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STRUCTURAL ATTRIBUTES AND SEQUENCE OF ENTRY OF INDEX MINERALS IN THE ROCKS AROUND SHINTAKU AREA OF SOUTHEASTERN PART OF LOKOJA, NORTH-CENTRAL, NIGERIA

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Abstract
This study delineates the structures (faults, folds, foliation trends, and joints) and index minerals on the schists, gneisses, migmatites and granites that are pervasive in the Shintaku area of the southeastern part of Lokoja, North-Central, Nigeria. Field descriptions of the rocks associated with the Basement Complex in the area under study revealed that the metamorphic rocks were deformed (foliated) in the NNE/SSW direction from the plot on the Rose diagrams. The trend on the same set of diagrams made from the joint sets showed that the major stress that impacted on the rocks occurred in the N/S direction while the minimum stress is in the E/W direction. The relationship between this structural trend and the Pan African orogeny is rather striking. The stresses caused by the Pan African orogenic events must have exceeded a critical value after the rocks had already undergone elastic behaviour making them susceptible to the deformations. The order of entry of the diagnostic minerals into the pelitic rocks also showed that metamorphism in the area ranges from greenschist to amphibolite facies. The prograde regional metamorphism is likely associated with the anatexis that formed the migmatites.
Keywords: *Foliations, joints, rose diagrams, thin section, anatexis.*

Introduction

Efforts have been made in the past by some authors on some aspects of the geology of the Shintaku area. Some of these contributions include those of [1]; [2]; [3]; [4]; [5] and [6] on the Regional metamorphism of the pelitic rocks, south-east of Lokoja, Nigeria; Staurolites in the pelitic schists, southeast of Lokoja, Nigeria: composition and petrologic implications; Rb/Sr ages of schists in the metasedimentary belts in the southeast Lokoja and their implications for the Precambrian evolution of central Nigeria; Plagioclases in metamorphosed rocks of Lokoja S.E.,Nigeria; Temperature-pressure distribution patterns in metamorphosed rocks of the Nigerian basement complex – a preliminary analysis; and Isotopic ages from the Oban Massif and southeast Lokoja: implications for the evolution of the Basement Complex of Nigeria, respectively. There has been near absence of geological information on the textural and mineralogical studies of rocks in the Shintaku area, especially in recent times. Textures and mineralogical compositions are keys to the classification of rocks especially the igneous and metamorphic rocks. This is in addition to their chemistry and mode of occurrences. This study, therefore, is an attempt to bring an update in this respect. The framework of the metamorphic rocks, in the Shintaku area of southeastern part of Lokoja, North Central, was investigated. The actual areas covered lie within longitudes $6^{o}45^{1}$E and $6^{0}50^{1}$E and latitudes $7^{0}40^{1}$N and $7^{0}45^{1}$N (Figure. 1). The deformations that impact solid rocks result from forces within the earth, causing folds, joints, faults and foliation [7]. Because the movements of magma is often intimately associated with the movement of solid rocks, it is opined (e.g. by [7]) to be the major cause of most structural deformations. Changes in temperature, pressure and time have also been implicated in the deformation of rocks.

The Basement Complex of Nigeria is dominated by gneisses, migmatites, metasediments and intrusive rocks of granitic composition [8]. Shintaku area is an integral part of this Basement Complex.

Methodology

Shintaku area was mapped between the eighth and the fifteenth days of March, 2018, and important features, locations, attitudes of planes and other structural features of the rocks were adequately observed and recorded. The basic procedures followed for this study include the following:

i) Location of outcrops and collection of fresh samples.
ii) Examination of outcrop: noting the type and features on the rocks.
iii) Thin section studies of the rock samples where the sections were viewed under the petrologic microscope after undergoing the following procedure:
   a. the glass slide used for the thin sections was glued flat to the rock sample in order for the rock section to end up with a constant thickness. The later was achieved when the slide was frosted to accomplish two goals: removal of the thick spots on the slide and adjust the slide face to be parallel to the grinding wheel's face.
   b. the slab was cleaned to remove any oil and grit from the slab saw process.
   c. the chip was cut to reduce the size of the slab to slightly smaller than a thin section.
   d. the frosted side of the slide was glued to the chip ensuring a constant epoxy across the section.
   e. the chip was cut off from the slide leaving a thin slice attached.
   f. the slide was ground to the appropriate thickness.
   g. the section was covered at this stage to protect it from damage and increase the clarity observed in the microscope and
iv) Plotting the field data on the map and their interpretation.

Structural features such as faults, folds, joints, foliations and foliation trends, trend of veins and intrusions were also described.

Thin sections of three (3) of the rock samples were prepared and analyzed for petrographic studies. Plane and cross photomicrographs of interest were taken to broaden knowledge of the mineralogy and probable field inclusions for each sample by placing the glass slide on the stage of a petrographic microscope, and access the cross polarized photomicrograph by changing the nicol.

The prepared thin section were examined under a petrological microscope to identify the mineral assemblage, morphology and other properties while the minerals' optical properties such as cleavage colour and relief (Tables 1, 2 and 3) were studied under a plane polarized Light (PPL) and cross polarized light (XPL) of the same microscope. The results obtained from these analyses were subjected to interpretation to delineate the texture, mineralogical, and modal composition of the rocks.

Results of the field studies

Lithological Description

The major lithological units mapped in the study area include granite, schist, porphyroblastic gneiss and migmatite gneiss (Figure 1).

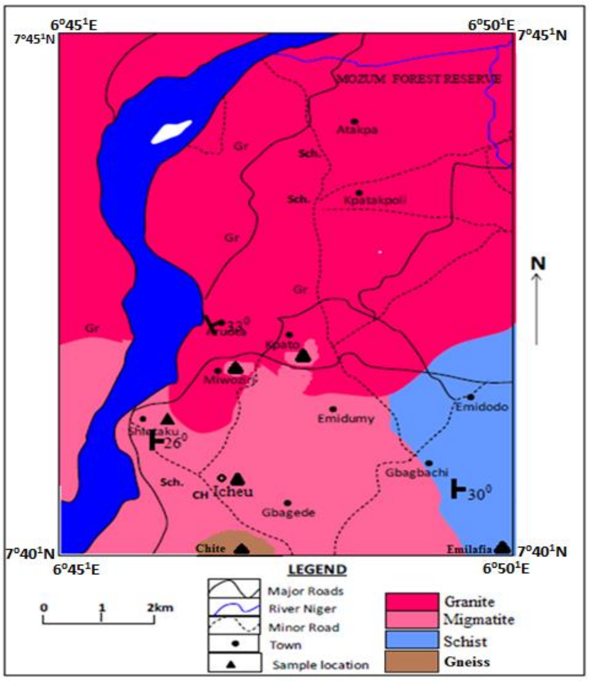


Figure **1**: Geological map of Shintaku

Others include pegmatitic veins and minor intrusives such as quartz veins and quartzofeldspathic veins. Alluvium, laterite and soil occur as superficial deposits.

Structural attributes of the rocks in the area

The structural features characterized in the field include brittle structures such as faults and ductile structures like folds.

Faults: Most of the faults found in the study area are dextral faults (Figure. **2**).

Figure **2**: Dextral fault on the exposure of Gneiss at Emiwoziri

Folds: Folds found in the study area are ptygmatic folds (Figure.**3**), open folds (Figure. **4**), isoclinal folds, and recumbent folds (Figure.**5**). They occur mainly in the migmatites found in the western part of Shintaku (locations 1 and 2).

Figure **3**: Ptygmatic folds on the exposure of Migmatite at Shintaku (SH)

Figure **4**: Open fold on the exposure of Migmatite at Kpata

Figure **5**: Recumbent folds on the exposure of Migmatite at Icheu (ICH)

Intrusions: Some of these intrusions contain magmatic or hydrothermal deposits. Examples of these intrusions are sills and veins (concordant - Figure.6) and dykes (discordant - Figure.7).

Figure **6**: An intrusion of quartzo-feldsparthic vein cutting through an exposure of Migmatite at Icheu.

Figure **7**: A 4cm quartzo-feldsparthic intrusion on the exposure of migmatite at Icheu.

Pegmatitic intrusions: These intrusions (Figures. **8** and **9**) must have formed by the late stage cooling of magma which results in larger crystals of minerals. They are also granitic in composition and most of the pegmatitic intrusions host economic minerals such as tourmaline, tantalite, and beryl in various degrees of composition but not at levels that could be described as economic. These are minerals associated with hydrothermal deposits. Most of the pegmatitic veins found in the study area run NW-SE, a few run NNE-SSW. They also occur in banded gneisses and migmatitic-gneisses.

Figure **8**: A pegmatitic vein trending NE-SW and marking the contact between the igneous and metamorphic feature on the exposure of Migmatite at Kpata

Figure **9**: A Pegmatitic vein on the exposure of Migmatite at Icheu

Joints: These joints (Figure.10) were products of brittle deformation of the rock body as a result of tensile stress which occurs when stresses exceed a critical value and thus only after a rock has already undergone some elastic and/or plastic behaviour. These tensile stresses were either imposed from outside, e.g. by the stretching of layers; the increase of pore fluid pressure as a result of either external compression or fluid injection; or the result of internal stresses resulting from the shrinkage caused by the cooling or desiccation of a rock body or layer whose outside peripheries or demarcations remained fixed.

Figure 10: Cross cutting joints on the Migmatite outcrop at Icheu.

Results of the petrographic studies

Petrography

Three samples from the study area were selected for thin section petrographic examination, in order to determine their mineral composition and likely fluid inclusions.The prepared thin section were examined under a petrological microscope to identify the mineral assemblage, morphology and other properties while the minerals optical properties such as cleavage, colour and relief were studied under a plane polarized light (PPL) and cross polarized light (XPL) of the same microscope.

The results obtained from these studies were subjected to interpretation to delineate the texture, mineralogical, and modal composition of the rock types being analysed [3]. Field work and petrography show that, gneiss, migmatite and schist in the study area have been deformed due to both the plastic and brittle deformations as evidenced by the presence of antiformal and synformal folds and shear fracture, respectively.

Table 1 reveals foliations on the migmatitic rock sample collected from Emiwoziri location 1 (EM1). These were confirmed from the orientation of the plagioclase feldspars (PF) and the micas - biotite (B) and muscovite (M) - in both the PPL (Figure 11) and under cross nicol (Figure 12). Symmetry and birefringence of the major minerals in the rock sample were also considered under both PPL and XPL in figures 11 and 12, respectively.

Table 1: Detailed Thin Section Analysis for EM 1 (006^0 46' 44.3''; 7^0 44' 06.8", 59.7m)

Location	Identified minerals in percentages	Properties	Structures	Rock type
1. EM 1	Anorthoclase Feldspar(Na, K) $AlSi_3O_8$ (AF, 30%) Plagioclase Feldspar ($NaAlSi_3 – CaAl_2Si_2O_8$) (PF, 20%) Biotite $K(Mg, Fe)_3AlSi_3O_{10}(OH, F)_2$ (B, 10%) Quartz (SiO_2) (Q, 25%) Muscovite $KAl_3Si_3O_{10}(OH, F)_2$ (M, 15%)	Symmetry = Triclinic R. I = 1.528 – 1.532 Birefringence = 0.007 – 0.008 Symmetry = Triclinic (+) or (-) R. I = 1.532 – 1.585 Birefringence = 0.007 – 0.013 Symmetry = Monoclinic (-) R. I = 1.605 – 1.696 Birefrigence = 0.04 – 0.08 Symmetry = Trigonal (+) R. I = 1.533 - 1.544 Birefringence = 0.009 Symmetry = Monoclinic R. I = 1.582 - 1.610 Birefringence = 0.036 – 0.049	Foliation	Migmatite

Location – EM 1

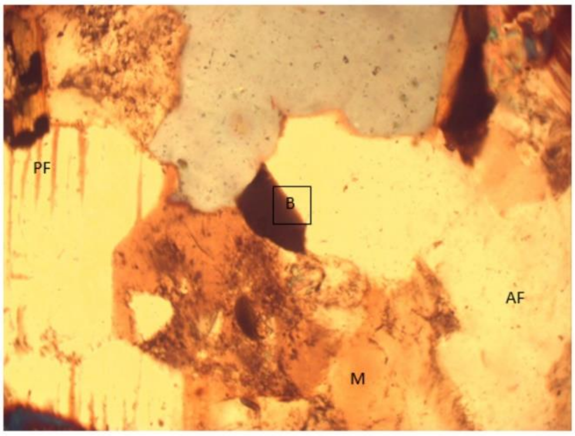


Figure 11: Plane Polarized Light Photomicrograph of EM 1

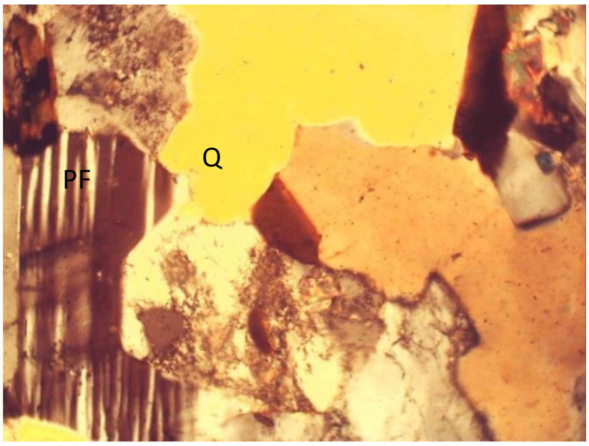


Figure 12: Cross Polarlzed Light Photomicrograph of EM 1

At Emilafia location 1 (EMLF 1) (Table 2), the schistocity defined on the schistose rocks as the intergrowth of quartz and orthoclase was very visible even under PPL (Figure 13). The granophyric texture and structures are clearer under cross polarized light (Figure 14).

Birefringence and crystal system of some of the mineral constituents of the sample were also noted under PPL (Figure 13) and under XPL (Figure 14).

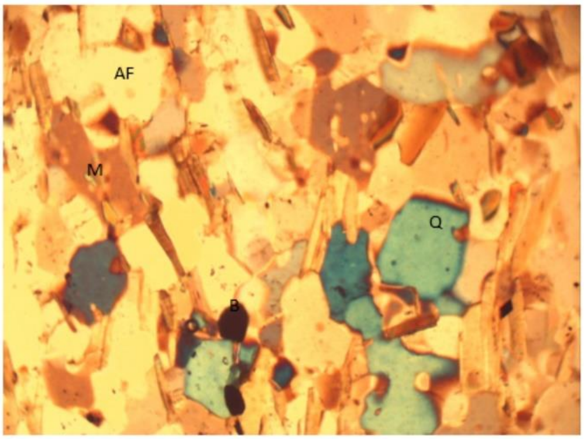


Figure 13: Plane Polarized Light Photomicrograph of EMLF1.

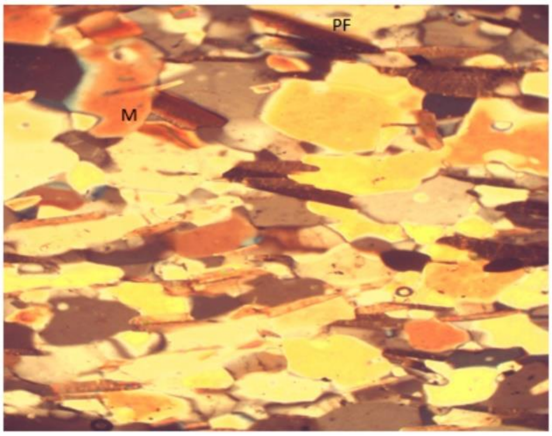


Figure 14: Cross Polarized Light Photomicrograph of EMLF1.

Table 2: Detailed Thin Section Analysis for EMLF1 (006^0 49’ 48.8”; 07^0 42’ 30.6”, 130.3m)

Location	Identified minerals in Percent (%)	Properties	Structures	Rock type
1.EMLF 3	Granophyric texture	An intergrowth of quartz and anorthoclase feldspar. The intergrowth is visible even in Plane Polarized Photomicrograph. Birefringence of the two minerals shows that the alkali feldspar is brown due to alteration whereas the quartz is clear.	Well foliated	Schist
	Muscovite$KAl_3Si_3O_{10}(OH, F)_2$ (M, 25%)	Symmetry = Monoclinic R. I = 1.582 - 1.610 Birefringence = 0.036 – 0.049		
	Biotite $K(Mg, Fe)_3AlSi_3O_{10}(OH, F)_2$ (B, 10%)	Symmetry = Monoclinic (-) R. I = 1.605 – 1.696 Birefrigence = 0.04 – 0.08		
	Anorthoclase feldspar $(Na, K) AlSi_3O_8$ (AF, 20%)	Symmetry = Triclinic R. I = 1.528 – 1.532 Birefringence = 0.007 – 0.008		
	Plagioclase Feldspar($NaAlSi_3$ – $CaAl_2Si_2O_8$) (PF, 20%)	Symmetry = Triclinic (+) or (-) R. I = 1.532 – 1.585 Birefringence = 0.007 – 0.013		
	Quartz (SiO_2) (Q, 25%)	Symmetry = Trigonal (+) R. I = 1.533 - 1.544 Birefringence = 0.009		

Location – EMLF1.

The rocks at Icheu location 6 (ICH6) (Table 3) are the most deformed of the samples studied. The faulting and foliation could be observed even under the plane polarized light (Figure 15).

The plagioclase feldspars (PF) are richer in the alkali (Na) variant (Figure 16). Optical properties of the major mineral compositions were also studied from figures 15 and 16.

Table 3: Detailed Thin Section Analysis for ICH6 (006^0 46' 51.8"; 07^0 42' 38.8", 77.1m)

Location	**Identified minerals in percent (%)**	**Properties**	**Structures**	**Rock type**
2. ICH 1B	Quartz (SiO_2) (Q, 40%) Anorthoclase feldspar (Na, K) $AlSi_3O_8$ (AF, 20%) Plagioclase Feldspar ($NaAlSi_3 – CaAl_2Si_2O_8$) (PF, 20%) Biotite K(Mg, Fe)$_3$AlSi$_3$O$_{10}$(OH, F)$_2$ (B, 20%)	Symmetry = Trigonal (+) R. I = 1.533 - 1.544 Birefringence = 0.009 Symmetry = Triclinic R. I = 1.528 – 1.532 Birefringence = 0.007 – 0.008 Symmetry = Triclinic (+) or (-) R. I = 1.532 – 1.585 Birefringence = 0.007 – 0.013 Symmetry = Monoclinic (-) R. I = 1.605 – 1.696 Birefrigence = 0.04 – 0.08	Presence of fault. The rock is also foliated.	Migmatite

Location – ICH6

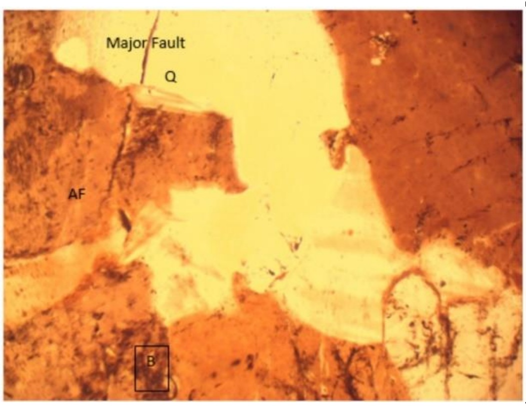


Figure 15: Plane Polarized Light Photomicrograph of ICH6

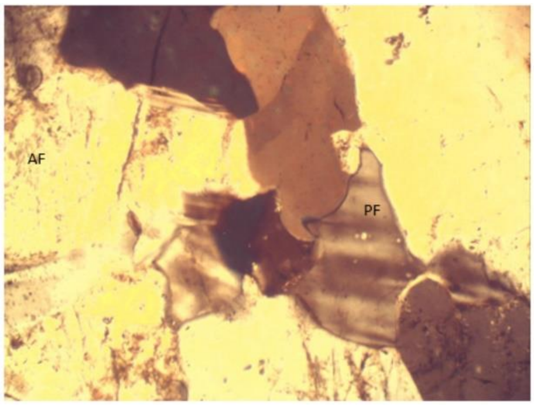
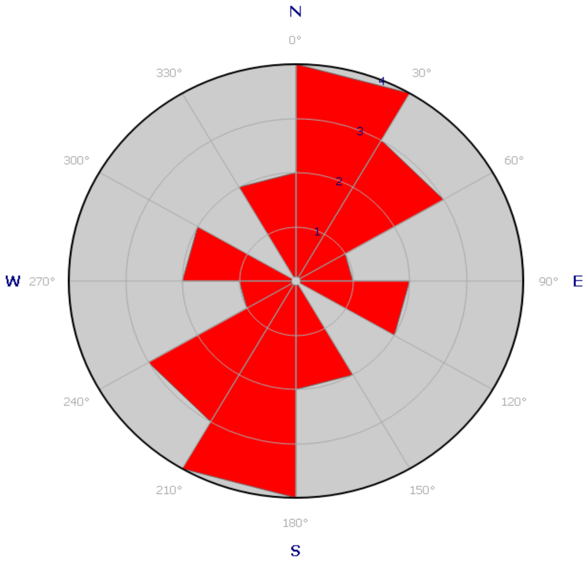


Figure 16: Cross Polarized Light Photomicrograph of ICH6

Discussions

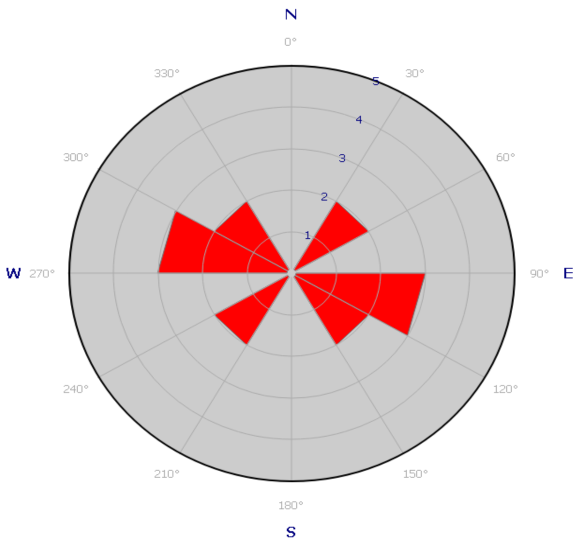
The major trends of the foliations in the study area lie in NNE/SSW direction illustrated by the rose diagram (Figure 17). This indicates that the rocks of the area were impacted by the Pan African Orogenic (600±50Ma) events as alluded to by [9].



Trends of Foiations
270
230
230
210
209
245
270
180
350
15

Figure 17: Rose diagram showing the major trend of foliation

Using the trend of joints illustrated by the rose diagram (Figure 18), the major stress that affected the rocks of the Shintaku area is in N/S direction while the minimum stress is in E/W direction. Cross cutting joints (Figure 10) may have resulted from brittle deformation that may have also occurred as a result of stresses that exceeded a critical value only after the rock had already undergone some elastic and/or plastic behavior. According to [10] and [11], the joints often result from contraction on cooling and are believed to be associated with a single episode of cooling and fracturing during epeirogenic uplift.



Trend of Joints
294
225
290
310
235
225
280

Figure 18: Rose diagram showing the major joint trend

Sequence of Entry of Index Minerals in the Rocks

The order of introduction of the diagonistic minerals: garnet-staurolite-cordierite (EMI, KT1, CHT2 and ICH6 (Figure 19)) into the pelitic assemblages of the Shintaku area shows that metamorphic facies ranged from Greenschist facies to the Amphibolite facies which further implies that the grade of metamorphism ranged from medium to high (formed at medium pressure and high temperature). The assemblages of the index minerals, that is, garnet-staurolite-cordierite shows that EMI, KT1, CHT2 and ICH6 belong to the amphibolite facies. The mineral assemblages, that is, plagioclase-muscovite-andalusite-sillimanite (Figure. 19) in SK1 (Exp2), KT6 and ICH3a indicate the greenschist facies which is a medium grade of metamorphism.

Even so, since the assemblage quartz+muscovite+staurolite is present in the rock (EMLF1), the bathozone of [12] has been attained. The presence of index minerals; almandine garnet, staurolite and cordierite as shown in (Figure 19) indicates that the rocks analyzed have undergone prograde regional metamorphism [13]. The association of cordierite and almandine which is observed in the Shintaku area is remarkable and shows that metamorphism occurred at medium pressures and that high temperatures were reached which led to the formation of migmatite as a result of partial melting (anatexis) in some of the rocks [5].

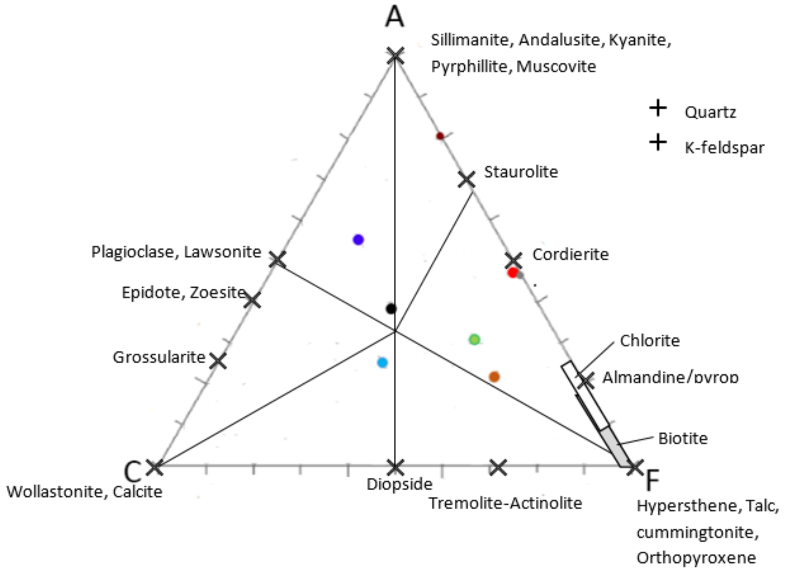


Figure 19: ACF diagram representing Mineral Assemblages [14]

Conclusion

All the rocks studied are foliated. The major trend of the foliations lies within NNE/SSW direction which suggests that the rocks were impacted by the events of the Pan African Orogeny. The stresses resulting from the Pan African Orogeny must have exceeded a critical value after the rocks had already undergone elastic behavior yielding them to the observed deformations.

The order of the introduction of the diagonistic (index) minerals: garnet-staurolite-cordierite into the pelitic assemblages of the Shintaku area shows that metamorphic facies range from greenschist facies to the amphibolite facies. The high temperatures associated with the amphibolite facies led to anatexis and the migmatization.

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