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Geological Mapping and Petrostructural Characterization of Precambrian Rocks in Oke-Ode Area, Southwestern Nigeria: Implications for Regional Tectonics and Geological Evolution

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Abstract

This study presents a comprehensive petrostructural investigation and geological mapping of the Oke-Ode region, southwestern Nigerian Basement Complex. To comprehend the mode of occurrence and field relationship of the crystalline rocks, a systematic geological mapping of the rocks was carried out. Representative samples of the various types of rocks that were encountered were chosen for petrographic examination. The study area is characterized by diverse lithological units including quartzite, schist, granite, granodiorite and pegmatite as revealed by lithological mapping and field investigations, which also demonstrated polyphase deformation and intrusive linkages. According to petrographic assemblages, the rocks are made up of different amounts of quartz, microcline, plagioclase, muscovite, and biotite indicating amphibolite to granulite facies metamorphism, with evidence of partial melting and anatexis in migmatitic units. The geological map provides comprehensive insights into the complex lithological relationships, structural patterns, and geological features that record a prolonged history of deformation, metamorphism, and magmatic processes. Structural analysis reveals predominantly NE-SW to NW-SE trending foliations and joint systems, consistent with Pan-African orogenic compression. To interpret subsurface relationships, two structural cross-sections (A–A′ and B–B′) were built. The intrusive event in the area is believed to be of Pan-African age which is similar events throughout the Basement Complex of southwestern Nigeria. A complicated history of sedimentation, regional metamorphism, granitic intrusions, and subsequent tectonic uplift is suggested by the sequence of tectono-metamorphic events. The findings provide insights into the crustal evolution processes of rocks in the study area and is consistent with current theories of the Pan-African orogeny. This also advances the understanding of the geological evolution of Nigeria's Precambrian basement.

Keywords: Basement Complex; Petrostructural analysis; Precambrian rocks; Petrography; Orogeny; Metamorphism

1. Introduction

Geologic mapping of outcrops is used to describe the primary lithology and morphology of rock bodies as well as age relationships between rock units. It is a process used to create maps that show the distribution, nature, and age relationships of rock formations and other geological features beneath the Earth's surface. Although the advent of modern geological mapping technologies such as geophysical surveys, remote sensing, and Geographic Information Systems (GIS) has transformed traditional mapping methodologies making the study of rocks much easier in recent times. Nevertheless, the importance of physical geological mapping remains essential and cannot be overemphasized. The detailed in-situ observation of rocks is fundamental for building a reliable geological model, which guides and enhances the interpretation of geophysical data and GIS-based analyses. Ultimately, modern methods still rely on the foundational information gathered through physical mapping as it provides the ground truth for their interpretations [13]. Of more

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important is that geological mapping is a planning tools for the economic development of any nation and it is imperative to update geological map of an area to gain full knowledge of the area's geological 'treasures' [5].

Petrostructural analysis is a combined approach that provides insights into rock's formation, kinematics of deformation, and alteration history, revealing clues about past tectonic events, metamorphism, and fluid interactions. It involves detailed lithological characterization, petrographical study and structural analysis of basement rocks which is crucial for understanding the comprehensive geological history of an area.

The Precambrian Basement Complex of southwestern Nigeria consists of igneous and metamorphic rocks that constitute the oldest, crystalline, solid physical foundation of the country. Regional mapping has consistently identified migmatites, gneisses, granitic rocks, and charnockites as the dominant lithologies. The Basement Complex represents a critical segment of the Pan-African orogeny, providing insights into the complex tectonic evolution of the West African Craton [14].

The importance of integrated petrostructural approaches in understanding basement complex rocks evolution has been increasingly recognized in recent literature [10, 19, 18, 1, 8]. The southwestern region of Nigeria exhibits diverse lithological assemblages dominated by gneisses, granites, and associated metamorphic rocks [23, 18, 2, 1, 3]. These basement rocks record a complex polycyclic history spanning approximately 3000 million years [22], involving at least four major orogenic cycles: the Liberian (2,700 Ma), Eburnean (2,000 Ma), Kibaran (1,100 Ma), and Pan-African (600 Ma) events [15]. The Pan-African orogeny (ca. 650-450 Ma) represents the most significant deformational episode, resulting in the characteristic N-S structural trends observed throughout the region [11, 7].

The extensive geological mapping and descriptive of the Southwestern part of Nigeria which has been carried out by various workers can indirectly be related to the study area. Some of the workers include [23, 18, 2, 1, 3].

According to the literature review, there is a notable gap in thorough petrostructural analysis and detailed geological mapping that are especially targeted at the Oke-Ode region. There seems to be little published work that thoroughly maps the local basement complex rocks and performs a comprehensive petrostructural analysis, despite the fact that there are several studies on geological mapping and petrostructural analysis in the broader southwestern Nigeria Basement Complex terrains. While building on established regional geological understanding, this study contributes to regional understanding of Precambrian basement complex evolution and fill the knowledge gap regarding detailed geological characteristics of the area.

This study presents a thorough geological mapping, petrographic and structural analysis of Oke Ode area with the goal of clarifying the local geological structure, lithological units, their occurrence, distribution, potential economic opportunities and its consequences for geodynamics of the area. By using detailed mapping techniques, systematic field observations, and structural analysis of rocks in the study area, this research adds to the expanding body of knowledge necessary for environmental stewardship and sustainable development in the area.

2. Geographical and Geological Setting

2.1. Location and Accessibility of the Study Area

The study area, Oke-Ode, is located in Sheet 203 (Lafiagi) SW and lies within the southwestern part of the Basement Complex of Nigeria. It is bounded by latitudes 8°30′N to 8°37′N and longitudes 5°00′E to 5°06′E of the topographic map with a scale of 1:50,000. It is comprised of Oke-Ode and its environs (Oke Ode–Elemosho–Agamsa Axis). The area is linked by major roads passing through Ogunbayo, Oke-Ode and to Eri-Alaji and another from Oke-Ode to Bayero village. There are minor roads and footpaths that link one place to another making movement easier. Significantly, the project was made easy by the presence of major and minor roads, footpaths, dried stream channels, and dried bushes which makes the outcrops to be easily accessible. The central portion and the Northeastern part of Oke Ode is of moderately high relief, they are hilly and has extensive ridge of weathered quartzites covered by tall trees and grasses. The quartzite ridges form the highest relief of 1545ft (470m) above sea level. The other areas are flat lying outing exposures with the lowest elevation marked by river channel of contour lines 800ft (243m) above sea level. The area is moderately drained showing a typical dendritic drainage pattern which is clearly visible from the major river in the area such as river Awewe, Gbokolaya and Agodonigbo. The climatic condition is of tropical wet-dry. It is characterized by wet summer, dry winter and moderate rainfall. The area is characterized by tall and short grasses, scattered shrubs and thorny plants which are products of a tropical wet-dry climate, hence the vegetation is of guinea savannah [17].

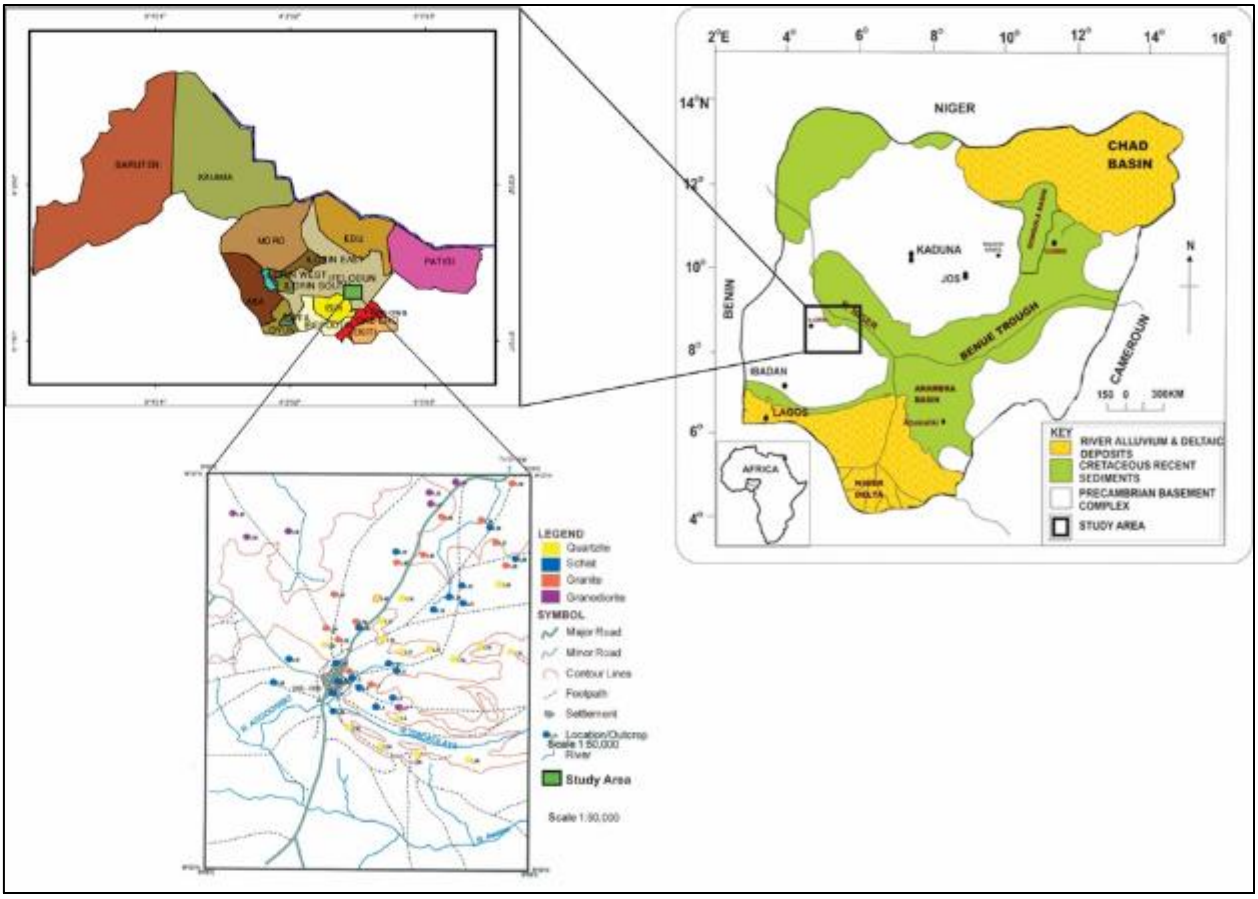

Figure 1 Location of Oke-Ode in Ifelodun LGA, Kwara State (Adebayo *et al.,* 2025)

2.2. Geology Setting

The Nigeria Basement Complex forms a part of the reactivated Pan-African mobile belt and forms part of the African shield. It lies between the West Africa craton to the west and the Congo craton to the Southeast. This mobile belt was affected by the wide spread Pan-Africa thermo tectonic event which led to the "structural differentiation of an original shield into craton and circumstructural (Orogenic) areas" about 500mya [12]. The three major rock types – igneous, metamorphic and sedimentary abound in Nigeria. Igneous and metamorphic rocks constitute the Precambrian Basement Complex which is the oldest, crystalline, solid physical foundation of Nigeria. Sedimentary rocks fill up the basins which are vast depression between basement landmass.

The major rock types in the area, similar to the rest of western Nigeria, are deformed, Pan-African schists, granites, amphibolites, pegmatites, quartzites and grey gneisses [23, 18, 2].

3. Materials and Methodology

3.1. Materials

The materials used to carry out this study were compass clinometer, topographic map, GPS, camera, geologist hammer, hand lens, sample bag, chisel, field note book, measuring tape, stationeries etc.

3.2. Methods

3.2.1. Lithologic Characterization and Sampling

Lithologic characterization involves field observations that show how rocks relate to nearby formations and other rock units by placing them within their geological context. It includes direct observation of rocks layers and describing their physical and mineralogical properties in the field. A systematic procedure of geologic mapping was used for lithological characterization. This involved mapping using footpaths, cattle tracks, stream and river channels. Key outcrops were examined for lithology, structural orientations (strike and dip), and intrusive relationships.

During the mapping exercise, outcrops were located and the rocks were critically studied to obtain necessary information needed for further study. As soon as the rocks were located, macroscopic studies (field observation) were carried out. This includes; description, classification, structure, texture and mineralogical composition. Different readings and measurements such as strike and dips, joint direction, dimension of intrusions etc were taken using clinometer compass. The Global Positioning System (GPS) was used to precisely record the location's coordinates. Photographs of important features such as folds, joints, xenoliths etc were taken using digital camera. For sampling, fresh rock samples were collected with the aid of geological hammer and were labelled appropriately while representative samples of rocks were selected for petrographic analysis. Finally, location map and geological map were produced to reveal the geology of the study area. Lithological contacts were traced using compass-traverse methods. Geologic cross-sections were constructed to give detail information about how the rocks strata are arranged beneath the surface, including their thickness, dip, and lateral extent.

3.2.2. Petrographic Analysis

Petrographical study focuses on the microscopic examination of rock samples to identify minerals, textures, and other features. It helps determine the rock type (igneous, sedimentary, or metamorphic) and its original composition providing valuable information about the tectonic and geological processes that have shaped their formation and location on Earth. Thin sections of the representative samples were studied under the optical microscope and results aided the identification of the various rock types. The type of rocks as well as their microstructure, mineral composition, and mineral parageneses were used for the deduction of deformation and metamorphic history.

3.2.3. Structural analysis

For the structural analysis, structural features were identified, studied and their orientations were measure. Foliation, lineation and faults were located and measurements were taken on available outcrops for their geometry. Structural data were treated with GeoOrient commercial program to analyze the geometric relationships between different structural elements. Also, Rose diagrams were constructed to visualize the dominant orientations of fractures, joints, and foliations.

4. Results

4.1. Rock Types and Lithological Relationship in the Study Area

From field study, the geology of Oke-Ode area is composed of typical basement rocks including; mica schists (metasedimentary origin), quartzites (highly resistant ridges/hills), granodiorite (older plutonic body) and granite (younger intrusive units). Pegmatite dykes, aplite dykes and quartz vein intrusions were also observed. The following lines present their field relationship, petrography and their evolution.

4.1.1. Mica Schist

Schist is the dominant lithology, extensively exposed across the region. It’s occupying approximately 60-65% of the mapped region. It exhibits foliation with NE–SW orientations. Likely represents metamorphosed sedimentary sequences (metasediments) or volcanic rocks that were subjected to regional metamorphism during the Pan-African orogeny. The schist forms large, continuous bodies throughout the central and eastern portions of the mapped area, with notable occurrences around the Oke Ode settlement and extending toward the Agunbayo area. They are folded, jointed and crosscut by pegmatite and quartz vein intrusion. They make a sharp contact with granite in some places. It forms the host rock for younger intrusions. In hand specimen, it contains felsic minerals as quartz, feldspar and muscovite with biotite as the mafic minerals.

4.1.2. Quartzites

Quartzites occur as discontinuous, lens-shaped outcrops, especially in the central-southern portion of the map particularly around Elemsho Hill and Agamsa Hill. Shows massive texture with few structural deformities, interpreted as metamorphosed sandstone. Quartzites typically form ridges and elevated areas due to their high resistance to weathering and erosion. They are light, foliated, and composed mainly of fused quartz typically white and little patches of muscovite in hand sample.

4.1.3. Granite

Granite is one of the late intrusive rocks. It is a non-foliated crystalline rock composed essentially of silicate minerals. They occur as discrete plutonic bodies, younger, linear intrusions cutting across all older units. Common along NE–SW trending zones, interpreted as post-tectonic and possibly associated with late Pan-African magmatism. The cross-cutting relationships visible in the cross-sections (Figure 3) suggest that granites intruded the pre-existing schist and other metamorphic units.

4.1.4. Granodiorite

Appears as large, rounded boulders, phorphyritic texture and compact intrusions in the northwestern flanks. They are characterized by large phenocryst of plagioclase and k-feldspar together with quartz crystals. It Shows textural gradation into surrounding schists, suggesting syn-tectonic emplacement. Pegmatite and quartz vein intrusion are common occurrences on the rocks.

4.1.5. Pegmatites

Pegmatites is a variety of igneous rock with extremely large crystals. They are the last rocks to crystallize from a solidifying body of magma. Pegmatites occur as intrusive and also as veins or dykes in almost all the rock types in the study area. In other places, they are exposed as rock bodies. They occur concordantly or discordantly to the trend of the host rocks also making sharp contact with the host rocks. They are coarse grained and having giant crystals of feldspar.

4.1.6. Aplite

Aplite is a fine-grained equivalent of pegmatite. Aplite occurs mainly as intrusion either as vein or dyke especially on granites. They make sharp contacts with the main rocks in which they intrude. They are light colored comprising of both felsic and mafic minerals (quartz, microcline, muscovite, plagioclase and biotite).

4.2. Geological Map of Oke-Ode Area

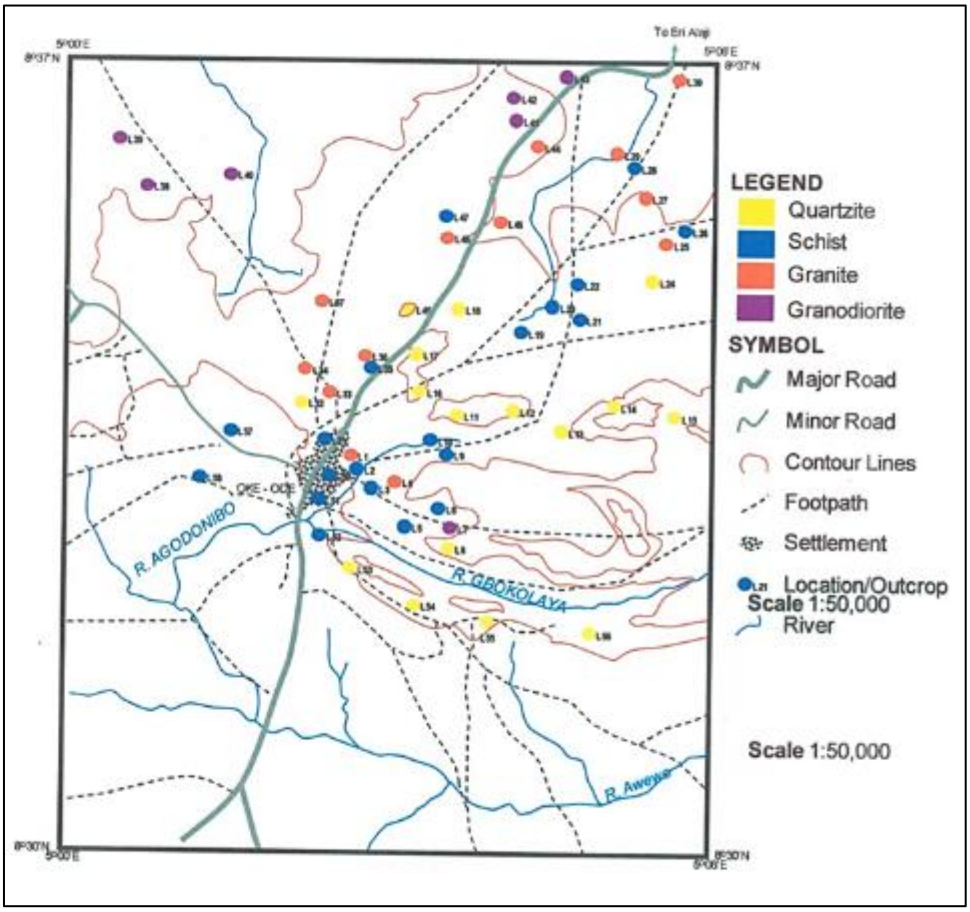

Figure 2 Map of geological outcrops of Oke-Ode Area

A geological map of the study area is constructed based on the distribution of the identified lithologies, their field relationship and recorded geological characteristics (Figure 3). The schists are the most dominant lithology, extensively exposed across the region and occupying approximately 60% of the mapped region. The quartzites occur as discontinuous, lens-shaped outcrops forming ridges and hills. Granodiorites has limited distribution appearing as large, compact intrusions in the western and northern flanks. Granites are present as irregular-shaped plutons in the northwestern and southwestern portions of the mapped area. They are common along NE–SW trending zones. Two geologic cross-sections (A–A′ and B–B′) were constructed to depict the subsurface geology.

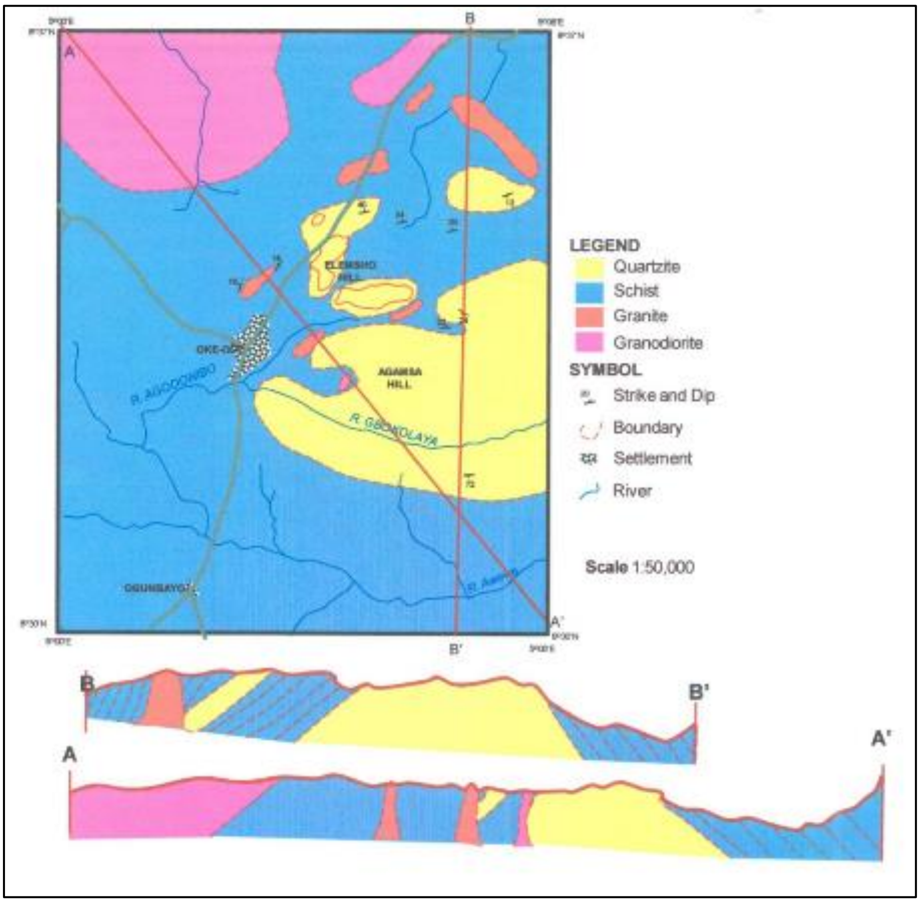

Figure 3 Geologic Map and cross section map (profile A-A[1] and B-B[1]) of Oke-Ode area

4.3. Petrographic (Microscopic) Description of Minerals

The rocks' thin sections reveal major minerals including quartz, plagioclase, microcline and biotite with other accessory minerals.

- Quartz: Under Plane Polarized Light (PPL), quartz is colorless, non-pleochroic, subhedral crystals which have very low relief relative to other minerals in the field of view. Under Cross Polarized Light (XPL), quartz showed white to pale-yellow interference, no sign of alteration and goes extinct 4 times on 3600 rotations of the microscope stage.
- Biotite: Biotite appeared as subhedral, brown crystals with a moderate relief and a mild pleochroism under PPL. There was no visible fracture or cleavage in the crystal. Under XPL, it appears brown, untwined, unaltered, and disappears at the same points during the microscope stage's 3600 rotation. Also, it appears as plates and laths that exhibit preferential alignment with the foliation planes.
- Plagioclase: Under PPL it appeared as colorless, subhedral crystals which are slightly pleochroic with low relief. The crystals also show two cleavages not perpendicular to each other. Under XPL, plagioclase showed grey interference color, displays albite polysynthetic twinning, and does go into extinction at same points in 360 rotations of the microscope stage.
- Microcline: Under PPL, the microcline crystals appeared as subhedral, colorless non pleochroic crystals that has a low relief and two cleavages which are not perpendicular to each other. Under XPL, the microcline crystals

displayed grey interference color, showed cross-hatch twinning (this is a distinctive optical property of microcline). It also does not show any sign of alteration.

Table 1 Summary of estimated mineralogical composition of analyzed rock samples (%)

Mineral in Sample	**Schist**	**Quartzite**	**Granite**	**Granodiorite**	**Pegmatite**
Quartz	40	80	43	20	26
Biotite	45	-	15	8	±
Plagioclase	-	-	30	45	-
Microcline	10	-	-	25	73
Muscovite	5	10	10	-	0.9
Magnetite	-	-	-	-	0.1
Accessory Minerals	-	-	2	2	-
Total	100	100	100	100	100

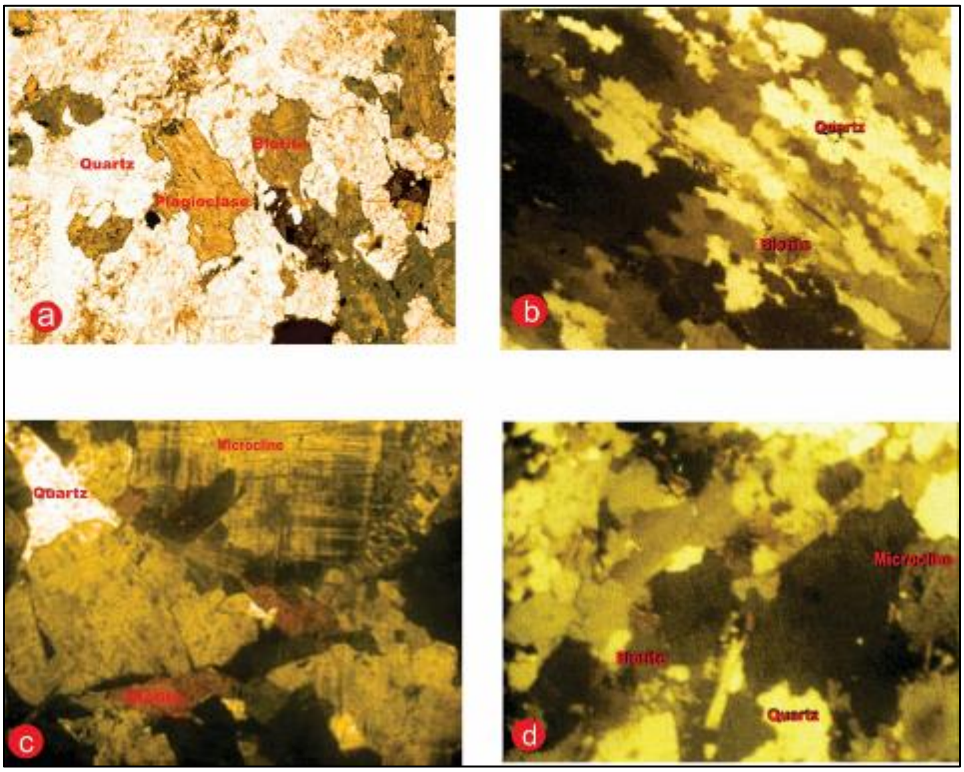

Figure 4 (a) Photomicrographs of Oke-Ode granodiorite (b) Photomicrographs of Oke-Ode granite (c) Photomicrographs of Oke-Ode quartz schist (d) Photomicrographs of Oke-Ode quartzite

4.4. Structural Studies

The structures observed in the study area can be said to be formed by force acting on the rocks subsequent to their formation and are called secondary structures. This could be as a result of tectonic forces like compression, shear etc. [16] suggested that almost all the foliation exhibited by basement rocks in southwestern Nigeria are tectonic in origin. Non tectonic forces such as igneous intrusion, metamorphism and other rock flowage coupled with differential compaction are also responsible for many of these secondary structures. Structures in the area may be conveniently divided into two groups via ductile and brittle structures. Ductile Structures preserve the permanent viscoplastic deformation in rock throughout geologic time. Ductile structures exhibited by rocks in Oke Ode area includes folds, foliation and lineation. Brittle Structures on the other hand records the brittle elastic failure of rocks in the past which results to loss of cohesion within rocks. Major brittle structures encountered in the study area are joints and faults.

- Fold: folds in the study area are commonly observed in the mica schist in form of quartz vein. Observed folds are minor isoclinals folds (Figure 5a) because their limbs and the axial plane dip essentially in the same angle and direction.
- Foliation: foliation describes the plain surface marked by the parallel preferred orientation of mafic and felsic minerals in rocks. Foliation planes are observed on mica schist in the area and they are moderately developed.
- Joints: joints are defined as divisional planes of fractures in rocks along which there have been no relative movement. Joints are common structures occurring in different rock types in the area of study. Most of the joints are discordant to the host rock and are trending N/W and N/E directions.
- Faults: faults are planar fracture planes across which there is relative movement between the two blocks of the rock mass. Faults in the area mapped were identified as dextral fault (Figure 5e) and are mostly observed within the granites.
- Vein: veins in the area of study are obviously transparent with fine to medium grained texture. They are tabular in shape, thickness and length ranges between few centimeters and meters respectively and trending in different directions. They are adjacent to the pegmatite intrusions sometimes concordant or discordant to the host rocks suggesting they are younger than the host rocks. The rosette diagram of the quartz veins also indicates an orientation predominantly trending in a NE SW direction.
- Xenoliths: xenoliths are fragment of rock (older rock) that becomes incorporated within another rock body (younger rock) of a different origin. Granites around Oke-Ode are charged with many xenoliths of migmatite gneiss (Figure 5f)

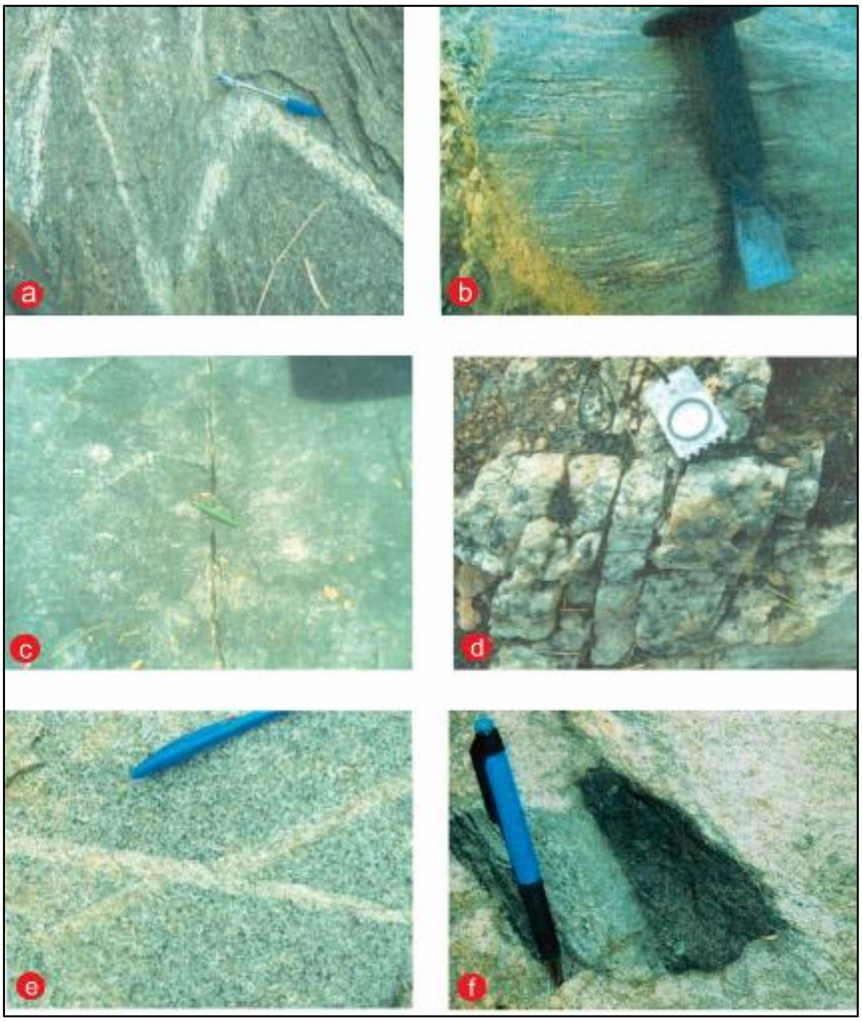

Figure 5 (a) Isoclinal fold, (b) Foliation on mica schist, (c) Joint on Granite, (d) Joints on Quartzite, (e) Dextral (Right-lateral strike-slip) Fault observed on granite, (f) Xenolith on granite

5. Discussion

Two categories of geological formations have been discovered, including metasedimentary rocks that are intruded by magmatic rocks and cover a significant portion of the research area. The lithologies seen are mica schists, quartzites and late intrusive rocks (granites and granodiorites), Petrographic and structural analyses of rock deposits in adjacent areas such as Ado-Ekiti [8], Saigbe [18] and others have revealed similar mineral assemblages and textural relationships, supporting the regional continuity of petrostructural processes. The schist and quartzite rocks show a mineral assemblage that consists of quartz-feldspars±biotite±Muscovite±accesory minerals. The mineral assemblages and the temperature ranges suggest that the metamorphic rocks co-existing in the study area are of moderate pressure greenschist facies and high temperature medium to lower grade amphibolite facies. Hence, the environment can said to be experiencing progressive regional metamorphism. In this case, minerals at low grade recrystallize to those of high grade. These different assemblages have similarities with the metamorphic paragenesis reported by [25].

5.1. Structural Analysis

The structural studies revealed that two major episodes of deformation have been identified in the Oke-Ode geological formations; An earlier ductile transpressure type with a prominent E-W compressional deformation resulting to a prominent NE-SW orientation that leads to the implementation of foliation and folding. There is other that characterizes a W-E orientation that result from brittle deformational event related to the Pan African orogeny and an extensive phase that is responsible for the fracturation occurring in the rocks. These episodes of deformation are similar to the direction of tectonic event responsible for the metamorphism and/or fracturing of rock in the southwestern region of Nigeria [5, 14]. Rosette Diagram plot showed foliation, fractures and veins on some rocks are more intersected and long, while some are shorter, indicating lithological control on fracture development. For the mapped joints/fractures, it is seen that the dominant trend directions are NW-SE, NE-SW, and minor W-E direction. Foliations trends are mainly in the NE-SW and NW-SE direction while vein directions are mainly NE-SW and NW-SE (Figure 6a-c).

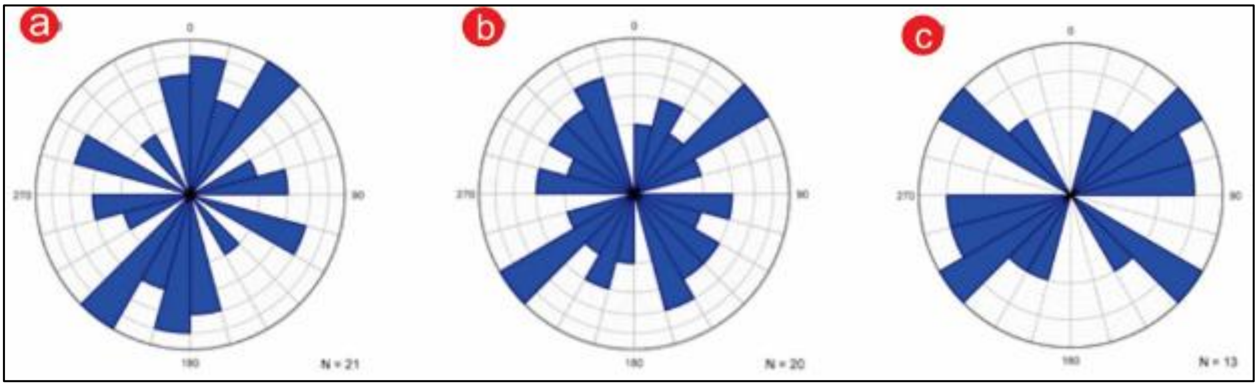

Figure 6 Rosette diagram of orientation of a) Foliations b) Joints c) Veins

5.2. Tectonism and Geological Evolution

The original sediments (e.g., sandstones and mudstones) were deposited. The sediments were metamorphosed to schist and quartzite during an orogenic event (regional metamorphism). Large-scale syn-tectonic or early post-tectonic intrusion of granodiorite occurred, modifying the metamorphic rocks. Then there was tectonic deformation resulting to structures like folding, faulting, and foliation especially in schist and quartzite. Strike and dip readings from quartzite and schist indicate multiple phases of folding. Later stage post-tectonic granite intrusions occurred along pre-existing structural weaknesses. The intrusions are associated with the Pan-African orogenic cycle. Granite dikes often follow foliation planes, implying emplacement along structural weaknesses. This is revealed in the cross-sections (A–A′ and B–B′) (Figure 3). It is seen that the granitic dikes intruding across both lithologies, extending vertically in the cross-section. At the later stage, differential erosion exposed the more resistant quartzite hills (Agamsa and Elemsho Hills), while rivers dissected the landscape. This sequence aligns with regional models of Pan-African orogenesis [6, 9]. Also, it is in line with previous studies in southwestern Nigeria which documented the presence of complex fold systems, shear zones, and igneous intrusions that collectively define the regional structural architecture. [20, 21, 24]

6. Conclusion

According to the current study, the Oke Ode area is primarily composed of quartzites and schists, with veins of late intrusive rocks made up of granites, granodiorites, and pegmatites occurring in small amounts. These exposed rocks in the Oke-Ode region are Precambrian in age and belong to Nigeria's Basement Complex. The assemblage of schist-quartzite (metamorphic) with granite-granodiorite-pegmatite (igneous) suggests a polymetamorphic terrain typical of Pan-African basement complexes. The geologic map reflects a classic Proterozoic or Pan-African geological setting common in the Nigerian Basement Complex. Common major structural characteristics in the region include joints, faults, foliation, folds, veins, and xenolith which is an indication that the rocks were subjected to tectonic activities. In line with Pan-African orogenic compression, structural investigation shows foliations and joint systems that trend primarily NW-SE.

Petrographic investigations indicate greenschist to amphibolite facies metamorphism, which has been concluded to be of medium to high grade facies of regional metamorphism. The comparison study indicates that the petrostructural characteristics of south-west Nigeria are representative of broader regional processes that affected the entire Nigerian part of the Pan-African belt. This geographical consistency supports theories for cogent orogenic evolution and provides a basis for understanding West Africa's crustal architecture. The region has a highly structurally complicated metamorphic basement terrain. Fundamentally, the petrostructural analysis of Oke-Ode rocks offers important information on the types and structures of rocks that are visible as well as the geological processes that produced them, offering important insights into the history of the Earth.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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