Research article

Pan African Nappe system: evidence of thrust structures from Okemesi, southwestern Nigeria

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ABSTRACT

The Okemesi area, southwestern Nigeria, is part of the Ilesha schist belt and play host to the Okemesi fold belt and the Ifewara Shear Zone. Nappe structures had been proposed for some parts of Southwestern Nigeria without very clear meso or micro structural evidence. This study provides a lot of new structural evidences to substantiate the inferred Nappe structures within the Okemesi fold belt. Mapping of the Okemesi fold has been hampered by thick vegetation in the past. However, a major deformation zone was exposed by the recent landslide activities in the area. Structures and lithologies exposed by the landslide were studied and structural features that are typical of transtensional and transpressional settings were observed. This paper presents the result of the systematic filed mapping which revealed the complete, fold transposition, elements of internal strain such as cleavages and mineral lineation, intrafolial folds, flexure slip, sheath, recumbent and conjugate kink folds, winged porphyroblast, faults (low angle reverse faults, dextral faults, normal faults), ramp and flat structures, etc. The characters and the geometry of the observed thrust structures make it an important piece of evidence, not only to infer the tectonic events in the area, but also to constrain the timing and nature of movement associated with thrusting in the area.

1. Introduction

The Okemesi area, southwestern Nigeria, is part of the Ilesha schist belt (Figure 1a, b and c) and also play host to the mega Okemesi fold belt and the Ifewara Shear Zone. This area is geologically and structurally important due to the presence of thrusts and close similarity with structures in the Taurerg Shield (Figure 1a) which probably suggest a southern extension of the shield. The extent of the nappe structure within southwestern Nigeria has been speculative. The result of this study adds strength to the presence of a large nappe structure in Southwestern Nigeria, has earlier proposed by Caby and Boesse (2001) based on regional structural analysis and petrographic studies. However, Caby and Boesse (2001) failed to relate the presence of the horizontal to gently foliations within southwestern Nigeria to the formation of the nappe structure, arguing that such could have formed during an extensional regime marked by post-collisional gravitational collapse rather than the transpressive regime that is common in most parts of the Taurerg Shield. This paper present new observations and evidences to prove that the nappe structure extends to the northern parts of the Okemesi fold belt. Although, field observation in this area is greatly hampered by inaccessibility problem due to thick vegetation. A major deformation zone was exposed by the recent landslide activities in the area. The geo-structural pattern exposed by the landslide was studied and related to possible thrusting in the northern part of Okemesi area. Nappe structures had earlier been proposed for the Ife – Ilesha area (southwestern part of the Ifewara Shear Zone) (Figure 1b). The newly observed structures in the northern part of Okemesi (northeastern part of the Ifewara Shear Zone) are synchronous with thrusting.

2. Regional geo-structural pattern in Southwestern Nigeria

2.1. Basic tectonic units

The study area is part of the Nigerian Basement Complex, which is hosted by the Pan African mobile belt, located within the West African and Congo Craton and south of the Taurerg Shield (Gasquet et al., 2008 (Figure 1a)).

The Nigerian Basement Complex lies within the reactivated convergent boundary of West Africa craton and the Pharusian (Obaje, 2009). At least four major deformational episodes have affected the Basement Complex rocks, which are made up of four petro-lithologic units, namely the Migmatite–Gneiss Complex (Pan African to Eburnean age), the Schist...
Belt (Upper Proterozoic age), the Older Granites (Pan African age) and the Undeformed Acid and Basic Dykes (post-Pan African). The nappe structure in Ibadan axis is characterized by upright, open folds and strike-slip tectonics of possible regional extent while recumbent folds are the dominant structures in Ife–Ilesha area (Caby, 1989) and Igarra area (Omitogun et al., 1991). Regional size nappe structures were reported at Ikare and Okene area by Annor and Freeth, (1985) and Annor (1995). A t Ikare crystalline nappe of migmatitic grey gneisses around Okene was reported from the analysis of satellite imageries. The metasediments are overlaid by gneisses, similar to those of the Igarra sequence. The possibility of another nappe of supracrustal material thrust above gneisses around Lokoja was reported by Ajibade and Wright (1989). Such Pan-African nappes indicate a significant crustal thickening in parts of southern Nigeria during the early Pan-African collision (Boullier, 1982; Caby, 1987) and might be related to the stacking of the crystalline units in response to NNE-SSW compression of the Archean palaeocontinent, west of the Nigerian Shield.

Thrusting in the deep-water Niger Delta area (southwestern, Nigeria), consist of imbricate and shear fault kinematic systems within a thick sedimentary succession, with either single or multiple basal detachment (Corredor et al., 2005).

2.2. Regional structural patterns

The structural style of the schist belts within the Nigerian shield is depicted by N-S upright folding with expanding lineations (Turner, 1985) indicating a compressive tectonic style similar to the description in many parts of the Tuareg Shield (Boullier, 1982; Caby, 1987). Liègeois et al. (2003) and Dada (1998) identified a northeastern vengeance for the main stage of deformation in the LATEA terrane of the Tuareg, can be associated with the 640-620 Ma collision. The movement of some cratons within the African plate (the West African Craton, the Congo Craton and the Saharan Metacraton) initiated this intracontinental deformation (Liègeois et al. 2000, 2003). This mega collisional orogeny implies that the thrust around Ife-Ilesha may extend downwards and merges with the granulite at depth. This is similar to the 565 Ma Nappe structure on the Congo Craton (Nzenti et al., 1988; Rolin, 1995).

2.3. Associated sedimentation

The schist belt consists of low grade metasediments and metavolcanic rocks (Ehuzee, 1988). The inner core of the Okemesi fold belt is made up of a metasedimentary assemblage which is post Archean. These
metasediments (massive quartzite, quartz schist and mica schist) have a sedimentary protolith from arkosic sediments with contribution from granitic rocks (Okunlola and Okoroafor, 2009). The quartz schist occupies the innermost core of the Okemesi fold.

2.4. Metamorphic associations and magmatism

The Nigerian shield is made up of a polycyclic Archean age basement with large sequence of syn Pan African metamorphic thrust sheets cover and mineral assemblage of green-schist to amphibolite facies. The presence of Pan-African charnockites and late stage magmas in the Nigerian shield resulted from the anataxis of the descending crust, just on the wane of crustal thickening and regional extension. The anatexic basement in the Tuarag Shield exhumed through elongate domes flanked by north-south trending syn-metamorphic faults. Black and Liégeois (1993) stated that both the passive margin at the western part of the craton and the eastern colliding continents contributed to the thickening of the eastern boundary of the West-African craton. The emergence of a proto-ocean in the frontal zone of collision between the Togo-Benin headland (of the West African craton) and the Nigerian shield is negligible (Duda and Rahaman 1995; Cottin et al., 1999; Black and Liégeois, 1993; Paquette et al., 1998).

3. Structure and geology of the study area

The quartzites of the Effon Psmamite Formation dominate the study area. They occur mostly as massive quartzites and quartz schists. The Effon Psmamite Formation, which extends to Okemesi (Okunlola and Okoroafor, 2009) is a belt of quartzites, quartz schist and granulites, which occurs largely east of Ilesha and extends NNE-SSW over a 175 km distance. Most of the folds in the study area result from the interaction of Shear Zones and penetrative foliation planes. Such planes are bent parallel to the shear plane. Mechanical instabilities followed by folding intensified rock shear (Ramsay, 1980; Skjernaa, 1980) i.e. the folding and shearing happened spontaneously. Passive shearing of pre-existing folds accompanied by progressive deformation accounted for the rotation of limbs (Flinn, 1962; Talbot, 1970; Sanderson, 1973; Escher and Watters-son, 1974; Ramsay, 1979; Skjernaa, 1980).

The structures that are related to thrusting in the study area includes folds, strike-slip faults, reverse faults, etc. Some of the folds related to nappes are intensively sheared and buckled until they rift apart.

4. Methods

The outcrops exposed by the landslide in northern Okemesi fold were carefully observed. Measurement of strike and dip values of outcrops and planes were recorded and later analyzed. The orientation of lineation, joints, fold axis, foliation, cleavages etc. were recorded. Composition and distribution of minerals for easy characterization of host rocks were carried out.

The presence, abundance and composition of minerals, such as mica, chlorite etc. which has a significant influence on mineral alignment and parting was documented. This work also constrains geological the overprinting features; this enhanced the systematic interpretation of the deformational stages. Structural analysis of joints, lineations, foliations, cleavages and other field data were carried out by plotting the data on stereonets and rose diagrams. Cross sections showing both the structural and geologic relationship between existing rocks were constructed.

5. Results

Structures mapped in this area includes foliation, cleavage and mineral lineation, features indicating shear sense: winged porphyroclast, lineation and syntectonic vein; intrafolial fold, flexure slip folds, shear folds, kink folds, recumbent fold, reverse fault.

5.1. Foliations, cleavages and other fabrics

Foliation crenulation or slaty cleavage and axial plane cleavage (Figure 2a and b) are present in the study area. This strong shape fabric is more common in the northern part than in the southern part, an indication of the presence of initially more phyllosilicate rich material in the northern part (Figure 2a). The foliation displayed on the outcrop is mainly schistose, defined by the similar orientation of mica in the quartz-schist. Crenulation cleavage is intense with a NW-SE trend parallel to the foliation trend and dips strongly to the west. On careful inspection of the outcrop, it would appear that two slaty cleavages are present (Figure 2c and d). Figure 2e indicates an initial sinistral sense of motion that was later superimposed by the more dominant dextral shear in Figure 2f due to reorientation of principal stress axes.

Mineral lineation formed by the similar orientation of both individual mineral grains or collection of mineral grains is indicated in Figure 2e. The lineations have sinistral sense of motion in most cases.

5.2. Shear sense indicators

5.2.1. Winged porphyroclast

Winged porphyroclast indicating dextral shear sense and northeast trend, related to D3 nappe transport direction and probably the most recent motion along the Ifewara Shear Zone was observed in the field and shown in Figure 2f. The upper part of the winged porphyroclast shows an S-shaped transected fold with intersecting cleavages.

5.2.2. Complex syntectonic vein array

These quartz veins are oriented differently, irregular in shape and crosses each other. The quartz veins penetrate deep into the rock in irregular arrays, often a few meters across. The vein arrays are of two types. Type I quartz veins contain massive white quartz while Type II are made up of fibrous quartz. The vein types and their morphology are shown in Figure 3a.

5.3. Low angle reverse fault

A minor low angle reverse fault (Figure 3b) otherwise known as thrust fault was observed. The fault formed by the displacement of quartzite over a recent quartz vein. The angle between the fault plane and the horizontal at the fault tip is 13°.

5.4. Intrafolial

Intrafolial folds are tight syn-shear overturned folds formed by ductile shear (Figure 3c). This is an evidence of fold transposition typically associated with thrusting.

5.5. Sheath fold

The sheath folds are formed from continuous shearing of preexisting folds which result into slight rotation or curvature of the initial fold hinge, (Ramsay, 1980) or double plunging folds (Williams and Zwart, 1977; Minnigh, 1979; Skjernaa, 1989). Sheath folds that occur at the interior parts of the Shear Zone often form and grow along dominant foliation planes within the Shear Zone (Figure 3d) (Carreras et al., 1977; Rhodes and Gayer, 1977; Bell, 1978; Quinquis et al., 1978; Henderson, 1981; Jiang and Williams, 1999).

The superposition of at least three generations of folds formed the sheath fold in the study area. The stretching lineation is at a high angle to the plane of the picture. Width of view is 20 cm.

5.6. Recumbent fold

Minor folds occur within fault-bounded layers (Figure 3e). The hinge zone of the minor folds is either straight or slightly curved, the
The recumbent fold has the axial plane parallel, to the foliation trend (Figures 3d, e, f and 4f, g). It is a sideways closing neutral structure that is neither a synformal nor an antiformal fold. A genetic link can be established between thrusting and folding cause most of the earlier folds were refolded by latter deformation thus the axial plane dips are not relevant because of the constant refolding. The limbs of the recumbent fold were later refolded to form inclined and upright fold (Figures 3d, e, f and 4a, b, c).
5.7. Flexure slip

Flexural-slip is observed within quartz-schist layers (Figure 3e). Bending of original rock strata or foliation planes in response to the movement of the underlying rock results in flexure slip especially in a compressional regime (Figure 3e) (Price and Cosgrove, 1990; Gross et al., 1997).

5.8. Passive folding

Passive folds form when the rheology is uniform within the layer that is affected by the folding (Figure 4c). Variation in displacement velocities along the boundaries of two layers is caused by heterogenous strain within the boundaries. Unexposed Nappe structure may be exposed along a deformation zone if the boundary condition changes. This result is the formation of similar folds within the affected layers. This type of folding is common in Nappe systems with irregular basal contact (Merle, 1998).

5.9. Conjugate kink folds

Kink bands occurring as a conjugate pair (Figure 4d) were observed in the southern part of the study area. These sets developed late in the tectonic history and possibly developed from flexure-slip fold mechanism. Kink folds are identified as conjugate folds with inclined axial planes (Anderson, 1987). Such folds are associated with thrust zones; they are widespread in most fold-mountains belts around the world. Kink folds in most places have been reported to represent the final period of deformation in multiple deformed areas.

6. Interpretation

6.1. Deformation stages and overprinting relationships from field observation

D1 is represented by tight to close East-West to ENE-SSW trending recumbent folds, while D2 is marked by the development of both axial planar S2 foliations, cleavages, lineations and folds at various scales. An overprinting relationship is observed between S2 and F1. F1 is truncated by S2 foliation as indicated in Figures 3b and 4c. Most D1 structures are transposed by subsequent deformations (Figures 3f and 4a). S2 foliation trend is subparallel to F2 fold axial plane (Figures 3f and 4a) and are restricted more to the hinterland on the field sketch (Figure 5) where more ductile shearing is taking place. The stereogram of the major fabric elements (Figure 5a, b, c and d) show the prominent trends and a generalized cross section of the area (Figure 5g). Figure 5g and h shows the lithologic and structural disposition of the study area in detail.

Quartz vein within weathered quartzite, (Figure 2e) the lineations have a sinistral sense of motion, while the winged porphyroclast (Figure 2f) shows a dextral shear sense. Thus indicating an earlier sinistral motion that was later superimposed by the more dominant dextral shear in (Figure 2f) due to reorientation of principal stress axes.

6.2. The significance of the Ifewara Shear Zone, the Ifewara-Zungeru fault, the recumbent folds and shear band to thrusting in this area

Ifewara fault is a part of the 550 km Ifewara – Zungeru mega fault that extends beyond Nigeria to the Niger republic (Odeyemi et al., 1999: Kolawole and Anifowose, 2001). This megafault is a NNE-SSW trending series of faults with ductile dextral movement (Kolawole and Anifowose, 2001). Part of Ifewara Shear Zone described by Caby and Boesse (2001), is the south-western and eastern part of the current studied area. This area is made up of both aluminous granite, mica schist, pegmatite and Archaean gneisses. Horizontal and sub-horizontal foliations in the Archaean gneisses are delineated by the leucosomes and clasts of feldspar. These are similar to the recumbent folds in the north-eastern part that is defined by the presence of minor folds in quartz schist and folded quartz veins. Shear bands in schists, indicate north to northeast directed movements. The onset of early dextral movements and the last recorded motion along the steep Ifewara Shear Zone occurred at the same time.

The Okemesi area lies within the north-eastern part of the Ifewara Shear Zone. The Shear Zone was formed due to shearing activities of late Precambrian times (Odeyemi, 1993). Interpretation of remotely sensed...
imageries, shows a general recumbent folding in the area (Fagbohun et al., 2017). This Shear Zone hosts the 250 km, NNE-SSW trending Ifewara fault. The Ifewara fault is a mega lineament that is connected to the Atlantic fracture system (Hubbard, 1975; Burke 1976; Adepelumi et al., 2008). Ilesha schist belt rocks on adjacent sides of the fault shows pronounced age difference. The western part consists of volcano sediments of post Archean age (Okunlola and Okoroafor, 2009). These contrasting lithologies can be separated into two structural units (Hubbard, 1975; Ako et al., 1978; Folami, 1992; Odeyemi, 1993) that is possibly associated with the growth of recumbent fold. West of the Ifewara Shear Zone, the region consists of large basin and dome structures. Studies revealed that synclines are found in the footwalls of thrusts and overturned asymmetric anticline in the hanging wall (Potts, 1983; Merle, 1998). Also, sutures with dextral movement occurred along the Ifewara transcurrent fault zones (which has been interpreted as a back-arc marginal basin by Rahaman (1988) and east-verging nappes by Caby and Boese (2001)). The younger stage of Ifewara Shear Zone movement is marked by a renewed northward displacement, possibly with dextral strike-slip displacement.

A close observation and analysis of the Okemesi Fold limbs on Google satellite terrain image (Figure 1c) show displaced ridge axes and splitting of a presumed single ridge into two (fault splays) on the western limb, with subsequent eastward curving on the adjacent eastern limb of the same fold. The first splitting of the ridge occurs southwest of Okemesi town. It is marked by the separation of the main N-S trending limb into two with a small rotation towards the NE. The second fault is observed around Esa-Oke while the third occur around Efon Alaye. The adjacent limb around these areas is marked by several E-W trending faults with some displaying strike-slip motion (Figure 1c). These features suggest an extensional regime especially where the splitting occurred. The Ifewara Fault splays into two around Ilesha area with an acute angle (less than 30°). However, the splay angle noticeably increases or widens southwards, suggesting a bilateral growth in length as well as a lateral extension of the two faults. These observations are in line with a possible lateral growth or long strike extension of several cm/year as suggested by Perrin et al. (2015), (and references therein) from the analysis of crustal faults, even though the process of growth was not fully explained.

7. Discussion

The field observation and structural analysis show that the rocks in the area have suffered at least three types of deformation D1, D2, and D3. The first deformation (D1) occurred concomitantly with the formation of close to tight recumbent folds with interlimb angles of less than 32°. D1 episode is marked by foliation parallel to sedimentary bedding (provides a preexisting mechanical anisotropy along which faults propagate). The regional, steeply-dipping foliation (S1), is defined by the development of schistosity and cleavage (Figure 3a and b). Some of the cleavages are shallow dipping axial planar cleavages S2 while some are folded as F3 (Figure 2). E-W foliation trends are common in the metasedimentary rocks, which are marked by the similar orientation of micaceous minerals (Figure 5). Measured deviation from the horizontal plane (i.e. the amount of dip) ranges from 60° to 88°.

The second deformation (D2) is associated with ductile shear deformation and refolding of the limbs of the F1 folds and S1 foliation, which developed, asymmetrical, open to tight to isoclinal minor folds and overturned folds (Figures 3c, d, e, f and 4a, b). The third deformation (D3) initiated as ductile deformation and later developed into brittle deformation in the lithological units which are characterized by several joint sets and faults example is the normal fault that forms the Horst and Graben structure shaped by the landslide (Figure 2). The initial D3 ductile deformation produced a series of planar to curvilinear, sigmodal foliation with NE-SW to E-W orientation and modification of the F2 fold. The last stage of the D3 deformation resulted into fracturing and displacement evidenced by the development of normal faults, strike-slip faults (Figure 5), joints and kink folds (Figures 2, 3, and 4, 4d). The opposite shear sense observed in the shear sense (Figure 2e, f, Figure 3 and Figure 5) can be attributed to either a change from ductile to brittle deformation phases, or a reorientation of the principal stress axes or an indication of fault separation. The two recent landslide exposures at the Northeastern part of the Okemesi Fold belt reveal a shallow Graben and Horst geometry formed from adjacent normal faults. It is possible
that these normal faults are continuous at depth/or may be attached to a basal detachment that cuts down through the crust and probably cuts deeper as a discrete Shear Zone. The basal detachment may be acting as a slip surface for the new generation of normal faults. It is also possible that the basal detachment is connected with the mega Ifewara shear fault. These recent structures deforming the northeastern part of the Okomesi Hill support the continuity, at present, of a regional N–S trans extensional structures, creating series of Horst and Graben, strike-slip faulting (Figure 5), and shear related folding.

The thrust plane is not totally exposed within the mapped area (Figure 5), but maybe inferred from the attitude of the foliation/deformed structures and changes in topographic slope. The sense and direction of displacement of the thrust based on the analysis of mapped internal strain elements is East-West. The observed deformations are likely due to the interaction of current tectonics and previous deformations.

Systematic traces and interpretation of the axial plane of folds revealed at least 4 (four) generation of folds (Figures 3f and 4a). The last being the observed conjugate fold, which probably represent the last stage of folding where folds tend to undergo brittle deformation.

Field observation presented here indicates that the minor folds might have developed by flexural slip folding. Flexure slip movement along bedding is probably the dominant fold mechanism. The development of thrust fault may be related to the exposed recumbent folding. Thrust–tip passage is usually initiated by rock folding in recumbent fold nappes. Fold mechanism may change due to lateral transmission ease. In which the fold propagation length will be determined by the lateral extension of the thrust plane. Long thrusts with large displacement develop when the folds are able to propagate without much resistance. However, the propagation may be restricted to shorter thrusts (as indicated in the mapped area) where many more thrusts exposures are necessary to yield the total displacement required by the thrust belt (Potts, 1983). It is also possible that the main thrust plane might be restricted to the inner arc of the Okemesi megafold along the NNE-SSW trending Ifewara fault which is connected with the Atlantic fracture system according to Hubbard (1975), Burke (1976) and Adepelumi et al. (2008). The remnant mafic/ultramafic bodies in many parts of the Nigerian Shield (probably represent an oceanic assemblage as proposed by Rahman (1988), might have been transported such thrust planes. Also, if the slip rate along the Ifewara fault exceeds the rate of fault tip propagation, the fault will be blind and will only propagate through the folds, as observed in the studied area. However, the splitting of the ridges, the synchronous curving of the adjacent limb where the ridge splits, spaying of Ifewara fault (in the south) to form Iwaraja fault (Figure 1b) and other smaller faults are all evidences of possible growth and extension along the Ifewara Fault. The growth and extension, normal faulting and strike-slip movements and subsequent landslide occurrence in this area imply active tectonics. Lots of well-polished rock samples were released during this landslide event (Bamisaiye, 2019), this further confirms motion along fault planes in the area. This may be due to periodic slip events along the fault planes. Investigation on possible indications of past seismic slips is ongoing.

8. Conclusions

The study area though small in extent (compared with the size of the Okemesi mega fold) provides some evidence of thrusting, based on the authors’ interpretation, the local structural development within this area is summarized below.

A possible sequence of events in the study area

i. Regional development of recumbent folds
   ii. Development of minor recumbent folds
   iii. Refolding of earlier folds to form overturned, inclined and upright folds and folding of all structural fabrics (foliation planes, lineations, cleavages)
   iv. Layer parallel thrusting
   v. Formation of conjugate kink folds
   vi. Development of extensional structures such as normal faults, strike-slip faults, ramp and flats/duplexes. This may also indicate the possible extension/lateral propagation of the thrust.

In conclusion, the authors suggest a continuous mapping along the two flanks of the Ifewara fault, in order to unravel the contentions surrounding the clear understanding of the Nappe system in Nigeria.

Declarations

Author contribution statement

Bamisaiye Oluseyi A: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Ajala Peter T: Performed the experiments; Contributed reagents, materials, analysis tools or data.

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Data included in article/supplementary material/referenced in article.

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The authors declare no conflict of interest.

Additional information

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