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Paleo and Neo Tectonic Evolution of Some Basement Complex Rocks

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Abstract
The Okemesi fold belt is an antiformal structure made up of massive quartzite and schist in southwestern Nigeria was investigated in order to quantify the local principal stress orientations and present day geometry of the rocks affected. This study describes both the past and active deformation and regional structural development. For the local stress orientation, inversion of seventy-five microtectonc data collected at nine sites, where a total of four local stress states were revealed. The criteria used to establish the local paleostress fields include cross-cutting striations, sigmodal tension gashes, micro faults, conjugate shear fractures, joints, pre and post folding stress state. Four principal deformation structures at both local and regional scale have been recognized: (1) sheared and folded structures (2) thrust fault (3) normal fault and (4) strike-slip fault. It indicates that the Okemesi fold belt of covers area of about 132 Km experienced a complex history of tectonics initiated by variable periods of transpression, stress regimes of contraction, shearing and is currently undergoing extension. The paleostress analysis shows: (1) compression in an NNE direction as inferred from both the fracturing and strike-slip faults; and (2) the presence of N-S and E-W extension billeted by normal faulting.

*This study describes both the past and active deformation and regional structural evolution of the Okemesi belt and Ifewara fault from both field mapping and geometric analysis of mega structures.

Keywords: *Tectonic evolution; paleostress; kinematic analysis; neotectonics; shearing; Ifewara Fault; Fold Buckling; transpression; schist belt.*

Introduction

The earth crust manifest stress in many ways, stress controls the formation of geological structures (such as fractures and folds), the movement of plates, earthquakes and plate tectonics (Xu 2004). Determination of stress orientation is achieved from fault slip vectors and other features that indicates the sense of movement in rocks (Michael 1984; Angelier 1994; Doblas 1998; Delvaux and Sperner 2003). Paleo stress analysis deals with the determination of past stress orientations/directions that resulted in the present structural geometry in rocks and their tectonic significance. Paleo stress analysis is also important in structural evolutionary studies especially in brittle rocks using fault slip data since stress and faulting are directly related. Fault Analysis of stress field that induced motion/slip on fault plane by determining the orientation of slip either directly from fault slip surface or from the focal point of earthquakes (Etchecopar et al. 1981; Angelier 1994; Kim et al. 2004; Fossen 2010; Lacombe 2012). It reveals the relative chronology of different phases of deformation and kinematics of such rocks. This study is part of an ongoing research to collate data on fault slip distribution, damage associated with fault and fold displacement and propagation in order to determine the evolution of structures. The relative period of previous fault slips and possible fault propagation direction along the Ifewara-Zungeru mega fault will also be investigated. This is borne from the recent account that the Ifewara fault now hosts most of the recorded epi centers of tremors occurring in Nigeria (Akinpelumi 2008), thus suggesting an active fault zone. No previous study has analysed in detail the morphology and kinematic significance of the Okemesi Fold belt acclaimed to have been affected by the accretion of the West African and Congo Cratons and the fundamental Ifewara fault believed to be part of the fractures that developed during the latter stages of the Gondwana breakup and has been liked with the some of the Mid-Oceanic Ridges (Olayanju 2015). The Basement rocks that makes up this environment is usually associated with gold fields in similar terrains in Canada, India, Brazil and Australia. Direct observation of fault striations in the field is quite difficult because few places on the fault surface retain such information and due to poor exposures resulting from rapid coverage of fault surfaces by weathered materials and vegetation. However, this area provides some Neotectonic evidences from the brittle layer of the upper crust as well as the ductile/plastic layers exposed by recent landslide activities were incorporated in this study. Faults reveal a lot about the brittle nature of deformation and are thus very useful in kinematic studies since most faults could be linked with seismicity at depth. Anytime a seismic event occurs along a preexisting fault plane a certain amount of slip occur along such planes. The amount of slip and stress released along pre-existing rock is assumed to be more than on an intact rock that was not previously fractured (Kaiser and Kim 2014). Knowledge of fault slip direction is useful in determining the possible rock failure direction, this is applicable in engineering and seismic disaster prediction and assessment. Fault planes can be recognized using slickensides, striations, groove and ridge, mineral fibre, asperites on fault slip surface and other kinematic indicators such as sigmodal tension gashes, conjugate shear fractures, joints, folds and other features that indicate sense/direction of motion, since paleo stress reconstruction can be carried out at different scales. Aside the field collection of outcrop scale fault slip data, outcrop/meso scale structural features such as fault slip data and geometric were collated to determine the regional stress analysis. The geometric data are useful in constraining both the strain and regional stress (Célérier et al. 2012).

This study provides information about the tectonics and kinematic history of the Okemesi fold belt on a meso and regional scale (as part of the mega Ifewara Zungeru Fault Zone).

Geology and Structure of the Area

The Okemesi fold belt is compressionaly deformed, this is evidenced by numerous folds and shear features present in the area, aside the mega NNE-SSW trending recumbent Okemesi fold. This area has been affected by polyphase tectonics. The area can be described as a ductile shear zone based on the presence of intense folding and high strain. Successive deformational episode revealed a thrust related deformation in the host rock (quartz schist) with a brittle-ductile shear zones and striated faults. The ductile shearing precedes the development of the brittle-ductile shearing that formed the striated faults. Small thrust structures are common especially at the northern- eastern part of the Okemesi fold, close to the hinge of the fold and probably fades out southwards. This area is underlined by the crystalline basement complex of Nigeria. The Okemesi fold belt is part of a larger Proterozoic Ife-Ilesha meta sedimentary schist belt in Nigeria (Omitogun and Ogbole 2017; Bolarinwa and Adepoju 2016; Rahaman *et al.* 1988; Hubbard 1975; Ajayi 1980; Elueze 1981). This fold belt consists of long hog back ridges that extends for over 150 km with elevation of more than 400 meters in most places. It is made up of low grade metasediments rocks (Elueze 1988). The inner core of the Okemesi fold belt is made up of a metasedimentary assemblage which is post Archean. The metasediments (massive quartzite, quartz schist and mica schist) are orthoquartzites of sedimentary origin from arkosic sediments with

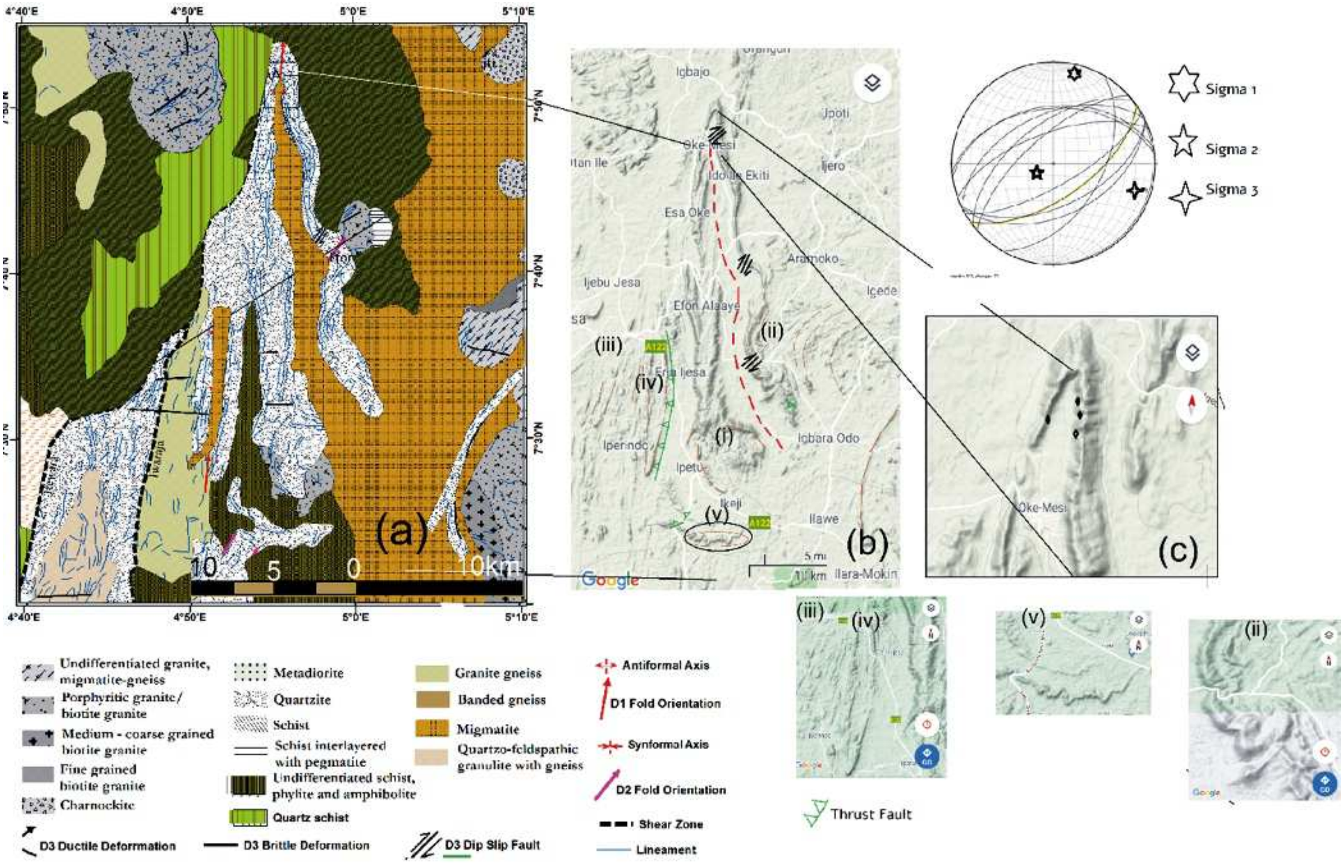

Fig. 1: Map of the Okemesi fold belt showing the study area at the central north in (a), the middle map shows the whole of the Okemesi fold on a Google Terrain map and the google terrain map (c) showing the mapped sites (7. 861459, 4.9335262; 7.861982, 4.933127 and 7.866434, 4.932919 on the eastern limb and 7.860651, 4.922028 on the western limb of the Okemesi fold).

contribution from granitic rocks (Okunlola and Okoroafor 2009). The quartz schist occupies the innermost core of the Okemesi fold. The metamorphic grade is low to medium grade. The D1 and D2 deformational episodes consist of E-W compression and formation of recumbent folds with NNE-SSW oriented axial planes (Odeyemi 1993; Fagbohun et al. 2017; Bamisaiye 2019). Early D2 is marked by the rotation of the initial NNE-SSW axial plane to NE-SW and formation of gentle and open folds. The D2 deformational episode is also associated with the development of dextral strike slip faults. D3 is marked by intense compression and shearing leading to the formation of sigmodal foliations. While the later part of the D3 was marked by brittle- shear deformation leading to the formation of E-W oriented fractures with NE-SW slip (Odeyemi 1993; Fagbohun et al. 2017; Bamisaiye 2019).

Methods

The author identified and mapped separately the fault plane markings, the sense of slip and the stress scheme deduced from each of the fault markings by adopting a modified method of stress inversion. This method is based on systematic mapping, measurement and careful analysis of fault plane data (to determine the direction of compression and extension and the principal stress directions). The study also involves the kinematics observation of small scale brittle-ductile structures from field exposures. The area investigated includes three E-W trending graben sites exposed by recent landslides in the area. Fault planes were recognized using slickensides, striations, groove and ridge, mineral fibre, asperites and other kinematic indicators such as sigmodal tension gashes, conjugate shear fractures, joints, folds and other features that indicate sense/ direction of motion were mapped. The strike, dip, dip direction, rake and slip sense/direction of each fault surface. The aim is to integrate all the details and use the information to deduce the local kinematics, principal stress axes, deformational fields and seismicity of the area.

Results

Fold and paleostress tensor determination

Stress tensor can be determined on a number of rock features that reveals rock motion along tangential traction, assuming that all motion within the same region are formed under a constant and similar stress field (Barton 1981; Micheal 1984) Thus slip data were obtained from both ductile and brittle features and incorporated into the deformation history. The area exhibits a complex fold pattern probably as a result of interference between earlier and later progressive folding associated with shearing or as a result of change in stress field orientation. Fold transposition, intrafolial folds and sheath folds were observed in the area (Bamisaiye 2019). Slips in Flexure slip folds has E-W trend in the folded rock layers encountered in the study area, this indicates the direction of slip of such surfaces.

Veins

Argles and Platt (1999) from the study of the Betic Cordillera, southern Spain confirmed that steps on veins can be used as shear sense indicators because they provide information that are consistent in orientation with the regional kinematic. Some of the veins are fault related and form parallel to fault planes, while some form along folds (Fig. 2 and 3) (Bons 2000; Bons et al. 2012). The current orientation of the vein is however consistent with the local shear sense since it forms along the foliation planes and parallel to striation.

Fig. 2: Bucked quartz vein oriented NNW-SSE indicating an early deformation phase prior to the formation of the larger/thicker, folded veins in the area. It also shows that the deformation and shearing occurred after the veins were formed.

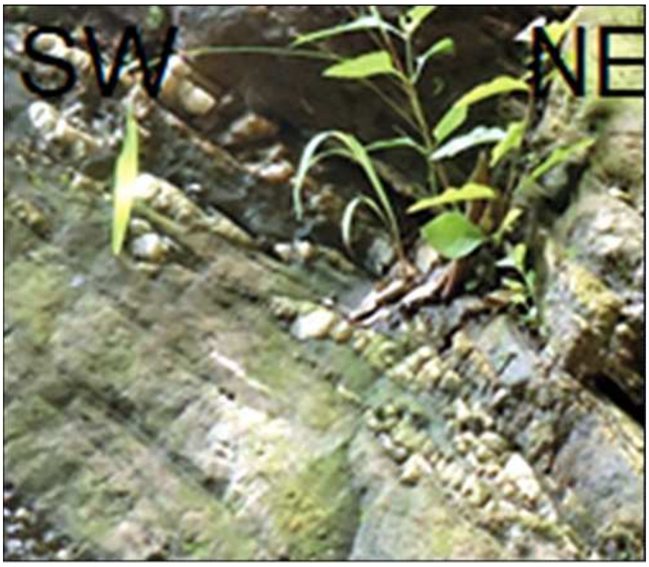

Fig. 3: Shear and fold related vein. The carrot shaped veins with tips pointing in the direction of motion (SE). The formation of these carrot-shaped veins may be consistent with previous carrot shaped grooves created during seismic activities in the area.

Joint

Joints represent discontinuity without apparent displacement in rock. The tectonic stress orientation determines joint orientation since the growth orientation at the tip of the joint of such is always perpendicular to the minimum stress orientation (Dyer 1988). The E-W orientation determined to be the landslide slip direction in this area coincides with the intermediate stress orientation of the joints (Fig. 4b). The propagation direction of the relic plumose also confirms the E-W intermediate stress axis (Bamisaiye 2019). The E-W joint orientation seems to be younger than the less prominent N-S joint orientation.

Fig. 4: Joints on rock outcrop (right) and plumose structure showing the principal stress orientations.

Grooves

More than one type of groove was encountered on the field (Fig. 5a, 5b and 5c), the most prominent one are the long polished, rod-like depressions with length of about one meter, dips (eastward)/slide towards the direction of motion, the slipped blocks were seen hanging down the dip direction in some cases. Such polished surface probably indicates more than one slip episode. The grooves are slightly curved in some cases (Fig. 5c); indicating post slip compression.

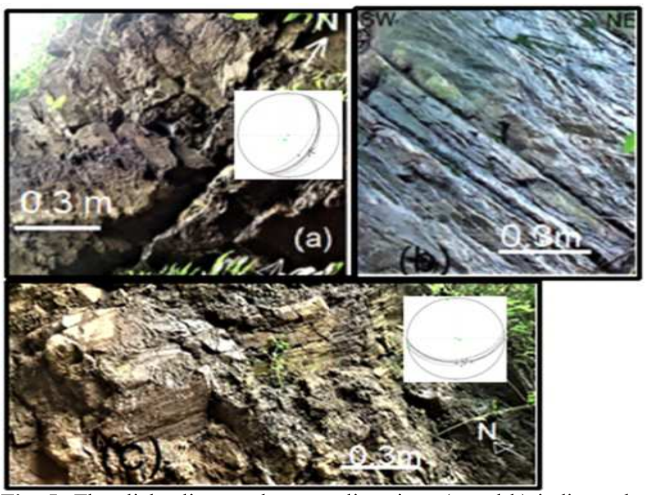

Fig. 5: The slickenlines and groove lineations (a and b) indicate the direction of slip, which is East. C indicates groove lineation associated with normal faulting and shearing.

Slip determination from conjugate fault planes

Here two fault planes intersect to form a single line. The faults intersect at approximately 60^0 .The intersection line between conjugate fault is the intermediate stress tensor (stress axis σ_2), the $\sigma1$ is the maximum principal stress axis and the compressional stress axis (oriented eastwards) that bisects the angle between the fault planes while $\sigma3$ (from west) is the tensional stress represented by the bisector of the obtuse angle Fig. 6 (b) (Lunina et. al. 2005; Diabat 2015). Conjugate NNW–NNE normal and NE–SW sinistral strike slip faults are particularly well-developed in this unit (Fig.7). These suggest bulk E-W shortening.

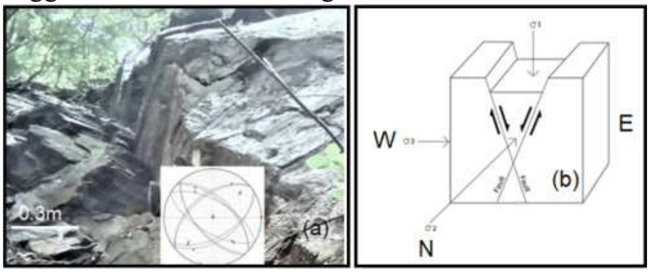

Fig. 6: Stereogram of the two opposite dipping planes, both are associated with normal faulting. The schematic diagram by the right hand illustrates the orientation of the principal stresses for conjugate faults (Source: https://structuredatabase.wordpress.com/).

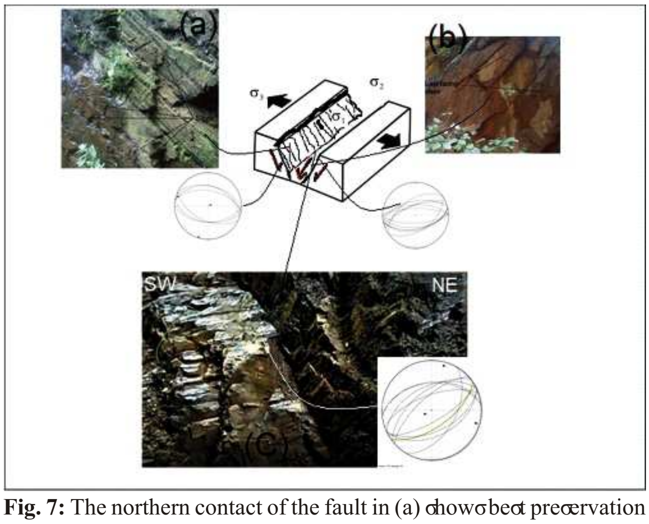

Fig. 7: The northern contact of the fault in (a) shows best preservation of foliations, joints, mylonitized quartzites, porphyroclasts and veins, indicating more brittleness and resistance to overprinting. (a) block is foliated, tilted to the west and trends SSW-NNE. The quartzite is schistose and highly foliated. (b) consist of folded massive quartzite (c) is the central portion between the dipping faults, the slip lineations indicates strike slip motion.

Fiber lineations

Fiber lineatons are significant brittle extensional features with greater damaging or failure potential. The displacement is perpendicular to the opening, minimum stress direction and stretching direction. The orientation of the fibers is commonly taken to represent the extension direction. The curved fibers in Fig.8 implies a change in extension from E-W towards the NE direction probably during deformation or due to shearing after the formation of the fibers.

Fig. 8: Fiber lineations on quartzite showing evidence of shearing

The chronology of striations on the fault surface is a bit complex. The E-W trending striations are more abundant and could erroneously be mistaken as the latest movement due to the magnitude and presence of long grooves. The fiber lines indicate extension along approximately E-W direction, However the chronological relationship indicates that the long fiber is sheared to the north. This shows that extension precedes compression in this area.

The veins record extensive hydraulic fracturing in low to medium grade metamorphic rocks, the examples described above appear consistent with independent shear-sense indicators and contribute to the regional kinematic scheme and distinct kinematic.

Foliation Curvature and S-C Structure

Foliation that are rotated during deformation will show a sense of direction that indicate the sense of motion. The C features are comparable to Riedel Shears in the brittle regime, while the folds are similar to "S" foliation especially at the eastern part of Fig. 9. The lower part of the Figure shows that the C-planes are predominated by straight quartz porphyroblast intersecting the S band. The C band maintain a consistent orientation and disappears beyond the shear zone boundary. The S band consist of S- shaped, curvilinear to sigmodal shear bands forming the S type bands whose degree of curvature depends on its amount of rotation. This reduces gradually to parallel (from top to bottom (Fig.9a)) and at the lower central part of the figure where the C bands are closest to each other and highly sheared. The S band stretches NE-SW representing NE-SW transtension and N-S compression.

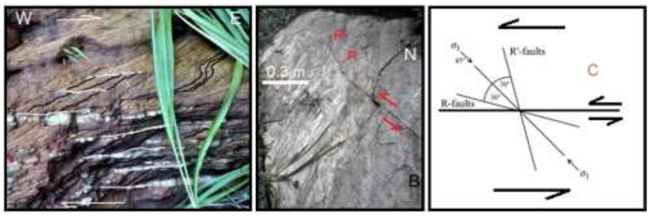

Fig. 9: C and S fabric defined in mylonitic quartzite which forms the S bands trend NE to the right and the C-type shear band formed by quartz porphyroblast, the C bands are straight and parallel with the shear band boundaries while the long axis of S type shear bands points to the shear boundary, (a) indicates dextral movement. Diagram (b) Riedel fractures with westward maximum compressional stress, in a sinistrial strike slip fault regime. C and S fabrics in (b) exhibit dextral kinematics with NE-SW transpression. (C) Schematic diagram of Riedel shears fractures showing variation in orientation of the R and R' fractures in (b).

Porphyroclast: Undeformed and Deformed

Kinematic analysis can be studied by investigating movement of rock component or material such as porphyroclasts that displays evidence of deformational modification. Porphyroclasts are relict component of metamorphosed rock that subsisted after recrystallization. The porphyroclast in Fig. 10a has a rotated morphology with a dextral sense of shear and a central unitaxial crystal growth towards the west and the presence of assymetric porphyroclast undergoing extension (Fig. 10b).

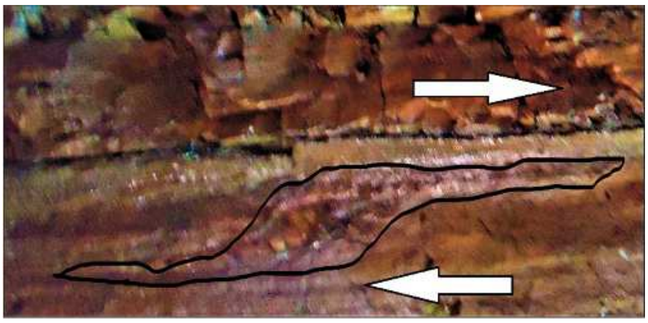

Fig. 10a: σ-type porphyroclast developed from recrystallized quartz mineral and influenced by coaxial deformation. This belongs to early D3 deformational episode (Odeyemi, 1993; Fagbohun *et al.* 2017).

Discussions

Regional Kinematic Description of the Study Area

The most recent stress state (D_4 deformation) is associated with tensional stress field from NNW-SSE through NNE-SSW to E-W, as recorded in most of the locations. This extension is related to normal and strike slip faulting, some of the folded structures such as veins and intrafoliation were formed during the D1, D_2 and early D_3 deformational episodes were also affected by this extensional stress. Nappe/thrust structures might have formed during the Pan African with southwest to

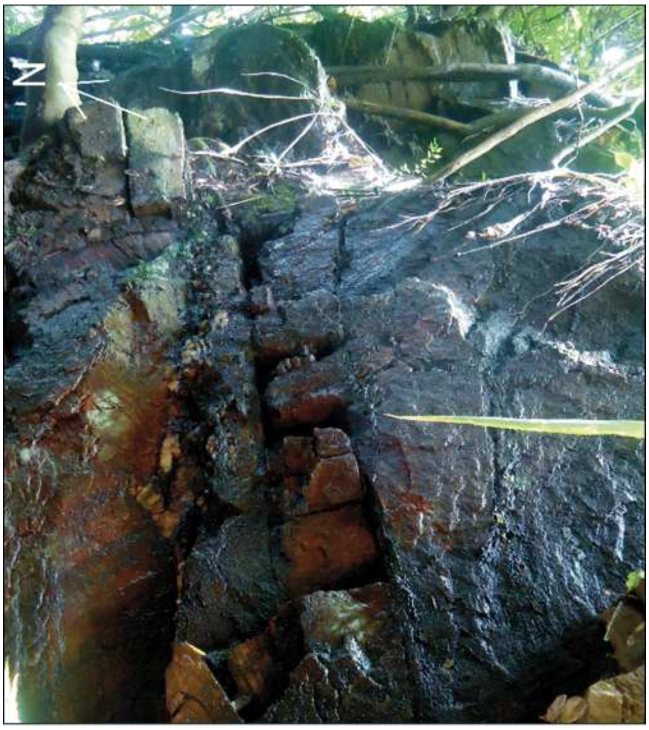

Fig. 10b: Asymmetric boudins/ antithetic shear fractures oriented NNE-SSW and formed by extension

western extension in the same direction with folds in brittle-ductile regimes, in response to compression the strain ellipsoid.

Most of the joints open along NE-SW and E-W, the foliations dip moderately to the west as a result of progressive deformation and strikes between 82^0-272^0, this wide variation in trend shows polyphase deformation. Joints are formed in response to tectonic stress regime, the σ_1 axis is oriented perpendicular to $\sigma3$ and considered to be radial or multidirectional extension (Armijo 1977). Joints propagate at right angle to the $\sigma3$. Joints are thus useful in defining the $\sigma3$ axis in a region. They open along the $\sigma2$ and $\sigma3$ direction but never along the maximum stress axis $\sigma_{1.}$ The $\sigma2$ and $\sigma3$ axis in the study area is along the E-W direction, this represents the joint opening direction. The joints are also related to local faulting and folding in this area, some develop due to extension and displacement of normal faults, while some form along the hanging block of warped thrust/reverse faults. Some of the joints form parallel to the hinge of folds in this area.

Stretch lineations are related to this late stage extension, at the fold hinges, along fold axis and are found associated with strike slip faulting. Some of the lineations are crosscutting, this indicates possible superposition of later lineation on earlier ones (early minor folds) or due to shearing and rotation, the axial plane of the later stage folding is horizontal. Late stage folding must have been associated with the development of a sinistral transpressional shear zone along NE-SW trend. Presence of fiber lineation indicate further fault movement after the initial slip.

The axial plane of relicts of earlier folds are oriented NNW- NNE. The maximum principal stress direction was either W or E, with nearly vertical compression in approximately N-S to NNE-SSW trend.

The second deformational episode is associated with NE-SW axial planar gentle to open folds formed under NNW- SSE compression with approximately E-W extension (Fig.6, 7, 8 and 9) and formation of dextral strike slip. These successions of paleostress fields described was established from field observations where successive grooves developed on the same fault plane: the first under a NNE-SSW extension of the earlier recumbent folds and the second under a strike-slip regime, suggesting a transpressive paleo stress regime.

The third deformation phase is characterized by E-W extension and brittle fracturing of the quartzites. Most of the joints, lineations, foliations are oriented in this direction (Fig. 5, 6 and 7). The most recent structures (slickenlines, grooves and lineations) exposed by recent landslides in this area reveals NNE-SSW to E-W maximum stress direction in normal fault and strike slip regime. The carrot grooves (Fig. 5) show extension in a SE direction and approximately N-S compression, which suggest that folds and faults formed in the same stress field.

Deformation in the southern parts of the Okemesi fold being a low grade metamorphic zone, is mainly controlled by the buckling and stretching of the competent metasedimentary layers. The stretched layers are eventually separated by thrust? (Fig. 1b). The nature of the fold around Efon Alaaye and southwards seems very complex due to multiple deformation and massive outcrop erosion leading to discrete/scattered outcrop exposures. Detail mapping of these features is hampered by thick vegetation, the monotonous lithologic nature of the rocks and erosion. The satellite images of the area are also a bit clumsy and unsuitable for detail structural mapping, despite these shortcomings Odeyemi 1993; Fagbohun et al. 2017 made a good attempt at describing the structures using satellite images. However, a careful study of the Google Terrain map of the area revealed more detail. The southwestern part, around Erin- Ijesha and Iperindo is made up of partly eroded extension parallel folds (the folds run parallel to Ifewara Fault) where compression is perpendicular to extension.

The eastern limb of the Okemesi fold is influenced by the post Nappe doming of the Archaean basement which resulted into buckling, shortening and juxtaposition of upright folds on the older recumbent fold, with possible cutting by thrust.

The western limb is undergoing extension. The rifting on the western limb is influenced by the NNE dextral strike-slip extension of the Ifewara fault. Fault splaying caused by E-W (horizontal) extension of the Ifewara fault (north of Okemesi fold). This is substituted in the southern part (Efon- Alaaye – Iperindo area) by oblique and orthogonal extension coupled with parallel shear. This transtensional displacement is responsible for the extension of the Ifewara fault (represented here by series of NNE parallel faults (Figure 1b (iii)) and the four-way closure anticlinal thrust-fold (Figure 1b (iv)). These reveal the imprint of pre- and syn kinematics of Ifewara Fault on the western limb of the Okemesi fold.

Rock buckling and ductile deformation in extreme southern part of Okemesi fold area (brown circle on Fig.1b(v)) indicates intense E-W horizontal/lateral compression with strongly compressed large scale (about 10 km long) sinuous folds. The axial planes of the folds are oriented almost vertically (N-S), west of the buckled fold in Figure 1b(v) are two fault-bend thrust fold with the western segment gradually dragging over the lower eastern segment.

The shortening on the eastern limb (between Aramoko and Igbara Odo (Fig. 1b (ii)) indicates a N-S transpression evident by eastward doming and classified as part of the early D_3 ductile deformation.

Conclusions

The observed local stress trajectories possibly reflect a combination of stress states that can be correlated with the development of major fold structures and the dominant regional stress field. Some of the tensors recorded conform to separate tectonic events thus reflecting multiple phases deformational episodes, while minor rotation of single phase deformation was also observed on folds.

Four principal deformation styles at both local and regional scale were identified: (1) sheared and folded structures (2) thrust fault (3) normal fault and (4) strike-slip fault. It indicates that the Okemesi fold experienced a complex history of tectonics initiated by variable stress regimes of contraction and thrust faulting while strike-slip and normal is currently dominant in the area because the area is undergoing extension. The paleostress analysis shows: (1) Late Pan- African to recent compression in a NNE direction as inferred from both the fracturing and strike-slip faults, and (2) the presence of E-W extension billeted by normal and strike slip faulting. The western part of Okemesi fold along the Ifewara Fault is dominated by horizontal extension in the north and vertical extension in the south. Both upper and the lower sections and the eastern limb of Okemesi fold are dominated by compression and shortening, the eastern limb by vertical compression and the lower section by horizontal shortening.

References

Adepelumi, A.A., Ako, B.D., Ajayi, T.R., Olorunfemi, A.O., Awoyemi, M.O. and Falebita, D.E. (2008). Integrated geophysical studies of the Ifewara transcurrent fault system, Nigeria. Jr. Afr. Earth Sc, v. 52, p161-166.

Ajayi, T.R. (1980). On the geochemistry and origin of the amphibolites in Ife-Ilesha area, SW Nigeria. *Journal of Mining and Geology, v.17,* (2), p179-196.

Angelier, J. (1994). Fault Slip Analysis and Paleostress Reconstruction. In: Hancock, P.L., Ed., Continental Deformation, Pergamon Press, Oxford, 53-100p.

Angles, T.W. and Platt J.P. (1999). Stepped fibers in sillmanite- bearing veins; Valid shear- sense indicators in high grade rocks? J. Struct. Geol., v. 21(2), p153-159.

Armijo, R. (1977). La Zone de failles de Lorca-Totana: Cordillères Bétiques, Espagne: etude 547 tectonique et neotectonique. Ph.D. thesis, Université Paris VII. 196p

Bamisaiye, O.A. (2019). Landslide in Parts of Southwestern Nigeria. SN Applied Sciences (2019) 1:745 Springer nature journal. https://doi.org/10.1007/s42452-019-0757-0.

Barton, C.M. (1981). Regional stress and structure in relation to brown coal open cuts of the Latrobe Valley, Victoria. *Journal of the Geological Society of Australia*, v. *28*(3-4), p333-339.

Bolarinwa, A.T. and Adepoju, A.A. (2017). Geochemical Characteristics and Tectonic Setting of Amphibolites in Ifewara Area, Ife-Ilesha Schist Belt, Southwestern Nigeria. Earth Science Research; v. 6 (1): p43-54.

Bons, P.D., 2000, The formation of veins and their microstructures. In: Jessell, M.W., Urai, J.L. (Eds.), Stress, Strain and Structure, A Volume in Honour of W D Means. Journal of the Virtual Explorer (on-line). https://www.tectonique.net/MeansCD/wdmrom_pdf/bons.pdf

Bon, P.D., Elburg, M.A. and Gimez-Rivas, E. (2012). A review of the formation of tectonic veins and their microstructures. Journal of Structural Geology. v.43, p 33-62. doi: 10.1016/j.jsg.2012.07.005.

Célérier, B., Etchecopar, A., Bergerat, F., Vergely, P., Arthaud, F. and Laurent, P. (2012). Inferring stress from faulting: From early concepts to inverse methods, Tectonophysics. v. 581, p 206 219.doi: 10.1016/j.tecto.2012.02.009

Delvaux, D., Sperner, B. (2003). New aspects of tectonic stress inversion with reference to the TENSOR program. Geological Society, London, Special Publications. v.212, no. 1, p75–100.

Diabat, A. (2015). Structural and Stress Analysis of the Area between Al-Akeider and Mughayer As-Sirhan, Northwestern Badia- Jordan. Jordan Journal of Earth and Environmental Sciences. v.7, no.1.p 37-48.

Doblas, M. (1998). Slickenside kinematic indicators. Tectonophysics. v.295. p187–197. doi.10.1016/S0040-1951(98)00120-6.

Dyer, R. (1988). Using joint interactions to estimate paleostress ratios. Journal of Structural Geology, v.10, no.7, p 685 - 699.

Elueze, A.A. (1981). Petrographic studies of metabasic rocks and meta-ultramafites in relation to mineralization in Nigerian Schist belts. *Journal of Mining and Geology, v.18 no.*1, p 31- 36.

Etchecopar, A., Vasseur, G. and Daigniere, M. (1981). An inverse problem in microtectonies for the determination of stress tensors from fault striation analysis. Journal of Structural Geology, v. 3, no. 1. pp. 51-65.

Fagbohun, B.J., Adeoti, B. and Aladejana, O.O., (2017), Litho-structural analysis of eastern part of Ilesha schist belt, Southwestern Nigeria, Journal of African Earth Sciences, v.133, p 123- 137. http://doi.org: 10.1016/j.jafrearsci.2017.05.017.

Fossen, H. (2010). Structural Geology. Cambridge University Press UK. 354-369p.

Hubbard, F.U. (1975). Precambrian crustal development in Western Nigeria; indications from Iwo region. Geological Society of America Bulletin, v. *86*, p 548-554.

Kaiser, P.K. and Kim, B, 2015, Characterization of Strength of Intact Brittle Rock Considering Confinement - Dependent Failure Processes. Rock Mechanics and Rock Engineering v.48, p 107 119. https://doi.org/10.1007/s00603-014-0545-5.

Kim, Y.S., Peacock, D.C. and Sanderson, D.J. (2004). Fault damage zones. *Journal of Structural Geology*, v.*26 no.*3, 503-517.

Lacombe, O., Mouthereau, F., Kargar, S. and Meyer, B. (2006). Late Cenozoic and modern stress fields in the western Fars (Iran): implications for the tectonic and kinematic evolution of central Zagros Tectonics, v.25 no.1. TC1003. doi: 10.1029/2005TC001831I

Lacombe, O. (2012). Do fault slip data inversions actually yield "paleostresses" that can be compared 639 with contemporary stresses? A critical discussion. Comptes Rendus Geoscience v.344, p159-173.

Lunina, O.V., Mart, Y. and Gladkov, A.S., (2005). Fracturing patterns, stress fields and earthquakes in the Southern Dead Sea rift. Journal of Geodynamics v.40, p 216–234.

Michael, A.J. (1984). Determination of stress from slip data: Fault and folds, journal. Geophys. Ser., v. 45, 289p. Elsevier, New York.

Michael, A.J. (1984). Determination of stress from slip data: faults and folds. Journal of Geophysical Research, Solid Earth, v.89 no. B13, p11517-11526.

Odeyemi, I.B. (1981). A review of the orogenic events in the Precambrian basement of Nigeria, West Africa, Geol. Rundsch, v.70, no. 3, p 897-909.

Odeyemi, I.B. (1993). A comparative study of remote sensing images of structure of the Okemesi fold belt, Nigeria, ITC Netherlands Journal, v.1, p 77-81.

Okunlola, O.A and Okoroafor, R.E. (2009). Geochemical and petrogenetic features of schistose rocks of the Okemesi fold belt, Southwestern Nigeria. RMZ – Materials and Geoenvironment v.56 no.2, p148-162.

Omitogun, A.A. and Ogbole, J.O. (2017). Lithologic, Hydrothermal Alteration and Structural Mapping of Okemesi Folds and Environs Using LandSat 8 OLI and ASTER DEM. Journal of Geography, Environment and Earth Science International v.12 no.3, p 1-19, Article no. JGEESI.36143. ISSN: 2454-7352

Petit, J.P. (1987). Criteria for the sense of movement on fault surfaces in brittle rocks. Journal of Structural Geology, Journal of Structural Geology v. 9, no. 5–6, p 597-608.

Rahaman, M.A., Ajayi, T.R., Oshin, I.O. and Asubiojo, F.O.I. (1988). Trace element geochemistry and geotectonic setting of Ile-Ife Schist belt. *In* Oluyide P.O (Ed.) *Precambrian Geology of Nigeria,* p, 241- 256,

Saintot, A., Stephenson, R. and Brem, A. (2003). Paleostress field reconstruction and revised tectonic history of the Donbas fold and thrust belt (Ukraine and Russia). TECTONICS, v. 22, no. 5, p10-59, doi:10.1029/2002TC001366, 2003.

Simón, J.L. (2018). Forty years of paleostress analysis: has it attained maturity? Journal of Structural Geology, v.11,526.

Xu, P. (2004). Determination of regional stress tensors from fault-slip data. Geophysical Journal International, v. 157, no.3, p1316-1330. Doi.org/10.1111/j.1365-246X.2004.02271.x.