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Research Article
Petrostructural Features of Metaconglomerate in Igarra and Otuo, South-Western Nigeria

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Abstract

Background and Objective: Petrostructural evaluation of Igarra and Otuo basement rocks is vital to understand the geology of the area. Petrostructural features of metaconglomerate in Igarra and Otuo areas, Southwestern Nigeria were investigated for mineralogical composition, characterization of structural features and complement existing research on the Basement Complex rocks of Igarra area. **Materials and Methods:** Six samples each from Igarra and Otuo were selected and prepared into thin section for optical examination while fresh whole rock samples of the metaconglomerate were pulverized for X-ray diffraction analysis following standard method. **Results:** Petrographical examination indicated that the rock matrix samples from both areas were dominated by quartz, chlorite, epidote and calcite while hornblende, magnetite and pyroxene constituted minor occurrence. X-Ray diffraction analyses indicated that Igarra metaconglomerate contained quartz (56%), epidote (9.7%), calcite (8.2%), chlorite (9.4%), hornblende (4.3%), feldspar (2.1%) and biotite (2.1%) while Otuo metaconglomerate had quartz (44.3%), epidote (13.2%), calcite (11.9%), chlorite (19.3%), hornblende (3.9%), magnetite (1.7%) and pyroxene (1.9%). Structural evaluation indicated that the rocks in both areas were strongly foliated with intense deformation. **Conclusion:** Petrographical and structural evaluation of metaconglomerate sequence in Igarra/Otuo area revealed mineralogical differences in the two areas but structurally, rocks in both areas were intensely deformed with dominant structural trend in the N-S direction. Prevalent brittle failures accompanied by viscous flow were responsible for the formation of the pinch and swell structures in the study area.

Key words: Petrostructural, metaconglomerate, mineralogical composition, matrix-supported, pinch and swell structures

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The three major rock types in the world (igneous, sedimentary and metamorphic) occur together in close vicinity at Igarra area apart from the various kinds of syn-formational (primary) and post-formational (secondary) structures that accompany many of the outcrops[1]. These attributes coupled with the favorable derived savannah vegetation that provides easy accessibility to the outcrops made the area to be unique for training Nigeria undergraduates in geological field mapping techniques.

Metaconglomerate is one of the major lithological successions within the study area[2]. Metaconglomerate is formed when conglomerate is subjected to metamorphism. It is easily identifiable by its pebbly and cobbly clasts set in a matrix of sand, silt or clay. It is a coarse-grained rock containing rounded to sub-angular fragments that are greater than 2 mm in diameter and distributed in a fine-grained matrix of metamorphic minerals[3]. Original primary sedimentary structure such as bedding is no more evident but clasts which show physical stretching and mineralogical changes are prominent features. The color of metaconglomerate could be highly variable depending on the original composition and metamorphic grade but usually contains quartz, chlorite, mica or calcite among others. Conglomerates often form at the bottom of a sequence on a former erosion surface and represent a time of formally rapid deposition.

Previous geological research works on the study area include[1,4-10] among others. All the workers only reported the metaconglomerate as a unit in the lithologic sequence. However, this research was undertaken with a view to elucidating petrostructural and compositional features of the metaconglomerate.

MATERIALS AND METHODS

Study area: The study area which is located between Lat. 7°15' N-7°28' N and Long. 5°00' E-5°15' E comprises of Igarra, Ibillo, Ososo, Somorika, Otuo, Ikao and other localities. The study area constitutes part of the Basement Complex of Nigeria which lies East of the West African craton in a mobile belt that has been affected by Pan-African thermotectonic events (Fig. 1a). Southwestern Nigeria in which the present study area lies, is one of the five major areas where the basement rocks are prominently exposed in Nigeria. The rocks of the basement complex fall into three main petrological units including: the migmatite gneiss complex, the schist belts and the Pan-African Granite (Fig. 1b). The migmatite gneiss complex is Achaean to Proterozoic in age and of amphibolites facies metamorphic grade. The gneissic complex has a long evolutionary history[11] and display chemical variations indicating they have heterogeneous sources[12]. The schist belts on the other hand, comprise pelitic and psammitic assemblages, paraschists and meta-igneous rocks represented by calc-silicates, schistose and talc-bearing rocks that are preserved in low-grade metamorphism[13,14]. The schist belts occur mainly as North-south trending belts and are more prominent in western part of the country[15,16]. The schist belts have distinct petrological, structural and metallogenic features[17,18]. The schist belts were interpreted to be relics now preserved in synclinal keels of a once widespread cover of sedimentary rocks that were deposited in a single basin[19-21]. The belts were believed to have developed separately because different lithological associations exist within the basins[12,22]. On the other hand the belts are of same age and origin having all undergone the same deformational episodes[23]. Pan-African Granites intruded the migmatite gneiss complex and the schist belts. The granite suites comprise rocks of wide range of compositions including granite, granodiorite, charnockite and pegmatite[24]. The associated dolerite dykes, syenite, pegmatite and undeformed rocks symbolize terminal stage of the Pan-African magmatism[25].

The local geology of the area can be divided into three major groups: (a) Migmatite and biotite hornblende gneiss, (b) Low grade metasediments (schists, calc-gneiss, marble, meta-conglomerate and quartzites) and (c) Syn-to late-tectonic porphyritic biotite-hornblende granodiorite, adamelites, charnockites and gabbros, while undeformed dolerite, pegmatite, aplite and syenite representing minor lithologies[10] (Fig. 1c).

The gneissic basement covers the Northern part of Igarra area and occupy about half of the entire land mass. The granite on the other hand, form the most spectacular topographic feature outcropping prominently around the neighbourhood of Igarra as inselbergs. It also forms a Northern prolongation of the extensive granite bodies that streches towards the South and Northwestern parts of Ibillo. Schistose rocks popularly known as low grade metasediments (muscovite schist, quartz schist and pebbly schist) occupy the central part of Igarra area.

Quartzite in the study area is very conspicuous, it is represented by noticeably fractured quartz rubbles and forms the most spectacular regionally folded lithologic unit.

Metaconglomerate outcrops are restricted in occurrence to areas around Igarra and Otuo where they occur generally as low-lying bodies. The rock is dark greenish grey in colour and

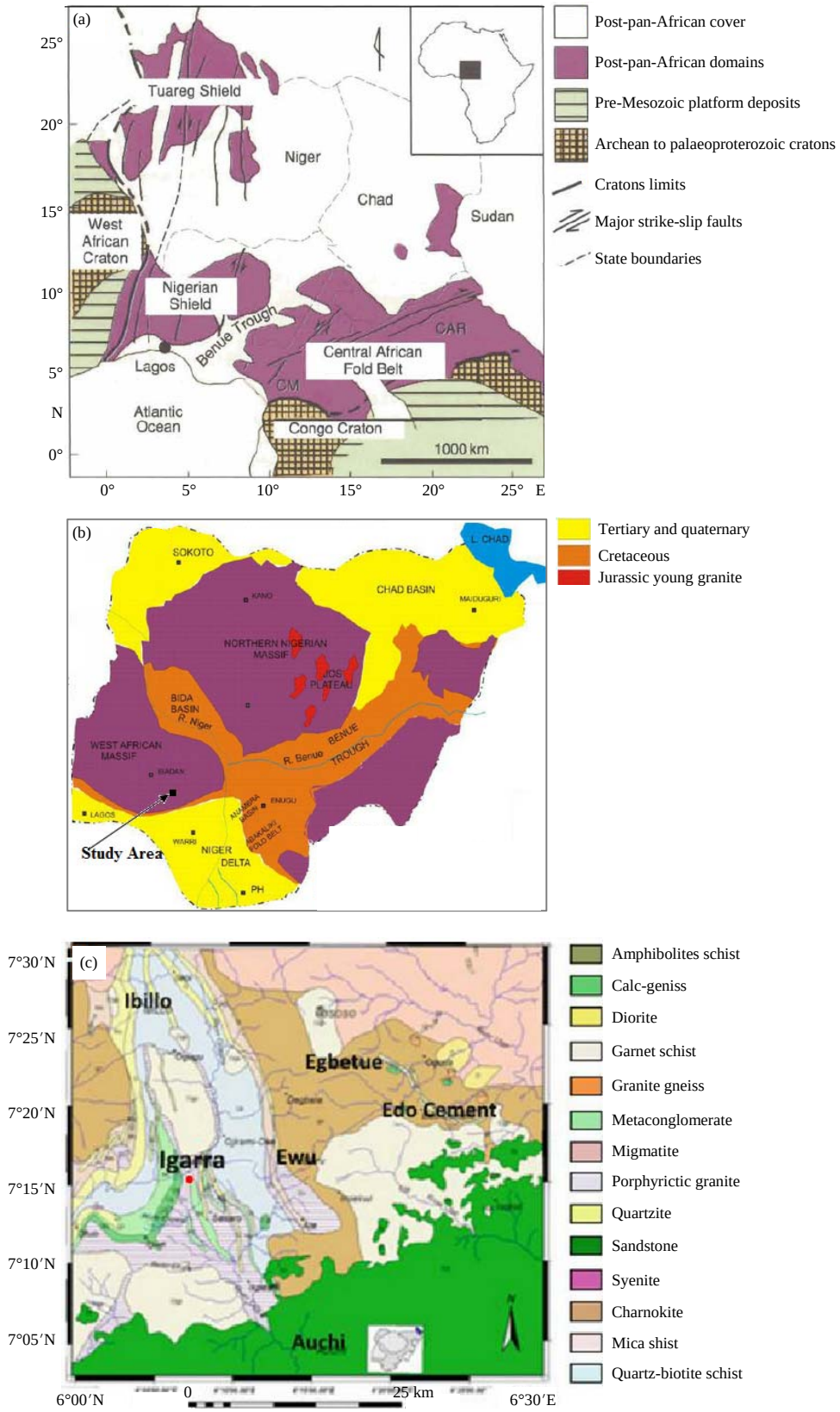

Fig. 1(a-c): Maps indicating Nigeria within reactivated Pan-African domain (modified after[16]), location of study and Geology of Igarra area (modified after[26])

Fig. 2(a-d): Otuo Metaconglomerate indicating occurrence of different types of clasts, (a) Different clast types in Otuo metaconglomerate, (b) A big granite-gneiss clast in Otuo metaconglomerate, (c) Clasts of granite-gneiss in Igarra metaconglomerate and (d) Pinch and swell structure formed by quartzite in Igarra metaconglomerate

strongly foliated. The surface of most outcrops is uneven owing to prolonged exposure to differential weathering. The rock unit consists of clast of varying sizes, some clasts measure up to 45 cm long while others are few millimetres in length. The diversity of sizes in the clasts may be attributable to the prevalence of high energy in the medium that deposited the original clastic sedimentary particles. The clasts are made of different lithologies including quartzite, calc silicate and gneiss (Fig. 2a). The heterogenous clasts in the polygenetic (polymictic) metaconglomerate mostly show varied morphological features. The clasts in all cases are fewer and less abundant than the rock matrix in which they are embedded, hence the rock is designated matrix-supported. One characteristic feature common to all the clasts in the metaconglomerate outcrops is that their longer axis is aligned parallel to the direction of maximum stress (strike direction). The clasts are sub-angular, to sub-rounded and very rarely, well-rounded (Fig. 2b and c).The degree of roundness in the clasts may also be a pointer to provenance or source rock evaluation. Even though Igarra metaconglomerate is highly foliated, preservation of good folds are very rare if not completely absent, the reason is that the rock rarely, if ever become folded. A most probable reason the metaconglomerate is devoid of fold structures is its hardness and non-ductile nature. However, the rock is highly susceptible to fracturing and many evidences of faulting were observed during the field sampling. Among the well-preserved structural elements in the rock is pinch and swell structures (Fig. 2d).

Sampling: Rock samples used for the research were obtained as rock chips hewed out from outcropping exposures of the metaconglomerate from the study area in a sampling process during the dry season. Specifically, the field work was undertaken between February, 10th and 16th 2015. Subsequently, the samples were processed for thin section petrography and X-ray diffraction investigation.

Thin section petrography: Systematic geological mapping was not undertaken because there is an already existing geological map[7]. However, sampling was carried out in the area using standard geological techniques with the use of a sledge hammer. Weathered samples were avoided, random sampling technique was adopted and samples were labelled appropriately. Six samples (three from each locality) were selected and prepared into thin section for optical

examination while the others are reserved for geochemical determination. The rock samples were cut to obtain two smooth surfaces using Logitech (CS 10) diamond-edge cut-off machine. One of the smooth surface is polished to allow good bonding. The slabs were washed thoroughly with clean water to remove any loose particles. They were laced on hot plate set at 100-200°C for baking and to remove water from the samples for about 30 min. The sample slides were allowed to cool to 50°C and each bonded to glass slide (75×25 mm) using Canada Balsam cement. The slabs were carefully pressed against the glass slides (using a bonding jog on hot plate for about an hour) to prevent the occurrence of gas bubbles in between the glass slides and the slabs. The slides were allowed to cool to room temperature and were subjected to rotary grinding with different grades of carborundum powder. The rocks were then grinded down with a lapping machine to a thickness of three hundredth of a millimetre such that every mineral in the rock become so thin that they will permit light to pass through them. Mineralogical analysis was conducted by identifying minerals in the slides based on their optical properties under plane polarized light (ppl) and cross nicols (cpl). Modal analyses were based on visual estimation and counting. Petrographic study of the rocks were undertaken on the rotating stage of Leica DLMS polarising microscope connected to a computer and a digital camera where structural and textural properties were investigated. The slides were prepared at the Department of Geology Laboratory, University of Ibadan, Nigeria; and the snapshots were taken at the University of Malaya, Kuala Lumpur, Malaysia.

X-ray diffraction analysis: Fresh whole rock samples of the metaconglomerate were reduced by grinding them in a jaw crusher, thereafter; it is prepared into rock powders (10 micron) by pulverizing in the Tema Mill. X-ray diffraction analysis was undertaken with a view to determine the quantitative and qualitative mineralogical composition of the metaconglomerate. The powdery rock samples were then loaded into a diffractometer (Rayons PANalytical EMPYREAN DY 1032) and scanned from 0-90° under Cu-Kα alpha radiation 40 kV, 30 mA scanning rate 2° 20 cm min^{-1} and time constant 4 sec. (raise 4×10^2 C.P.S). Mineralogical determinations were based on x-ray beam passing through the powdery rock samples. As it moves, the X-ray beam identifies the structural layers which are dependent on the characteristic d-spacing of each mineral constituting the rock. As this happens, it gives peaks that are typical of each mineral which make up the rock. The heights of these spikes correspond to the concentration or abundance of each mineral. X-ray analysis was undertaken at the Laboratory of the Department of Geology, University of Malaya, Kuala Lumpur, Malaysia.

RESULTS

Petrography: Optical microscopy shows that the matrix of the metaconglomerate is essentially fine-grained. The prominent minerals in Igarra metaconglomerate are quartz, feldspar, biotite, chlorite, epidote and calcite, while hornblende, magnetite, pyroxene and opaque minerals only occur as minor constituents (Fig. 3a). Quartz crystals occur as small, unaltered euhedral to appear cloudy. Many quartz grains occur as interstitial aggregates with undulatory extinction. Few quartz grains are found as inclusions in plagioclase. The feldspar type is mainly albite and occurs as euhedral crystals that are recognized by its carlsbad twinning. They show well defined outlines, few crystals however exhibits distorted twinning. Feldspar is observed only in the Igarra metaconglomerate and does not form major component mineral in Otuo samples. Biotite occurs as platy and bladed minerals showing preferred orientation, they appeared stretched along same direction impacting a physically recognizable foliation in the samples (Fig. 3d). It also occurs as major groundmass mineral with low-medium relief and strong birefringence colours (Fig. 3g). Epidote has colours ranging from green, brown and purple and occurs in granular to columnar aggregates with high relief and fractures (Fig. 3c). It has moderate to strong birefringence and the interference colors range from middle first order to upper second order colors. The middle first order colors are anomalous blue to purple interference colors. Elongate sections show parallel extinction. Epidote is sometimes seen mantling brown blue to purple chlorite grains. In thin section, this rock contains bands of light coloured minerals which are not completely segregated from the schistose fabrics. Chlorite occurs as brown, purple and green mineral with a characteristic acicular, fibrous and lath-like appearance. The foliation imparted by parallel to sub-parallel arrangement of biotite which is not segregated from the felsic components (quartz and feldspars) is distinct. The rock occasionally contains large porphyroblasts (Fig. 3e and f) of quartz which are regularly arranged while the flaky minerals (muscovite and biotite) cluster in some roughly parallel bands which are in association with a very fine groundmass.

X-ray diffraction: The X-ray diffraction traces (Fig. 4a, b and c) of the conglomeratic rock is presented. X-ray diffraction trace of metaconglomerate sample from Igarra (Fig. 4a) indicates

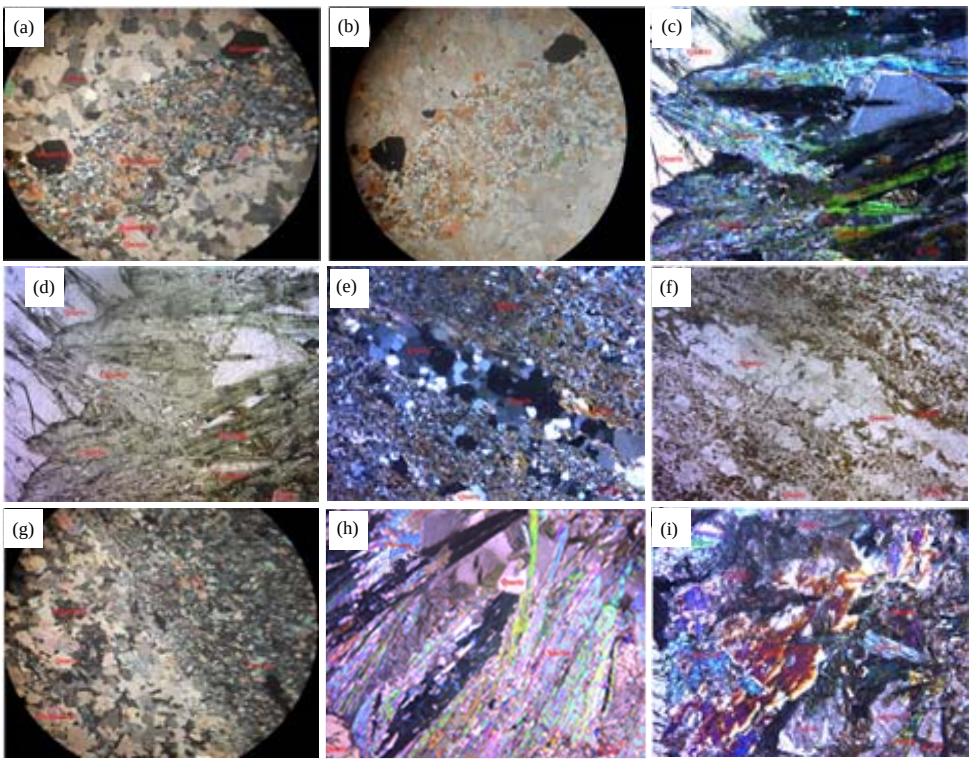

Fig. 3(a-i): Photomicrographs of Igarra and Otuo Metaconglomerate, (a) Photomicrograph of Igarra metaconglomerate in transmitted light (cross polarized light-cpl), (b) Plane polarized light (ppl) showing fine grained quartz and hornblende as groundmass minerals in diagonal direction of the photo, magnetite are dark euhedral grains, (c) Igarra metaconglomerate under cpl, (d) Igarra metaconglomerate under ppl showing few isolated quartz grains among acicular epidote crystals, (e) Granite-gneiss clast in Igarra metaconglomerate under cpl, (f) ppl indicating porphyroblasts of quartz in diagonal direction in ground mass of biotite and quartz, (g) Otuo metaconglomerate under (cpl) showing compositional layering in the rock-matrix, (h) Otuo metaconglomerate (cpl) showing isolated quartz grains among fibrous chlorite minerals and (i) Photomicrograph of Otuo metaconglomerate (cpl) showing epidote (blue and green), chlorite (reddish brown) and calcite (grey)

that the rock contains quartz (56%), epidote (9.7%), calcite (8.2%), chlorite (9.4%), hornblende (4.3%), feldspar (2.1%), biotite (2.1%) and others (8.6%).

The diffraction trace for the granite-gneiss clast in Igarra metaconglomerate (Fig. 4b) is dominated by quartz, feldspar and biotite, where quartz constitute 60%, biotite 21.3%, feldspar 5.3% while other constituents contributed about 13.3% to the mineralogy.

Otuo metaconglomerate (Fig. 4c) contains: Quartz (44.3%), chlorite 19.3%, epidote 13.2%, calcite 11.9%, hornblende 3.9%, magnetite 1.7%, pyroxene 1.9% and others 3.7%. The rock from the two areas demonstrates a seemingly similar mineralogical composition. However, the percentage composition of the different mineral constituents varies slightly. For instance, while the rocks from both areas contains and shear quartz, epidote, calcite, chlorite and hornblende; Igarra metaconglomerate contains feldspar and biotite in addition, while Otuo samples have traces of magnetite and pyroxene.

DISCUSSION

Structural geology: Almost from the moment sediments are deposited, they begin to respond to a variety of deformational forces. They are compressed by a heavy overlying rocks, squeezed and stretched along the margins of moving rock bodies and subside or rise as they strive to attain equilibrium with denser rocks that lie far beneath the earth's surface. All these contribute to making of geological structures. Even though, deformational structures associated with shearing forces are more prevalent in cataclastic metamorphic terrains of the world, Igarra area is not without its own share of

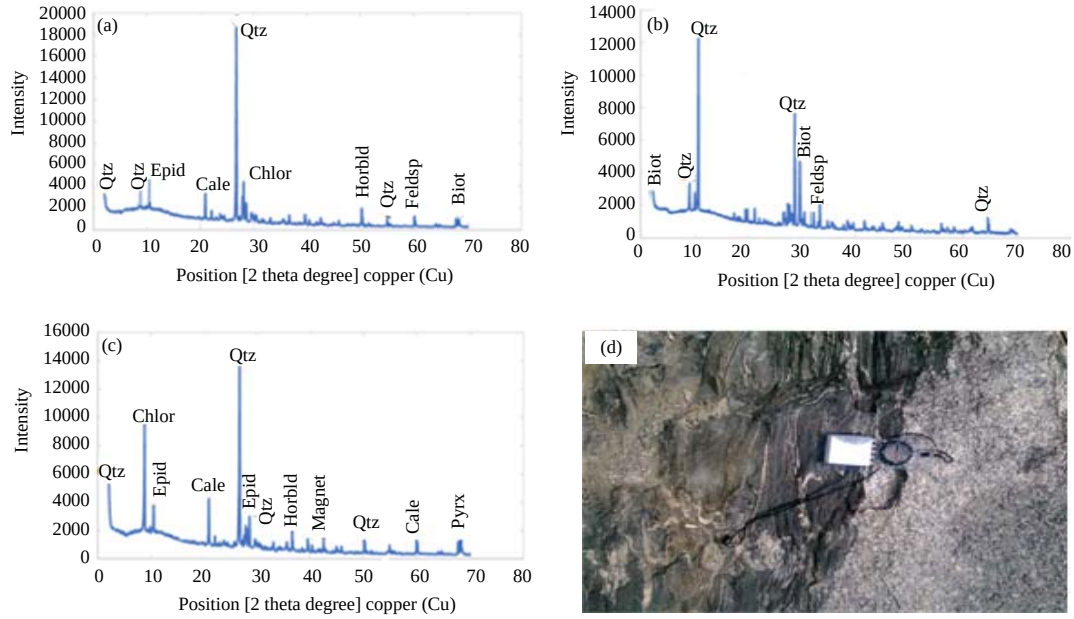

Fig. 4(a-d): Rock outcrop of metaconglomerate /granite and X- ray diffractograms of rocks from the study area, (a) X-ray diffraction trace of Igarra metaconglomerate, (b) X-ray diffraction trace of the granite-gneiss clast in Igarra metaconglomerate, (c) X-ray diffraction trace of Otuo metaconglomerate and (d) A sharp contact relationship between metaconglomerate and granite exposed within a river valley in Igarra area

structures such as faults, folds and boudins. However, the way a rock responds to structure- producing forces is influenced by its mineralogical features. Metaconglomerate is one of such rock in Igarra area with diverse structures. Rock deformation in the Earth's crust is known to be highly heterogeneous[27,28], with localized domains of highest strain seen in metamorphic zones of the earth. Crustal-scale numerical models of tectonic processes using rheological flow properties have provided important insights into scenarios such as continental break-up and collision and their surface expression in the earth's surface[29]. While there is ongoing discussion of appropriate rheological models for the upper crust[30], it is generally accepted that the most suitable rheological model for the middle to lower crust is thermally activated viscous flow[31]. For decades, geologists have used field evidence of different structures to derive the flow characteristics of crustal rocks. For example[32]; used deformed pebbles[33]; used shear zones, whereas boudins and mullions have been used in several studies[34,35].

Contact relationships: The significance of lithologic contacts in geologic mapping cannot be overemphasized.

However, from the nature of the contacts a geologist can give more information about rocks relationship and geologic processes that had operated in the past. Even though the geologic contacts between most of the basement rocks are not well-exposed in most parts of the study area, however, in specific areas, lithologic boundaries are distinct. The contacts between metaconglomerate and granite were observed in two places in Igarra area; one along the river channel through Balogun axis into Somorika road (Fig. 4d), which is sharp and the other exposed at a road cut along Igarra-Ibillo new road. The geological contact exposed by the road cut is gradational due to assimilation and exchange of materials through metasomatism to produce an aureole (Fig. 5a). At this point, a complete digestion and assimilation of the components of the metaconglomerate into the granitic mass to produce a hybrid rock of different composition, mineralogy and texture was observed.

Quartz vein intrusions: Quartz vein intrusion is not as frequently encountered in the metaconglomerate as in other rocks in the basement complex. This structural feature cannot be mapped on the scale of the study. Quartz vein intrusions around Igarra are essentially hyper-leucocratic quartzo-feldspartic impregnations that are easily distinguished from the host rock by their colour, texture and mineralogy. The veins are frequently oriented in N-S or NE-SW directions, while in few locations; it is oblique to the general N-S foliation trends of the rock (Fig. 5b). Quartz veins usually

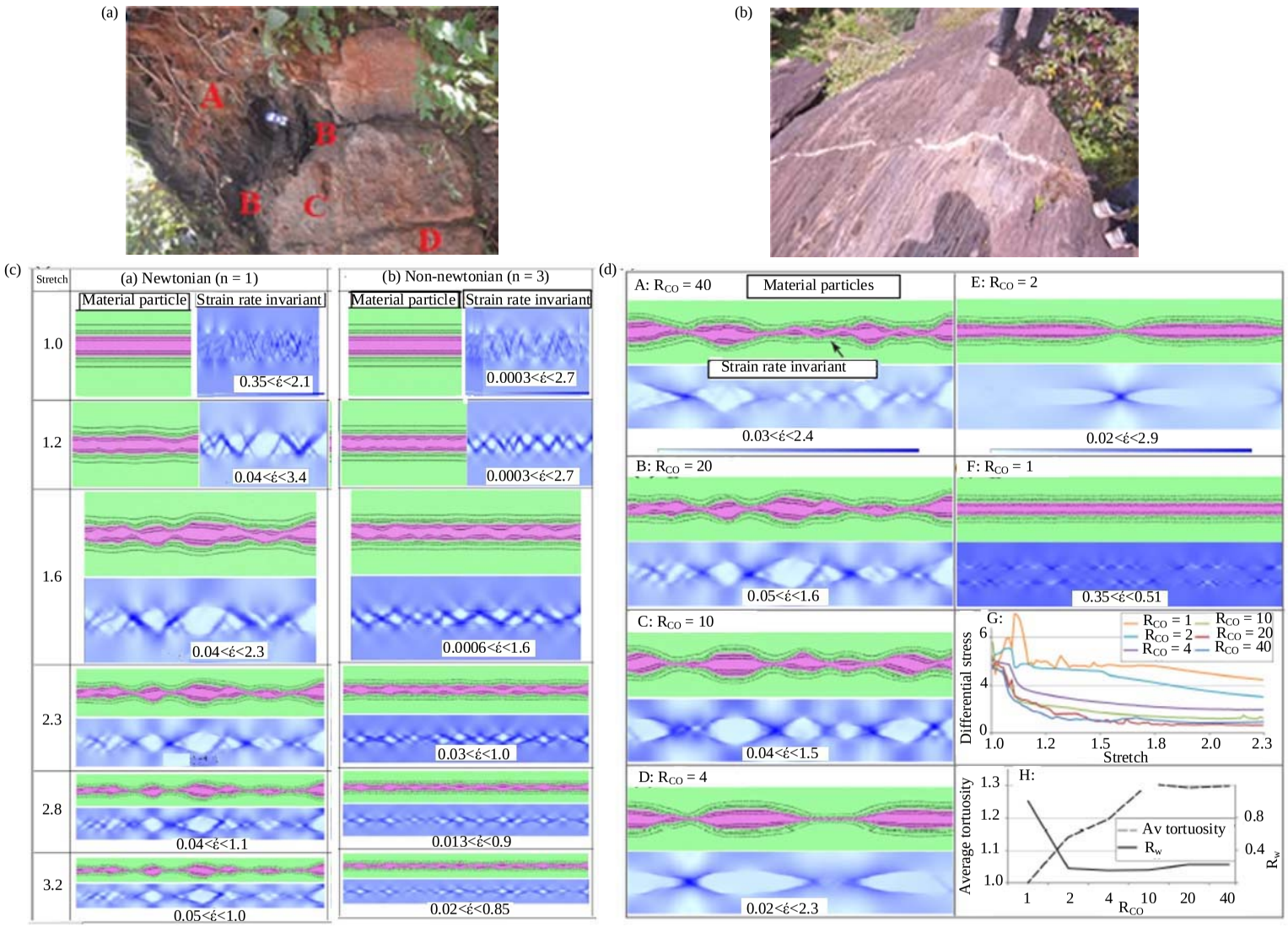

Fig. 5(a-d): Contact of metaconglomerate with intrusive granite and 2-D simulation model for evolution of pinch and swell structure, (a) Geologic contact between metaconlomerate (A) with relics of foliation and granite intrusion (B) exposed at a road cut along Ibilo-Auchi road near Igarra. Metasomatic zone (C) of the granite is altered mineralogically, texturally and structurally by assimilation and exchange of materials, (b) Quartz vein intrusion (white) obliquely emplaced into a foliated metaconglomerate in Balogun area, Igarra, (c) 2-D (3 layers) simulation model for evolution of pinch and swell structure with variation in the amount of stretch[29] and (d) 2-D results for different strain rate invariant and cohesion ratios[29]

take advantage of pre-existing cracks, fractures or any other plane of discontinuity within the host rock, so they form fracture fillings and as quartz injections. Veins offer convincing evidence for channelled flow of fluids through fractured rocks. They are most commonly of quartz but locally include other minerals, such as feldspar. Mineral assemblages in some veins are like those in the host wall rocks, suggesting formation during peak metamorphic conditions and possibly local interchange of material via a fluid into an open fissure. Many petrologists have considered how quartz veins are formed and all have come to the same conclusion that copious amounts of fluid, principally aqueous solutions are required, even though quartz is one of the most soluble minerals under metamorphic conditions.

Pinch and swell structures: Boudins are chains of rock fragments sometimes joined by thin necks giving them the appearance of a string of sausages[36]. They form when a more competent layer undergoes layer parallel extension in a weaker matrix and can range in size from microscopic to outcrop and to regional scales[37-39]. Boudins have been used to suggest that rock units are deformed by a mixture of brittle and/or semi-brittle to ductile flow[40-44]. Pinch and swell structures, also called drawn or necked boudins, are a subset of boudins that retain continuity of the drawn layers but show variable thinning of the original layer thickness. Pinch and swell structures found in a high strain zones suggest that the structures may be initiated by brittle failure of the more competent layer in conjunction with subsequent material softening[29]. Pinch and swell structures often develop in a competent layer, in both Newtonian and non-Newtonian flow, provided the competent layer has sufficient viscosity contrast and can localize strain to form shear bands[29]. The degree of material softening after the initial strain localizing behaviour is shown to impact pinch and swell characteristics, while extensive material softening causes the formation of thick necks between swells by limiting the focused localization of strain into shear bands[29]. Once initiated through strain localization, pinch and swell structure evolution is influenced by the flow properties of all the layers[45]. Based on these observations[29], conceptualize a numerical model to describe the growth of pinch and swell structures to encompass: (1) No specified geometric perturbation in the competent layer; (2) The ability to deform by brittle failure, resulting in pairs of fault planes that occur dynamically; (3) The ability to soften the material to variable degrees after brittle failure has occurred and (4) The ability to implement both Newtonian and non-Newtonian viscous flow. As the stretch increases (Fig. 5c), all layers are elongated and thinned. The necks thin more quickly than the swells, causing the marker layer to distort near the localization of strain in the neck. Three stages of pinch and swell structure were distinguished as the structures develop with progressive deformation, that is, with decreasing RW and increasing stretch: Stage 1 is where zones of localized strain are establishing and the structures have not started to form: 0.4<RW<0.75 (Fig. 5c stretch 1.2-1.6). Stage 2 is where the strain has localized and pinch and swell structures have successfully been initiated and are starting to separate: 0.2<RW<0.4 (Fig. 5c stretch 1.6-2.5). Stage 3 is where the pinch and swell structures have successfully formed and are well-defined and separated: RW<0.2 (Fig. 5c stretch 2.5-3.2). Attenuation of the neck is developed where RW<0.05. Results for different strain invariant ($\acute{\varepsilon}$) and cohesion ratios ($40<R_{Co}<1$) before and after softening (Fig. 5d). (a-f) model results at stretch 2.3 showing the effect of varying cohesion after softening in Newtonian flow with RV D = 10. R_{Co} is the ratio of initial cohesion to cohesion after softening; high RCo (a, b) indicates strong material softening while RCo D = 1 (f) Has no material softening[29].

CONCLUSION

The field relationship, mineralogical and structural characteristics of Igarra and Otuo metaconglomerates have been investigated to highlight their similarity and/or dissimilarity as well as update the geology of the area. Petrographical evaluation reveals a seemingly similar mineralogy except that feldspar is absent in the mineral component of Otuo. Absence of feldspar at Otuo suggests that the feldspar might have weathered into clay deposit. Structural elements in the two areas (lineations, joints, faults, folds and matrix supported polymictic clasts) indicate a highly strained area that has undergone polycyclic deformation. The pinch and swell structures in such environment were formed as a result of plastic and brittle deformation mechanism.

SIGNIFICANCE STATEMENT

This study discovers that the mineralogical composition of Igarra and Otuo metaconglomerates are similar except that feldspar is absent in that of Otuo. Structural elements (lineations, joints, fractures, folds, faults and boudins) indicate a high strain environment that has undergone polycyclic deformation.

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REFERENCES

1. Odeyemi, I.B., 1990. The petrology of a Pan-African pluton in Igarra area, Southwestern, Nigeria. Niger. J. Sci., 24: 181-193.
2. Odeyemi, I.B., 1976. Preliminary Report on the Field Relationships of the Basement Complex Rocks around Igarra, Mid-West. In: Geology of Nigeria, Kogbe, C.A. (Ed.). Elizabethan Publishing, Surulere, Lagos State, Nigeria, pp: 59-63.
3. Ocan, C.O., S.L. Coker and I.G. Egbuniwe, 2003. The geology of Igarra-Auchi area. Proceedings of the 39th Annual International Conference of the Nigerian Mining and Geosciences Society, March 2-8, 2003, Itakpe, Nigeria, pp: 52.
4. Odeyemi, I.B., 1977. On the basement rocks of Bendel State of Nigeria. Ph.D. Thesis, University of Ibadan, Nigeria.
5. Odeyemi, I.B., 1988. Lithostratigraphy and Structural Relationship of the Upper Precambrian Metasediments in Igarra, Area Southwestern Nigeria. In: The Precambrian Geology of Nigeria, Oluyide, P.O., W.C. Mbonu, A.E. Ogezi, I.G. Egbuniwe, A.C. Ajibade and A.C. Umeji (Eds.). Esho Publ., Kaduna, Nigeria.
6. Rahaman, M.A. and O. Ocan, 1988. The Nature of Granulite Facies Metamorphism in Ikare Area, Southwestern Nigeria. In: Precambrian Geology of Nigeria, Oluyide, P.O., W.C. Mbonu, A.E. Ogezi, I.G. Egbuniwe, A.C. Ajibade and A.C. Umeji (Eds.). Geological Survey of Nigeria, Kaduna, Nigeria, pp: 157-163.
7. Odeyemi, I.B. and M.A. Rahaman, 1992. The petrology of a composite syenite dyke in Igarra, Southwestern Nigeria. J. Mining Geol., 28: 255-263.
8. Obasi, R.A. and O.L. Anike, 2012. Geochemical and economic application of marble from Igarra and Ikpeshi areas, S.W. Nigeria. Int. J. Eng. Technol., 2: 1723-1727.
9. Obiadi, I.I., A.G. Onwuemesi, O.L. Anike, C.M. Obiadi and N.E. Ajaegwu *et al*., 2012. Imaging subsurface fracture characteristics using 2D electrical resistivity tomography. Int. Res. J. Eng. Sci. Technol. Innov., 1: 103-110.
10. Oloto, I.N. and D.E. Anyanwu, 2013. Petrology of Ibillo-Magongo area of Igarra, Edo State, Nigeria. Adv. Applied Sci. Res., 4: 140-145.
11. Emofurieta, W.O., 1985. The geochemistry and petrology of two prominent gneiss in the basement complex around Igbetti, Southwestern Nigeria. J. Min. Geol., 22: 125-135.
12. Elueze, A.A., 1981. Geochemistry and petrotectonic setting of meta sedimentary rocks of the schist belt of Ilesha area S.W. Nigeria. Precambrian Res., 19: 167-177.
13. Rahaman, M.A., 1976. A Review of the Basement Geology of South Western Nigeria. In: Geology of Nigeria, Kogbe, C.A. (Ed.). Elizabethan Publishing, Surulere, Lagos State, Nigeria, pp: 41-58.
14. Elueze, A.A., 1988. Geology of the Precambrian of Schist Belt in Ilesha Area, Southwestern Nigeria. In: Precambrian Geology of Nigeria, Oluyide, P.O., W.C. Mbonu, A.E. Ogezi, I.G. Egbuniwe, A.C. Ajibade and A.C. Umeji (Eds.). Publication of Geological Survey of Nigeria, Kaduna, Nigeria, pp: 72-82.
15. Rahaman, M.A., 1988. Recent Advances in the Study of the Basement Complex of Nigeria. In: Precambrian Geology of Nigeria, Oluyide, P.O., W.C. Mbonu, A.E. Ogezi, I.G. Egbuniwe, A.C. Ajibade and A.C. Umeji (Eds.). Geological Survey of Nigeria, Kaduna, Nigeria, pp: 11-43.
16. Turner, D.C., 1983. Upper proterozoic schist belts in the Nigerian sector of the Pan-African province of West Africa. Precambrian Res., 21: 55-79.
17. Adekoya, J.A., 1996. The Nigerian schist belts: Age and depositional environment implications from associated banded iron-formations. J. Min. Geol., 31: 35-46.
18. Okunlola, O.A., 2005. Metallogeny of Ta-Nb mineralization of precambrian pegmatites of Nigeria. Books of Abstracts, Nigeria Mining and Geosciences Society, International Mineral Wealth, 137/2005.
19. Russ, W., 1957. The geology of parts of Niger, Zaria and Sokoto provinces: With special reference to the occurrence of gold. Geological Survey of Nigeria Bulletin No. 27, pp: 1-42.
20. Oyawoye, M.O., 1964. Geology of the Nigerian basement complex. J. Nig. Min. Geol. Metallurgi. Soc., 1: 87-102.
21. McCury, P., 1976. The Geology of the Precambrian to Lower Palaeozoic Rocks of Northern Nigeria: A Review. In: Geology of Nigeria, Kogbe, C.A. (Ed.). Elizabethan Publishing, Surulere, Lagos State, Nigeria, pp: 15-39.
22. Black, R., 1980. Precambrian of West Africa. Episode, 4: 3-8.
23. Ajibade, A.C., 1980. Geo tectonic evolution of the Zungeru region, Nigeria. Ph.D. Thesis, University College Wales, UK.
24. Truswell, J.F. and R.N. Cope, 1963. The geology of parts of Niger and Zaria provinces, Northern Nigeria. Geological Survey of Nigeria Bulletin No. 29, pp: 1-52.
25. Elueze, A.A., 2002. Compositional character: Veritable tool in the appraisal of geomaterials. An Inaugural Lecture, University of Ibadan, February 28, 2002, pp: 1-43.
26. Anifowose, A.Y.B., O.A. Bamisaye and I.B. Odeyemi, 2006. Establishing a solid mineral database for a part of Southwestern Nigeria. Geospatial Application Paper, Nigeria, pp: 1-3.
27. Rudnick, R.L. and S. Gao, 2003. Composition of the Continental Crust. In: Treatise on Geochemistry, Volume 3: The Crust, Rudnick, R.L. (Ed.). Chapter 3.01, Elsevier Ltd., USA., ISBN-13: 978-0080448473, pp: 1-64.

28. Taylor, S.R. and S.M. McLennan, 1985. The Continental Crust: Its Composition and Evolution. Blackwell, Oxford, UK., ISBN-13: 978-0632011483, Pages: 312.
29. Gardner, R.L., S. Piazolo and N.R. Daczko, 2015. Pinch and swell structures: evidence for strain localisation by brittle-viscous behaviour in the middle crust. Solid Earth, 6: 1045-1061.
30. Moresi, L. and H.B. Muhlhaus, 2006. Anisotropic viscous models of large-deformation Mohr-Coulomb failure. Philos. Mag., 86: 3287-3305.
31. Molnar, P. and G.A. Houseman, 2004. The effects of buoyant crust on the gravitational instability of thickened mantle lithosphere at zones of intracontinental convergence. Geophys. J. Int., 158: 1134-1150.
32. Treagus, S.H. and J.E. Treagus, 2002. Studies of strain and rheology of conglomerates. J. Struct. Geol., 24: 1541-1567.
33. Ramsay, J.G., 1980. Shear zone geometry: A review. J. Struct. Geol., 2: 83-99.
34. Kenis, I., J.L. Urai, W. van der Zee and M. Sintubin, 2004. Mullions in the High-Ardenne Slate Belt (Belgium): Numerical model and parameter sensitivity analysis. J. Struct. Geol., 26: 1677-1692.
35. Urai, J.L., G. Spaeth, W. van der Zee and C. Hilgers, 2001. Evolution of mullion (boudin) structures in the variscan of the Ardennes and Eifel. J. Virtual Explorer, 3: 1-16.
36. Lohest, M., 1909. De l'origine des veines et des geodes des terrains primaires de Belgique. Ann. Soc. Geol. Belgique, 36: 275-282.
37. Goldstein, A.G., 1988. Factors affecting the kinematic interpretation of asymmetric boudinage in shear zones. J. Struct. Geol., 10: 707-715.
38. Klepeis, K.A., N.R. Daczko and G.L. Clarke, 1999. Kinematic vorticity and tectonic significance of superposed mylonites in a major lower crustal shear zone, Northern Fiordland, New Zealand. J. Struct. Geol., 21: 1385-1405.
39. St-Onge, M.R., J.A.M. van Gool, A.A. Garde and D.J. Scott, 2009. Correlation of Archaean and Paleoproterozoic units between Northeastern Canada and Western Greenland: Constraining the pre-collisional upper plate accretionary history of the Trans-Hudson orogen. Geol. Soc. London Spec. Publ., 318: 193-235.
40. Abe, S. and J.L. Urai, 2012. Discrete element modeling of boudinage: Insights on rock rheology, matrix flow and evolution of geometry. J. Geophys. Res.: Solid Earth, Vol. 117. 10.1029/2011JB008555
41. Arslan, A., C.W. Passchier and D. Koehn, 2008. Foliation boudinage. J. Struct. Geol., 30: 291-309.
42. Komoroczi, A., S. Abe and J.L. Urai, 2013. Meshless numerical modeling of brittle-viscous deformation: First results on boudinage and hydrofracturing using a coupling of Discrete Element Method (DEM) and Smoothed Particle Hydrodynamics (SPH). Comput. Geosci., 17: 373-390.
43. Marques, F.O., P.D. Fonseca, S. Lechmann, J.P. Burg, A.S. Marques, A.J.M. Andrade and C. Alves, 2012. Boudinage in nature and experiment. Tectonophysics, 526-529: 88-96.
44. Van der Molen, I., 1985. Interlayer material transport during layer-normal shortening. Part II. Boudinage, pinch-and-swell and migmatite at Sondre Stromfjord Airport, West Greenland. Tectonophysics, 115: 297-313.
45. QScott, B.H., 1977. Petrogenesis of kimberlites and associated potassic lamprophyres from West Greenland. Proceedings of the 2nd International Kimberlite Conference, October 3-7, 1977, Santa Fe, NN., USA., pp: 3.