Microstructural and Mineralogical Evolution of the Oke Awon Shear Zone in the Jebba Area, S.W. Nigeria.

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ABSTRACT

The Jebba area of southwestern Nigeria is underlain by metasedimentary and metaigneous rocks which have been intruded by probable Pan-African (ca.600 Ma) granitic rocks. Locally, in the west, these rocks have been tectonised within two N – S trending brittle-ductile shear zones. Granitic mylonites contain elongate quartz ribbons surrounded by finer grained groundmass of microcline, quartz and plagioclase. Metabasic mylonites contain fine-grained hornblende and plagioclase defining the mylonitic, $S_{2,}$ fabric. Locally, the assemblage is epidote, actinolite, albite, and quartz indicating a marked retrogression. Semi-pelitic rocks, the mineralogy contain syntectonically rotated garnets with sigmoidal inclusion trails, fractured and elongated garnet, fine-grained biotite and muscovite, late porphyroblastic muscovite, and locally, minor epidote and chlorite resulting from partial retrogression. The quartzites are marked by microstructures ranging from cataclasites to ultracataclasites.

These observations indicate two generations of shearing, an earlier one under amphibolites facies conditions at deeper structural levels which was locally overprinted by brittle deformation under greenschist facies conditions following exhumation.

(Keywords: Jebba area, southwest Nigeria, Oke Awon shear zone, microstructures, mineralogy)

INTRODUCTION

Major shear zones occur in different tectonic settings and are associated with varying tectonic displacements in the various orogens. Some such as the Puros Shear zone in the Kaoko Belt of Namibia mark large scale transcurrent displacement following transpression (Konopasek et al., 2005).

In the Tuareg Shield of the Pan-African Trans - Saharan Belt several major strike-slip or thrust-slip shear zones separate shield into 23 terranes with their own lithological and structural characteristics (Black et al., 1994). The Central Hoggar made up of four terranes is generally regarded as the northern segment of the Trans-Saharan Belt which extends to the Nigerian basement complex in the south. The terranes are separated by megashear zones (Liegeois et al., 2003) which mark early thrusts associated with collision and later large horizontal displacements of adjoining blocks.

Regional scale, steep, generally north-south trending shear zones have been recognized in the western part of the Nigerian basement complex (Ajibade, 1982; Grant, 1978; Caby, 1989; Odeyemi, 1993; Anifowose et al., 2007). These shear zones have been traced north wards to and correlated with those of the Central Hoggar (Caby, 1989, 2003). These zones are marked by mylonites and cataclasites produced by the shearing of the rocks at different crustal levels (temperatures and confining pressures) and activities of the fluid phase.

This paper examines the microstructural and mineralogical features of various rocks within the earlier deep crustal and the later brittle, major N-S trending shear zones of Oke Awon, Jebba area, S. W. Nigeria (Figures 2, 3, and 5).

GEOLOGIC SETTING

Nigerian basement complex forms the southern part of the Trans Saharan mobile belt (Caby

1989, Ferre et al 2002, Caby 2003) in the Pan-African orogenic belt east of the West African craton (Figure 1). This basement complex comprises Archean and Proterozoic rocks which have been subjected to Liberian (ca. 2700 Ma), Eburnean (ca. 2000 Ma), and Pan-African (ca. 600Ma) orogenic events (Grant, 1970; Oversby, 1975; van Breemen et al., 1977; Fitches et al., 1985; Rahaman, 1988; Dada et al., 1994).

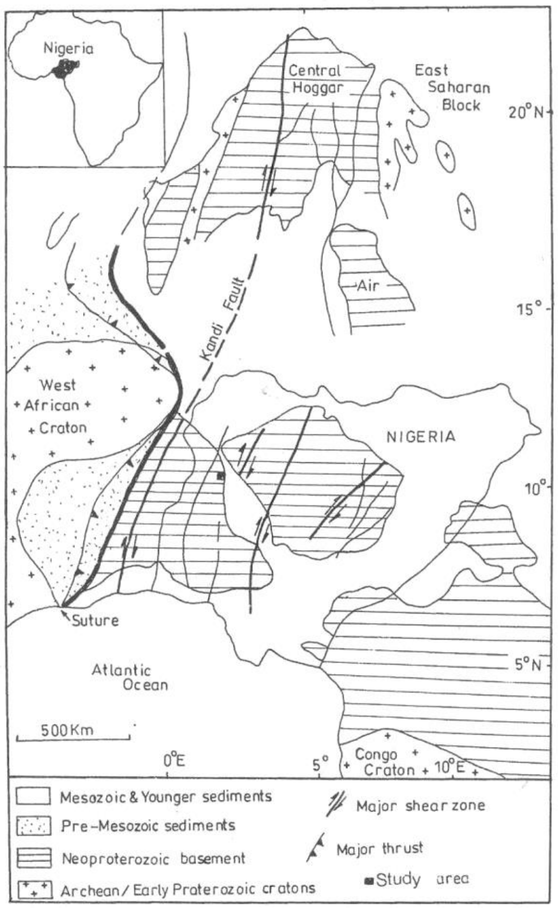

Figure 1: Index map of western Africa showing the location of the study area in the Trans-Saharan mobile belt between the West African and the Congo cratons (after Ferre et al., 2002).

The Jebba area of southwestern Nigeria is underlain by metasedimentary and metaigneous rocks which have been intruded by probable Pan-African (ca. 600Ma) granitic rocks including pegmatites (Figure 2). In the west, Oke Awon area (Figure 3), these rocks have been cut by an approximately N-S trending, steeply – dipping, ductile shear zone, 2-3 km wide, which has been cut and locally reworked by younger, narrow, NNW-trending, brittle shear zones (Figure 3). Because these shear zones also affected granitic rocks of probable Neoproterozoic age, they are believed to be late Pan-African, although the earlier ductile shear zone may have had a more complex history of displacement. In the mylonites, stretching lineations and shear sense indicators show a dominantly subhorizontal, dextral, strike-slip displacement. It has not been possible to determine the amount of displacement because of the lack of appropriate markers.

The major shear zone separates a terrain dominated by migmatitic and augen gneisses to the west from that dominated by metasedimentary rocks including quartz-mica schists and quartzites to the east (Figure 3). Locally, sub-horizontal displacements in quartzites indicate a component of dip-slip motion which could possibly be correlated with low-angle thrusts observed in the Jebba area to the east (Okonkwo, 2006) indicating some crustal shortening. The early, ductile thrust brittle faulting, a relationship common in many orogenic belts where strike-slip movements generally postdate the main phase of thrusting (eg. Konopasek et al., 2005; Oyhantcabal et al., 2010; Passarelli et al., 2011).

Four lithological groups have been recognized in the Oke Awon (Aderan) area (Okonkwo & Folorunso, 2013); and are described briefly below.

Migmatitic Gneiss

This unit crops out in the western part of the area (Figure 2) and comprises a sequence of variably migmatized gneisses with concordant quartzofeldspathic segregations and bands. Locally, it contains augen gneiss intercalations characterized by large feldspar grains in gneissic matrix. Similar augen gneisses in Igbeti area, about 40 km to the west, yielded a Rb/Sr whole rock age of ca 1900 Ma (Rahaman et al., 1983).

Quartzite

This is largely made up of 10- to 15m-thick quartzites which locally contains thin micaceous bands as well as thin conglomeratic layers containing pebbles of white vein quartz.

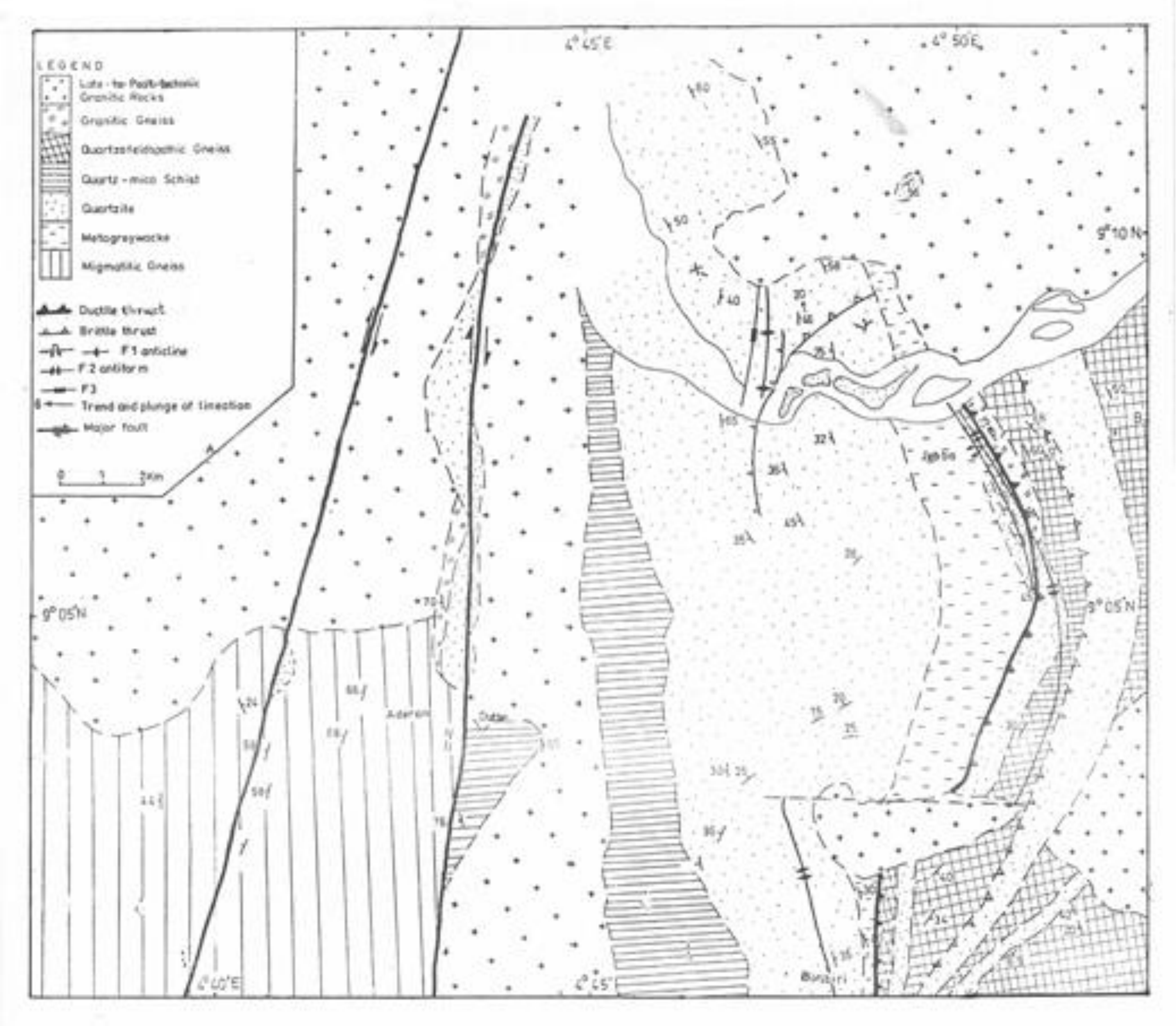

Figure 2: Geological Map of Jebba Area, Southwestern Nigeria (after Okonkwo 2006).

In the Oke Awon area the quartzite occurs as rather discontinuous low ridges (Figure 3) locally cut by shear zones and marked by extensive fractures as well as localized secondary quartz veining. More extensive quartzite ridges occur east of Oke Awon in the Jebba area (Figure 2).

Quartz-Mica Schist

A sequence of quartz-biotite-muscovite schists structurally overlies the quartzites in the area (Figure 3) locally the schists contain thin psammitic bands which may represent original sedimentary layering. They range from dominantly muscovite-rich variety to biotite-rich rocks exposed in a N-S belt in the central part of the area (Figure 2).

Granitic Rocks

Several types of granitoids including granodioritic gneiss, granitic gneiss, granodiorite, medium-grained granite, porphyritic granite and pegmatite intruded the metamorphic rocks in the area (Figure 3). The granitic gneiss often occurs as in inclusions (xenoliths) in the other granitoids and appear to have been deformed prior to the emplacement of the younger granitoids. These granitic rocks have not been dated but similar rocks dated in Igbeti and other parts of southwestern Nigeria have yielded Neoproterozoic ages of emplacement (Rahaman et al., 1983).

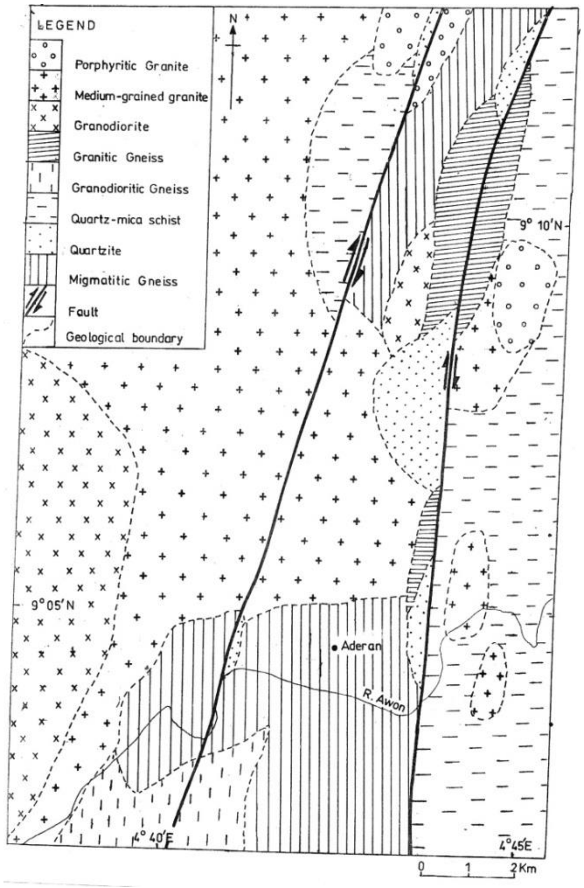

Figure 3: Lithological Map of Oke Awon (after Okonkwo & Folorunso, 2012).

Structural Geology

The metamorphic rocks of Oke Awon area have undergone polyphase deformation involving foliation development, folding and fracturing including faulting (Figure 4a). Outside the shear zone, the first episode gave rise to the development of foliations (S_1) in the quartz-mica schist, quartzite and gneisses, including the migmatitic banding in the migmatitic gneiss.

These foliations generally trend NNW to NNE and dip moderately steeply to the west (Figures 4a & 4b). The second episode involved formation of tight, asymmetrical minor folds in the rocks. The early structural fabrics have been reworked in a ductile shear zone to produce steeply dipping, S_2 shear foliation in the rocks (Figures 4a, 4b & 5a).

In the shear zone, the S_1 foliation, defined by the alignment of the micas in the quartz-mica schist has been reworked in the early, ductile shear zones to an S_2 shear fabric defined by syntectonically rotated garnets with curved, sigmoidal Si inclusion trails (Figure 5b) as well as stretched and pulled-apart garnet grains.

Shear sense indicators in the various rock types show dextral movement in the shear zone (Figure 5a). These were later followed by the formation of the narrow N-S- to NNE-trending brittle shear zones which later, locally, reworked the wider ductile shear zone (Figure 4a). Stretching lineations in the mylonites are generally sub-horizontal, with trends to NNW (Figures 4a & 4b).

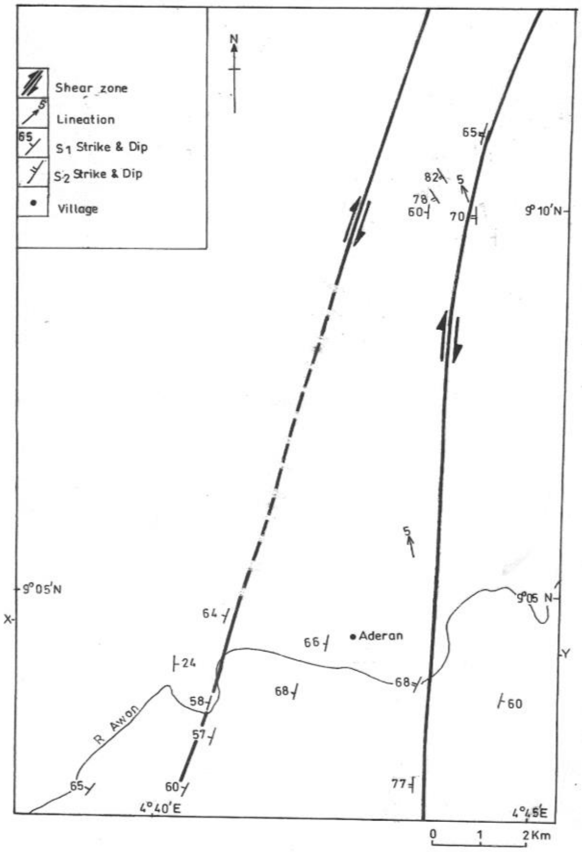

Figure 4a: Structural Map of Oke Awon showing the Orientations of the Deformational Fabrics.

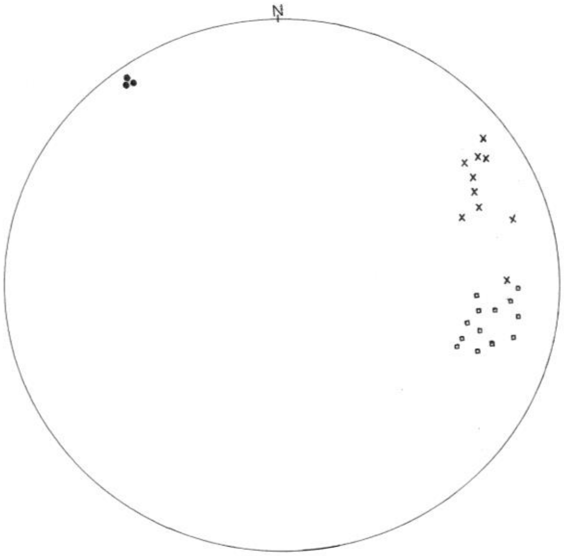

Figure 4b: Equal area stereographic plot of poles to the early, S1 foliations (crosses) and the S2 (shear zone) foliations (squares) as well as the plots of the shear zone lineations (filled circles) in Oke Awon.

Figure 5a: Dextral shear sense (arrows) in sheared migmatitic gneiss indicated by asymmetric augens of quartzo-feldspathic material.

MICROSTRUCTURES AND MINERALOGY

The Oke Awon shear zone, Jebba area, has affected the various rocks differently due to differences in deformation intensity, rates, pressure-temperature conditions (crustal depths), annealing, fluid activity and the mechanical characteristics of the different minerals (Sibson, 1977). These differences are reflected in the various microstructures and mineral assemblages produced in the different rock types at different locations within the shear zone. These features are described and discussed below with respect to the various rock types.

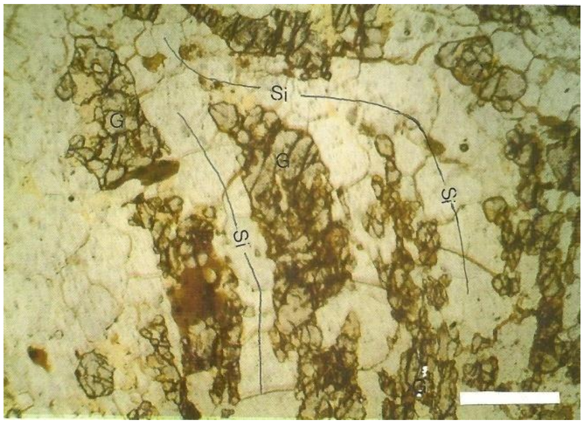

Figure 5b: Photomicrograph of quartz-mica schist showing elongated and pulled apart garnet with curved inclusion trails, Si. Plane polarized light. Scale bar represents 0.5mm.

Granitic Mylonites

The primary mineral phases of undeformed granite are medium-grained (1-5mm) equigranular microcline, quartz, plagioclase and biotite (Figure 6a). Within the shear zones, granites are transformed into mylonitic gneiss composed of relict porphyroclasts of potassium-feldspar within a fine-grained matrix of recystallised quartz and feldspar.

Generally, the mylonite is banded with fine-grained, (<0.1mm), feldspar- and quartz-rich bands alternating with phyllosilicate-rich bands (Figure 6b).The phyllosilicate-rich bands contain fine-grained, (<0.1mm), chlorite, biotite and sericite. Accessory minerals include late-stage muscovite, magnetite, sphene and zircon. In this case, deformation was characterized by crystal-plastic processes (White et al., 1980) with insignificant mineralogical transformation. The most obvious change is the production of strong shear fabrics and grain size reduction (Figure 6b) compared to granites outside the shear zone.

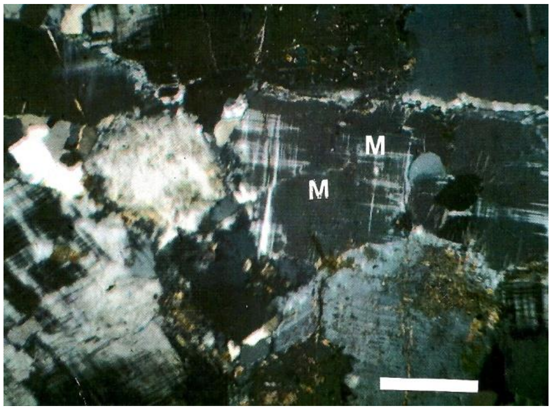

Figure 6a: Photomicrograph showing equigranular microcline crystals (M) in undeformed granite. Crossed polars. Scale bar represents 0.5mm.

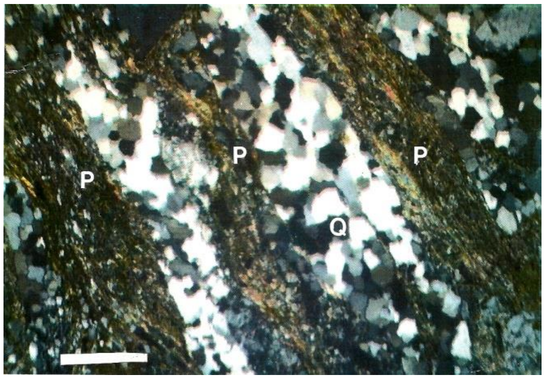

Figure 6b: Photomicrograph showing very fine-grained feldspar and quartz-rich bands (Q) alternating with phyllosilicate-rich ones (P) in granitic mylonite. Quartz grains show evidence of grain boundary migration. Crossed polars. Scale bar represents 0.5mm

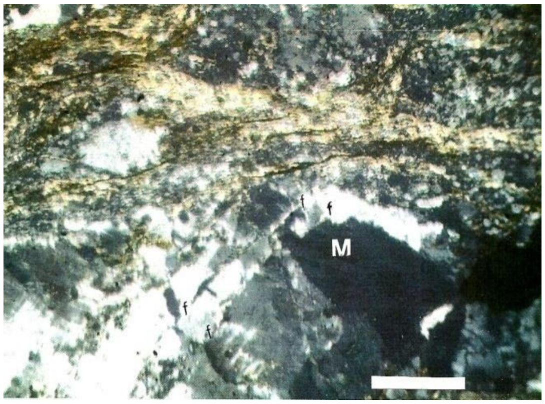

Figure 6c: Photomicrograph showing a microcline porphyroclast (M) with intracrystalline fractures-(f-f), oblique to the foliation, and displaced fragments in the granitic mylonite indicating a dextral sense of shear. Crossed polars. Scale bar represents 0.5mm.

Locally an intensely sheared granitic mylonite is marked by ovoid microcline porphyroclasts surrounded by thin quartz ribbons composed of recrystallised, polygonised quartz grains (Figure 6c). Fine grains of chlorite and leucoxene(<0.05mm) after biotite are also finely interbanded with the quartz ribbons along with some sericite and epidote. Such marked retrogression was probably associated with the introduction of a hydrous fluid and some reaction softening. Microcline porphyroclasts show deformation bands and development of flame perthites. Some microcline porphyroclasts contain intracrystalline fractures with fragments displaced obliquely to the mylonitic foliation (Figure 6c). Fracture orientation indicates porphyroclast rotation under non-coaxial strain with a dextral sense of movement (Passchier &Trouw, 2005).

Metabasic Mylonite

The primary minerals in unsheared amphibolites are hornblende and plagioclase. Within the shear zones this assemblage is transformed into fine grains (<0.1mm) of strongly aligned hornblende porphyroclasts rimmed by fibrous actinolite, epidote, albite as well as minor biotite and sericite (Figure 7a). At higher strains rocks are marked by very fine-grained (<0.05mm) actinolite, epidote, albite, chlorite and quartz (Figure 7b). Locally these zones are marked by late shear fractures with minor contractional displacement. Formation of this retrograde assemblage intense was associated with some hydration (Brodie & Rutter, 1985). Reaction softening or reaction enhanced ductility (White et al., 1980) as well as strain-enhanced reactivity were probably important processes.

Semi-Pelitic Schists

Unsheared semi-pelitic schists contain biotite muscovite, quartz, garnet and plagioclase. In sheared rocks, the new assemblage consists of stretched, shear –fractured, pulled-apart and shear-rotated garnet grains (Figure 5b) as well as fine-grained (<0.05mm) biotite and muscovite grains. The growth of some chlorite and epidote as retrograde replacements of biotite and plagioclase, respectively, indicates that some reaction – enhanced ductility contributed to strain softening.

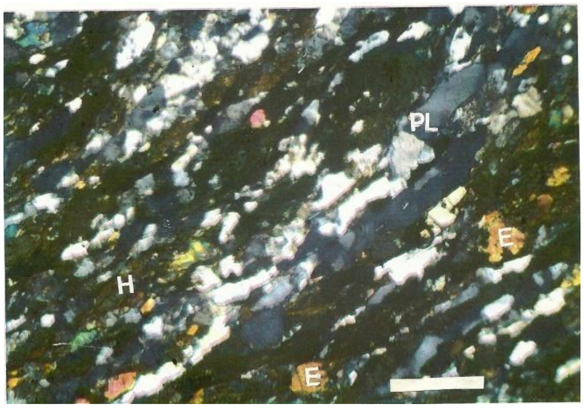

Figure 7a: Photomicrograph of the metabasic mylonite showing strongly aligned hornblende (H) and plagioclase crystals (PL) overgrown by epidote (E) . Crossed polars. Scale bar represents 0.5mm.

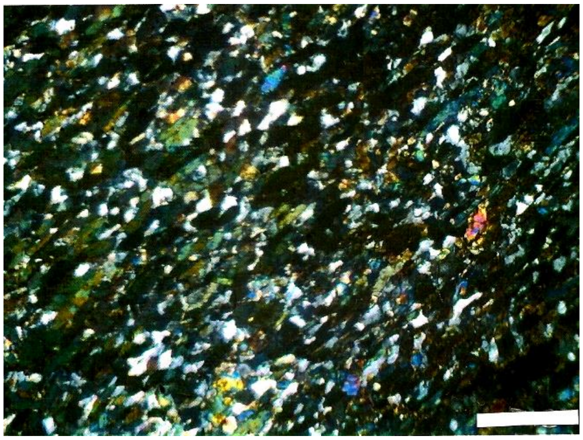

Figure 7b: Photomicrograph showing a more intensely sheared metabasic mylonite with very fine grains of actnolite, epidote, albite, chlorite and quartz. Crossed polars. Scale bar represents 0.5mm.

Quartzites

Outside of the shear zone, quartzite is generally massive and coarse-grained with grains showing undulatory extinction as a result of lattice strain. At the level of exposure, quartzites have been affected by varying degrees of cataclasis ranging from cataclasite to ultracataclasite. Cataclasites are characterized by a few angular porphyroclasts (Figure 8a) surrounded by fine-grained quartz. At advanced levels of grain size reduction ultracataclasites are formed. Fine-grained opaque minerals (iron oxides) may occur locally within the groundmass. The ultracataclasite is extensively cut by late, thin, (0.1- 2mm), quartz veins (Figure 18b). The quartz grains in the veins are coarser and are polygonised, showing very little or no strain. These veins document a late (post-cataclastic) silicification associated with the focussing of siliceous fluids along channels produced by the advanced cataclasis. Locally, muscovite grains are observed in these veins.

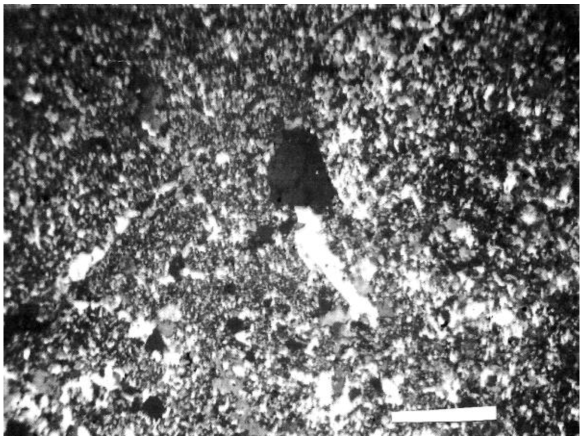

Figure 8a: Photomicrograph showing cataclastic quartzite with very fine grains of quartz. Crossed polars. Scale bar represents 0.5mm.

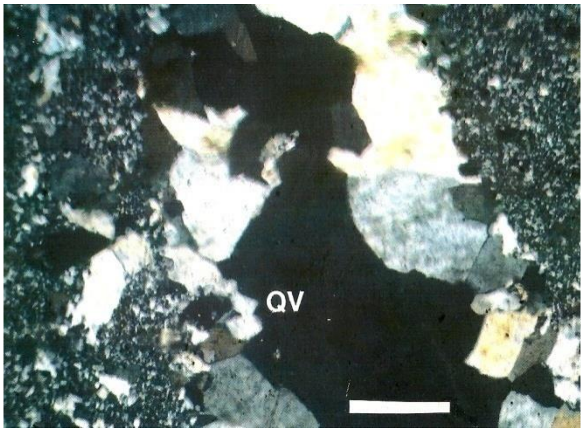

Figure 8b: Photomicrograph of ultracataclastic quartzite with very, very fine grains of quartz which have been cut by a late, thin quartz vein (QV). Crossed polars. Scale bar represents 0.5mm

DISCUSSION

The microstructural and mineralogical changes record the geodynamic and thermal history of the shear zone. In the granitic rocks two generations of shearing can be recognized- an earlier one marked by crystallo-plastic, ductile deformation mechanisms under amphibolite facies conditions which have been locally reworked by brittle shear zones developed under greenschist facies conditions.

Early deformation by crystal plastic processes involved grain size reduction through dynamic recrystallization to produce mylonites. At lower temperatures, neomineralisation associated with retrograde metamorphism and reaction-induced softening was important (Brodie & Rutter, 1985). These were associated with strain-enhanced reactivity in the mylonitic rocks.

Later, cataclasis gave rise to enhanced porosity and permeability which promoted fluid influx and the development of greenschist facies mineral assemblages in the rocks. The evolution from dominantly crystal plastic to largely cataclastic deformation mechanisms was in response to progressive deformation of the rocks, from the ductile processes which operated in the hotter, deeper levels of the crust to the brittle processes which were active in the colder, shallower levels as a result of exhumation during the later phases of the Pan-African tectonism.

Several works on the Nigerian basement complex have documented the occurrence of some major lineaments defined by major transcurrent shear zones especially the Ifewara Fault system in the southwest and Zungeru Shear belt in the northwest (Odeyemi, 1993; Anifowose et al., 2006) which have been linked up on remotely-sensed imagery. The Oke Awon Shear zone occurs in the intervening region between these two major lineaments indicating that these lineaments represent major shear zones which played a very important part in crustal displacements and aggregation during the later stages of the Pan-African orogeny (Caby, 1989; 2003).

CONCLUSIONS

The shear zones in Oke Awon, Jebba area, are part of the major system of approximately N-S trending shear zones which cut the Precambrian rocks of the Nigerian basement complex during the latter stages of the Pan-African orogeny. These steep, ductile and brittle shear zones were developed within granitic rocks, amphibolites, semi-pelitic schists and quartzites in the area during NeoProterozoic times. Locally, the ductile shear zones are cross-cut by brittle shear zones indicating that ductile deformation preceded brittle faulting; this is also reflecting a change in the deformation mechanisms as rocks which were deformed under ductile conditions at presumably greater depths were later subjected to cataclasis at shallower crustal conditions during tectonic uplift and exhumation.

Cataclasis was accompanied by enhanced porosity and permeability in rocks thus favoring fluid influx and the development of a greenschist facies assemblage from an amphibolite facies protolith (e.g., in the amphibolite). High fluid pressures in turn promoted cataclasis and cataclastic flow.

Mesostructural and microstructural as well as petrographic evidence presented here indicate two generations of shear zones in the study area, an early ductile shear zone locally reworked by localized brittle shearing. The early ductile shearing occurred at amphibolite facies conditions presumably at deeper crustal levels whereas the later brittle deformation took place at greenschist facies conditions at presumably upper crustal levels. The evolution of deformational mechanisms from ductile shearing to localized brittle shearing along N to NNE-trending faults was associated with late orogenic uplift and exhumation following oblique convergence during the Pan-African orogeny.

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