DOI: https://dx.doi.org/10.4314/gjgs.v20i1.1

GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL. 20, 2022: 1-17
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STRUCTURAL FRAMEWORK AND DEFORMATION EPISODES IN THE IGARRA SCHIST BELT, SOUTHWESTERN NIGERIA

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(Received 14 September 2021; Revision Accepted 1 December 2021)

ABSTRACT

The structural framework of the Igarra schist belt consists of brittle (mainly fractures) and ductile (foliation, cleavage, folds, lineations, strain markers) structures. The geometry of these structures reveals two major occurrences of transpressional deformation affected the schist belt. These are an older dominantly ductile deformation with NW–SE λ_1 which developed foliations, cleavage, folds, and mineral/stretching lineations deforming only the metasediments and a younger brittle–ductile, E-W tectonic shortening deformation which closed deformations in the Igarra schist belt, deforming both the metasediments and granitoids, producing almost all the brittle structures in the belt. Minor fracture trends which are not associated with any of the major episodes of deformation and E-W transposition foliation in marble and gneisses constitute a relic of an unconfirmed possibly older episode of deformation. Ductile and semi-brittle shear zones in the Igarra schist belt are few and usually occur on small scale (outcrop scale), hence, they do not constitute a major episode of deformation. Mineralizations in the Igarra schist belt are pegmatite and quartz which are emplaced mainly in fractures with industrial minerals like marbles.

KEYWORDS: Igarra schist belt, tectonic shortening, extension fractures, foliations, folds

1. INTRODUCTION

Rock deformation and tectonic plate evolution are dependent on the deformation behaviour of rocks over geochronological scales (Czeck et al. 2009). The structural framework of a geological material or region is therefore a function of the deformation history over space and time. While there are numerous more deterministic methods (conjugate shear fracture studies, paleostress inversion, fault kinematic studies, strain analysis, etc) that describes the configuration of paleostress, strain, and even deformation history of a region, individually, these methods cannot give the complete deformation history of a region especially in regions with polycyclic episodes of deformation.

There are over thirteen schist belts in Nigeria formed or reworked by the Pan African orogeny including the Igarra schist belt which is outstanding because of its level of exposure, structural variance, and heterogeneity in terms of rock types within the belt. This study, though aimed mainly to unravel the complete deformation history and structural framework of the Igarra schist belt, also serves to discuss the folding pattern within the belt which can be crucial to understanding the nature and structural history of other structures within the belt which may trap natural resources (Esmaeili et al., 2015). Previous structural studies in the Igarra schist belt reveals that at least two episodes of deformation or folding affected this schist belt (Odeyemi 1976;

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Rahaman 1989; Udinmwen 2016). However Ocan (2016) identified five episodes of deformation.

This study utilised both spatial and temporal, field–based information to elucidate the structural framework of the Igarra schist belt Nigeria. Thus it was possible to discuss the deformation history of the schist belt within plausible errors. The study reveals two major episodes of transpressional deformation that affected the Igarra schist belt with relics of a third, probably earlier deformation observable in some rock types. Furthermore, mineralization in the schist belt occurs systematically along planes of weakness (foliation and fractures), with the majority of minerals occurring in fractures.

2. Regional geologic setting

Nigeria and a sizeable part of West Africa bear evidence of the Pan African Orogeny (Turner, 1983) and it is located within the Pan African mobile belt (Fig. 1). Tectonic shortening is evident at the Pan African mobile belt boundary and the West African Craton while its boundary with the Saharan Metacraton boundary shows evidence of shearing (Ferré et al., 1995). The Nigerian schist belts, sometimes regarded as infolded belts (Turner, 1983) and rests/overlain on a repetitively deformed and poly metamorphosed migmatite-gneiss complex (McCurry, 1976; Grant, 1978). In terms of petrology, structures, and metallogenic the Nigerian schist belts, which occupy a basically N-S trending trough (Elueze 2002; Elueze and Okunlola 2003), and are common in western and northern Nigeria (Turner, 1983; Danbatta, 2003). Nevertheless, schist belts and regions occur in the central and eastern portions of Nigeria (Oluyide and Okunlola, 1995; Oden, 2012a; Asinya et al., 2016; Oden et al., 2017).

The Igarra schist belt is located to the east of Nigeria's southwestern basement complex. The rock assemblages found in the 50-kilometer-long, NNW-SSE-trending Igarra schist belt are diverse and are as follows;

i. Basement rocks (gneiss)

ii. metasediments e.g., calc-gneisses, phyllites, quartzites and schists as well as metaconglomerate,

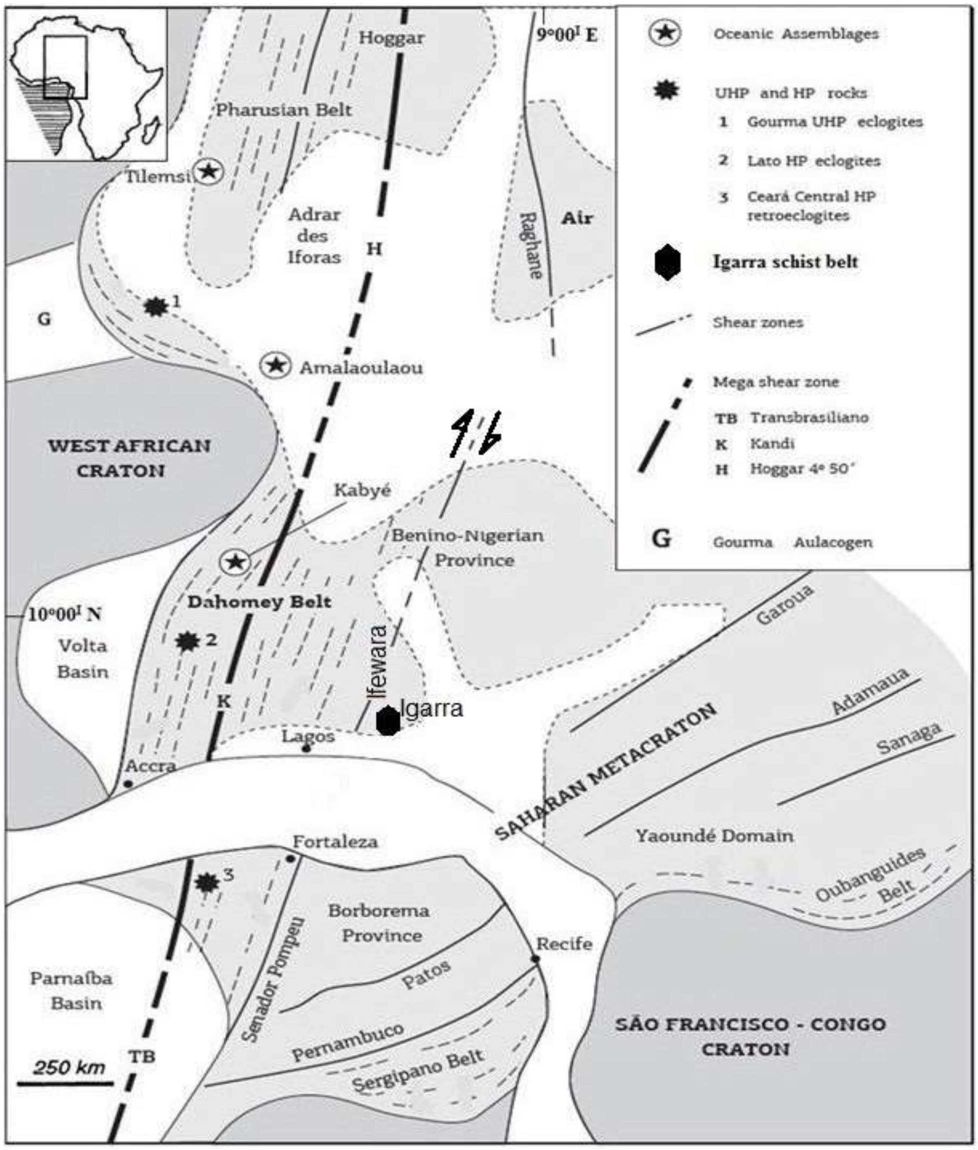

Figure 1: The key vertical shear zones and the location of the Igarra schist belt to other regional features are highlighted in this Pre-Mesozoic fit between the northern Borborema Province (NE Brazil) and the southern Nigerian shield (Africa). Modified from Cordiani, et al., (2014). The shear sense in the Ifewara shear zone is inserted from Ferré et al., (1995).

iii. the Older Granite intruded primarily the rims and centers of the metasediments and gneiss basement (Fig. 2), and is thought to be of syn-collisional, volcanic arc origin (Onwualu– John, 2015) and

iv. Syenite dykes that are late discordant and non-metamorphosed. Numerous dykes of lamprophyre are found intruding the schist and phyllite while pegmatite dykes are widespread throughout the schist belt.

The Igarra metasediments are laid on the gneiss basement and forms a linear/semi-linear component which was most likely emplaced in a miogeosynclinal trough. The Pan African thermo-tectonic occurrence folded and metamorphosed this sequence (Odeyemi, 1976).

Metamorphic grades in the Igarra schist belt range from dominant greenschist to lower amphibolite facies with Barrovian type metamorphism (Egbuniwe and Ocan, 2009). The Igarrametapelites consist of andalusite-staurolite-garnet metamorphic assemblage equilibrized at temperatures and pressures of 550±50 °C and c. 3 kbar (Omitogun et al., 1991; Egbuniwe and Ocan, 2009). The effects of contact metamorphism reflect as oval spots (0.5 to 2 cm) common in phyllites and mica schist (Udinmwen 2016; Udinmwen et al., 2016a) towards the southern section of the schist belt in close affinity with granite plutons (Egbuniwe and Ocan, 2009; Udinmwen 2016; Udinmwen et al., 2016a). Rahaman (1989) documented three occurrences of metamorphism in the pelitic schist with some associated with major episodes of folding. Early Proterozoic crusts have remained dated in this belt (Annor, 1998) though it is presumed that the schist belt (Igarra) is of Pan African origin (Turner, 1983; Archanjo et al., 2013). The formation of metasediments in Nigeria has no confirmed ages however minimal for metamorphic cooling ages of 750–450 Ma have been derived from Rb-Sr and K-Ar studies (Dada, 2008).

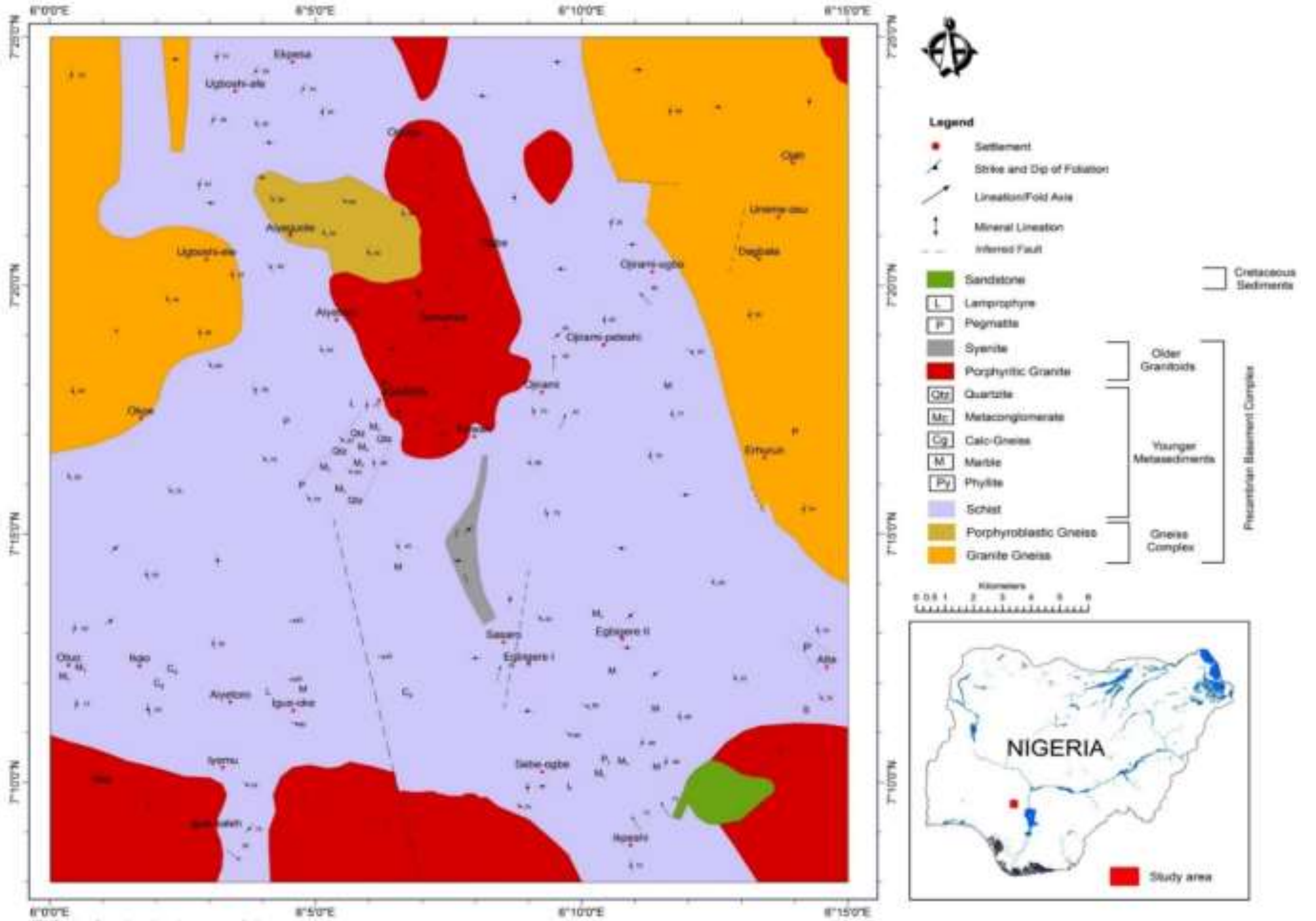

Figure 2: The study area geological map (modified after Nigerian Geological Survey (Lokoja Sheet 62) and Odeyemi (1976)).

The Igarra schist belt lies many kilometres to the east of the Ifewara shear zone and this shear zone appears to have a similar trend as other shear zones notably the Senador Pompeu shear zone in Brazil (Archanjo et al., 2013). This schist belt and shear zones are associated with granitic magmatism as well as high temperature/low-pressure metamorphism (Lima, 1987; Zeh and Holness, 2003).

Conjugate shear fracture studies reveal at least two axes of tectonic shortening in the schist belt (Udinmwen, 2016) which somewhat corresponds to the ideas of Odeyemi (1976) and Rahaman (1989). However, Ocan (2016) identified at least four episodes of ductile deformation (D_1-D_4) and late semi-brittle shear zones and faults (D_5).

3. MATERIALS AND METHODS

This research entails extensive mapping of rocks and structures, with a focus on the schist belt's structural profile.

The Igarra schist belt mapping was carried out on a scale of 1:25,000 over about 850 km^2. Using ArcGIS 10 software, the geology and structures of the study area were methodically mapped, and a geologic/structural map of the schist belt was produced (Fig. 2).

4. RESULTS

4.1. Mesoscopic structural profile

The rocks of the Igarra schist belt contain various structures such as joints, folds, faults, mineral lineations, foliation’s, schistosity, cleavage, mullions, strain markers, and ductile shear zones. Some parts of the Igarra area are well exposed (Egbuniwe and Ocan, 2009) thus mapping of the rocks and structures is quite easy. The schists are the belt's most extensive rocks, consisting of upper greenschist facies metapellite with interlayered quartzite, marbles, and metaconglomerates that form a supracrustal overlay on older migmatites (Hockey et al., 1986, Ocan et al., 2003) and the pelitic schist sometimes forms continuous ridges overlain by a narrow band of quartzite. The high rising granite plutons in the schist belt occur as “bell shape” ellipsoidal plutons or as ‘‘table-top’’ elongated plutons which may be porphyritic or non-porphyritic (Figs. 3a and b) and they intrude gneisses, schist, and metaconglomerate where they display a sharp contact relationship with a thin chilled zone as observed in the granite-schist contact along Igarra Somorika road (Fig. 3c). The high degree of jointing in the Older Granites in this region and their high resistance to weathering tends to result in good topographic expression and a degree of out-cropping noticeably higher than the other major components of the basement complex. The granite generally averages about 500m above sea level and trends in the N-S/NNW-SSE directions. The post to late-tectonic, unmetamorphosed composite syenite dyke measuring 6km by 0.7 km and cutting obliquely across the metasediments, is emplaced in perhaps the last events to affect the geology of this area (Odeyemi, 1976). The gneisses are foliated and are usually porphyroblastic or granite gneisses which readily contain pegmatite veins. These veins run along foliation planes or in fractures. The marbles occur in economic quantities (Fig 3d) and are found mainly in Ikpeshi, Igue, Igarra, Egbigere, and Ojirami.

Figure 3: (a) High rising granite pluton along Igarra-Somorika road (b) Non-porphyritic granite in Dagbala (c) Sharp contact between schist and intruding granite showing a thin chilled zone (d) Marble quarry in Ojirami.

The marbles are foliated, jointed, folded, and sometimes contain bands of white and brownish colour especially at Igue. Recent geochemical analysis and economic potential studies of some marbles in the Igarra schist belt are contained in Obasi and Anike (2012), Obasi et al. (2015).

4.2. Planar Structures

4.2.1. Fractures

Fractures in the study area are joints, few faults (mostly schlieren wrench faults), and exfoliation fractures in granites (Figs. 4a-d). The joints in the rocks show varying degrees, nevertheless the attitude of fractures forming joint sets in the schist belt is fairly constant (Fig. 4a–d). The stereographic projections of the various rocks in the Igarra area from poles to planes of joints, which was contoured with the Fisher distribution counting method. The stereographic examination of the joints in the gneisses reveals that they are of high-angle, and the structures are primarily trending E-W (Fig. 5a). Furthermore, the granites show a similar scenario with the main two joint sets which are of high angle, trending E-W, and a minor medium angle trending N-S commonly found/noticed along Igarra-Ibillo expressway road (Fig. 5b). The marble has high-medium angled E-W trending joints (Fig. 5c) while the fractures in metaconglomerates are oriented in the N-S direction (Fig. 5d). The phyllites are the only rocks in the study area with medium angle NE-SW trending joints (Fig. 5e) while the quartzite and schist show/reveal dominant high angle trending E-W joints (Figs. 5f and g). The syenite dyke which is believed to be a late-stage granitoid (Odeyemi and Rahaman, 1992), contains high angle E-W trending joints with dextral schlieren strike-slip fault parallel to the E–W direction (Fig. 4d), nevertheless a minor N-S trending, medium angle set also occurs (Fig. 5h). Within the study area, they are generally two major dominant patterns of jointing; the E-W trending fractures and the sparsely occurring N-S trending joints.

Figure 4: Joints and fault in the study area (a) The succession of N-S trending joints along Igarra – Ibillo expressway (b) T – joints in granite showing their age relationship along Igarra – Enwan road (c) Exfoliation/sheet joints along Igarra – Somorika road (d) Schlieren dextral strike – slip fault with offset parallel to the E-W direction.

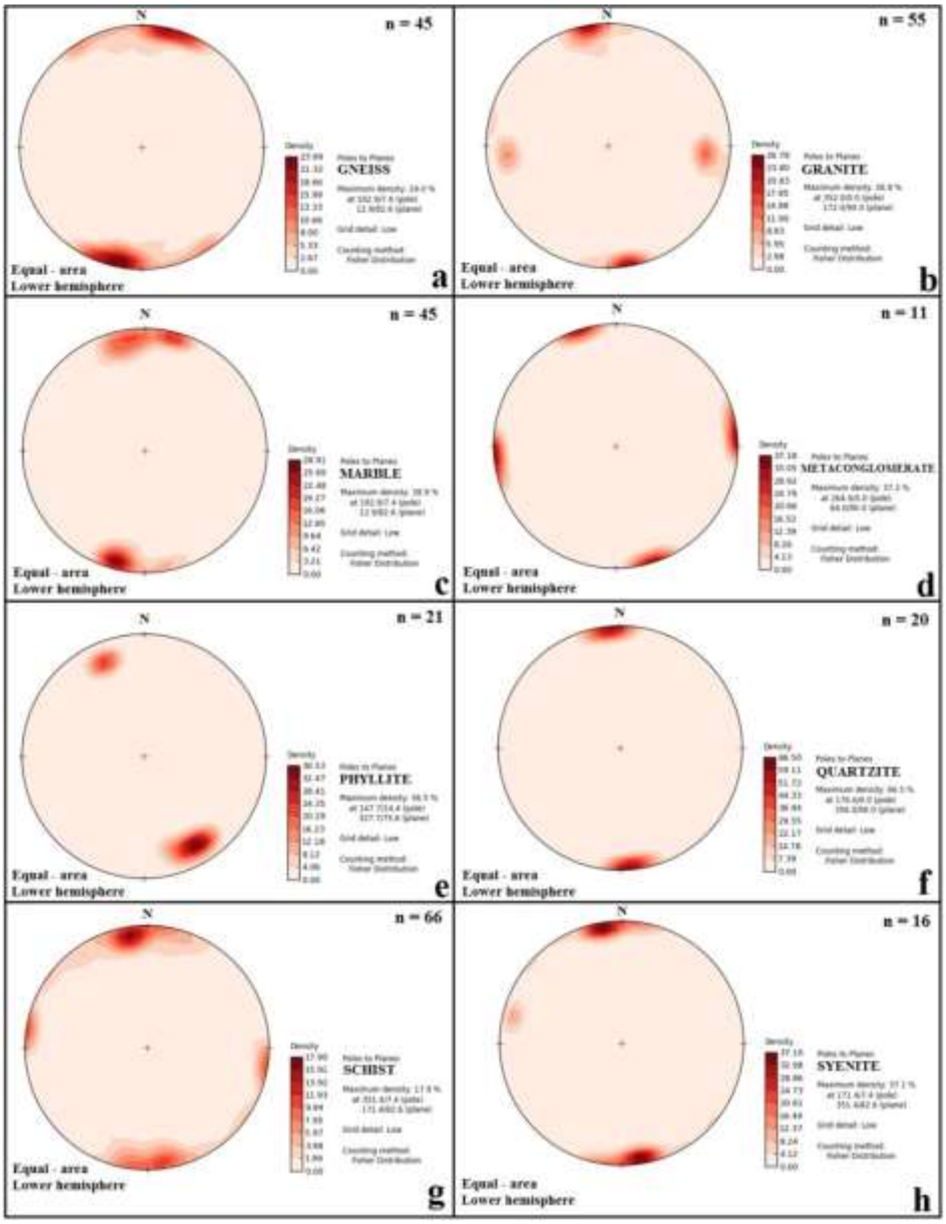

Figure 5: The stereographic projections of the lower hemisphere joints as poles (a) Stereographic projection of joints in gneiss (b) Stereographic projection of joints in granite (c) Stereographic projection of joints in marble (d) Stereographic projection of joints in metaconglomerate (e) Stereographic projection of joints in phyllite (f) Stereographic projection of joints in quartzite (g) Stereographic projection of joints in schist (h) Stereographic projection of joints in syenite.

The observed joints are typically of high to medium angle, with no preference for dip direction. Apart from the dominant fracture orientation described above, minor NE-SW trending fractures occur in the gneisses, metaconglomerates, schists, and syenites. ESE–WNW fractures were observed in the gneisses and schists while minor NW-SE trending fractures are found in the granites. These fracture sets are highly insignificant compared to the dominant fracture sets which trending in the E-W and N-S directions. Exfoliation (sheet) joints though not common in the Igarra granites, occur in a few plutons along Igarra-Somorika road (Fig. 4c). This suggests a near-surface deformation most likely related to cooling and exhumation or unroofing of the granites.

In most regions, there are at least two and perhaps more prominent joint sets that form the joint system in area (Hills, 1972). In the Igarra schist belt, there is two prominent joint sets which are the E-W and N-S trending fractures with the former more dominant (Fig. 5). The granites commonly contain T-Intersection joint patterns (Fig. 4b); the joint is labelled ‘x’ trending E-W direction, while the joint trending N-S is labelled ‘y’. The most fundamental joints in any tectonically active region are the ‘ac’ extension fractures parallel to the tectonic shortening axis (σ_1) and they develop first (Gudmundsson, 2011; Oden and Udinmwen, 2014a, 2014b; Oden et al. 2016). The ‘bc’ tensile fractures, on the other hand, form by absolute tension, normal to $\sigma_1$and ‘ac’ extension fractures, which may be parallel to the fold axis and are mostly confined to the shallow part of the crust (Gudmundsson, 2011). Thus, the older E-W trending fractures are the ‘ac’ extension fractures while the younger N-S trending fractures are the ‘bc’ tensile joints. The major fractures in the schist belt formed at different times within the same episode of deformation (E-W tectonic shortening) however, the presence of minor trends (NE-SW, ESE-WNW, NW-SE) shows the possibility of fractures from other deformation episodes. The dominance of E – W tectonic fractures implies that either this deformation episode had a strong healing effect on fractures of older episodes of deformation or the older episodes of deformation was predominantly ductile.

4.2.2. Foliations

The study area comprises of foliated rocks which are schist, gneiss, marble, quartzite, metaconglomerate, phyllite, and calc-gneiss (Figs. 6a-d). The foliation planes in the schist are well developed but sometimes show poor cleavage (Fig. 6a) and are vertical in some cases (Fig. 6b). The metaconglomerate shows weak but discernible foliation and the planes are in most cases gently inclined (Fig. 6c). The marbles are strongly foliated and dip steeply (Fig. 6d). Fig. 7 shows the plots of the attitudes of foliation planes measured in the Igarra schist belt. The gneisses are distinctly foliated trending in the N-S direction, while a minor foliation plane trending in E-W direction were observed (Fig. 7a). The gneissose foliation dips range from very low to medium angle (Fig. 7b). The schist foliation planes are high to medium degrees of dips, and their preferred orientation trends in the NW-SE and N-S direction (Fig. 7c and d). The quartzite is basically foliated strictly/predominantly in the NW-SE direction with angle dips ranging from 30^0 and 70^0 (Figs. 7e and f). The metaconglomerates shows a good foliation plane in the N-S and NW-SE directions (Fig 7g) and the dips vary widely (Fig. 7h). Like the gneisses, foliations in the marbles have a strong preference for the N-S d with a minor E-W direction (Fig.7i), and their dip angles are dominantly high with few medium angle dips also occurring (Fig. 7j). Generally, the metamorphic rocks foliation planes preferred two main directions, which are N-S and NW-SE, with dips ranging from medium to steep. (Figs. 7 k and l).

Foliations are homogeneously distributed planar structures in a rock (Twiss and Moores, 1993) and the foliation planes are usually perpendicular to the λ_3 direction, according to strain studies in foliated rocks (Cloos, 1971; Singhal and Gupta, 2010).

Figure 6: Foliation planes features in the study area (a) Poor fissility foliation plane (b) Vertical foliation plane in the schist (c) Foliation in metaconglomerate (d) Steeply inclined foliation in marble.

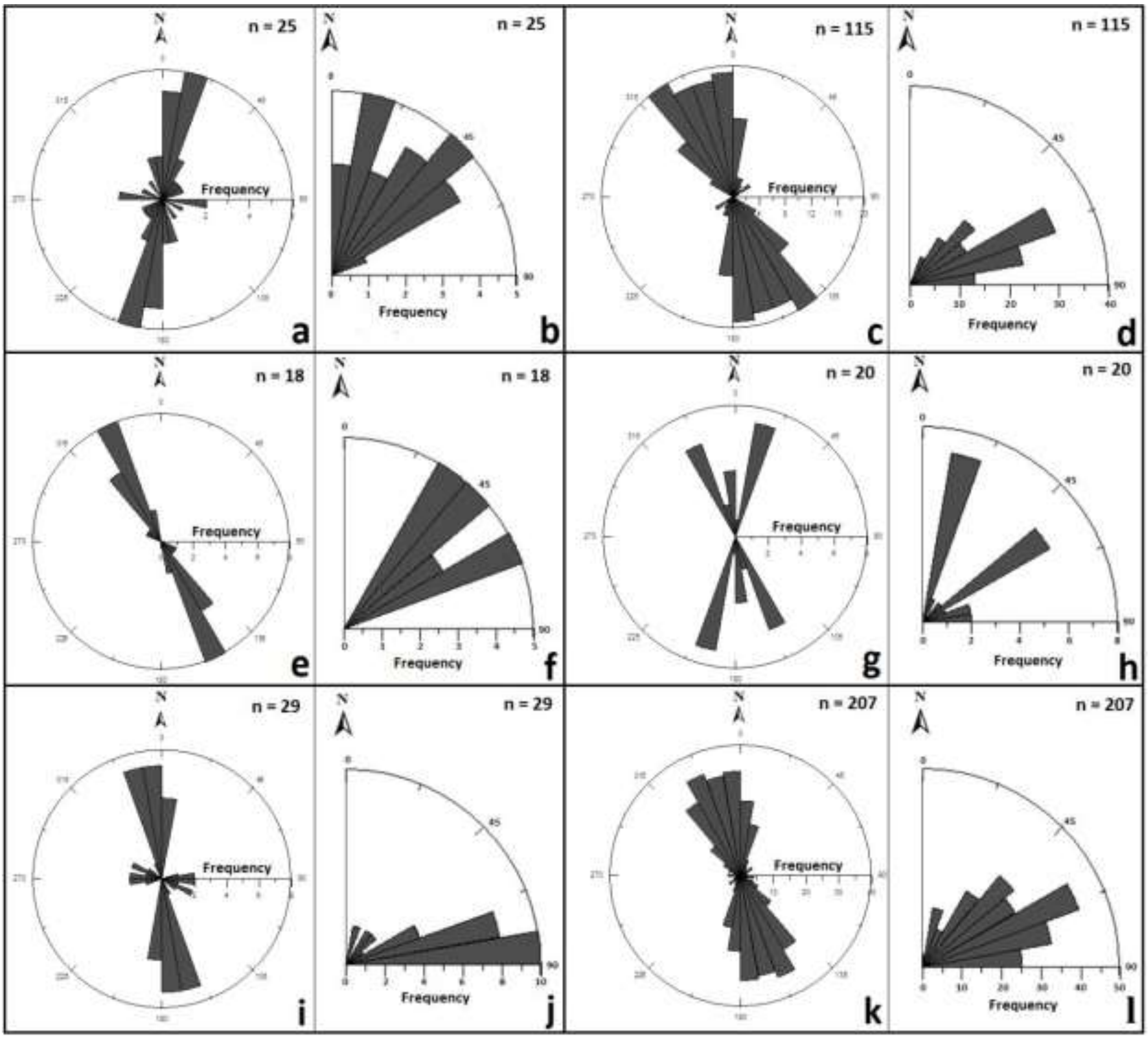

Figure 7: Foliation planes from rose and dip diagrams (a) Foliation planes in gneiss as represented from rose diagram (b) Dip diagram of foliation planes in gneiss (c) Rose diagram of foliation planes in schist (d) Dip diagram of foliation planes in schist (e) Rose diagram of foliation planes in quartzite (f) Dip diagram of foliation planes in quartzite (g) Rose diagram of foliation planes in metaconglomerate (h) Dip diagram of foliation planes in metaconglomerate (i) Rose diagram of foliation planes in marble (j) Dip diagram of foliation planes in marble (k) Rose diagram showing the general orientation of foliations in the study area (l) Dip diagram showing the general dip range of foliation planes in the study area.

The dominance of foliation planes in the N–S and NW–SE directions, therefore, suggests two different episodes of stretching/deformation in the schist belt. Insignificant but conspicuous E–W trending foliation planes were found in the gneisses and marbles. This probably represents relics of a possibly older episode of deformation which have been destroyed and reworked by the younger conspicuous episodes.

4.2.3. Cleavage

Cleavage in the Igarra schist belt is either refracted cleavage as it passes from one lithology to another or crenulation (strain – slip) cleavage (Figs. 8a - d). Crenulations or strain-slip cleavage is an earlier foliation formed by the preferred orientation of silicates which is then folded (Crenulated) on a micro-scale (Hobbs et al, 1976). The earlier foliations (S_1) have a NW – SE orientation while the latter foliations (S_2) are orientated in the N-S direction. The occurrence of strain – slip cleavage in the schist in the Igarra schist belt shows that the schist was poly-deformed and from the orientation of the cleavage (Figs. 8c and d), there are two episodes of deformation as suggested by the foliation planes. Generally, cleavage planes are normal to the direction of maximum compression (Billings, 1972). Refraction cleavage as it passes from one lithology to another has been recorded at Ojirami Peteshi (Fig. 8b). Crenulation cleavage is found in Igue – Saleh (Fig. 8c) and Ojirami Peteshi (Fig. 8d).

4.2.4. Mineral Veins and Dykes

The mineral veins in the study area are quartz and aplite veins (Figs. 9a and b). The quartz veins are widespread in virtually all the rocks in the schist belt while the aplite veins were found only in the granite. Minerals in the Igarra schist belt are emplaced mostly in fractures and along foliation planes (Fig. 9 a and b) however, fracture filling veins are predominant.

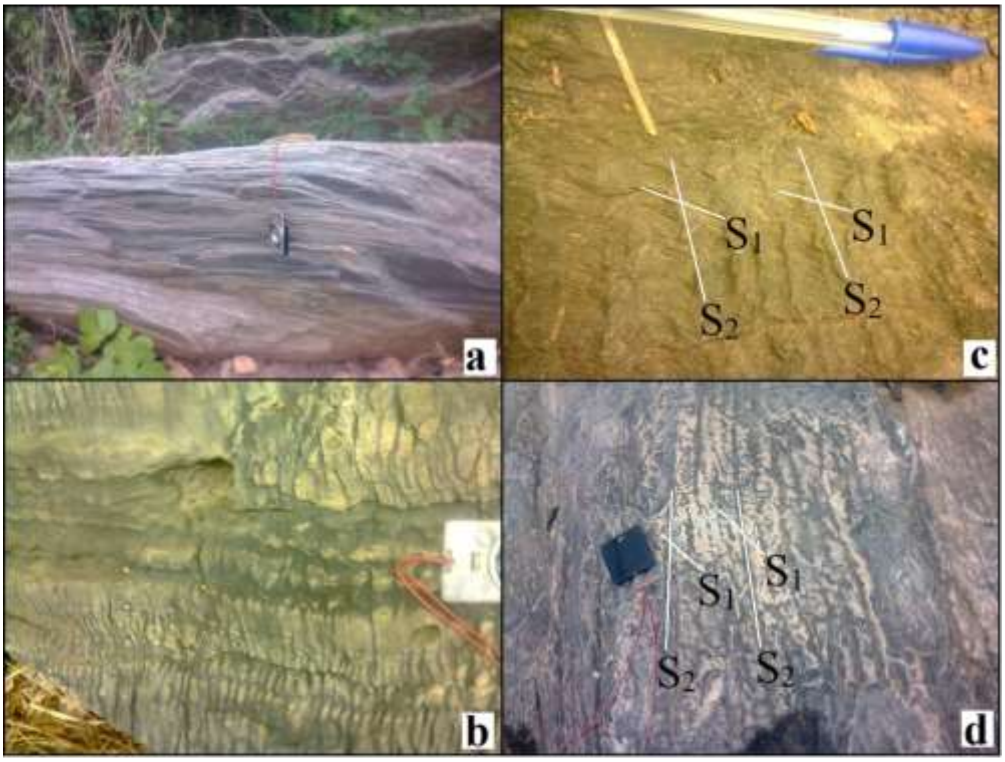

Figure 8: Cleavage in the study area (a) Cleavage in schist at Uneme Nekhua/Aiyegule (b) Refraction cleavage as it passes from one lithology to another at Ojirami Peteshi (c) Crenulation cleavage at Igue – Saleh (d) Strain – slip cleavage at Ojirami Peteshi.

Figure 9: Mineral veins and dykes in the Igarra schist belt (a) Quartz vein emplaced in E-W trending fractures in Dagbala (b) Quartz vein along foliation in quartzites west of Igarra (c) pegmatite dyke intruding gneisses in Erhurun (d) lamprophyre dyke intruding phyllites using foliation planes as conduit around Sebe-Ogbe.

The veins in fractures have a high angle dip, whereas those on foliation planes have a moderate angle dip. The dominant vein orientation in the Igarra schist belt is E-W, N-S, NW-SE, and very minor NE-SW sets. The E-W trending veins in the study area seem wider, fill 'ac' extension fractures, and are thought to be emplaced through a crack-seal process (Udinmwen 2016; Udinmwen et al., 2016b). The N-S veins on the other hand are very thin to the order of few centimetres and fills 'bc' tensile fractures while the NW-SE trending veins are usually thin, dips gently, and are emplaced along foliations commonly found in schists and quartzites (Fig 9b). Mineral grains that grow parallel to λ_1 tends to elongate fastest (Kamb 1959) and mineral veins preferentially forms in 'ac' extension fractures parallel to the tectonic shortening direction (Oden, 2012b, Oden, 2012c, Oden and Udinmwen, 2014a, Oden et al., 2015, Oden et al., 2016). The dominance of veins along E-W trending fractures further buttresses the idea that these are the 'ac' extension fractures parallel to σ_1.

The dykes in the Igarra schist belt are pegmatites and lamprophyres (Fig. (c and d) which mainly occur at or towards the south of Igarra (Fig. 2). The pegmatite dykes are dominant in the gneisses, schists, and granites (Fig 9 c) while the lamprophyres are found intruding schists and phyllites (Fig. 9 d). While the pegmatite dykes steeply dip and parallel to the E-W direction, the lamprophyres also dip steeply but seem to intrude the schists/phyllite via the foliation planes thereby assuming its orientation. The largest pegmatite dyke in the study area was found in Atte, it is over 50 m wide and was traced for about 500 m.

4.3. LINEAR STRUCTURES

4.3.1. Lineations

Lineation is used to describe all linear structures that occur repetitively in a rock such as elongate pebbles, slickenside striae, fold hinges, intersecting foliations, mineral lineations, rods, mullions, boudins (Hobbs et al, 1976). The preferentially aligned minerals which define mineral lineations may either be individual elongate mineral grains or elongated polycrystalline aggregate. Mineral lineation's are usually parallel to λ_1 direction because mineral grains grow fastest parallel to that direction (Kamb, 1959). Lineations were observed in most parts of the study area (Fig. 10a – d). The most common linear structure in the study area is mineral lineation where feldspar and biotite crystals in granite and syenite respectively are strongly oriented that it gives the rock a linear fabric (Figs. 10a and b). The phenocrysts and xenoliths in the granites are oriented in the N-S and NNW-SSE directions while slender biotite crystals in the syenite are strongly oriented in the N-S direction. Other linear structures in the Igarra schist belt include slickenside striae and mullions (Figs. 10c and d). In most cases, these linear features plunge towards the north.

4.3.2. Folds Axis

Folding in the Igarra area is readily observed in the schist and phyllite although the marble, quartzite, and calc-gneiss are also folded Figs. 11 and 12). These are mainly closed to isoclinal folds with few open and recumbent folds in the region (Figs. 11, Fig 12). Most of the folds are well exposed at Ikpeshi (Fig. 11a and b; Fig 12a) however they are also well exposed at Ojirami including a large antiform and synform occurring at Ojirami Peteshi along the Ojirami-Dagbala road (Fig. 11d). Parasitic folding containing z-type folds with dextral vergence, M-type folds at the axis, and S-type folds with sinistral vergence were observed along Ikpeshi road in a schist (Fig. 12a). Also observed in this area are symmetric brittle folds in phyllite (Fig. 12b) and drag folds in the schist around Igarra main town (Fig. 12c). Recumbent folding (Fig. 12d) is scarce in the study area and they are believed to belong to one of the earliest deformations that affected this region possibly pre-Pan African (Odeyemi, 1976; Egbuniwe and Ocan, 2009).

Figure 10: Lineations in the study area (a) Strong alignment of phenocrysts giving the rock a linear fabric in Ososo granite (b) Alignment of a slender, needle - like biotite crystals in syenite(c) Stretching lineation in schist at Ojirami Peteshi (d) Mullions, found a few kilometres west of Igarra.

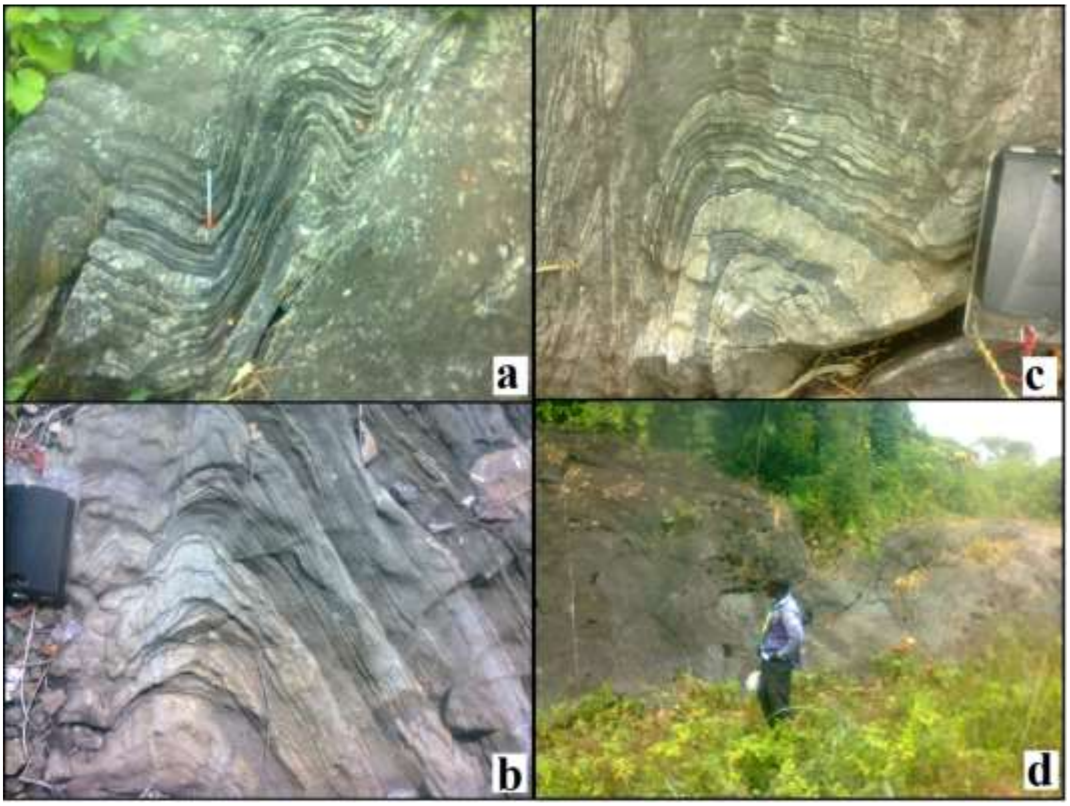

Figure 11: Folds in the schist of the study area (a) Close folds at Ikpeshi (b) Open fold with exposed gently plunging fold axis at Ikpeshi (c) Well developed folds at Ikpeshi (d) Large antiform and synform at Ojirami Peteshi.

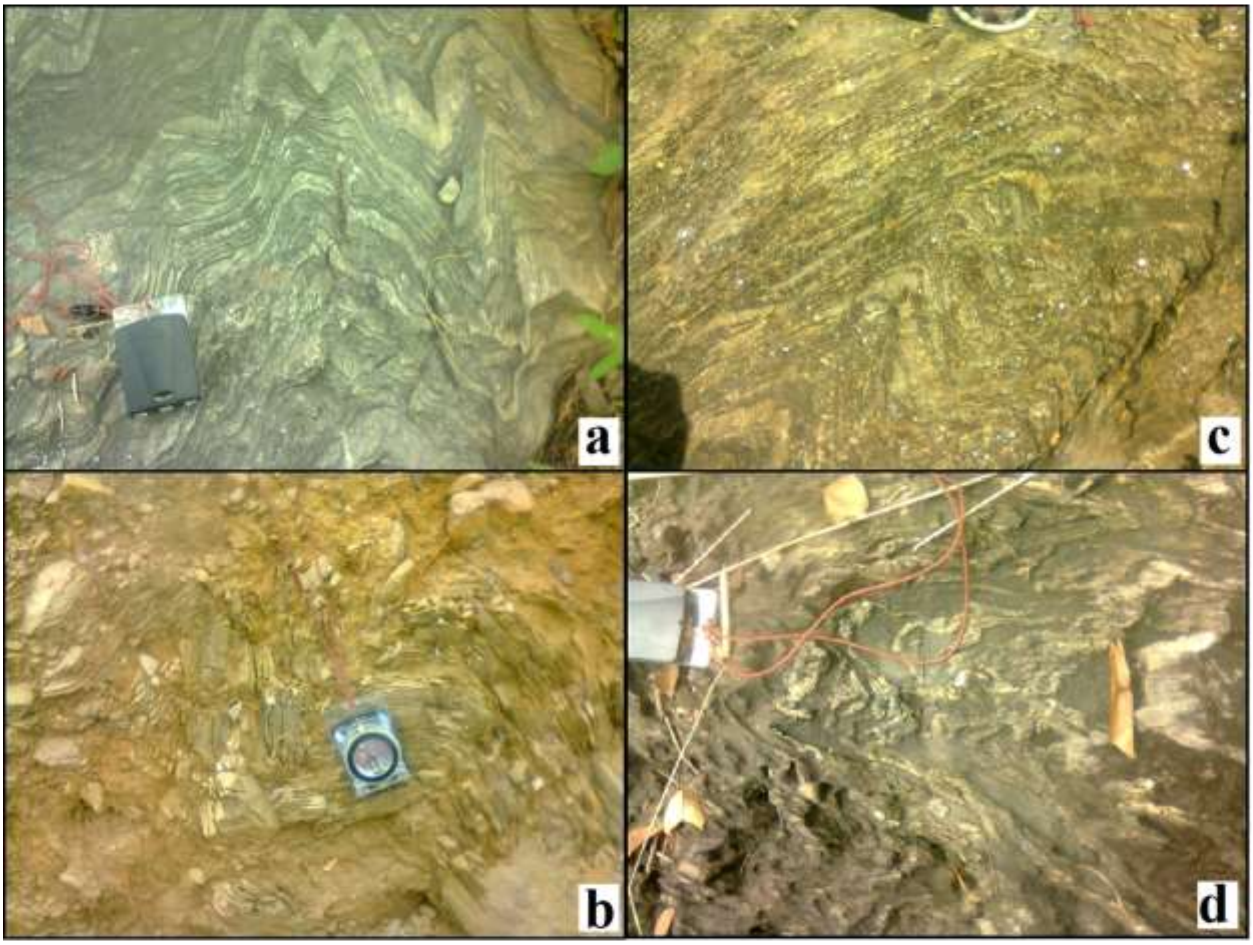

Figure 12. Fold geometry in the study area (a) S, M, and Z varieties of parasitic folds in schist along Igarra-Ikpeshi road (b) Symmetric brittle folds in phyllite (c) Drag folds in schist Igarra (d) Recumbent folds in schist along Igarra-Ikpeshi road.

A stereographic projection of the plunge magnitude and plunge direction of the fold axes (Fig. 13) shows that majority of the folds plunge towards the north and trend in basically in the NNW-SSE direction but a few a plunge in the N-S or NW-SW direction (Fig. 13). Fold axes are usually normal or near-normal to the σ_1 direction (Bruno and Winsterstein, 1994) thus the variation of the plunge direction of the folds implies multiple deformation episodes.

4.4. OTHER STRUCTURES

4.4.1. Strain markers and Shear zones

Strain markers and ductile shear zones are other structures that occur in the Igarra schist belt. The strain markers here are phenocrysts (Fig 10a) and xenoliths in granites, metamorphic spots in phyllite/schist (Fig 14a), and polymictic clasts in metaconglomerate (Fig 14b). The metaconglomerates are clast supported and contain clasts of pegmatites, quartz, and metasediments while the contact metamorphic effect is extensive/widespread around Sebe-Ogbe in form of oval spots 0.5 to 2 cm across in phyllite and mica schist (Udinmwen, 2016). These spots are mainly of quartz and muscovite, have been resolved/determine into rectangular-shaped cordierite and andalusite porphyroblasts near the Ikpeshi (Egbuniwe and Ocan, 2009). Detailed description of the strain markers and strain analysis results in the Igarra schist belt is contained in Oden and Udinmwen (2013), Oden and Udinmwen (2014b), Udinmwen (2016), Udinmwen and Oden (2016) and Udinmwen et al. (2016c).

Areas of high deformations, often localized in narrow zones and sub-parallel-sided are loosely called shear zones (Ramsay, 1980). The ductile shear zone in the metaconglomerate occurs a few kilometres west of Igarra with the clasts in the metaconglomerate smeared almost 3 to 4 times their original length without any physical break in the clast (Fig 14c).

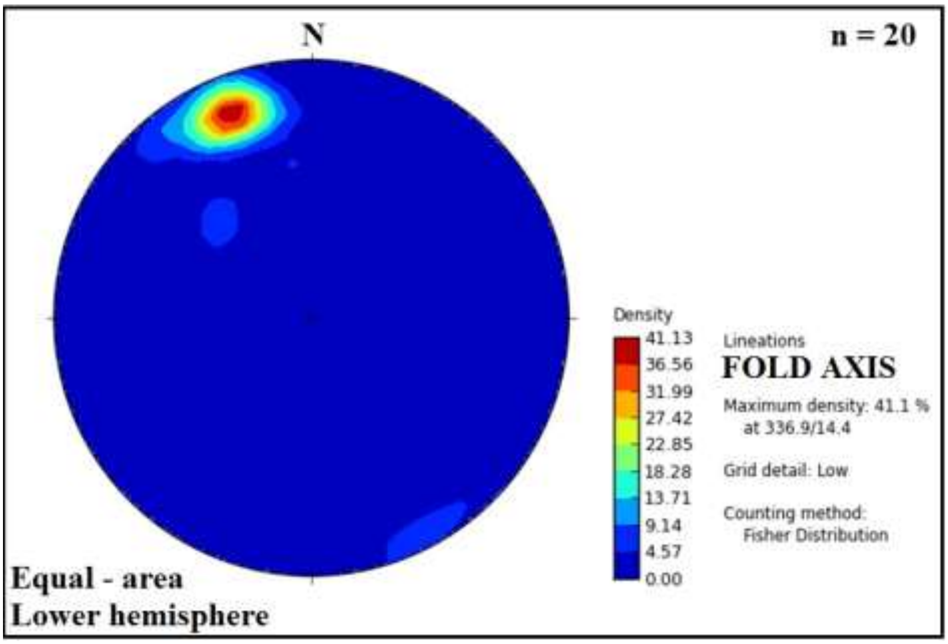

Figure 13: Stereographic projection of fold axes in all rock types in the study area.

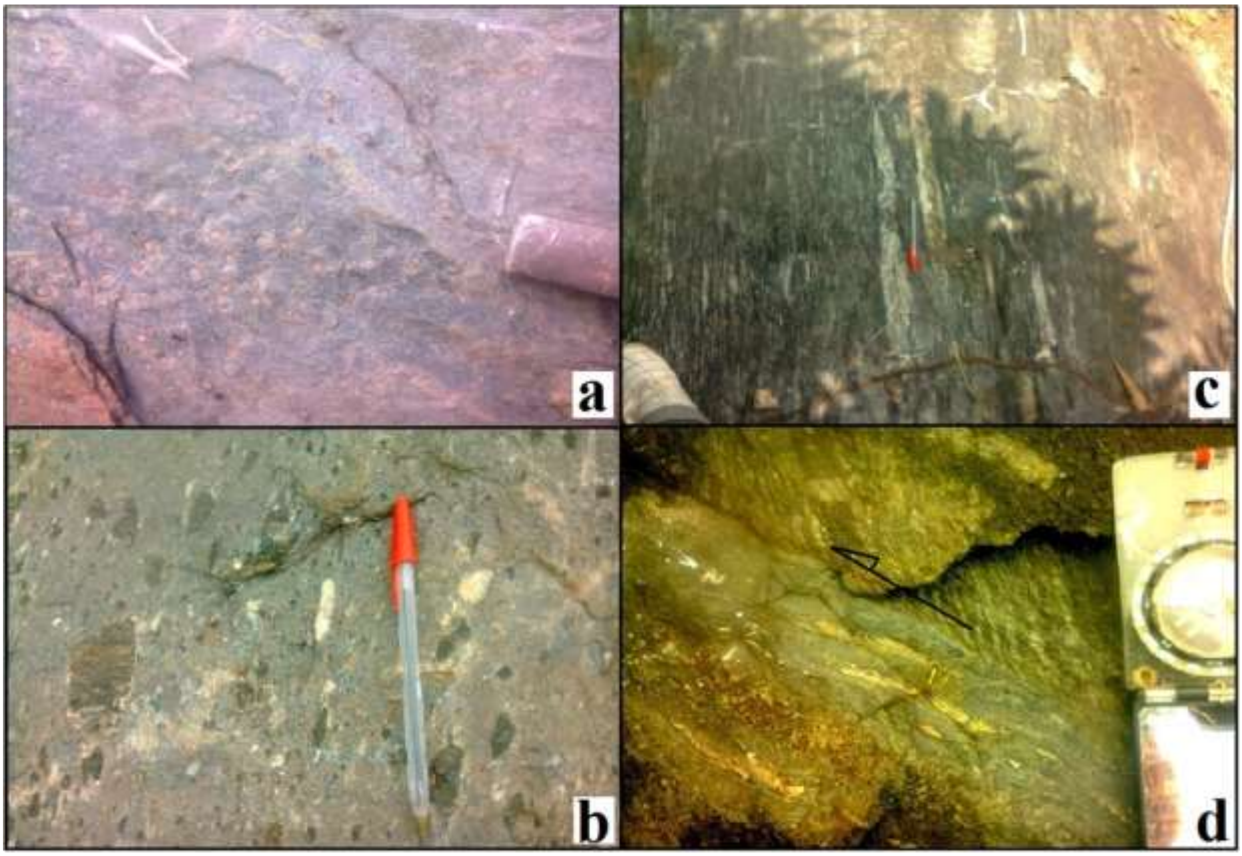

Figure 14: Strain markers and shear zones in the study area (a) Circular to oval metamorphic spot in schist
(b) Metaconglomerate with schistose and calc-gneiss clast around Sebe-Ogbe (c) Ductile shear zone in metaconglomerate showing the stretching of pegmatitic clasts without physical break west of Igarra (d) Ductile shear zone in schist showing a strong discordance of the features within the shear zone from those outside the shear zone at Igue-Saleh, South of Igarra. Such shear zone is not restricted to the metaconglomerate as it was also observed in schist close to the schist – granite contact at Igue-Saleh (Fig. 14d) where the schist is closely bound by granite bodies (Fig. 3)

5. DISCUSSION

The structural framework of the Igarra schist belt gives a clear insight into the deformation history of the belt. The brittle structures in the schist belt are fractures. Fractures within the Igarra schist belt are dominantly oriented in the E-W and N-S. The E-W fractures are older from the T-intersection joints in granite (Fig. 4b) and their dominance throughout the schist belt strongly suggests that they are the fundamental fractures in the schist belt parallel to the E-W tectonic shortening axis (σ_1), thus these fractures (E-W) are interpreted as 'ac' extension fractures parallel to σ_1 direction while the N-S joints are the 'bc' tensile joints of the same episode/occurrence of deformation. Therefore, the fracture system in the Igarra schist belt shows a single deformation episode with E-W tectonic shortening. The granite plutons, phenocrysts, and xenoliths are elongated in the N-S direction, thus this direction is probably the direction of maximum stretching (λ_1) as a result of an E-W tectonic shortening. In detail, the phenocrysts and xenoliths in the granites are stretched in the NNW-SSE through N-S direction, however, those oriented in the N-S direction strained highest (Oden and Udinmwen, 2013; Oden and Udinmwen 2014b). Assuming a pure shear deformation, the N-S direction will be associated with maximum stretching (λ_1) due to E-W shortening. However, the deviation of phenocryst orientation from the N-S pure shear direction to the NNW-SSE direction suggests the possibility of a simple shear component of deformation. This episode of deformation (E-W tectonic shortening) is therefore a combination of pure and simple shear deformation (transpressional deformation). Mineral lineation's (Fig. 10b) in the syenite is strongly parallel to the N-S which implies E-W compression assuming a pure shear deformation thus since the syenite dyke is believed to be the last event to affect the geology of this region (Odeyemi and Rahaman, 1992), the E-W σ_1 is, therefore, the youngest episode of deformation to have affected the Igarra schist belt. It should be noted that minor fracture trends (NE-SW, ESE-WNW, and NW-SE) may point to other episodes of deformation that occur in the schist belt but these will be at best speculative due to their insignificant occurrence.

The ductile structures (folds, lineation's, foliation, cleavage strain markers) show that the schist belt suffered at least two episodes of deformation. Folds, foliations, and mineral lineation's are all oriented parallel to the N-S direction. In a pure shear setting, this can develop from the E-W tectonic shortening as identified from fractures. However, these ductile structures are also preferentially oriented in the NW-SE. This implies another episode of deformation with NW-SE λ_1. This stretching direction was observed from foliations, fold axis, and mineral lineations in the metasediments. Crenulation cleavage in Igue-Saleh and Ojirami Peteshi (Figs. 8c and d) clearly illustrate the existence of these two episodes of deformation in the schist. The common occurrence of foliations and mineral lineation's parallel to the NNW-SSE direction which is between the two major λ_1 directions (N-S and NW-SE) is not considered as a separate deformation from the two established episodes of deformation rather it is considered as a simple shear effect from either episode of deformation. The absence of the NW-SE stretching in the granite and syenite which intruded the metasediments suggests that this episode of deformation is older than the granitoid. It is worth mentioning that E-W trending foliation was observed in the gneisses and marbles. This structure does not belong to any of the two main episodes of deformation in this schist belt; it is probably a relic of much older deformation which was not completely obliterated. Some authors designate the shear zones in the Igarra schist belt to a separate episode of deformation (Ocan, 2016; Agomuo and Egesi, 2016) however, these shear zones are not widespread throughout the schist belt and they occur in a small scale (mostly outcrop scale) (Figs. 14c and d) thus if they are not associated with the well-established episodes of deformations, they do not constitute a major episode of deformation. I therefore recommend a very detailed structural and petrographic analysis of these minor shear zones to determine their origin.

In summary, the structural framework of the metasediments in the Igarra schist belt shows evidence of at least two major episodes of deformation which are i) a dominantly ductile deformation with NW-SE stretching direction and ii) a brittle – ductile E-W tectonic shortening deformation while the structural geometry of the granitoid shows evidence of a single dominantly brittle E-W tectonic shortening deformation.

CONCLUSION

The structural framework and deformational episodes of the Igarra schist belt has been evaluated. Within the study area, two major episodes of deformation were identified; an older dominantly ductile deformation with NW-SE λ_1 and a younger brittle-ductile E-W tectonic shortening deformation. Minor fracture trends which are not associated with any of the major episodes of deformation and E-W transposition foliation in marble and gneisses constitute relict of unconfirmed possibly older episode(s) of deformation. The major episodes of deformation in the Igarra schist belt are associated with both pure and simple shear deformations thus the schist belt is largely subjected to transpressional deformations. Ductile and semi-brittle shear zones in the study area are few and usually occur on small scale (outcrop scale) thus do not constitute a major episode of deformation. Mineralizations in the Igarra schist belt are pegmatite and quartz which are emplaced mainly in fractures with industrial minerals like marble.

REFERENCES

Agomuo M. S., Egesi, N., 2016. Petrology and structural geology of Ikpeshi and its environ of Igarra schist belt, southwestern Nigeria. International Journal of Science Inventions Today. 5 (4), 303 – 319.

Annor, A. E., 1998. Structural and chronological relationship between the low grade Igarra schist and its adjoining Okene migmatite-gneiss terrain in the Precambrian exposure of S.W. Nigeria. J, Min. Geol. 34: 197 – 194.

Archanjo, C. J., Viegas, L. G. F., Hollanda, M. H. B. M., Souza, L. C and Liu, D., 2013. Timing of the HT/LP transpression in the Neoproterozoic

Seridó Belt (Borborema Province, Brazil): Constraints from U\Pb (SHRIMP) geochronology and implications for the connections between NE Brazil and West Africa. Gondwana Research 23, 701–714.

Asinya, E. A., Oden, M. I., Ephraim, B. E., Udinmwen, E., and Edem, S. U., 2016. Mesoscopic Structural Analysis of the Schist Enclaves in Oban Massif, South-Eastern Nigeria. Asian Journal of Physical and Chemical Sciences, 1-14.

Billings, M. P., 1972. Structural Geology. Prentice Hall, New Jersey. 606p.

Bruno, M. S., and Winterstein, D. F., 1994. Some influences of stratigraphy and structure on reservoir stress orientation. Society of Petroleum Geophysicists. Terralog Technologies, Acadia.

Cloos, E., 1971. Microtectonics along the western edge of the Blue Ridge, Maryland and Virginia. John Hopkins University Press, Baltimore. 234p.

Cordiani, U. G., Pimentel, M. M., De Araujo, C. E. G., Basei, M. A. S., Fuck, R. A., and Girardi, V A. V., 2014. Reply to comment by E. Tohever and R. Trindade on “Was there a Clymene Ocean in central south America?”. American Journal of Science, 3114, 814 – 819.

Czeck, D. M., Fissler, D. A., Horsman, E., and Tikoff, B., 2009. Strain analysis and rheology contrasts in polymictic conglomerates: An example from the Seine metaconglomerates, Superior Province, Canada. Journal of Structural Geology 31, 1365–1376.

Dada, S. S., 2008. Proterozoic Evolution of the Nigeria–Borborema Province. West Gondwama: Pre-Cenozoic Correlations Across the South Atlantic Region: In: Pankhurst, R.J., Trouw, R.A.J., BritoNeves, B.B., De Wit, M.J. (Eds.), Geological Society of London, Special Publications, 294, pp. 121–136. http://dx.doi.org/10.1144/SP294.7.

Danbatta, U. A., 2003. The structural framework underlying the metamorphic evolution of the Kazaure schist belt, NW Nigeria. Global Journal of Geological Sciences, 1, 73-83.

Davis, G. H., and Reynolds, S. J., 1996. Structural Geology of Rocks and Regions. John Wiley and sons. 371p.

Egbuniwe, I G., and Ocan, O. O., 2009. Selection of fieldwork area for teaching/training: Igarra Area as an example. In: Proceedings of field mapping standardization workshop. D.O Lambert-Aikhionbare and A. I Olayinka (Eds). University of Ibadan press. 79 – 95.

Elueze, A. A., 2002. Compositional Character: Veritable Tool in the Appraisal of Geomaterials. An Inaugural Lecture, University of Ibadan, Ibadan, Nigeria, 43p.

Elueze, A. A. and Okunlola, O. A., 2003. Petrochemical and petrogenetic characteristics of Metasedimentary Rocks of Lokoja-Jakura Schist belt, Central Nigeria. Journal of Mining and Geology, 39(1) 21-27.

Esmaeili R., Faghih A., Razaian., and Ebrahimi M., 2015. Structural overview of the Halab – Gheydararea, southwest Zanjan, NW Iran.Iranian Journal of Earth Sciences. 7, 50 – 58.

Ferré, E., Gleizes, G., Bouchez, J. L., and Nnabo, P. N., 1995. Internal fabric and strike-slip emplacement of Pan-African granites of Solli Hills, Northern Nigeria. Tectonics, 14, 1205 - 1219.

Grant, N. K., 1978. Structural distinction between a metasedimentary cover and an underlying basement in the 600myr.Old Pan-African domain of North western Nigeria, West Africa. Bulletin of Geological Society of America, 89: 50-58.

Gudmundsson, A., 2011. Rock fractures in geological processes. Cambridge University Press, New York.

Hills, S E., 1972. Elements of Structural Geology. Chapman and Hall. London, 502p

Hockey, R D., Sacchi, R., Muotoh, E. O. G., and Graaff, W. P. F. H., 1986. The Geology of Lokoja-Auchi Area. Geol. Sury. Nig. Bul. 39. 71.

Hobbs, B. E., Means, W. D., and Williams, P. F., 1976. An Outline of Structural Geology. John Wiley and Sons, New York. 571p.

Kamb, W. B., 1959. Theory of preferred crystal orientation develop by crystallization under stress. Journal of Geology, 67: 153-170.

Lima, E. S., 1987. Evoluçãotermo-barométrica das rochasmetapelíticas da egião do Seridó, Nordeste Brasileiro. Revista Brasileira de Geociências 17, 315–323.

McCurry, P., 1976. The geology of the Precambrian to lower palaeozoic rocks of northern Nigeria- a review. in: C.A Kogbe (Editor), Geology of Nigeria. Elizabethan Publ, Lagos. 15-39.

Obasi, R. A., and Anike, O. L., 2012. Geochemical and economic application of marbles from Igarra and Ikpeshi areas, S.W Nigeria. 2 (10), 1723 – 1727.

Obasi, R. A., Anike, O. L., and Ogungbuyi, P., 2015. Trace and rare earth elements geochemistry from Ikpeshi, its provenance and palaeo – redox conditions. 4 (1), 14 – 25.

Ocan, O. O., 2016. The structural and metamorphic evolution of the rocks of the Igarra schist belt, Edo State, Nigeria. Season of Rahaman, Book of Abstracts for Professionals' Symposium, p 12.

Ocan, C. O., Coker, S. L., and Egbuniwe, I. G., 2003. The geology of Igarra-Auchi area, Excursion guide at the Annual Conference of the Nigerian Mining and Geosciences Society (NMGS), Itakpe, Nigeria. 52p.

Oden, M. I., 2012a. Strain Partitioning and Dimensional Preferred Orientation in a Syn-Tectonic Granitoid, Southeast, Nigeria. Science World Journal, 7(1), 9-14.

Oden, M. I., 2012b. Barite veins in the Benue Trough: Field characteristics, the quality Issue and some tectonic implications. Environment and Natural Resources Research, 2(2), 21-31.

Oden M. I., 2012c. The Pegmatite Veins of Western Oban Massif: Tectonic and Lithological Controls on Physical Properties. Research Journal of Environmental and Earth Sciences. 4 (4), 381-389.

Oden, M. I., Asinya, E. A., and Udinmwen, E., 2017. The schist enclaves of Oban massif Southeastern Nigeria: Consistency of dihedral angle and other natural physical mechanical properties. Journal of Geography, Environment and Earth Science International, (1), 1-13.

Oden, M I., and Udinmwen, E., 2013. The behaviour of K-feldspar phenocrysts and strain anisotropy in Igarra syn-tectonic granite, southwestern, Nigeria. Current Advances in Environmental Science, 1(2), 9-15.

Oden, M I., and Udinmwen, E., 2014a. Mesoscopic structural profile of a syn – tectonic granite, southwestern Nigeria. IOSR Journal of Applied Geology and Geophysics. 2(2), 67 – 76.

Oden, M I., and Udinmwen, E., 2014b. Fracture characterization, mineral vein evolution and the tectonic pattern of Igarra syn- tectonic granite, southwestern Nigeria. British Journal of Applied Science and Technology.4(17), 2417 –2429.

Oden, M. I., Egeh, E. U., and Amah E. A., 2015. The Ikom- Mamfe basin, Nigeria: A study of fracture and mineral vein lineament trends and Cretaceous deformations. Journal of African Earth Sciences. 101, 35-41.

Oden, M. I., Umagu, C. I, and Udinmwen, E., 2016. The use of jointing to infer deformation episodes and relative ages of minor Cretaceous intrusive in the western part of Ikom – Mamfe basin, south-eastern Nigeria. Journal of African Earth Science. 121, 316 – 329. DOI: 10.1016/j.jafrearsci.2016.02.010.

Odeyemi, I. B., 1976. Preliminary report in the relationships of the Basement complex rocks around Igarra, Mid-west. In: Geology of Nigeria, edited by C.A Kogbe. Elizabethan Publ. Lagos.59-63.

Odeyemi, I. B., and Rahaman, M. A., 1992. The petrology of a composite syenite dyke in Igarra, southwestern Nigeria. Journal of Mining and Geology. 28 (2), 255-263.

Oluyide, P. O. and Okunlola, O. A., 1995. Lithostructural setting and emplacement history of Precambrian carbonate deposits, Burum central Nigeria. Book of abstract 31 Annual International Conference of the Nigerian Mining and Geosciences Society, Calabar. 20p.

Omitogun, A. A., Caby, R. and Debat, P., 1991. Le métamorphism pan-African de la partiecentrale de la zone mobile du Nigéria (Ceintureschisteused'Igarras.l.). ComptesRendus de l'Académie de Science. Paris t. 313, Série II, 1417–1423.

Onwualu - John, J. N., 2015. Petrochemistry and implication of the high contents of some trace elements in the granitoids in Okpe, basement complex, southwestern Nigeria. Geochemistry Journal. 2 (2), 1 – 5.

Rahaman, M. A., 1989. Review of the Basement Geology of Southwestern Nigeria. In: Geology of Nigeria, edited by C.A. Kogbe, Rock's view (Nig) Ltd, Jos. Nigeria, 39-56.

Ramsay, J. G., 1980. Shear Zone Geometry: a review. Journal of Structural Geology. 2 (1/2), 83 – 99.

Singhal, B. B. S., and Gupta, R. P., 2010. Applied hydrogeology of rocks (2nded). Springer, Dordrecht. 401p.

Turner, D. C., 1983. Upper Proterozoic schist belts in the Nigerian sector of the Pan-African province of West Africa. Precambrian research, 21(1-2), 55-79.

Twiss, R. J., and Moores, E. M., 1993. Structural Geology. W.H Freeman and Company, New York. 532p.

Udinmwen, E., 2016. Strain analysis and structural evolution of the Precambrian rocks of southern Igarra schist belt, southwestern Nigeria. Unpublished M.Sc Thesis, University of Calabar, Nigeria. 168p.

Udinmwen, E., and Oden, M. I., 2016. Strain analysis and tectonite classification using polymicticmetaconglomerates in the Igarra schist belt, southwestern Nigeria. Arabian Journal of Geosciences. 9 (8), 1 – 11. DOI: 10.1007/s12517-016-2567-7.

Udinmwen, E., Oden, M. I., Ukwang, E. E., and Ibegbulam, E. O., 2016a. Strain conditions indicated by metamorphic spots in the southern Igarra schist belt, southwestern Nigeria. Archives of Current Research International. Vol. 6 (3), 1 – 9. DOI: 10.9734/ACRI/2016/30937.

Udinmwen, E., Oden, M. I., Rufai, A., and Asinya, E. A., 2016b. Structural control on mineral vein geometry in the Igarra schist belt, southwestern Nigeria. Journal of Earth and Atmospheric Sciences. 1 (1), 10 – 21.

Udinmwen E., Oden, M. I., and Danbatta, U. A., 2016c. Strain conditions tracked by metamorphic spots in the Igarra schist belt, southwestern Nigeria. Season of Rahaman, Book of Abstracts for Professionals' Symposium, p14.

Zeh, A., and Holness, M. B., 2003. The effect of reaction oversteps on the garnet microstructures in metapelitic rocks of the Ilesha schist belt, SW Nigeria. Journal of Petrology 44, 967–994.