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Global Journal of Geosciences and Geoinformatics

Research Article Open Access

ISSN: 2449-1861 Vol. 10 (1). pp. 1-12
March, 2022

Structural geological mapping and mineralization potential indicators in the psammitic rocks of efon-alaaye and environs, Southwestern Nigeria

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Received: 14-Jan-2022, Manuscript No. GJGG-22-48320; **Editor assigned:** 17-Jan-2022-PreQC No. GJGG-22-48320 (PQ); **Reviewed:** 31-Jan-2022, QC No. GJGG-22-48320; **Revised:** 14-Mar-2022, Manuscript No. GJGG-22-48320 (R); **Published:** 31-Mar-2022; DOI: 10.2449-1861.22.10.001

ABSTRACT

The geological and structural studies of the Basement Complex rocks in Efon-Alaaye and Environ area revealed that the basement rocks has undergone polyphase deformation episodes leading to its structural realignment. The dominant rock types are the metasedimentary assemblages referred to as the “Efon Psammite Formation” and the older quartzo- feldspathic gneisses. Two phases of deformation have affected the entire study area. The first phase was characterized by intense deformation and folding accompanied by regional metamorphism. It is mostly a fabric forming deformation that also resulted in low angle plunge and mineral lineation development generally in the N-S direction, synformal, antiformal and overturned folds are typical of this deformational stage. Also, the development of associated fault to the Iwaraja (ductile) shear zone occurred during the second deformation episode, as well as the N-S trending pegmatite vein that crystallized along the lineation of the granitic gneiss. Extensional fractures (joints) in the various outcrops have bi-modal orientations in the NE-SW, E-W and ESE-WNW directions. These structures are believed to be imprinted on the basement rocks during the end of the Pan African orogeny, and are believed to be themineralization potential indicators in the study area.

Keywords: Efon, Psammite, Deformation, Structures, Mineralization, Orogeny

INTRODUCTION

The Pan-African deformation was accompanied by a regional metamorphism, migmatization and extensive granitization and gneissocity that produced syntectonic granites and homogeneous gneisses [5]. Late tectonic emplacement of granites and granodiorites and associated contact metamorphism accompanied the end stages of this last deformation [6]. The end of the orogeny was marked by faulting and fracturing [7]. The aim of this research is to evaluate the geology and structural framework of the Psammitic rocks and determine its mineralization potentials and controls in the study area [8].

MATERIAS AND METHODS

Description of the Study Area

The study area is located within longitudes 4°52'0'' E and 4°57''0''E and latitudes7°35'0''N and 7°41'0''N and falls within the eastern unit of the Ilesha Schist Belt (Figure 1) [9].

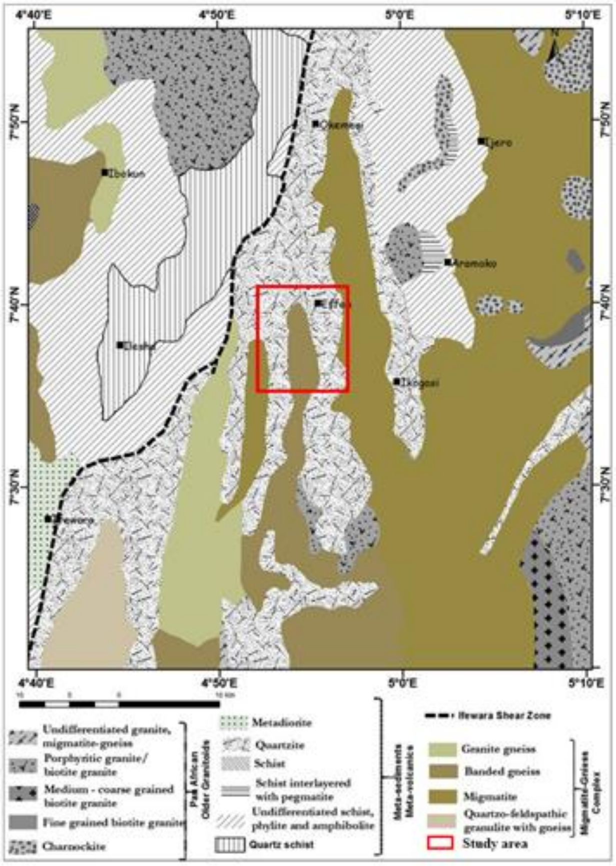

Figure 1: Geology of Ilesha Schist Belt, also showing the study area. (Modified after Nigerian Geological Survey Agency 2006, Odeyemi 1993).

It comprises of meta-sedimentary rocks which include; schistose quartzite, quartz schist, quartz- mica-schist [10]. In addition, the unit also comprises of migmatite-gneiss complex (Odeyemi, 1993; Okunlola and Okorojafor, 2009; Adeoti and Okonkwo, 2016; Ayodele, 2014) [11]. The metasedimentary assemblages have been hitherto referred to as The Efon Psammite Formation (Hubbard *et al*., 1975) [12]. The study area is dominated by prominent north-south trending ridges, separated by relatively lowland (Figure 2) [13]. This is an indication of an active area of orogeny and other geological processes (Ayodele, 2014); hence the ridges are structural markers that delineate folds and lineaments [14].

The Northern flanks of the study area Okemesi (Figure 1), have been widely investigated by several workers such as (Odeyemi 1993; Anifowose and Borode, 2007; Ayodele, 2010) [15]. They studied the area using remote sensing techniques to map out its geology and structures as well as evaluate itsmineralization potentials [16]. However, there seems to be paucity of information as regard the bedrock geology, structures, and mineralization potentials of the psammites in Efon area which necessitates this research [17].

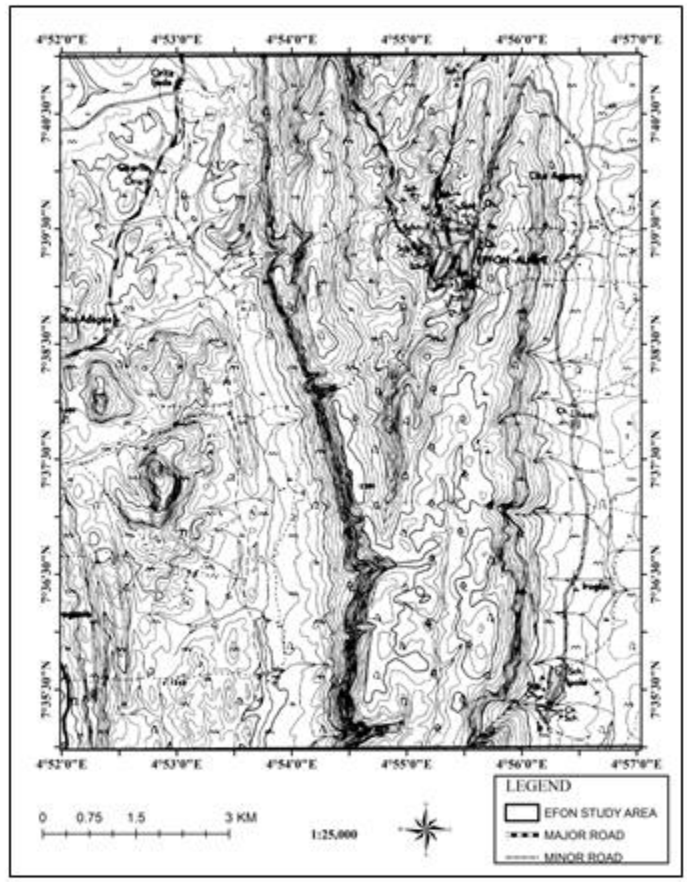

Figure 2: Topographic Map of the study area. (Source: Sheet 243, Ilesha Southeast, Federal Surveys, Nigeria, 1966).

Landsat 8 and Shuttle Radar Topography Mission imagery (SRTM), both of path 190 and row 055 were processed and integrated with detailed geological field mapping to discriminate lithology's and geological lineaments. The remote sensing data were downloaded from USGS website. Firstly the Landsat 8 imagery was uploaded to the ArcGIS 10.3 software, whereby Principal Component Analyses (PCA) was carried out to get the best imagery. This imagery and the SRTM imagery were then exported to PCI Geomatica 2015 software, where the lineaments were automatically extracted using the LINE module, based on automatic detection algorithms (canny algorithms). Rose diagram of the lineaments was generated using the Rockworks 17 software. This was done after the lineaments extracted was exported into the ArcGIS 10.3 environment where it was prepared by creating X_start, X_end, Y_start, Y_end, X-mid and Y_mid coordinate using the Calculate Geometry tool and exported in CAD format [18]. The rose diagram was finally generated in Rockworks 17 software and exported as a jpeg image [19].The Digital Elevation Model map was generated from the processing of the SRTM imagery in the ArcGis environment [20]. The geological field mapping was done with a topographic sheet at a scale of 1:25,000. Measurements of structures which includes; lineations, foliations, and joints orientation were carried out on different outcrops encountered on the field. Rock units encountered were systematicallysampled at 200 m sampling interval, wherefore twenty (20) fresh rock samples were collected during the field study, while seven (7) out of it was prepared for petrographic analysis. Three of the rock samples whose thin sections indicated opaque minerals were later cut and prepare df or ore microscopic studies.

RESULTS AND DISCUSSIONS

Lineaments

The raw Landsat 8 and SRTM imageries of the study area are shown in Figures 3 and 4 respectively. They were analyzed to produce the lineament map presented in Figure 5. The rose diagram generated for the lineaments in the study area (Figure 6) showed a total of 138 lineaments with total length of 147. 948.08 Km and revealed that the lineaments are bi-directional. The major fractures are ENE-WSW direction while subsidiary ones are in the E-W and NW-SE directions. The schistose quartzites are the most and highly fractured rock type in the study area with the fracture mostly trending ENE-WSW direction. The Digital Elevation Map (DEM) (Figure 7) revealed that the schistose quartzite is generally high in elevation and ranges from 445 m to 728 m, while the quartz schists and the quartz-mica-schists are generally low-lying ranging from 295 m to 444 m whereas, the granitic gneiss appears to have moderate elevation ranging 379 m to 616 m. A likely fault (Figure 7) was detected from the DEM map of the study area and also from visual inspection of the Landsat 8 imagery. The sharp contrast between the lowest elevation of the quartz- schists and highest elevation of the schistose quartzite is suspected to be a reverse fault, which had earlier beenestablished by Odeyemi 1993; Anifowose 2006 in the Ilesha schist belt. They reported that these faults are associated with the Ifewara Fault and are indicative of possible subduction zone in an oceanic basin.

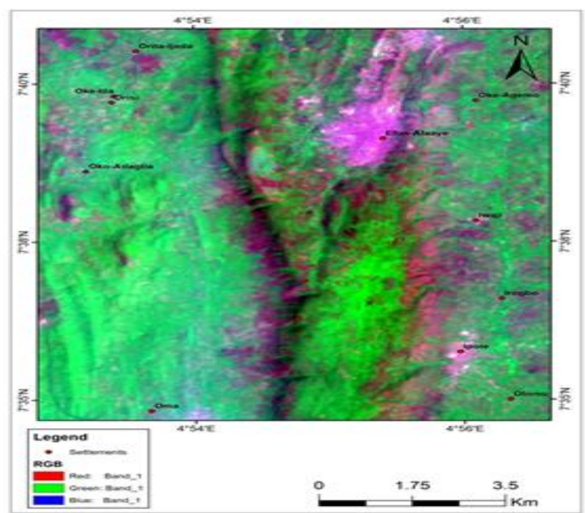

Figure 3: Raw Landsat 8 imagery of Efon-Alaaye and environs (Earthexplorer).

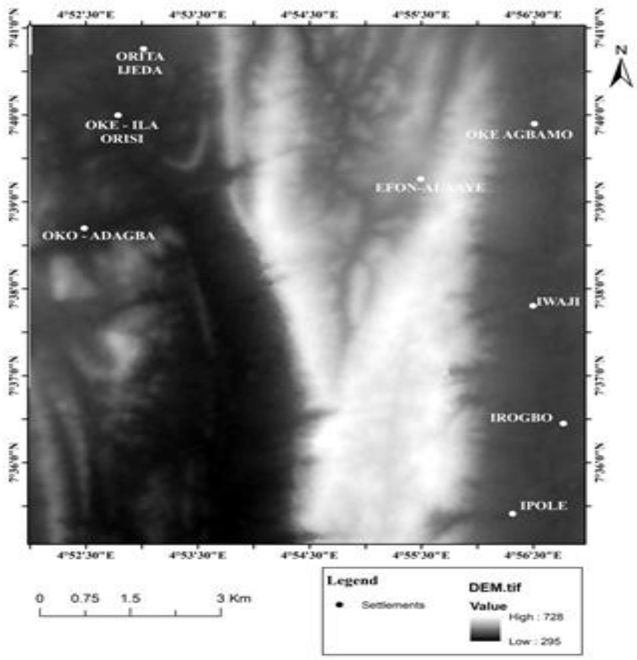

Figure 4: Raw SRTM imagery of Efon-Alaaye and environs (Earthexplorer).

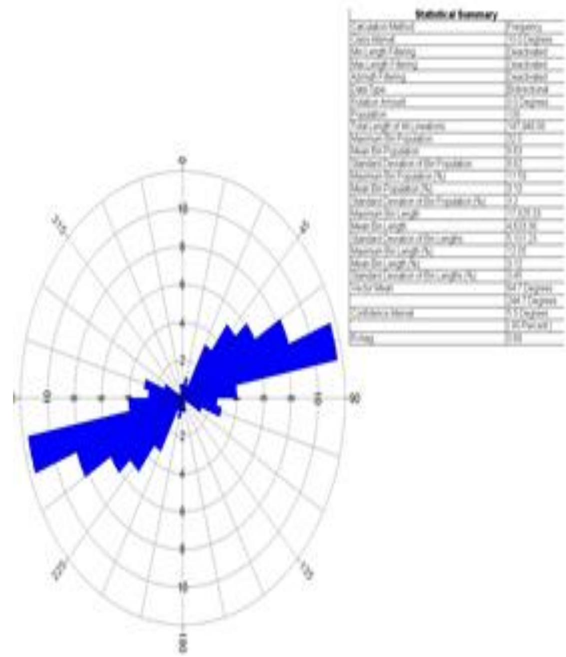

Figure 6: Rose diagram generated from the lineament map.

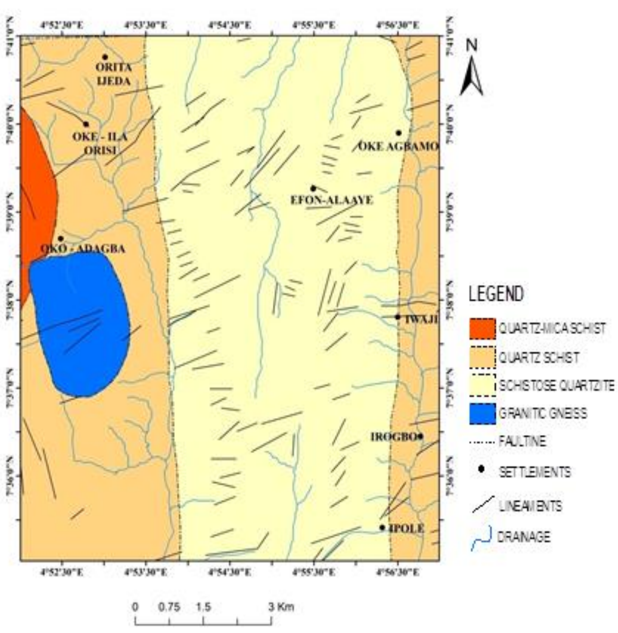

Figure 5: Lineament map of the Study area.

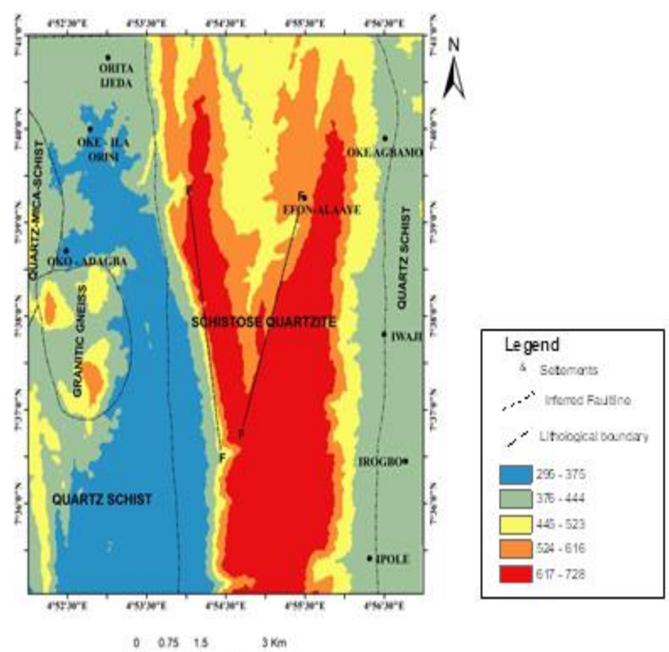

Figure 7: DEM map of the study area with the inferred faultline (Reverse Fault).

Geologyof Efon and environ

The Efon area is underlain by schistose quartzites, quart schists, quartz-mica-schist and quartzo-feldspathic granitic gneisses. The geologic and cross sectional map (Fig.8) revealed that the schistose quartzite occupies the centerstage of the study area, and hadexperienced multiple folding episodes. As a result of the polyphase deformation established on the litho-stratigraphic sequences, it is very difficult to establish the hierarchy of the folded structures with certainty. However, the distribution and mode of field occurrences of the lithology, structures and their relationships are discussed below;

Schistose Quartzite

The schistose quartzite (Figure 9a) is the most dominant rock type in the study area. They occur as prominent hunch back ridges trending north-south of the study area. The texture varies from fine to medium grained size and having colours ranging from pink, milky white, whitish grey to brown. Quartz, muscovite, biotite, sillimanite and opaque minerals are the major minerals identified in the thin sections (Figures10a and 10b). They consist mainly of quartz which occurs as irregular fine to medium grained crystals with interlocking grains of muscovite. On the average, quartz composition in all the samples is greater than 70%, biotite about 7%, and muscovite 7%. The presence of sillimanites averaging 10% and opaque mineral of about 5% are seen in some of the schistose quartzite samples close to the fault (Figure 10a). However, the roe microscopic studies of the schistose quartzites also revealed the presence of chalcopyrite, a brassy yellow coloured mineral with poor cleavage and metallic lustre (Figures 10d and 10e). The structures mapped are basically strike/dip, lineations, fractures and joints. The schistose quartzites are trending north-south ranging from 170º to 210° and dips both east and west ranging from 15º to 66º.

Quartz Schist

This lithology (Figure 9b) is widespread in the study area. Although, it is highly weathered in most places, but road cuts and some few low-lying outcrops along road path provided good sections where the lithology could be clearly examined. It outcrops mainly at the foot of schistose quartzite ridges. The mineralogy from field observation comprises quartz about 60%, muscovite 20%, and microcline 20% in composition. Okunlola and Okoroafor (2009) reported that this lithology around okemesi is fine to medium– grained, and they display incipient schistocity and contains quartz, microcline, muscovite with accessory hematite and zircon**.** It exhibits strong foliation with its strike orientating generally to the N-S ranging from 138º to 210º and steeply dipping east-west ranging from 50º to 74º. The schistocity of this rock is defined by the alignment of the platy minerals dominantly muscovite.

Quartz-Mica-Schist

This lithology (Figure. 9c) occurs mainly as a low lying outcrop in the extreme western part of the study area. It is intensely weathered in most places just like the quartz schist, but road cuts provided good sections where the lithology could be clearly examined. The rock is strongly foliated and trending generally in the NNE-SSW direction. The foliation on the outcrop is defined by mineralogical banding of mica streaks, particularly muscovite. The schist is generally coarse-grained and contains mainly muscovite, biotite and minor quartz. Okunlola and Okoroafor (2009) reported that in thin section, quartz occurs as coarse-grained, stretched, and white to greyish anhedral blasts. The structures mapped are basically strike, ranging from 180º to 188º, and dips of 80ºW, and lineations. Structures such as veins joints are not clearly seen due to the weathered nature of the rock and the minerals are fine to medium grained showing reddish brown to brown coloration.

Granitic Gneiss

The rock (Figure 9d) occurs as pluton, obviously standing out at the western part of the study area. Texture is medium to coarse-grained, possessing moderate to strong foliation, trending N-S. These foliations are defined by grain alignment of elongate feldspars and quartz with segregated thin layers of biotite. The granitic gneiss is also locally marked by mineral lineation, defined by grain shape of quartz and feldspar. The petrographic studies of the granitic gneiss and its modal composition revealed the presence of minerals such as plagioclase feldspar 6%, quartz 52.57%, microcline 18%, muscovite 1.43%, biotite 21.14%, and opaque mineral 0.86% (Figure 10c). The quartz identified are randomly distributed with subhedral grains, showing white to grey colour under cross nicol and colorless under plane polarised light. The biotite is moderately distributed showing green to brown colour under cross nicol and light brown under plane polarised light. The muscovites are scarcely distributed showing blue-pink colour under cross nicol. The microcline displays cross hatch twining and plagioclase display albite twinning. Ore microscopy study of the granitic gneiss also revealed the presence of chalcopyrite (Figure 10f).

Metamorphism

The rock of the study area has mineral assemblages comprising quartz ± biotite ± muscovite ± sillimanite. This mineral assemblage varies especially in the occurrence of muscovite and sillimanite which are metamorphic index minerals. Areas close to the fault zone has both sillimanite and muscovite while sillimanite is completely absent in area far away from the fault zone. This is indicative of higher temperature close to shear zones and it reduces far away from more active zone, thus the area has experienced regional metamorphism

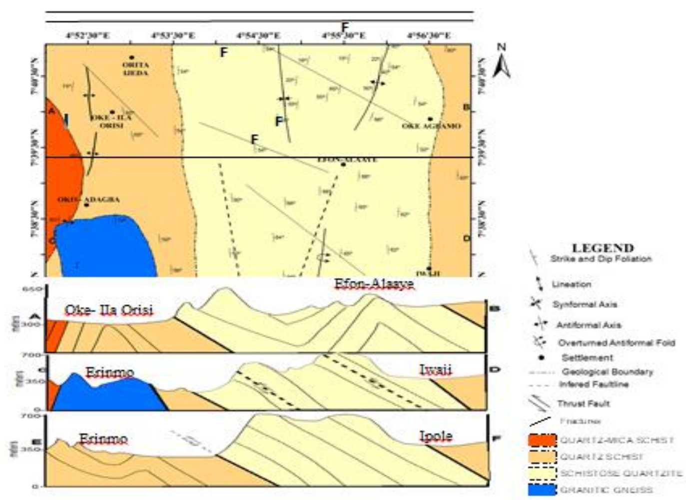

Figure 8: Structural and Cross-section Map of the Study Area.

Figure 9: Photographs of mode of occurrences of the lithological units (a) schistose quartzite exposed as a result of mining activity, section showing series of joint sets cutting perpendicularly to the trend of the rock (b) weathered road cut exposure of quartz-schist (c) weathered road cut exposure of quartz-mica-schist along erinmo road, showing the foliation on the rock (d) a portion showing sequence of pegmatite bands cutting into the granitic gneiss.

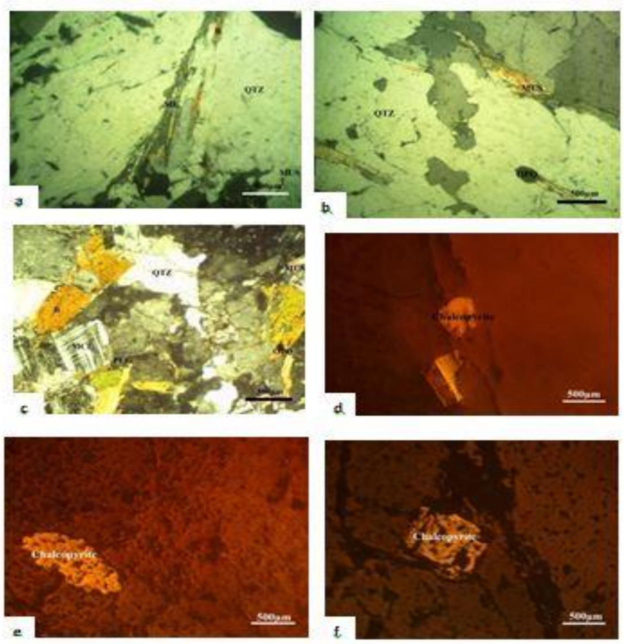

Figure 10: Photomicrographs of selected thin sections and polish sections (a)mineralogy of the schistose quartzite close to the fault, containing fibrous-like pale green mineral identified to be sillimanite (b) mineralogy of schistose quartzite far away from the fault showing presence of opaque mineral (c) medium to coarse-grained texture of the granitic gneiss in Erinmo (d) a brassy yellow metallic mineral identified to be chalcopyrite in the schistose quartzite close to the fault (e) chalcopyrite in the schistose quartzite far away from the fault (f) chalcopyrite in the granitic gneiss in Erinmo.

NOTE: QTZ=Quartz, B=Biotite, SIL=Sillimanite, MCL= Microcline, PLG=Plagioclase, MUS=Muscovite, OPQ= Opaque mineral.

In most of the granitic gneiss outcrops, veins of quartzo-feldspathic compositions are noticeable, pegmatite dykes cut concordantly with the granitic gneiss foliations (Figure 10d).

The thickness of these veins range from 0.4 – 16 cm. Also quartz veinlets mainly trending perpendicular to the granitic gneiss foliation were seen in some locations.

Structural Geology of the study area

The structural geological map and cross sections of the study area are presented in Figure 8.The structural geological mapping of the study area established that the psammitic rocks in Efon area have been subjected to polyphase deformation which led to the development of various metamorphic fabrics (foliations, lineations), folds, ductile shear zones and brittle structures. The lithologic units studied in the area bear imprint of two episodes of deformation denoted as D_1 and D_2, and they are discussed in this section.

First Deformation

D_1 structures in the study area is characterized by the development of regional steeply to moderate dipping foliation (S_1), which is characterized by development of foliation in the meta-sedimentary rocks and the granitic gneisses.The dip angle of the planar surfaces is generally sub-vertical, with value ranging from 15º-85º.The metamorphic foliations (S_1) are generally plunging 10º and trending 010º (Figure 11).Generally, during the D_1 episode, the rock of the study area experienced folding and refolding, which caused variation in the dip orientations to the east and west forming mega synform-antiform assymetrical folds and overturned folds with observable thrust faults (Figure 8). The thrusted relationship between the schistose rocks and the quarzites in Erinmo and Efon (Figure 8) is typical of this deformational episode. In brief, these earlier structures are typical of overthrusting, crustal shortening and mountain building area, in an area of convergence (Odeyemi, 1993).

Second Deformation

Deformation (D_2) in the study area gave rise to the fault which was mapped on the Digital Elevation Model (DEM) map (Figure 7) which is a reverse fault earlier reported similar structures in the study area. The D_2 deformation also gave rise to the N-S trending pegmatite vein (Figure 13a) that crystallized along the lineation of the granitic gneiss (Figure 12a). The quartz veins and veinlets on the granitic gneiss (Figure. 12b) are trending ENE-WSW (Figure13b), which is the major direction of stress during the D_2 deformational episode.

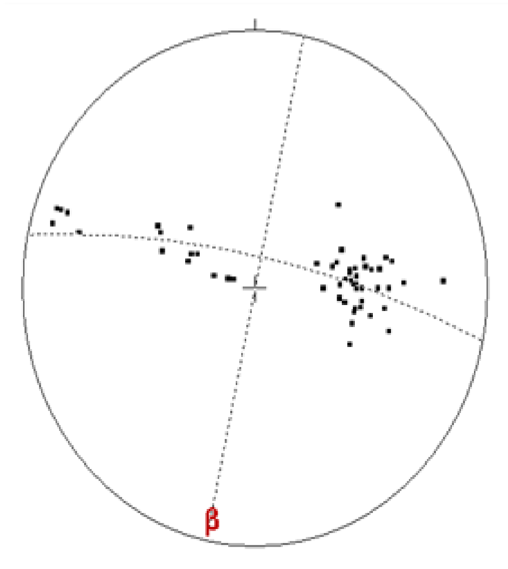

Figure 11: Equal area stereographic projections plot of foliation indicates that the fold axis plunges 10º and trends 010º. The wide scattering of plot of poles shows polyphase deformation.

Brittle deformation in the lithological units are characterized by several joints sets that were observed in most of the outcrops and also mapped as lineaments from the Landsat 8 and SRTM data (Figure 5), In the schistose quartzite rock, extensional joints cut perpendicularly to (S_1) surfacesand they are mostly set of parallel joints (Figure 12c) with bi-modal orientation predominantly trending ESE-WNW followed by the set that trends E-W (Figure13c). Joints on quartz-schist rocks (Figure 12d) showed bi-modal direction predominantly in the ESE –WNW and the subsidiary in NE-SW (Figure. 13d), while joints on granitic gneiss rocks (Figure 12e) shows major direction in the NE-SW (Figure 13e).

Mineralization Potential Map

The integration of all the field data acquired followed by its analysis and synthesis (geological and structural), a workable mineralization potential map of the study area wasproduced and presented (Figure 14). The map showed the mineralization potential map of Efon from the lineament maps, Digital Elevation Model (DEM) map and the structural geological map. Areas, where there is coincidence of delineated structures on the lineament map with structures on the DEM, and on the structural geological map are typical of mineralized zones. These mineralized zones also coincide with areas where mining activities are being conducted, in Efon township area, there are abandon mine pits that are now sources of pavement stones and sand fills.The mineralization map also reveals potential zones where ore deposits can be assessed such as around Efon-Alaaye, Oke-Adagba in Erinmo, and Ipole.Mineralization is observed to be distributed mainly on schistose quartzite and the granitic gneiss units. With the reddish coloration observed in the rocks, the presence of chalcopyrite which is an ore minerals, all these are indications of metallic (base and precious) and gemstone mineralization. The structural pattern reveals that considerable mineralization within the area lies predominantly along ENE-WSW, NE-SW and ESE – WNW directions and rarely along E-W trending structures and along the N-S trending fault. The overlay of the mineralization map with the geologic map of area suggests that mineralization is associated more with the schistose quartzite and contact between rocks. Therefore, the mineralogical potential map (Figure14) suggests that the mineralizations in Efon-Alaaye area is structurally controlled.

Discussion

The lithologic relationship in the study area showed that the granitic gneiss is the oldest rock. The Ilesha schist belt's granitic gneiss has been described as Archaean basement rock. The early sediments are thought to have been metamorphosed into the current meta-sediments by intrusive igneous processes and orogenesis. According to available geochronological data and litho-stratigraphic classification, the granitic gneiss, which has been variously referred to as orthogneisses in some literatures (Rahaman, 1988), provided an age of ca. 1850 Ma (upper intercept) by the U-Pb technique on zircon. Although this overlaying relationship was not observed in the study area, the meta-sediments are thought to overlie the orthogneisses in the Ilesha schist belt. The metasedimentary assemblages in the study area have been earlier referred to as the Effon Psammite Formation. The schistose quartzite occupies about 50% of the entire study area occupying the central part while the quartz schist which forms at the base of the schistose quartzite ridge occur as low-lying outcrops. It exhibits strong foliation with its strike orientating generally to the north and steeply dipping to the east and west. They are fine to medium grained, displays incipient schistosity and contain quartz, microcline, and muscovite. Similar to those described . The quartz-mica-schist is generally low-lying and steeply dipping to the west. Mineral assemblages in quartz-mica-schist is quartz, biotite, and muscovite similar to that described by. The D_1 structures in the study area is characterized by the development of regional steeply to moderate dipping foliation (S_1), which is characterized by development of foliation in the meta-sedimentary rocks and the granitic gneiss rock. These rocks have experienced folding and refolding, which caused variation in the dip orientations to the east and west forming mega synform-antiform assymetrical folds and overturned folds. The thrusted relationship between the schistose rocks and the quarzites in Erinmo and Efon is typical of this deformation episode.

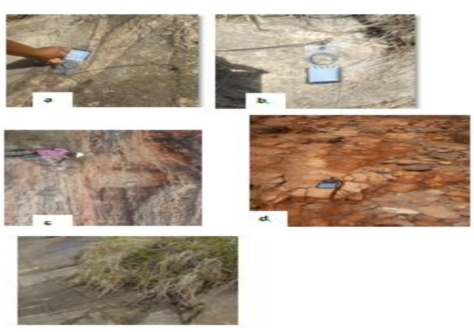

Figure12: (a) field photograph of pegmatitic veins on granitic gniess (b)field photograph of quartz vein on the granitic gneiss (c) field photographs of Joint sets on schistose quartzite rock exposed by mining activities (d) field photograph of Joint on quartz schist rock exposed by road path (e) field photograph of Joint on granitic gneiss rock.

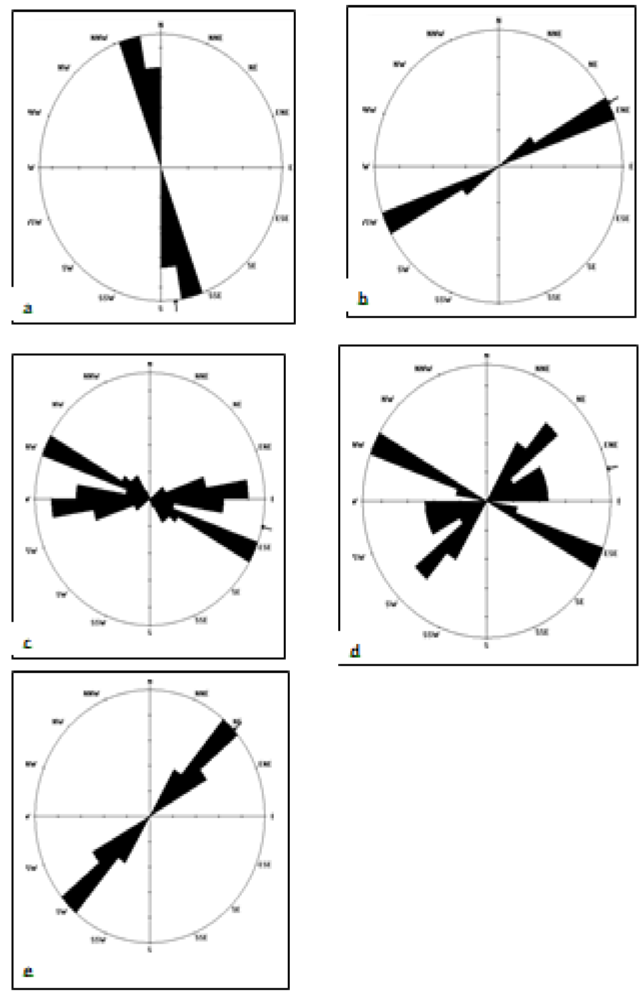

Figure 13: (a) N-S trending pegmatitic vein on the granitic gneiss (b)ENE-WSW trending quartz vein on the granitic gneiss-the major direction of stress in the area (c) joints orientation on schistose quartzite rocks show bi-modal orientation predominantly in the ESE-WNW and the subsidiary in E-W(d) joints on quartz-schist rocks shown bi-modal direction predominantly in the ESE – WNW and the subsidiary in NE-SW (e)joints on granitic gneiss rocks showing major direction in the NE-SW.

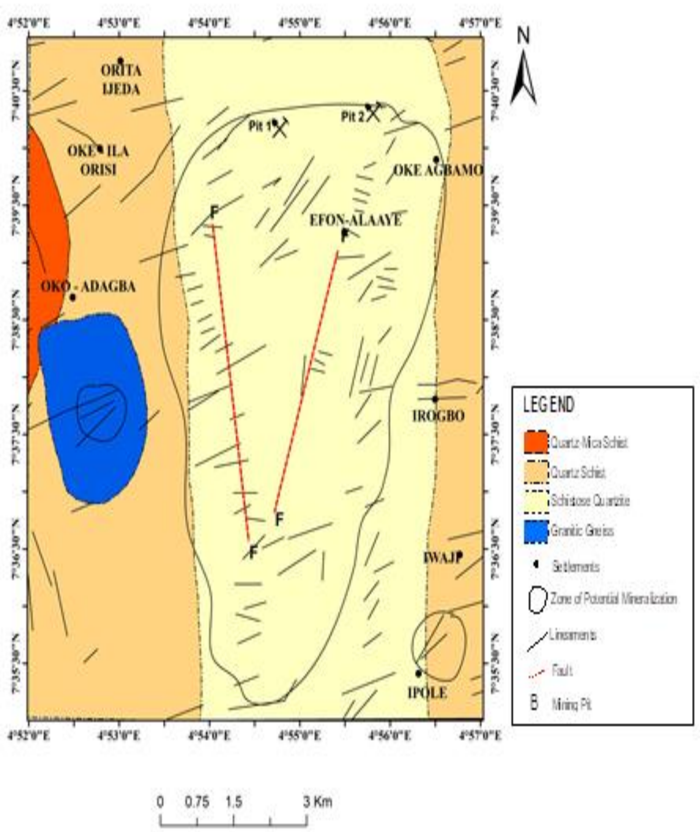

Figure 14: Mineralization potential map of the study area.

Odeyemi (1993), Anifowose and Borode (2007) and Ayodele (2014) earlier reported a reverse fault that was now mapped during this study, these faults are associated to the development of the Ifewara shear zone during the Pan-African.orogeny. This D_2 deformation also gave rise to the N-S trending pegmatite vein that crystallized along the lineation of the granitic gneiss. The major direction of stress during the D_2 deformational episode is typical of the ENE-WSW direction of quartz veins and veinlets on the granitic gneiss trending. Several joints sets that were observed in most of the outcrops and also mapped as lineaments from the remotely sensed data are bi- directional cutting perpendicularly to (S_1) surfaces and they are mostly set of parallel joints predominantly trending ESE-WNW followed by the set that trends E-W, on the schistose quartzite, ESE –WNW and NE-SW on quartz schist while joints on granitic gneiss rocksshows major direction in the NE-SW.

CONCLUSION

The study area is underlain by schistose quartzites, quartz schists, quartz-mica-schist and granitic gneiss. The rocks of the study area have been subjected to polyphase deformation, which are the manifestations of the tectonic deformation that pervaded the study area in the geologic past. The earlier deformation event includesformation of structures like schistosity in the meta-sediments, as well as foliation of rocks in the entire area, synform-antiform assymetrical folds, and overturned folds. The earlier deformational event was succeeded by the localized intense deformation that happened during the Pan-African orogeny, this gave rise to the ESE-WNW, NE-SW, E-W trending fractures and joints in conjunction with the veins trending ENE-WSW, which is the major direction of deformation during the Pan-African orogeny. These structures generally cut through almost perpendicularly to the foliation and lineation directions of the rocks. The fractures established in this study to host mineralization are the NE-SW, ESE – WNWand E-W trending types which also confirmed the assertion that mineralization in the studied area are structurally controlled.

ACKNOWLEDGEMENTS

The author really appreciates the effort and support of Dr. O. S. Ayodele (Associate Professor, Department of Applied Geology, Federal University of Technology, Akure). My sincere thanks to the editor and the anonymous reviewer for providing constructive comments on the original manuscript, which significantly enhanced the quality of this work

Funding No funds or grants were received.

DECLARATIONS

Conflict of interest.

Authors declare that there is no conflict of interest.

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