Geol. Bull. Univ. Peshawar, 1990, Vol. 23, pp. 67-85

SODIC PYROXENES AND AMPHIBOLES FROM KOGA SYENITES OF AMBELA GRANITIC COMPLEX, N.W.F.P., PAKISTAN

IHSANULLAH MIAN[1] & NUSRAT JABEEN[2]

[1]Department of Geology, University of Peshawar

[2]National Centre of Excellance in Geology, University of Peshawar

ABSTRACT

The Koga syenites are intruded and fenitized by at least two corbonatite intrusions having different Na/K ratios. The carbonatite with high Na/K ratio formed Na-fenites, while the low Na/K ratio produced K-fenites.

Amongst the fenitic pyriboles, Na-pyroxene shows a trend from acmitic to diopsidic and/or hedenburgitic component in contrast to magmatic trend. The fenitic Na-amphibole occurs only in Na-fenitized rocks and shows a trend from magnesio-arfvedsonite to richterite which is opposite to the magmatic subsolidus trend. The amplibole composition shows an increase in MgO ratio with increasing intensity of fenitization and suggests the crystallization of fenitic amphibole under strong oxidation conditions.

INTRODUCTION

Carbonatites are typically surrounded by metasomatic aureoles, which develop as a result of metasomatism of country rocks by the carbonatite fluids emanating during the emplacement. Although many authors (Mckie, 1966; Currie & Ferguson, 1971; Le Bas, 1977; Vartiainen, 1980; Viladkar, 1980; Woolley, 1982; Rubie & Gunter, 1983; Mian & Le Bas, 1986,1987,1988) have made extensive studies of fenitization by carbonatites but the process is still not well understood. This is partly because of the uncertainties of the nature of the fenitizing fluids, but also because of the variation in mineralogical composition, texture, chemical reactivity, the state of oxidation and permeability of the country rocks. At Koga in NW Pakistan carbonatites and/or ijolites have intruded and fenitized the syenitic rocks.

To understand the process of fenitization in general and behaviour of Na-pyroxene and Na-amphibole (pyriboles) in particular, samples are collected from different syenitic rocks of Koga. This paper presents the variation in the chemistry of magmatic and fenitic pyrobole as a result of fenetic fluids emanating from the carbonatite. The revers changes in chemistry, in contrast to the magmatic pyroboles, correlate with the grade of fenitization by the carbonatites having different Na/K ratios.

GEOLOGICAL SETTING

The Koga syenites occupy the eastern part of the Ambela granitic complex of the alkaline igneous province, NW Pakistan, which is located at the border of Swat and Mardan districts near Koga village at a distance of about 56 km northeast of Mardan. The syenitic rocks constitute an oval-shaped body (about 40 sq. km) and are emplaced in Chinglai gneisses to the east and granites and syenites in the north and west (Fig. 1). The rock unites of Koga are alkali syenites, nepheline syenites, ijolites, carbonatites and their fenites.

The Koga syenites and carbonatites were first reported by Siddiqui et al. (1968). Chaudhry et al. (1982) described the preliminary petrology and chemistry of these rocks and suggest the emplacement of magma along a weak zone developed south of Main Mantle Thrust in the sequence as Babaji Soda granite, pulaskite, nephelinitic syenites, foyaite, sodalite syenite, and carbonatites and their fenites. Rafiq (1987) suggested the generation of magma by partial melting of the lower crust, contaminated during later phases by the influx from the activated upper mantle and progressive desilicification of the magma which led to the formation of the quartz syenite, syenite and feldspathoidal syenites. Le Bas et al. (1986) gave the preliminary petrography of the Babaji Syenites and Koga syenites and suggested an age of 315±15 Ma for Babaji Syenites and 297±4 Ma for Koga syenites on the basis of Rb-Sr isotopic ratios.

PETROGRAPHY AND MINERALOGY

Detailed petrography of the syenitic rocks and carbonatites, ijolites and their fenites is the subject of another contribution (Jabeen & Mian, in preparation). However, petrography of the magmatic Na-pyroxenes and Na-amphiboles (pyriboles) in the syenites, nepheline-syenites and the fenitic pyriboles which formed as a result of metasomatizing fluids emanating from the carbonatites and/or ijolites is discussed in the following.

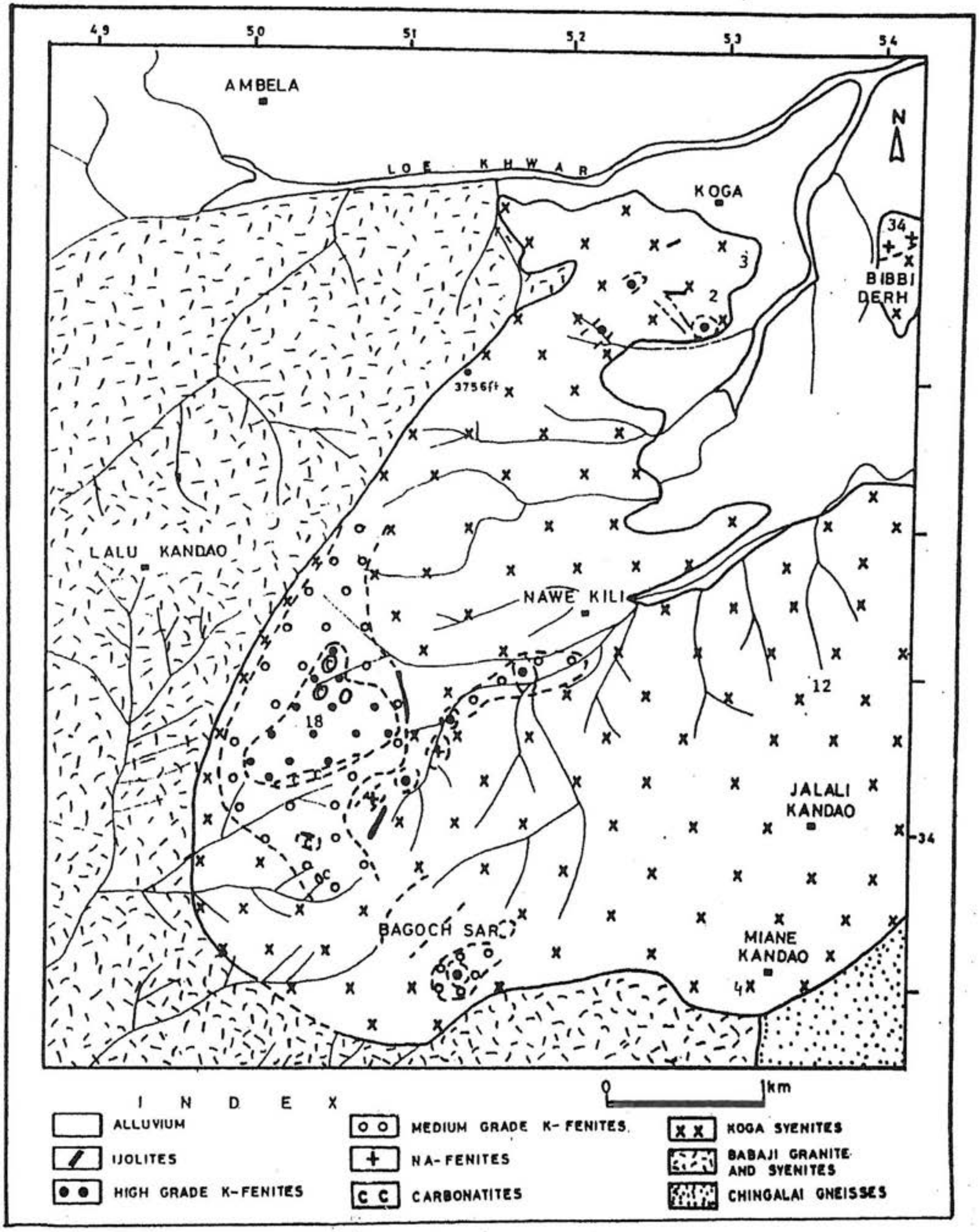


Fig. 1. Geological map of Koga syenites.

Amongst the pyroboles, pyroxene is more abundant in the unfenitized rocks both in the central and marginal rocks at Koga. The pyroxene in the unfenitized syenites is fine- to medium-grained, subhedral and is yellowish green in colour. In the low grade fenites it is medium-grained, yellowish-brown in colour wich is corroded and altered along margins and cleavages. The change in the colour from yellowish-green to yellowish-brown increases with the intensity of fenitization. In the high grade fenites pyroxene shows zoning, where the relict yellowish-green pyroxene is surrounded by yellowish-brown pyroxene. The dusty brown rim around the relict green pyroxene is interpreted as the reaction rim between the original pyroxene of the protolith and fenitizing fluids, low in Na/K ratios emanating from the carbonatite. Even the core of zoned pyroxene is dusty at places. The pleochroism of pyroxene is well correlated with the chemistry (Table 1).

Na-amphiboles are abundant in the fine- to medium-grained syenites and nepheline syenites. These syenites and nepheline syenites occur along the contact with Babaji granite and syenites. Na-amphibole in unfenitized rocks is taramite, which is fine- to medium-grained, subhedral and is mostly parallel to the primary foliation. These taramites are unzoned and have strong absorption. The pleochroism scheme is α = yellowish-brown, β = greenish-brown and γ = bluish-green. Biotite also occurs in the form of needles parallel to the fabric.

The amphibole in the low grade fenites is medium-grained, and mostly parallel to the foliation but at places the overgrowth of the amphibole crosscut the primary foliation. The amphibole is zoned which can be seen also in thin section. The core of the amphibole is taramite which has the same pleochroism as described above apart from the which γ is now pale brown. The margin is kataphorite and the pleochroic scheme is α = yellowish-green, β = greenish-blue, and γ = greenish-yellow to orange. Needles of amphibole can also be found which radiate from the zoned amphibole. The amphibole in the medium-grade fenites is formed in granitic rocks. These granitic rocks are present as xenoliths in the syenitic rocks between Nawe Killi and Naranji Kandao, and are composed of quartz, perthite and muscovite. These granitic rock are foliated. The foliation is marked by the parallel alignment of quartz and perthite. The fenitic amphibole and pyroxene are formed at the expanse of quartz as clusters and from these clusters Na-amphibole radiates. Relict quartz is present sometimes in the middle of the cluster of amphibole and pyroxene. The radiating grains of amphibole cross-cut the primary foliation.

The newly formed amphibole in the granitic xenoliths is magnesio-arfvedsonite which shows iron leaching along the cleavages. The amphibole is zoned in thin section but little variation is present in the chemistry (Table 2). The pleochroic scheme is α = greenish-blue, β = pale-indigo, γ = greenish-yellow.

TABLE 1. REPRESENTATIVE ANALYSES OF PYROXENE FROM KOGA SYENITES.

Anal.No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Samp.No.	K12P3x2	K12P3x4	K12P3x7	K18P1A1	K18P1A3	K18P1A4	K34P1C1	K34P1C3	K34P3A1	K34P3A2	K31P1A1	K318P1A2	K318P1A3
	(MID)		(MAR)	(MID)		(MAR)	(MID)	(MAR)	(MID)	(MAR)	(MID)		(MAR)
SiO_2	51.18	53.06	53.53	52.23	53.35	53.39	51.14	52.75	53.23	52.96	53.45	52.13	53.71
TiO_2	0.31	0.28	0.27	0.05	0.02	0.03	1.30	0.17	0.81	0.73	0.36	0.21	0.19
Al_2O_3	1.61	2.11	3.52	4.15	0.99	1.19	3.17	3.30	3.61	0.74	2.32	1.21	2.22
Fe_2O_3	9.48	22.62	27.19	31.53	28.12	24.32	16.59	18.74	24.39	27.84	27.53	26.09	24.96
FeO	9.58	2.05	0.00	0.00	0.00	0.76	6.11	4.39	2.79	0.07	3.48	2.09	5.16
MnO	1.34	0.44	0.14	0.00	0.10	0.10	0.29	0.42	0.03	0.14	0.28	0.83	0.64
MgO	5.18	3.29	0.88	0.04	3.97	4.45	2.63	2.72	0.66	0.71	1.13	2.48	1.44
CaO	15.34	6.31	2.19	0.10	7.21	8.64	8.53	7.72	1.77	1.58	2.34	4.62	3.33
Na_2O	4.68	10.20	12.94	14.81	10.36	09.50	8.70	9.43	12.55	13.04	11.96	10.63	11.08
Total	98.70	100.36	100.66	102.91	104.12	102.38	98.46	99.64	99.84	97.81	102.85	100.29	102.73
	No. of Oins on the bases of 6 oxygen												
Si	1.991	1.997	1.999	01.900	01.952	01.976	02.054	02.095	02.131	02.116	01.984	01.985	01.999
Ti	0.009	0.008	0.008	00.001	00.001	00.001	00.039	00.005	00.240	00.032	00.010	00.006	00.005
Al	0.074	0.094	0.155	00.177	00.043	00.051	00.150	00.154	00.170	00.176	00.102	00.055	00.097
Fe^{3+}	0.287	0.641	0.764	00.857	00.774	00.675	00.482	00.528	00.692	00.783	00.769	00.748	00.699
Fe^{2+}	0.312	0.065	0.000	00.000	00.000	00.023	00.197	00.139	00.088	00.002	00.108	00.067	00.161
Mn	0.044	0.014	0.004	00.000	00.003	00.003	00.010	00.014	00.001	00.005	00.009	00.027	00.020
Mg	0.300	0.185	0.049	00.003	00.216	00.246	00.158	00.161	00.038	00.042	00.062	00.141	00.080
Ca	0.039	0.254	0.088	00.004	00.287	00.343	00.367	00.318	00.076	00.068	00.093	00.189	00.133
K	0.353	0.744	0.937	01.038	00.735	00.682	00.678	00.726	00.974	01.010	00.861	00.785	00.799
Ma	35.000	73.900	94.600	99.727	76.931	71.477	64.517	69.346	88.027	95.351	82.756	77.044	75.382
Mg	29.700	18.300	5.000	00.273	22.688	25.743	14.996	15.379	3.452	03.992	06.004	13.800	07.556
$Fe^{2+}Mn$	35.300	3.800	0.400	00.000	00.531	02.779	20.487	15.275	8.521	00.657	11.240	09.157	17.062

Magmatic pyroxene from Koga; Analyses No.1-3.
Fenitic pyroxene from K-fenites; Analyses No.4-6.
Fenitic pyroxene from Na-fenites; Analyses No.7-13.

TABLE 2. REPRESENTATIVE ANALYSES OF Na-AMPHIBOLES FROM KOGA.

Anal.No.	1	2	3	4	5	6	7	8	9	10
Samp.No.	K1P1 (MID)	K1P3	K2P3 (MID)	K2P3 (MAR)	K34K1A1 (MID)	K34K1A2 (MAR)	K3P1A2 (MID)	K3P1A3 (MAR)	K3P18P1 (MID)	K318P2 (MAR)
SiO_2	38.04	37.10	36.80	37.08	42.19	37.30	50.06	50.52	52.63	52.20
TiO_2	0.78	0.60	1.12	0.37	0.85	0.46	00.87	00.42	00.12	00.16
Al_2O_3	11.62	13.35	10.42	12.54	13.30	12.88	01.63	01.49	01.07	00.69
Fe_2O_3	2.20	5.26	5.05	9.29	2.33	9.88	12.23	10.45	10.15	09.43
FeO	21.27	24.50	21.56	18.17	18.75	17.63	13.53	14.12	08.07	09.74
MnO	1.19	1.38	1.60	1.28	1.36	1.14	01.43	01.35	02.18	02.29
MgO	3.14	1.67	3.64	3.13	4.69	3.03	07.66	07.73	11.60	10.79
CaO	6.70	6.67	9.94	7.52	7.64	6.59	02.58	02.97	02.65	02.41
Na_2O	4.19	4.22	3.31	3.50	3.93	4.02	06.30	05.82	06.46	06.43
K_2O	1.89	3.11	1.86	2.98	1.78	3.13	01.31	01.35	01.66	01.26
Total	91.02	97.86	95.30	95.86	96.82	96.06	97.60	96.22	96.59	95.40
				No. of Ions on the basis of 23 Oxygens						
Si	6.424	6.009	6.092	6.020	6.523	6.029	07.587	07.733	01.814	07.877
Aliv	1.576	1.991	1.908	1.980	1.477	1.971	00.413	00.267	00.186	00.123
Alvi	0.737	0.557	0.125	0.419	0.947	0.479	00.000	00.002	00.001	00.000
Ti	0.099	0.073	0.139	0.045	0.099	0.056	00.099	00.048	00.013	00.018
Fe^{3+}	0.280	0.641	0.629	1.135	0.271	1.200	01.394	01.204	01.134	01.071
Fe^{2+}	3.004	3.318	2.689	2.468	2.425	2.380	01.715	01.807	01.002	01.229
Mn	0.170	0.189	0.224	0.176	0.178	0.156	00.184	00.175	00.274	00.293
Mg	0.790	0.403	0.898	0.758	1.081	0.729	01.731	01.764	02.568	02.427
Ca	1.212	1.157	1.710	1.308	1.266	1.140	00.419	00.487	00.422	00.390
Na	0.788	0.843	0.290	0.632	0.734	0.860	01.581	01.513	01.578	01.610
Na	0.584	0.482	0.772	0.470	0.444	0.398	00.270	00.214	00.282	00.270
K	0.407	0.643	0.393	0.617	0.351	0.645	00.253	00.264	00.314	00.243
Vacancy in A site	0.009	0.000	0.000	0.000	0.158	0.000	00.115	00.425	00.404	00.437
Mg ratio	18.610	8.885	18.390	16.700	27.330	16.323	34.338	35.630	51.590	48.350

COMPOSITION OF PYRIBOLES

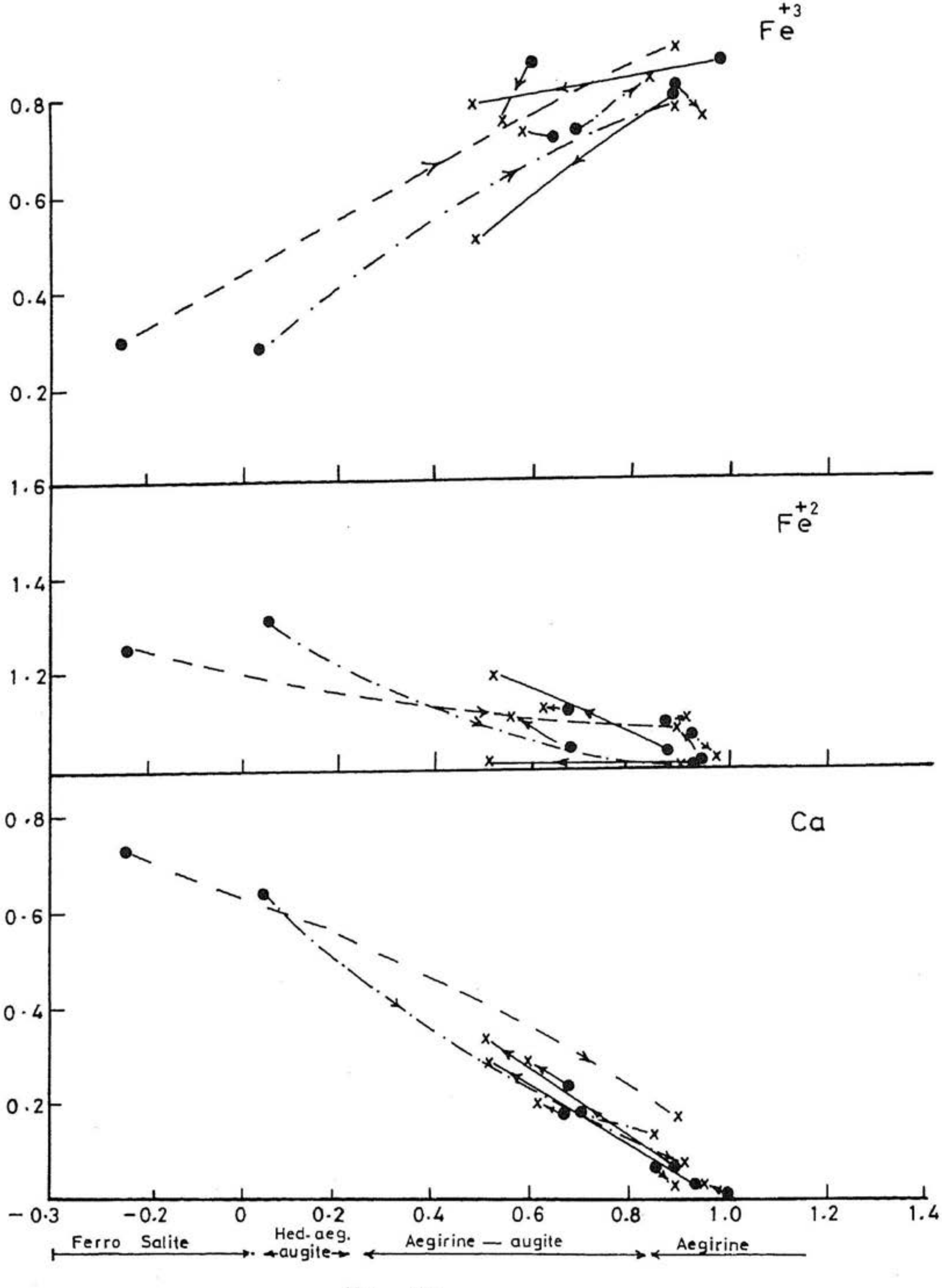
The pyroxene from the Koga granites and syenites is aegirine-augite and amphibole is taramite, ketaphorite and magnesium arfvedsonite (IMA nomenclature; Leak, 1978). Jeol microprobe analyses of pyriboles were made measuring three or four crystals per sample and two or more spots per crystal. Tables 1 and 2 give the representative analyses of the core and margins of the pyroxene and amphibole for each sample respectively. The data for pyroxene is recalculated on the basis of six oxygens and four cations and for amphibole recalculation scheme is on the basis of 23 oxygens and 13 cations exculding Ca, Na and K.

COMPOSITION OF PYROXENES

Na-pyroxene is one of the important mineral present in syenite and nepheline syenite formed during magmatic process. The composition of these pyroxenes have been studied in detailed in such type of rocks. Different authors have given different trends for magmatic pyroxenes. Magmatic pyroxene ranges in composition from diopsidic to aegirine-augitic in syenetic rocks fractionated during magmatic emplacement (Yogi, 1953; Taylor & King, 1967; Varet, 1969; Gomes et al., 1970; Stephenson, 1972; Platt & Woolley, 1986; Mian, 1987).

In Fig. 2 the parameter Na-Mg in atoms per formula unit is used by Stephenson (1972) as a fractionation trend during the emplacement of different types of igneous rocks. The composition of magmatic pyroxene from Koga syenite and nepheline syenite follows similar trend as given by Stephenson (1972) for nepheline syenites of south Qoroq Centre, south Greenland. The pyroxene from Koga nepheline syenite along the contact with Babaji granites and syenites and along the road to Miane Kandao, shows magmatic trend from hedenbergitic aegirine-augite (Na-Mg=1) to aegirine-augite (Na-Mg=0) in core and margin of the grain respectively (Fig. 2). In the coarse-grained rock, present in the middle of Koga syenites, little variation is present in the composition of magmatic pyroxene. Although this variation is small but the trend is the same from diopside or hedenbergite to aegirine.

The above parameter has been chosen to distinguish between the magmatic and fenitic pyroxenes. The fenitic pyroxene shows a reverse trend on Fig. 2 with increasing degree of intensity of fenitization. The composition of the relict green pyroxene is aegirin in the core in which Na-Mg is approximately 1 while in the overgrown brown pyroxene Na-Mg decreases to 0.5. Ca and Fe^{2+} decrease in magmatic pyroxene with fractionation while Fe^{3+} increases. In fenitic pyroxene Ca and Fe^{2+} increase. Similarly Na+K increases with the decrease of Mg ratio (100 Mg/(Mg,Fe,Mn) in the magmatic pyroxene, showing a fractionation trend during the evolution of syenites and nepheline


Fe^{+3}
0.8
0.6
0.4
0.2
1.6
Fe^{+2}
1.4
1.2
Ca
0.8
0.6
0.4
0.2
−0.3
−0.2
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Ferro Salite
Hed. aeg. augite
Aegirine — augite
Aegirine
Na — Mg

syenites. The fenitic pyroxenes show a reverse trend (Fig. 3). Some of the analyses show little but a reverse trend than that of the magmatic pyroxene.

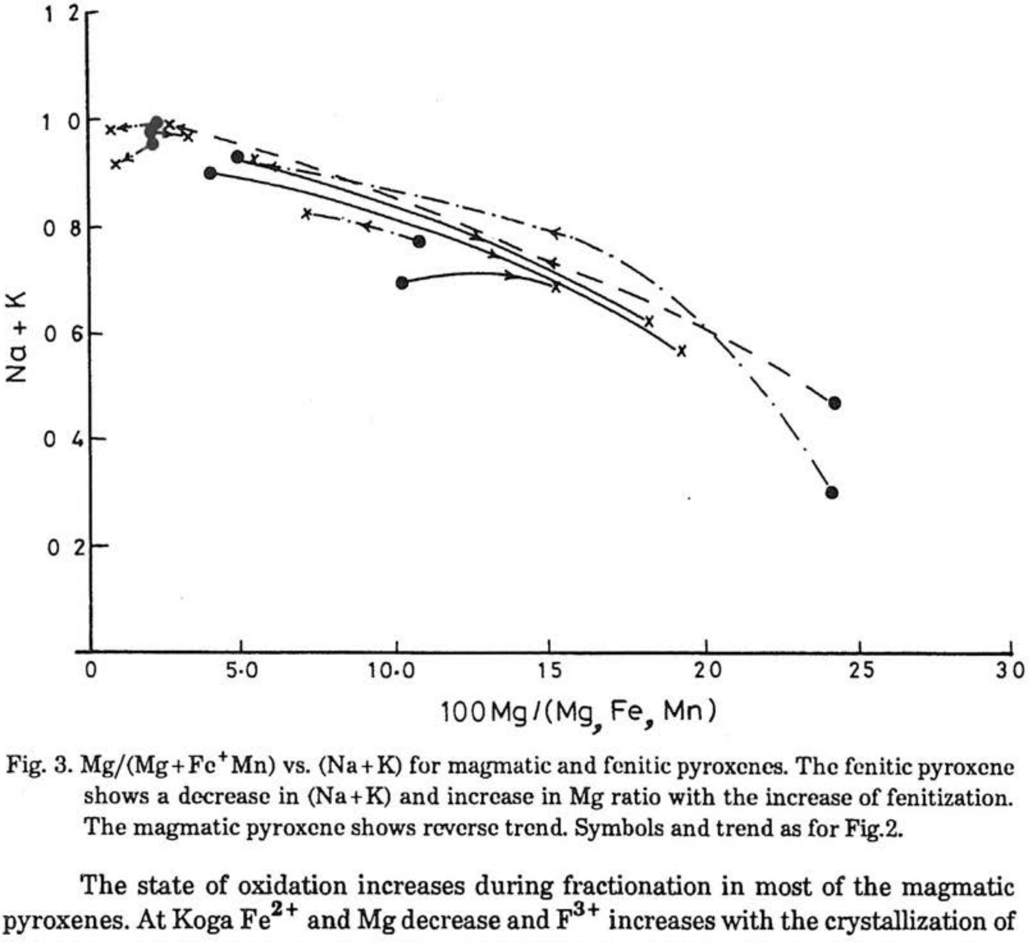


Fig. 3. $Mg/(Mg+Fe^{+}Mn)$ vs. $(Na+K)$ for magmatic and fenitic pyroxenes. The fenitic pyroxene shows a decrease in $(Na+K)$ and increase in Mg ratio with the increase of fenitization. The magmatic pyroxene shows reverse trend. Symbols and trend as for Fig.2.

The state of oxidation increases during fractionation in most of the magmatic pyroxenes. At Koga Fe^{2+} and Mg decrease and F^{3+} increases with the crystallization of pyroxene with fractionation from the early to late stage intruded rocks. However, some pyroxenes show a reverse trend of Mg and Fe^{2+} with respect to Fe^{3+} with the increase of intensity of fenitization by the carbonatites. Again some of the rocks show little

Fig. 2. (Facing page) Plot of Ca, Fe^{2+} and Fe^{3+} against (Na-Mg) of the pyroxene showing that composition of magmatic pyroxene from Koga and South Qoroq alkaline rocks changes from hedenburgite to aegirine while the fenitic pyroxenes of Koga syenite show an opposite trend from aegirine to aegirine-augite. (dash dot arrow) = magmatic pyroxene of Koga syenite, (dash arrow) = pyroxene of South Qoroq, (solid arrow) = fenitic pyroxene of Koga. Crosses = margin, dots = core.

variation but reverse to that of magmatic pyroxene. The revers change in contrast to the magmatic trend is interpreted as the result of fenitic fluids emanating from the carbonatites (Fig. 4).

Figure 5A shows the magmatic fractionation trend of Na-pyroxene in Koga syenites and nepheline syenites. The composition of magmatic pyroxene shows an increase in the actmitic component with fractionation in most of the rocks, particularly from the marginal rocks of Koga. The magmatic pyroxene in coarse-grained syenites and nepheline syenites from the middle of the complex shows magmatic trend from diopsidic to acmitic component. However, the fenitic pyroxenes show a reverse trend from acmitic to diopsidic component in both fenitized syenites and granite (Fig. 5). The fenitic pyroxenes show two different trends: a) diopsidic component increases with little

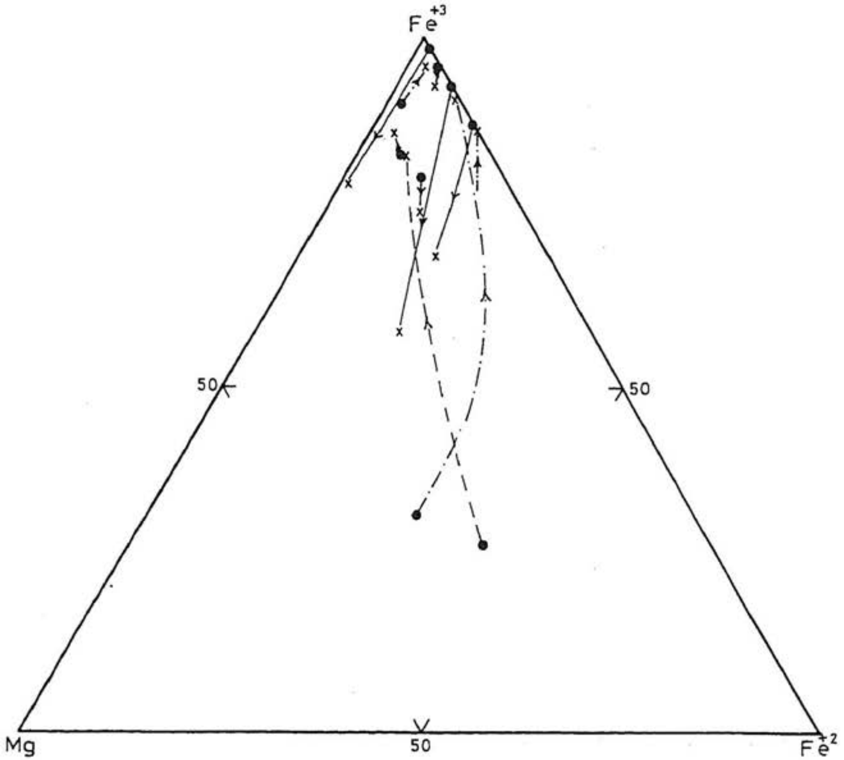


Fig. 4. Plot of Koga pyroxene in terms of Fe^{2+} -- Fe^{3+} Mg -- Mg and Fe2+ increases with respect to Fe^{3+} in fenitic pyroxenes but, reverse in the case of magmatic pyroxenes. Symbols and trends as for Fig. 2.

increase in hedenbergitic component and, b) both diopsidic and hedenbergitic components increase. These trends are interpreted as the result of the variation in Na/K ratio of the fenitizing fluids, low in the first trend and high for the second trend. A trend similar to the second one is also reported by Kresten and Morogan (1986) for the pyroxene from the Fen Complex. The authors suggested an ijolite-type magma for the fenitization of these rocks. The magmatic and fenitic pyroxenes from Koga are compared with the published data of other magmatic pyroxenes in Fig. 5B.

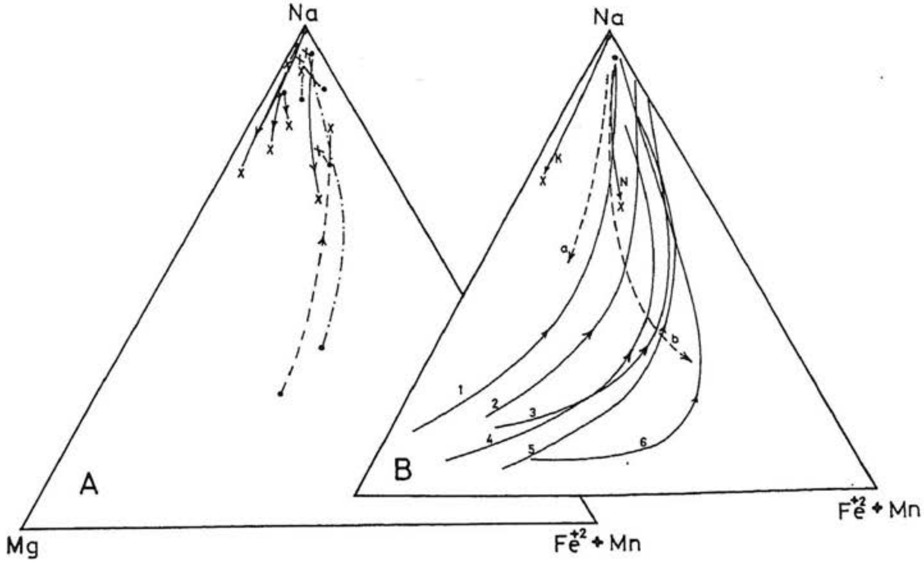


Fig. 5 A. Plot of Koga pyroxenes in terms of Ac-Di-Hed showing the decrease of acmite relative to diopside with the increasing degree of intensity of fenitization. Symbols and trends as for Fig.2.

B. Pyroxene trend in Koga syenites (N = Na-fenitized and K = K-fenitized) is compared with published data alkali pyroxene trends (a,b) Fen Complex, southern Norway (Kresten and Morogan, 1986); (1) Auvergne, France (Varet, 1969); (2) Itapirapua, Brazil (Gomes et al., 1970); (3) Chambe, Mulanji, Malawi (Platt and Woolley, 1986); (4) Uganda (Tyler and King, 1967); (5) South Greenland (Stephenson, 1972).

COMPOSITION OF NA-AMPHIBOLE

The Na-amphybole like Na-pyroxene is a common mineral present in alkaline igneous rocks particularly in granites and syenites. At Koga magmatic Na-amphibole, mostly occuring in the marginal nepheline syenites, is taramite. These amphibole grains are unzoned and show little variation in chemistry and optical properties. The fenitic amphiboles have been studied in detail in granites and syenites which are intruded by carbonatites and ijolites (Vartiainen & Woolley, 1976; Vartiainen, 1980; Hogarth & Lapointe, 1984; Mian & Le Bas, 1986). However, magmatic and fenitic Na-amphiboles are present in Koga fenitized syenites and granites.

Strong and Taylor (1984) show that with the progressive crystallization of peralkaline magmas, the Na-amphiboles progress from barroisite through richterite to arfvedsonite (Fig. 6A). At Koga the magmatic Na-amphibole (taramite) shows a normal trend of fraction from core to margin whereas in the highly fenitized rocks at Koga Na-amphiboles show a revers trend from magnesio-arfvedsonite to richterite (Fig. 6B).

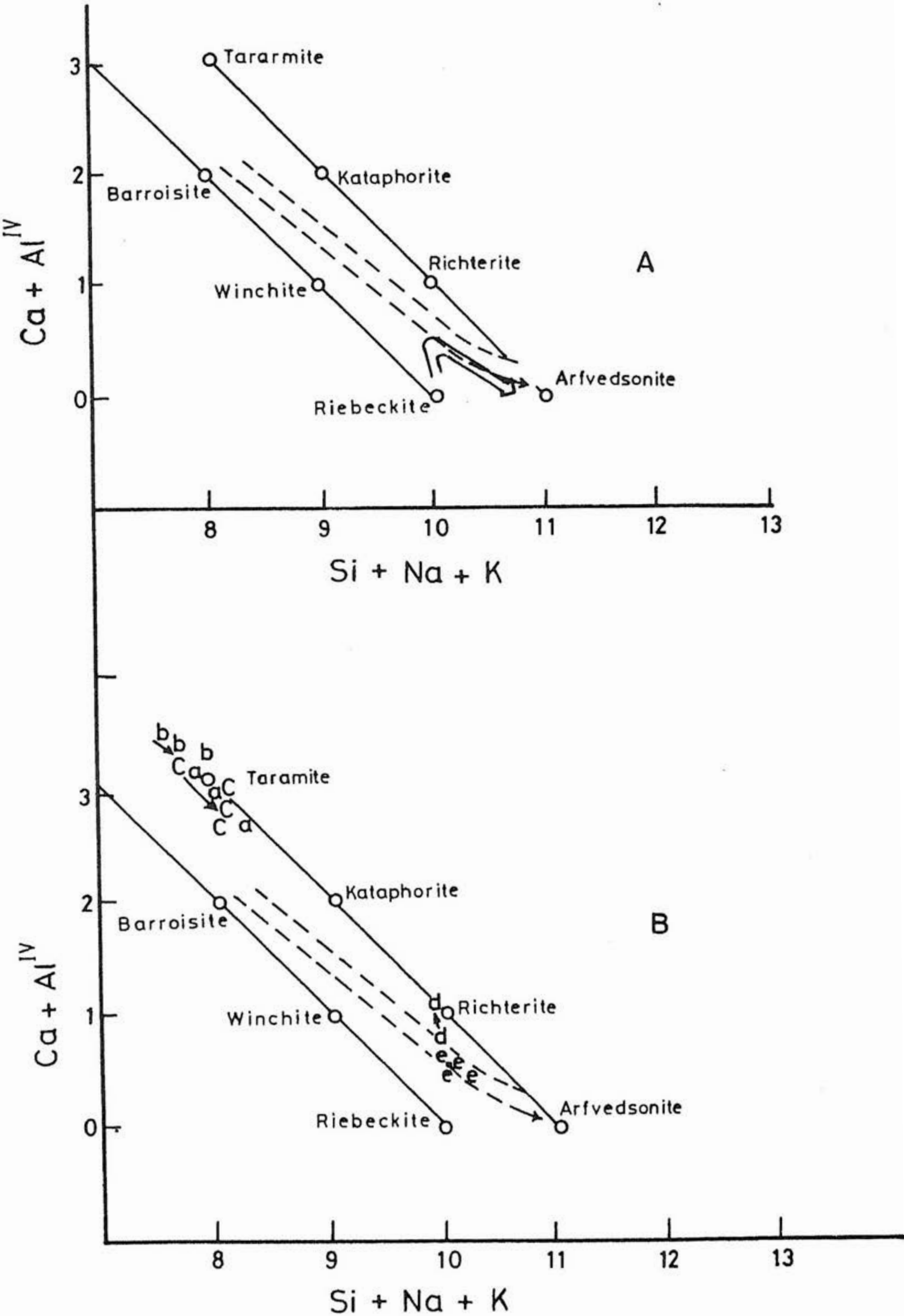
Hogarth & Lapointe (1984) gave two separate evolution trends for amphiboles from fenites at Cantley, Quebec, magnesio-arfvedsonite from biotite gneiss; and magnesio-ricbeckite from pyroxene gneiss (MA and MR respectively in Fig. 7). They suggested that magnesio-arfvedsonite and riebeckite make solid-solution series with winchite. Mian & Le Bas, (1986) gave solid solution series from magnesio-riebeckite to magnesio-arfvedsonite with increasing intensity of fenitization by the carbonatites (Fig. 7). While at Koga fenitic amphiboles show an increase in monovalent cations from magmatic to fenitic amphiboles as a result of which the vacancies in A site increase with the increasing intensity of fenitization.

The variation in (Na+K) content from magmatic amphibole to fenitic amphibole in Koga granite and syenites shows a smooth rise as Mg ratio increases (Fig. 8; low in unfenitized syenites and high in fenitized syenites and granites). Similar trend is given by Mian & Le Bas, (1986) for the Na-amphiboles of Loe Shilman. Na-amphiboles from Loe Shilman and Koga show increase in Mg ratio with increasing fenitizaion.

The slope of the straight line given by plotting the Mg-ratio against MgO for fenetic Na-amphiboles from Koga is steeper than that for magmatic Na-amphiboles (Fig. 9). Data for magmatic amphiboles are taken from Deer et al. (1963) and Coldwell syenitXe igneous complex in Ontario, Canada (Mitchell & Platt, 1982). This type of kinking between unfenetized and fenitized Na-amphiboles was first reported by Vartiainen & Woolley, (1976) from Sokli, Finland. According to Mian & Le Bas (1986) this kinking at about 30 Mg ratio between magmatic and fenetic amphiboles is a product of differing oxidation states, with that in the metasomatic rocks being the high. Therefore, the kinking in the slope in amphiboles from Koga is also interpreted as the result of difference in the state of oxidation in magmatic and fenitic amphiboles.

DISCUSSION

The Na-pyriboles developed in alkaline igneous and metamorphic rocks have compositions related to their host rocks, those developed during fenitization depend not


A
Tararmite
Kataphorite
Barroisite
Richterite
Winchite
Arfvedsonite
Riebeckite
Ca + Al^{IV}
0
1
2
3
Si + Na + K
8
9
10
11
12
13
B
b
b
b
C
a
C
a
C
C
a
Taramite
Kataphorite
Barroisite
Richterite
Winchite
d
d
e
e
e
e
Arfvedsonite
Riebeckite
Ca + Al^{IV}
0
1
2
3
Si + Na + K
8
9
10
11
12
13

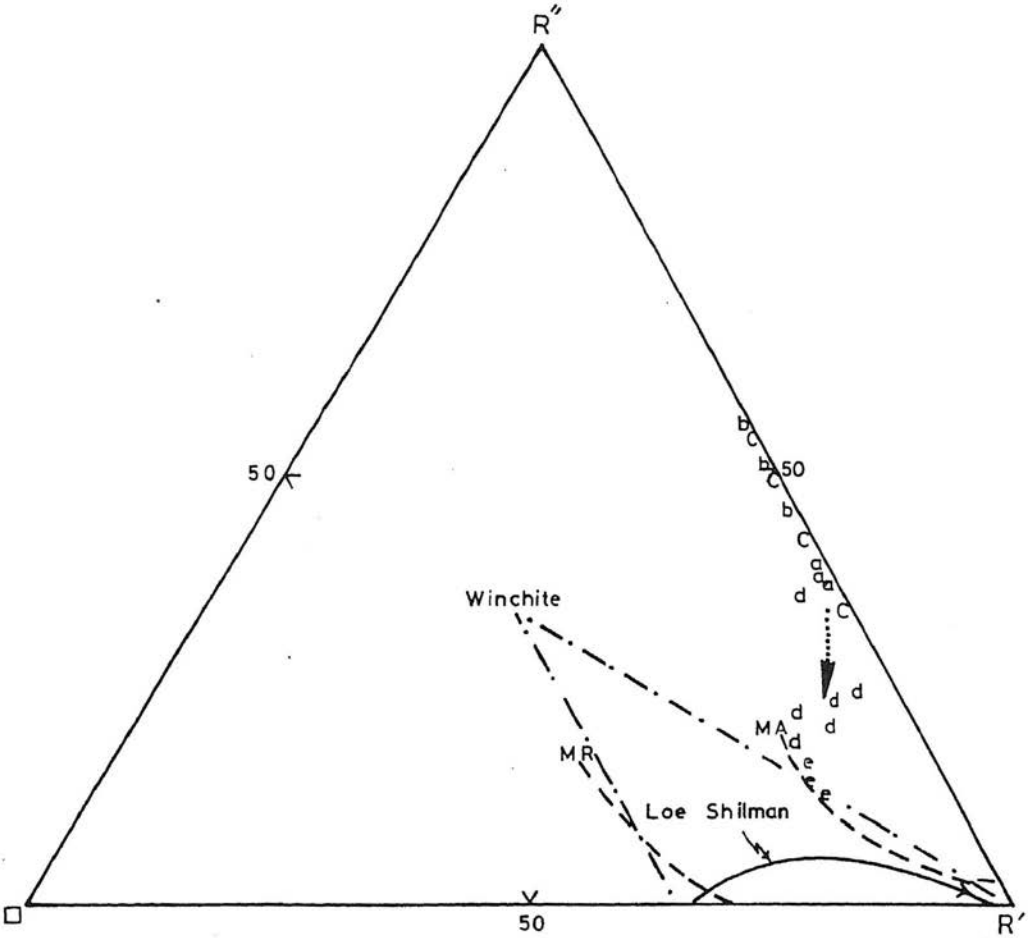


Fig. 7. The Na-amphiboles (a to e) from Koga syenites plotted with respect to monovalent cations R', divalent cations in B site R", and vacancies (O) in A site. Also shown (as dashed lines) are the fenites trends in gneisses and the solid solution series between magnesio-arfvedsonite (MA) and magnesio-riebeckite (MR) with winchite (dotted lines) as given by Hogarth and Lapointe (1984). Solid line shows the trend of fenitic amphibole of Loe Shilman (Mian and Le Bas, 1986) and arrow shows the trend of fenetic amphiboles from Koga syenites. Symbols as for figure 6.

Fig. 6. (Facing Page) A. (Ca+Al^{iv}) vs. (Si+Na+K) plot after Strong and Taylor (1984), showing the magmatic-subsolidus trend for Na-amphibole (dashed arrows) and compared with he fenitic amphiboles from least to the highly fenitized slates and phyllites from Loe Shilman.

B. The magmatic Na-amphibole (taramite) from Koga shows a normal fractionation trend, while fenitic Na-amphibole shows a reverse trend from arfvedsonite to richterite, opposite to magmatic trend given by Strong and Taylor (1984). a= magmatic Na-amphibole (K-1), b= Na-amphibole from low grade fenites (K-2), c=Na-amphibole from medium grade fenites (K-34), d & e = Na-amphibole from high grade fenites from Koga rocks.

only on host rocks composition but also on the composition of fenitizing fluids emanating from alkaline igneous rocks. Amongst the pyriboles magmatic Na-pyroxene shows various trends of fractionation during emplacement of alkaline rocks. These trends given by different authors (Fig. 5) show the enrichment of acmitic component during the fractionation. Similar trend is present in magmatic Na-pyroxene in Koga rocks. However, Na-pyroxene in fenitized syenites and granites of Koga show reverse trends which are from acmitic to diopsidic and/or hedenburgitic component. It is suggested that there are two types of fenitic pyroxenes: 1) when pyroxene is not present in the protolith before fenitization as in shale/slates and phyllites at Loe Shilman, then the newly formed

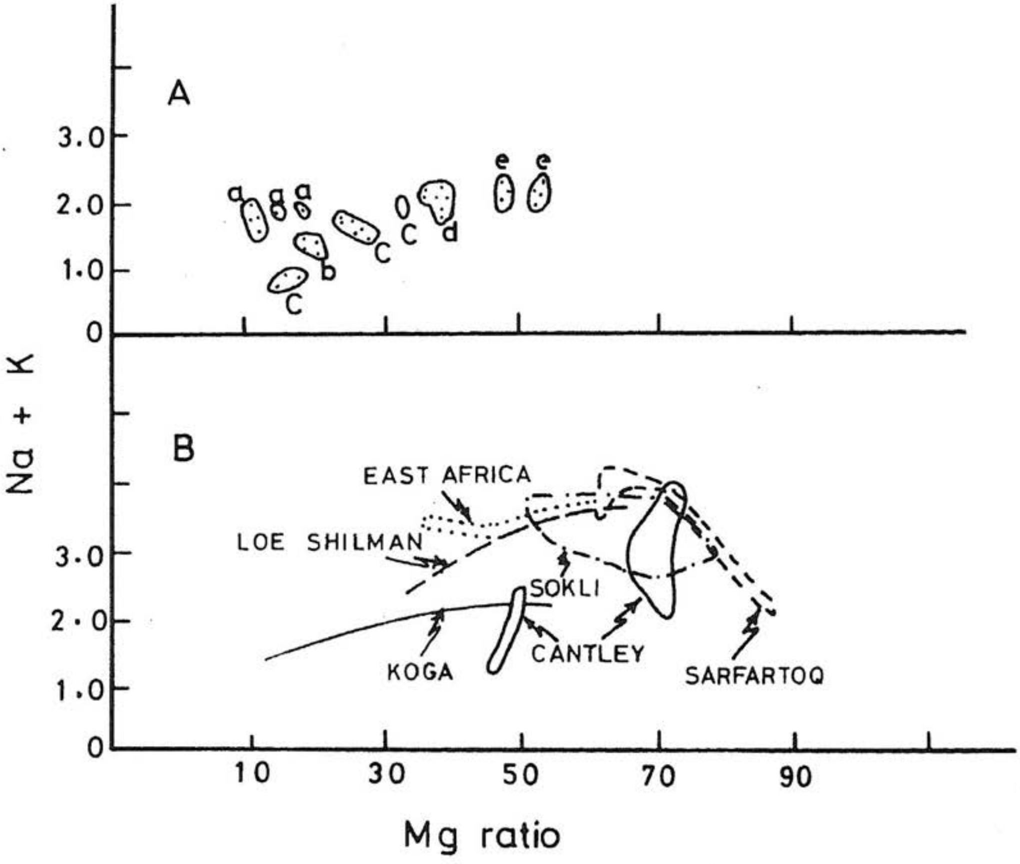


Fig. 8. Plot of Mg ratio against Na+K (A) for amphibole in fenites at Koga, showing regular increase in Na+K with increasing Mg ratio; (B) the trend for amphibole from Loe Koga syenites is compared with fenitic amphibole from Loe Shilman (Mian & Le Bas, 1986) Sokli, Finland (Vartianen and Woolley, 1986); Sarfartoq, West Greenland (Secher and Larsen, 1980); Cantley, Quebec (Hogarth and Lapointe, 1984) and from East Africa (Sutherland, 1969). Symbols as for Fig. 6.

pyroxene may not show regular variation in the chemistry and optical properties from the less to highly fenitized rocks. This is interpreted as due to the newly formed nuclei in equilibrium with the carbonatitic fenitizing fluids. Such type of pyroxenes are present in the granitic xenolith, in which pyroxenes grow radially and are formed at the expanse of quartz as a result of Na-fenitizing fluids by the carbonatite. In this case very little but regular change in composition is present because there was originally no pyroxene. 2) When pyroxene is present in the protolith, then the overgrowing pyroxene does not require any nucleus for their crystallization. In this case fenitic pyroxene grows around the magmatic pyroxene of the host rock. During the overgrowth the original pyroxene (magmatic or metamorphic) reacts with the fenitizing fluids and a change occurs in the

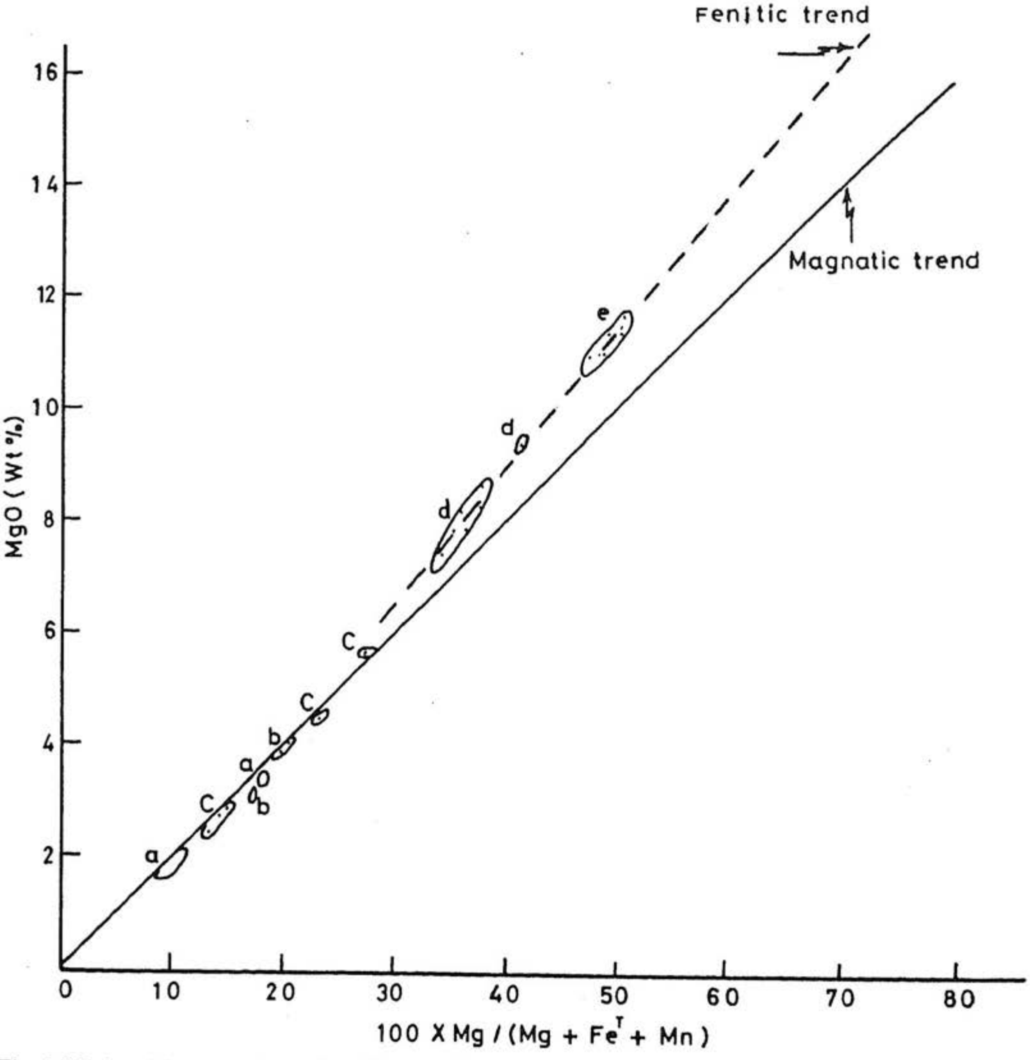


Fig. 9. MgO vs Mg ratio plots after Mian and Le Bas (1986) distinguishing the trends of magmatic and fenitic amphiboles. Symbols as for Figure 6.

composition and optical properties. The original pyroxene of the protolith may be preserved depending upon the intensity of fenitization. Such type of Na-pyroxene is present in the Koga fenitized syenites.

The pyroxene compositional trends for different alkaline rocks are shown in Fig. 5 which represent the cooling history of the alkaline rocks. In this figure all the trends show enrichment of the acmitic component. The reverse trend (i.e. from acmite to diopside) is not reported in pyroxenes during fractional crystallization of the alkaline magma. The reverse trends which are observed in the individual grain of pyroxene from Koga fenitized syenites are interpreted as the result of fenitizing fluids having different Na/K ratios, emanating from the carbonatites. The trend K is the result of fenitizing fluids having low Na/K ratio while trend N is due to emanating fluids having high Na/K ratio. Similar reverse trends have been reported from the Fen Complex which, according to Kresten & Morogan (1986), are due to the fenitization by the ijolites. In Koga the fenitization of syenites and granites due to the fluids having high Na/K ratio (trend N) occurs, the possibility of fenitization by ijolite cannot be overruled. However, the major, trace and REE geochemistry (Jabeen and Mian, in preparation) favours the metasomatism by the carbonatite fluids having high Na/K ratio. The behavior of the second carbonatite (i.e. having high Na/K ratio is almost same as that of the amphibole carbonatite at Silai Patti. In contrast to the fenitic pyroxenes, metasomatic Na-amphibole occurs only in the Na-fenitized syenites.

CONCLUSION

The study of pyriboles from Koga syenites suggests:

1) Fenitization of the rocks by the fluids emanating from carbonatite intrusion.

2) The fenitic pyroxene shows the trend of evolution from acmitic to diopsidic component in contrast to the magmatic trends.

3) The composition of pyroxene further suggests that the Koga rocks have been intruded by at least two carbonatite intrusions having different Na/K ratios.

4) The fenitic Na-amphibole shows trend from magnesio-arfvedsonite to richterite which is also opposite to the magmatic subsolidus trend.

5) The amphibole composition shows an increase in MgO ratio with increasing intensity of fenitization and crystallization of fenitic amphibole under strong oxidation state. However, Na-amphibole occurs only in the Na-fenitized syenites.

REFERENCES

Chaudhry, M.N., Ashraf, M. & Hussain, S.S., 1982. Petrology of Koga nepheline syenites and pegmatites of Swat district. Geol. Bull. Univ. Punjab 16, 1-14.

Currie, K.L. & Ferguson, J., 1971. A study of fenitization around alkaline carbonatite complex at Callander Bay, Ontario. Can. J. Earth Sci. 8, 498-517.

Deer, W.A., Howie, R.A. & Zussman, J., 1963. Rock Forming Minerals, 2. Longman, London.

Gomes, C.DE B., Moro, S.L. & Dutra, C.V., 1970. Pyroxenes from the alkaline rocks of Itapirapua Sao Paolo, Brazil. Am. Min. 55, 224-230.

Hogarth, D.D. & Lapointe, P., 1984. Amphibole and pyroxene development in fenite from Cantley, Quebec. Can. Mineral. 22, 281-295.

Kresten, P. & Morogan, V., 1986. Fenitization of Fen Complex, Southern Norway. Lithos 19, 27-42.

Leake, B.E., 1978. Nomenclature of amphibole. Min. Mag., 42, 533-563.

Le Bas, M.J., 1977. Carbonatite-Nephelinite Volcanism. Wiley, London.

Le Bas, M.J., Mian, I. & Rex, D.C., 1986. Age and nature of carbonatite emplacement in North Pakistan. Geol. Rund. 76, 317- 323.

Mckie, D., 1966. Fenitization. In: Carbonatites (O.F. Tuttle & J. Gittins, eds.). Wiley, New York, 261-294.

Mian, I., 1987. The mineralogy and Geochemistry of the carbonatites, syenites and fenites of N.W.F.P. Pakistan. Unpub. Ph.D. thesis, University of Leicester.

Mian, I. & Le Bas, M.J., 1986. Sodic amphibole in fenites from the Loe Shilman Carbonatite Complex, NW Pakistan. Mineral. Mag. 50, 187-197.

Mian, I. & Le Bas, M.J., 1987. The biotite-phlogopite series in fenites from Loe Shilman Carbonatite Complex, NW Pakistan. Min. Mag. 51, 397-408.

Mian, I. & Le Bas, M.J., 1988. Feldspar solid solution series in fenites from Loe Shilman carbonatite complex, NW Pakistan. Geol. Bull. Univ. Peshawar, 21, 71-83.

Mitchell, R.H. & Platt, R.G., 1982. Mineralogy and petrology of nepheline syenite from Coldwell Alkaline Complex, Ontario, Canada. J. Petrol. 23, 186-214.

Platt, R.G. & Woolley, A.R., 1986. The mafic mineralogy of peralkaline syenites and granites of Mulanji Complex, Malawi. Min. Mag. 50, 85-99.

Rafiq, M., 1987. Petrology and Geochemistry of the Ambela granitic complex, N.W.F.P. Pakistan. Unpub. Ph.D. thesis, University of Peshawar.

Rubie, D.C. & Gunter, W.D., 1983. The role of speciation in alkaline igneous fluids during fenite metasomatism. Contrib. Mineral. Petrol. 82, 165-175.

Siddiqui, S.F.A., Chaudhry, M.N. & Shakoor, A., 1968. Geology and petrology of feldspathoidal syenites and associated rocks of the Koga area, Chamla, Valley, Swat, West Pakistan. Geol. Bull. Univ. Punjab 7, 1-30.

Stephenson, D., 1972. Alkali pyroxenes from nepheline syenites of south Qoroq Centre, South Greenland. Lithos 5, 187-201.

Strong, D.F. & Taylor, R.P., 1984. Magmatic-subsolidus and oxidation trends in composition of amphiboles from silica-saturated peralkaline igneous rocks. Tschermaks Min. Petrol. Mitt. 32, 211-222.

Tyler, R.C. & King, B.C., 1967. The pyroxenes of alkaline igneous complex of eastern Uganda. Min. Mag. 36, 5-21.

Vartiainen, H., 1980. The petrography, mineralogy and petrochemistry of the Sokli carbonatite massif, northern Finland. Geol. Surv. Finland, Bull. 313, 126p.

Vartiainen, H. & Woolley, A.R., 1976. The petrology, mineralogy and chemistry of the fenites of the Sokli Carbonatite intrusion, Finland. Geol. Surv. Finland, Bull. 280, 87p.

Viladkar, S.G., 1980. The fenitization aureole of the Newania carbonatites, Rajastan. Geol. Mag. 117, 285-292.

Woolley, A.R., 1982. A discussion of carbonatite evolution and nomenclature, and generation of sodic and potassic fenites. Min. Mag. 46, 13-17.

Varet, J., 1969. Les pyroxenes des phonolites du Cantal (Au vergne, France). Neues. Jb. Miner. Mh. 4, 174-184.

Yagi, K., 1953. Petrochemical studies of the alkalic rocks of Morotu district, Sakhalin. Bull. Geol. Soc. Am. 64, 769-810.