent deformations D2 (ductile–brittle event) were identified on both the muscovite schist and quartzites rock units. It is suggested that movements associated with the Pan-African compression coupled with the prevalent temperature conditions may have led to D2 deformations; reactivation of pre-existing rocks and fractures (Van Breemen et al., 1977). This deformation event led to the development of an S2 crenulation cleavage which overprinted the initial S1 schistosity and also a folding of an S1 into a major tight to isoclinal F2 folds with an NNE-SSW trend of axial plane. Late stages of deformation can be attributed to brittle tectonics marked by late sub-vertical fractures which are granitic veins, pegmatites, and joints that trend NNE-SSW. Table 3 shows a summary of the chronological order of structures within the study area.

16. Conclusion

Rocks within Danko area have undergone polyphase deformation, with earlier structures being deformed by later deformations. Later ductile deformational structures produced the regional tectonic fabric, S1, on an S0 bedding plane. Subsequent heterogeneous deformations (D2) affected the D1 deformations producing large-scale F2 major folding with an S2 axial planar cleavage. This was followed by late brittle tectonics involving transcurrent dextral faulting, veining, and joints that have a NE-SW trend.

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