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Lithologic Relationship and Structural Features of Crystalline Rocks in Ekiti, Southwestern Nigeria: A Geological Report on the Basement Complex

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Abstract

This paper investigates and report field relationship and structural features of the basement rocks in Ekiti, southwestern Nigeria. Systematic geological mapping reveals that Ekiti is underlain by migmatite-gneiss, quartz schist, quartzite, granite, and charnockite. These lithologies were intruded by series of aplite, dolerite, and pegmatite dykes. Structural deformations attributable to polycyclic orogenic activities manifested in all the basement rocks. Migmatite and its gneissic subunits form the country rock and exhibits complex folds, abundant quartz veins and haphazardly emplaced dykes. Foliation and lineament are oriented N-S, strike values range between N5oE -N18oE with westerly dip of 72º to 84º. Quartzite and quartz schist exhibits distinctive joint and fracture system which runs parallel to one another while minor ones are oblique. The polymetamorphic terrain has older tectonic fabrics massively overprinted by younger ones. The gneiss units are porphyroblastic to granoblastic, xenoliths of varying sizes are embedded within the granite bodies indicating the magmatic liquid was forcefully injected into the country rock. The presence of parallel fractures in fine-grained granite indicate Ekiti area is a shear zone. The occurrence of dykes of heterogenous lithologies on single granite outcrop suggests pluton assemblage occur as discrete pulses during the intrusive phases. Contact relationship indicate age decreases from migmatite to granite-charnockite to microgranite while dykes are the youngest. Deformation, metamorphism, and intrusive phases are the dominant geodynamic features of Ekiti area while the regional and local changes in rocks resulted from environmental constraints of pressure, temperature, and fluid activity. The plutonic activities which accompanied orogenic events resulted in deformation which is genetically related to evolution and geodynamic setting of Ekiti area.

Keywords: Ekiti, field relationship, orogenic activities, polymetamorphic terrain, geodynamic setting.

Introduction

Modern laboratory techniques have made the study of rocks much easier in recent times. This is particularly true since the advent of microscopic analysis of structures. However, the importance of in-situ assessment of rocks cannot be overemphasized. Lithologic appraisal which incorporates careful evaluation of rocks in the field allows Earth's Scientists to decipher the conditions under which rocks developed. Such evaluation reveals how tectonic forces affect rock's spatial relationship. Most often, the evolutionary pathway of rocks and how it developed is inferred from geological interpretation of its structural attributes. Southwestern Nigeria as a regional extension of the study area contain migmatite-gneiss, schistose rocks and granitoids which bear imprints of several cycles of deformation. The polymetamorphic terrain stretches from non-riverine areas of Ondo State into sedimentary sequence of the Nupe Basin towards north and Southeast Dahomey Basin towards the south. The eastern limit of basement complex of southwestern Nigeria is terminated against Cretaceous sequence of the Lokoja sub-basin around the confluence of River Niger and Benue (Figure 1). Meticulous and diligent literature search revealed scanty publications on structural evaluation of rocks in Ekiti as previous works focused mainly on economic mineralization, geochemical studies and hydro-geophysical investigations. Paucity of information on structural attributes of rocks in this area necessitates this investigation. Hence, this study presents field geology and how the structural framework of rocks in Ekiti relates with their evolution.

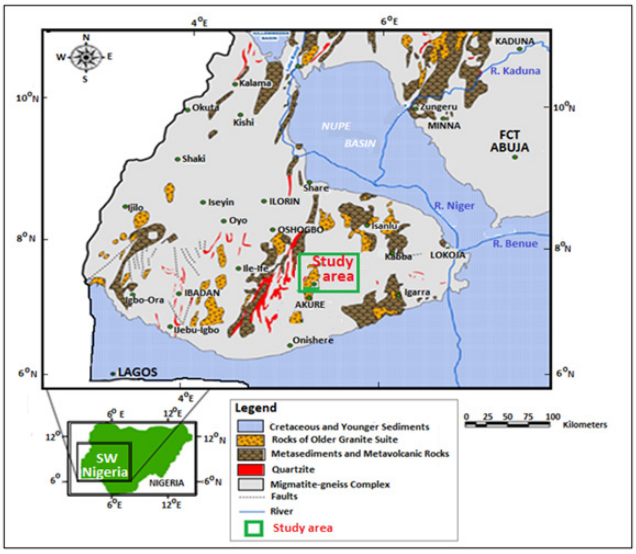

Figure 1: Map of Southwestern Nigeria showing location of Ekiti State (Modified after Akinola and Obasi, 2020).

The Study Area

Ekiti State lies between latitudes 7°15′ 00″ – 8°5′N and longitudes 4°44′ – 5°45′E covering approximately 6 353 km^2 (Talabi, 2013). The undulating topography of the terrain which stands between 180-425 m above the mean sea level is consequent on the occurrence of several erosion-dissected residual hills. These residual hills (mainly granite, charnockite, quartzite and pegmatite) are of variable sizes and shapes. These hills are concentrated in the west and central part of Ekiti State, while a few others are scattered towards the north. The lush and luxuriant vegetal signature of the area reflects a combination of fertile soils and a humid tropical climate. Ekiti area experiences two seasons- rainy and dry seasons. The rainy season extends between April and October while the dry season is between November and March. With an annual rainfall between 1250 mm to 1900 mm and an average of 1500 mm, precipitation is highest between June to August each year. The rains decrease both in frequency and intensity from September to the end of the raining season. The temperature fluctuates between 25.5°C and 28.3°C with a relative humidity of 60–80 % most months of the year. Climatic variation exerts great influence on stability of rocks precipitating intense weathering and erosion.

Geological Setting

Located between West Africa and Congo Cratons lies the Nigeria basement which has been reactivated by Pan-African orogenic events (Akande, 1991; Woakes et al., 1987; Odeyemi, 1981). This domain forms part of N-S trending orogenic belt which extends from Hoggar Massif of Algeria into the Brazilian orogen of South America (Grant, 1970, 1978; Bertrand & Davison, 1981; Caby, 1989; Black and Liégeois, 1993; Castaing et al. 1994; de Wit et al. 2008; Goodenough et al. 2014; Adetunji et al. 2016). In addition to migmatite-gneiss-quartzite complex and the schist belts which constitute older lithologic units, concomitant deep-sited granitoids common to other Pan-African countries also outcrop prominently in Nigeria. Southwest and northcentral Nigeria forms two large areas where the Precambrian basement is exposed. However, three smaller areas occur toward eastern part of the country as extension of the Bamenda, Hawal, and the Oban Massifs (Obiora, 2005). Migmatite-gneiss complex which is basal to other lithologies is a heterogenous assemblage of migmatite and composite gneisses that grades into one another. Sometimes, the gradation is so systematic that distinguishing the rock units and their boundaries is difficult (Oluyide et al., 1998). In earlier research, (Hockey et al., 1986) has attributed this to structural complexity which persist over the entire basement. Pan-African thermo-tectonic events had a homogenizing effect on all the basement rocks (Oluyide *et al*., 1998). They were product of metasomatism, dynamic metamorphism and magmatism, and the feature of the rocks depends on their original compositions (Dada, 2006, 2008). All types of migmatite-looking and gneissic rocks are lumped together as undifferentiated migmatite-gneiss-quartzite complex in previous works. This is particularly true of the Geological Survey of Nigeria. Migmatite apart from being the most complex structurally, it is the oldest and most widespread rock in Nigeria; the schistose units (schist belts) comprise pelite, semi-pelitic rocks, psammitic, polymict metaconglomerate, calcareous and mafic to ultramafic rocks (Rahaman, 1988). The schist belts represent relicts now preserved in synclinal keels of a once widespread cover of sedimentary rocks deposited in a single basin (McCurry, 1976). These supracrustal rocks is of low-grade greenschist to amphibolite facies metamorphism. Older granite is the most obvious manifestation of the Pan-African orogeny in Nigeria, it forms batholiths and plutons across western and northern Nigeria (Goodenough et al. 2014; Adetunji et al. 2016). Granite in neighbouring Ghana, Togo, and Benin were emplaced between 660–550 Ma (Kalsbeek et al., 2012) while alkaline plutons are 590 million years old (Nude et al., 2009). Many granites in southwestern Nigeria are I-type granite (Fitches et al., 1985) associated with rare metal pegmatites (Matheis & Caen-Vachette, 1983; Kuster, 1990; Okunlola, 2005; Adekeye & Adedoyin, 2007; Adetunji & Ocan, 2010; Melcher et al., 2013; Adetunji et al., 2016). These hornblende-biotite granites suites have been dated 630–580 Ma and are like those in eastern Nigeria (Key et al., 2012; Tubosun et al., 1984). Ekiti area is underlain by Migmatite-gneiss, Quartzite/ Quartz-schist, granite and charnockite (Figure 2).

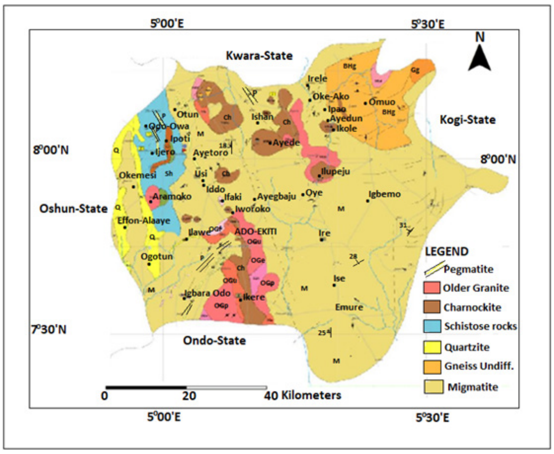

Figure 2: Geological map of Ekiti State (Modified after OlaOlorun et al., 2023).

Materials and Methods

Geological investigation involving mapping and interpretation of structural features of rock units in the study area was undertaken. Mapping was executed by a hand-held Global Positioning System (GPS) (GARMIN GPS Map 76 CSX) and a compass clinometer. Samples were investigated in-situ and their structural appraisal done in the field. Structural data are collected through direct observation of outcrops and hand specimens were collected using conventional geological tools like sledge hammer and a Hammer drill. Hand specimen samples are examined for mineralogical variations while random sampling was adopted in the study. As part of standardization process, weathered samples were avoided and snapshot of geological structures are taken using Nikon Coolpix (L820) Digital Camera. The outcome of this investigation was collated and described in two broad sub-headings. These are: field/lithologic relationship and structural geology.

Results

Field Relationship

Field geology reveals migmatite-gneiss, quartzite/quartz-schist, granite and charnockite underlie the study area. Aplite dykes, pegmatite dykes and quartz vein intrusions were also observed. Migmatite-gneiss in the study area exhibits complex structural features. Based on field structures, the lithology is categorized into four subunits. These are: migmatite, banded gneiss, biotite-hornblende gneiss, and garnet gneiss.

Migmatite

Migmatite is the most extensive unit and constitutes the country rock, it forms low-lying outcrops with poorly developed mineralogical banding. The rock consists of two main parts. Light quartzo-feldspartic part distinctly contain quartz and feldspar, while dark portions comprise mainly biotite and hornblende. A typical example occurs in Iworoko Ekiti where the rock is exposed in a depression between a charonockite outcrop and granite (Fig. 3a). (Oyinloye & Obasi, 2006) believed the light portion forms the leucosome with characteristic pale-colored assemblages dominated by quartz, plagioclase, and K-feldspar. The authors described this part as texturally medium-grained but with relatively coarse crystals of plagioclase. The other part, the melanosome contains hornblende and garnet. The palaeosome has appearance of an ordinary metamorphic rock (gneiss), which is intermediate in color between the leucosome and melanosome. Migmatite in Ekiti exhibit folds, quartz vein intrusions, fractures and joints.

Biotite-hornblende Gneiss

Biotite-hornblende gneiss unit in Ekiti is notable for its poor foliation. Mineralogical banding is sometimes lost leaving indiscernible relics of alternating leucocratic (quartz and feldspars) and melanocratic minerals typified by preponderance of biotite flakes and hornblende (Fig. 3b). Outcrops of this unit are prominent in Omuo-Oke where it is exposed as residual hills with average elevation. The typically fine to medium-grained rock is remarkable for high biotite contents which sometimes mask the quartzo-feldspartic portions making the rock to assume a seemingly dark grey colour.

Banded Gneiss

Banded gneiss shows segregation of light and dark parts into fascinating mineralogical banding (Fig. 3c). Low lying outcrops around Erio-Ekiti exhibit bands traceable for several meters. The banded structure is unique; however, outcrop morphology of banded gneiss around Ora-Ekiti is like the other gneiss types but are structurally distinctive. Twisting and dragging of the intensely folded bands is common around west of Ikere-Ekiti and Omuo area.

Garnet Gneiss

Garnet gneiss occupies a small area on the north eastern side of Omuo, this lithology extends into Ikare-Akoko area of Ondo State that was regarded as high-grade metamorphic terrain. Another smaller mass trends N-S on the outskirt of Iworoko town (north of Ado-Ekiti) where it is conspicuously exposed in a road cut along Iworoko-Ifaki road. The low-lying outcrop show dark-brown specks of garnet which is evident throughout the entire rock mass (Fig. 3d). The rock exhibits the most complex fold structures, other notable structures include fracture and joint.

Calc Gneiss

Calc-gneiss is well exposed in eastern part of Ijero, it is characteristically greyish to greenish in colour with weakly developed foliation (Fig. 3e). The rock is devoid of quartz vein intrusion, it is restricted to a narrow strip on eastern part of Ijero Ekiti, it extends to Ipoti and Odo-Owa town. (Oyinloye & Adebayo, 2005) reported that the calc-gneiss probably weather to contribute to clay formation in the area.

Biotite Schist and Amphibole Schist

Biotite schist and amphibole schist in Ekiti occurs in Ijero-Ekiti area, the rock is low-lying and shows north-south foliation trend. Outcrops are relatively soft, poorly exposed, and highly weathered. Extensive outcrop of the rock is common in Ijero-Ekiti and Odo-Owa towns (Fig. 3f). Lineaments impacted on the rock unit is by alignment of fibrous, acicular, rod-like and platy mineral aggregates which often assume preferred orientation.

Figure 3: (a) Migmatitic-gneiss outcrop in Iworoko Ekiti, (b) biotite-hornblende gneiss outcrop exposed in Omuo-Oke, (c) a finely banded gneiss outcrop with weathered surface from Erio-Ekiti, (d) garnet gneiss outcrop along Iworoko-Ifaki road, (e) Calc-gneiss form Ijero-Ekiti, (f) Biotite schist form Odo-Owa in Ijero Local Government.

Granite

Granite in Ekiti is part of the extensive granite suites which is common throughout the Pan -African province. Like in other parts of southwestern Nigeria, granite in the study area forms intrusion into both ancient migmatite-gneiss and schistose rocks (Oyinloye, 2002, 2011; Folorunso & Okonkwo, 2011; Omosanya et al., 2012; Okonkwo & Folorunso, 2013). Granite is concentrated around Ikere-Ado-Ekiti, Aramoko, Ilupeju, and NE of Otun-Ekiti. However, few isolated plutons occur around Osin-Itapa and Ikole area in northern part of Ekiti. The different textural units mapped in this study are undifferentiated granite (OGu), porphyritic granite (OGp), medium grained granite (OGe) and fine-grained granite (OGf). All the rocks have their minerals quite visible to unaided eyes. The different suites generally lack foliation, the fine to medium-grained types have compact and interlocking crystal structure. The unit is common around west of Ado-Ekiti metropolis. Granite is one spectacular topographic entity of the basement terrain of Ekiti-State and forms massive bodies. Many of the granite masses attain heights ranging between 400-650 m above the general pediment. Oyinloye and Obasi, (2006) reported that granites around Ado-Ekiti took advantage of the north-south trending regional fracture direction in the basement. The granite covers substantial parts of the landmass of the Ado-Ekiti and Ikere-Ekiti, while the remaining area is taken up by gneisses which form an envelope around them. (Oyinloye & Obasi, 2006) equally reported that there are broadly two major textural varieties of granites in Ado-Ekiti, which are: (i) medium to coarse-grained biotite and biotite-hornblende granite; and (ii) the coarsely porphyritic biotite-hornblende granite.(Olarewaju, 1988) reported that the geological contacts between granite and other lithologies are obscured owing to poor exposures in critical areas and rugged topography. Notable among the hills formed by porphyritic granite are two towering inselbergs, Olosunta Hill in the heart of Ikere-Ekiti and the Orole Hill on the outskirt of Ikere town (Figs. 4a and 4b). The feldspar phenocrysts vary in size, the larger ones measure up to 3 cm in length and about 1.2 cm in width. The shape of feldspar porphyries is rounded (Fig. 4c) whereas in other places, it is rectangular (Fig. 4d). The coarse-grained biotite and biotite-hornblende granite is exemplified by the outcrop exposed around Ori Apata area, Ado-Ekiti. The rock show faint phenocrystic alignment making it look like the porphyroblastic granite described around Idanre.

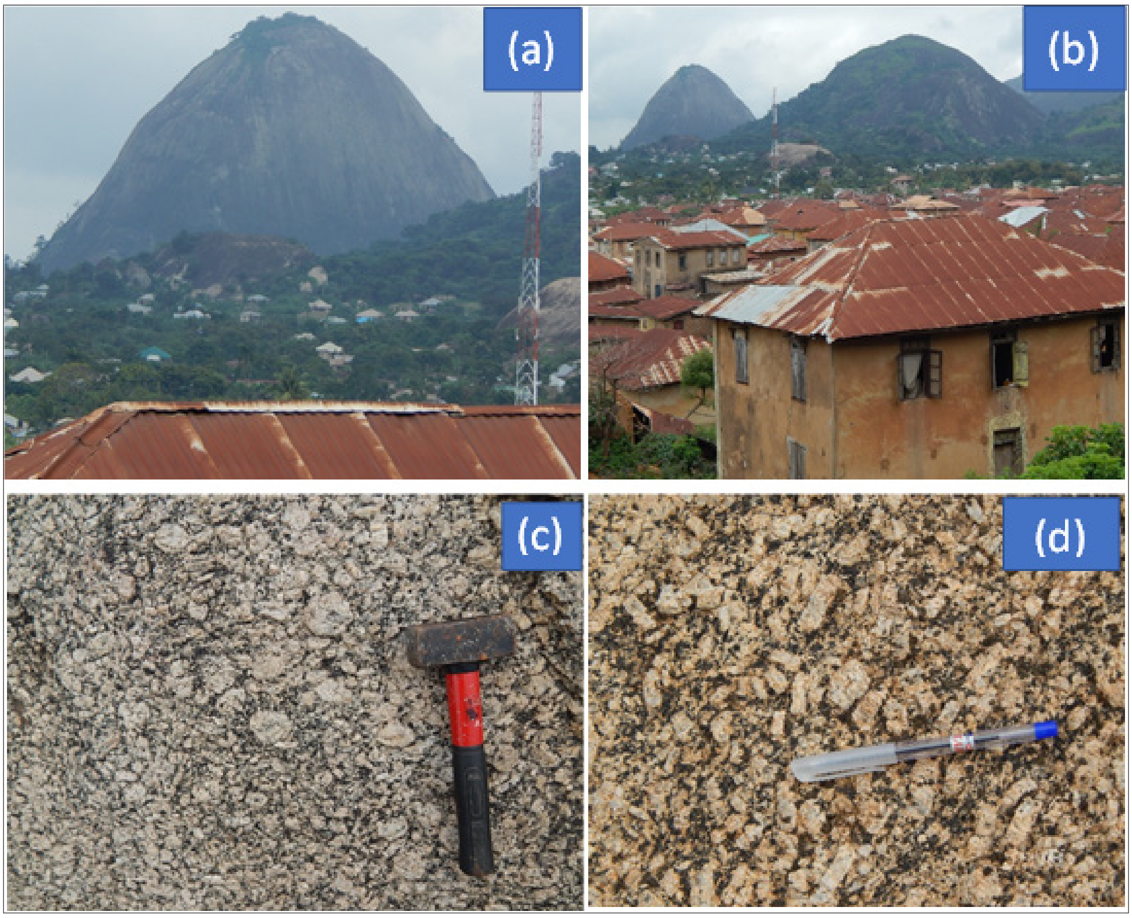

Figure 4: (a) The steep-sided granite inselberg (Orole Hills) in the outskirt of Ikere-Ekiti, (b) Ikere-Ekiti town (foreground), Olosunta Hill (with gentler slope) in the middle of photograph and Orole Hill (background) photograph taken from 2km along Ikere-Emure road, these two granite bodies form the major peaks in Ikere-Ekiti, (c) a closer view of granite with rounded feldspar phenocrysts in Ijede area of Ikere-Ekiti, (d) porphyritic granite with rectangular feldspar phenocrysts in Ado-Ekiti.

Quartz Schist/Quartzite

Quartz-schist/quartzite in the study area occurs as resistant and extensively fractured unit. Quartzite is derived from sandstone during tectonic compression, a geological process during which increasing heat and pressure beneath the earth's surface cause quartz grains to recrystallize to form a new rock. Surficial expression of quarzitic environment is quartz rubbles and a platform standing prominently above its surroundings. One spectacular quartzite ridge extends from Ipetu-Ijesha area in the neighboring Osun State into Effon-Alaye and Okemesi area of Ekiti State, covering about 45 km in length. Part of this quartzite is exposed by roadcut between Itawure and Ita-Ido junction (Figs. 5a). The colour of the rock varies from white to light brown and pinkish. The quartzite is jointed along three mutually perpendicular directions (Fig. 5b). In another segment of the outcrop, weathering and creeping due to earth movement is observed (Fig. 5c). Another notable quartzite outcrop intersected at Ajebandele area of Ado-Ekiti (Fig. 5d) is hummocky, ferruginous and fractured. Usually, the prominence of quartzite outcrop in the study area is attributed to its toughness, its non-porous nature, and ability to resist weathering. Ferruginous quartzite veins associated with red clays are common in many parts of Ekiti while several residual quartzite hills are at various stage of laterization (Fig. 5e). Despite its prominent topographic characteristics, sufficiently good exposures for study and sampling are rare (Fig. 5f).

Figure 5: (a) Massive quartzite exposed by roadcut between Itawure and Ita-Ido junction in Ekiti, (b) massive quartzite showing three perpendicular direction of split, (c) fractured hummock quartzite outcrop tilted by earth movement, this exposure occurs along Erio road, (d) massive quartzite with extensive parallel fractures obliquely inclined to foliation planes in Ajebandele, Ado-Ekiti, (e) a massive ferruginous quartzite opposite Ekiti-State Pavilion, NTA road, Ado-Ekiti, (f) laterization in a massive quartzite exposed behind WAEC office, Ikere-Ado Ekiti road.

Charnockite

Charnockite is an important rock in the basement complex areas because of its aesthetic features (Olarewaju, 1988), the controversy that trails it origin and deformation of its feldspar (Ademeso, 2009) and its age relationship with granite (Akinola et al., 2021). Charnockite exposures in Ekiti area are of average heights with characteristic rounded outlook. The most noticeable feature is its greyish-green color (Fig. 6a) and diagnostic spheroidal weathering. It occupies a linear strip underlying the built-up areas of Ikere-Ekiti and extends northwards into Ado-Ekiti. Charnockite occurs in close associated with granites in many parts the basement complex of Nigeria, this association is observed around Itapa-Osin and Ayede-Isan areas of Ekiti. In the study area, charonockite is surrounded by medium to coarse-grained biotite granite and porphyritic granite. Granite and charnockite units occur along north-south direction until the two rocks are terminated around Ado-Ekiti. (Olarewaju, 1987) reported two textural varieties of charnockite from Ado-Ekiti area. These are: (i) the coarse-grained charnockite; and (ii) fine to medium-grained gneissic charnockite. Sometimes, both types occur in close proximities, while in other occurrences, the coarse-grained type appears more massive and dominant. A prominent outcrop in which there is intermix of granite and charnockite has been reported from a roadcut along Ikere-Ado-Ekiti Road. At this location, the colour contrasts distinguishes the different units, charnockite is dark and the porphyritic granite is light in colour (Fig. 6b). (Olarewaju, 1988) believed that it may be difficult to establish the age relationship of the granite-charnockite association in the field, but the author thought their intimate association probably indicates a common origin. The occurrence of charnockite and the porphyritic granite together on an outcrop tend to confirm the suggestion by (Olarewaju 1988; 1987) that the older granites and the charnockite in Ekiti area were formed contemporaneously. (Akinola et al. 2021) believed based on Lu-Hf isotopic study arrived at 590.3±5.3 million years age for a similar unit in Idanre.

Fine-grained Granite

Fine-grained granite is of restricted occurrence in the study area, a few low-lying outcrops occurred around Okeyimi and along Nova Road within the Ado-Ekiti metropolis. In Okeyimi area, the rock forms a north-south trending intrusion into a porphyritic granite (Fig. 6c). The low-lying rock has been weathered and chattered into boulders with rounded edges (Fig. 6d).

Pegmatite

Pegmatite in Ekiti area exhibits two morphological forms, these are: intrusive steeply inclined tabular masses (dykes), and as massive copular bodies (Matheis, 1987). Extensive and mappable pegmatite occurs within Ijero, Ikoro, and Aramoko areas of Ekiti. However, pegmatite dykes occur on many outcrops across diverse locations within the granite terrain and range in size from few centimeters to several meters in thickness. Some of the larger types extends across hundreds of meters. (Matheis, 1987) reported that economic tantalum-niobium potential of pegmatite in Ekiti occurs within the tabular pegmatite of Ijero-Ikoro area. The massive copular pegmatite (Fig. 6e) is not mineralized (barren). (Okunlola, 2005; Okunlola & Akinola 2010) also reported the massive pegmatite have poor tantalum potential but are rich source of lepidolite (Fig. 6f). Pegmatite dyke is common within Ado-Ekiti metropolis where it intrudes porphyritic granite. Generally, the pegmatite is of simple mineralogy (quartz + feldspar ± mica). Many aplite, dolerite and pegmatite dykes in the study area are not mappable at the scale of this study.

Structural Geology

Rocks as aggregate of minerals experience inhomogeneous deformation when subjected to stress (Taylor & McLennan, 1985; Rudnick & Gao, 2003). Domains of maximum strain occur in high-grade metamorphic zones of the earth (Gardner et al., 2015). According to these authors, rheological properties of rocks is crucial to interpretating several global structures which manifested in earth's surface as structural defects in rocks. Evidence of deformation in crustal rocks have been established from deformed pebbles (e. g., Treagus & Treagus 2002); shear zones (e.g., Ramsay, 1980); boudins and mullions (e. g., Kenis et al., 2004; Urai et al., 2001). Rocks begin to respond to forces of deformation soon after they are formed, when rocks experience stress, shortly after, the strain component manifests as geological structures. (Odeyemi et al., 1999) suggested that almost all the foliation exhibited by basement rocks in southwestern Nigeria are tectonic in origin. The authors believed pre-existing primary structures have been obliterated by subsequent deformations. Shear structures are more prevalent in cataclastic metamorphic domains, however, rocks within Ekiti exhibits several structural elements of secondary origin, this includes fractures, fold, joints, and faults.

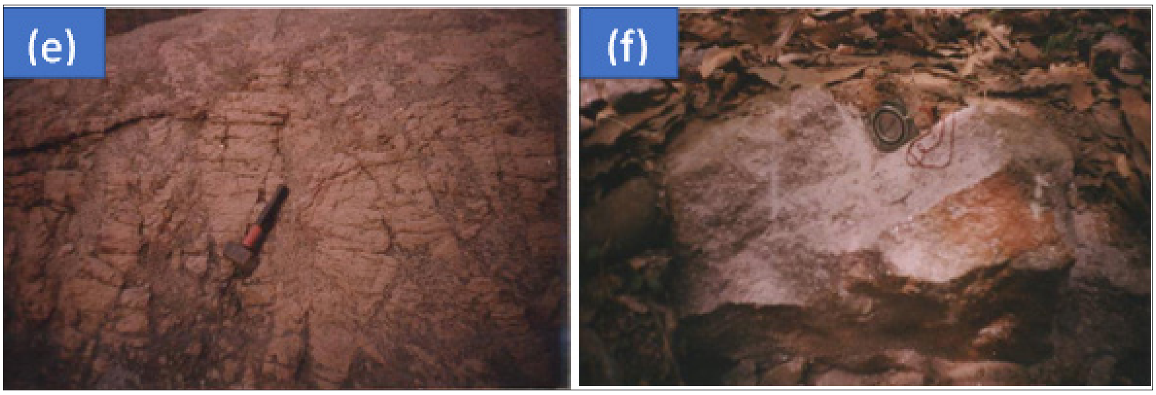

Figure 6: (a) A freshly blasted medium-grained charnockite in Ado-Ekiti with typical greyish-green color (b) intermix of charnockite and porphyritic granite exposed in a roadcut at Ikere-Ekiti, (c) fine-grained granite with a felsic intrusion (d) Fine-grained granite chattered into boulders along Nova School road, Ado-Ekiti, this unit forms a large dyke extending over several kilometers into Okeyinmi area of Ado-Ekiti metropolis, (e) A typical massive pegmatite from Sabo area, Ijero-Ekiti, (f) a lepidolite recovered from Ijero-Ekiti area.

Fractures and Joints

Fracture symbolizes discontinuity in rocks, it connotes deformation in which there is no noticeable displacement. When rock fractures, it suggests the endurance limits have been exceeded. Fractures are produced in rocks as a response to extensional forces. The size and magnitude of fracture depends on the amount of stress, composition of rocks, and duration or length of time for which the force acted. However, fractures are more prominent in brittle rocks like quartzite, gneiss, and granites and less frequent in schistose assemblages which often undergo folding. Microgranite in Okeyimi area, Ado-Ekiti exhibits fantastic display of parallel N-S fractures (Fig. 7a) which suggests the area is a shear zone. Garnet gneiss (Fig. 7b), and quartzite (Fig. 7c) displays several dilatational features that are inclined almost at right angles to lineation direction of the rock. Fractures in quartzite include parallel fractures running obliquely to the strike direction of the rock, others are crisscrossing fractures that network themselves across the entire rock surfaces and are responsible for splitting and shattering rock mass into rubbles with angular fragments. The quartzite outcropping between Itawure and Ita-Ido junctions is typically fractured. Joints frequently occur as discontinuities along which stress is released in a rock. Joints are well-preserved in quartzite and microgranite of Ekiti area. Some joints are oriented parallel, some are oblique while others are perpendicular to the strike direction. Specifically, massive granites from the study area contain unloading joints (Fig. 7c). Such joints are usually aligned horizontally symbolizing the direction of stress relief when the overburden is released. Unloading joint is a feature common to many whale-back granite masses. This structure develops when granite which was once deep within the earth crust now become exposed at the earth's surface by removal of the overburden through million years of erosion. By this, they split into horizontal joints to balance the reduction in pressure. Adekoya, (1977) believed tectonic joints are quantitative and directional manifestation of the operative forces that can give clue to the possible stress distribution in deformed rocks.

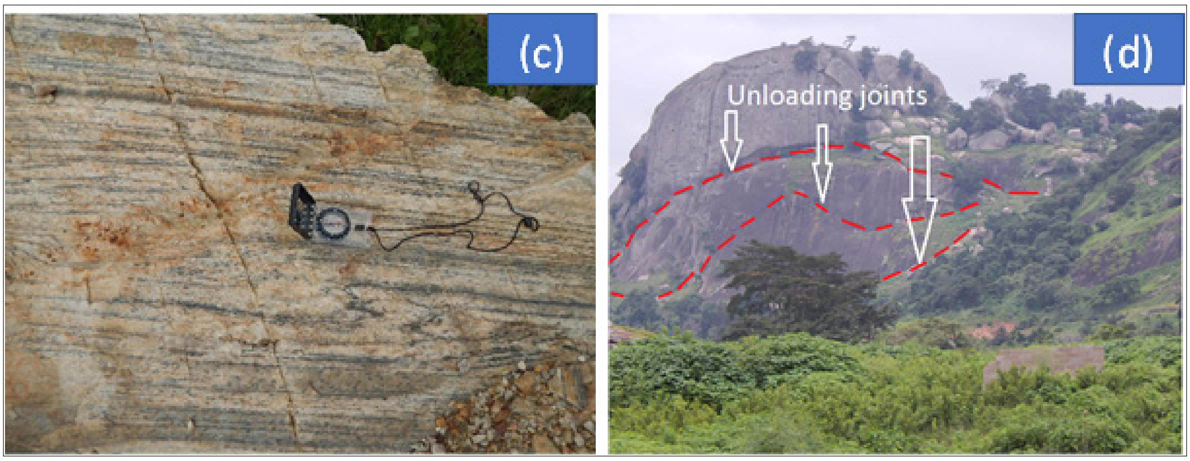

Figure 7: (a) A chattered outcrop of fine-grained granite from Okeyinmi area of Ado-Ekiti with set of parallel fractures. This rock shows some displacement (red portion of hammer) along the plane of discontinuity, (b) a fracture oriented parallel to the axial surfaces of folds in garnet gneiss around Iworoko area, (c) vertical fractures oriented perpendicularly to strike direction in quartzite from Itawure Junction, (d) a large unloading joint in a granite inselberg along Old Ado-Iyin Road, Ado-Ekiti.

Folds

Fold is a flexure or curvature in rocks. Unlike fractures, which is produced by extensional forces, fold is a product of compressional forces. Two of the most studied aspects in structural geology are morphology and genesis of folds (Ramsay, 1967; Hudleston & Lan, 1993; Ez, 2000; Harris et al., 2002; Harris, 2003; Alsop and Holdsworth, 2004; Mandal et al., 2004; Carreras et al., 2005; Bell, 2010; Hudleston and Treagus, 2010; Godin et al., 2011; Harris et al., 2012a, 2012b; Llorens et al., 2013). In the field, folds are easy to recognize, this is particularly true of sedimentary sequences because all sedimentary strata are initially horizontal. Folds vary from those on microscopic scale to mega folds that are recognizable on a regional scale. Fold is the commonest means by which metamorphic rocks are differentiated from sedimentary and igneous rocks. In Ekiti area, migmatite gneiss and garnet gneiss display pervasive fold structures of variable size, shape, and complexity. While migmatite show relatively simple open folds, garnet gneiss exhibits the most complex fold structure with thinned limbs and thickened crests (Fig. 8a). Stress causes rocks with inhomogeneous mineralogy (e.g., banded rock where interlayering of competent and incompetent materials) to behave differently. The competent layer is folded because of strain while the incompetent layers become fractured leading to formation of boudins (Kenis et al., 2004; Urai et al., 2001). The dominant axial trend of the folds in Ekiti area like many other basement complex areas is N-S. However, in few cases, NNE-SSW trend exist.

Xenoliths

Xenoliths are fragmented residue of older rocks encapsulated within a granitic rock. Xenoliths are particularly important in accessing the stress regime of any magmatic intrusion. Small and rounded xenolith connote low energy regime, while massive types with random shapes symbolize catastrophic (forceful) emplacement accompanied by rapid cooling. Usually, xenoliths are older than the rocks hosting them. Porphyritic granite around Ori-Apata (Km 1, Ado-Ekiti-Iworoko road) is charged with many xenoliths of migmatite gneiss (Fig. 8b), while fine-grained granite carries xenoliths of porphyritic granite around Okeyinmi area of Ado-Ekiti (Fig. 8c).

Pinch and Swell Structures

Pinch and swell structures occur in few areas within the basement complex of Ekiti. It is observed on migmatite-gneiss outcrop (Fig. 8d) around Ilukuno and Oke-Oro area. Others occur in the neighborhoods of Ora-Ekiti. Pinch and swell represent chain of rock fragments sometimes joined by thin necks giving them an appearance resembling a stringed sausage or beads-on-string structure. The structure is common in many metamorphic terrains where shearing is prevalent. It forms when a more competent layer undergoes parallel extension in a weaker matrix and can range in size from microscopic to regional scales. When two rock units of variable ductility or competence are simultaneously subjected to stress, the different lithologies exhibit variable strain components. As stretching increases, all layers are elongated and thinned. The neck thin more quickly than the swells causing the marker layer to undergo distortion near the localization of strain in the neck (Gardner et al., 2015). Pinch and swell structures in Ekiti area occur in Ora-Ekiti and Oke-Oro Ekiti (Fig. 8d). The structure resembles those observed in Igarra schist belt where quartz veins within metaconglomerate produce boudins (Akinola et al., 2017). This structure is common in high grade metamorphic terrains around the world.

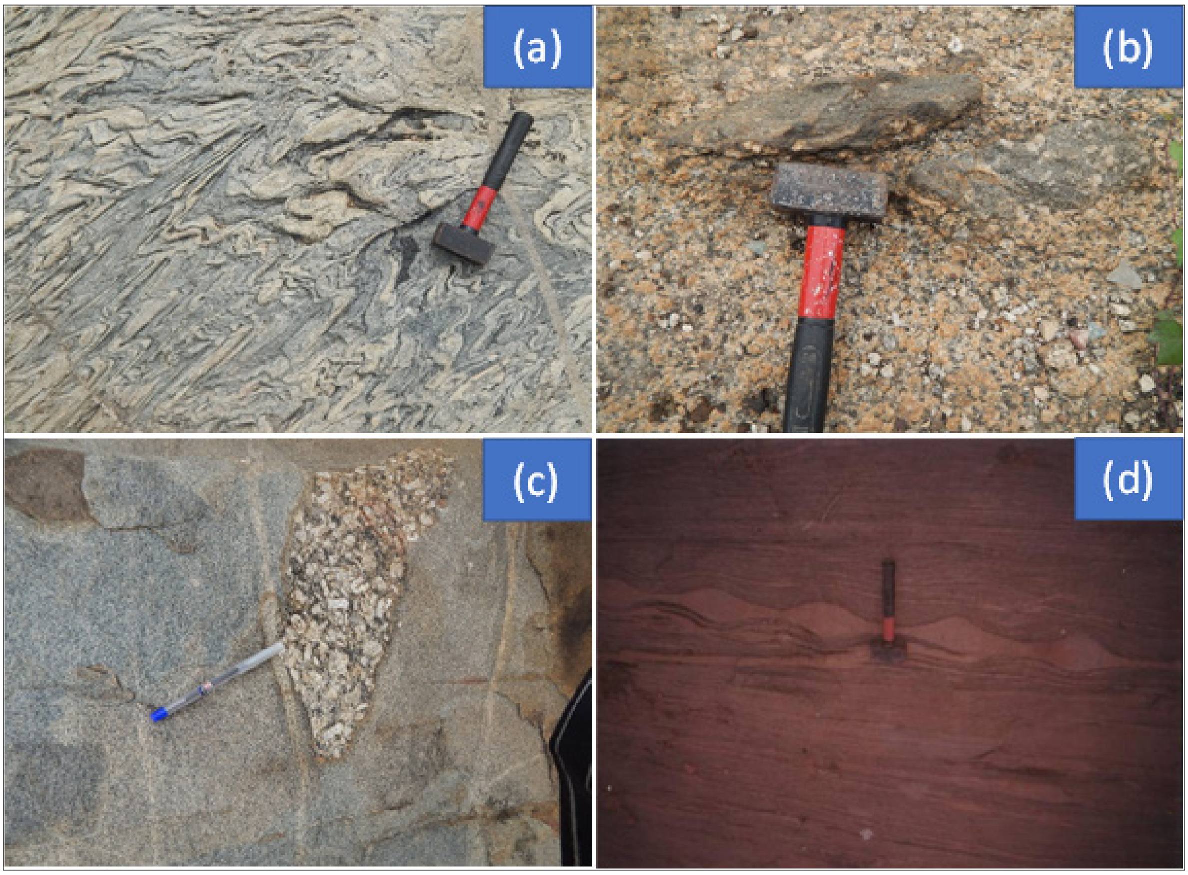

Figure 8: (a) Complex fold structure on a garnet gneiss outcrop along Ifaki-Iworoko Road, (b) a bulging xenolith of the country rock knotted within porphyritic granite along university road, Ado-Ekiti, (c) xenolith of granite porphyry in a fine-grained granite, (d) Pinch and swell structure on an outcrop in Oke-Oro Ekiti.

Veins and Dykes

Crosscutting veins found in almost all rock types are the easiest structures to recognize within Ekiti. According to (Fossen, 2010) it is possible to infer stress directions by studying attitude of veins. Veins develop commonly orthogonal to the max¬imum instantaneous extension axis and have been considered as a good shear sense indicator (Davis and Reynolds, 1996). Thus, careful study of complex vein system has successful applications in tectonic studies (Maeder, 2014). Leucosome (felsic) veins cutting across each other are common features of Ekiti terrain. Relationships like this has been reported from many migmatite terrains (Mukherjee, 2010; Mukherjee & Koyi, 2010).

Quartz vein is the commonest structural feature in Ekiti area. It occurs as tabular leucocratic bodies emplaced within the host rocks. Their texture, mineralogy and color are quite distinctive. In the study area, quartz veins are of variable sizes, large ones measure up to 50 cm in width and are traceable for tens of meters, while the small ones are few millimeters wide. Large quartz veins with sharp margins are common on many gneissic rocks. However, quartz is formed in veins after cooling of hydrothermal fluids ascending through fractures in the rock or by mobile hydro fractures (Bons, 2001). Quartz veins are common in silicified zones and are formed by quartz injection or sucking-in (Elliston, 2018). Quartz being able to form under low temperature-pressure conditions can withstand denudation, it tends to persist in granite and other siliceous rocks. In Ekiti area, quartz veins are oriented parallel or obliquely to the foliation directions of their host. Other intrusive bodies observed during the field investigation include dolerite, pegmatite, and aplite dykes. Prominent among these bodies is dolerite dyke intrusion into a medium-grained granite (Fig. 9a) at the Yinka Quarry, along Iyin Road, Ado-Ekiti. A similar dyke has been subjected to tectonic actions (twisted) around Dalimore area of Ado-Ekiti (Fig. 9b). Dykes are usually straight-edged and regarded as representing terminal stage of Pan African tectono-thermal event. The bending of the dyke symbolizes post-orogenic tectonic activity. Others are pegmatite dyke within a porphyritic granite (Fig. 9c). Aplite dykes are also common intrusive bodies within the porphyritic granite along University Road, Ado-Ekiti (Fig. 9d). In the field, it forms a raised platform higher than the host rock due to its resistance to erosion.

Weathering

The location of Nigeria near the equator suggests it has tropical type of climate. Since Ekiti State lies within southwestern Nigeria, the weather condition has a high humidity. This coupled with temperature which range between 26 – 30°C, indicate that rocks in Ekiti experiences serious disaggregation by both physical and chemical weathering. Both mechanical and chemical weathering is dominant in the basement complex of Ekiti. It is a major process by which rocks decay to undergo transformation in humid subtropical and tropical regions. Evidence of chemical weathering manifests in rocks as color change which is attributable to oxidation during incipient rock rot, a hollow sound when struck by hammer and considerable amount of softness. Weathering processes which often lead to laterization are dictated by such controls as alternation of wet and dry seasons, pH, Eh, ionic mobility, ionic potential and parent-rock chemistry (Du Preez, 1949; McFarlane 1991; Nwajide, & Hoque, 1976). Measurable degrees of weathering are evident on outcrops that are exposed to denudation continually. Physical weathering which involves mechanical disintegration of rock to yield its component aggregates is also prevalent along the slope of many hills where massive boulders are shattered around the periphery of large granite masses. The extent of weathering in any rock however depends on the fabric characteristics and the mineral components. Rocks are more susceptible to weathering when they are porous, soft, flat-lying or fractured. The style of weathering may be a diagnostic feature of rock's identification. Many charnockite outcrops in the study area show spheroidal weathering style with rounded outlook. In many parts of Ikere-Ekiti, some of the porphyritic granite has changed from the usual pinkish look to whitish due to intense chemical decay (Fig. 9e). Evidence of chemical weathering manifests on several granite outcrops in Ekiti, porphyritic granite in a large expanse of the area have transformed into laterite and saprolite through intense chemical weathering and leaching (Fig. 9f).

Figure 9: (a) A dyke emplaced into a medium-grained granite exposed by mine workings in Yinka Quarry site, Ado-Ekiti, (b) a bent dolerite dyke emplaced into medium-grained granite around Dallimore area Ado-Ekiti; the bent structure must have resulted from post emplacement tectonic activities, (c) a pegmatite dyke intrusion in a porphyritic granite opposite School of Nursing, Ado-Ekiti, (d) aplite dyke in a medium-grained granite, Ado-Ekiti, (e) porphyritic granite in Ikere-Ekiti exhibiting color change arising from feldspar porphyries undergoing chemical weathering, (f) a granite now transformed into laterite; the upper part is ferruginous and form a hard protective cover over the underlying whitish saprolite in Ijede area of Ikere-Ekiti.

Conclusions

Petrological and structural features of the basement rocks in Ekiti was investigated through extensive field geological exercise. The fieldwork reveals migmatite-gneiss, quartz schist/quartzite, granite, charonockite and pegmatite with series of intrusive dykes (aplite, dolerite, and pegmatite) underly Ekiti area. Rocks interrelationship as recorded through outcrop examination reveal that regional and local changes in rocks in the area occurs as a response to environmental constraints dictated by temperature, pressure, and fluid activity. The attendant structural components of rocks of Ekiti are results of polymetamorphic episodes and intrusive igneous phases which accompanied Pan-African magmatic activities.

The complex fold patterns in the country rock, the abundant veins and dykes haphazardly emplaced within the granitoids, the profuse jointing that manifested in quartzite and quartz-schist, and the parallel fractures in fine grained granite may indicate that Ekiti area is an active shear zone.

Evidence of older tectonic signatures being massively overprinted by new ones, typical metamorphic textures with porphyroblastic aggregates in the gneisses, and the seemingly undeformed dykes indicate the polymetamorphic terrain was last acted upon by Pan-African orogenic activities. The occurrence of huge and randomly placed mafic enclaves in the granite units indicates the granitoids were forcefully emplaced into the basement complex as liquid, implying that the granitoids in Ekiti are not product of ultra-metamorphism. Contact relationships indicate migmatite is the oldest unit in Ekiti, granite and charnockite are contemporaneous and are formed next, fine-grained granite and microgranite are younger while the undeformed dykes are the youngest. Thus deformation, metamorphism and intrusive phases are the dominant geodynamic features of Ekiti area.

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References

1. Akande, S. O. (1991). Geological setting and evolution of vein gold deposits in the Nigerian schist belts (poster presentation) Brazil Gold ’82, E. A. Ladeira (ed.), 257-260, Balkema, Rotterdam.
2. Woakes, M., Ajibade, C. A., & Rahaman, M. A. (1987). Some metallogenic features of the Nigeria basement. *Journal of African Earth Science*, 5, 655-664. DOI: https://doi.org/10.1016/0899-5362(87)90004-2
3. Odeyemi, I. B. (1981). A review of the orogenic events in the Precambrian basement of Nigeria, West Africa. *Geologische Rundschau* 70, 897-909. Retrieved from https://link.springer.com/article/10.1007/BF01820170
4. Grant, N. K. (1970). Geochronology of Precambrian basement rocks from Ibadan, southwestern Nigeria; *Earth and Planetary Science Letters, 10*(1), 29-38. DOI: https://doi.org/10.1016/0012-821X(70)90061-0
5. Bertrand, J. M. L., & Davison, I. (1981). Pan Africa granitoid emplacement in the Adrar des Iforas mobile belt (Mali). A Rb/Sr. Isotope study. *Precambrian Research* 14, 333-361. DOI: https://doi.org/10.1016/0301-9268(81)90044-9
6. Caby, R. (1989). Precambrian terranes of Benin-Nigeria and northeast Brazil and the late Proterozoic South Atlantic fit. In: Dallmeyer, R. D. (Ed), Terranes in the Circum-Atlantic Palaeozoic Orogens. *Geological Society of America Special Paper*, 230, 145-158.
7. Castaing, C., Feybesse, J. L., Thieblemont, D., Triboulet, C., & Chevremont, P. (1994). Palaeo-geographical reconstructions of the Pan-African/Brasiliano orogen: closure of an oceanic domain or intracontinental convergence between major blocks? *Precambrian Research*, 69. 327-344. DOI: https://doi.org/10.1016/0301-9268(94)90095-7
8. de Wit, M. J., Stankiewicz, J., & Reeves, C. (2008). Restoring Pan-African-Brasiliano connections: more Gondwana control, less trans-Atlantic corruption. In: Pankhurst, R. J., Trouw, R. A .J., Brito Neves, B .B., De Wit, M .J. (Eds.), Pre-Cenozoic Correlations Across the South Atlantic Region. *The Geological Society, London. 294*(1), 399-412. DOI: http://dx.doi.org/10.1144/SP294.20
9. Goodenough, K. M., Lusty, P. A. J., Roberts, N. M. W., Key, R. M., & Garba, A. (2014). Post-collisional Pan-African granitoids and rare metal pegmatites in western Nigeria: Age, petrogenesis, and the ‘pegmatite conundrum. *Lithos, 200*(1), 22-34. DOI: http://dx.doi.org/10.1016/j.lithos.2014.04.006
10. Adetunji, A., & Ocan, O. O. (2010). Characterization and mineralization potentials of granitic pegmatites of Komu area, Southwestern Nigeria. *Resource Geology* 60, 87–97. DOI: https://doi.org/10.1111/j.1751-3928.2010.00116.x
11. Obiora, S. C. (2005). Field Description of Hard Rocks with examples from the Nigeria basement complex (1st ed.) *Snap Press* (Nig.) Ltd. Enugu, 14.
12. Oluyide, P. O., Nwajide, C. S., & Oni, A. O. (1998). The Geology of the Ilorin area; Bulletin, GSN, 42, 84. Retrieved from https://www.scirp.org/reference/referencespapers?referenceid=2240799
13. Hockey, R. D., Sacchi, R., De Graft, W .P .F .H. & Muotoh, E. O. G., (1986). The geology of Lokoja-Auchi area; *Bulletin*, GSN, 39, 71. Retrieved from https://www.scirp.org/reference/referencespapers?referenceid=2451163
14. Dada, S. S. (2008). Proterozoic evolution of the Nigeria-Boborema province. In: Pankhurst, R. J., Trouw, R. A .J., Brito Neves, B. B., de Wit, M .J. (Eds.), *Geological Society of London, Special Publication, 294*(1), 121-136. DOI: http://dx.doi.org/10.1144/SP294.7
15. Rahaman, M. A. (1988). Recent Advances in study of the Basement Complex of Nigeria Precambrian geology of Nigeria. In: Oluyide, P. O. et al., (eds) Precambrian Geology of Nigeria. *Geological Survey of Nigeria Publication*, Kaduna, 11-43.
16. Ramsay, J. G (1980). Shear zone geometry: A review, Jour. Struct. Geol. 2, 83–99. Retrieved from https://blogs.egu.eu/divisions/ts/2021/01/21/ts-must-read-ramsay-1980-

shear-zone-geometry-a-review/
17. McCurry, P. (1976). The Geology of the Precambrian to Lower Paleozoic rocks of northern Nigeria – a review of Geology of Nigeria, C. A. Kogbe (ed.) Elizabethan Publishing Company, *Lagos*. 15–39. Retrieved from https://www.scirp.org/reference/referencespapers?referenceid=1160488
18. Adetunji, A., Olarewaju, V. O., Ocan, O. O., Ganev, V. Y., & Macheva, L. (2016). Geochemistry and U-Pb zircon geochronology of the pegmatites in Ede area, southwestern Nigeria: A newly discovered oldest Pan African rock in southwestern Nigeria. *Jour. of Afr. Earth Sci*. 115, 17-190. DOI: https://doi.org/10.1016/j.jafrearsci.2015.12.006
19. Kalsbeek, F., Affaton, P., Ekwueme, B., Frei, R., Thrane, K. (2012). Geochronology of granitoid and metasedimentary rocks from Togo and Benin, West Africa: comparisons with NE Brazil. *Precambrian Research 196*(197), 218–233. DOI: http://dx.doi.org/10.1016/j.precamres.2011.12.006
20. Nude, P. M., Shervais, J. W., Attoh, K., Vetter, S. K., Barton, C. (2009). Petrology and geochemistry of nepheline syenite and related carbonate-rich rocks in the Pan-African Dahomeyide orogen, south-eastern Ghana, West Africa. *Journal of African Earth Sciences 55*(3), 147–157. DOI: http://dx.doi.org/10.1016/j.jafrearsci.2009.03.010
21. Matheis, G., Caen-Vachette, M. (1983). Rb–Sr isotopic study of rare-metal bearing and barren pegmatites in the *Pan-African reactivation zone of Nigeria, 1*(1), 35-40. DOI: https://ui.adsabs.harvard.edu/link_gateway/1983JAfES...1...35M/doi:10.1016/0899-5362(83)90029-5
22. Kuster, D. (1990). Rare-metal pegmatites of Wamba, central Nigeria -their formation in relation to late Pan-African granites, 25, 25-23. Retrieved from https://link.springer.com/article/10.1007/BF03326380
23. Okunlola, O. A. (2005). Metallogeny of tantalum-niobium mineralization of Precambrian pegmatites of Nigeria. Minera Wealth, (137), 38-50. Retrieved from https://www.scirp.org/reference/referencespapers?referenceid=2240832
24. Adekeye, J. I. D., & Adedoyin, A. D. (2007). Economic potentials of the pegmatites of Eruku area, Southwestern Nigeria. *Continental Journal of Earth Sciences*, 2, 1-6. Retrieved from https://zenodo.org/records/824279
25. Tubosun, I. A., Lancelot, J. R., Rahaman, M. A., & Ocan, O. O. (1984). U–Pb Pan-African ages of two charnockite–granite associations from Southwestern Nigeria. *Contributions to Mineralogy and Petrology, 88*(1), 188–195.DOI: https://doi.org/10.1007/bf00371422
26. Oyinloye, A. O. & Obasi, R. A. (2006). Geology, geochemistry, and geotectonic setting of Pan-African Granites and Charnockite around Ado-Ekiti. *Pakistan Journal of Scientific and Industrial Research. 49*(5), 299-308. Retrieved from https://www.researchgate.net/publication/286862450_Geology_geochemistry_and_geotectonic_setting_of_the_Pan-African_granites_and_charnockites_around_Ado-Ekiti_Southwestern_Nigeria
27. Oyinloye, A. O. (2002). Geochemical Studies of granite gneisses: the implication on source determination. *Journal of Chemical Society of Nigeria, 26*(1), 131–134.
28. Oyinloye, A. O., & Adebayo, O. F. (2005). Petrophysical and chemical properties of calc-gneiss and clay deposit in Ijero-Ekiti area as industrial raw materials. *Global Journal of Mechanical Engineering, 6*(1).
29. Folorunso, I. O., & Okonkwo, C. T. (2011). Petrographic investigation of Oke-Awun rocks, southwestern Nigeria. *International Journal of Science and Advanced Technology* 1, 10, 162–165.
DOI: https://doi.org/10.1144/gsjgs.142.2.0319
30. Okunlola, O. A., & Akinola, O. O. (2010). Petrochemical characteristics of the Precambrian rare metal pegmatite of Oke-Asa area, Southwestern Nigeria: Implication for Ta-Nb Mineralization. RMZ–Materials and Geo Environment, 57, 525-538. Retrieved from https://www.scirp.org/reference/referencespapers?referenceid=2240828
31. Omosanya, K., Adebowale C., Sanni, R., Laniyan, T., Mosuro, G., Omosanya, H., & Falana, L. (2012). Petrography and Petrogenesis of Pre-Mesozoic rocks, Ago-Iwoye NE, SW Nigeria. In: (Ed.) Gordon S. Lister, General Contributions, *Journal of the Virtual Explorer*, 40, 1. DOI: doi:10.3809/jvirtex.2012.00313
32. Oyinloye, A. O. (2011). Geology and Geotectonic Setting of the Basement Complex Rocks in South Western Nigeria: Implications on Provenance and Evolution. Earth and Environmental Sciences, Imran Ahmad Dar (Ed.), Available from 68geotectonic- setting-of-the-basement-complex-rocks in-South-western-Nigeria-implications. DOI: http://dx.doi.org/10.5772/26990
33. Olarewaju, V. O. (1988). Petrology and geochemistry of the charnockite and associated granitic rocks of Ado-Ekiti Akure, S.W. Nigeria- In. Precambrian Geology of Nigeria, P.O. Oluyide (co-ordinator), 129-143, Geology Survey of Nigeria Publications, Lagos, Nigeria.
34. Olarewaju, V. O. (1987). Charonockite-granite association in SW Nigeria, Rapakivi granite type and charnockite plutonism in Nigeria. *Journal of Africa Earth Sciences. 6*(1), 67-77. DOI: https://ui.adsabs.harvard.edu/link_gateway/1987JAfES...6...67O/doi:10.1016/0899-5362(87)90108-4
35. Ademeso, O. A. (2009). Deformation traits in the charnockitic rocks of Akure area, Southwestern Nigeria. *Asian Jour. Of Earth Sciences, 2*(4), 113-120.
DOI: http://dx.doi.org/10.3923/ajes.2009.113.120
36. Akinola, O. O., Talabi, A. O., & Muhammad, H. R. (2017). Petrostructural feature of metaconglomerate in Igarra and Otuo, Southwestern Nigeria. *Asian Journal of Earth Sciences, 10*(1), 33-43.
DOI: http://dx.doi.org/10.3923/ajes.2017.33.43
37. Akinola, O. O., Ghani, A. A., & Talabi, A. O. (2021). Lu-Hf Isotope and Geochronometry of Idanre Charnockite, Southwestern Nigeria: implications for petrogenesis, *Journal of Mining and Geology. 57*(1), 163-176. Retrieved from https://www.researchgate.net/publication/357062050_Lu-Hf_Isotope_and_Zircon_U-Pb_Geochronometry_of_Idanre_Charnockite_Southwestern_Nigeria_Implications_for_Petrogenesis
38. Matheis, G. (1987). Nigerian rare-metal pegmatites and their lithological framework. *Geological Journal, 22*(S2), 271-291. DOI: http://dx.doi.org/10.1002/gj.3350220620

39. Akinola, O. O., & Obasi, R. A. (2020). Migmatite and Gneisses in the basement complex of Southwestern Nigeria: a re-appraisal of their structural, mineralogical and geochemical diversity. *Journal of Applied Science, 6,*(8), 1-17.
40. Taylor, S. R., & McLennan, S. M. (1985). The continental crust: Its composition and evolution, Blackwell Scientific Palo Alto, CA, USA, Medium: X, 328 1985. Retrieved from https://www.scirp.org/reference/ReferencesPapers?ReferenceID=1779877
41. Rudnick, R. L., & Gao, R. (2003). Composition of the Continental Crust. In treatise on Geochemistry, 3, the crust, Rudnick, R. L. (Ed.) Chapter 3.01, Elsevier Ltd., USA., isbn-1-64. DOI: https://ui.adsabs.harvard.edu/link_gateway/2003TrGeo...3....1R/doi:10.1016/B0-08-043751-6/03016-4
42. Gardner, R. L., Piazolo, S., & Daczko, N. R. (2015). Pinch and swell structures: evidence for strain localization by brittle-viscous behavior in the middle crust. *Solid Earth, 6*(3), 1045-1061. Retrieved from https://se.copernicus.org/articles/6/1045/2015/
43. Treagus, S. H., & Treagus, J. E. (2002). Studies of strain and rheology of conglomerates, *Journal of Structural Geology, 24*(10), 1541–1567 DOI: http://dx.doi.org/10.1016/S0191-8141(01)00162-6
44. Ramsay, J. G., (1967). Folding and Fracturing of Rocks. McGraw Hill, New York. 568. Retrieved from https://www.scirp.org/reference/ReferencesPapers?ReferenceID=1688431
45. Kenis, I., Urai, J. L., van der Zee, W., & Sintubin, M. (2004). Mullions in the High-Ardenne Slate Belt (Belgium): numerical model and parameter sensitivity analysis, *Journal of Structural Geology, 26*(9), 1677–1692. DOI: https://doi.org/10.1016/j.jsg.2004.02.001
46. Urai, J., Spaeth, G., van der Zee, W., & Hilgers, C. (2001). Evolution of mullion (boudin) structures in the Variscan of the Ardennes and Eifel, *Journal of the Virtual Explorer*, 3, 1–16. DOI: http://dx.doi.org/10.3809/jvirtex.2001.00027
47. Adekoya, J. A. (1977). A note on jointing in the basement complex of the Ibadan area, Oyo State, Nigeria. *Journal of Mining and Geology*, 14, 48-52.
48. Hudleston, P. J., & Lan, L. (1993). Information from fold shapes. Journal of Structural Geology 15, 253–264. Retrieved from https://www.academia.edu/50612328/Information_from_fold_shapes
49. Harris, L. B., Godin, L., & Yakymchuk, C. (2012). Regional shortening followed by channel flow induced collapse: a new mechanism for—dome and keel geometries in Neoarchean granite-greenstone terrains. *Precambrian Research, 212*(213), 139–154. DOI: http://dx.doi.org/10.1016/j.precamres.2012.04.022
50. Harris, L. B. (2003). Folding in high-grade rocks due to back-rotation between shear zones. *Journal of Structural Geology, 25*(2), 223–240. DOI: http://dx.doi.org/10.1016/S0191-8141(02)00024-X
51. Mandal, N., Samanta, S. K., & Chakraborty, C. (2004). Problem of folding in ductile shear zones: a theoretical and experimental investigations. *Journal of Structural Geology*, 26, 475–489. DOI: http://dx.doi.org/10.1016/j.jsg.2003.07.004
52. Hudleston, P. J., & Treagus, S. H. (2010). Information from folds. a review. *Journal of Structural Geology, 32*(12), 2042–2071. DOI: http://dx.doi.org/10.1016/j.jsg.2010.08.011
53. Godin, L., Yakymchuk, C., & Harris, L. B. (2011). Himalayan hinterland-verging superstructure folds related to foreland-directed infrastructure ductile flow: Insights from centrifuge analogue modelling. *Journal of Structural Geology, 33*(3), 329–342. DOI: http://dx.doi.org/10.1016/j.jsg.2010.09.005
54. Harris, L. B., Yakymchuk, C., & Godin, L. (2012). Implications of centrifuge simulations of channel flow for opening out or destruction of folds. *Tectono¬physics, 526*(529), 67–87. DOI: http://dx.doi.org/10.1016/j.tecto.2011.05.002
55. Llorens, M. G., Bons, P .D., Griera, A., Gomez-Rivas, E., & Evans, L. A. (2013). Single layer folding in simple shear. *Journal of Structural Geology*, 50, 209–220. DOI: http://dx.doi.org/10.1016/j.jsg.2012.04.002
56. Fossen, H. A. (2010). Structural Geology. Cambridge University Press. 122–123. Retrieved from https://assets.cambridge.org/97811070/57647/frontmatter/9781107057647_frontmatter.pdf
57. Davis, G. H., & Reynolds, S . J. (1996). Structural Geology of Rocks and Regions, second ed. John Wiley and Sons, Inc. Retrieved from https://www.scirp.org/reference/referencespapers?referenceid=1975473
58. Ekiti state, SW-Nigeria RMZ-M&G, vol. 60, pp 73-86.
59. Mukherjee, S. (2010). Structures in meso- and micro-scales in the Sutlej section of the Higher Himalayan Shear Zone, Indian Himalaya. e-Terra 7, 1–27. Retrieved from https://www.researchgate.net/publication/272827178_Structures_at_Meso-and_Micro-scales_in_the_Sutlej_section_of_the_Higher_Himalayan_Shear_Zone_in_Himalaya_e-Terra_7_1-27
60. Mukherjee, S., & Koyi, H. A. (2010). Higher Himalayan Shear Zone, Sutlej section: structural geology and extrusion mechanism by various combination of simple shear, pure shear, and channel flow in shifting modes. *International Journal of Earth Sciences, 99*(6), 1267–1303. DOI: http://dx.doi.org/10.1007/s00531-009-0459-8
61. Bons, P. (2001). *The formation of large quartz veins by rapid ascent fluids in mobile hydro-fractures Tectonophysics, 336*(1), 1-17 DOI: http://dx.doi.org/10.1016/S0040-1951(01)00090-7
62. Elliston, J. (2018). Hydration of Silica and Its Role in the Formation of Quartz Veins – Part 1. *Substantia, 2*(2), 43-71. DOI: https://doi.org/10.13128/Substantia-60
63. Du Preez, J. W. (1949). Origin, classification, and distribution of Nigerian laterites: Proceedings, 3rd West African Conference, Ibadan, 223-234.
64. 64. Nwajide, C. S. & Hoque, M. (1976). On laterization and Nigerian laterites: *Journal of the Indian Academy of Geoscience*, 19, 1-13.
65. Okonkwo, C. T., & Folorunso, I. O. (2013). Petrochemistry and Geotectonic Setting of Granitic Rocks in Aderan Area, S.W. Nigeria. *Journal of Geography and Geology, 5*(1), 30–44. DOI: http://dx.doi.org/10.5539/jgg.v5n1p30

66. Harris, L. B., Koyi, H. A., & Fossen, H. (2002). Mechanisms for folding of high-grade rocks in extensional tectonic settings. *Earth-Science Reviews*, 59, 163–210. Retrieved from http://www.glyfac.buffalo.edu/mib/course/326/Ref/HaHoFo02.pdf
67. Alsop, G. I., & Holdsworth, R. E. (2004). Shear zone folds: records of flow perturbation or structural inheritance? In: Alsop, G. I., Holdsworth, R. E., McCaffey, K. J. W., Hand, M. (Eds.), *Flow Processes in Faults and Shear Zones, 224*(1), Geol. Soc. London, Special Publication, 177–199. DOI: http://dx.doi.org/10.1144/GSL.SP.2004.224.01.12
68. Bell, T. H. (2010). Deformation partitioning, foliation successions and their significance for orogenesis: hiding lengthy deformation histories in mylonites. In: Law, R. D., Butler, R. W. H., Holdsworth, R. E., Krabbendam, M., Strachan, R. A. (Eds.), Continental Tectonics and Mountain Building: The Legacy of Peach and Horne, 335. *Geol. Soc. London, Special Publication*, 275–292. DOI: http://dx.doi.org/10.1144/SP335.13
69. Black, R., & Liegeois, J. P. (1993). Cratons, mobile belts, alkaline rocks and continental lithospheric mantle; the Pan-African testimony. *Journal of the Geological Society of London*, 150, 89-98. DOI: http://dx.doi.org/10.1144/gsjgs.150.1.0088
70. Carreras, J., Druguet, E., & Griera, A. (2005). Shear zone-related folds. *Journal of Structural Geology*, 27, 1229–1251. DOI: http://dx.doi.org/10.1130/SPE230-p145
71. Dada, S. S., (2006). Proterozoic Evolution of Nigeria. In: Oshin, O. (ed.) The Basement Complex of Nigeria and its Mineral Resources. Petrochemical. Services Ltd. Ibadan, Nigeria. 29 - 44. Retrieved from https://www.scirp.org/reference/referencespapers?referenceid=1425168
72. Ez, V. (2000). When shearing is a cause of folding. *Earth-Science Reviews, 51*(1), 155–172. DOI: http://dx.doi.org/10.1016/S0012-8252(00)00020-9
73. Fitches, W. R., Ajibade, A. C., Egbuniwe, I. G., Holt, R. W., & Wright, J. B., (1985). Late Proterozoic schist belts and plutonism in NW Nigeria. *Journal of the Geological Society of London*, 142, 319–337. DOI: https://doi.org/10.1144/gsjgs.142.2.0319
74. Grant, N. K. (1978). Structural distinction between a metasedimentary cover and an underlying basement in the 600 My. Old Pan-African domain of northern Nigeria, West Africa. *Geological Society of Amer. Bull*, 89, 50-58. DOI: https://doi.org/10.1130/0016-7606(1978)89<50:SDBAMC>2.0.CO;2
75. Key, R. M., Johnson, C. C., Horstwood, M .S .A., Lapworth, D .J., Knights, K .V., Kemp, S .J., Watts, M. J., Gillespie, M., Adekanmi, M .A., and Arisekola, T .M. (2012).Investigating high zircon concentrations in the fine fraction of stream sediments draining the Pan-African Dahomeyan Terrane in Nigeria. Applied Geochemistry, 27, 1525–1539. Retrieved from https://core.ac.uk/download/pdf/9697139.pdf
76. ship to late Pan-African granites. *Mineralium Deposita, 25*(1), 25–33. DOI: https://ui.adsabs.harvard.edu/link_gateway/1990MinDe..25...25K/doi:10.1007/BF03326380
77. Maeder, R. (2014). Complex vein systems as a data source in tectonics: An example from the Ugab valley, NW Namibia. *Journal of Structural Geology*, 62, 125–140. DOI: http://dx.doi.org/10.1016/j.jsg.2014.01.011
78. 78. Matheis, G., Caen-Vachette, M. (1983). Rb-Sr isotopic study of rare-metal bearing and barren pegmatites in the Pan-African reactivation zone of Nigeria. *Journal of African Earth Sciences, 1*(1), 35–40. DOI: https://doi.org/10.1016/0899-5362(83)90029-5
79. McFarlane, M. J. (1991). Some sedimentary aspects of lateritic weathering profile development in the major bioclimatic zones of tropical Africa. *Journal of African Earth Sciences (and the Middle East), 12*(1-2), 267-282. Retrieved from https://www.sciencedirect.com/journal/journal-of-african-earth-sciences-and-the-middle-east/vol/12/issue/1
80. Melcher, F., Graupner, T., Gabler, H.E., Sitnikova, M., Henjes-Kunst, F., Oberthur, T., Gerdes, A., & Dewaele, S. (2013). Tantalum– (niobium–tin) mineralisation in African pegmatites and rare metal granites: constraints from Ta–Nb oxide mineralogy, geochemistry, and U–Pb geochronology. Ore Geology Reviews. Retrieved from https://www.scirp.org/reference/referencespapers?referenceid=1964579
81. Odeyemi, I. B., Anifowose, A .Y .B., & Asiwaju-Bello, Y. A. (1999). Multitechnique graphical analysis of fractures from remotely sensed images of basement region of Nigeria. *Journal of Mining and Geology, 35*(1), 9-21. Retrieved from https://scirp.org/reference/referencespapers?referenceid=200596.