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Examination of the Pan–African Orogeny: Implications on the Architecture of Basement Rocks in Igarra, Southwestern Nigeria

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ABSTRACT

Investigation of basement rocks around Igarra, Southwestern Basement Complex of Nigeria was carried out to assess the impact of the Pan African Orogeny on the architecture and evolution of rocks in the study area. The area spans approximately 40 km^2 covering Igarra town and environs in Akoko-Edo Local Government Area of Edo State, Nigeria. The investigation includes systematic mapping and interpretations of structural elements in the rocks using standard geological techniques. The granites and metasediments were dissected by a network of quartzo-feldspathic dykes and veins of various dimensions. The Pan-African orogeny had been documented as the most pervasive of all the tectonic events that affected the Nigeria Basement rocks. Field mapping of the area revealed that the Pan-African granites are structurally controlled intrusions in the host metasedimentary rock sequence. The syn to late tectonic emplacements of the Pan-African granitoids during the neoproterozoic period (600 Ma ± 150 Ma) has affected the evolution of the rocks. The granite intruded the folded metasediments in N-S direction and their emplacements reactivated the E-W fault zone in the country rocks with injection of magmatic materials into dilation zones in the metasediments and fault breccias within Igarra and environ.

1. Introduction

Nigeria lies within the Pan-African mobile belt bounded by the West Africa Craton in the west and Congo Craton in the Southeast. The geology of Nigeria can be classified into two broad groups. The first group is the Precambrian Basement (Nigeria Basement Complex Rocks)-dominated by crystalline rocks and Schist Belts. The second group is made up of the Sedimentary Basins containing sedimentary rocks of Cretaceous to Recent age. Both group occurred approximately in equal proportions (Woakes et. al., 1987).
The complexity of the Nigeria Basement Complex (NBC) as the name suggests, is a reflection of the superimposition of imprints of different tectonics activities on the NBC from different orogenies, multiple deformational episodes and metamorphism. Several works have been done on the Nigerian Basement Complex which have confirmed this polycyclic nature and had been well reported (Oyawoye, 1972; Odeyemi, 1976; Rahaman, 1988) among others.

More also, the Pan-African orogeny (600Ma ±150Ma ago) has been documented as the most pervasive of all tectonic events in the evolution of the NBC. The event is characterized by regional metamorphism, emplacement of the Pan-African granites and its associated minor intrusives: granodiorite, pegmatite, aplite, dolerite, lamprophyre and syenite (Odeyemi, 1988; Rahaman, 1988).

According to Obiadi et. al. (2015), the Pan-African event played a major role in the structural evolution of the Schist Belts, a submission that agreed with earlier workers - (Oyawoye, 1972; Annor et. al., 1990; Oluyide, 1998; Akintola and Adekeye, 2008) - and further established that distribution of structural elements and alignment of geologic resources in the NBC generally agrees with the tectonic location, orientation as well as the geologic and lithologic relationships of the Pan-African suites.

Although the Pan African event was pervasive, it is pertinent to note that the event was not generally homogeneous. Annor and Freeth (1985) noted that the Pan-African tectono-metamorphism was heterogeneous in style, degree and grade. Hence this work examines the impact of the Pan-African Orogeny on the evolution and architecture of rocks in the study area. This by extension will improve the exploration data base for geologic prospecting in the Southwestern Basement Complex as well contribute to the repository of knowledge of the geology of the study area.

2. Location and Accessibility

The study area underlies Igarra town and environ in Edo State, Nigeria. It is part of the Igarra Schist Belt in Southwestern Basement Complex (Fig. 1). The area is covered in Nigeria Geological Survey map (Auchi Sheet 266) and bounded by Lat. 7˚15'N - 7˚20 N and Long 6˚03'E - 6˚10'E covering area of approximately 40 km^2. The area is drained by a system of subsequent streams flowing from the north to the south. Most of the water channels are parallel to the strike of the schistose rocks and along faults and fractures suggesting they are structurally controlled as they flow towards the southern part of the study area except along the E-W fault zone (Fig. 2).

3. Geologic Setting of Igarra Schist Belt

The Igarra Schist belt comprises rocks of Precambrian Basement Complex with three major groups of rocks in the area. They are: Migmatite-Gneiss Complex, Metasediments: (schists, calc-silicate, quartzites, marble and metaconglomerates) and porphyritic older Granite suites which are discordant together with non-metamorphosed syenite dyke (Odeyemi, 1988; Rahaman, 1988; Ajibade et. al., 1989). The metasediments are the country rock intruded by the granitic rocks of Pan-African orogeny. Within the study area, the lithological units mapped are: metamorphic rocks (quartz-biotite schist, quartz-sericite schist, metaconglomerates, quartzites, marble/calc-gneiss and fault breccia) and the igneous rocks comprise porphyritic granites, granodiorite and their associated minor intrusive, veins and dykes (Fig. 3).

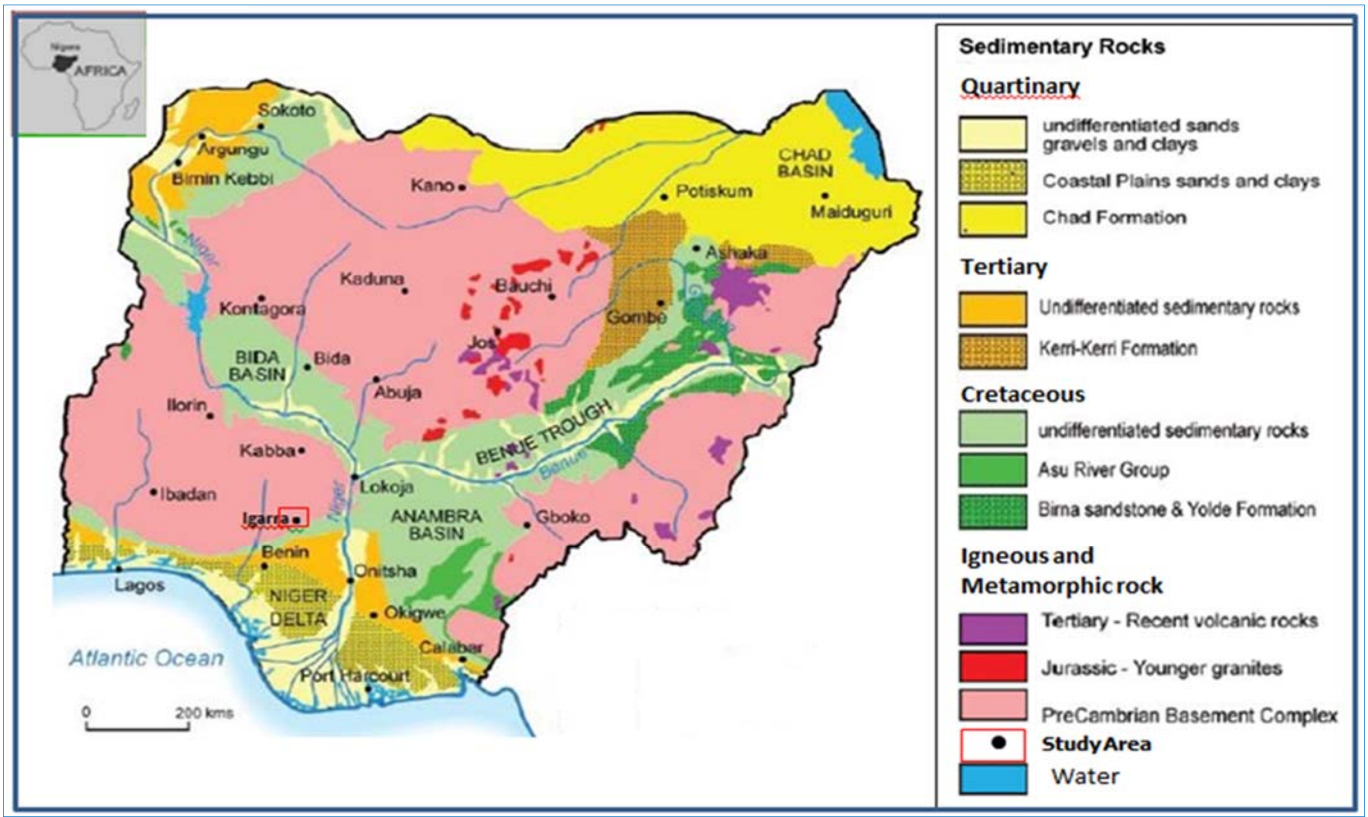

Fig. 1. Generalized geological map of Nigeria (modified after MacDonald et. al., 2005). Insert: map of Africa showing Nigeria

4. Method of Investigation

This research work employed literature review, study of satellite imageries of the area, field mapping and statistical analyses of structural elements. Google Earth view of the study area was used for reconnaissance survey prior to field mapping exercise.

Features such as fault lines, rivers, drainage channels, relief, major roads networks as well as settlements and vegetative covers were visible and recognised on the satellite and terrain imageries. It was integrated with topographic base map for "ground-trothing" during the field mapping exercise.

The field work involved mapping of the area using transverse method, studying and taking measurements of lineations and structural features in outcrops on a scale of 1:50.000. Topographic base map of the area was used to aid navigation in the field. Compass-clinometer and GPS software (GPS Map Camera Lite Version 1.3) were used to capture images, co-ordinates and altitude of the outcrops.

Field measurements were subjected to statistical analysis using geological soft wares: (GeoRose version 0.51) for preparing the rose diagrams and (NetProg version 5.5) for stereographic plot of the rocks.

5. Field Geology of the Study Area

5.1. Metasedimentary Rock Suites

5.1.1. The Quartz-Biotite Schist (QBS)

QBS is a low lying dominant rock in the study area. Fresh outcrops are fine grained, foliated and dark grey in colour with bands of light coloured minerals that gives the rock a lamina appearance (Fig. 4a). Minerals in the light bands include quartz, feldspars and muscovite while the dark greenish portions consist of hornblende and platy minerals like biotite and chlorite. QBS is inter-bedded with quartzite units (Fig. 4b). QBS is deeply weathered especially within the fault zone and well exposed along the Auchi-Ibillo Express Road (Figs. 4b-c).

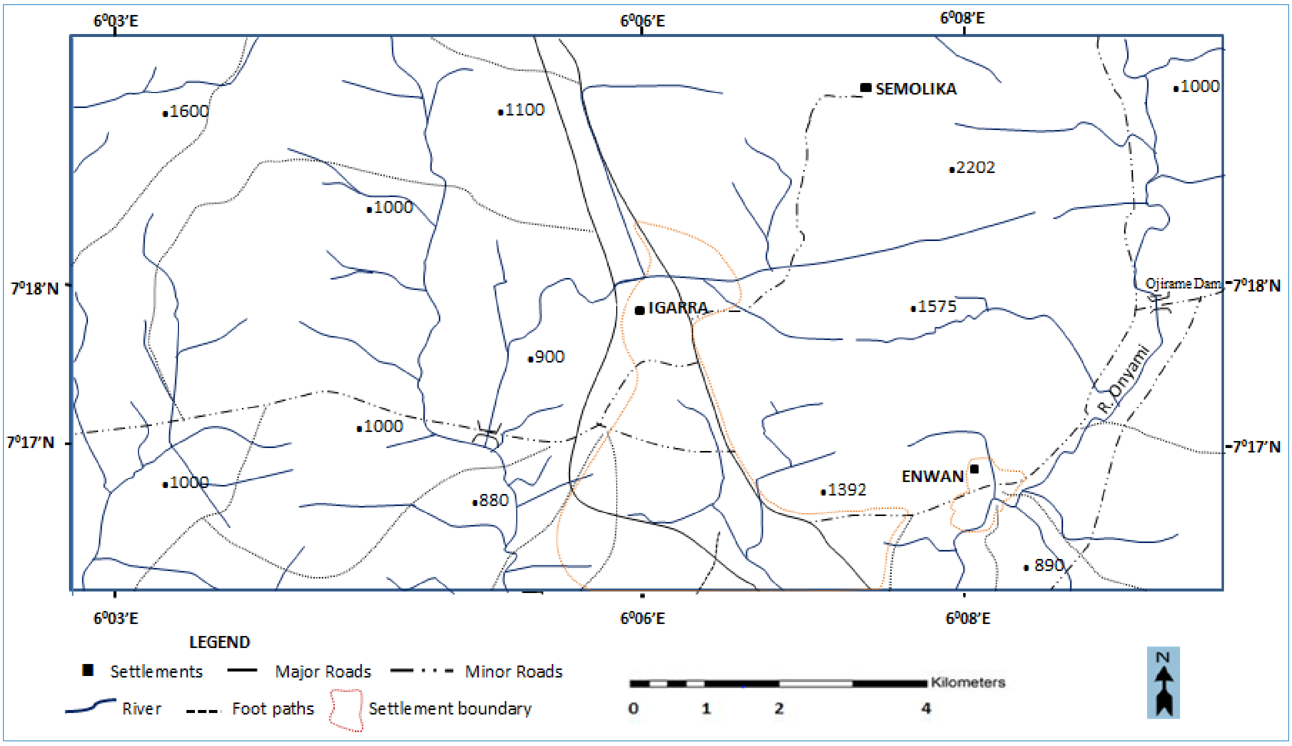

Fig. 2. Map of the study area showing drainage pattern and road networks

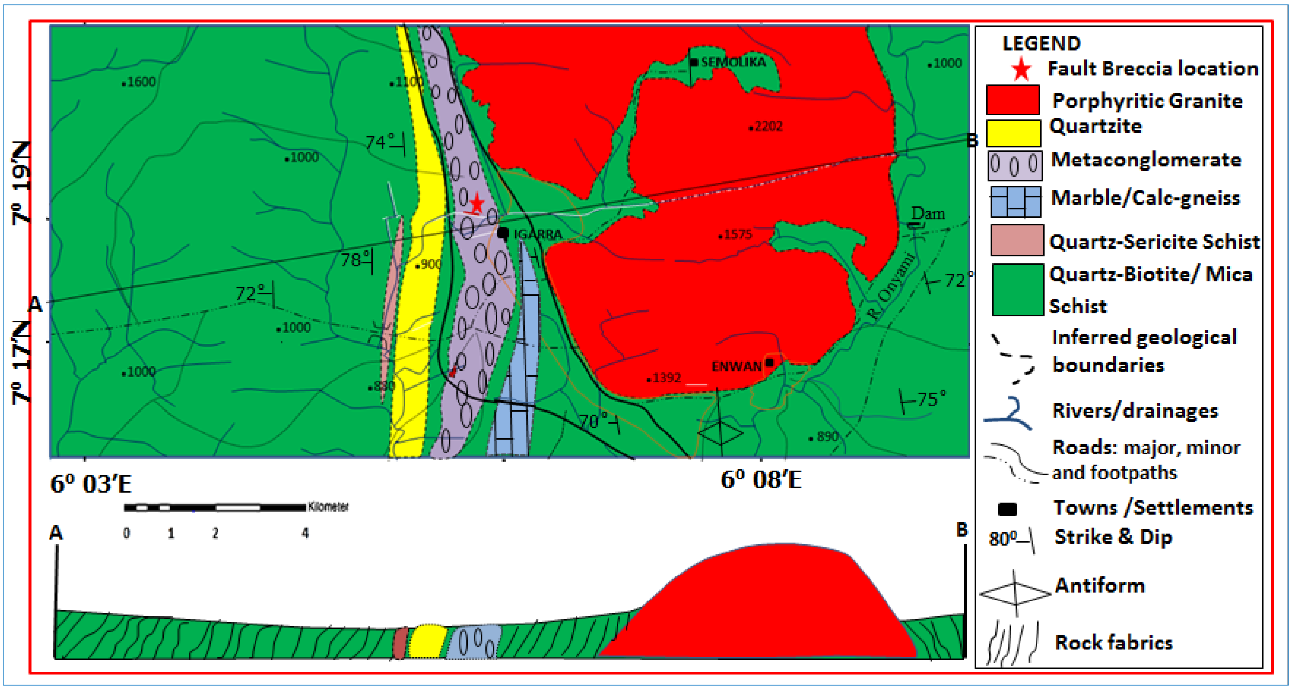

Fig. 3. Geology map of the study area with cross section AB

Fig. 4. (a) An outcrop of QBS with well foliated planes in N-S direction. (b) Quartzite unit in weathered schist outcrop dipping to the west (65˚W-75˚W) exposed in road cut along Auchi – Ibillo Road. (c) Deeply weathered QBS outcrops showing relics of foliation planes in N-S direction by Igarra-Okpe junction

5.1.2. Quartz-Sericite Schist (QSS)

QSS outcrop appears foliated and folded. It outcrops mainly at the foot of quartzite ridges and in some places; it is interbedded with the quartzite. The outcrops are few, low-lying and weathered in most places (Figs. 5a-d). Along the stream channels, the QSS is highly fractured in places and provided good sections where the lithology was clearly examined (Figs. 5a-d). The rock schistosity is defined by the alignment of the platy minerals; white mica, biotite and predominantly fragmented fine grained minerals made up of feldspars and quartz. The parallel orientation of platy minerals such as mica creates a definite zone of weakness allowing the rock to break along nearly parallel planes (Ogbe et. al., 2018).

Fig. 5. (a) Boulders of sheared QSS along the E-W river channel in the fault zone (b) Sets of parallel E-W Fractures in QSS (c) Shows tight to isoclinal folds (F1) in the QSS in Igarra with an enlarged view in (d). Note: dotted red lines depict axial plane of F1 folds

5.1.3. Metaconglomerate (MTC)

The metaconglomerate have been described as polymictic by previous workers (Odeyemi, 1976, 1988, Rahaman, 1988). It occurs as a north-south trending band within the QBS. The lithologic unit is characterized with large stretched pebbles and cobbles of varying sizes aligned in N-S direction. The stretching is a secondary lineation in the metaconglomerate superimposed by the deformed pebbles, cobbles and boulders orientation in rocks. These are evidence of shearing during a compression regime that affected the rocks (Fig. 6a). The alignment of the deformed clasts (boudins) make the rock appears foliated (Fig. 6b). The stretched pebbles are encrusted in fine groundmass of dark and light coloured bands reflecting greenish and silvering colouration in hand samples.

5.1.4. Quartzite (QTZ)

QTZ was mapped in the western part of the area where it occurs as a zone of low-lying, fragmented, scattered cobbles and boulders of quartzite trending in N-S direction (Fig. 7). This field relationship suggests the lithology is a relict of quartzite ridge which had been shattered due to multiple paleo-stresses that affected the area. It is an evidence of brittle deformation and shearing in the area.

5.1.5. Marble/Calc-Gneiss (MCG)

Outcrops of calc–silicate gneiss are often low-lying between metaconglomerate and quartz-biotite schist. Marble and calc–silicate gneiss is concordantly inter–banded with quartz-biotite schist.

5.1.6. Fault Breccia (FTB)

Fault breccias are common products along upper crustal fault zones, particularly in the top few kilometers of crust where the potential for dilational strain increases the range of breccia formation processes (Woodcock and Mort, 2008). Fault breccia is low-lying and was mapped in one location where it trends in a narrow band comprises series of boulders along the E-W fault lines (Fig. 8).

The fault breccia has an estimated stretch of about 700–800 feet long and width of 100–150 feet. The fragments are materials from the metasediments (host rocks) frozen together in magmatic material. They are randomly oriented and partially assimilated fragments encrusted in fine dark-grey groundmass.

5.2. Syn-to-Late Tectonic Intrusive Suites

5.2.1. Porphyritic Biotite Granite (PBG)

The porphyritic biotite granite covered almost the entire eastern half of the study area. Like the metasediments, the granites trend in N-S direction suggesting that the rock was structurally emplaced with conspicuous xenoliths of the country rock (schist) in the granite. The presence of the xenoliths in the granite is evidence that magmatic stopping mechanism must have played key role in the ascension and emplacement of the Pan African granites. Settled detached wall and roof fragments (pendants and xenoliths) seen on the granite are rotated and abundant in the western margin of the pluton (Fig. 9).

Fig. 6. Outcrop of MTC (a) Pinch and swell structures in MTC. (b) A large ellipsoidal strained clast in MTC. (c) A large outcrop of MTC near the faults line. (d) Highly strained boudinages closer to the fault zone. Note the plunging of outcrops towards the fault lines

Fig. 7. Outcrop of Quartzite seen as shattered cobbles and boulders in Igarra

5.2.2. Granodiorite

The granodiorite rock is a member of the Pan African intrusive suite. According to Jones and Hockey (1964) and Rahaman (1988) the granodiorite belong to the early phase of the three main groups of the Pan African intrusive suite. The granodiorites were mapped in one location along the Auchi–Ibillo Expressway about 2.5 km from Okpe Junction in Igarra. It outcropped as a small sub-circular cross-cutting stock along the new road. The hand sample appears as a cloudy white fine to coarse grained rock with visible greenish specks of hornblende crystals.

5.2.3. Veins and Dykes

Quartz veins are common features in all the rock units in the locality. From field relationships, there are several generations of veins virtually in all the mapped lithologies (Fig. 10). Veins in the area appear to have history of repeated "crack and seal" growth activities in response to the various tectonics and deformations. This observation agreed with Oden and Udinmwen (2014). In tectonic settings, hinge zones of actively forming folds and bends along active faults provide potential voids for magma injection. The residual magmatic fluid permeates the country rocks filling joints, fractures and other voids as dykes and veins. The swarm of dykes and veins are conspicuous in the weathered schist along the road cut (Fig. 10a). Their thicknesses vary from few millimeters to tens of centimeters and several meters in length especially in the metasediments. Syenite dyke was mapped within the fault zone where it cut through metaconglomerate in an E-W direction (Fig. 10b).

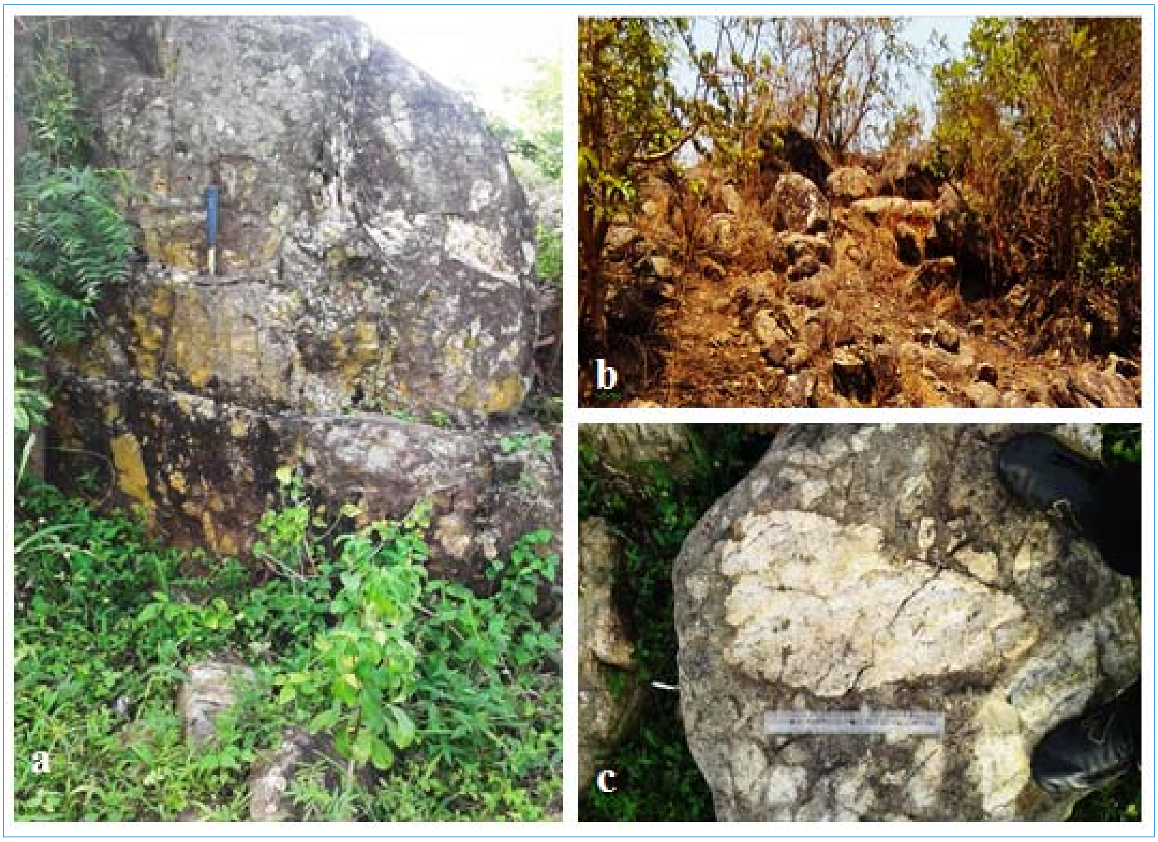

Fig. 8. Outcrop of the Igarra fault breccia. (a) The outcrop exposed along the E-W fault line. (b) Boulders of matrix supported breccia spread across the area. (c) A large partially assimilated leucosome breccia in a boulder

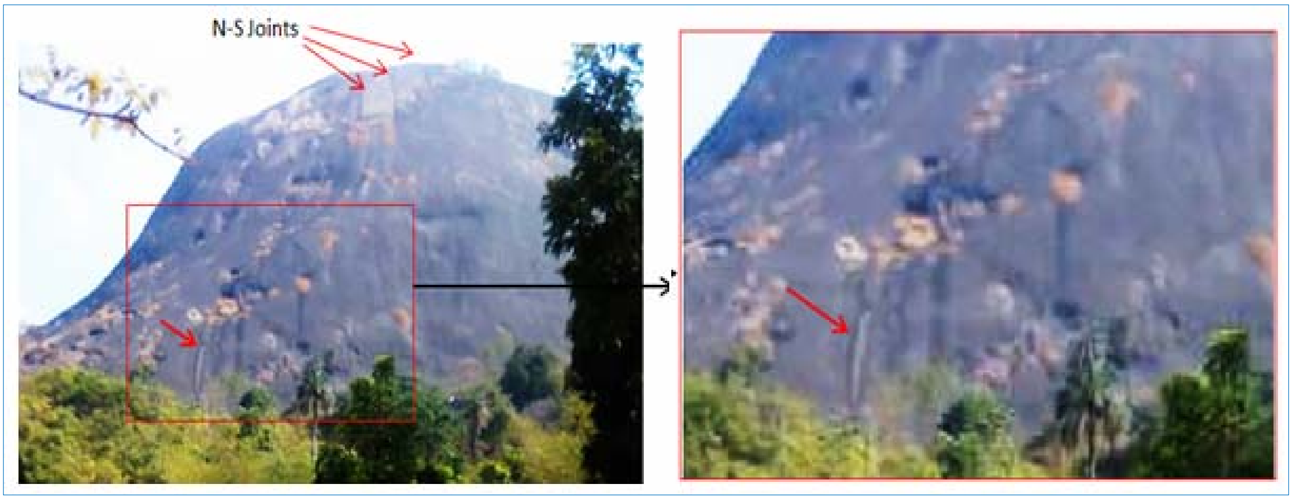

Fig. 9. (a) The Igarra PBG outcrop at the entrance to Somolika road in Igarra. Note: the set of parallel N-S joints set at the peak of the pluton. (b) Xenoliths in porphyritic granite. Note: red arrow pointing at an enclosed detached rock (xenolith or pendant); also depressions (hollows) on the pluton are relics (casts) of removed subsumed country rocks

6. Discussion

Structural features identified in the Precambrian Basement Complex rocks in Igarra area include: faults, joints, foliations, veins and dykes, folds and other microstructures. Rock boundaries can be said to be sharp contact where there is a clear cut and visible separation plane delineating their limits. In the area, sharp rock boundaries were seen in few locations while other boundaries were inferred.

6.1. Satellite Imagery / Structures

Structural elements mapped and traced in the field were correlated and matched with the lineations identified in satellite imageries. Almost all the major identified features in the imageries were mapped in the field except in the inaccessible terrain in the area covered by the pluton (Fig. 11).

6.2. Joints, Fractures, Veins and Faults

Different generations of joints and fractures were conspicuous in all the rocks attesting to multiple regimes of tectonics activities in the belt. These openings serve as sites for deposition of fluid from anatexis or magmatic activities forming ***veins*** and ***dykes*** as clearly shown by the orientation of the syenite dyke (Fig. 10b). Most veins are seen in two–dimensional view on surface of the outcrops and their orientations are often interpreted as vertical (Figs. 12a-e). However, within the fault zone they are sub-vertical and incline toward the north in the metasediments (Fig. 12f). This might be results of rotation in response to the E–W normal fault movement. Their spatial orientations in space and time are also coeval with the prevailing stress pattern characteristics of the Pan-African event. The E-W trending fault lines were recognized in the Google Earth Map imageries and confirmed in the field during the mapping exercises. The fault was mapped as a normal dip-slip fault that cuts across the metasediments. The fault lines were traceable and were mapped in several locations in the metasediments. The fault zone is depicted by the E-W trending sloped topography.

Fig. 10. Veins and dykes seen in the host rocks along Auchi-Ibillo road (a) Swarm of dykes and veins in weathered schist. (b) Syenite dyke cut a MTC. Note: the red arrow points at dyke

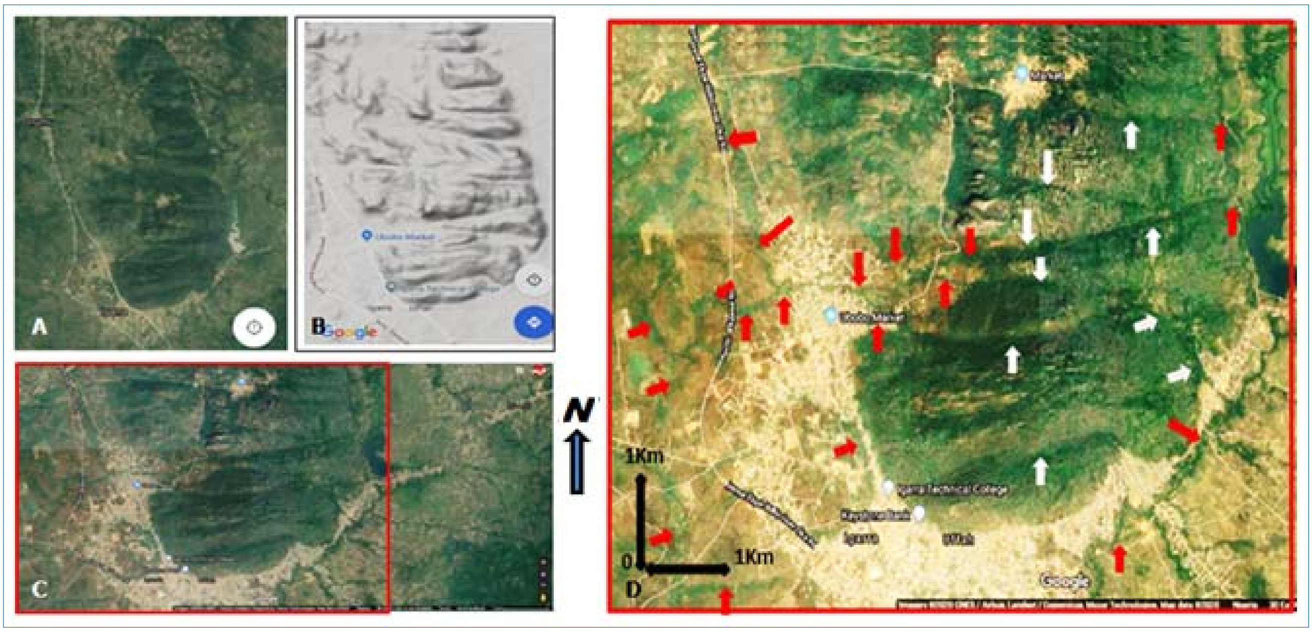

Fig. 11. Satellite imageries of study area of Igarra from Google Earth (a) Satellite view of Igarra Note: the cropped area is the study area. (b) The terrain view (c) Enlarged Satellite views of the study area from 11a. (d) Shows some of the mapped faults. Note: the red arrows pointing at some of the mapped faults and white arrows point at visible lineaments identified on Google Earth Satellite but are inferred due inaccessibility of the terrain)

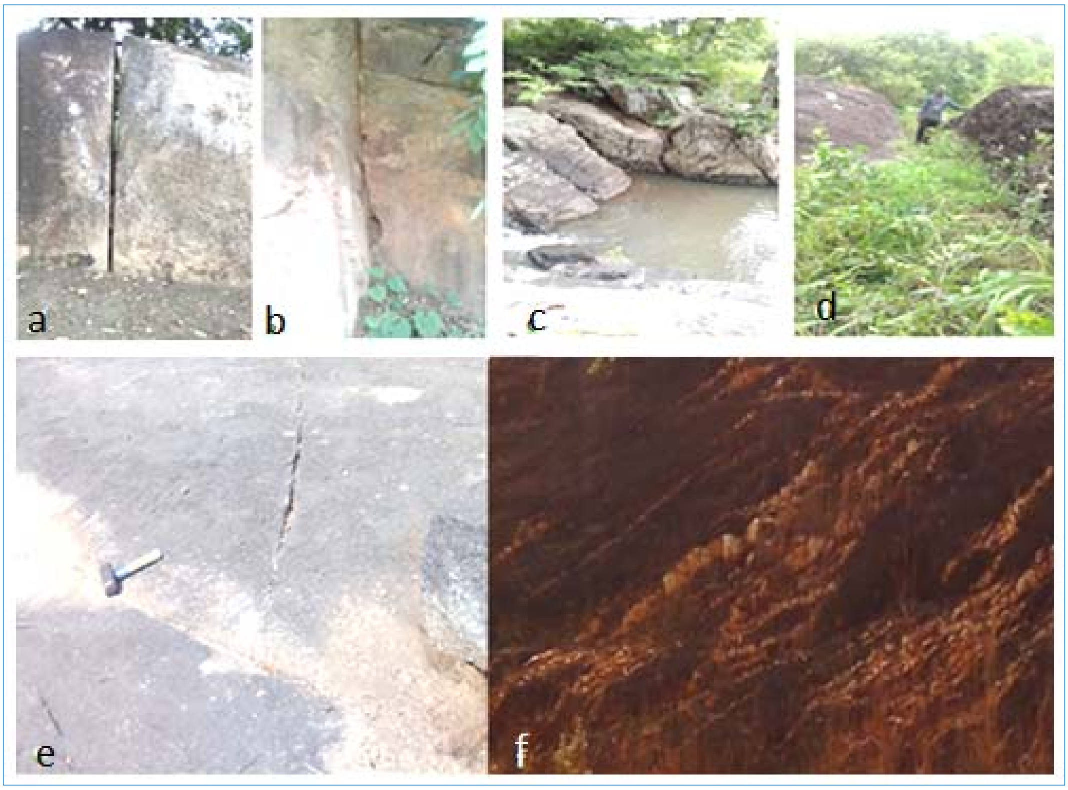

Fig. 12. (a) Vertical E-W joint in granite along Enwen road (b) Vertical E-W joint in granite along Auchi – Ibillo road. (c and d) Mapped E-W Faults in QSS and MCG (e) A vein trending in N-S direction (blue arrow) in granite terminated a younger E-W fracture (red arrow). (f) Sub-vertical swarm of quartzo-feldspartic dykes

The fault causes the change of drainage flow direction in the area from relatively N–S to E-W and flow from the pluton at Somolika Road junction in Igarra with a stretch of over 4 km and terminated by N–S fault along the Igarra–Okpe Road. The E–W fault is one of the longest water channels in the study area and the rocks within the fault zone are remarkably weathered.

6.3. Foliations and Folds

6.3.1. Foliation

Foliation is a continuous or discontinuous layer structure in metamorphic rocks formed by the segregation of different textures. Foliation also occurs in form of lithological banding or minerals realignment (schistosity) due to pressure and temperature conditions. The primary foliation (S_0) is the horizontal bedding plane formed as a result of compaction and lithification of the precursors of the metasediments i.e. lithostatic pressure. It was formed parallel to the first secondary foliation (S_1) during the first deformation (D_1) in the Schist belts also described as earlier minor phase by Odeyemi (1988). Large parts of the primary foliations, S_0 have been affected by this later deformation. The first recognized planar fabric in the metasediments is designated S_1 foliation. It is a common feature in the rocks except the quartzite and is defined especially by the alternating bands of leucocratic and melanocratic minerals. The schists in the area exhibit mineralogical banding that trend in N-S and NNW-SSE with the stretched pebbles and boulders in the metaconglomerate that makes the rock appears foliated.

The S_1 is the secondary foliations in the metasediments and the later S_2 foliations are associated with the D_2 deformation during the main stage of the Pan-African event. This foliation is pervasive and occurs in all the metasediments, trending generally in NW-SE to N-S directions. The dip directions also varied from west to the east in the quartz-biotite schist which suggests the presence of an antiform in the area (Figs. 13b and 3).

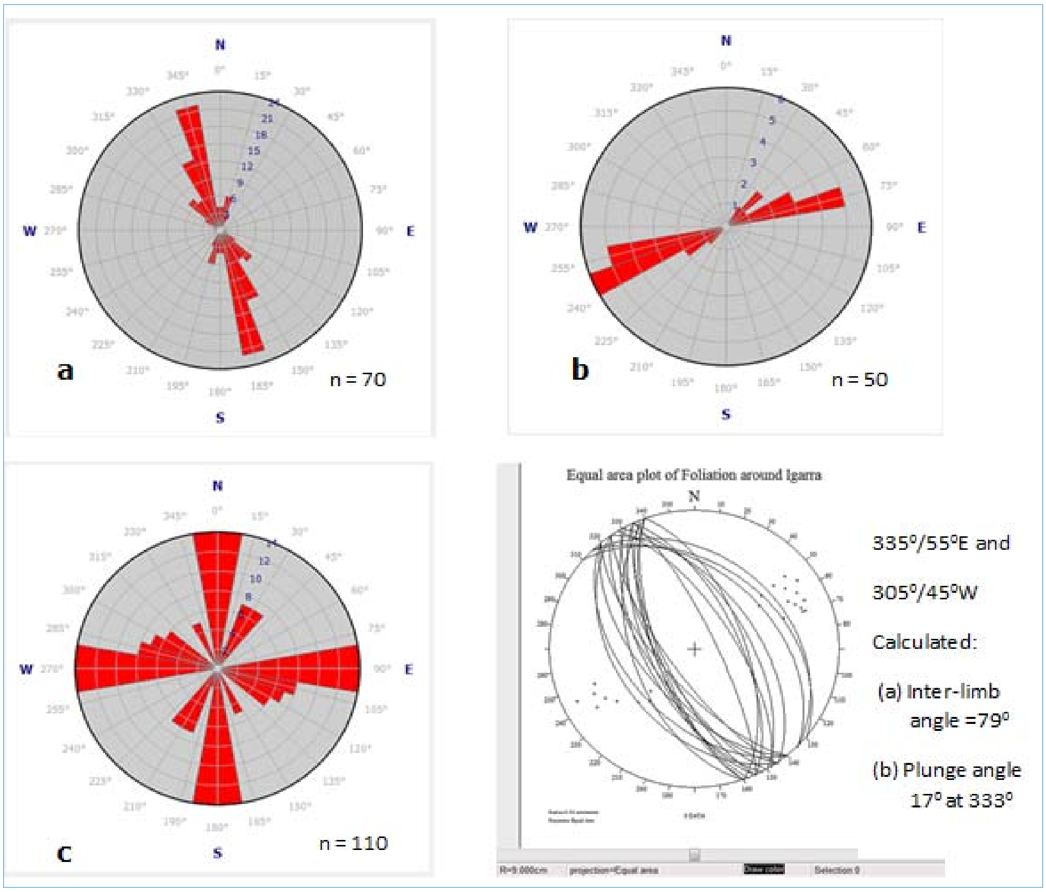

Fig. 13. Rose diagrams for difference structures in the study area. (a) Strike of foliation planes in the schist (b) Dip directions in QBS (c) Trend of fault planes. (d) Equal area plot of foliations in schist

6.3.2. Folds

Folds represents plastic deformation of rocks under medium to high pressure and temperature conditions usually deep beneath the earth. They are documented evidences of ductile deformation in the affected rocks. Two sets of folds were mapped - the regional fold (F_2) and the minor fold (F_1). During the D_1 deformation phase, the S_1 was probably folded (F_1) with axial plane sub-vertical to the initial S_0 orientation. The S_1 was refolded during a later phase of progressive deformation. These two foliations became parallel to produce S_1-S_2 composite foliation.

7. Structural and Evolution Model for the Study Area

The Igarra Schist Belt among other belts is believed to have evolved through ensialic evolution processes (Turner, 1983). The crustal thinning of older metasediments (granite gneiss) about 1000 Mya during an extension regime and subsequent continental rifting culminated in the formation of N-S trending basins that accommodated the precursors of the schist belts. Table 1 summarized the suggested sequence of geological events for the area. The early phase is characterized by development of foliation (S_1) parallel to the bedding plane S_0 in the precursors of the metasediments in response to lithostatic pressure. The foliations are defined by development of schistosity in the metasedimentary rocks by orientation of linear minerals like hornblende and platy minerals such as biotite and muscovite. The schists were later deformed during the compressional regime (D_1) that closed the basins causing the folding (F_1) of the trapped sediments that formed the schist belts (Fig. 14).

The Pan-African tectonics probably reactivated the belt during the main phase of the Pan-African Orogeny. This phase was also associated with the second deformation regime (D_2) and subsequent refolding of (F_1) fold to tight and isoclinal fold in the limb of the regional fold F_2. The dip angles of the regional planar surfaces are generally sub-vertical and corresponding to NW-SE and NNW-SSE strike directions that depict attitude of the major fold (Fig. 14). This deformation also produces a plunging direction in 333^0 at moderate angles of 17^0 to the north in the metasediments (Fig. 13d).

The late Pan-African tectonic phase is characterized with emplacement of undeformed dykes, final shearing and uplift due to erosion (exhumation), faulting and weathering that results in the present topography (Fig. 14f). Presence of boudins in the metaconglomerates indicates occurrence of extensional stress on competent quartz veins within the incompetent rock probably during the stage of deformation and shearing. The different stress regimes left imprints of various generations of joints, fractures and faults. The E-W fault was reactivated and initiated normal block faulting along the fault zone.

Table 1. Suggested Sequence of geological events in Igarra area

Stages	Geological Events	Age
8	Final shearing, uplift , reactivation of faults and weathering	Post-Pan-African
7	Emplacement of undeformed basic dykes	Late Pan-African
6	Emplacement of granodiorite and quartz veins	
5	Metamorphism (M2) and deformation (D2) of metasediments (folding/faulting). Emplacement of granites and formation breccias	Main stage Pan African (600 ±150 m.y)
4	Metamorphism (M1) and deformation (D1) of the granite gneiss and sediments to form schist, calc-sillicates and quartzite	Early Pan-African
3	Deposition of shale, siltstone, sandstone, limestone/marls in the basins.	??
2	Formation of a shallow basin	
1	Emplacement of granitic rocks which was metamorphosed to form migmatite-gneiss	Eburnean??? (2000 ± 150 m.y.)

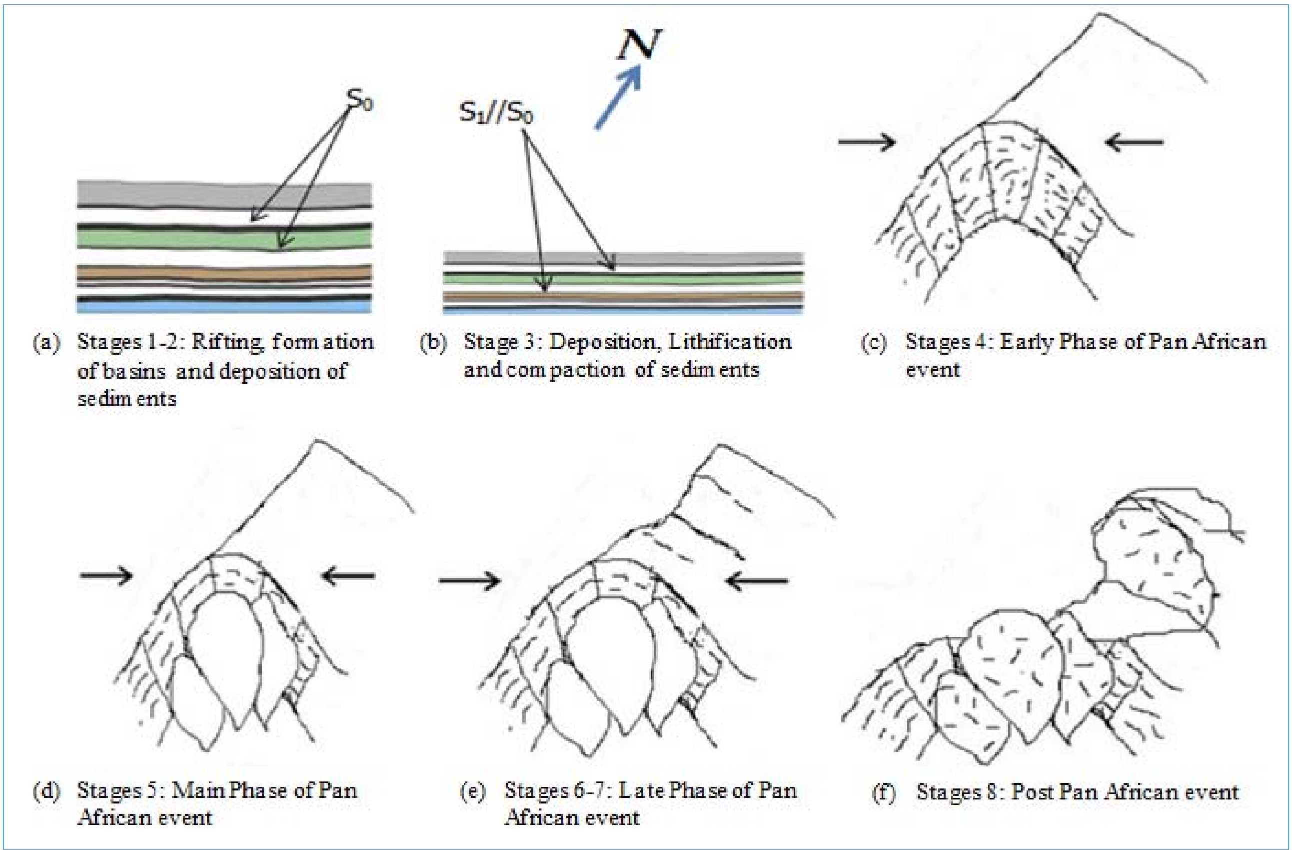

Fig. 14. a-f: Schematic diagrams of geologic evolution model of the study area in Igarra and the associated deformation stages

The tectonic event did not only reactivate pre-existing faults; it is also associated with N-S trending directions with complementary NW-SE and NE-SW joints sets. This interpretation also laid credence to Danbatta (2010); Udinmwen et. al., (2016); Ogunleye et. al. (2018). Although some structural features in the area support several episodes of deformation, the Pan-African Orogeny had a stronger control and impact on the evolution of rocks in the area.

5. Conclusion

The study established that the rocks in the area comprised suites of metasediments and the Pan African granitoids (porphyritic biotite granite, minor intrusions–granodiorite and quartzo-feldspartic dykes). Evidences from field relations and observations confirmed the Pan African granitoids intruded the QBS in N-S direction along the antiform of the regional fold. The emplacement was coeval with metamorphism (M_2) and deformation (D_2) in the meta–sediments. The granitoid emplacement was characterized by reactivation of pre-existing faults, joints and an assessment of the Pan-African orogenic influence on the Igarra Schist Belt within the study area has yielded the following confirmations:

- The orogeny initiated the granitoid emplacement and shears movement in the fault zone. This event had greatly affected the architecture of the rocks.
- Metasediments are the host rocks to the granitoids.
- Pan African magmatic activities contributed to the minerals distributions and injection of materials in the dilational zones in the metasediments.
- Granitoids emplacement initiated, reactivated and mineralized some fractures and joints seen as veins in the schist belt.

The Pan-African stress patterns were boldly expressed as veins, joints and foliations which trended mainly in the N-S, NW-SE and NE-SW.

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