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Geological and geophysical mapping of fracture anisotropy at Aiyegunle and environs, Igarra area South western Nigeria

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Characterization of fracture anisotropy in Aiyegunle area of Igarra Southwestern Nigeria was done by geologic mapping of exposed outcrops and azimuthal resistivity survey (ARS) at three vertical electrical sounding (VES) stations. Rose diagrams, stereographic projections, and resistivity anisotropy polygons were used to delineate and integrate surface and subsurface structural trend. Dominant joints orientation is North-west-South-east (NW-SE) and North- South (N-S). The orientation of fracture in the subsurface is N-S with anisotropy prominent in the NW-SE direction. The coefficients of anisotropy (λ) at depth are less than 2.2, with the degree of fracturing opening and closing with depth. The diversity of fracture attitude implies they were products of different tectonic episodes corroborating evidence of multiphase deformation. The fracture directions suggest that surface structures are hard-linked and produced by similar tectonic event relative to subsurface fractures of Pre-Pan African orogenies.

Key words: Fractures, orientation, surface, subsurface, anisotropy.

INTRODUCTION

Fracture anisotropy is associated with electrical and hydraulic variation resulting from the preferred orientation of fracture sets (Slater et al., 2006). Fracture networks are important consideration for prediction of underground contaminants, groundwater and mineral exploration, and foundation investigations. Azimuthal resistivity survey is a technique used for determining the principal directions of electrical anisotropy and intensity; a change in apparent resistivity with azimuth is indicative of fracture anisotropy (Slater et al., 2006; Boadu et al., 2005; Skyernaa and Jorgensen, 1993).

The architecture of fractures is space and time related, the intensity of fracturing in an area can be observed on different scales, from megascopic (seismic section,

satellite images, and aeromagnetic maps), macroscopic (joints, faults and veins in outcrop) to microscopic scale in thin sections (Omosanya et al., 2012 a,b).

Depth-related fractures observed in macroscopic scale are therefore, deep seated, hard-linked and apparently connected to regional tectonic events or trend. The Nigerian Schist belts represent the structural grains of the basement rocks (Rahaman, 1981; Olade and Elueze, 1979). The structural information of the entire basement rocks was derived or up-scaled from studies of the belts. The Igarra schist belt is characterized by a complex geological framework made of different structures and rocks.

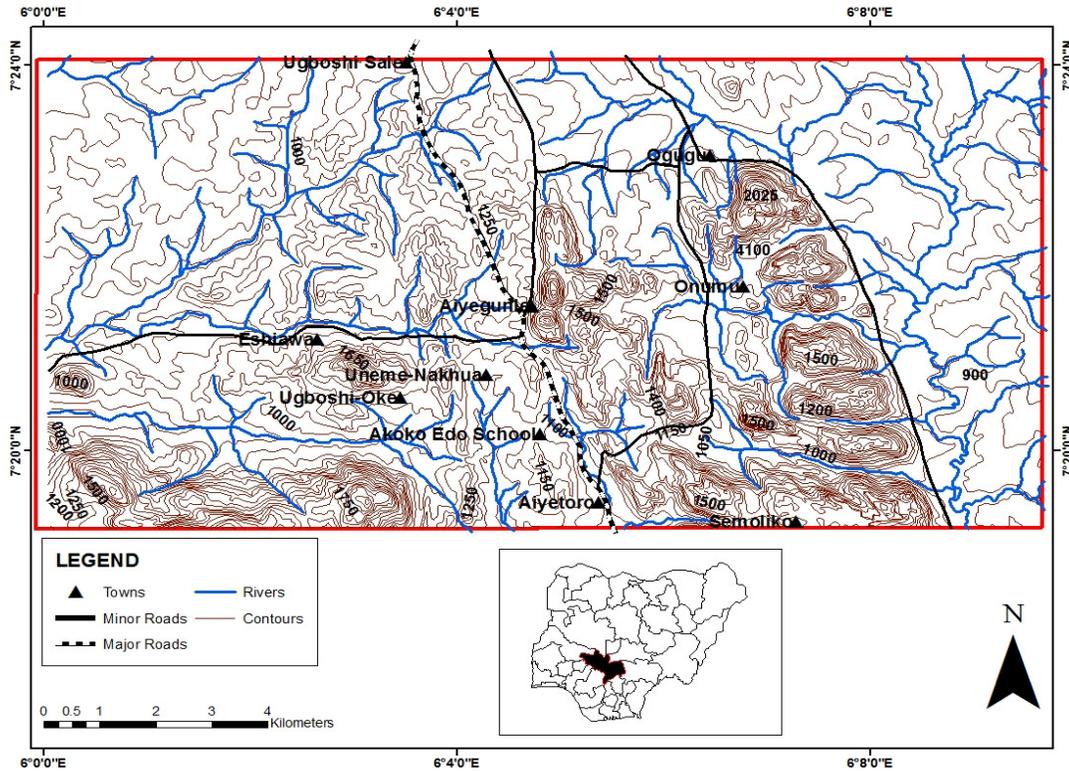The aims of this work include (a) identifying fracture

Figure 1. Topographical Map of the study area (Auchi NW sheet 226). Inset: the study area on the map of Nigeria

trend in outcrops in the study area (b) understanding the subsurface fracture orientations and (c) integrating the data from both studies with a viewing to correlating them with regional structural orientations. These pieces of information are important for characterizing the distribution of ore deposits, ground water accumulation and construction works. In this paper, we used orientation plots such as anisotropy polygons to correlate surface and subsurface fractures in the study area. We start by discussing the geological settings, methods used for the research, results and a discussion on the connection between surface and subsurface fracture trends and how they link regional pre- and post- Pan African orientations (Figure 1 and 2).

Local geological setting

Nigeria is located within the mobile belt that separates the West African Craton (WAC) from the Congo Craton (CC) (Black, 1980). The geology of the country is divided into equal proportion of crystalline and sedimentary rocks (Woakes et al., 1987). The Precambrian Basement Complex of Nigeria is polycyclic in nature (Ukaegbu, 2003; Ajibade and Fitches, 1988) as it has been affected by different orogenies accompanied by deformation and metamorphism. The most prominent of these being the Pan African/ Brasiziliano Orogeny which overprinted and obliterated earlier structures of the basement rocks (Van Breemen et al., 1997; Fitches et al., 1985).

The Precambrian basement rocks of Nigeria include the Migmatized gneissic complex (MGC) of Achaean to early Proterozoic age (Dada, 1999; Dada et al., 1993; Grant et al., 1972), N-S trending schist belts of Upper Proterozoic age (Rahaman, 1988) and the Older Granitoid of Pan African age (Fitches et al., 1985). The Migmatized Gneiss complexes are the most widespread and occupy about 60% of the total surface area of Nigeria (Rahaman and Ocan, 1978). The polycyclic Migmatized-Gneiss complexes are characterized by grey foliated biotite acid/biotite hornblende quartz feldspathic gneiss of tonalitic to granodioritic composition; Mafic to ultramafic component which outcrops as irregular boudinaged lenses or concordant sheet of amplibolites with minor amount of biotite-rich ultramafite; and Felsic component, a diverse group comprised of pegmatite, aplite quartz-oligoclase veins, fine-grained granite gneiss, and porphyritic granite (Rahaman, 1981).

The schist belts represent N-S trending synformal troughs infolded into the migmatite-gneiss complexes which are best developed in the western part of the country. The schist belts are largely sediment-dominated
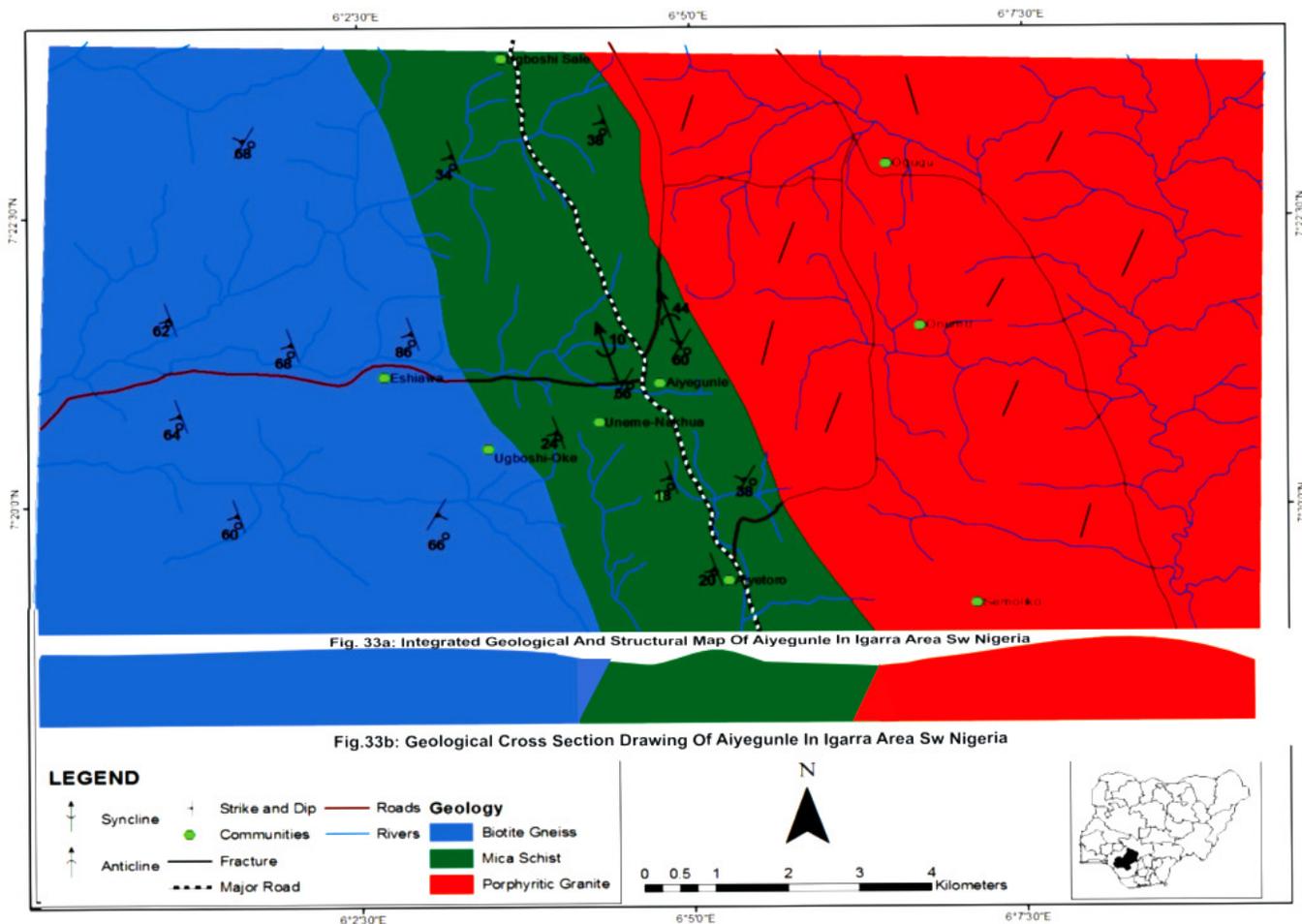
Fig. 33a: Integrated Geological And Structural Map Of Aiyegunle In Igarra Area Sw Nigeria

Fig.33b: Geological Cross Section Drawing Of Aiyegunle In Igarra Area Sw Nigeria

Figure 2. Integrated geological and structural map of the study area.

in contrast to other schist belts of South Africa and Australia. The most important lithologies are pellites, semi-pellites, banded iron formation and quartzite (Turner, 1983). This rock suite provides information on the structural pattern of the basement rocks. The contact between the migmatites and the metasediments are fault-bounded in most cases (Odeyemi et al., 1999) while the schists are presumably a fault-controlled rift like structure (Olade and Elueze, 1979). The metasedimentary succession in the Igarra formation consists of (a) Quartz biotite Schist (b) Mica Schist (c) Marble and Calc-Silicates and (d) Metaconglomerates. The presence of both calcareous rocks and conglomerates is peculiar to the Igarra Schist belts in Nigeria. These rock types together with quartzites occur as bands in the dominant biotite schists. The gneisses at the margin of the metasediments may be a highly metamorphosed basal part of the sequence.

The older granites correspond to the last rock types of the basement; these rocks represent a diverse and

lasting magmatic cycle (750-450Ma) associated with the Pan African orogeny (Woakes et al., 1987). The older granite rocks constitute about 40 to 50% of the basement complex outcrop. They vary in composition from tonalite through granodiorites to granite; syenite granodiorite composition is the most common. The location of the study area is shown in Figure 1, the area is characterised by undulating topography which accounts for the sub-dendrite like drainage pattern. Climatic condition of the area is typical tropical rain forest of southern Nigeria characterised by alternation of wet and dry seasons.

METHODOLOGY

The method for this research was divided into surface fracture mapping and subsurface geophysical investigations. A recon-naissance survey was done by traversing along footpaths with the aid of a base map, compass clinometers and global positioning system (GPS). The GPS was used to update the base map to reflect the positions of modern infrastructures. During the course of

structural field mapping, attention was paid to the topography and vegetations at each location to provide hint on the geology (cf. Barnes, 1981; Ekwueme, 2004). Strike and dip of structural features such as joints, faults, and veins were measured on exposed outcrops. The respective positions of these data were adequately inked onto the base map. Furthermore, the attitudes of the structures were plotted on rose diagrams and stereographic projections in order to understand the trend of the major tectonic force(s) in the region. Fresh unweathered representative rock samples were collected and prepared for detailed petrographic examination of the rocks in the laboratory.

For the subsurface geological study, Azimuthal resistivity sounding/ survey using Schlumberger electrode configuration (ARS-VES) was employed at three sites in the study area namely; Ako mixed Grammar School, that is, Akograms (7°20^{1}207^{11}N and 6°05^{1}1^{11}E), Uneme Nakhua Primary School (7°20^{1}542^{11}N and 6°04^{1}960^{11}E) and Aiyegunle community secondary school (7°20^{1}896^{11}N and 6°04^{1}804^{11}E). Azimuthal resistivity measurements were performed by rotating the electrode array from 0°, 45°, 90° and 135° corresponding to the E-W, NE-SW, N-S, and NW-SE direction around a central fixed point at the AKOGRAMS ARS-VES station. In contrast, the electrode configuration was rotated at an increment of 0°, 60° and 120° corresponding to the E-W, NE-SW, and NW-SE direction for the other two ARS-VES stations due to accessibility and restriction by cultural features. The survey traverse was 100 m for AKOGRAMS and 50 m for the other two stations. The measured resistance R (Ω) from the field were converted to apparent resistivity (Ωm) using the geometric factor for Schlumberger array. Consequently, the resistivity values for the different AB/2 spacing(s) were plotted on a polar diagram along the selected directions. The directional magnitude of the resistivity anomalies obtained from the anisotropy plots provided information on the subsurface fracture trend and variations with azimuth.

The anisotropy polygon was plotted with increasing AB/2; by contouring lines of equal resistivity value along azimuths of AB/2 separations. Anisotropy at values of AB/2 < 12 m were neglected as the resistivity anisotropy is often associated with surface irregularities at such depth (Omosanya et al., 2012b). Electrode spacing was converted to depth by the product of AB/2 and 0.6. For an isotropic homogeneous formation, the resistivity anisotropy polygon will assume a circular shape. Any deviation from a circle to an ellipse is indicative of anisotropic nature of the Formation (Malik et al., 1983, Skerjenaa and Jorgensen, 1993). The direction of the longest axis of the polygon corresponds to the strike (orientation) of the structures and the ratio of the long to short axis is an indication of the presence of fractures in an area if high, and otherwise if low (Skjernaa and Jorgensen, 1993). The direction of electrical anisotropy is parallel to the direction of maximum apparent resistivity in the anisotropic polygon (Habberjam, 1972).

RESULTS

Surface rock types and fracture pattern

Rock types identified during the mapping exercise include Quartz Biotite Schist, Mica Schists, Gneisses and Metaconglomerates (Figure 2). The Schists are dark coloured and fine grained with narrow, alternating dark and light grey bands. The darker bands are dominated by biotite in contrast to the lighter band comprised of quartz minerals. Other schist types include the biotite- muscovite Schist. Marbles in the study area are calcic and dolomitized. The calc-silicate rocks can be classified into three main lithological groups, (a) Strongly banded calc-

silicate gneisses (b) Calc-silicate schists and (c) Massive calc-silicate rocks. The calc-silicate gneisses form the dominant and most widespread of the calc-silicate rocks. Marbles form numerous lenses and bands of variable dimensions intercalated with the calc-silicate rocks, which structurally overlie the quartz-biotite schist. The metaconglomerates are dark coloured conglomerates found in three principal zones, upper, middle and lower zones. These rocks had undergone various deformations with the adjacent migmatites-gneiss-quartzite complex. This is evidenced by migmatization, granitization and emplacement of Pan African granite plutons which marks the last of the Precambrian activities that affected the Igarra area (Anifowose et al, 2008).

Detailed petrography study was carried out on four representative rock samples to ascertain textural and mineralogical characteristics of the rock (Figure 3); the modal percentages of mineral in each slide were plotted on the histogram (Figure 3e-h). The mineral identified include quartz, biotite, muscovite, plagioclase, microcline and other opaque minerals. The dominant minerals in thin section are quartz, plagioclase and biotite. The observed mineral conforms to the result obtained from the initial geological mapping shown in Figure 2. Structural features identified from thin section include schistosity associated with sample 3 (Figure 3c).

The orientation of joints measured from the outcrop shows that joints found in the Schist and Gneisses are dominantly oriented in NW-SE with minor directions of N-S and ENE-WSW (Figure 4f), Joints in the porphyritic granite are trending N-S to NE-SW (Figure 4g) and the Veins are in the NW-SE direction. The metamorphic event, M$_1$ identified in the thin section corroborates the foliation observed in the gneisses. These foliations are oriented in the N-S to NW-SE direction (Figure 5a). The direction of dip for foliation planes are dominantly NW-SE. Stereographic projection revealed that schistosity in the Schist dips SE, NE, and SW with minor inclination in the N-S direction. However, foliations in the Gneisses are inclined in all direction (Figure 5b).

Subsurface fractures

The results of the Azimuthal resistivity sounding (ARS) are presented in Tables 1, 2 and 3. Coefficient of anisotropy was calculated from the square root of the ratio of maximum to minimum apparent resistivity at any AB/2 spacing (Equation 1). For a formation characterised by anisotropic fractures pattern, the apparent resistivity (ρt) measured normal to its strike direction is greater than apparent resistivity (ρs) measured along the strike direction, when Schlumberger configuration is used (Lane et al., 1995).

The strike direction for fractures at ARS-VES Station 1 are oriented E-W at depth of 15 m (AB/2=25 m) and N-S at 7.2 m (AB/2=12 m) respectively (Figure 6a). Fracture
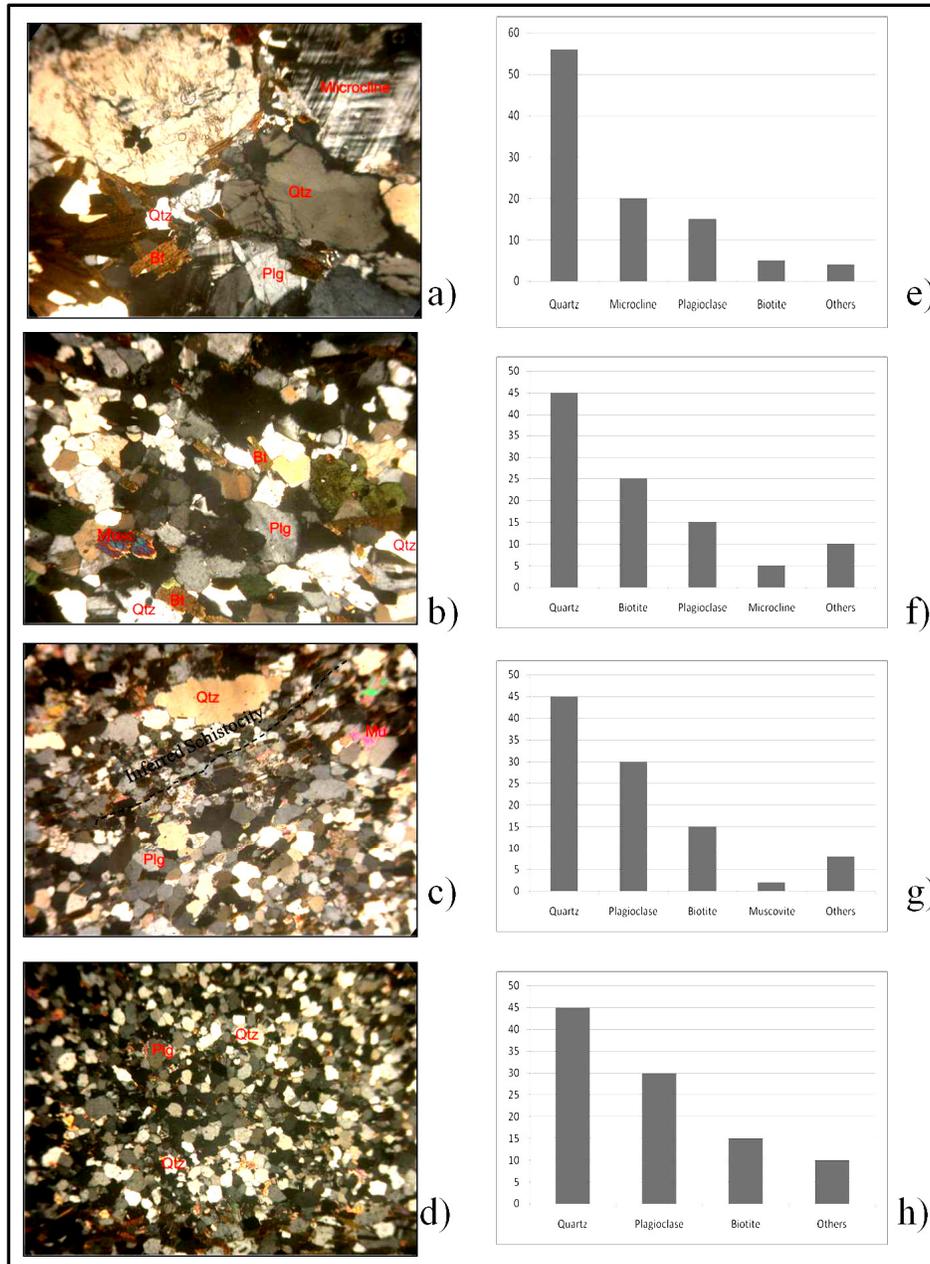
Figure 3. Photomicrograph of porphyritic granite showing phaneritic texture in which the mineral grains are angular and coarse. b) Biotite Gneiss with irregular crystalline bands and poorly defined schistosity. c) Mica Schist showing monocrystalline quartz grains unit with extinction and traces of muscovite flakes. d) Microgranular texture in Mica Schist. (Mag. X40). e- f) Histograms for corresponding modal mineral percentages.

orientation at ARS-VES Station 2 and 3 is N-S at depth of 7.2 m (AB/2=12 m) and 30 m (AB/2=50 m) respectively (Figure 6b and c) and NW-SE at depth 30 m (AB/2=50 m) at Station 3 (Figure 6b). The computed coefficient of anisotropy varies from 1.0861 to 2.9949, 6.3055 to 22.8736 and 8.573 to 21.609 for the three stations. The degree of fracturing at Aiyegunle closes with depth and

then open up at 15 m (λ=1.054) and start to close up again at 24 m (λ=1.117) (Table 1, Figure 6d). Similar fracture dynamics was observed at Uneme-Nekua, the fracturing is constant with depth and closes at 15 m depth (λ=1.11) and later open up at 25 m (λ=1.12) (Table 2, Figure 6e). However, at Akograms, the degree of fracturing is initially constant with depth and later closes
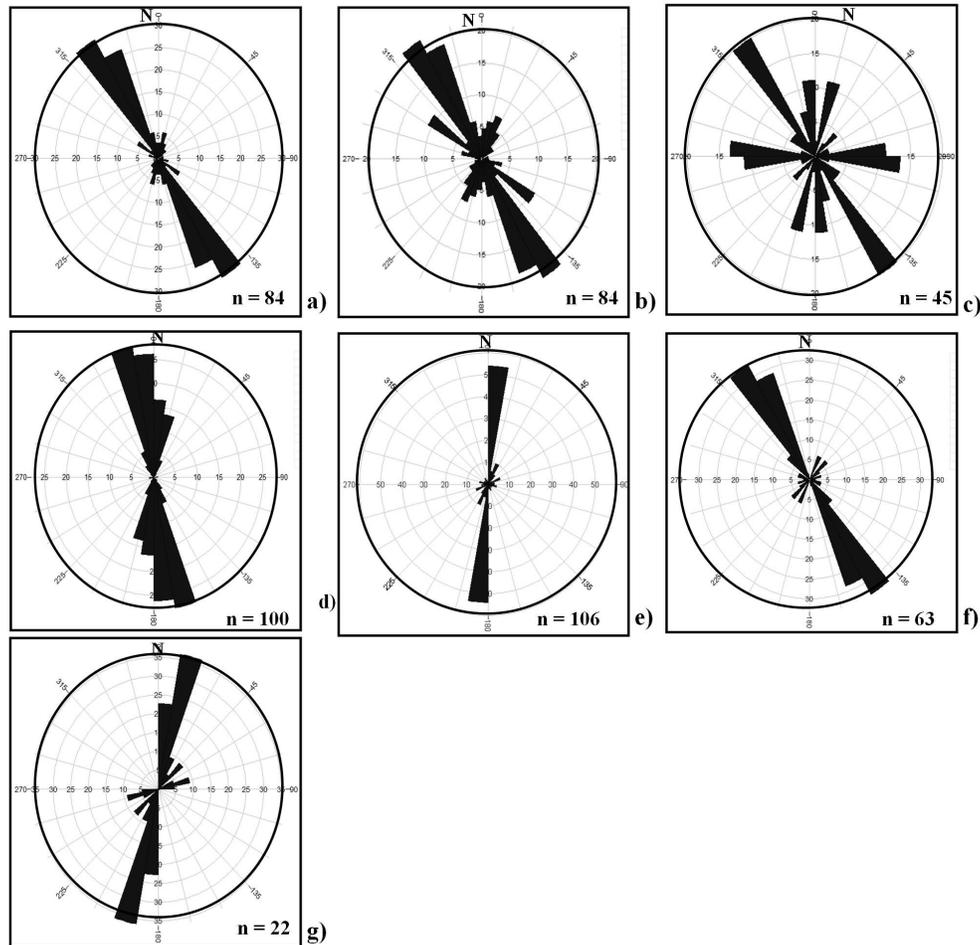
Figure 4. Rose diagrams for different structures around Aiyegunle a) Mineral Lineation. b) Strike of Quartzofeldparthic vein. c) Joints in Mica-schist. d) Strike of foliation planes. e) Strike of axial planes of fold. f) Joints in Gneiss and g) Joints in Porphyritic Granite.

up at 24 m (λ=1.86) to re-open at 48 m (λ=2.99) and finally closing up at depth of 60 m (λ=1.46) (Table 3, Figure 6f).

$$\lambda = \sqrt{(\rho t / \rho s)} \qquad (1)$$

DISCUSSION

The rock types identified in the study area include older granites in the eastern part to mica-schist and biotite-gneiss westward (Figure 2). These rocks form part of the basement complex of Nigeria (Rahaman, 1988; Dada, 1989; Oyawoye, 1972); they are mainly metamorphosed semi-pelitic assemblage of syntectonic to late tectonic origin that intruded into both the migmatite gneiss complex and the schist belts. Structurally, the mica-schist

and biotite-gneiss are folded and highly fractured. The textural and structural heterogeneity of the metasedimentary rocks of Aiyegunle area provides evidence for polyphase deformation and metamorphism. Foliation with dip amount of 10 to 80° are in the N-S to the NW-SE (0-45) direction in the major structures while minor overprinted structures with dip of 50-80° are in ENE-WSW to E-W directions. Ductile deformation is indicated by foliations folded into anticlines and syncline, which thicken towards their hinge with plunge of 10 to 42°. Mineral lineation (quartz and Quartzo feldspathic vein), foliation trend and joint orientation indicate linear features (Tables 1 to 3).

Surface structures in the rock exposures of the Aiyegunle are oriented NW-SE, N-S, NE-SW and ENE-WSW direction presumably formed by NE-SW, E-W, NW-SE and NNW-SSE oriented forces. The sub surface structures are oriented in N-S, NW-SE, and E-W direction. Thus, the NW-SE and N-S oriented structures
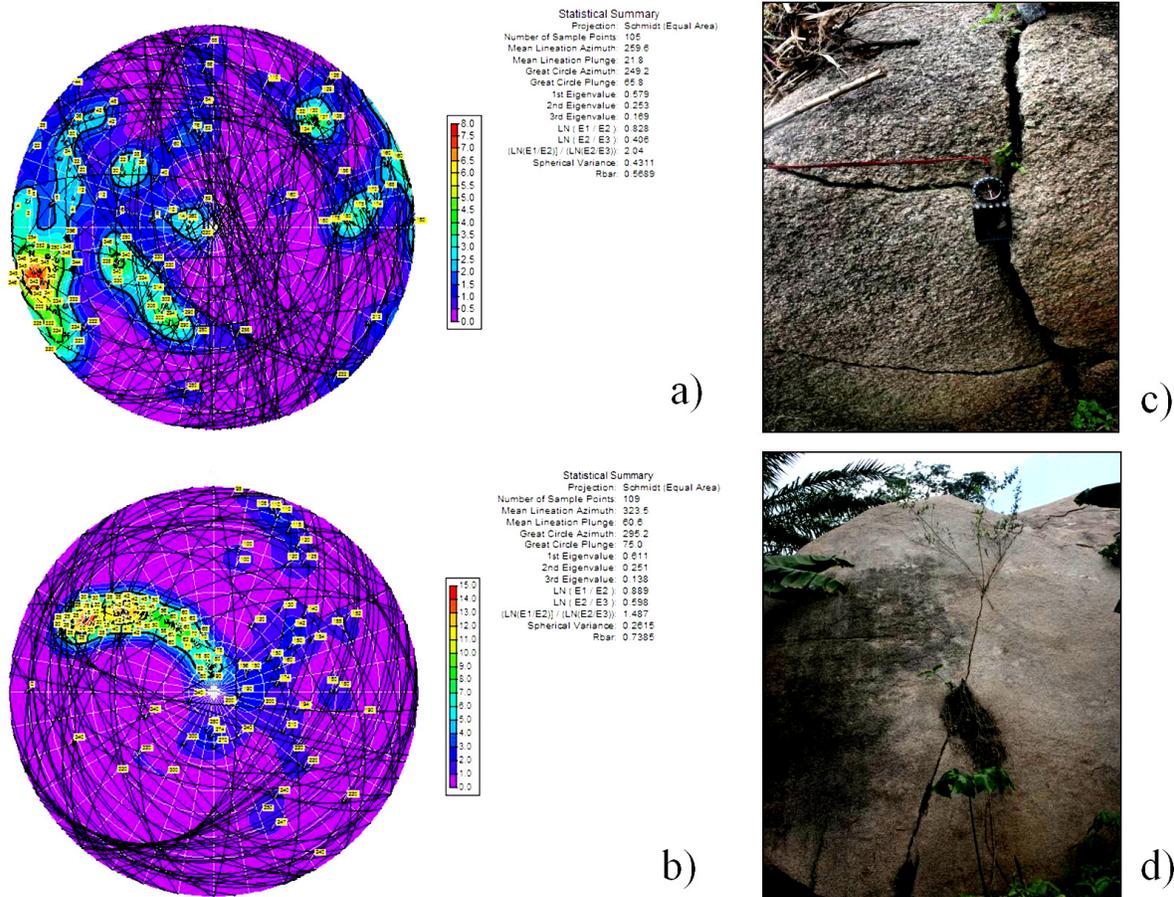
Statistical Summary
Projection: Schmidt (Equal Area)
Number of Sample Points: 105
Mean Lineation Azimuth: 259.6
Mean Lineation Plunge: 21.8
Great Circle Azimuth: 249.2
Great Circle Plunge: 66.8
1st Eigenvalue: 0.579
2nd Eigenvalue: 0.253
3rd Eigenvalue: 0.169
LN (E1 / E2): 0.828
LN (E2 / E3): 0.406
(LN(E1/E2)] / (LN(E2/E3)): 2.04
Spherical Variance: 0.4311
Rbar: 0.5689

Statistical Summary
Projection: Schmidt (Equal Area)
Number of Sample Points: 109
Mean Lineation Azimuth: 323.5
Mean Lineation Plunge: 60.6
Great Circle Azimuth: 295.2
Great Circle Plunge: 75.0
1st Eigenvalue: 0.611
2nd Eigenvalue: 0.251
3rd Eigenvalue: 0.138
LN (E1 / E2): 0.889
LN (E2 / E3): 0.598
(LN(E1/E2)] / (LN(E2/E3)): 1.487
Spherical Variance: 0.2615
Rbar: 0.7385

Figure 5. Stereo projections for foliation a) Schist and b) Gneisses. c) Biotite gneiss with porphyroblastic texture provided evidence for partial melting of rocks around Aiyegunle area. d) Older Granite with joints and porphyritic texture in Aiyegunle.

are deep seated and connected at depth. The ARS revealed significant anisotropy at 15 to 25 m depth with orientation of E-W, NE-SW, N-S, and NW-SE at AKOKO-EDO, UNEME-NEKHUA and AIYEGUNLE respectively. Coefficient of anisotropy shows that the degree of fracturing at the three stations are generally closing and opening with depth. The numerous orientations of fractures suggest differently oriented tectonic forces through the evolution of the structures. In addition, it implies that the different fractures were produced at different time.

Regionally, the collision of the West African craton and westward moving plate created N-S to NE-SW trending structures parallel to the edge of the West African craton (Black et al., 1979; Champenois et al., 1987; Oluyide, 1988; Egesi and Ukaegbu, 2010). These E-W movements is regionally replicated as highly deformed series of multidirectional orientations common in folds, lineaments and faults in the whole of the Nigerian basement complex and northern Cameroun (McCurry, 1976; Rahaman, 1976; Onyeagocha, 1984; Toteu et al.,

1990). The N-S and NE-SW structures are presumably associated with the Pan African orogeny while pre-Pan African structures are oriented differently to these directions in the basement (Onyeagocha and Ekwueme, 1982; Toteu et al., 1990). Nevertheless, the Pan African orogeny as a later and presumably the last tectonic events in the basement reconfigured and obliterated earlier structures (M[c]Curry, 1976; Rahaman, 1976).

Consequently, the N-S fracture orientations in the study area are thought to be Pan African fabric which wiped out some of the older structures trends. The NW-SE trend is persistent with pre Pan African structural trends and consequently accounts for the connections established for this trend in the surface and subsurface data. Regardless of the N-S orientation of the Nigerian schist belts, the NW-SE trend in the study area may be a localised orientation. This further compounds the understanding of the structural trends in the schists belts. Results from this study indicates that the schists belts of the Igarra area may not be Proterozoic in age but connected to earlier Pan African events in order to

Table 1. Apparent resistivity values derived for all the directions at Akoko-Edo Grammar School (ARS-VES Station 1).

			Akoko-Edo		
AB/2	**0°**	**45°**	**90°**	**135°**	**λ**
1	1610.668	1270.743	1503.447	-	1.1258
2	1110.972	1009.772	941.7281	-	1.0861
3	1025.541	848.0651	796.3949	-	1.1347
4	1082.635	881.031	-	-	1.1085
6	1177.7099	896.5502	852.7388	-	1.1751
6	1045.4227	906.6995	743.9384	891.8724	1.1854
9	1012.329	698.989	499.5678	746.9414	1.4235
12	866.2887	543.8017	307.4467	626.9076	1.6785
15	710.4014	417.2726	265.16477	459.0775	1.6367
15	614.0724	369.8511	221.2068	405.7453	1.6661
20	748.4338	253.3016	580.8824	378.6674	1.7189
25	371.1431	369.1825	1830.228	302.1297	2.4612
32	334.6051	316.4445	-	-	1.0282
40	554.1632	840.7761	479.2951	561.4384	1.3244
40	311.6706	537.6121	155.3345	362.8481	1.8603
50	273.4542	244.6201	142.1805	308.5567	1.4731
65	136.6358	193.183	152.3035	228.8928	1.2942
80	430.3099	47.97293	167.7043	217.7264	2.9949
100	299.3083	180.225	206.3632	140.9876	1.4570

Table 2. Apparent resistivity values obtained at Uneme-Nekua Primary Sch. (ARS-VES 2).

		Uneme Nekua		
AB/2	**0°**	**60°**	**120°**	**λ**
1	523.2019	487.9722	255308	22.87360
2	162.6126	163.8745	26648.07	12.80135
3	65.31786	61.33027	4005.962	8.08194
4	39.76005	39.24929	1560.554	6.30555
6	33.7203	40.73751	1375.306	6.38636
9	37.52467	52.82378	1982.195	7.26799
12	47.46973	63.59408	3018.794	7.97458
15	56.8079	65.10567	3717.926	8.08995
20	54.62815	68.44973	3739.282	8.27343
25	66.13131	82.73766	5471.55	9.09602
32	63.46568	111.6957	7088.847	10.56862
40	92.54315	103.571	9584.782	10.17698
50	117.3853	119.3875	14014.33	10.92645

conform with the regional N-S orientation of the belts and metallogeny.

Conclusion

Azimuthal resistivity surveys and geologic field mapping conducted at Aiyegunle area was aimed at characterizing fractures in the study area. Structural parameters obtained from the field measurements included fracture attitude, coefficient of anisotropy, mean resistivity of subsurface layers. These parameters are useful in making preliminary inference on the degree of fracturing and permeability of the rock mass.

Fracture trends are produced by dominant E-W to NE-SW tectonic forces and therefore the joints are exten-

Table 3. Apparent resistivity values measured at Aiyegunle community secondary school (ARS-VES 3).

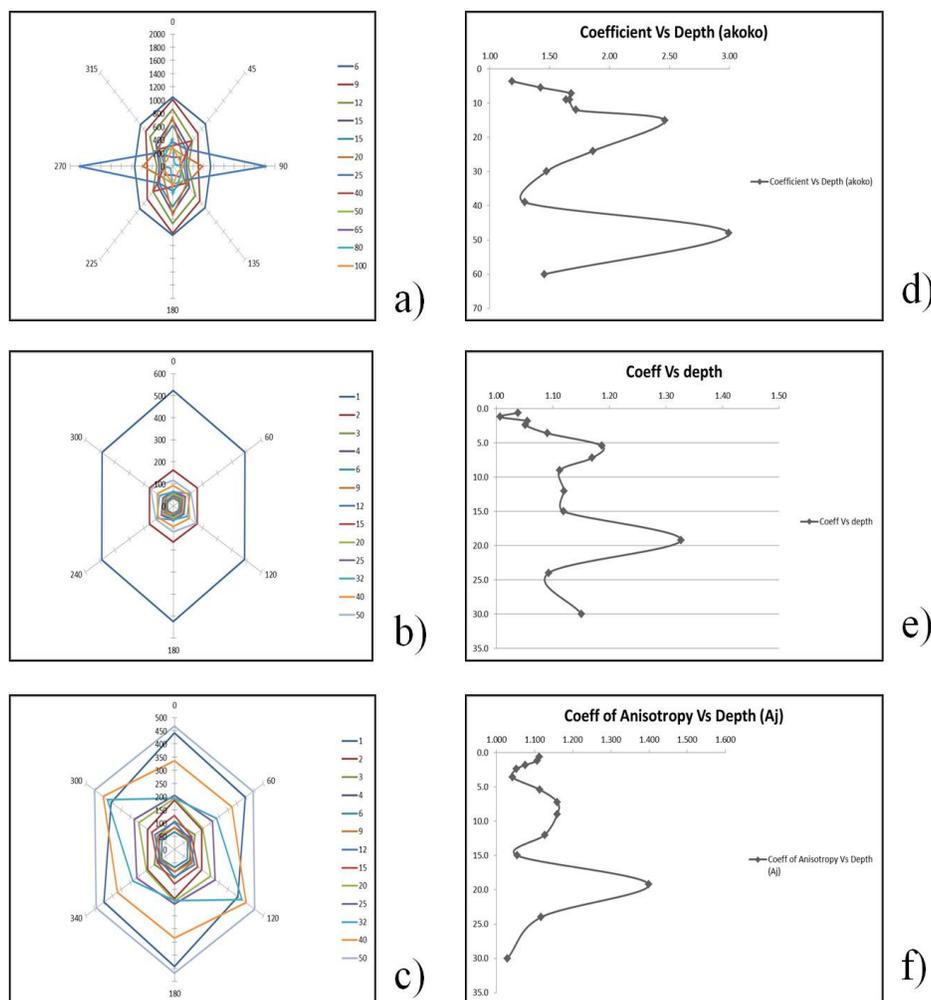|	Aiyegunle			
AB/2	0°	60°	120°	λ
1	442.0794	397.4237	175692.8	21.025
2	186.6136	153.0123	28554.17	13.660
3	107.7211	114.0114	12281.43	10.677
4	83.09549	91.98897	7643.869	9.591
6	68.61048	73.49487	5043.094	8.573
9	84.13239	76.36867	6425.079	9.172
12	103.7017	82.9704	8604.172	10.183
15	136.1394	112.0137	15348.82	11.705
20	194.4424	159.2772	30970.24	13.944
25	205.0796	214.0984	43907.21	14.632
32	193.4988	236.0878	45682.72	15.365
40	377.32	321.3395	121187.1	19.419
50	466.9876	441.2878	206075.9	21.609

Figure 6. Anistropy Polygon for a) ARS-VES 1 (AKOGRAMS). b) ARS-VES 2 (UNEME NEKUA) and c) ARS-VES 3 (AIYEGUNLE). d- f) Plot of coeffcent of anisotropy wth depth.

sional structures. Overlap between fractures oriented at shallow subsurface reveal by electrical resistivity anisotropy polygon plot and that of fracture orientation on the surface rock exposures in the study area; suggest that fractures are penetrative and hard-linked. Thus, the fractures at both levels are produced by similar tectonic events.

REFERENCES

Ajibade ZF, Fitches, WR (1988). The Nigerian Precambrian and the pan African orogeny in GSN: Precamb. Geol. Nig., pp. 45-53.

Anifowose AYB, Odeyemi IB, Bamisaye CA (2008). Establishing a Solid mineral database for part of southwestern Nigeria Geospatial world (www.gisdevelopment.net).

Barnes JW (1981). Basic geological mapping. John wiley and Sons, New York. p.776

Black R (1980). Precambrian of West Africa. *Episodes 4:3-8.*

Black R, Ba H, Ball E, Bertrand JM, Boullier AM, Caby R, Davison I, Fabre J, Leblanc M, Wright LI (1979). Outline of the Pan-African Geology of Adrar des Iforas (Republic of Mali). Band 68, Heft 2, seite 543 – 564.

Boadu FK, Gyamfi J, and Owusu E (2005). Determining subsurface fracture characteristics from azimuthal resistivity survey: A case study at Nsawam, Ghana, Geophy., 70: B35-B42.

Champenois M, Boullier AM, Sautter V, Wright LI, Barbey P (1987). Tectonometamorphic evolution of the gneissic Kidal assemblage related to the Pan –African thrust tectonics (Adrar des Iforas, Mali). J. Afr. Earth Sci., 6(1)19- 27.

Dada SS (1999). "Pb-Pb and Sm-Nd Isotope Study of Metaigneous Rocks of Kaduna Region: implications for Archaean Crustal Development in Northern Nigeria". Global J. Pure Appl. Sci., pp.6:7.

Dada SS, Tubosun IA, Lancelot JR, Lar AU (1993). Late Achaean U–Pb age for the reactivated basement of Northeastern Nigeria. J. Afr. Earth Sci., 16:405–412.

Dada SS, Lancelot JR, Briqueu L (1989). Age and origin of the annular charnockitic complex at Toro, Northern Nigeria: U–Pb and Rb–Sr evidence. J. Afr. Earth Sci., 9:227–234.

Egesi N, Ukaegbu VU (2010). "Petrologic and Structural Characteristics of the Basement Units of Bansara Area, Southeastern Nigeria". Pac. J. Sci. Technol., 11(1):510-525.

Ekwueme BN (2004). Field geology and geological map production and interpretation. Bachudo Science, Calabar, p.165.

Fitches WR, Ajibade AC, Egbuniwe IG, Holt RW, Wright JB (1985). Late Proterozoic schist belts and plutonism in N.W. Nigeria. J. Geol. Soc. Lond., 142:319-337.

Grant NK, Hickman M., Burkhotder FFt, Powell JL (1972). "Kibaran metamorphic belt in Pan-African domain of West Africa". Nature Phys. Sci., 238:90-91.

Habberjam GM (1972). The effects of Anisotropy on Square Array Resistivity measurements. Geophys. Pospect., 23:211-247.

Lane JM Jr, Haeni FP, Waston WM (1995). Use of a Square-Array Direct-current Resistivity method to detect fractures in crystalline Bedrock in New Hampshire Ground water, 33(3):476-485.

Malik SB, Bhattachrya DC, and Nag SK (1983) Behaviour of fractures in hard rocks a study by surface geology and rapid VES method. Geoexploration, 21(3):181-189.

Mc Curry P (1976). The Geology of the Precambrian to Lower Paleozoic Rocks of Northern Nigeria. A review, in Geology of Nigeria, Edited by C.A. Kogbe published by Elizabethan Co. Lagos. Pp.15-39.

Odeyemi IB, Asiwaju-Bello YA, Anifowose AYB (1999) Remote sensing Fracture Characteristics of pan-African Granite Batholiths in the Basement complex parts of Southwestern Nigeria. J. Tech. Sci., 3: 56-60.

Olade MA, Elueze AA (1979). Petrochemistry of the Ilesha amphibolite and Precambrian crustal evolution inthe Pan-African domain of SW Nigeria. Precamb. Res., 8:303-318.

Oluyide PO (1988). "Structural Trends in the Nigerian Basement Complex". In: P.O. Oluyide. Precambrian Geology of Nigeria. Geol. Surv. Nigeria: Lagos, Nigeria. 93-98.

Omosanya KO, Akinbodewa AE, Mosuro GO (2012a). Integrated Mapping of Lineaments in Ago-Iwoye SE, SW Nigeria- Intl. J. Sci. Technol., 1(2):68-79.

Omosanya KO, Mosuro GO, Azeez L (2012b) Combination of geological mapping and geophysical surveys for surface-subsurface structures imaging in mini-campus and Methodist Ago-iwoye NE areas, southwestern Nigeria. J. Geol. Min. Res., 4(5):105-177.

Onyeagocha AC (1984). Petrology and Geological History of N.W. Akwanga in Northern Nigeria. J. Afr. Earth Sci. 2(2):441-50.

Onyeagocha AC, Ekwueme BN (1982). "The Pre-Pan-African Structural Features of North central Nigeria". Niger. J. Min. Geol., 19(2):74-77.

Oyawoye MO (1972). "The Basement Complex of Nigeria". African Geology. Geology of Africa T.F.J Dessauvagie and A.J. Whiteman (eds.). 67-99. University Ibadan: Ibadan, Nigeria.

Rahaman MA (1976). Review of the Basement Geology of South-western Nigeria. In: Geology of Nigeria, edited by C.A. Kogbe, Elizabethan Publ. Co., Lagos. pp.41-58

Rahaman MA (1981). "Recent Advances in the Study of the Basement Complex of Nigeria". First Symposium on the Precambrian Geology of Nigeria, Summary.

Rahaman MA (1988) Review of the basement Geology of Southwestern Nigeria. In Kogbe (ED): Geology of Nigeria. Rocks view (Nig) Ltd, Jos. Nigeria. pp.39-56.

Rahaman MA, Ocan O (1978). On relationship in the Precambrian migmatic gneisses of Nigeria. Niger. J. Min. Geol., 15:23-32.

Skjernaa L, Jorgensen NO (1993). Evaluation of local fracture systems by Azimuthal Resistivity surveys. Examples from South Norway. Intl. J. Hydrogeol., 2:19-25.

Slater LD, Wishart DN, Gates EA (2006). Self potential improves characterization of hydraulically-active fracture from azimuthal geoelectrical measurements, Geophys. Res. Lett., 33:L17314.

Toteu SF, Macaudiere J, Bertrand JM, Dautel D (1990). "Metamorphic Zircons from North Cameroon: Implications for the Pan-African Evolution of Central Africa". Geol. Rundsch., 79:777-788.

Turner DC (1983). Upper Proterozoic schist belts in the Nigerian sector of the Pan-African Province of West Africa. Precamb. Res., 21:55-79.

Ukaegbu VU (2003). The petrology and Geochemistry of parts of Obudu Plateau, Bamenda Massif, Southeastern Nigeria. Unpublished Ph.D Dissertation, University of Port Harcourt, pp.251-258.

Van Breemen OR, Pidgeon, Bowden P (1997). Age and isotopic studies of Pan-African granites from north-central Nigeria. Prec. Res., 4:307-319.

Woakes M, Ajibade CA, Rahaman MA (1987). Some metallogenic features of the Nigerian Basement, J. Afr. Sci., 5:655-664.