Journal of Basic and Applied Research International
3(2): 66-74, 2015

International Knowledge Press
www.ikpress.org

STRUCTURAL EVIDENCE FOR PAN-AFRICAN EVENT IN THE SW BASEMENT BLOCK OF NIGERIA: THE IGARRA EXAMPLE

I. I. OBIADI[1*], C. M. OBIADI[1], N. E. AJAEGWU[1], E. K. ANAKWUBA[1], N. E. ONUIGBO[1], U. V. MADUEWESI[1], C. M. OKOLO[1] AND O. E. EZIM[1]
[1]Department of Geological Sciences, Nnamdi Azikiwe University, Awka, Nigeria.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Received: 9th December 2014
Accepted: 10th January 2015
Published: 17th February 2015

Research Article

ABSTRACT

Fractures and folds are common evidences for post-formational deformation in rocks. They result from the action of stress on the rocks and as such bear imprints of the nature and magnitude of the deformative force. The style and orientation of the recorded strain reflect the interaction between the applied force (stress) and the pre-existing rock body. Force is a vector quantity, having both magnitude and direction. The stress acting normal against a surface can be resolved into three mutually perpendicular principal axes of maximum stress σ_1, intermediate stress σ_2 and minimum stress σ_3; while the resultant strain can also be resolved into three mutually perpendicular principal strain axes. There exist some relationship between the applied stress and the resultant strain (structures). This relationship shows correspondence between the principal stress axes and the principal strain axes. Structural analysis using the stress and strain relationship technique was carried out at Igarra. Fractures and folds characterized in the crystalline basement rocks at Igarra shows that the orientation of the strike of the fractures and the fold axes of the folds are dominantly in the N-S direction. Assuming pure shear, and that the strain on a large scale is essentially homogeneous statistically, reflecting both the orientation and size of the bulk finite strain; the orientation, style and intensity of the mapped structures suggest a dominantly E-W directional compressional stress. This generally agrees with the tectonic location and orientation, geologic and lithologic relationships of the Pan-African suites and indicates that the Pan-African event played a major role in the structural evolution of the Schist Belt.

Keywords: Fractures, folds, stress, strain, crystalline rocks.

1. INTRODUCTION

Secondary structures (post-formational structures) such as folds and fractures result from deformation of pre-existing rocks. The type of deformation and the resultant structure(s) produced by the deformation is dependent on factors such as confining pressure, temperature, pore fluid pressure and chemistry, strain rate, time, amongst others. Ductile failure (folds) refers to deformation in rocks without discontinuity. It is usually associated with higher confining pressure and temperature, lower strain rate and active pore fluid chemistry. On the other hand, brittle failures (fracture) are deformation in rocks with discontinuity

---

**Corresponding author: Email: izuchukwuig@yahoo.com;*

and it is usually associated with relatively lower confining pressure and temperature and higher strain rate. These discontinuities or cracks are planes across which the cohesion of the host material is lost. Deformation is caused by stress and the form and orientation of the deformed body reflects the interaction between the deformational forces and the pre-existing rock body.

2. SIMPLE CONCEPT OF STRESS AND STRAIN

Deformation of a material is the process whereby physical changes are produced in the material as a result of the action of applied forces. The forces acting on a portion of rock arises in various ways and produces a set of stresses. The amount of deformation caused by these stresses is measured by the change in dimension of the body. This change may consist of a change in shape, or volume, or both shape and volume and constitute the strain [1].

Force is a vector quantity, and thus possesses both amount (magnitude) and direction. It can be represented by a line whose length specifies the magnitude and whose direction specifies the orientation of the force. The sense of direction may be indicated by an arrow. In rock deformation, we usually neglect any overall acceleration of a body and treat the system of forces as closed, i.e. opposing forces cancel out. This situation is governed by Newton’s third law of motion which states that for a body at rest or in uniform motion, to every action there is an equal and opposite reaction. Thus a stress results from force acting on a surface surrounding or within a body, and comprises both the force and the reaction of the material on the other side of the surface. The magnitude of the stress depends on the magnitude of the force and on the surface area over which it acts. Since strain result from the action of stress, there exists a direct geometrical relationship between the two. However, since the geometry of both stress and strain fields change with time, the relationship may not be a simple one.

3. THE STUDY AREA – IGARRA

Igarra is located in Akoko-Edo Local Government Area, in the Northern part of Edo State, Nigeria. It is bounded by latitudes N7^{o}14^{1} and N7^{o}18^{1}; and longitudes E6^{o}4^{1} and E6^{o}8^{1} (Fig. 1).

The major road that runs across the study area is the new Auchi-Igarra road which extends northwest to southeast. The topographic relief is influenced by the underlying geology. It is characterised by highland (mainly the tall ranking older granite suites) adjoining relatively low lying plains (essentially the weathered schist belt). The area is drained by a system of flowing streams, flowing generally in the North-South direction. The stream channels are almost parallel to the strike of the schistose rocks suggesting they are structurally controlled. Igarra is part of the southwest block of the Nigerian Basement Complex. Lithologically, it comprises mainly the slightly Migmatised to Unmigmatised Schist belt (the Igarra Schist belt) (Fig. 2) bounded and underlain by the Migmatite-Gniess Complex and intruded by the Older.

Granite which forms good topographic features rising up to over 100m above the surrounding terrains. The contacts between the Migmatite-Quartzite Complex and the Schist Belt are sometimes fault bounded. The Igarra Schist Belt runs for about 60 km in a generally NNW-SSE direction [2], and comprises Quartz-Biotite Schist, Mica Schist, Quartzite and Quartz Schist, Calc-Silicate and Marble, and Conglomerates.

The Schist Belt, which is of the upper greenschist facies, is believed to be relics of a supercrustal cover which was infolded into the Migmatite-Gneiss Complex [3]. Several researchers have proposed models for the tectonic evolution of the Schist Belt in relation to the Basement Complex. Ajibade [4] suggested an initial crustal extension and continental rifting at the West African craton margin about 1000 Ma leading to the formation of graben – like structures in western Nigerian and the subsequent deposition of the rocks of the schist belts. Closure of the ocean at the cratonic margin about 600 Ma and crustal thickening in the Dahomeyan led to the deformation of the sediment, the reactivation of pre-existing rocks and the emplacement of the Pan-African granites. Recognition of suture along the eastern margin of the West African craton led Turner [5] to relate the schist belt to the subduction processes in the cratonic margin. He is of the view that the schist belt was deposited in a back-arc basin developed after the onset of subduction at the cratonic margin. However, the distance of the nearest Nigerian schist belt from the site of subduction is at least 200 – 250 km, exceeding the 100 – 150 km from arc to back-arc basins in present day arc system [6]. The possibility that the schist belt may represent additional micro-continent separating pre-existing macro-continents has also been suggested by McCurry and Wright [7].

4. METHOD OF INVESTIGATION

Field trips were embarked upon to study and characterize the structures in the study area. These structures include folds and fractures (faults and joints). This was done at several representative outcrops scattered all over the study area (Fig. 3). The outcrops are mainly exposed Schist and Granites. Measurements of the fracture parameters such as fracture trend/orientation, aperture and length were taken and documented. Also measurements were made of the orientations of the fold axes and tightness (a reflection of the inter-limb angle of the fold) of the folds observed at the outcrops. The tightness of the folds and other parameters measured is a direct consequence of the deformative forces responsible for the formation of the structures. These parameters were analyzed and discussed; and valuable deductions made from results.

5. DATA ANALYSIS, RESULTS AND DISCUSSION

The attitude of the fractures observed at the outcrops was documented. The fractures at each station were grouped according to the azimuth of their strike in intervals of 20º. These were subsequently plotted in the Cartesian coordinate for easy appreciation of the orientation of the strike of the fractures in the study area as observed from surface geological mapping (Fig. 4). Few folds were also observed and the orientation of their fold axes documented.

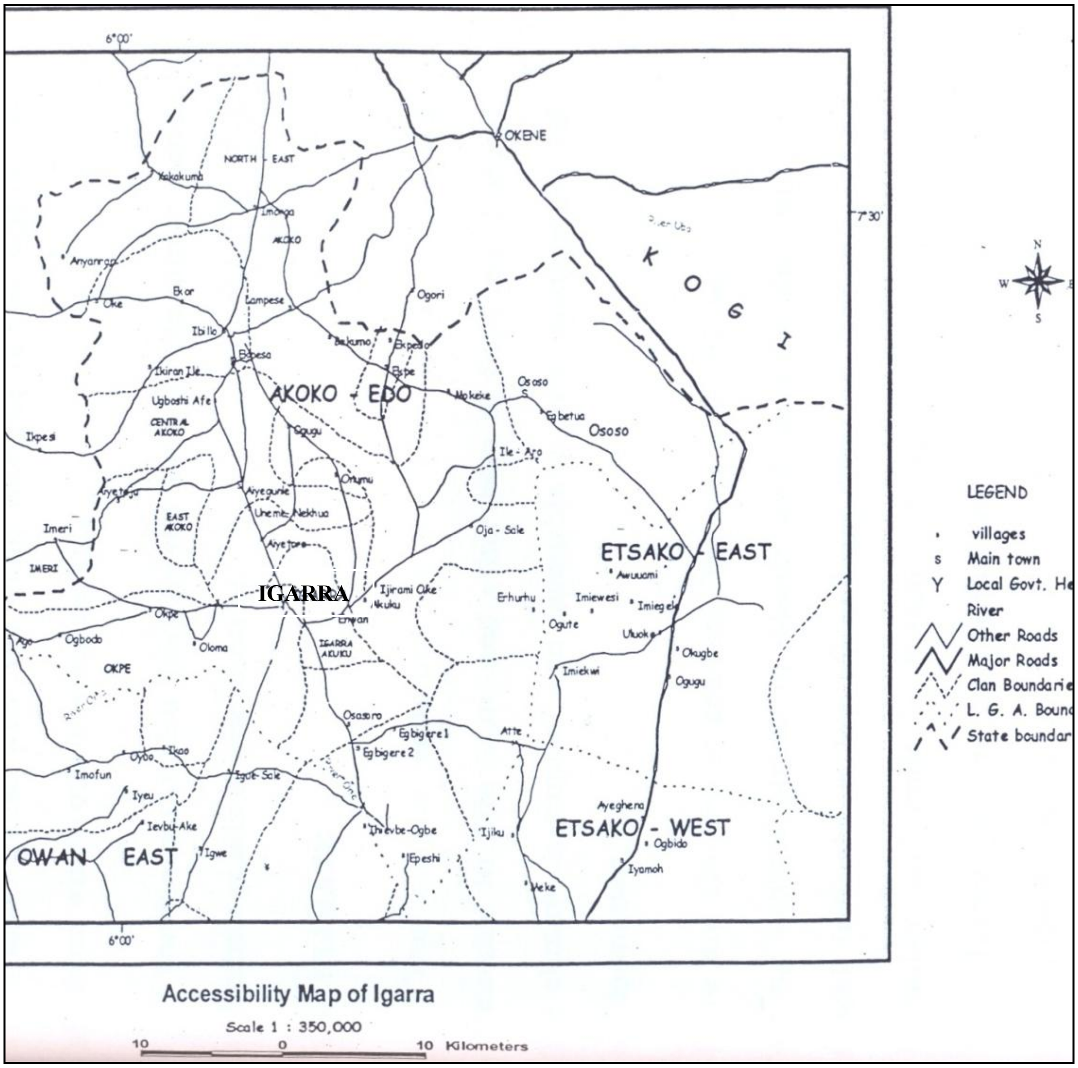

Fig. 1. Location map of study area- Igarra [8]

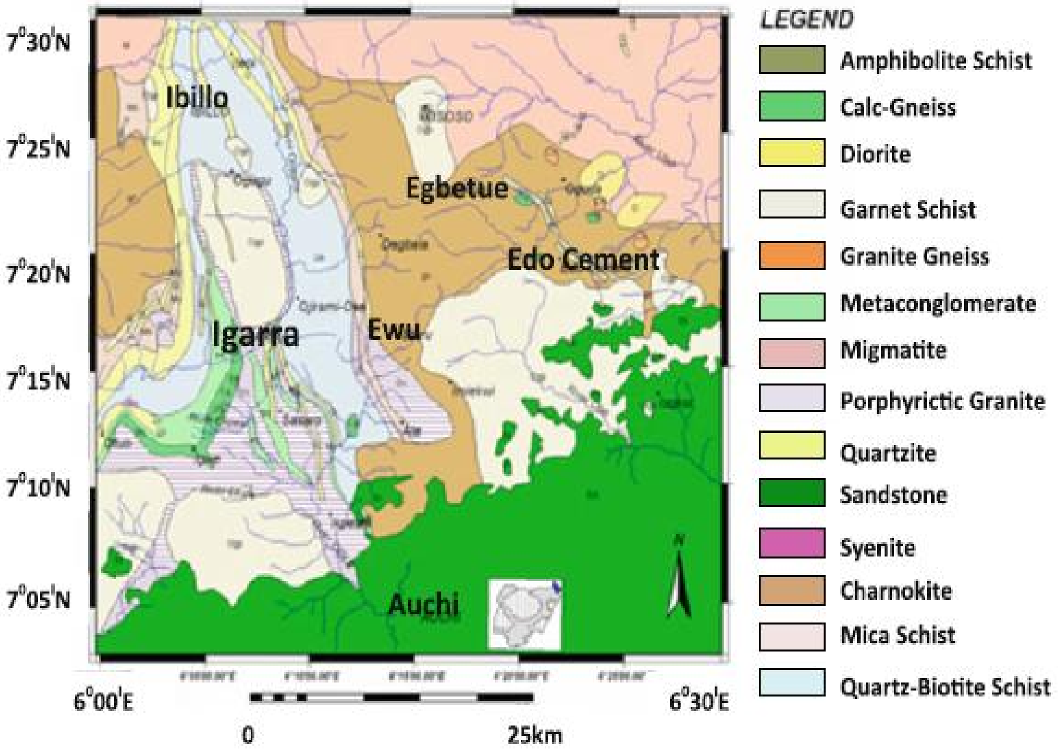

Fig. 2. The Igarra Schist belt (Modified from [9])

Fig. 3. Outcrop of slightly weathered schist with near vertical quartz veins (fractures) and some horizontal veins terminating against the vertical ones

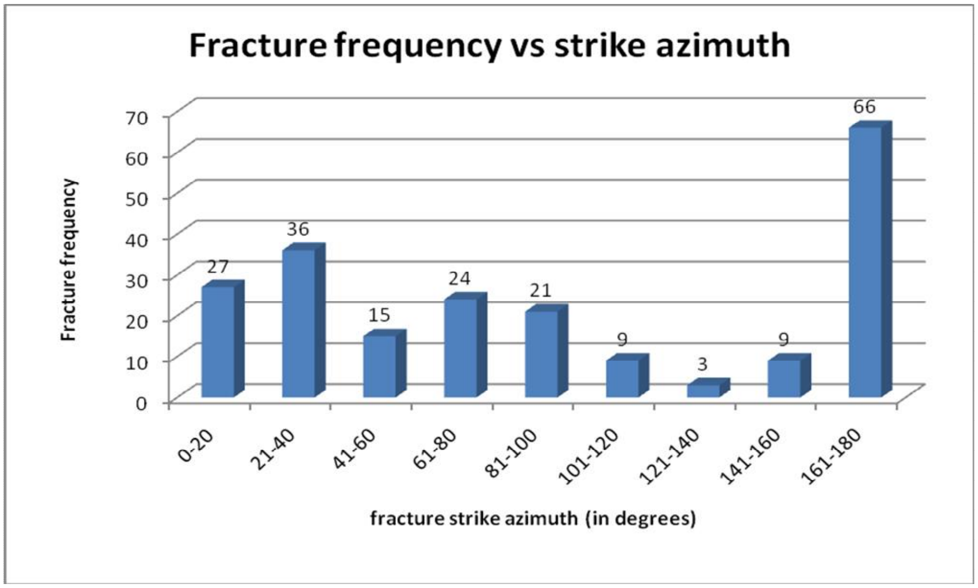

Fig. 4. Plot of fracture frequency against fracture azimuth

Results of the analysis show that the strike of the fractures in the study area is dominantly in the N-S direction. This is also the case for the orientation of the fold axis of the few folds observed in the area. They have orientation values of 350º, 178º and 180º.

These observed structures and their characteristics, result when the applied stress overcome the cohesive strength of the rock (in the case of fractures) or when it exceeds the elastic limit (yield stress) of the rock.

Stress acting on a body can be resolved into normal stress acting perpendicular to the surface, and shear stress acting parallel to the body. The normal stress acting against a body can be resolved into three mutually perpendicular planes on which the shear stress is zero. The normal stress along these planes are called the principal stress with the notation σ_1, σ_2 and σ_3 where $\sigma_1 > \sigma_2 > \sigma_3$ (Fig. 5). A state of stress on a body is specified completely by giving both the direction and the size or magnitude of the three principal stresses.

Strain is the geometrical expression of the amount of deformation caused by the action of a system of stresses on a rock body. Strain is expressed as dilation (volume change) or distortion (shape change), or a combination of both. The strain on a body can also be resolved along three mutually perpendicular axes, X, Y, Z such that they are parallel to the direction of greatest, intermediate and least elongation (or contraction) of the strained body respectively. These axes, X, Y, Z are known as the principal strain axis. They may be conveniently regarded as the axes of an ellipsoid, the strain ellipsoid, which is the shape taken up by a deformed sphere of unit radius (Fig. 6). To complete the description of the geometry of the strain, the orientations of X, Y, Z have to be given.

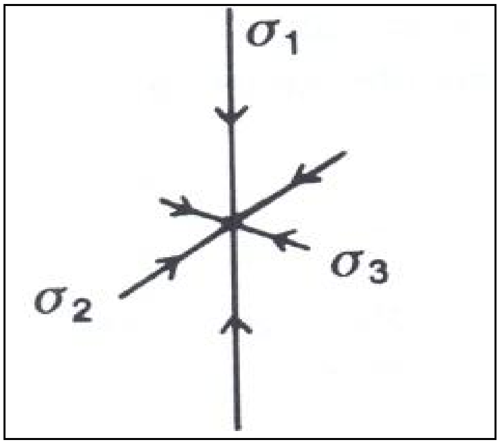

Fig. 5. The stress axial cross showing principal stress axes ($\sigma_1 > \sigma_2 > \sigma_3$) [1]

Quantitative evaluation of the total or bulk finite strain in a given area resulting from deformation is very important in the structural evaluation of orogenic complexes. A simple approach to this is by assuming that the strain on a large scale is essentially homogeneous statistically and that the statistical arrangement of all planar and linear structural elements throughout the area reflects both the orientation and size of the bulk finite principal strain. This approach has been particularly useful in dealing with highly deformed zones in certain Precambrian gneiss terrains [1]. Assuming pure shear, the orientation of the principal finite strain axis and the principal stress axes correspond, that is the direction of greatest extension (X) corresponds or is parallel to the direction of minimum stress σ_3 (which in many cases would be negative or tensional) and the direction of shortening (Z) corresponds to the direction of maximum stress σ_1. This is also the case for the intermediate strain which is parallel to the intermediate stress σ_2 axis.

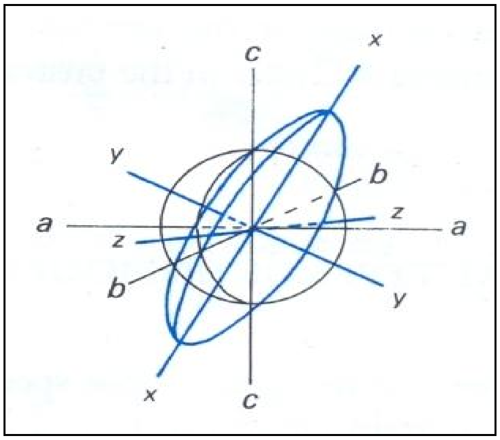

Fig. 6. The strain ellipsoid showing principal strain axes X, Y, Z [1]

Brittle failure (fractures) in rocks is preceded by weakening of the rock material. Weakening involves the initiation, propagation and nucleation of micro-cracks at the process zones. According to Griffith theory, the propagation of cracks in materials extends in the direction in which the tensile stress acts.

In compressional stress environment, the shortening parallel to the direction of maximum stress σ_1 and the corresponding elongation in the direction of minimum stress σ_3 can be accompanied by boudinage in the elongated sector. This produces local tensional stress field in the elongated sector usually characterized by fractures with orientation generally perpendicular to the direction of maximum stress σ_1 and minimum strain Z and parallel to the direction of minimum stress σ_3 and maximum strain X. Experimental results, however have shown that fractures can sometimes be inclined at smaller angles to the principal stress in a compressive regime. This may be due to some physical and chemical factors at play as well as minor imperfections in the rock mass. Compressional stress can also form folds of various wavelengths and inter-limb angle (a measure of the openness or tightness of the fold). The strain on a folded rock mass is dictated by extension around the outer arc and compression in the inner arc (Fig. 7), usually separated by a neutral surface of no strain near the center region. The extensional structures (fractures) at the outer arc are usually parallel to the orientation of the axial plain/fold axis of the host fold (Fig. 7). These features were observed on the folds in the course of the field work exercise.

Analysis of the field data showed that the orientation of the mapped fractures and the fold axes of the mapped folds are dominantly in the N-S direction. This is in agreement with previous research works in the study area [2-4,8,10-12]. It also corresponds with the result of Azimuthal Resistivity Survey analysis carried out in the area by Obiadi et al. [13].

Applying the principle of strain/stress orientation relationship, the fractures strike and fold axes orientation are parallel to the direction of minimum stress σ_3 and maximum strain Z. This suggests that the maximum stress σ_1 direction is generally in the West-East direction.

Several researchers have proposed models for the tectonic evolution of the schist belt in relation to the whole Basement Complex. They all recognized the importance of compressional tectonics related to the Pan-African orogenic event as playing a major role in the structural evolution of the schist belt of the Nigerian Basement Complex [3,12,14-17]. The Nigerian Schist Belt occurs in a 400m wide zone which runs parallel to the boundary between the Pan-African province and the West African craton (Fig. 8). The Pan-African event is seen as a collision-type orogeny in which a subduction zone dipped eastwards beneath the Pan-African province [18]. The suture line is marked by a paired linear gravity anomalies but according to Bessoles and Trompette [18], the suture line has no surface expression in the form of ophiolites. This correlates with the finding of Burke and Dewey [14], Black et al. [12] and Caby et al., [15], which suggest that evidence from the eastern and northern margins of the West African Craton indicates that the Pan-African belt evolved by plate collision which involved the collision between the passive continental margin of the West African Craton and the active continental margin (Pharusian belt) of the Tunreg Shield to the east about 600 ma ago (Fig. 8).

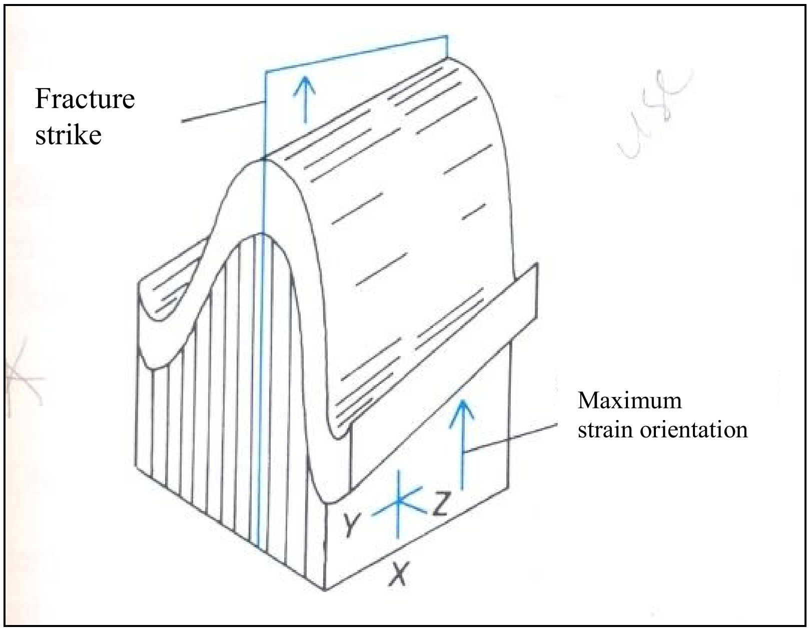

Fig. 7. A folded surface showing the relationship between the principal strain axes and fracture characteristics and orientation (modified from [1])

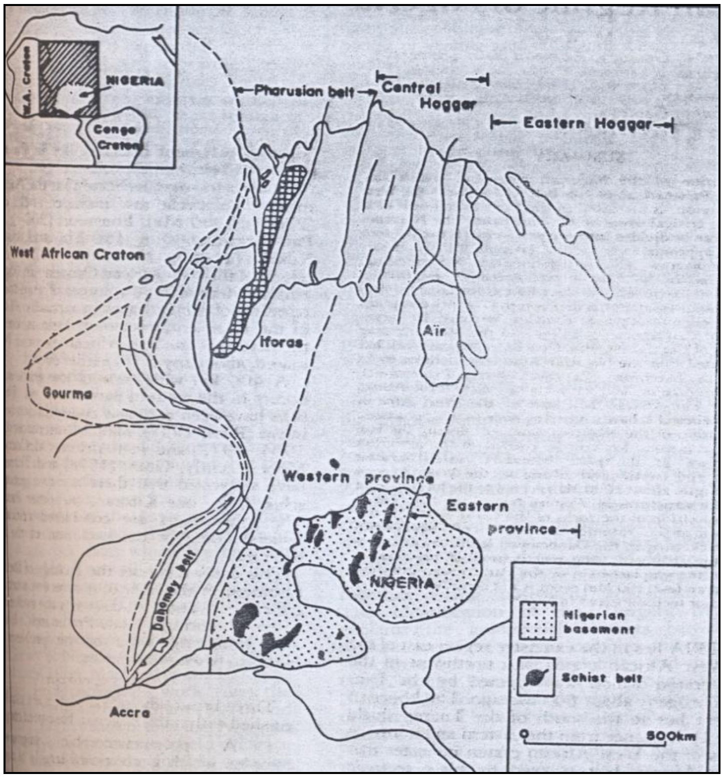

Fig. 8. Generalized geologic map of the Pan-African belt east of the West African Craton showing the relative position of schist belt of the Nigerian Basement Complex and the Taureg shield (modified from [16])

The orientation, style and intensity of the mapped structures in the study area suggest a dominantly West-East directional compressional tectonics. This generally agrees with the tectonic location and orientation, geologic and lithologic relationships of the Pan-African suites. It also correlates very well with the submissions of early workers in the region as discussed above. The presence of few structures in other orientations may have resulted from earlier tectonic events or cleavages and imperfections in the rock. Dating of these sets of structures may help constrain interpretation.

6. CONCLUSION

Secondary structures such as folds and fractures result from deformative forces that act on pre-existing rock bodies and as such bear imprints about the nature and magnitude of the causative force. There exist some relationship between the force (stress) acting on the rock and the resultant structures (strain). This relationship shows correspondence between the principal axes of the stress and strain regime.

Structural evidence shows that the fractures mapped in the Igarra area and the fold axis have dominant strike orientation in the N-S direction. This suggests a dominantly W-E directional compressional tectonics which generally agrees with the tectonic location and orientation, geologic and lithologic relationships of the Pan-African suites. This also corresponds to previous research works in the area and the tectonic framework of the domain, indicating that the Pan-African event played a major role in the structural evolution of the Schist Belt.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Park RG. Foundations of structural geology (Third edition). Routledge Taylor and Francis Group. London and New York. 1997;202.
2. Rahaman MA. A review of the basement geology of south-western Nigeria. In Kogba, C.A. (ed), Geology of Nigeria. Elizabethan Publ. Co., Lagos. 1976;41-58.
3. McCurry P. Geology of degree sheet (Zaria). Overseas Geol. Min. Res. 1973;45.
4. Ajibade AC. Geotectonic evolution of the Zungeru Region, Nigeria. Unpublished PhD thesis, University of Wales, UK; 1980.
5. Turner, D.C. Upper Proterozoic schist belt in the Nigerian sector of the Pan-African province of West Africa. Precambrian Research. 1983;(21):55-75.
6. Gass IG. Pan-African (Upper Proterozoic) plate tectonics of the Arabian-Nubian shield. In Kroner A. (ed), Precambrian Plate Tectonics, Elsevier, Amsterdam. 1981;387-402.
7. McCurry P, Wright JB. Geochemistry of calc-alkaline volcanic in northwestern Nigeria, and a possible Pan-African suture zone. Earth Planet. Sci. Lett. 1977;(37):90-96.
8. Oseghe DO. A report of independent field mapping carried out in Igarra south west II (plot 4). An unpublished B.Sc thesis, University of Benin, Nigeria; 2006.
9. Anifowose AYB, Bamisaye OA, Odeyemi IB. Establishing a solid mineral database for part of Southwestern Nigeria, Geospatial World Newsletter; 2006. Available:www.geospatialworld.net
10. Grant NK. Structural distinction between a meta-sedimentary cover and an underlying basement in the 600 Ma old Pan-African domain of North-Western Nigeria, Bull. Geol. Soc. Amer. 1978;(89):50-58.
11. McCurry P. The geology of the precambrian to lower paleozoic rocks of Northern Nigeria, a review. In Kogbe CA., (ed), Geology of Nigeria, Elizabethan Publ. Co., Lagos. 1976;15-39.
12. Black R, Ba H, Ball E, Bertrand JML, Boullier AM, Caby R, Davison I, Fabre J, Leblanc M, Wright LI. Outline of the Pan-African geology of Adrar des Iforas (Republic of Mali). Geol. Rundsch. 1979;68(2):543-564.
13. Obiadi II, Onwuemesi AG, Anike OL, Ajaegwu NE, Anakwuba EK, Nwosu CM, Akpunonu EO, Onuigbo EN, Onuba OL. Determining subsurface fracture characteristics from Azimuthal Square Array Resistivity Survey at Igarra, Nigeria, Pure and Applied Geophysics. 2013;(170):5:907-916.
14. Burke KC, Dewey JF. Orogeny in Africa. In Dessauvagie TFJ, Wright LI. (eds). Outline of the Pan-African geology of Adrar des Iforas (Republic of Mali). Geol. Rundsch. 1972;68(2):543-564.
15. Caby R, Bertrand JML, Black R. Pan-African ocean closure and continental collision in the Hogger-Iforas segment, Central Sahara. In Kroner A. (ed), Precambrian plate tectonics, Elsevier, Amsterdam. 1981;407-434.
16. Leblanc M. The late Proterozoic ophiolites of Bou Azzer (Morocco) evidence for Pan-African plate tectonics. In A. Kroner, (ed),

Precambrian plate tectonics, Elsevier, Amsterdam. 1981;435-451.

17. Russ W. The geology of parts of Niger, Zaria and Sokoto provinces. Geol. Survey of Nigeria Bull. 1957;(27):42.
18. Bessoles B, Trompette R. Geology of Africa. The Pan-African string ' area MobilED Central Africa (Sub part) and area mobilesoudanaise'. Mem. Bur. Rech. Geol. Minieres. 1980;(92):396.
