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An Interpretation of Tectonic Elements of the Kanke Basement, Central Nigeria

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Abstract: Tectonic elements including planar as well as brittle discontinuities of the gneissic basement in the Kanke area were mapped and analyzed with the sole aim of understanding the tectonic evolution of the terrain. The evolution commenced with a ductile gneissose layering phase which led to the emplacement of a major NE-SW and a minor N-S planar foliation surfaces. This was followed by a probably Pan-African phase which is more brittle and led to the formation of NW-SE fracture systems including joints, quartzo-feldspathic veins, pegmatitic, quartz and doleritic veins.

Key words: Tectonic, evolution, basement gneisses, ductile, brittle, pegmatitic

INTRODUCTION

The Nigerian basement complex forms part of the rejuvenated rocks sandwiched between the West African and Congo Cratons and belong to the pre-drift Pan-African mobile belt that have been linked to the Boborema province of Brazil (Caby, 1989; Dada, 2008). This reworked and polycyclic basement poses major NE-SW and N-S structural trends (Fig. 1) emplaced within major basement flexures (Oyawoye, 1972; Woakes *et al*., 1987) and ever since, the evolution of these tectonic structures have been the focus of local as well as regional investigations especially in resource exploration.

Crustal extension and continental rifting at the West African cratonic margin about 1000 Ma led to the formation of graben-like structures in western Nigeria and deposition of rocks of the schist belt (Ajibade *et al*., 1984). The small scale structures of the greenschist facies schist belt has been interpreted to be of two contrasting styles, the older gneissic structures being modified by the in-folding of the schist (Fitches *et al*., 1985; Grant, 1978). To the east of the schist belt is the gneissic basement where the Kanke area falls into Fig. 1.

The rocks in this province have been the least studied chiefly because of the attention being focused on the sedimentary basins and Younger Granites both of which are mineralized (Ajibade *et al*., 1984). Mineralization of the basement such as iron ores are confined within the N-S structural trends; gold quartz veins carrying galena and pyrite are also hosted by a general N-S to NNE-SSW structures and probably of >1 period of mineralization (Ajibade *et al*., 1984; Fitches *et al*., 1985). Overall, most structures that have been mapped within the gneissic basement including pegmatites are broadly conformable within the N-S to NE-SW brittle structures including the trend of the younger granites (Fig. 1). In the adjoining Benue Trough sedimentary basin, similar regional trends have been mapped as principal host to mineralization such as uranium in the upper sub-basin (Ojo, 1988; Suh and Dada, 1997) and the Pb-Zn mineralization in the middle to lower Trough (Ofodile, 1989). Trends of structures in the Nigerian basement have been documented in terms of orientations and magmatic induced veins and dykes such as quartz veins and pegmatites (Ajibade *et al*., 1984; Rahaman, 1988). Deformation of the basement appear to be in two phases, a ductile phase which is responsible for the formation of planar structures (foliations) and a brittle phase resulting in jointing and fractures, many of which have been filled with quartzo-feldspathic veins, dolerite dykes, pegmatitic and aplitic veins and dykes. As shown in Fig. 2, the planar structures are confined to the gneisses and schists (metasediments) while the brittle structures truncate all rocks of the basement.

This study aims at systematically mapping all these phases from tectonic evidences supplied by the orientation, disposition and attitude of the deformation. The study is informed by the excellent exposure of planar as well as brittle lineations and discontinuities in the Kanke area and it is hoped that it will contribute to the understanding of the basement tectonic evolution.

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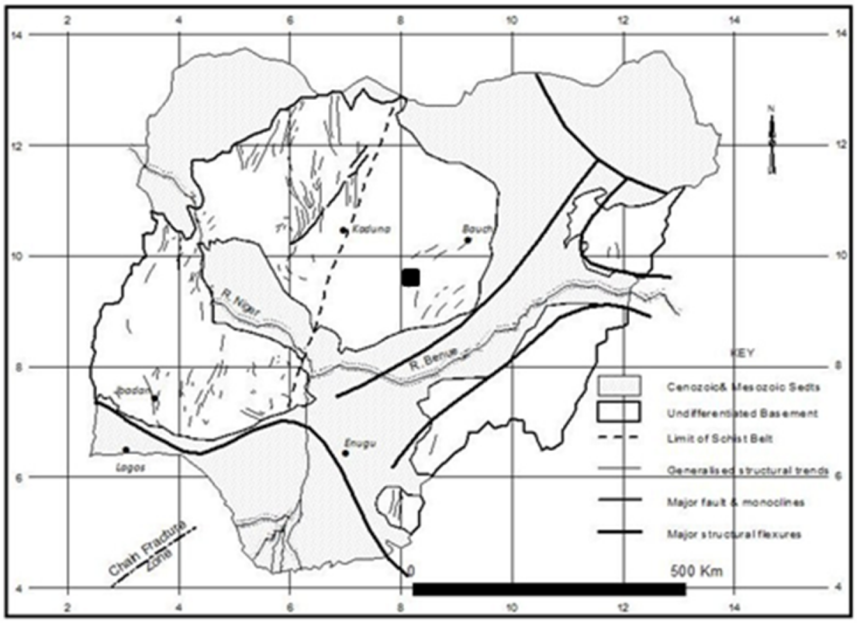

Fig.1: Generalised geological map of Nigeria showing the Western Nigerian metasedimentary trends after Oyawoye (1972) and location of the study area

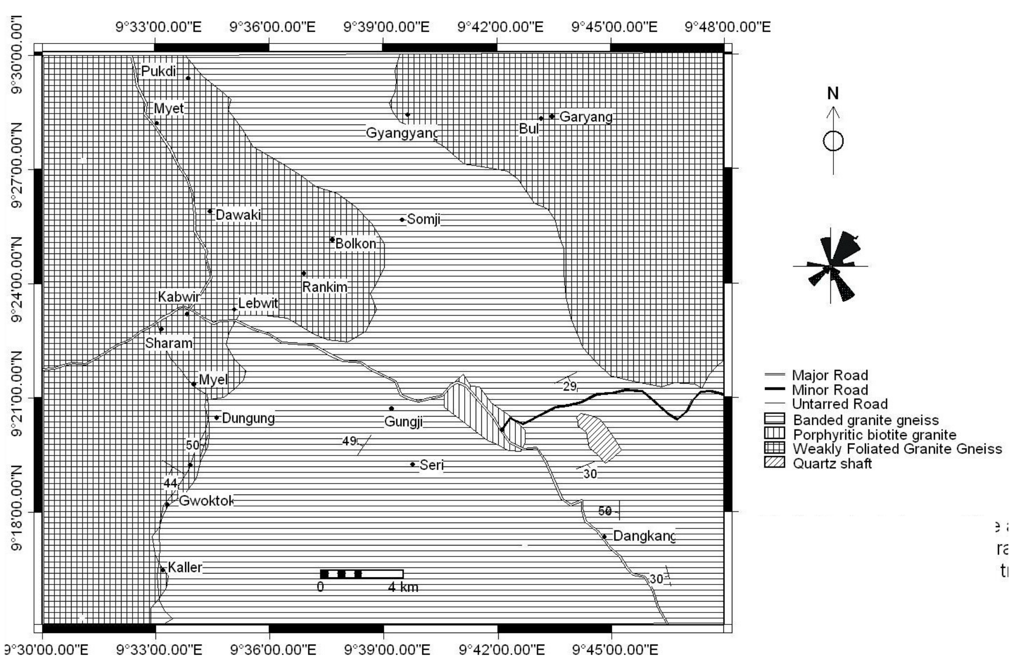

Fig. 2: Geological map of the area. Rose show principal structural orientetions. Black foliation trends, hatched fractures

GEOLOGY

The basement rocks of the Kanke area are low lying highly deformed rocks that represent a contact zone bordering the intrusive high level anorogenic ring complexes of central Nigeria. The major rocks are the banded lit-par-lit biotite gneisses that have been extremely sheared and emplaced into a near N-S synclinorial troughs with a gentle to steep dips of between 40-60°W with a few almost vertical. Nearly, all the gneisses mapped have a consistent N-S to N40°E foliation fabric. The low grade nature of the gneisses is typified by dominant biotite in the mode. The biotite and in some cases muscovite-rich layers alternate with predominantly quartz and feldspar rich bands and the strong megacrystic alignment of the feldspars outline strong lineation of symmetrical and augen shapes.

These provide excellent foliation surfaces on which planar measurements were carried out. Elongated boudins were observed in places where the shear was intense. Unfilled fractures truncate orthogonally the gneissose layering which grade weakly into the undeformed granites. The granites range texturally from fine to coarse grained. A few are porphyritic augen alkali feldspars. The batholitic granites have been fractured variably into joints and in some cases impregnated by quartzo-feldspathic and pegmatitic veins. Muscovite-rich pegmatites maintain a consistent N-S and NE-SW orientations around the Amper-Gumshir axis, their specialization though non-prospective because of the dominance of alkali feldspar and absence of albite will still be assessed in a separate study. Care was taken to systematically isolate and record each of these fractures, dolerite dykes quartz veins and pegmatite veins in different classes for structural plotting using Georient version 9.2.

STRUCTURAL DATA AND INTERPRETATION

Two types of structural data were collected: Planar (foliations) surfaces were obtained on gneisses and a total of 49 were measured during field mapping while 31 fracture related readings cutting across all lithologies were obtained. The planes non-cylindrically plotted on an equal-area lower hemisphere (Schmidt's net), β-diagram

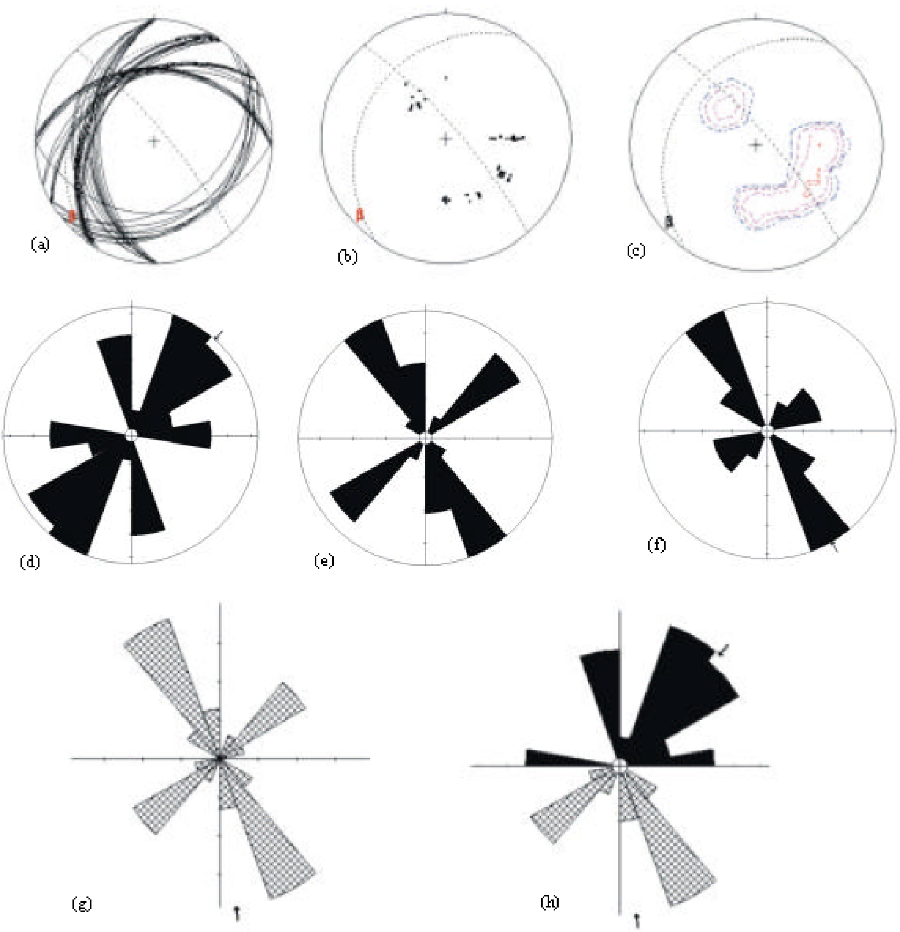

Fig. 3: Structural data presentation for area. a) wult lower hemisphere stereographic (β-diagram); b) equal area lower hemisphere (Schmidt net) stereographic projection of poles (π-diagram) to foliations; c) contour 3-6-12-24% per 1% area, of pole to foliation with 24% maxima; d) rose plot of foliation planes; e) rose plot of measured veins (dolerites, quartz and pegmatitic); f) rose plot of joints on the rocks; g) composite rose plot of brittle phase deformatio and h) composite rose plot of ductile deformation (black), brittle deformation (hatched)

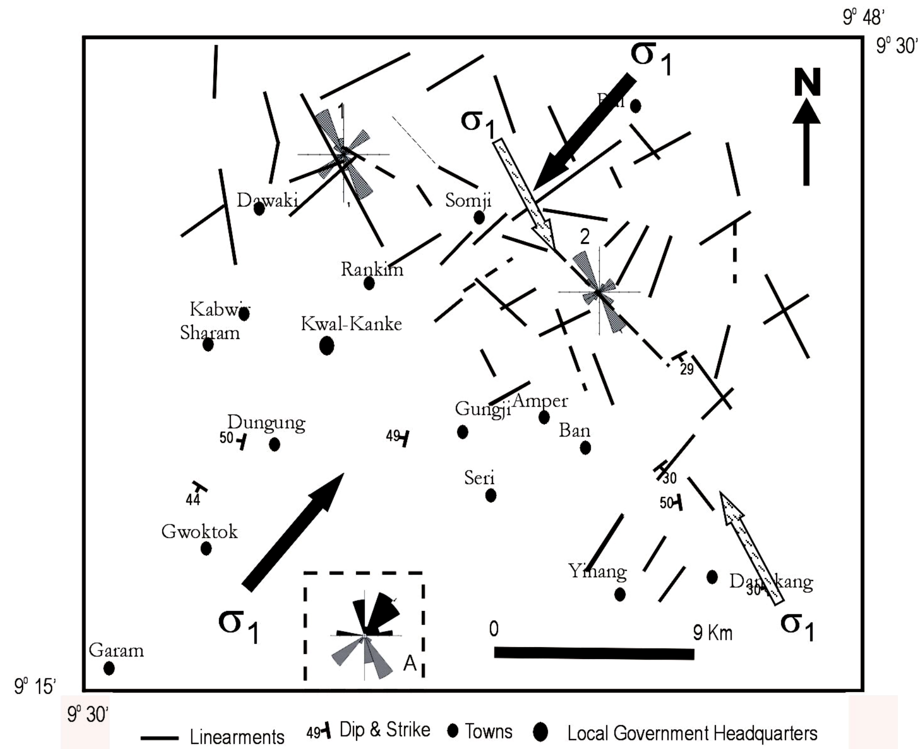

Fig. 4: Fracture map generated from landsat ETM data for the kanke area, 1, 2 are roses from field measurements for brittle sturcturesand measured joints, respectively inset the map for comparism. A is composite rose from field measurements. Principal stress direction, σ_1 (black arrow): pre-pan African and σ_1 (white arrow) Pan-African

and π-diagram (Fig. 3a, b) with a predominantly NE-SW trend was obtained and this was corroborated by the contoured poles of the readings (Fig. 3). For the fractures or joints, rose diagrams for the measurements were plotted and subsequently, orientations of both phases of deformation were compared. An attempt was made to isolate the data based on lithology but it was discovered that the fractures maintain consistency hence were possibly of the same generation. However, one set appears to follow the foliation trend. The orientations of the ductile phase of the deformation (gneissose layering) are generally everywhere NE-SW. The density plot (Fig. 3c) shows that the data plotted in the NW and SE portion of the net which confirms majorly the NE-SW trend. Similarly, the stereographic β-diagram and π-diagrams gave a predominantly NE-SW trend for the planes.

The specific orientations of the planes and fractures were obtained by plotting the data-frequency azimuth roses. The rose plot of the planes (Fig. 3d) gave 3 principal orientations with the corresponding percentages of the data given below:

- N20-30°E (23.5%-13 data), N30-60°E (21.6%-12 data)
- E-W (8 data)
- N0-10°W (10 data)

From the data, it is obvious that the original gneissose layering is predominantly NE-SW and this defines the principal stress axis of the area during the earlier ductile deformation regime. The minor axes of N-S- NNW and the E-W planar structures are rare and could have been latter stages of the ductile distortions or may be linked to the latter more brittle NW-SE structures. In any case, the ductile phase appears to agree with the N-S, NE-SW structural models for the far Western schist belts (Oyawoye, 1972; Wright *et al*., 1985; Woakes *et al*., 1987). The rose plot for brittle fractures (Fig. 3e, f) define 2 principal directions:

- A major NW-SE trend for both quartz veins, dolerites and pegmatitic veins
- A minor NE- SW directions

Field relations show that these brittle fractures are younger and cut orthogonally the gneissose layering. Figure 3g represent a composite rose plot for the brittle deformation and Fig. 3h compares the ductile deformation with the later brittle event. Figure 4 is a lineament map produced from Landsat ETM data. Majority of the linear features, many of which are traceable to some structures have dominantly NW-SE orientations. Rose plots 1 and 2 of measured fractures have been superimposed to compare field data from the arial view.

RESULTS AND DISCUSSION

The gneissic rocks of the Kanke area show defined structural trends that resulted from two principal poly-deformational events. An attempt to decipher the tectonic evolution of this terrain will include systematic mapping of all structural elements and to synthesize them to be able to understand their orientations. The terrain is defined by a major NE-SW planar structures represented by gneissose layering as well as a N0-N20°W set which statistically are suboptimal. These gneissose layering obviously predate all other structures though their specific age has not been established. On a regional scale, though they represent the last stage in the series of metamorphic events that occurred in the tectonic evolution of the Nigerian basement which generally have been given a lower intercept of Pan-African (Bruguier *et al.*, 1994; Dada, 1998). They may not necessarily represent the original layering as observed by Suh and Dada (1997), since they may have been affected by other metasomatic differential segregation processes. The emphasis here is to establish from relationship with other structures their chronology in the post emplacement history. This information basically is lacking on the gneissic basement of Nigeria.

The second set of structures are the more brittle fractures represented by jointing, doleritic, pegmatitic and quartz veins which are marked principally by a NW-SE trend. These brittle structures are not confined to any rock type represented in the area and hence have pervasively affected the whole area. In nearby terrains in the northeast around Dass and Bauchi, such structural elements have been observed (Oyawoye, 1972).

Chronology of deformation: The earlier NE-SW and N-S structures represent a ductile metamorphic deformation which probably occurred during the pre-Pan-African event and lead to the wide spread emplacement of gneissose layering in the rocks of the basement. This trend is replicated in the schist belts in the far Western Nigeria and in central Nigerian metasediments where the brittle structures also truncate the marble and banded iron formation of the Muro area (personal mapping) but there is no evidence of modification of the earlier structures (Fitches *et al.*, 1985; Grant, 1978). In both layered gneisses, the petrography of the rocks are consistently the same consisting of the amphibolite biotite and garnet assemblages. All quartz veins that fall within this pattern result from metamorphic segregation of the earlier rocks. In order to understand the paleo-stress fields existing during the pre- and Pan-African regimes, it is necessary to resolve the brittle deformation jointing in terms of their orientation relative to the principal stress σ_1. Conventionally, during compressive stress fields, joints develop in the conjugate shear directions making lower angles with the major principal stress direction while in tensional stress fields, joints could develop by stretching normal to the tensile stress direction which is usually the minor principal stress. In this case, the principal stress field prevailing in the NE-SW ductile gneissose layering is stretching and tensile hence jointing developed as a result of such phenomenon will be normal to the NE-SW direction. Field relationship of the gneissose layering and the jointing system reveal that there was no systematic relationship that exists. But the joint patterns show that the subsequent brittle deformation must have been compressive in the NW-SE direction producing a conjugate joint set though due to difficulty of exposure, it was difficult to assess striations or grooves that would buttress such assertion.

The obviously much younger brittle structures are marked by orientations that are orthogonal to the gneissose layering and are consistently NW-SE. The foliation planes could have provided zones of weaknesses along which a smaller percentage of the quartz and quartzo-feldspathic veins (Fig. 3e) were emplaced. What we try to establish is the marked orthogonal relationship between the gneissose ductile layering and the more brittle deformational structures of the gneissic basement. This compares well with similar terrains further east in Cameroon where ductile gneissose deformation is followed by brittle fracturing and faulting with similar trends (Njome and Suh, 2005).

This study definitely provides a parlance on which a model for the gneissic basement can be reviewed. Most researchers of the basement (Ajibade *et al.*, 1984; Wright *et al.*, 1985) have generally classified the structural elements of the basement on the basis of the orientation without taking cognizance of the nature of deformation (ductile and brittle) and chronology. McCurry (1989) observed that the main structural trends in especially Northern Nigeria have been resolved into an early E-NE to W-SW trending moderately dipping foliation planes that have been transpressed by a more dominant later deformational N-S steeply dipping structures. This assertion contrast sharply with the findings in which we are proposing that the N-S structures postdate the NE-SW ductile structures. It therefore means that the evolution of the structural elements and deformation started with an early NE-SW and N-S ductile deformation followed by a latter brittle mainly NW-SE phase. The submission in this research is that the structures are definitely stratified along ductile and brittle boundaries. We believe that this will be a vital tool for explorations since mineralization will normally be confined to this latter brittle phases.

CONCLUSION

The geological and structural mapping of the Kanke area has led to the conclusion that the basement gneisses have undergone a tectonic evolution that involved two distinct episodes. The first is the ductile medium grade metamorphic phase that led to the production of mainly NE-SW and a minor N-S gneissose layering. It is not clear whether they are contemporaneous or episodic. The second phase is more brittle and distinctly orthogonal to the earlier event with an established NW-SE and a sub-optimally SW-NE trend. We have established that the structures of interest for explorers will be the NW-SE structures in the gneissic basement rather the N-S structures as suggested by other researchers of the basement (Wright *et al*., 1985; Rahaman and Lancelot, 1984). We believe that this revelation will be of vital importance to the understanding of the gneissic basement which hitherto has not received the desired attention.

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