

CHARACTERISTICS OF PYROXENES IN THE MAFIC-ULTRAMAFIC ROCKS OF THE UBO MARBLE AREA, SW. NIGERIA

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ABSTRACT

Pyroxene crystals of a dolerite, gabbro and pyroxenite that intruded in the Ubo marble area have been analysed on the basis of 4 cations and 6 oxygen anions using conventional electron microprobe coupled with a scanning electron microscope. The results show that SiO₂ in the pyroxenite (51.43–52.52%) was slightly higher than that of the gabbro (48.32–50.83%) and that of the dolerite (47.83–48.95%) due to disilication of dolerite and gabbro liquids. The magnesium content of the pyroxenite (12.29–12.95%) is relatively higher than that of the gabbro (9.95–12.31) and dolerite (4.72–6.33%) because of the more primitive nature of the pyroxenite. 'Others' in the pyroxenites (Cr, Ni, Ba, Zr, Ti, Al) were more abundant in the gabbro (8.38–13.92) and dolerite (5.96–6.98) than that of the pyroxenite (2.45–4.51) which was probably due to crystallization modes of the different rocks.

The CaO content of all pyroxenes was (21.99–24.43) which appears to be on the high side when compared to calcic pyroxenes from several diverse bulk compositions. The high abundant CaO enhanced a Wo-content of (41.43–49.36) and $X_{Ca} = Ca/(Ca+Mg)$ (0.57–0.78) suggesting an excess of $X_{Ca} = (0.02-0.23)$.

The intergrowth of amphiboles with the pyroxenes is thought either due to exsolution-hydration process of genetic solid solution or due to both. When cation exchange and site occupation characteristics of the pyroxenes are investigated, high concentration of Al^{VI}, Al/Si, and Ti/Al implied high pressure/temperature crystallization conditions under bimodal or tholeiitic-alkaline transition magmatism in an island arc environment.

Key words: Pyroxenite Ultramafic amphibole Island arcs.

INTRODUCTION

In the Ubo marble area, northeast of Edo State, in the Southern borders of Kogi State, some mafic (dolerite and gabbro) and ultramafic (pyroxenite) rocks intruded and made contact with marble bodies at several locations. The gabbro polysected the major marble body into several smaller bodies while the dolerite formed as apophyses of the gabbro made several dykes cutting through the different marble bodies. Less mafic to felsic rocks (microgranite, aplite and pegmatite) which were probably generated as late partial multacentred differentiates of the mafic-

ultramafic magma intruded the gabbro and pyroxenite as dykes. There seems to be a layering structure as the pyroxenite lies to the north of gabbro while the less mafic ones predominate as dykes southwards (Fig. 1)

The pyroxenite consists essentially of clinopyroxenes that appeared to have reequilibrated as there were no apparent zoning of the crystals. In some pyroxenite locations, nodules of pyroxene crystals measure up to 8 cm in what appears to be subvolcanic emplacement (Ashidi in preparation). Pyroxene crystals interlock subophitically with plagioclase laths in the gabbro with some amphibole crystals

bordering and hosted by the pyroxenes. At higher optical magnification, the pyroxenes have the appearance of a mosaic of exsolved blebs consisting of islands of smaller crystals. The plagioclase crystals were more severely affected tectonically and by late

hydrothermal alteration. Late magmatic effects have generated titanite and scapolite crystallization which replaced much of plagioclase in the gabbro body. The dolerite is of two textural types-one finer grained the other much coarser though not as coarse as the gabbro. In place with

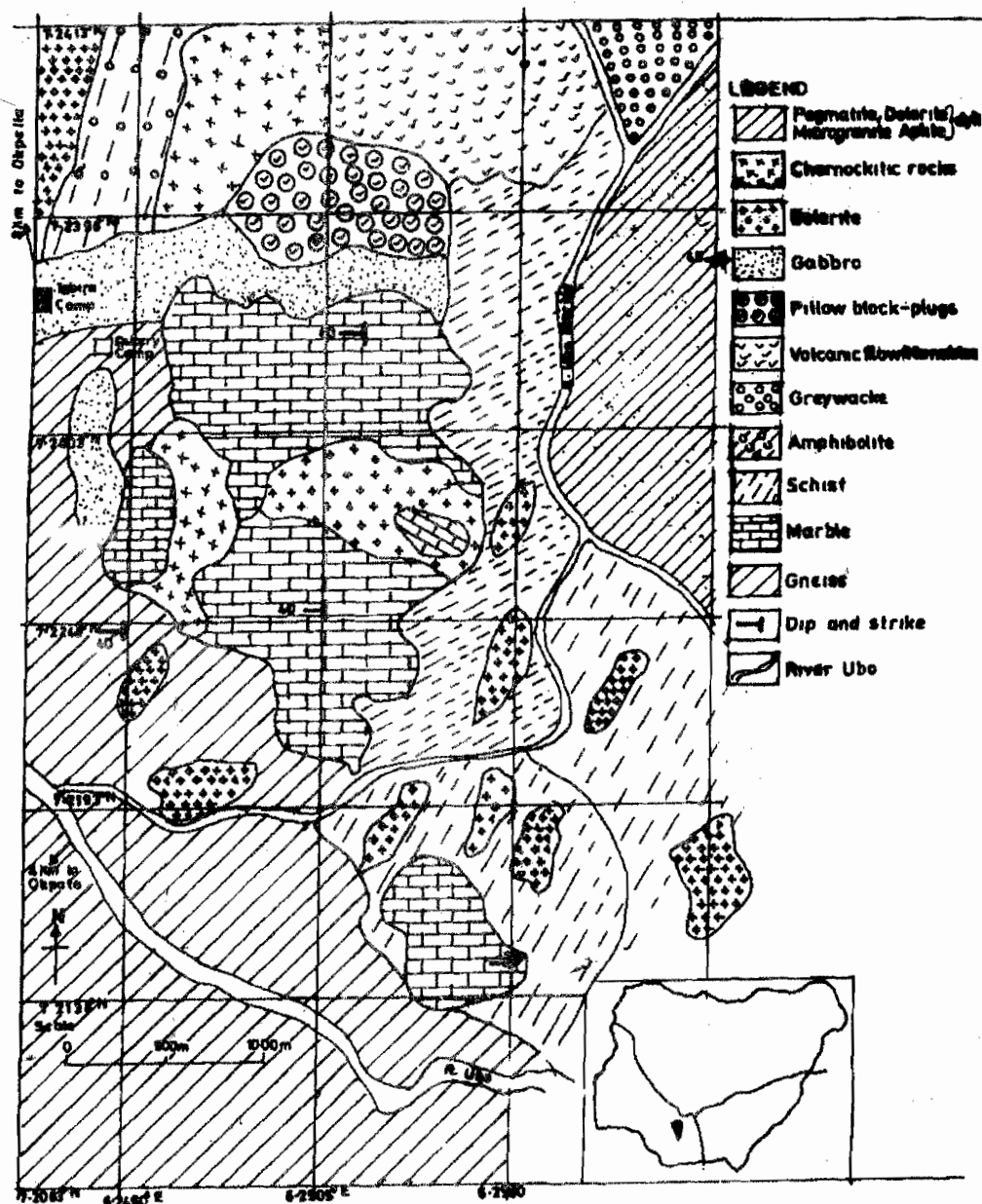


Fig 1: Geological map of Ubo area. Insert map of Nigeria showing Ubo marble area.

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Table 1A Pyroxene Micro analysis pyroxenitic.

Probe	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO ₂	51.62	51.83	51.43	51.52	51.65	52.16	52.41	52.19	52.27	52.37	52.43	52.30	52.08
TiO ₂	0.04	0.04	0.00	0.02	0.02	0.01	0.03	0.03	0.02	0.01	0.03	0.00	0.05
Al ₂ O ₃	0.84	0.83	0.87	0.88	0.91	0.76	0.63	0.64	0.55	0.59	0.63	0.69	0.64
FeO	9.82	10.13	10.18	10.24	10.50	9.92	9.74	0.67	9.63	10.10	10.06	9.82	9.62
Fe ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.21	0.29	0.14	0.19	0.20	0.25	0.17	0.23	0.20	0.21	0.27	0.28	0.09
MgO	12.30	12.24	12.21	12.47	12.52	12.50	12.70	12.76	12.77	12.54	12.73	12.95	12.60
CgO	23.79	24.00	24.05	23.74	23.39	24.19	24.21	24.27	24.28	24.18	24.40	24.28	24.43
NgO	0.27	0.28	0.27	0.30	0.30	0.27	0.24	0.23	0.24	0.24	0.28	0.27	0.25
K ₂ O	0.01	0.02	0.01	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.01	0.01	0.00
Pa ₂ O ₅	----	----	----	----	----	----	----	----	----	----	----	----	----
Cr ₂ O ₃	0.05	0.00	0.00	0.05	0.00	0.01	0.00	0.00	0.02	0.00	0.04	0.04	0.00
NiO	----	----	----	----	----	----	----	----	----	----	----	----	----
Total	98.95	99.46	99.16	99.41	99.51	100.07	100.15	100.06	99.98	100.24	100.88	100.64	99.80
Formula													
Si	1.97	1.96	1.96	1.96	1.96	1.97	1.97	1.97	1.97	1.97	1.96	1.96	1.97
Aliv	0.03	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Alvi	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe ²⁺	0.31	0.32	0.32	0.33	0.33	0.31	0.31	0.30	0.30	0.32	0.32	0.31	0.30
Fe ³⁺	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mn	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
Mg	0.70	0.69	0.69	0.71	0.71	0.70	0.71	0.72	0.72	0.70	0.71	0.72	0.71
Cg	0.97	0.98	0.98	0.97	0.95	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.99
Ng	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
K	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P	----	----	----	----	----	----	----	----	----	----	----	----	----
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ni	----	----	----	----	----	----	----	----	----	----	----	----	----
Total cation	4.02	4.03	4.03	4.03	4.02	4.02	4.02	4.02	4.02	4.02	4.03	4.03	4.03
Others%	3.36	3.42	3.18	3.49	3.49	3.11	2.59	2.73	2.45	2.54	2.94	3.01	2.70
Plotting													
Wo	48.18	48.55	48.68	47.94	47.17	48.55	48.61	48.74	48.92	48.60	48.81	48.51	49.36
En	35.79	35.14	34.97	35.64	35.92	35.60	35.93	35.96	35.89	35.40	35.46	36.12	35.45
Fs	16.03	16.32	16.36	16.42	16.90	15.85	15.46	15.29	15.19	16.00	15.72	15.37	15.19
Acmite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jadeite	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Na	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al ⁴	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

the marble are other metasedimentary units-agneiss which has stabilized minor sillimanite and staurolite occur east and west of the marble bodies, while a quartzite lies to the east of the pyroxenites. Between the marble and the intrusive phases and in some locations bordering

the intrusive are thin bands of skarns and calcisilicates in which wollastonite, scapolite, grossular-andradite garnets, epidotes and vesuvianites have been stabilized.

The crystals of the dolerite are aligned due to emplacement constraints along fractures

of the marble bodies. The geology of the Ubo marble area has been described by Arcelloni (1965), Ashidi (1998) and the setting of the marble bodies within the younger metasediments have been discussed by Odeyemi (1976) while the occurrence of mafic to ultramafic intrusives as

members within the older granite intruding the older metasediments in the Southwest has been reiterated by Rahaman (1976, 1988). Bafor (1988) discussed same in the Egbe area west north-west of the area of study. In this work the characteristics of pyroxenes in the mafic

Table 1B Pyroxene Micro Analyses (gabbro)

	14	15	16	17	18	19	20	21
SiO ₂	49.93	48.55	48.32	50.17	50.45	48.90	50.83	50.65
TiO ₂	0.57	0.17	0.89	0.46	0.43	0.56	0.36	0.32
Al ₂ O ₃	3.30	0.84	1.90	2.66	2.77	4.60	2.56	2.71
FeO	10.08	11.48	12.34	9.46	9.29	10.99	9.46	9.70
Fe ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.20	0.18	0.14	0.21	0.18	0.15	0.22	0.19
MgO	11.80	10.53	9.95	11.83	11.89	11.27	11.89	12.31
CgO	23.77	23.21	23.11	23.88	23.84	21.72	23.63	23.41
Ng ₂ O	0.51	0.54	0.52	0.46	0.52	0.67	0.49	0.55
K ₂ O	0.00	0.00	0.01	0.02	0.00	0.06	0.01	0.03
P ₂ O ₅	-----	-----	-----	-----	-----	-----	-----	-----
Cr ₂ O ₃	0.00	0.09	0.06	0.02	0.00	0.00	0.00	0.00
NiO	-----	-----	-----	-----	-----	-----	-----	-----
Total	100.16	99.79	99.51	99.17	99.37	98.82	99.45	99.87
Formular								
Si	1.89	1.86	1.86	1.91	1.91	1.87	1.93	1.91
Al _{iv}	0.11	0.14	0.14	0.09	0.09	0.13	0.07	0.09
Al _{iv}	0.03	0.04	0.05	0.03	0.04	0.08	0.04	0.03
Ti	0.02	0.03	0.03	0.01	0.01	0.07	0.01	0.01
Fe ²⁺	0.32	0.37	0.40	0.30	0.29	0.35	0.30	0.31
Fe ³⁺	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mn	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01
Mg	0.66	0.60	0.57	0.67	0.67	0.64	0.67	0.59
Cg	0.96	0.95	0.95	0.97	0.97	0.89	0.96	0.95
Ng	0.04	0.04	0.04	0.03	0.04	0.05	0.04	0.04
K	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P	-----	-----	-----	-----	-----	-----	-----	-----
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ni	-----	-----	-----	-----	-----	-----	-----	-----
Total cation	4.02	4.04	4.04	4.04	4.04	4.04	4.04	4.04
Others %	10.35	13.08	12.96	8.70	9.01	13.02	8.32	8.88
Plotting	I	I	I	I	I	I	I	I
Wo	46.21	45.68	45.14	47.23	46.93	41.43	46.52	45.62
En	36.36	33.70	32.35	36.42	36.90	37.98	36.97	37.52
Fs	17.43	20.62	22.51	16.34	16.17	20.71	16.51	16.84
Acumite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jadwinite	0.04	0.04	0.04	0.01	0.01	0.09	0.04	0.03
Na	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al ^{IV}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 1C Pyroxene Micro Analyses (doleritic)

	22	23	24	25
SiO ₂	48.28	48.63	48.95	47.83
TiO ₂	0.10	0.18	0.12	0.10
Al ₂ O ₃	1.60	1.49	1.97	1.90
FeO	2.58	21.62	18.74	21.99
Fe ₂ O ₃	-----	-----	-----	-----
MnO	0.39	0.31	0.55	0.44
MgO	4.72	4.97	6.33	4.72
CgO	22.44	22.35	22.76	21.95
Ng ₂ O	0.42	0.43	0.39	0.39
K ₂ O	0.03	0.00	0.01	0.00
P ₂ O ₅	-----	-----	-----	-----
Cr ₂ O ₃	0.02	0.00	0.02	0.03
NiO	0.00	0.04	0.02	0.03
Total	99.58	100.02	99.64	99.44
Formular				
Si	1.94	1.94	1.94	1.93
Al _{iv}	0.06	0.06	0.06	0.07
Al _{iv}	0.01	0.01	0.03	0.02
Ti	0.00	0.01	0.00	0.00
Fe ²⁺	0.12	0.72	0.60	0.75
Fe ³⁺	0.00	0.00	0.00	0.00
Mn	0.01	0.01	0.01	0.01
Mg	0.28	0.30	0.37	0.28
Cg	0.97	0.96	0.96	0.95
Ng	0.03	0.03	0.03	0.03
K	0.00	0.00	0.00	0.00
P	-----	-----	-----	-----
Cr	0.00	0.00	0.00	0.00
Ni	0.00	0.00	0.00	0.00
Total	4.03	4.03	4.03	4.04
Others %	6.27	5.96	6.50	5.94
Plotting	I	I	I	I
Wo	47.32	47.14	46.82	46.60
En	14.77	15.36	19.36	14.92
Fs	37.90	37.45	33.76	38.09
Acumite	0.00	0.00	0.00	0.00
Jadwinite	0.03	0.01	0.01	0.01
Na	0.00	0.00	0.00	0.00
Al ^{IV}	0.00	0.00	0.00	0.00

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Table 2 Microprobe Analysis of Pyroxene Crystals *et al.*, 1974

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO ₂	57.73	50.08	45.95	54.09	48.34	52.92	46.61	49.68	48.90	52.84	49.72	51.92	64.89	59.38
TiO ₂	0.04	0.64	0.10	0.28	0.08	0.50	1.18	0.56	0.12	0.22	0.85	0.77	-	0.04
Al ₂ O ₃	0.95	1.23	0.90	1.57	0.30	2.80	3.47	0.78	3.86	0.44	0.90	1.85	26.74	25.82
Fe ₂ O ₃	0.42	2.34	0.31	0.74	1.50	0.85	0.90	3.29	4.65	1.06	1.72	31.44	0.57	0.45
Cr ₂ O ₃	0.46	-	-	2.03	-	0.88	-	-	-	-	-	-	-	0.01
FeO	3.57	27.85	41.65	1.47	22.94	5.57	20.18	18.15	25.35	16.89	27.77	0.75	0.04	-
MnO	0.08	0.85	5.02	0.09	3.70	0.15	1.11	0.59	0.51	0.56	0.98	-	0.01	0.00
NiO	0.35	-	-	0.03	-	0.10	-	-	-	-	-	-	-	-
MgO	36.13	15.78	3.49	16.96	1.06	16.40	7.27	16.19	6.87	23.51	12.69	-	0.00	0.12
CaO	0.23	1.44	1.43	21.10	21.30	19.97	17.24	9.90	7.96	4.06	3.80	-	0.00	0.13
Na ₂ O	-	0.05	-	1.37	0.14	0.35	1.04	0.65	0.58	0.19	0.23	12.86	0.05	13.40
K ₂ O	-	0.02	-	0.15	0.03	0.01	0.24	0.15	0.20	0.00	0.12	0.19	0.16	0.02
H ₂ O ⁺	0.52	-	0.65	0.22	0.46	0.10	0.42	0.10	0.57	-	1.27	0.17	0.48	0.22
H ₂ O ⁻	0.04	0.00	0.09	0.08	-	0.07	0.04	0.00	0.35	0.22	0.08	-	0.06	0.16
Total	100.52	100.28	99.59	100.64	99.85	100.67	99.73	100.04	99.92	99.99	100.13	99.95	100.12	99.95
Si	1.97	1.94	1.97	1.96	1.99	1.93	1.86	1.91	1.94	1.96	1.97	1.99	2.03	2.00
Al	0.03	0.06	0.03	0.04	0.01	0.07	0.14	0.03	0.06	0.02	0.03	0.01	-	0.00
Al	0.01	-	0.02	0.03	0.01	0.05	0.02	-	0.12	-	0.01	0.07	0.98	1.02
Ti	0.00	0.02	0.00	0.01	0.00	0.01	0.04	0.02	0.00	0.01	0.03	0.02	-	0.00
Fe ⁺³	0.01	0.07	0.01	0.02	0.05	0.02	0.03	0.09	0.14	0.03	0.05	0.91	0.01	0.01
Cr	0.01	-	-	0.06	-	0.03	-	-	-	-	-	-	-	0.00
Mg	1.84	0.91	0.22	0.92	0.07	0.90	0.43	0.93	0.41	1.30	0.75	-	-	0.01
Ni	0.01	-	-	0.00	-	0.00	-	-	-	-	-	-	-	-
Fe ⁺²	0.10	0.90	1.50	0.05	0.79	0.17	0.67	0.58	0.84	0.52	0.92	0.02	0.00	-
Mn	0.00	0.03	0.18	0.00	0.13	0.01	0.04	0.02	0.02	0.02	0.03	-	-	-
Co	0.01	0.06	0.07	0.82	0.94	0.78	0.74	0.41	0.34	0.16	0.16	-	-	0.01
Na	-	0.00	-	0.10	0.10	0.02	0.08	0.05	0.05	0.01	0.02	0.95	0.00	0.87
M	-	0.00	-	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00

ultramafic rocks intruding the Ubo marble with the following objectives: (i) To find out the influence of contact metamorphism on their mineral chemistry (ii) To determine the genesis of the massive exsolution features observable in their petrography. (iii) To suggest possible genetic relation between the amphiboles and the pyroxenes.

METHOD OF ANALYSIS

A semi-automated method of preparing polished thin section for microprobe analysis was used for the pyroxene analysis in the University of Munich, Germany. Conventional sections of circular cross-sections are ground to a thickness of about 40µm instead of the more usual 30µm. The sections were mounted on a vacuum chuck and polished on felt laps on a rotating table. Diamond polishing paste 13 µm to ¼ µm grit sizes

were successively introduced to achieve satisfactory finish. A carbon film was deposited on the surface of polished samples section to induce electricity conductivity.

The polished samples were subjected thereafter to a Camebax probe microanalysis with an electron beam accelerated to 15 KV, 5 nA. Characteristic X-rays generated within the sample are detected using energy dispersive spectrometers (4) set at about 54° to the vertical. The system has a scanning electron microscope (SEM) producing back scattered and secondary electron signals. Potts (1992) has given general operation modes on microprobe and SEM analyses.

Some 23 whole rock samples (mainly from the gabbro) were analysed using wet chemical methods after Shapiro and Brannock (1962) in which ignition methods were used for the determination of water and carbon dioxide. The

Table 3: Chemical Composition of Whole Rock Samples

	A	B	C	R	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X
SiO ₂	53.19	44.09	44.07	50.23	63.89	46.99	44.26	47.30	48.09	48.25	50.07	51.94	49.09	54.79	48.46	48.83	48.74	68.53	52.29	50.15	44.64	60.98	51.64
TiO ₂	0.14	0.62	1.72	0.38	0.74	1.54	1.74	1.77	2.05	1.40	0.83	0.64	0.14	1.68	0.14	1.67	0.32	0.19	0.69	1.07	4.15	0.84	0.21
Al ₂ O ₃	9.69	7.42	11.40	13.26	13.05	9.38	10.36	11.39	8.23	7.76	15.67	15.36	15.37	14.92	19.76	7.53	6.77	19.73	17.69	15.36	6.09	12.97	8.41
Fe ₂ O ₃	-	0.60	1.85	0.91	1.54	2.66	2.66	1.53	3.31	1.42	0.99	0.96	0.34	1.16	0.53	1.72	1.19	1.16	1.03	1.35	1.64	0.60	1.06
FeO	0.87	3.64	7.29	1.56	2.41	4.95	5.60	8.46	7.27	8.55	5.26	4.79	0.71	6.30	0.64	8.24	1.00	2.26	4.48	5.26	8.77	2.17	0.84
MnO	0.02	0.60	0.80	0.06	0.06	0.08	0.08	0.10	0.11	0.10	0.09	0.08	0.05	0.01	0.04	0.11	0.07	0.06	0.09	0.09	0.11	0.05	0.06
MgO	2.00	6.78	5.56	0.48	0.60	4.71	4.91	4.89	4.49	5.00	5.04	5.96	0.10	2.98	0.10	6.50	0.90	3.97	4.74	4.69	5.16	0.55	0.27
CaO	22.79	30.13	22.29	28.59	8.57	25.61	25.34	20.34	21.51	22.65	15.83	14.74	29.30	12.96	24.02	21.65	39.12	0.20	13.55	17.16	23.45	9.92	38.71
Na ₂ O	1.06	0.41	0.84	1.23	1.91	0.71	0.43	1.35	1.35	1.40	3.17	3.44	1.40	3.70	2.45	1.09	-	-	2.81	2.10	0.70	1.69	1.20
K ₂ O	6.09	0.10	0.13	0.19	5.06	0.10	-	0.28	0.32	0.23	0.39	0.30	0.68	0.16	0.67	0.17	-	1.95	0.15	0.38	-	-	-
P ₂ O ₅	0.20	0.06	0.06	0.11	0.08	0.08	0.07	0.08	0.17	0.04	0.15	0.06	0.11	0.08	0.07	0.34	0.12	0.05	0.08	0.16	2.07	8.24	0.44
Loss on Ignite	4.73	6.17	3.85	1.75	1.42	2.75	1.27	2.51	3.10	2.89	2.32	1.62	1.85	1.17	2.25	1.85	1.95	1.47	1.44	1.77	2.37	0.11	0.16
CO ₂	3.58	5.00	2.65	1.76	0.22	1.75	3.07	1.39	2.00	1.69	1.12	0.42	0.65	-	1.05	0.45	0.75	-0.27	0.22	0.57	1.17	0.73	2.65
TOTAL	100.83	100.08	99.74	98.96	98.34	99.76	99.72	99.77	100.00	99.76	99.81	99.89	99.14	100.00	99.13	99.05	100.18	98.57	99.13	99.54	99.15	98.85	100.65

procedures are as stated in Potts (1992) pg 70-73.

RESULTS

Table 1 shows the microprobe analysis of pyroxene crystals from three different rock types: Pyroxenite-1A; gabbro-1B and dolerite 1C. The SiO₂ values of the dolerite (47.83-48.95)%, and gabbro (48.32-50.83)% are both slightly less than the SiO₂ values of the pyroxenite (51.43-52.52)%.

The Al₂O₃ of the dolerite (1.49-1.97)%; the gabbro (2.56-4.60)%, are both higher than that of the pyroxenite (0.55-1.16)%. A similar trend is observed for TiO₂ values, dolerite (0.10-0.18)%, gabbro (0.32-1.17) and pyroxenite (0.0-0.11). MgO and FeO values were more apparent in distinguishing the different intrusive MgO; dolerite (4.72-6.33)%, gabbro (9.95-12.31)% pyroxenite (13.21-12.95). FeO for dolerite is (18.74-21.99), is much higher than the gabbro (9.29-12.34)% and the pyroxenite (9.47-10.24)%. CaO in the dolerite is (21.99-22.76), gabbro (21.72-23.88)% and pyroxenite (23.79-24.43)%. The magnesium number (Mg/Mg + Fe) of dolerite is (27-37);

gabbro (59-69) and pyroxenite (69-71). The values of 'others' non stoichiometric elements such as Ni, Cr, Al etc. in the dolerite are (5.96-6.98)% in the gabbro (8.38-13.92%) but for the pyroxenite (2.45-4.51%).

Table 2 lists the analysis of pyroxene crystals from 14 different localities Deer et al (1974) Comparison of table 2 with table 1 shows that, analysis 1, 13 and 14 which are respectively enstatite, spodumene and jadeite have high SiO₂ that Ubo marble complex samples. The project samples compare favorably with 4-12 of table 2 which are augite-diopside related pyroxenes. However, the CaO content of the project samples are all higher than the CaO content of the fourteen reference samples. In addition CaO content of the three different intrusives of this study are the least diverse when compared with the other oxides of the same samples.

The jadeite component of the project pyroxene (X_{jd} = 0.02-0.05) when compared to X_{jd} = (0.68-0.84) of Patrick and Day (1999) in which SiO₂ (57.20-58.89), Al₂O₃ (16.52-20.75) were much higher than those of the pyroxenes in this

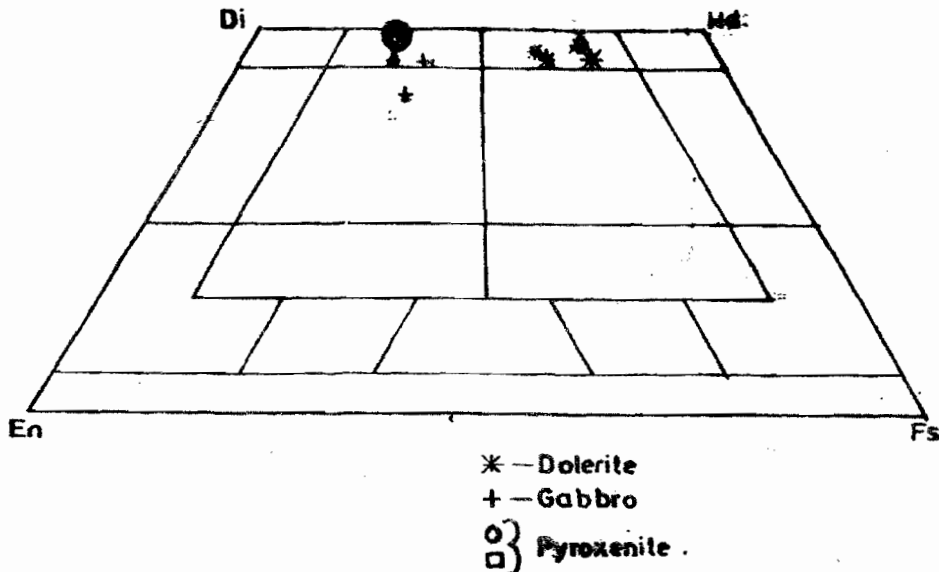


Fig. 2 Projection of pyroxene microprobe analysis into the E-Di-Hd-Fs quadrilateral

After-analysis points	15	16	17	18	19	20	21	22	37	38	39	40	50	51	52	53	54	55	56	57	58	59	60	81	84	91	92	
SiO ₂	50.17	50.45	48.80	50.83	50.65	47.75	37.78	49.93	51.62	51.63	51.43	51.52	50.27	52.79	51.65	52.16	52.41	52.19	52.27	52.37	52.43	52.30	52.00	52.03	52.06	52.06	52.14	52.52
TiO ₂	0.46	0.43	0.56	0.36	0.32	0.25	0.11	0.57	0.04	0.04	0.00	0.02	0.03	0.03	0.02	0.01	0.03	0.03	0.02	0.01	0.03	0.00	0.05	0.06	0.07	0.11	0.08	
Al ₂ O ₃	2.66	2.77	4.60	2.56	2.71	2.48	1.67	3.30	0.84	0.83	0.87	0.88	6.76	0.81	0.92	0.76	0.63	0.64	0.55	0.59	0.63	0.69	0.64	0.70	0.74	1.16	0.83	
FeO	9.46	9.29	10.99	9.46	9.70	14.07	7.24	10.08	9.82	10.13	10.18	10.24	16.35	10.51	10.50	9.92	9.74	9.67	9.63	10.10	10.06	9.82	9.62	9.47	9.70	9.91	0.58	
MnO	0.21	0.48	0.16	0.22	0.19	0.15	0.17	0.20	0.21	0.29	0.14	0.19	0.17	0.23	0.20	0.25	0.17	0.23	0.20	0.21	0.27	0.28	0.09	0.17	0.21	0.17	0.26	
MgO	11.83	11.89	11.28	11.90	12.31	11.83	9.57	11.80	12.30	12.34	12.21	12.47	11.81	12.52	12.52	12.50	12.70	12.76	12.77	12.55	12.73	12.95	12.60	12.52	12.30	12.41	12.75	
CaO	23.88	23.84	21.72	23.63	23.41	16.13	32.02	23.77	23.79	24.00	24.15	23.74	12.52	23.69	23.35	24.19	24.21	24.27	24.28	24.18	24.40	24.28	24.43	24.40	24.11	24.28	24.29	
Na ₂ O	0.46	0.52	0.67	0.49	0.55	0.91	0.43	0.51	0.27	0.28	0.27	0.30	0.88	0.30	0.30	0.28	0.24	0.23	0.24	0.24	0.28	0.27	0.29	0.34	0.36	0.41	0.33	
K ₂ O	0.18	0.00	0.06	0.06	0.03	0.46	0.00	0.00	0.01	0.02	0.01	0.00	0.33	0.01	0.00	0.00	0.02	0.00	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.02	
Total	99.20	99.45	98.82	99.45	100.00	98.74	186.94	100.15	99.01	99.54	99.16	99.44	99.39	100.90	99.62	100.09	100.15	100.05	99.99	100.26	100.88	100.60	99.81	99.78	99.56	100.62	100.75	
Formula																												
Si ⁺⁴	1.90	1.90	1.85	1.91	1.90	1.81	1.59	1.87	1.96	1.95	1.95	1.95	1.91	1.91	1.95	1.96	1.96	1.96	1.96	1.96	1.96	1.95	1.95	1.96	1.96	1.96	1.94	1.94
Ti ⁺⁴	0.01	0.01	0.02	0.01	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al ⁺³	0.12	0.12	0.21	0.11	0.12	0.33	0.08	0.15	0.04	0.04	0.04	0.03	0.03	0.04	0.04	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.05	0.04	
Fe ⁺³	0.10	0.90	0.11	0.07	0.11	0.07	0.11	0.25	0.12	0.06	0.08	0.09	0.00	0.05	0.08	0.07	0.06	0.07	0.07	0.07	0.09	0.10	0.09	0.08	0.07	0.09	0.04	
Mn ⁺²	0.20	0.20	0.24	0.23	0.19	0.34	0.00	0.19	0.25	0.24	0.24	0.23	0.52	0.28	0.25	0.24	0.24	0.23	0.23	0.23	0.25	0.22	0.21	0.22	0.22	0.24	0.22	
Mg ⁺²	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	
Ca ⁺²	0.67	0.67	0.64	0.67	0.69	0.67	0.60	0.66	0.70	0.69	0.69	0.70	0.67	0.70	0.70	0.70	0.71	0.71	0.71	0.71	0.70	0.71	0.72	0.71	0.70	0.69	0.69	
Na ⁺¹	0.97	0.96	0.88	0.95	0.94	0.66	1.44	0.95	0.97	0.97	0.98	0.96	0.51	0.95	0.95	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.98	0.98	0.97	0.97	0.97	
K ⁺¹	0.03	0.04	0.05	0.04	0.04	0.07	0.04	0.02	0.02	0.02	0.02	0.02	0.07	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	
K ⁺¹	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

1. Enstatite, pyroxenite, North Carolina (Hess, 1952)
2. Ferrohyalstherne, hypersthene-diospide-plagioclase (Muir and Tilley, 1958)
3. Chloerostilite, thermally metamorphosed iron rich rock, Manchuria (Tsuru and Henry, 1952)
4. Chrome diopside, kimberlite, S. Africa (Holmes, 1937)
5. Hedenbergite, California (Wyckoff *et al.*, 1925)
6. Chromian, augite, gabbro, Bushveld Complex (Hess, 1949)
7. Ferroaugite, syenite, South-West Africa (Simpson, 1954)

8. Sub calcic augite, basalt, Japan (Kuro, 1955)
9. Sub calcic ferroaugite, andesite, Japan (Kuro and Inoue, 1949)
10. Mg-ferrian pignoneite, andesite, Japan (Kuro and Negoshima, 1952)
11. Pignoneite, andesite, Scotland (Hallmond, 1914)
12. Aegirine, rebeckite-albite granite, Nigeria (Greenwood, 1951)
13. Wine-yellow spodumene, pegmatite, Sweden (Quensel, 1938)
14. White jadeite, serpentinite, California (Coleman, 1955)

Table 9(a): Recalculated microprobe analysis of pyroxenes on basis of 4 cations and 5 oxygens.

Micro-analytical points	15	16	17	18	19	20	21	22	27	37	38	39	40	50	51	52	53	54	55	56	57	58	59	60	81	84	91	92			
SiO ₂	50.17	50.45	48.80	50.83	50.65	47.75	37.78	49.93	51.62	51.63	51.43	51.52	50.27	52.79	51.65	52.16	52.19	52.27	52.37	52.43	52.30	52.30	52.08	52.03	52.06	52.14	52.52				
TiO ₂	0.46	0.43	0.56	0.36	0.32	0.25	0.11	0.57	0.04	0.04	0.00	0.02	0.03	0.03	0.02	0.01	0.03	0.03	0.02	0.01	0.03	0.00	0.05	0.06	0.07	0.11	0.08				
Al ₂ O ₃	2.66	2.77	4.60	2.56	2.71	2.48	1.67	3.30	0.64	0.83	0.87	0.88	6.76	6.81	0.92	0.76	0.63	0.64	0.65	0.59	0.63	0.69	0.64	0.70	0.74	1.16	0.83				
FeO	9.46	9.29	10.99	9.46	9.70	14.07	7.24	10.08	9.82	10.13	10.18	10.24	16.35	10.51	10.50	9.92	9.74	9.67	9.63	10.10	10.06	9.82	9.62	9.47	9.70	9.91	0.58				
MnO	0.21	0.48	0.16	0.22	0.19	0.15	0.17	0.20	0.21	0.29	0.14	0.19	0.17	0.23	0.20	0.25	0.17	0.23	0.20	0.21	0.27	0.28	0.09	0.17	0.21	0.17	0.26				
Total	11.92	11.89	11.28	11.90	11.91	11.83	9.81	11.80	12.30	12.34	12.21	12.47	11.91	12.52	12.52	12.50	12.70	12.76	12.75	12.55	12.73	12.95	12.60	12.52	12.30	12.41	12.75				
CaO	23.38	23.39	21.72	23.39	23.39	16.13	32.02	23.77	23.79	24.00	24.05	23.74	23.52	24.69	23.69	23.39	24.19	24.21	24.21	24.21	24.40	24.28	24.28	24.28	24.28	24.28	24.29				
Na ₂ O	0.45	0.52	0.67	0.49	0.35	0.91	0.43	0.51	0.27	0.55	0.27	0.30	0.50	0.30	0.30	0.28	0.24	0.24	0.24	0.24	0.24	0.27	0.49	0.34	0.36	0.11	0.33				
K ₂ O	0.15	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
Total	99.20	99.45	98.82	99.45	100.00	98.74	88.94	100.15	99.01	99.54	99.16	99.44	99.39	100.80	99.92	100.09	100.15	100.05	99.99	100.29	100.88	100.64	99.91	99.78	99.56	100.52	100.75				
Formula																															
Si ⁴⁺	1.90	1.90	1.85	1.91	1.90	1.81	1.59	1.87	1.96	1.95	1.95	1.95	1.91	1.91	1.91	1.95	1.96	1.96	1.96	1.96	1.95	1.95	1.96	1.96	1.96	1.96	1.94				
Ti ⁴⁺	0.01	0.01	0.02	0.01	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
Al ³⁺	0.12	0.12	0.21	0.11	0.12	0.33	0.08	0.15	0.04	0.04	0.04	0.04	0.03	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.05	0.04			
Fe ³⁺	0.10	0.90	0.11	0.07	0.11	0.11	0.25	0.12	0.06	0.08	0.05	0.05	0.00	0.05	0.09	0.07	0.06	0.07	0.07	0.07	0.09	0.10	0.01	0.01	0.08	0.07	0.09	0.08			
Li ³⁺	0.20	0.20	0.24	0.23	0.19	0.34	0.00	0.19	0.25	0.24	0.24	0.23	0.52	0.28	0.28	0.25	0.24	0.24	0.23	0.23	0.25	0.22	0.21	0.22	0.22	0.24	0.22	0.22			
Mn ²⁺	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01			
Mg ²⁺	0.67	0.67	0.64	0.67	0.69	0.67	0.60	0.66	0.70	0.69	0.69	0.70	0.67	0.70	0.70	0.70	0.70	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.70	0.69	0.69	0.71		
Ca ²⁺	0.97	0.96	0.88	0.95	0.94	0.66	1.44	0.95	0.97	0.97	0.98	0.96	0.51	0.95	0.95	0.95	0.97	0.97	0.98	0.98	0.97	0.97	0.97	0.98	0.98	0.97	0.97	0.97			
Na ⁺	0.03	0.04	0.05	0.04	0.04	0.07	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.20	0.20	0.02	0.03	0.03	0.03	0.24			
K ⁺	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			

1. Enstatite, pyroxenite, North Carolina (Hess, 1952)
2. Ferropyroxenite, hypersthene-diospide-plagioclase (Muir and Tilley, 1958)
3. Chondrofolite, thermally metamorphosed iron rich rock, Manchuria (Tsuru and Henry, 1937)
4. Chrome diopside, Kimberlie, S. Africa (Holmes, 1937)
5. Heulenbergite, California (Wyckoff et al., 1925)
6. Chromian, augite, gabbro, Bushveld Complex (Hess, 1949)
7. Ferroaugite, syenite, South-West Africa (Simpson, 1954)
8. Sub calcic augite, basalt, Japan (Kuno, 1955)
9. Sub calcic ferroaugite, andesite, Japan (Kuno and Inoue, 1949)
10. Magnesian pigeonite, andesite, Japan (Kuno and Nagabashima, 1952)
11. Pigeonite, andesite, Scotland (Hallinond, 1914)
12. Aegirine, riebeckite-albite granite, Nigeria (Greenwood, 1951)
13. Wine-yellow spodumene, pegmatite, Sweden (Quensel, 1938)
14. White jadeite, serpentinite, California (Coleman, 1955)

COEXISTING PYROXENE AND AMPHIBOLES

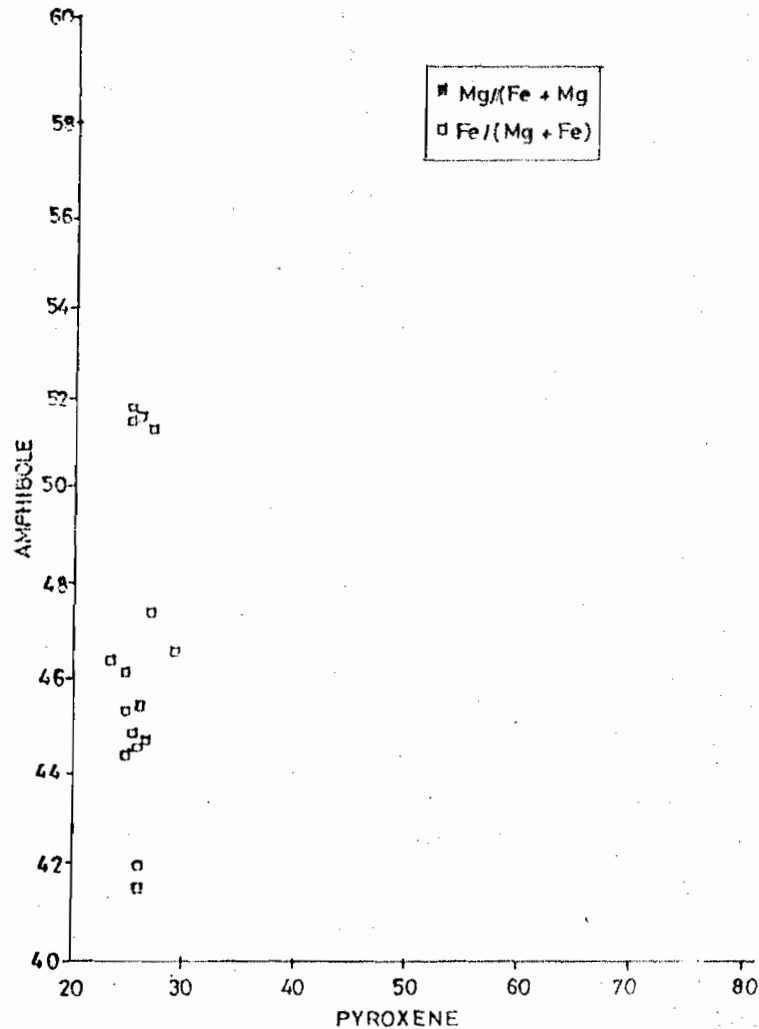


Fig. 3 Magnesium number Mg_{no} and fractionation indices of pyroxenes and amphiboles.

study while their MgO (0.44-1.38) and CaO (0.78-2.03) were far lower than those of the present study. Ohnenstetter and Brown (1992) analysed augites from a four-pyroxene boninite dyke, New Caledonia and found SiO_2 (43.16-52.6), TiO_2 (0.05-1.79), Al_2O_3 (1.6-12.02), CaO (11.3-19.44), MgO (6.87-18.20) and FeO (9.53-17.55). These readings are similar to the pyroxene compositions of this study.

The analysis of clinopyroxenes of the layered gabbro of Northern Cameroon (Parsons et al (1986) yielded SiO_2 (49.95-52.91), Al_2O_3 (0.87-3.43), TiO_2 (0.18-1.91) and CaO (19.67-23.19), MgO (9.54-14.46) and FeO (7.86-16.55), and were suggested by the author to be gabbro noritic in composition. Papike (1980) in discussing the mineralogy of pyroxenes from the moon and meteorites, suggested that the most

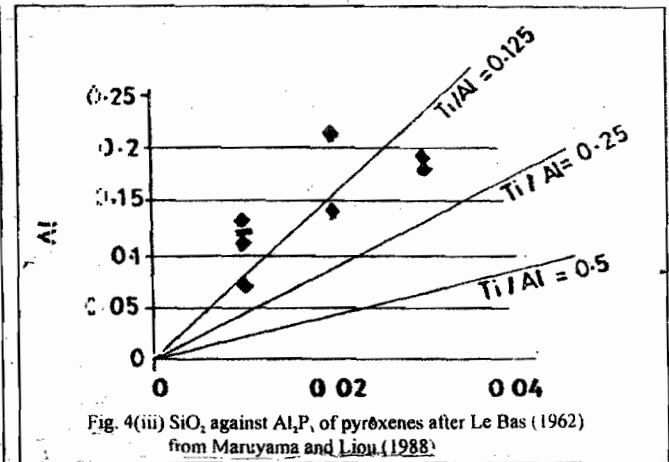
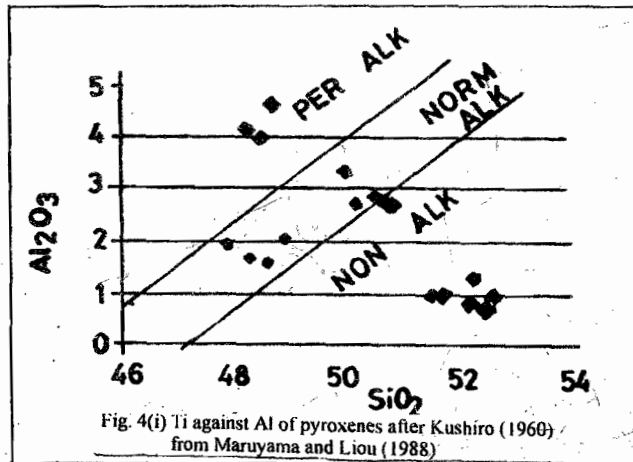
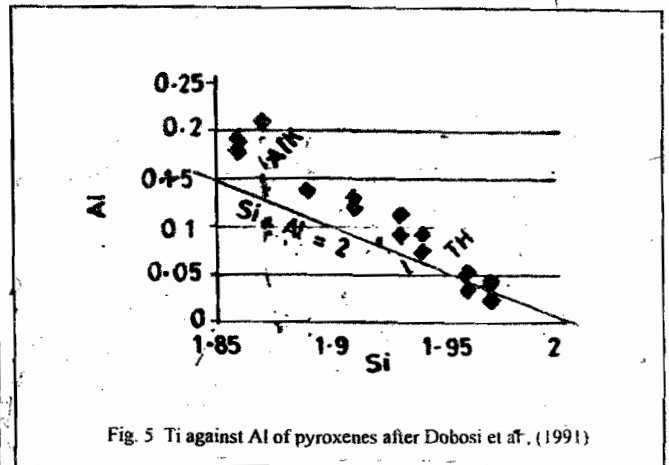
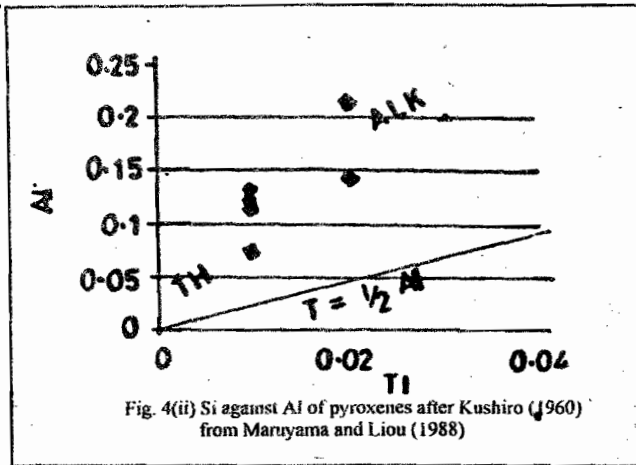
magnesian pyroxenes are found from the lunar highlands, Island arcs, Archean basements, deep sea and Hawaiian suites – which imply that the magnesian abundance is related to the most primitive basalts. The author related high concentration of pyroxene 'others' –(Cr, Al, Ti, Na etc) to rapid cooling histories while the anomalous trends of Cr concentration in equilibrated eucrites was thought to be as a result of Cr residing in finely dispersed phases and not in the pyroxenes as a result of subsolidus annealing. The magnesium components of pyroxenes from the pyroxenite are much higher than those of the gabbro and dolerite in that order suggesting from the pyroxenite to be more primitive and probably the gabbro was partial differentiated from the pyroxenite and the dolerite also from the gabbro. The 'others' component is least in the pyroxenite and highest in the gabbro and this is hereby attributed to the effects of contact of the gabbro with the country rocks subsequent to a higher rate of cooling. While the rocks of the study area have anomalous abundance of Ni and Cr (Ashidi in press) the low abundance-less than detection limit of these elements in the pyroxenes supposed to be the major 'housing' phase of Cr and Ni (Deer et al 1974, Rankama and Sahama 1955) may be due to the reasons suggested by Papike et al – that is, Ni and Cr now reside in finely dispersed phases due to subsolidus annealing. Fig 2 represents the projection of pyroxene analysis into the En-Di-Hd-Fs pyroxene quadrilateral. The pyroxenes from, the different rocks are distinguished from one another as those of the pyroxenite aggregate closer to diopside sector due to high magnesium and wollastonite content, while the dolerite samples were closer to the hedenbergite joint due to their considerably higher FeO content.

The projection of exsolved augites from a northosites complex of Wyoming, Livi (1987) produced Wo (31.99-43.02) En (20.95-22.24) and Fs (36.02-45.77) when compared to those of the Ubo marble complex Wo (41.43-49.36), En (14.92-37.86) and Fs (15.10-39.70) shows that the study samples had more abundant Wo and En but apparently far less Fs components than the pyroxenes of the anorthosites.

At high temperatures solid solution in the clino-enstatite-wollastonite system $X_{Ca} = Ca/(Ca + Mg)$ may increase from $X_{Ca} = 0.0$ (clinoenstatite) to $X_{Ca} = 50$, (diopside) which represents a crystal chemical limit as solid solution between $X_{Ca} = 0.50$ and $X_{Ca} = 1.0$ (wollastonite) stops around $X_{Ca} = 0.55$, (Oberti et al, 1991). The pyroxene, samples analysed in this project have $X_{Ca} = (0.57-0.78)$. This trend appears to be anomalous for the pyroxenes when related to Oberti et al, as stated above. The high wollastonite content is a factor that favourably affects and promoted the free energy difference in the Fe-Mg exchange reactions (Molin and Zanazzi, 1991) as the M_2 site in the pyroxenes is occupied mainly by Ca + Na (0.94-1.01). The authors further suggested that a similar effect should be expected for the R^{3+} content (M1-site) based on previous works of Saxena et al (1987); and (Molin 1989). Similar relations were reported by Dobosi et al (1991), in which he concluded that the Ti-Al ratio of pyroxenes crystallized under elevated pressures must be low (0.1-0.20) or less while for low pressure pyroxenes Ti/Al must be about 0.5 Ti/Al of project samples is about (0.03-0.16) (Fig. 5) which implies characteristic elevated crystallization pressures. High Al^{VI}/Al^{IV} ratio and high Al^{VI} content of the M1-site of pyroxenes is favoured by high-pressure conditions.

Kundari and Salviulo (1987) proposed that the preferential entry of Al^{VI} in the Somma-Vesivious clinopyroxenes under relatively reducing conditions prevailed during subvolcanic clinopyroxene crystallization. This fact is corroborated in the samples for this study ($Al^{VI}/Al^{IV} = 0.63$ and further supported by the low Fe_2O_3/FeO content of net analyses of the gabbro samples) (0.1-0.5) (table 3).

Hazen and Finger (1977) proposed that with increasing pressure the mean inter atomic distance in diopside and fassaite decreases regularly, subsequently, the different polyhedrals compress differentially such that the mean compressibility coefficient for interatomic distances increase in the following order $T-O < M_1-O < M_2-O$. This in effect implies that small



size, high charge components become more favoured at high temperature and pressure conditions. As the M_2 - site is more or less occupied by Ca + Na (0.94-1.01), the effect of changing temperature and pressure is reflected more in the M_1 - site, thus suggesting that high Ti, Cr, Al^{VI}, Mn, abundance implies considerable pressure and temperature as found in the pyroxene samples studied here.

The gabbro mainly and the dolerite to some extent, have amphibole crystals that are either well developed discrete small to medium sized grains or minor phases exsolved from the pyroxenes. Fig. 3 shows a composite diagram in which the magnesium number m_{no} ($Mg/Mg +$

Fe) x 100% and the fractionation index $[Fe/(Fe+Mg)]\%$ of both phases-pyroxene and amphiboles are supposed to be at equilibrium. The pyroxenes have higher m_{no} than the amphiboles which have higher Fe/(Fe + Mg) values than the pyroxenes. Strotzki et al (1991) proposed that exsolution of clinopyroxenes from pyroxene was as a result of tectonic evolution of the Balmuccia massif. The author believed that exsolution of hornblende from augite implies the existence of a finite solid solution between pyroxene and clinopyroxenes-some limited solubility of H or OH- in the pyroxene structure. Robinson, (1988) suggested the possibility of

Table 9(b). 14 examples from the literature (Deer *et al.*, 1966)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO ₂	57.73	50.08	45.95	54.09	48.34	52.92	46.61	49.68	48.90	52.84	49.72	51.92	64.89	59.38
TiO ₂	0.04	0.64	0.10	0.28	0.08	0.50	1.18	0.56	0.12	0.22	0.85	0.77	-	0.04
Al ₂ O ₃	0.95	1.23	0.90	1.57	0.30	2.80*	3.47	0.78	3.86	0.44	0.90	1.85	26.74	25.82
Fe ₂ O ₃	0.42	2.34	0.31	0.74	1.50	0.85	0.90	3.29	4.65	1.06	1.72	31.44	0.57	0.45
Cr ₂ O ₃	0.46	-	-	2.03	-	0.88	-	-	-	-	-	-	-	0.01
FeO	3.57	27.85	41.65	1.47	22.94	5.57	20.18	18.15	25.35	16.89	27.77	0.75	0.04	tr
MnO	0.08	0.85	5.02	0.09	3.70	0.15	1.17	0.59	0.51	0.56	0.98	-	0.01	0.00
NiO	0.35	-	-	0.03	-	0.10	-	-	-	-	-	-	-	-
MgO	36.13	15.78	3.49	16.96	1.06	16.40	2.27	16.15	6.87	23.51	12.69	-	0.00	0.12
CaO	0.23	1.44	1.43	21.16	21.30	19.97	17.24	9.90	7.96	4.06	3.80	-	0.00	0.13
Na ₂ O	-	0.05	-	1.37	0.14	0.35	1.04	0.65	0.58	0.19	0.23	12.86	0.05	13.40
K ₂ O	-	0.02	-	0.15	0.03	0.01	0.27	0.15	0.20	0.00	0.12	0.19	0.16	0.02
H ₂ O*	0.52	-	0.65	0.22	0.46	0.10	0.42	0.10	0.57	-	1.27	0.17	0.48	0.22
H ₂ O	0.04	0.00	0.09	0.08	-	0.07	0.04	0.00	0.35	0.22	0.08	-	0.06	0.16
Total	100.52	100.28	99.59	100.64	99.85	100.67	99.73	100.04	99.92	99.99	100.13	99.95	100.12	99.75
Si	1.97	1.94	1.97	1.96	1.99	1.93	1.86	1.91	1.94	1.96	1.97	1.99	2.03	2.00
Al	0.03	0.06	0.03	0.04	0.01	0.07	0.14	0.03	0.06	0.02	0.03	0.01	-	0.00
Al	0.01	-	0.02	0.03	0.01	0.05	0.02	-	0.12	-	0.01	0.07	0.98	1.02
Ti	0.00	0.02	0.00	0.01	0.00	0.01	0.04	0.02	0.00	0.01	0.03	0.02	-	0.00
Fe ⁺³	0.01	0.07	0.01	0.02	0.05	0.02	0.03	0.09	0.14	0.03	0.05	0.91	0.01	0.01
Cr	0.01	-	-	0.06	-	0.03	-	-	-	-	-	-	-	0.00
Mg	1.84	0.91	0.22	0.92	0.07	0.90	0.43	0.93	0.41	1.30	0.75	-	-	0.01
Ni	0.01	-	-	0.00	-	0.00	-	-	-	-	-	-	-	-
Fe ⁺²	0.10	0.90	1.50	0.05	0.79	0.17	0.67	0.58	0.84	0.52	0.92	0.02	0.00	-
Mn	0.00	0.03	0.18	0.00	0.13	0.01	0.04	0.02	0.02	0.02	0.03	-	-	-
Ca	0.01	0.06	0.07	0.82	0.94	0.78	0.74	0.41	0.34	0.16	0.16	-	-	0.01
Na	-	0.00	-	0.10	0.01	0.02	0.08	0.05	0.05	0.01	0.02	0.95	0.00	0.87
K	-	0.00	-	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00
Mg	93.90	46.90	12.40	50.80	3.30	47.60	22.80	45.60	23.30	63.90	39.20	-	-	-
Fe	5.70	50.00	83.90	3.80	49.00	10.70	38.60	34.30	57.30	28.10	52.40	-	-	-
Ca	0.40	3.10	3.70	45.40	47.70	41.70	38.60	20.10	19.40	8.00	8.40	-	-	-

hydration-exsolution in which amphibole is produced from pyroxene which had housed all the other components except water. Some other workers have suggested natural amphibole pyroxene compounds (in effect, an ordered submicroscopic amphibole-pyroxene intergrowth that could be recrystallized to separate pyroxene amphibole lamellae. However Parsons et al (1991) have a slightly different view proposing that the more evolved phases in the Mboutou complex acquired calc-alkaline characteristics, probably because of increased water infiltration into residual batches of the magma. The pyroxene amphibole relationship in the study area could be adequately explained by all of the above.

Maruyama and Liou (1988) used the relationship between Al/Ti , Al/Si and Al_2O_3/SiO_2 as shown in figure 4 i-iii on primary pyroxenes to characterize the chemistry and magma of the Francisca metabasites. As applied here, most of the points fall within the transition zone between alkaline and tholeiitic. In 4(i-ii) and 4(iii) majority of the points fall within non-alkaline field and a few points fall within the normal alkaline field. This bimodal nature of the magmatism in the Ubo marble area has been highlighted in [Ashidi in press (ii and iii)]. Dobosi et al (1991) graphically expressed the Ti/Al ratio as an expression of relative pressures. In fig 5, the Ti/Al ratio of the samples suggest that all points fall at $Ti/Al \leq 0.175$. Probably very high pressures were involved in the crystallization of the pyroxenes of the study area.

Given the probably high pressure and temperature that characterized the crystallization of pyroxenes, addition of calcium which causes increased precipitation of augite and anorthite and depletion of the magma in silica, magnesium, iron and alumina, may also lead to desiccation of the liquid (McBirney 1979). This appropriately explains why the silica content SiO_2 of the dolerite is less than that of the gabbro which is also less than that of the pyroxenite (dolerite; 47.83-48.95%, gabbro, 48.32-50.83)% and pyroxenite (51.43-52.55%).

Ranlov and Dymek (1991) proposed that

in the course of magmatic assimilation, the uptake of cations in photosites is dependent on factors such as the rate of growth and the charge/radius ratio of the cations. In the case of rapid crystal growth, there may not be sufficient time for resorption of undesirable cations Ti , Zr , Al^{3+} ; thus high charge/radius ratio elements are retained selectively because of their ability to adhere more tenaciously to the crystal surface. Such goes to explain why 'others' in the pyroxene crystals are more abundant especially for the gabbro.

CONCLUSION

The different rocks-dolerite, gabbro and pyroxenite are characterized by pyroxenes which could be distinguished on the basis of their chemistry. The SiO_2 content of the dolerite and gabbro are lower than that of the pyroxenite due to desilication resulting from carbonate effects on the magmas. As the gabbro made contact with the marble bodies, rapid crystallization enhanced massive incorporation of 'others' more in the gabbro and dolerite than the pyroxenite.

Either as a result of some limited solid solution between pyroxene and clin amphibole or possibility of 'hydration-exsolution' in which amphibole is produced from pyroxene, or due to an ordered submicroscopic amphibole-pyroxene intergrowth that could be recrystallized to separate pyroxene-amphibole lamellae, there was abundant intergrowth of pyroxene and amphiboles in the samples. The abundance of amphibole lamellae could be attributed to hydrous influx into a magma which resulted in a bimodal (tholeiitic-alkaline) transition zone characteristic of Island arc setting.

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