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METAMORPHIC EVOLUTION OF A METABASITE DYKE FROM OGBAGI AKOKO AREA, SOUTHWESTERN NIGERIA

Oziegbe, E. J.[1,*], Ocan, O. O.[2], Adetunji, A.[3] and Oziegbe, O.[4]

[1] Department of Geosciences, University of Lagos, Lagos, Nigeria.
[2] Department of Geological Sciences, College of Science, Engineering and Technology, Osun State University, Osogbo, Nigeria.
[3]Department of Geology, Obafemi Awolowo University, Ile-Ife, Nigeria.
[4]Department of Biological Sciences, Covenant University, Ota, Nigeria.
[*]Corresponding Author's Email: eoziegbe@unilag.edu.ng

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ABSTRACT

Petrography, mineral chemistry and whole rock analyses were conducted on a metabasite dyke hosted by pelitic gneiss (metapelite) in Ogbagi Akoko area with the aim of determining its metamorphic evolution. The dyke is about 40 cm wide and traceable for some meters along strike. It has a discordant contact relationship that is pencil sharp with the host pelitic gneiss and lack any internal fabric. The mineral assemblage includes: garnet + biotite + plagioclase + quartz + orthopyroxene + K-feldspar + ilmenite, with apatite occurring as an accessory mineral. Plagioclase has anorthite content of about 76 (An_{76}) suggesting bytownite ($An_{76}Ab_{24}Or_0$) while garnets are poikiloblastic almandine-pyrope rich with XFe of 0.73-0.75. Orthopyroxene has a composition of $Wo_0En_{50}Fs_{50}$ suggesting hypersthene that is depleted in Ca. The mineral assemblage, presence of bytownite, absence of amphibole and lack of internal fabric indicate that the rock has undergone metamorphism at a high temperature and moderate pressure without deformation at granulite facies metamorphism. The absence of deformation structure in the dyke is an indication that the intrusion occurred after the cessation of the regional metamorphism but prevalent high temperature that recrystallized the rock. The whole rock composition and some elemental ratios of the dyke indicate that the metamorphism had little or no effect on the bulk chemistry of the rock.

Keywords: Almandine-pyrope, Hypersthene, Granulite facies, Metabasite.

INTRODUCTION

Metabasite are metamorphosed dark mafic rocks of igneous origin (Frost and Frost, 2019). These igneous protoliths of metabasites include basalt, dolerite and gabbro (rich in Fe and Mg) that have been subjected to a very high temperature and pressure different from the ones under which they were formed. Metabasite can occur as intrusive dykes (Srivastava *et al*., 2012; Hosseini *et al*., 2015) and are capable of preserving records of high-grade metamorphism in the form of mineral assemblage and chemical composition. Because of these, metabasites are excellent rocks that can be used to evaluate metamorphic evolution of any geological terrane that have undergone high grade metamorphism. The studied metabasite occurred in Ogbagi Akoko area about 10.8 km from Ikare Akoko and is located in the Basement Complex of southwestern Nigeria. The Basement Complex (Figure 1) is a component of the three major litho-petrological units that make up the solid geology of Nigeria and it forms part of the Pan-African mobile belt which lies between the West African and Congo Cratons and south of the Tuareg Shield (Black, 1980). The other two components of the three litho-petrological units of solid geology on Nigeria are the Younger Granite suites and Cenozoic to recent volcanics. The Basement complex of Nigeria has two sub-divisions (Ajibade *et al*., 1979; Haruna, 2017) the Western Province and the Eastern Province (Figure 1). Ikare area of the Basement Complex falls under the western province. Dempster (1966), described the rocks of Ikare as variably migmatized, undifferentiated, biotite and biotite-hornblende-gneiss with intercalated amphibolite (Migmatite-Gneiss Complex). The Basement Complex outcrop of Ikare area had been reported to comprise of over 90% of the Migmatite gneiss-quartzite Complex (Rahaman, 1978). Studies in Ikare area have identified discontinuous bands of pelitic gneiss enclosed in quartzo-feldspathic gneisses (Rahaman and Ocan, 1988) and in some cases intercalated with quartzo-feldspathic gneisses (Oziegbe *et al*., 2021). The study area

(NW of Ikare) lies within the Ogbagi-Ikare pelitic band that stretches from Ogbagi through Ikare to Iboropa (Figure 2). The metabasite at Ogbagi is dark coloured, fine-medium grained and poorly foliated (Figure 3). The rock, a dyke of about 40 cm wide intrudes a metapelite (Figure 3). Numerous large porphyroblasts of garnet that are up to 5 cm in length were observed (Figure 3). Similar metabasite dykes have been studied in the Ukwortung and Okordem parts of Bamenda massif in the Eastern Nigerian Terrane (Ukwang and Ukaegbu, 2016).

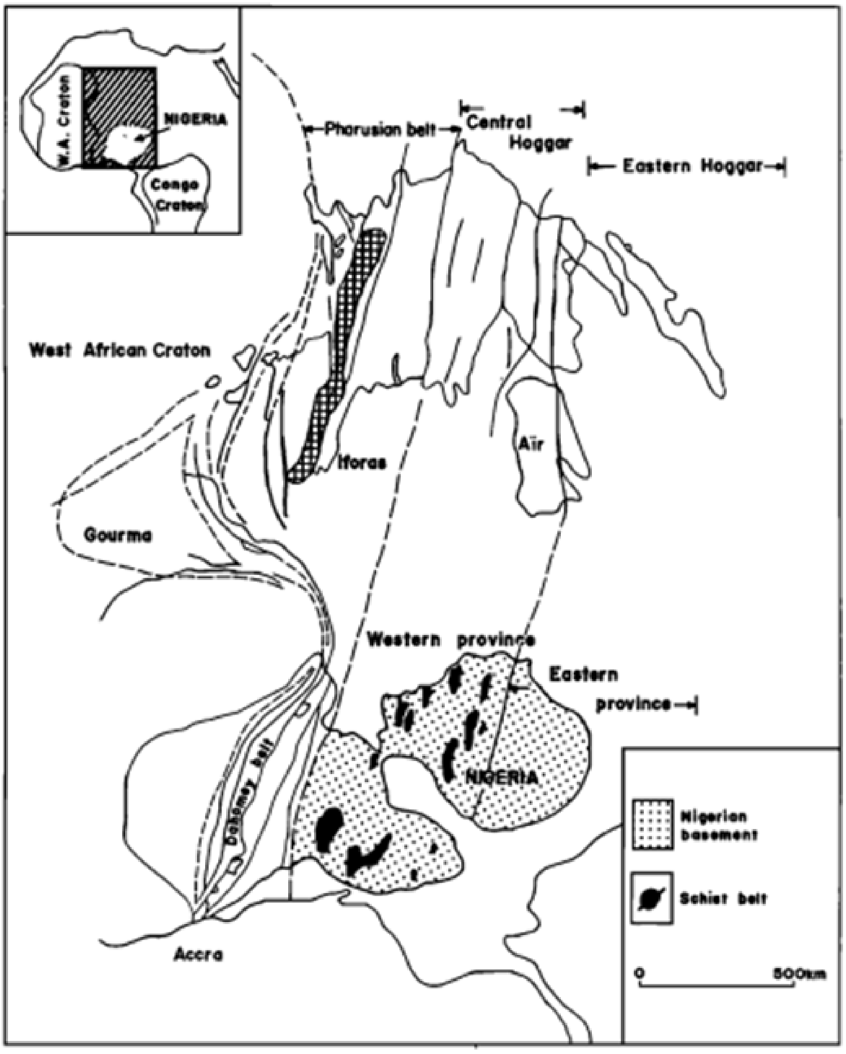

Figure 1: Figure showing the position of the Nigerian Basement (adapted from Ajibade *et al.*, 1987).

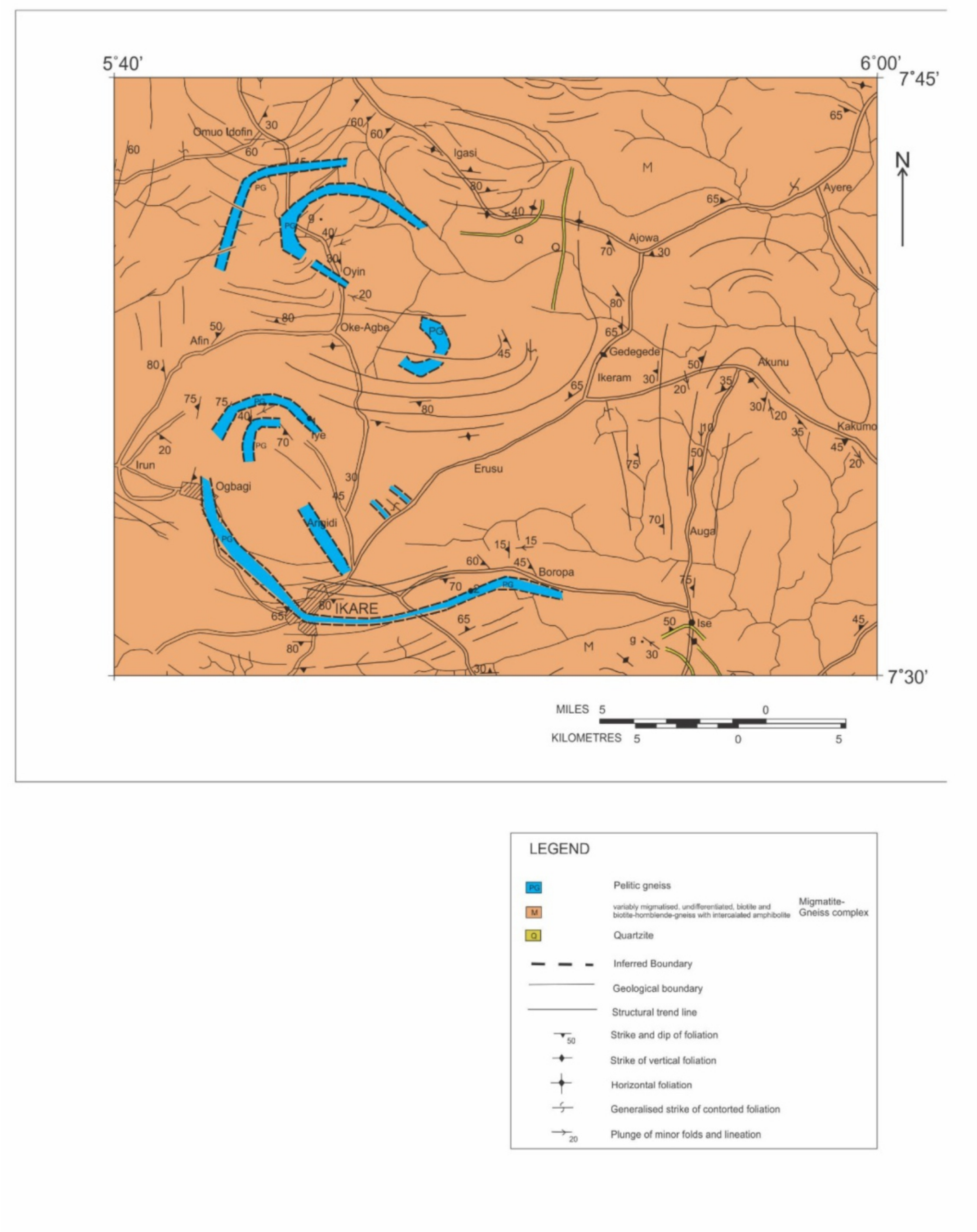

Figure 2: Geological map of the study area (adapted from Oziegbe and Oziegbe, 2023).

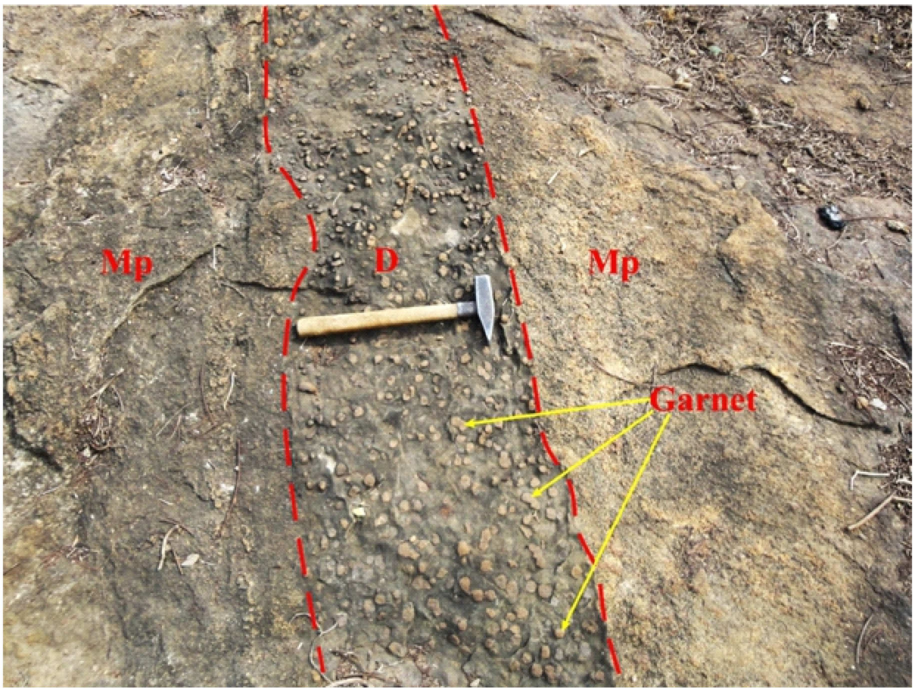

Figure 3: Field photograph of a metamorphosed basic dyke (metabasite) intruded into a metapelite at Ogbagi. Take note of porphyroblasts of garnet in the dyke (Mp: Metapelite, D: Dyke).

Studies on metabasites and those that are in close association with pelitic gneiss have been carried out in different parts of the world (for examples, Liou *et al.*, 1985; Faryad and Bernhardt, 1996; Graessner and Schenk, 2001; Bhowmik and Roy, 2003; Micheletti *et al.*, 2008; Šída and Kachlík, 2009; Braund *et al.*, 2011). Lenticular bodies of metabasites and meta-ultramafics intercalated within staurolite bearing metapelitic schists have been reported in the Schist Belt of Nigeria (Ige *et al.*, 1998). High pressure granulites comprising metapelites and metabasites have been reported from north-central Cameroon (Bouyo *et al.*, 2013). Locally, Rahaman and Ocan (1988) reported the existence of granulite facies on the basis of petrography of the pelitic and charnockitic gneisses in the area. Oyawale and Ocan (2020) studied the structural evolution and nature of transition to granulite facies in the area. Based on the petrographic studies of the pelitic and charnockitic gneisses, the authors proposed four episodes of deformation, three episodes of metamorphism and showed that granulites facies was attained through prograde dehydration reactions aided by reduction in H_2O fugacity and influx of CO_2. These earlier studies did not consider the metabasite in the area. This study thus used petrography, mineral assemblages and chemical data of the metabasite from Ogbagi Akoko to constrain the metamorphic evolution of the terrane.

MATERIALS AND METHODS

Thin sections for petrographic studies were prepared at the Department of Geology, Rhodes University South Africa. Detailed petrographic studies were done at the laboratory of Rhodes University of the same Department. The mineral chemistry was determined using a JEOL JXA 8230 Superprobe, with 4 WD spectrometers at Rhodes University, South Africa. The conditions of operations used were 15 kV acceleration voltage, 20 nA probe current 20 nA, beam size of ~1 micron, counting time of 10 s on peak and 5 s on each lower and upper background, respectively. Major elemental analysis was determined by XRF spectrometry on a PANalytical AxiosWavelength Dispersive spectrometer at the Central Analytical Facilities (CAF), Stellenbosch University, South Africa. At CAF also, Laser Ablation ICPMS was used for the determination of trace and rare elements.

RESULTS

Petrography

The metabasite is dark grey with essentially granoblastic texture and comprises garnet + biotite + orthopyroxene + plagioclase + K-feldspar + quartz + ilmenite as dominant mineral assemblage with apatite occurring as an accessory. Garnet crystals occur as porphyroblasts in the matrix of quartz, biotite and feldspar. Porphyroblasts of garnet are poikiloblastic towards plagioclase, biotite, quartz and ilmenite as a result of their presence as inclusions in the garnet porphyroblasts (Figures 4a & 4b). Grains of biotite are reddish brown and slightly pleochroic (Figures 4c & 4d) indicating high temperature species. Also, xenoblastic biotite grains are concentrated around plagioclase and quartz. Orthopyroxene is xenoblastic, colourless and in close association with biotite and plagioclase (Figures 4e & 4f). Orthopyroxene grains occur in contact with ilmenite (Figures 5a & 5b). Also, orthopyroxene grains were found to be concentrated in garnet-free domains with abundant plagioclase and biotite (Figures 4e & 5a).

Plagioclase has numerous inclusions of ilmenite (Figure 5f) and apatite. Ilmenite grains are idioblastic to sub-idioblastic (Figures 4e, 5a-5f), and are included in both pyroxene and garnet while others occur in the matrix. K-feldspars have microperthitic intergrowth (Figure 5e). Apatite grains are needle-like, idioblastic and are mostly included in garnet, plagioclase, K-feldspar and quartz (Figures 5c & 5d). The presence of quartz and plagiocalse are confirmed by Wavelength Dispersive Scan (Figures 6 &7), although these are presented in the form dominant elements in the figures.

Mineral Chemistry

The mineral chemistry of garnet from core-rim (Table 1) shows higher values of SiO_2 and FeO at the rim while TiO_2 and CaO values are generally higher at the core.

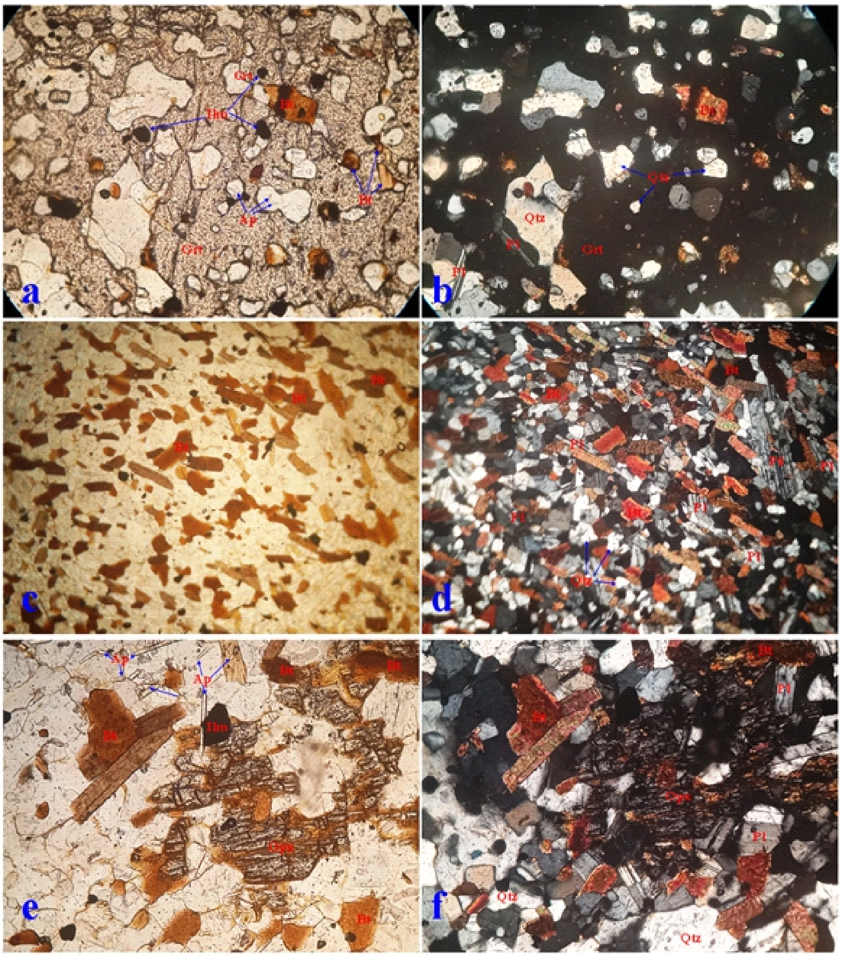

Figure 4: Photomicrographs of metabasite showing: (a) poikiloblastic texture; inclusions of ilmenite (Ilm) and biotite (Bt) in porphyroblast of garnet (Grt), PPL (b) poikiloblastic texture; inclusions of quartz (Qtz) and plagioclase (Pl) in porphyroblast of garnet (Grt), XPL (c) reddish brown biotite (Bt) grains, PPL (d) biotite (Bt) interlocked with plagioclase (Pl) and quartz (Qtz) grains, XPL (e) orthopyroxene (Opx) in contact with xenoblastic grains of biotite, take note of idioblastic apatite (Ap) crystals, PPL (f) plagioclase (Pl) surrounded by xenoblastic orthopyroxene XPL.

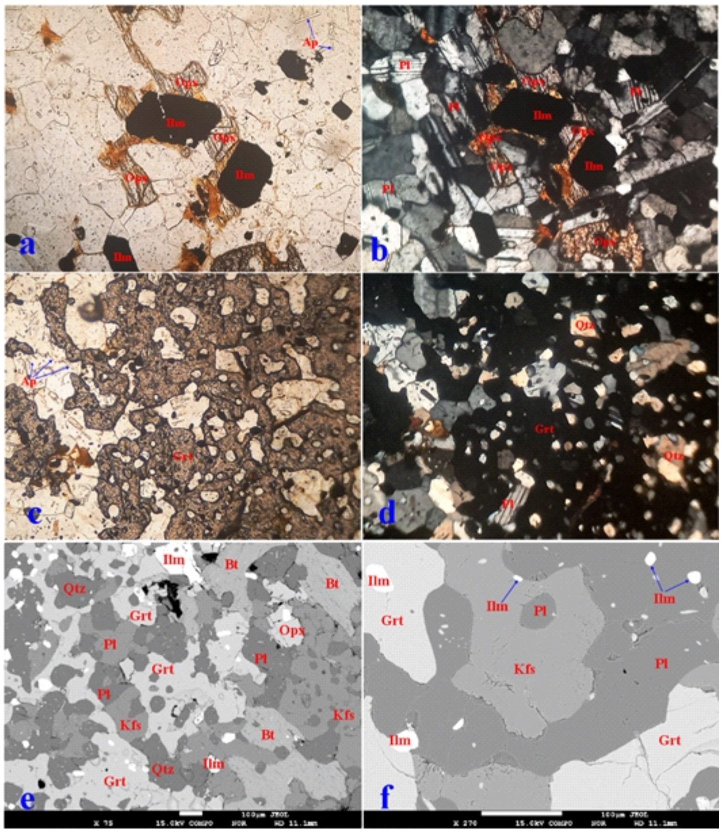

Figure 5: Photomicrographs of metabasite showing: (a) xenoblastic orthopyroxene (Opx) in contact with idioblastic ilmenite (Ilm) grains, PPL (b) orthopyroxene (Opx) in the matrix of quartz (Qtz), plagioclase (Pl) and K-feldspar (Kfs), XPL (c) garnet (Grt) grains with inclusions of apatite (Ap) crystals, PPL (d) garnet (Grt) grians with inclusions of K-feldspar (Kfs) and quartz (Qtz) grains, XPL (e) BSE image of metabasite; showing orthopyroxene (Opx) in close contact with microperthite and biotite (Bt), take note of quartz inclusions in garnet (Grt) grain (f) BSE image of metabasite; ilmenite (ilm) inclusions in garnet (Grt) and plagioclase (Pl) grains; microperthitic intergrowth between plagioclase (Pl) and K-feldspar (Kfs).

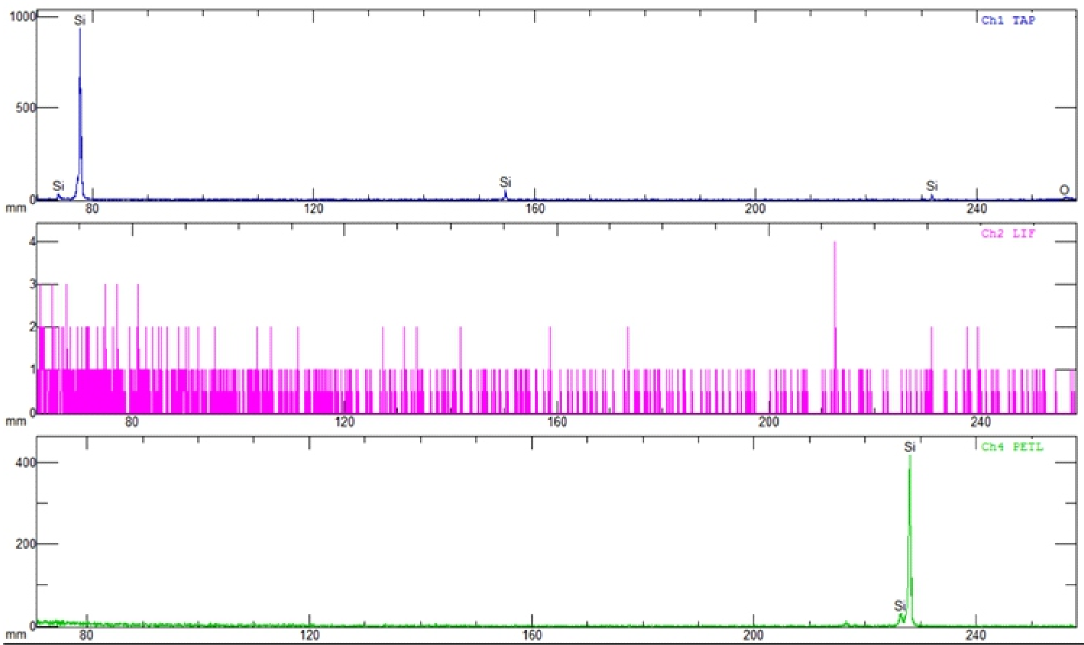

Figure 6: Wavelength Dispersive Scan (WDS) image of metabasite showing quartz.

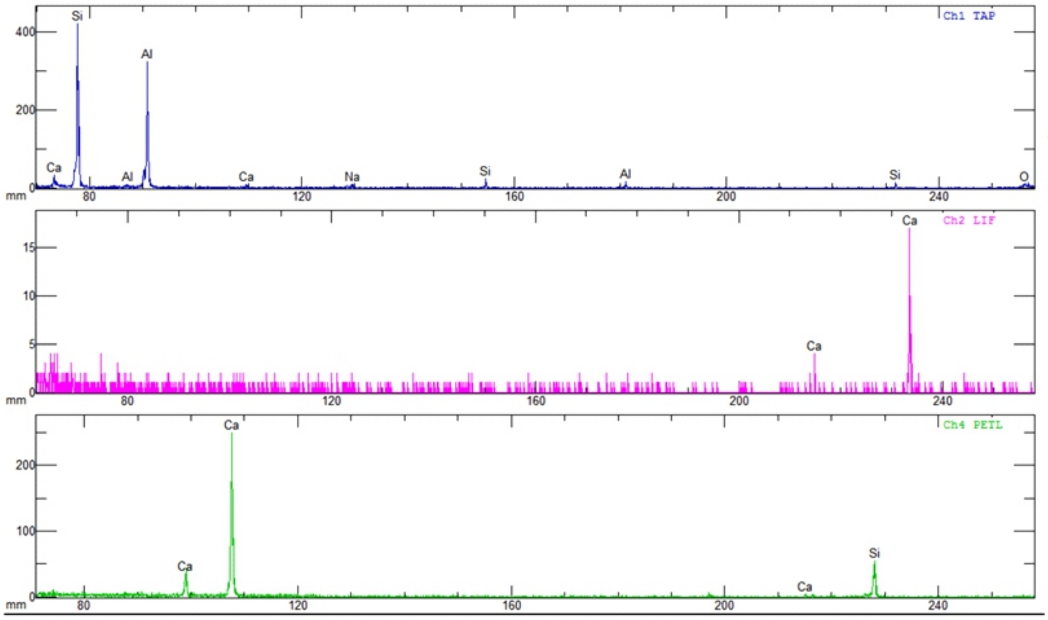

Figure 7: Wavelength Dispersive Scan (WDS) image of metabasite showing plagioclase feldspar.

Table 1: Chemical composition of garnet in metabasite.

Sample	22_1g1c1	22_1g1r1	22_1g2c1	22_1g2r1	22_3g1c1	22_3g1r1	22_3g2c1	22_3g2r1
SiO_2	39.14	39.31	39.76	39.4	39.43	39.67	39.52	39.61
TiO_2	0.05	0.04	0.03	0.00	0.05	0.01	0.00	0.06
Al_2O_3	21.30	21.26	21.42	21.27	21.13	21.51	21.35	21.61
Cr_2O_3	0.07	0.03	0.00	0.05	0.02	0.04	0.06	0.04
FeO	30.50	31.37	31.32	32.06	28.55	30.73	30.68	30.34
MnO	0.45	0.56	0.37	0.46	0.62	0.49	0.68	0.54
MgO	6.11	5.97	6.28	6.01	5.59	6.28	6.28	6.20
CaO	2.88	2.77	2.77	2.66	4.93	3.13	3.30	3.00
Na_2O	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02
Total	100.43	101.28	101.95	101.86	100.3	101.83	101.81	101.38
Si	3.058	3.054	3.063	3.045	3.081	3.054	3.044	3.062
Ti	0.003	0.002	0.002	0.000	0.003	0.001	0.000	0.004
Al(VI)	1.961	1.946	1.945	1.937	1.946	1.952	1.938	1.969
Cr	0.004	0.002	0.000	0.003	0.001	0.002	0.004	0.002
Fe^{2+}	1.992	2.038	2.017	2.072	1.865	1.978	1.976	1.961
Mn	0.030	0.037	0.024	0.030	0.041	0.032	0.044	0.035
Mg	0.712	0.691	0.721	0.692	0.651	0.721	0.721	0.714
Ca	0.241	0.231	0.229	0.220	0.413	0.258	0.272	0.248
Na_2O	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.003
SUM Z (Si,Al)	3.060	3.056	3.064	3.045	3.084	3.055	3.044	3.066
SUM Y (R^{3+})	1.968	1.950	1.946	1.940	1.950	1.955	1.942	1.975
SUM X (R^{2+})	2.974	2.996	2.991	3.015	2.970	2.989	3.014	2.960
Prp	23.92	23.07	24.11	22.97	21.92	24.11	23.93	24.14
Alm	66.98	68.01	67.44	68.73	62.80	66.18	65.57	66.27
Sps	1.00	1.23	0.81	1.00	1.38	1.07	1.47	1.20
Grs	8.07	7.68	7.64	7.29	13.87	8.62	9.02	8.37
Uv	0.02	0.00	0.00	0.01	0.01	0.01	0.02	0.01
Total	99.99	99.99	99.99	100.00	99.98	100.00	100.00	99.99
XFe	0.74	0.75	0.74	0.75	0.74	0.73	0.73	0.73

The distribution of other elements is not consistent across the two zones. XFe is almost uniform as the values vary from 0.73-0.75. Even though, there are slight variations in elemental compositions from the core to rim of the garnet, no compositional zoning was observed in the BSE image (Figures 5e & 5f). Pyroxene has high orthopyroxenes (49.99-50.12 wt % enstatite and 49.4-49.59 wt % ferrosilite), a composition indicating hypersthene (Table 2). Plagioclase feldspar has high anorthite content > 76 wt % (Table 2).

Table 2: Chemical composition of pyroxene, plagioclase in metabasite.

	Pyroxene		Plagioclase	
Sample	22 core	22 rim	Sample	22
SiO_2	51.55	51.37	SiO_2	49.20
TiO_2	0.08	0.04	TiO_2	0.01
Al_2O_3	1.87	2.00	Al_2O_3	31.65
FeO	30.18	30.3	FeO	0.08
Cr_2O_3	0.05	0.04	MnO	0.02
MnO	0.16	0.13	MgO	0.00
MgO	17.15	17.32	BaO	0.01
CaO	0.2	0.23	CaO	15.19
Na_2O	0.02	0.00	Na_2O	2.60
K_2O	0.03	0.03	K_2O	0.07
Total	101.28	101.45	Total	98.82
TSi	1.962	1.951	Si	2.271
TAl	0.038	0.049	Al	1.721
TFe^{3+}	0.000	0.000	Fe^{3+}	0.000
M1Al	0.046	0.040	Ti	0.000
M1Ti	0.002	0.001	Fe^{2+}	0.003
$M1^{Fe3+}$	0.000	0.007	Mn	0.001
$M1Fe^{2+}$	0.000	0.000	Mg	0.000
M1Cr	0.002	0.001	Ba	0.000
M1Mg	0.950	0.951	Ca	0.751
M2Mg	0.024	0.030	Na	0.232
$M2Fe^{2+}$	0.961	0.955	K	0.004
M2Mn	0.005	0.004	Cations	4.984
M2Ca	0.008	0.009	X	3.992
M2Na	0.001	0.000	Z	0.992
M2K	0.001	0.001	Ab	23.49
Cations	3.999	3.999	An	76.05
WO	0.42	0.47	Or	0.44
EN	49.99	50.12		
FS	49.59	49.4		

M1: smaller octahedral site, M2: larger octahedral site, WO: wollastonite, EN: enstatite, FS: ferrosilite, Ab: Albite, An: anorthite, Or: orthoclase.

Whole Rock Geochemistry

The whole rock chemistry result (Table 3) shows the major oxide content of SiO_2 as 42.01 wt %. CaO (10.23 wt %) is high while TiO_2 (2.84 wt%) is low. K_2O is extremely low with a value of 0.83 wt%. Trace element composition show a high content of V, Cr, Zn, Cu, Co and Ni with values of 420.4 ppm, 171.2 ppm, 106.7 ppm, 39.72 ppm, 34.7 ppm and 56.1 ppm, respectively (Table 3). Large Ion Lithophile Elements (LILE) Ba (1176 ppm) and Sr (451 ppm) are high while Rb (7.84 ppm) is low (Table 3). There is a general depletion in the amount of High Field Strength Elements (HFSE), Zr (40.39 ppm) content is high, while Nb (2.12 ppm), Ta (0.1 ppm) and Hf (1.13 ppm) have low concentrations. The concentration of radioactive elements U and Th is very low (Table 3). There is an enrichment of light rare earth elements (LREE) with respect to heavy rare earth elements (HREE). The chondrite normalized REE plot shows a slight enrichment of Eu with small positive Eu anomaly (Eu/Eu* = 1.217) (Figure 8). Cerium also displays very small anomaly 1.021 (Table 3). Other important elemental ratios are also presented in the Table 3.

Table 3: Whole rock composition of metabasite (major elements in wt.% and trace elements in ppm).

Major Elements	(wt.%)	Trace Elements (ppm)		REE (ppm)	
Sample	22	Sample	22	Sample	22
SiO_2	42.01	V	420.4	Sc	35.68
Al_2O_3	12.38	Cr	171.2	Y	22.07
CaO	10.23	Co	34.7	La	27.3
Fe_2O_3	19.24	Ni	56.1	Ce	63.11
MgO	7.39	Cu	39.72	Pr	8.95
K_2O	0.83	Zn	106.7	Nd	41.38
MnO	0.24	Rb	7.84	Sm	8.06
Na_2O	2.31	Sr	451.1	Eu	3.04
TiO_2	2.84	Zr	40.39	Gd	7.23
P_2O_5	1.58	Nb	2.12	Tb	0.834
Cr_2O_3	0.03	Mo	0.56	Dy	4.75
LOI	0.34	Cs	0.22	Ho	0.858
Total	99.42	Ba	1176	Er	2.115
		Hf	1.13	Tm	0.271
		Ta	0.1	Yb	1.59
		Pb	2.31	Lu	0.209
		Th	0.51	Eu/Eu*	1.217
		U	0.13	Ce/Ce*	1.021
		Zr/Y	1.83	La/Th	53.53
		K/Rb	883.38		
		Rb/Sr	0.02		
		Th/U	3.92		

Europium anomaly: Eu/Eu* and Cerium anomaly: Ce/Ce*.

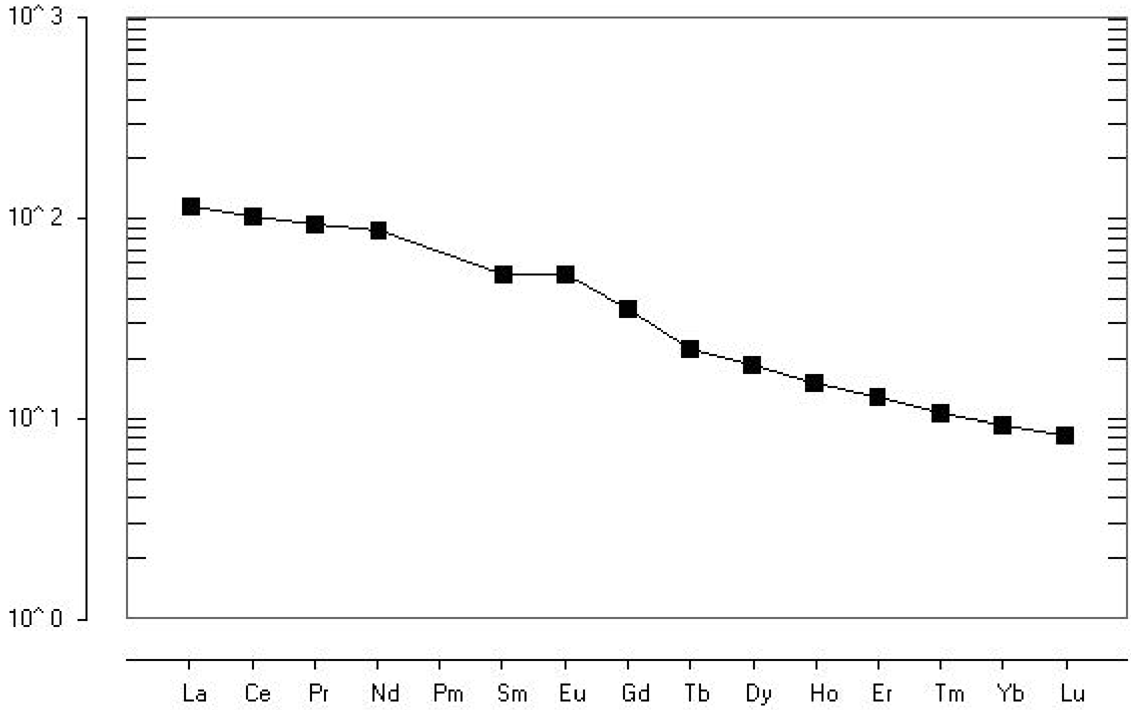

Figure 8: Chondrite normalized REE plots of metabasite; after Sun and McDonough (1989).

DISCUSSION

The metabasite under study is a mafic dyke and it occur in close association with metapelite, with a similar case reported from Tchollirė and Banyo regions, in which metabasite has been found adjacent to pelitic rock in Cameroon (Bouyo *et al.*, 2013). The fact that the metabasite occur as a dyke makes it an ortho-metabasite (Misra, 1971; Harte and Graham, 1975). The absence of deformed structure in the metabasite as against the metapelite which is foliated and deformed (Figure 3) is an indication that the intrusion of the dyke occurs towards the later stages of metamorphism when the temperature was still high and active, but the deformation process had ceased. Pelitic gneisses of Ikare area are foliated and highly deformed (Rahaman and Ocan, 1988; Oziegbe *et al.*, 2021). Also, metamorphism suggesting high temperature and low-medium pressure have been suggested for metapelites of this region (Oziegbe *et al.*, 2021). The mineral assemblage in the metabasite is indicative of granulite facies metamorphism. The textural relationship observed (Figures 4a, 4b & 4d) can be represented by the dehydration reaction involving biotite in Equation (1):

$$\text{Biotite} \rightarrow \text{Garnet} + \text{Orthopyroxene} + \text{K-feldspar} + H_2O \quad (1)$$

Orthopyroxene is concentrated in zones dominated by biotite (Figure 4e). The occurrence of quartz as an inclusion in garnet can be supported by the reaction in Equation (2) (De Waard, 1965):

$$\text{Biotite} + \text{Quartz} \rightarrow \text{Orthopyroxene} + \text{Almandine} + \text{Orthoclase} \quad (2)$$

This reaction (Equation 2) suggests biotite and quartz as prograde minerals. The significant amount of quartz grains present makes it a quartz-bearing granulite. Such quartz-bearing metabasite has been reported in NW China (Zhang *et al.*, 2005). Plagioclase of the granulite facies has the highest anorthite (An) content (An_{35-55}, but rarely 80 %), and the plagioclase of the metabasite fall within this range (Table 2). Plagioclase has been reported to be more anorthitic with increasing grade of metamorphism (Laird and Albee, 1981). Also, high amount of almandine and pyrope (Table 1) have been reported in garnet of the granulite facies (Raase *et al.*, 1986). Plagioclase occurring as inclusion in garnet is indicative of a prograde mineral and can be represented by reaction in Equation (3):

$$\text{Biotite} + \text{Plagioclase} + \text{Quartz} \rightarrow \text{Garnet} + \text{K-feldspar} + H_2O \quad (3)$$

The orthopyroxene + plagioclase relationship in (Figure 5e) mineral assemblages suggests intermediate-pressure granulites (Green and Ringwood,1967). Mineral assemblages in Metamorphosed mafic igneous rocks (MMIR) can be used to estimate the grade of metamorphism (Srivastava, 2012). The Th/U value is 3.92 when calculated from values in Table 3, and this is indicative of igneous origin and mafic rock inclusive according to Sun and McDonough (1989). The Fe and Mg content in this rock is an indication that it evolved from MgO – FeO rich protolith. The characteristic of the major element (Table 3) can be said to be similar to that of basic igneous rocks with a low silica content of 42.01 wt %. The low MgO content (Table 3) could be linked to the protolith having its origin from a differentiated melt (Turkina, and Nozhkin, 2014). Rb, U and K_2O values are extremely low (Table 3), suggesting that the basic intrusive attained a very high grade of metamorphism. K and Rb reduced with a higher grade in metabasites (Smalley *et al.*, 1983). Rb and U have been found to be potentially mobile during a high-grade form of metamorphism (Rudnick *et al.*, 1985). Granulite facies metamorphism often causes depletion of Rb to K and Sr, resulting in increase of K/Rb ratios to over 1000 in certain case, and decrease of Rb/Sr ratios to less than 0.02 sometimes (Tarney and Windley, 1977; Jahn and Zhang, 1984). In normal igneous rocks, the K/Rb ratios are less than 350, sometimes less than 250 (Guo *et al.*, 2002). The studied metabasite has K/Rb of 883 and Rb/Sr ratios of 0.02 indicating limited effect caused by metamorphism.

In most igneous rocks, the Th/U ratios are 3.5-4 (Rogers and Adams, 1978), while in most granulites, the Th/U ratios are usually higher than 4 because of U depletion to Th during metamorphism (Rudnick *et al.*, 1985). However, the Th/U ratio for the Ogbagi metabasite is approximately 4, indicating that the metamorphism has no effect on the chemistry of the rock. The ratio of La/Th is not affected by the metamorphism. Depletion of LILE could also be a result of primary igneous fractionation (Field *et al.*, 1980). There is a high enrichment of Ba a LILE element (1176 ppm) which could be ascribed to extraction from the host metapelite (Schussler *et al.*, 1989). The depletion in HFSE (Table 3) is comparable to the basalts of subduction zones (Turkina and Nozhkin, 2014; Pearce *et al.*, 1995). The slight positive Eu anomaly observed (Figure 8), could be a result of magmatic accumulation of plagioclase possibly due to fractionation (Pallister and Knight, 1981). Intrusion and fractionation of basaltic magmas in the lower crust serves to create mafic and ultramafic cumulates with positive Eu anomalies (Rudnick, 1992). MMIR such as the metabasite studied, helps in understanding the evolution of a metamorphic terrain (Spear, 1993).

CONCLUSION

The composition of garnet (almandine-pyrope-rich), orthopyroxene (hypersthene) and plagioclase feldspar (bytownite) are all indicators of high-grade metamorphism up to granulite facies. Thus, can be classified as high-grade metabasite of granulite. The absence of deformation structure in the metabasite is an indication that the intrusion occurred when the temperature was still high to cause metamorphic recrystallization. The elemental compositions and ratios indicate that the bulk chemistry was not affected by the metamorphism

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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