

FRACTURE SYSTEMS IN THE YOUNGER GRANITE ROCKS AROUND *FOBUR*, NORTHERN NIGERIA: PRODUCT OF RESIDUAL STRESS?

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ABSTRACT

Outcrop-scale fractures and associated veins found in the Younger Granite rocks around *Fobur*, Northern Nigeria were studied in relation to similar structures in their host rocks (Migmatites-gneisses -quartzite complex). Fractures and veins attitude (strike and dip) data were collected across the study area and subjected to graphical and stereographic analyses. The result revealed a predominant N-S strike with variations in the NE-SW and NW-SE directions; and others trending in the E-W direction (dip joints). Field observations indicated neither deformation of joints planes nor distortion of joint directions which confirmed that the jointing occurred in an anorogenic setting. Nevertheless, the joint structural trend in the Younger Granite rocks replicated those found in the surrounding orogenic basement rock exposures. This could reflect the likely existence in the host Migmatite-gneiss-quartzite complex imposed residual stresses of the Pan African event that were not fully relieved. These ancient stress systems possibly helped to orient the fractures and other structures in a later emplaced Younger Granite complex in a fashion similar to the enclosing basement complex rocks.

KEY WORDS: Residual Stress, Fractures, Younger Granites, Fobur, Nigeria.

INTRODUCTION:

Fractures are the most ubiquitous structures in the crust of the earth, occurring in a wide range of rock types and tectonic settings. They control the physiography of many spectacular landforms and play an important role in the transport of fluids and mineralization. Fractures along which there has been no appreciable displacement parallel to the fracture and only slight movement normal to the fracture plane are joints. They are extensional, with fracture plane oriented parallel to σ_1 and σ_2 and perpendicular to σ_3 (Hatcher, 1995). It is a fact that joints reveal rock strain accommodated by brittle fractures, and the establishment of reliable relationships between them and their causes can provide the structural geologist with important tools for inferring the state of stress and mechanical behavior of rocks (Pollard and Aydin, 1988). Although much work has been done on the structures of the Younger Granites, especially with respect to ring dykes, cone sheets, volcanic cauldrons, and high level granite plutons (Turner, 1989), very little is known about the patterns of fractures and the stress fields that produced them. This paper examines the structural

attitudes of fractures in the Younger Granite rocks around *Fobur* (northwestern part of sheet 169, *Maijuju*) and their course of emplacement.

The study area lies between latitudes $9^{\circ} 46'$ and $9^{\circ} 56' N$ and longitudes $9^{\circ}00'$ and $9^{\circ}05' E$, covering an area of 216.85km^2 (fig.1).

Geological Setting

The Younger Granites of Jos Plateau, Nigeria, are made up of alkaline feldspar granites in association with rhyolites, minor gabbros and syenites. They occur mainly as sub-volcanic intrusive complexes of ring dykes and related annular and cylindrical intrusions. The Granites have been variously mapped and elucidated by a number of workers: Ajakaiye (1970); MacLeod *et al* (1971); Jacobson and MacLeod, (1972); Turner and Webb (1974); Buchanan *et al* (1971); Bowden *et al* (1989), Bowden (1970); Bowden and Turner (1974); Ajakaiye *et al* (1985); Ibe *et al* (1985); Imeokparia (1985); Ike and Sakoma (1985), Badejoko (1986); Turner (1986, 1989); Abaa (1991); Aina and Olarewaju (1992); Mücke (2003), and Ogunleye *et al* (2005). The great

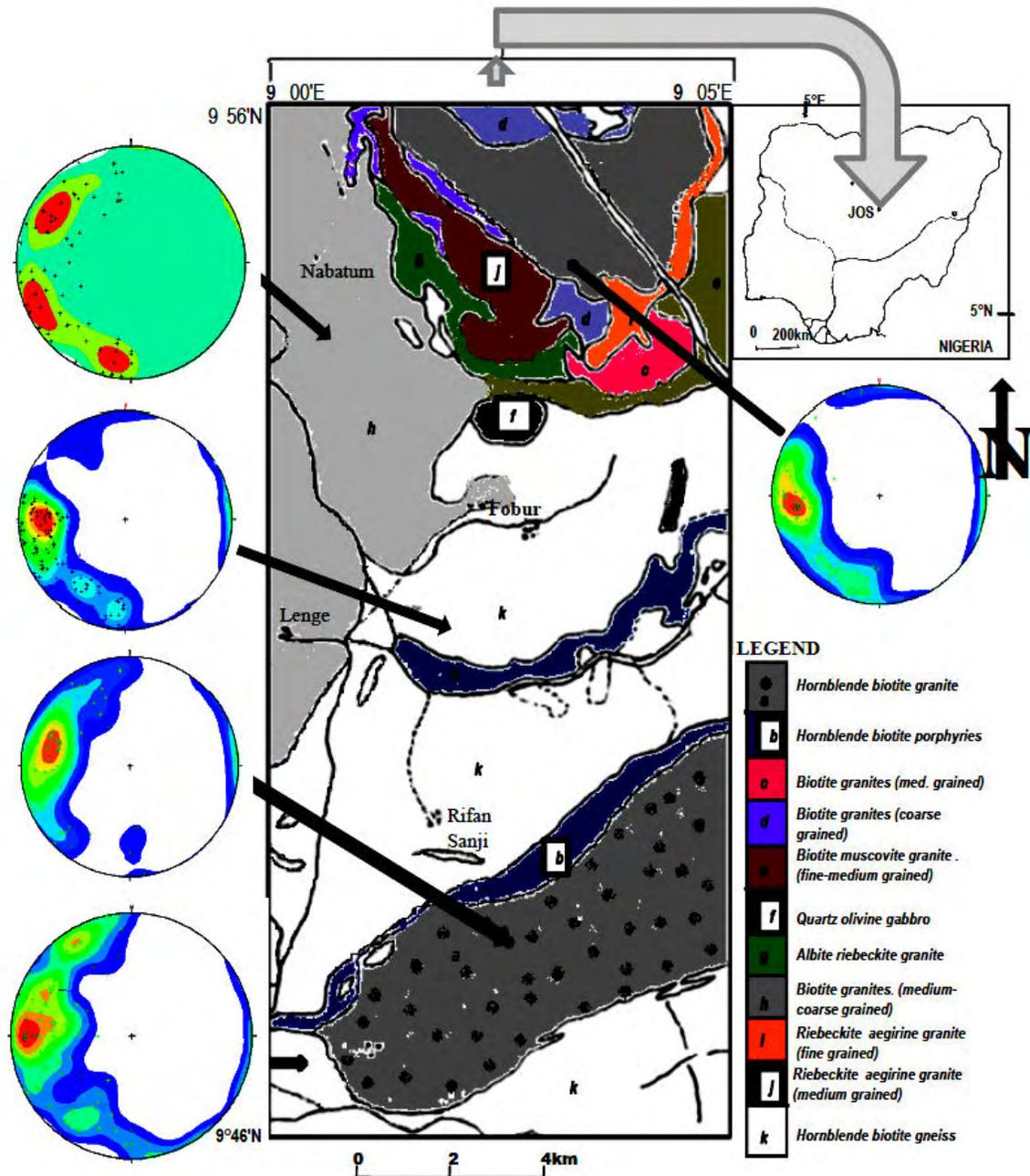


Fig. 1. Location/geological map (modified after Geological Survey of Nigeria, sheet 169) of the study area with stereographic projection of joints (Schmidt net, lower hemisphere). Insert is a map of Nigeria indicating study area.

variety of different rock types (ring complexes) and the economic importance of the region have given impetus to much of the geologic interests. Throughout most of its history, the Precambrian crust (basement) of Nigeria has been subjected to series of essentially similar cycles of events. Each cycle was marked by deposition of supra crustal sediments and volcanics, succeeded by deformation and metamorphism, basement reactivation and emplacement of granitic intrusions. These developments are products of four orogenies which affected the Nigerian basement during the Precambrian. These are: *Liberian* (2700ma), *Eburnean* (2200ma), *Kibaran* (1300-1400ma) and *Pan African* (450-1100ma). Each of these orogenies left its structural imprints on the basement rocks due to the poly-phase deformation (Ekwueme, 1994). Other authors are of the opinion that due to the pervasive nature of the last tectono-thermal event (Pan African) earlier structures were obliterated (Mc Curry, 1971; Rahaman, 1976). Although the Pan African event was pervasive, it did not completely homogenize the rocks in the basement, as such traces of earlier structures remained (Grant, 1978; Onyeagocha and Ekwueme, 1982; Ekwueme, 1987; Oluyide, 1988). Structures produced by the Pan African are reported to trend North-South (N-S) to North East-South West (NE-SW, 0-30°) while earlier events produced structures trending 50-70°, E-W and NW-SE (Mullan, 1979; Grant, 1978; Ekwueme, 1987). The deformed basement appeared to have exerted a measure of structural control in the emplacement of the Younger Granites of Nigeria. This emplacement is said to have been controlled by the N-S trending fractures (Ibe *et al*, 1985; Udoh, 1988). Other controls include ring faulting, and cauldron subsidence. Their emplacement is completely anorogenic and of Jurassic age (160-170ma) (Badejoko, 1988; Ogunleye *et al*, 2005; Jacobson *et al*, 1963). This is in sharp contrast with the calc-alkaline Older Granites of the basement that are Pan African in

age (≈650ma) and orogenic in origin (Van Breeman and Bowden, 1973).

Materials and Methods:

Field Study and Data Treatment: The field study involved a detailed geologic mapping on a scale of 1:10,000. The observed rock types were described on the basis of lithological properties. Measurements of azimuths (strikes and dips) of structural features especially those of joints and veins were systematically taken and recorded. About one thousand measurements of strikes and dips of joints and strike directions of veins were taken on the rocks of the area. These data were statistically analysed and plotted using *StereoStat* geological software. The generated rose diagrams and stereogram plots are indicated in figures 1 and 2. The study area was divided into five structural domains. Each domain is represented by a rose diagram and contoured stereogram (fig. 1). Point diagrams on an equal-area net generally expressed as contour maps were prepared for each of the small areas (figs. 1 and 2).

Description of the Lithological Units:

The study area consists of gneisses forming the basement complex rocks which have been intruded by per alkaline Younger Granite rocks. The gneisses are mainly hornblende biotite gneiss. They are low lying, outcropping mostly in ephemeral stream channels. This lithology underlies about 40% of the study area (fig. 1). In some localities this rock is dissected by quartz veins. The Younger Granite rocks include Hornblende biotite granite, Albite riebeckite granite, and Riebeckite aegirine granites.

Granites form prominent hills which have been well exposed by weathering and erosion and often appear rugged. There is a tendency for horizontal sheeting developed in the weathered

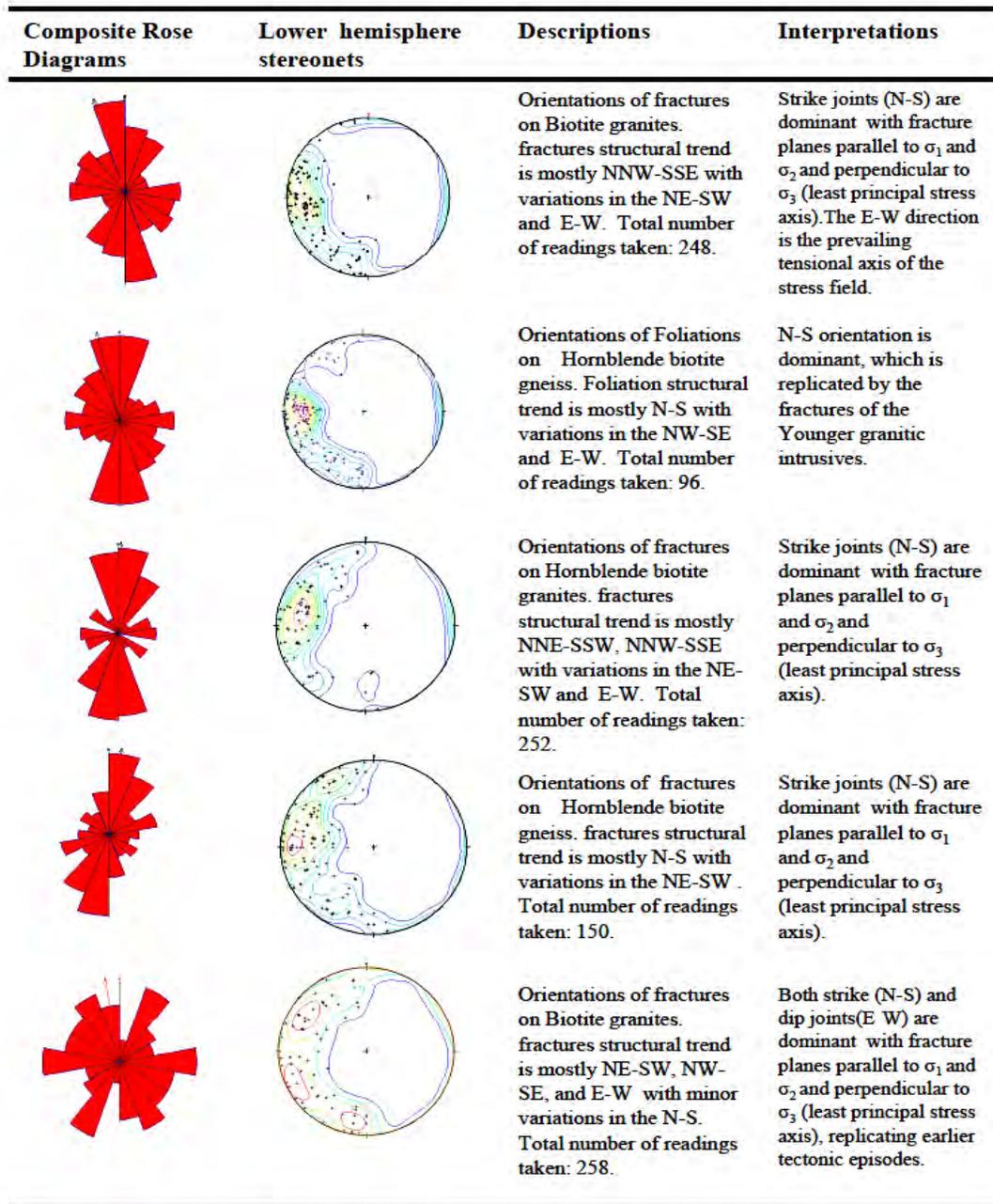


Fig. 2. Joint orientation data collected in the study area. Composite rose diagrams show the average strike direction of fractures. Lower hemisphere stereonet show the orientations of pole to fractures (joints) as observed in the field (measured). Contours are plotted at intervals of two and highlight the clustering of poles.

Granite outcrops (fig.3A), a feature that produced the spectacular towers of perched boulders which add to the scenic attraction of the *Fusa Hills*. Contacts between the basement rocks and the granite intrusives are usually not very distinct. Xenoliths of basement rocks which are trapped in the granitic rocks appear to have been formed through magmatic 'stoping'.

Structural Geology

Both planar and linear structures were mapped in the study area.

Planar Structures: While fractures appeared on all rock types, foliations were exhibited only by basement gneissic rocks. Foliations observed on the gneisses are depicted by alternation of leucocratic and melanocratic bands of felsic and mafic minerals respectively that are products of metamorphic deformation and migmatitic processes that affected the basement. Poor exposures

of these low lying gneisses allowed only a few measurements (about one hundred readings) of strikes and dips of foliations. Statistical analyses indicate the dominant foliation directions as NNE-SSW, NNW-SSE, and NW-SE (fig.2). Foliation dips ranged from 75° to 80° .

Fractures: Fractures are common to all rock types of the study area. They ranged from tight (0-0.1cm) to open joints (0.1-5cm), and vary in length from 10m to several metres. Most of the joints occur in sets giving the rock exposures a dissected, blocky or fragmented appearance (fig.3B and C). In terms of their attitudes some of the joints are vertical, while others vary from inclined to horizontal (fig.3A). Although, most of the joints have planer surfaces, no visible sign of movement parallel to them were recognized. In some cases, slight or major movements at right angles to the joints produce open joints.

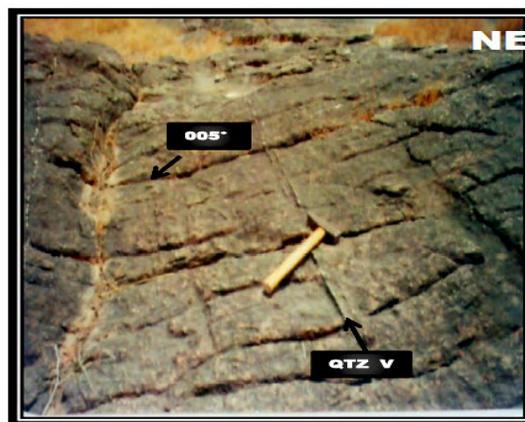


(A)



(B)

Fig. 3. Fracture patterns present on Younger Granites. (A) Horizontal sheeting found on some outcrops. (B) A dissected abutting relationship created by joint sets. (C) Sets with average strikes of 005° and 101° . Note the abutting relationship between the quartz veins (QTZ V) and the joints set almost at 090° to each other.



(C)

Quartz veins occur in abundance on the granitic rocks. Some of these quartz veins cross-cut joint sets which suggest that the veins are younger. It is obvious that the joints were formed first before the veins (fig.3C). The mechanism by which veins formed is of special interest to our understanding crustal deformation. Ramsay (1980) presented evidences that many if not all of extension veins are formed by an accretionary process involving the formation of a narrow fracture or

joint followed by filling of the open space by crystalline material(s) through a mechanism he termed "crack-seal". Most of the quartz veins proved more resistant to weathering than their host rocks (fig. 3C).

Discussion:

The Younger Granites of Nigeria are per alkaline in nature and anorogenic in origin. However,

they show similar fracture trends with the orogenic basement rocks. The structural orientation of the basement rocks is an expression of structural deformation relicts or imprints traceable to the various thermo-tectonic events that they have undergone. In this work, attention is directed mostly at fractures, and veins. Generally these structures are secondary or mostly tectonic in origin. Statistical analyses of the structures measured in the field revealed that they strike predominantly N-S and dip westerly (fig. 2). This structural attitude mimics those found in the surrounding basement rocks. Previous studies have also revealed the dominance of such north-southerly trend in the Nigerian basement (Oluyide, 1988). The jointing recorded by the Younger Granites of the study area could be termed as post tectonic or anorogenic because neither deformation of the joint planes nor distortion of

the directions was observed, as would be expected of joints formed as a result deformational episode(s).

For the fact that tectonic joints are quantitative and manifestation of the direction of the operative forces during deformation, they give a clue to the possible stress distribution in a deformed area (Adekoya, 1978). In discussing the origin of tectonic joints, Price (1959) was of the view that they are surface expressions of residual stresses released after deformation. It is important to note that joints form in response to the variations in magnitude and direction of the prevailing stress field. The strike joints (N-S) have fracture planes parallel to σ_1 and σ_2 and perpendicular to σ_3 (least principal stress axis) (fig.4A). In this case E-W direction is the prevailing tensional axis of the stress field. For the dip joints (E-W), the fracture plane is parallel to the σ_1 and σ_2 and N-S is the prevailing tensional axis of the stress field (fig.4B).

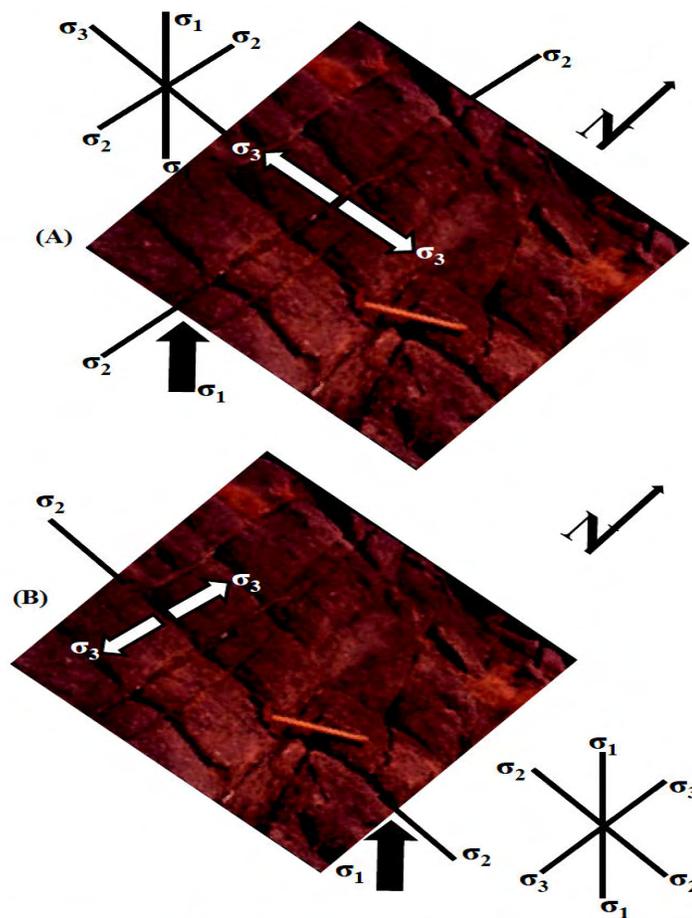


Fig. 4. Approximate Joint orientations related to principal stress axes in (A) Strike Joint stress field and (B) Dip Joint stress field.

The Pan African event has been described as the most penetrative and wide spread deformational episode producing N-S to NE-SW trending structures. Such structural trend is dominant and wide spread in the Nigerian basement (Ekwueme, 1994). Pre-Pan African deformational episodes produced the E-W and NW-SE trending structures. Earlier it has been mentioned that the observed field structures are similar in orientation and type to the basement structures that are widely known to be orogenic. This is an indication that they are products of similar stress fields operating at different geologic times. A plausible explanation for this is the likely existence of residual stresses. These may be tectonic stresses that were not fully relieved. Such remaining ancient stresses serve to orient the joints and other structures in a manner replicating that of the basement. This supports the view earlier held by Udoh (1988) that the Younger Granites' emplacement was controlled by the structures of the basement rocks. Clearly, the Younger Granites of Nigeria though have not undergone any orogenic event, their structures especially joints are of residual stresses induced by past orogenic events. The interpretations here presented are considered preliminary. It is hoped that subsequently further field mapping and the use of satellite imagery will enable definitive conclusions.

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