

CHEMISTRY OF CLINOPYROXENE FROM THE DEOSAI VOLCANICS, BALTISTAN, N. PAKISTAN

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ABSTRACT

Seventy analyses of clinopyroxene phenocrysts from the Deosai volcanics were obtained and tested for substitutions and other petrogenetic characters. The data show an overall core-margin substitution of $x\text{Ca}+x\text{Na}+x\text{Fe}^{3+}+x\text{Al}+x\text{Ti}=x\text{Si}+x\text{Mg}+x\text{Fe}^{2+}+x\text{Mn}$ type in the phenocrysts, with "x" representing the actual amount of a cation entered or replaced, and which can be determined precisely from its variation along with unit variation of Si. The data also indicate crystallization in a temperature range of 1100-1200°C, under highly variable pressure, from a basaltic magma of alkaline (but transitional to non-alkaline) characters.

INTRODUCTION

Volcanic rocks overlaying the Laddakh batholith east and south-east of Nanga-Parbat have been described as Dras volcanics in India by de Terra (1935). These volcanics which are associated by the marine metasediments have been studied by various workers in India (Misch, 1936; Wadia, 1937; Gansser, 1964; Raiverman & Mishra, 1974; Shah et al., 1976; Gupta et al., 1983). On the basis of faunas associated with the metasediments these volcanics are regarded to be of Cretaceous age (Wadia, 1937; Frank et al., 1977; Gergan, 1978). Gergan (1978) and Shah and Gergan (1978) described these volcanics to be massive and amygdoloidal varying in composition from arc tholeiite through andesite to shoshonite, with occurrence of spilites and pillow lavas (see also Gupta et al., 1983).

In Pakistan these volcanic are exposed at the various peaks of the Laddakh batholith, east and south-east of Nanga Parbat, at Deosai, Kalapani, Burjal pass, Choota Deosai and Gul Tari, just north of the Main Mantle Thrust (MMT) and close to the Indian boarder (Fig. 1). The Laddakh batholith cross cuts these volcanics and xenoliths of the latter are frequently noticed in the former. No detailed petrographic and geochemical data is available on these rocks in Pakistan. When fresh and massive,

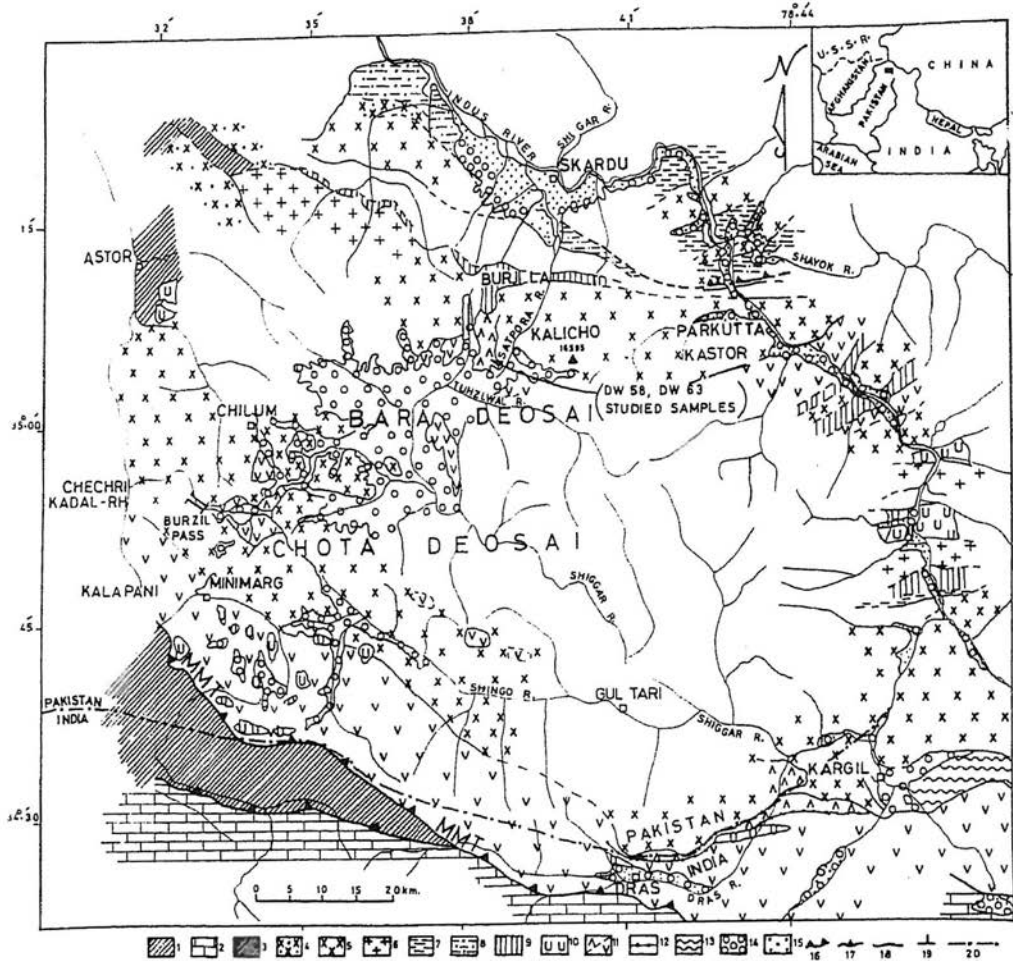


Fig. 1. Geological map of the Deosai plateau and surrounding areas, Baltistan, N. Pakistan; (Modified after Desio, 1978). Volcanic outcrops along the north-eastern bank of Shingo river and between Minimarg and Kalapani are added during the present work. Legend: 1. Salkhala Formation, 2. Upper Triassic limestone, 3. Burji Formation, 4. Diorite, 5. Deosai quartz diorite & granodiorite with epidiorite inclusions, 6. Granite, 7. Gneiss, 8. Katzarah schists, 9. Hornfels, 10. Mafic & ultramafic rocks, 11. Dras volcanics, 12. "Conulites" (?) limestone, 13. Wakka Formation, 14. Glacial & fluvio-glacial deposits, 15. Alluvial deposits, 16. Overthrust, 17. Fault, 18. Limit of the formations, 19. Dip of beds, 20. International boundary.

they appear to be basaltic, basaltic-andesitic and dacitic in composition. Plagioclase is a common phenocryst in the porphyritic varieties, however, large idiomorphic hornblende and clinopyroxene phenocrysts up to 1cm in diameter have been found in the massive basaltic andesite (DW58, DW63), occurring as large blocks at an altitude of 13500 feet and the north-eastern extremity of the Deosai plateau (SW of Satpora lake and Skardu; Fig. 1). At Kalapani and Burzil pass, the presence of chlorite in these volcanics indicates metamorphism up to lower green schist facies.

The present study was carried out to analyze clinopyroxene from the porphyritic varieties found at Deosai, observe their chemical systematics and obtain possible petrogenetic interpretations. Only two samples (DW58, DW63) were found to be rich both in hornblende and clinopyroxene phenocrysts. Therefore, about 70 core-margin spot analyses were carried out on ten phenocrysts of clinopyroxene (A,C-L) and the Means and Standard Deviations of individual phenocrysts are shown in Table 1.

CHEMISTRY OF CLINOPYROXENE

Mineral formulae and ferric and ferrous iron calculations were carried out using the methods of Deer et al. (1962) and Papike et al. (1974). All the analyses cluster near the junction of the diopside, augite and salite fields with majority of these showing salite and Ca-augite compositions in the Poldervaart and Hess (1951; cf. Deer et al., 1962) quadrilateral (Fig. 2a). On the Q vs J plot of Morimoto et al. (1988) these clinopyroxene data occur in the QUAD field with 88-92% QUAD component (Fig. 2b).

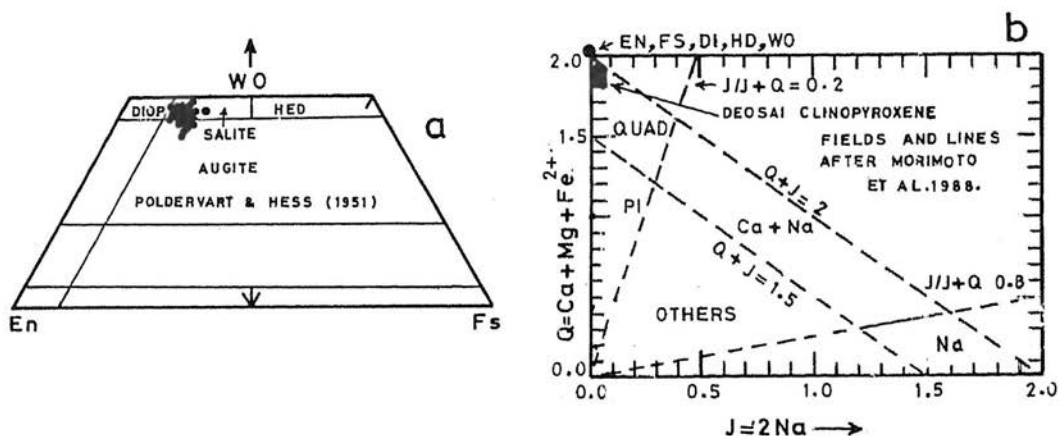


Fig. 2. Clinopyroxene composition from the Deosai volcanics shown: (a) in the Poldervaart and Hess (1951) quadrilateral and (b) on the Q vs J plot of Morimoto et al. (1988).

Substitutions

Cameron and Papike (1981) on the basis of their charge balance equation (i.e. ${}^{vi}\text{Al} + \text{Fe}^{3+} + {}^{vi}\text{Cr}^{3+} + 2{}^{vi}\text{Ti}^{4+} = {}^{iv}\text{Al} + \text{M}^{2+}\text{Na}$) have defined eight important substitutional couples including ${}^{vi}\text{Al}-{}^{iv}\text{Al}$, $\text{Fe}^{3+}-{}^{iv}\text{Al}$, $\text{Cr}^{3+}-{}^{iv}\text{Al}$, $\text{Ti}^{4+}-2{}^{iv}\text{Al}$, $\text{Na}-{}^{iv}\text{Al}$, $\text{Na}-\text{Fe}^{3+}$, $\text{Na}-\text{Cr}^{3+}$ and $2\text{Na}-\text{Ti}^{4+}$ in clinopyroxenes. In the Deosai clinopyroxene phenocrysts Si, Mg, Fe^{2+} and Mn are depleted while Ca, Na, ${}^t\text{Al}$ (total alumina), Ti, and Fe^{3+} are

TABLE 1. MEANS AND STANDARD DEVIATIONS OF INDIVIDUAL CLINOPYROXENE PHENOCRYSTS. ANALYSES 1-8 (A-J) ARE FROM SAMPLE DW63 AND 9-10 (K-L) FROM SAMPLE DW58.

	1 (13 anals)		2 (2 anals)		3 (4 anals)		4 (3 anals)		5 (11 anals)	
	MEAN-A	STD-A	MEAN-C	STD-C	MEAN-D	STD-D	MEAN-E	STD-E	MEAN-F	STD-F
SiO ₂	49.028	0.843	48.505	0.345	48.540	1.239	48.540	1.239	49.385	0.815
TiO ₂	0.645	0.040	0.800	0.000	0.727	0.175	0.727	0.175	0.658	0.065
Al ₂ O ₃	4.472	0.277	4.980	0.500	4.543	1.147	4.543	1.147	4.415	0.486
FeO	8.677	0.239	8.995	0.165	9.133	0.488	9.133	0.488	7.540	0.804
MnO	0.132	0.019	0.130	0.020	0.180	0.064	0.180	0.064	0.132	0.041
MgO	13.964	0.350	13.635	0.095	13.873	0.818	13.873	0.818	14.493	0.445
CaO	23.415	0.376	22.420	0.250	22.650	0.992	22.650	0.992	22.029	0.342
Na ₂ O	0.362	0.028	0.330	0.030	0.333	0.039	0.333	0.039	0.380	0.049
Cr ₂ O ₃	0.008	0.012	0.020	0.010	0.013	0.012	0.013	0.012	0.166	0.147
Total	100.705		99.815		99.993		99.993		99.198	
Formulae on the basis of 6 oxygens										
Si	1.832	0.015	1.827	0.016	1.829	0.037	1.829	0.037	1.855	0.016
Ti	0.018	0.001	0.023	0.000	0.020	0.005	0.020	0.005	0.019	0.003
Al	0.197	0.014	0.221	0.022	0.202	0.052	0.202	0.052	0.195	0.022
Fe ³⁺	0.128	0.025	0.104	0.011	0.124	0.016	0.124	0.016	0.081	0.012
Fe ²⁺	0.143	0.023	0.180	0.017	0.164	0.030	0.164	0.030	0.156	0.025
Mn	0.004	0.001	0.005	0.001	0.006	0.002	0.006	0.002	0.004	0.001
Mg	0.778	0.016	0.765	0.006	0.779	0.042	0.779	0.042	0.811	0.023
Ca	0.938	0.013	0.905	0.010	0.914	0.043	0.914	0.043	0.886	0.013
Na	0.028	0.002	0.024	0.002	0.024	0.003	0.024	0.003	0.028	0.003
Cr	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.005	0.004
ivAl	0.168	0.015	0.174	0.016	0.171	0.037	0.171	0.037	0.145	0.016
viAl	0.029	0.012	0.048	0.006	0.031	0.015	0.031	0.015	0.050	0.010
Formulae on the basis of 6 oxygens										
Si	1.884	0.014	1.883	0.025	1.853	0.016	1.846	0.038	1.873	0.021
Ti	0.017	0.002	0.017	0.005	0.020	0.003	0.020	0.002	0.018	0.001
Al	0.141	0.021	0.139	0.039	0.205	0.022	0.223	0.026	0.172	0.030
Fe ³⁺	0.073	0.007	0.081	0.009	0.077	0.011	0.076	0.045	0.071	0.017
Fe ²⁺	0.211	0.015	0.221	0.006	0.146	0.009	0.133	0.016	0.164	0.022
Mn	0.007	0.001	0.005	0.001	0.002	0.001	0.005	0.006	0.006	0.001
Mg	0.827	0.022	0.827	0.037	0.812	0.022	0.804	0.007	0.798	0.022
Ca	0.856	0.019	0.846	0.014	0.888	0.011	0.891	0.009	0.906	0.020
Na	0.018	0.002	0.021	0.004	0.031	0.003	0.036	0.002	0.026	0.003
Cr	0.003	0.003	0.001	0.000	0.003	0.003	0.003	0.003	0.001	0.000
ivAl	0.116	0.014	0.117	0.025	0.147	0.018	0.154	0.038	0.127	0.021
viAl	0.025	0.007	0.023	0.015	0.058	0.007	0.070	0.013	0.045	0.011

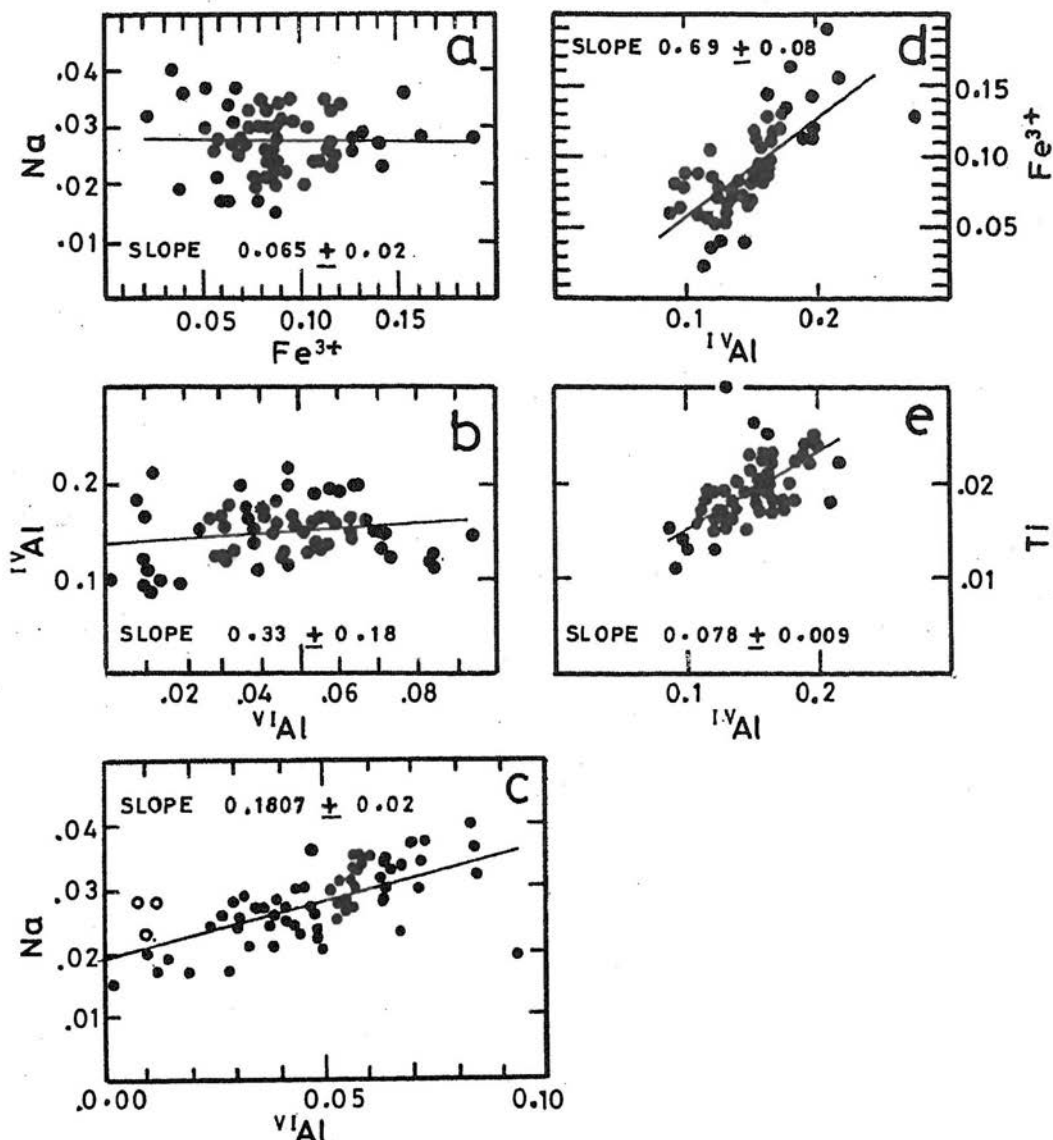


Fig. 3. Na vs Fe^{3+} , $ivAl$ vs $viAl$, Na vs $viAl$, Fe^{3+} vs $ivAl$ and Ti vs $viAl$ plots of the Deosai clinopyroxene.

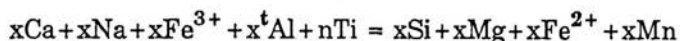
enriched in cores relative to rims. Figures 3 and 4 show plots of various cations against each other for these phenocrysts. As the slope values represent the amount of cation along X-axis coupled with each cation against it (Marcelet et al., 1983) therefore, relevant regression curve parameters are also presented on these plots. Na vs Fe^{3+} and $ivAl$ vs $viAl$ plots are scattered but Na vs $viAl$ plots show a linear positive correlation with a slope value of 0.19 indicating the formation of (a minor amount of) jadite rather than acmite (Figs 3a-c). Fe^{3+} on the other hand, linearly correlate with $ivAl$ indicating a slope value of 0.69 (Fig. 3d). Ti also shows a positive correlation with $ivAl$ (Fig. 3e) but with a slope value (0.08) much lower than shown by Fe^{3+} vs $ivAl$ plot. These features suggest the

formation of $\text{Fe}^{3+}\text{-}^{\text{iv}}\text{Al}$ and $\text{Ti-2}^{\text{iv}}\text{Al}$ couples but with the former representing the most important one. As Ca decreases along with Fe^{3+} , Ti and $^{\text{iv}}\text{Al}$, from cores towards margins of the phenocrysts, the $\text{Fe}^{3+}\text{-}^{\text{iv}}\text{Al}$ and $\text{Ti-2}^{\text{iv}}\text{Al}$ couples must be representing $\text{CaFe}^{3+}\text{SiAlO}_6$ and $\text{CaTiAl}_2\text{O}_6$ molecules, respectively, in a proportion related to the slope values of the corresponding couples in the Deosai clinopyroxene (see also Cameron & Papike, 1981). Cameron & Papike (1981) also suggested that the most important coupled substitutions in clinopyroxenes are:

1. $\text{Mg} + \text{Ca} + \text{Si} = \text{Ti} + \text{Na} + ^{\text{iv}}\text{Al}$
2. $\text{Mg} + \text{Si} = ^{\text{iv}}\text{Al} + ^{\text{vi}}\text{Al}$
3. $\text{Mg} + \text{Si} = \text{Fe}^{3+} + ^{\text{iv}}\text{Al}$
4. $\text{Mg} + 2\text{Si} = \text{Ti} + 2^{\text{iv}}\text{Al}$

For the Deosai clinopyroxene Fe^{3+} and Ti vs $^{\text{iv}}\text{Al}$, Mg vs Si and Na vs $^{\text{iv}}\text{Al}$ plots are linear (Figs. 3d,e; 4a,b). The interesting feature of these phenocrysts is however, the general positive correlation between Na and Ca and their negative correlations both with Si or Mg (Figs. 4c; 5e,f). Besides, Fe^{2+} vs Mg plots are relatively scattered but their sum plotted against Ca and Si show linear positive and negative correlations, respectively (Fig. 4d-f). Mn follow Fe^{2+} with some scatter (Fig. 4g). Considering a negative correlation of Ca with Si or Mg, substitution (1) of Cameron & Papike (1981) is totally discarded for the Deosai clinopyroxenes. Similarly, on the basis of the lack of a strong correlation between $^{\text{iv}}\text{Al}$ and $^{\text{vi}}\text{Al}$, substitution (2) is also not emphasized. Substitutions (3) and (4) could have been the possible choice but, these two do not take care of the variations in Ca, Na and Fe^{2+} .

Mg, Fe^{2+} and Mn correlate positively whereas Ca, Na, Ti, Fe^{3+} and $^{\text{iv}}\text{Al}$ correlate negatively with Si and therefore, Si can be considered as the best correlation index in the Deosai clinopyroxene (Fig. 5). As mentioned earlier, Si, Mg, Fe^{2+} and Mn are depleted whereas Ca, Na, Ti, Fe^{3+} and $^{\text{iv}}\text{Al}$ are enriched in cores relative to margins in these phenocrysts. Therefore, if apart from these, no other cation is playing any major role in the chemistry of the Deosai clinopyroxenes, then the sum of variations in Si, Mg, Fe^{2+} and Mn must correspond with the sum of variations in Ca, Na, Fe^{3+} , Ti and $^{\text{iv}}\text{Al}$. Also plots of the two sums against each other must follow a straight line with a negative trend and a slope value close to unity. Using these criteria, variations of individual cations with a unit variation in Si (i.e. 0.1 in this particular case) were determined, on Si vs cations plots (Fig. 5) and the sum of the variations of the two groups of the cations were plotted against each other in Figure 6 which followed a straight line with a negative correlation and a slope value close to 1; all indicating that an overall substitution of:



type occurred in the Deosai clinopyroxenes from cores towards margins along with fractionation. (x = variation in a particular cation against 0.1 Si; Fig. 5). Such a core to

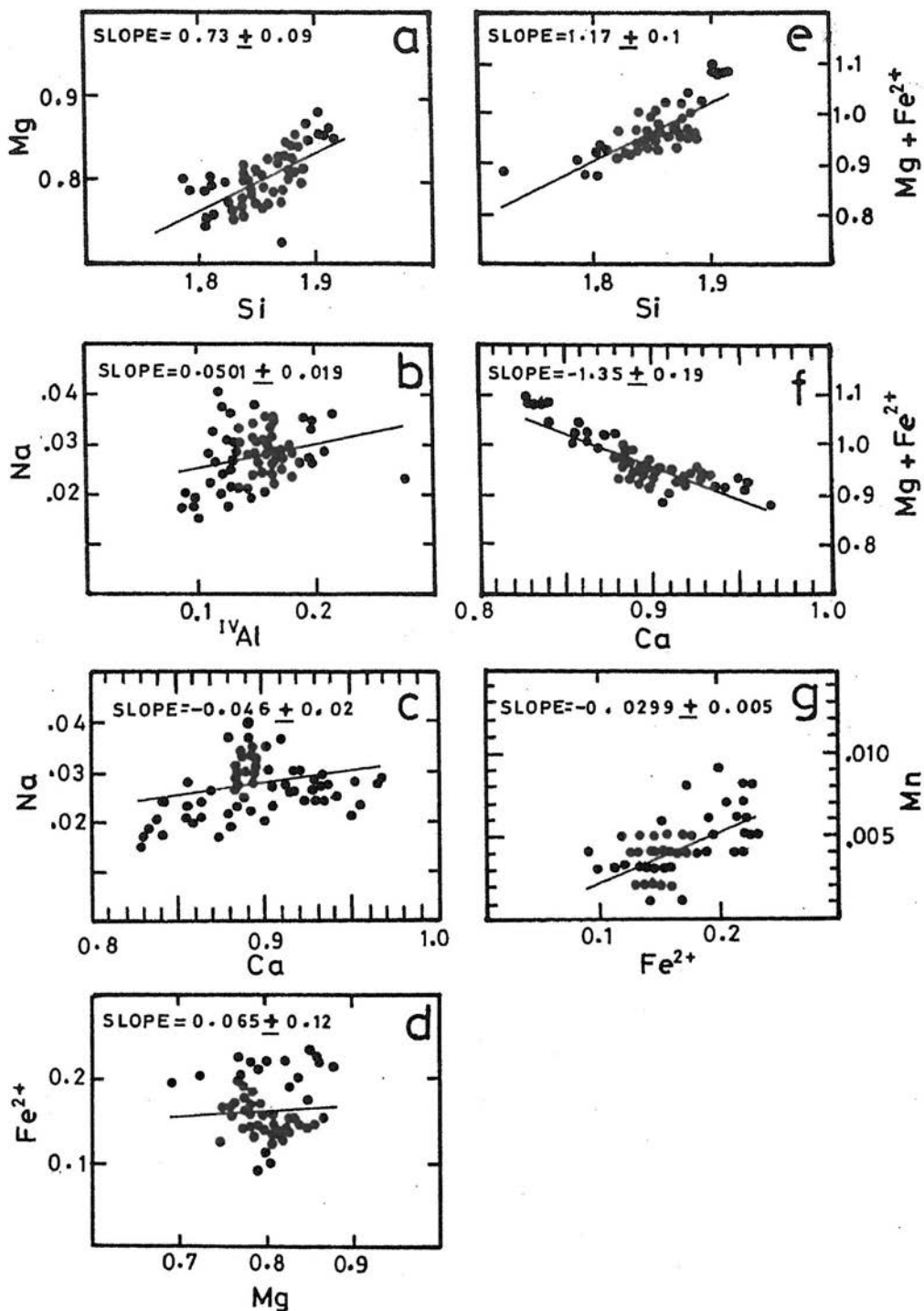


Fig. 4. Mg vs Si, Na vs ^{iv}Al , Na vs Ca, Fe^{2+} vs Mg, $Mg + Fe^{2+}$ vs Si, $Mg + Fe^{2+}$ vs Ca and Mn vs Fe^{2+} plots of the Deesai clinopyroxene.

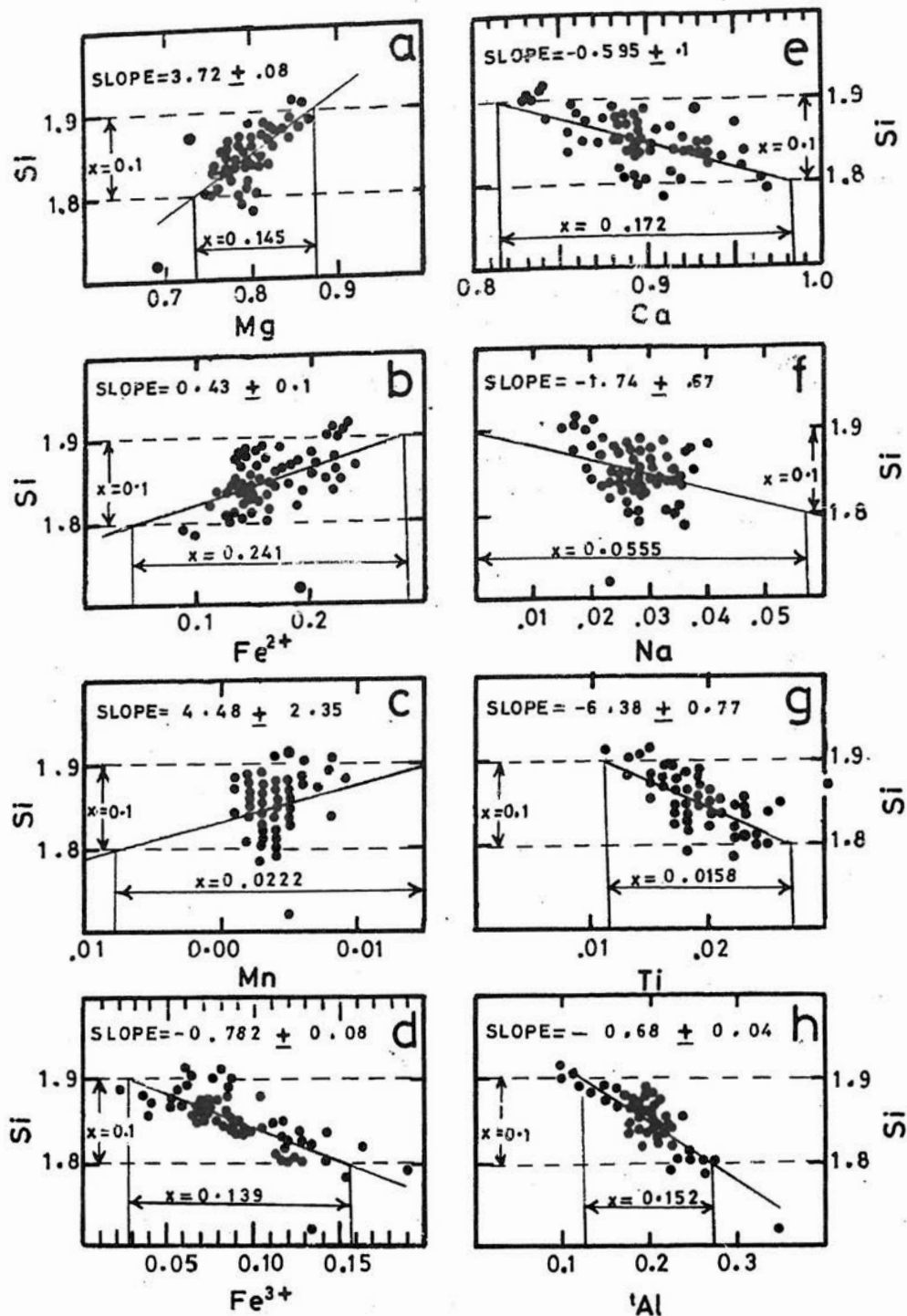
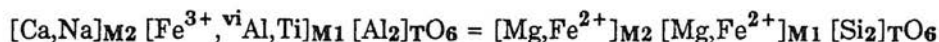


Fig. 5. Si plotted against all other major cations including Mg, Fe^{2+} , Mn, Fe^{3+} , Ca, Na, Ti and 4Al . Plots show "x" variations of individual cations against the $x (=0.1)$ variation of Si.

margin variation indicates that both Ca and Na in M_2 site were together replaced by Mg and Fe^{2+} (Mn) and a major substitution of:



type was responsible not only for $Wol=(En+Fs)$ type variation within the pyroxene quadrilateral (cf. Fig. 2a) but also for the removal of OTHERS components including jadite, $CaFe^{3+}SiAlO_6$ and $CaTiAl_2O_6$ from the lattice by the $En+Fs$ components, along with fractionation.

A maximum number of analyses contain Cr_2O_3 below 0.1 wt.% but certain analyses show higher values up to 0.43 wt.% in the Deosai clinopyroxene (Table 1). No correlation has been however, established between Cr and any other cation and therefore, the role played by Cr-bearing molecules is not clear.

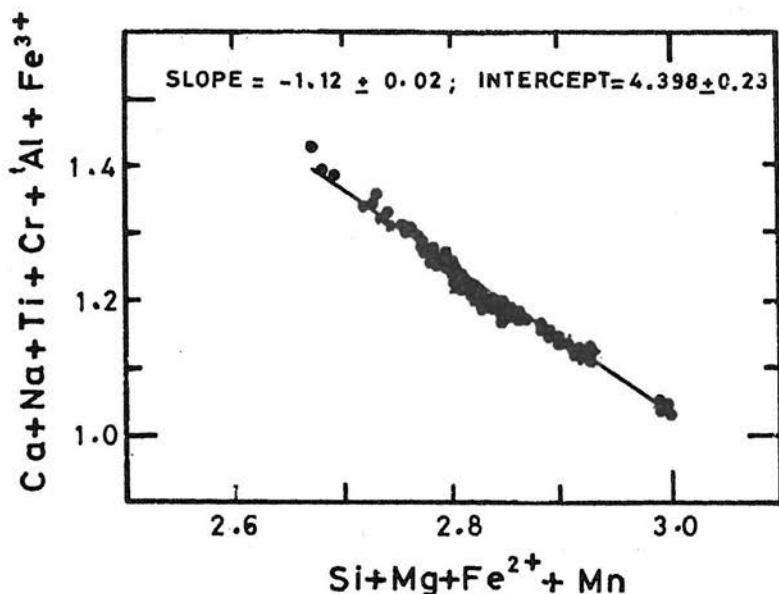


Fig. 6. $Ca+Na+Fe^{3+}+{}^tAl+Ti$ vs $Si+Mg+Fe^{2+}+Mn$ plot of the clinopyroxene from the Deosai volcanics. The overall variations of the X and Y coordinates are the sum of the variations (i.e., "x" values; cf. Fig. 5) of individual cations in the respective coordinates. For X-coordinate the ΣXi (i.e., $xSi+xMg+xFe^{2+}+xMn$) = 0.508 = A whereas for Y-coordinate the ΣXi (i.e., $xCa+xNa+xTi+x{}^tAl+xFe^{3+}$) = 0.534 = B; Then $B/A = 1.05$, which is close to unity and to the actual slope (i.e., 1.12) of the regression line on this particular graph.

Temperature estimation

Petrographic and textural characters of the Deosai volcanics clearly indicate that at least all the phenocrysts including clinopyroxene in these rocks are the products of igneous crystallization from a basaltic liquid. Clinopyroxene of diopside-salite composition generally crystallizes above 1000°C at and above 1 atm. pressure in $\text{CaMgSi}_2\text{O}_6$ - $\text{CaFe}^{2+}\text{Si}_2\text{O}_6$ and $\text{CaMgSi}_2\text{O}_6$ - $\text{CaAl}_2\text{Si}_2\text{O}_8$ systems (Schairer & Yoder, 1962; 1970; Yoder 1965), indicating that the Deosai clinopyroxene might also be grown at similar temperatures. Single pyroxene thermometers are rare and the available ones carry a long list of precision and thermodynamic constraints (see Jean-claude Mercier, 1976). Lindsley (1983) has devised a graphical two pyroxene geothermometer based on calculation of end member molecules which according to him can also be used for a single pyroxene, provided the total of QUAD (Wol+En+Fs) molecules exceed 90%. Earlier in the calculation of end member molecules for the Deosai clinopyroxene, we preferred to form jadeite before acmite because of the lack of correlation between Na and Fe^{3+} (cf. Fig. 3a). However, to follow strictly the Lindsley procedure, end members were also calculated with acmite before jadeite and both the sets of data with Wol+En+Fs \geq 90 were plotted on Lindsley's graphical thermometer diagram. Temperatures between 1100-1200°C were obtained for both the data sets, for 1 atm. pressure (Figs. 7a-b). Similar temperatures were also obtained on diagrams devised for pressure varying from 5 to 15 kb (not represented).

Pressure estimation

$^{iv}\text{Al}/^{vi}\text{Al}$ ratio would decrease under increasing pressure in clinopyroxene (Was, 1979 cf. Pemberton & Offler, 1985). The core to margin variation of this ratio is highly inconsistent in the Deosai clinopyroxene phenocrysts, with 3 out of 8 phenocrysts indicating a substantial increase (5.62-11.9, 3.85-6.64, 4.07-9), two indicating a marginal increase (3.5-3.85, 2.35-2.44) and three indicating a substantial to moderate decrease (17.42-2.9, 3.05-1.53, 4.51-3.47), reflecting highly variable pressure during crystallization (Fig. 7c). The crystallization of hornblende phenocrysts following clinopyroxene is indicative of ~3-6kb pressure (Hamidullah in prep.). These features indicate that the clinopyroxene in the Deosai volcanics has probably grown under a fluctuating pressure of < 3 kb.

Magmatic affinity

The chemistry of clinopyroxene is considered to be the best criterion for recognition of the magmatic affinity and tectonic setting of the basaltic suites (Kushiro, 1960; LeBas, 1962; Deer et al., 1977; Nisbet & Pearce, 1977; Leterrier et al., 1982). Not having the rock chemistry in hand, it would be interesting to envisage the magmatic affinity

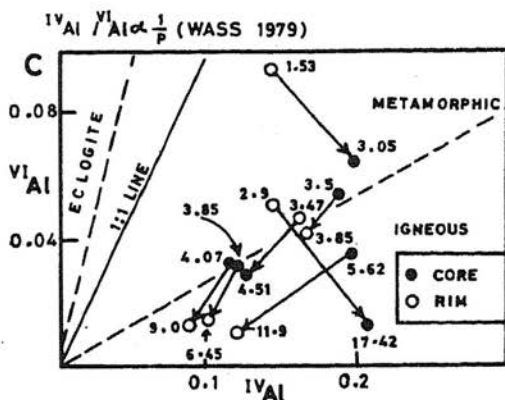
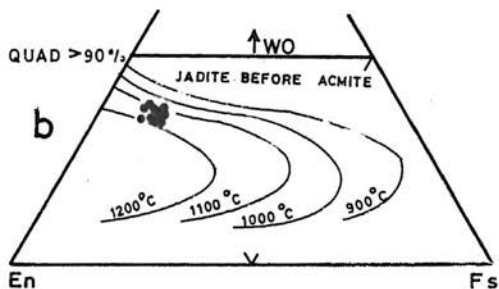
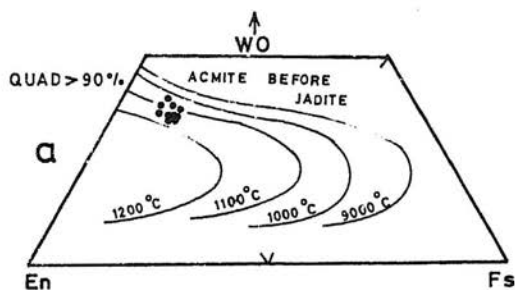


Fig. 7.(a-b) Temperature estimation of the clinopyroxene analyses with $QUAD \geq 90$ on Lindsley (1983) thermometry diagrams. Figure 7a shows end members calculated with acmite before jadeite. Figure 7b has jadeite before acmite. No significant difference has been noticed in the estimated temperatures on the basis of the two procedures. (c) $^{iv}Al/^{vi}Al$ ratios shown for the cores and rims of individual clinopyroxene phenocrysts from the Deosai volcanics on ^{iv}Al vs ^{vi}Al plot of Pemberton and Offler (1985).

and tectonic setting for the Deosai volcanics from the chemistry of clinopyroxene. Nisbet and Pearce (1977) devised discriminant analyses factors (F_1 , F_2) using clinopyroxene chemistry for the identification of magmatic characters. The Deosai clinopyroxene exclusively plot in the field of volcanic arc basalts (above subduction zones in island arcs) (Fig. 8a). Papike (1982) has defined fields on various diagrams for pyroxenes from different environment. In majority of the cases these fields overlap each other. When the Deosai clinopyroxenes were plotted on these diagrams, the data remained restricted to the island arc field, though in areas of overlap, on most of these plots (not presented).

However, on $\text{Na} + \text{Al}^{\text{IV}} \text{ vs } \text{Al}^{\text{VI}} + 2\text{Ti} + \text{Cr}$ plot the Deosai clinopyroxene can be discriminated from all other types except the Deep Sea data and on $\text{Na} \text{ vs } \text{XFe}^{2+}$ plot 80% of the Deosai clinopyroxene data plot only in the island arc field where there is no overlap with any other field (Fig. 8b, c). As mentioned earlier, the Deosai clinopyroxenes are diopside-salite and Ca-rich augite (cf. Figs. 2a); types typical of alkaline rocks but also occur in non-alkaline rocks (Deer et al., 1977; Hamidullah & Bowes, 1987). When these data was plotted on the $\text{SiO}_2 \text{ vs } \text{Al}_2\text{O}_3$ plot of LeBas (1962), 80% of the data (mostly cores) plot in the field of normal alkaline rocks (Fig. 8d). On the $\text{Al}_2 \text{ vs } \text{TiO}_2$ plot of LeBas (1962), though majority of the data plot in the field of non-alkaline rocks, analyses from cores show alkaline characters (plot not shown) and reflect a decrease in alkalinity with increase in fractionation. Similarly, on the $\text{Ti} \text{ vs } \text{Ca} + \text{Na}$ discriminant diagram of Leterrier et al. (1977) the data follow a linear trend cross-cutting the boundary between the two fields, with cores plotting in the field of alkaline rocks and rims in that of the non-alkaline rocks indicating transitional characters and decreasing alkalinity with increasing fractionation (Fig. 8e). The overall substitution in these clinopyroxenes indicating a core to margin decrease in Na along with Ca in M_2 site thus seems to be a function decreasing of alkalinity in the residual magma. According to Leterrier et al. (1977) if the data tends to plot in the alkaline field, on their first discriminant diagram (i.e., Fig. 8e), then their second and third diagrams are not applicable. As the Deosai data show partial non-alkaline characters, these data were also tested on the remaining two plots (Figs. 8f-g). On the second discriminant plot the data exclusively plot in the field of orogenic basalts. On the third diagram the data linearly follow the boundary between the fields of calcalkaline and tholeiitic basalts and is therefore inconclusive.

DISCUSSION

The Deosai volcanics are the continuation of Dras volcanics in India. In the latter types, on the basis of whole rocks chemistry, Gupta et al. (1983) have reported compositional variation from arc-tholeiites through andesites to shoshonites and spilites and an affinity variation from non-alkaline to alkaline. Similar characters are reflected in the clinopyroxene chemistry at Deosai. With certain reservation related to the absence of whole rock chemistry of these volcanics, it can be suggested that the magma type from which the Deosai clinopyroxenes were evolved was of primitive alkaline type and its alkalinity decreased with increasing crystallization, probably due to changing magma composition as a result of changes in the source region (see Petterson & Windley, 1991). The unusual core-margin decrease of Na along with Ca in the clinopyroxene can be also attributed to such a phenomenon.

Earlier it was generally believed that the alkalinity of the erupted magmas in island arc should increase away from the trench (Kuno, 1959; Sugimura, 1973). Many arcs however, deviate from this norm and several show reverse characters. The com-

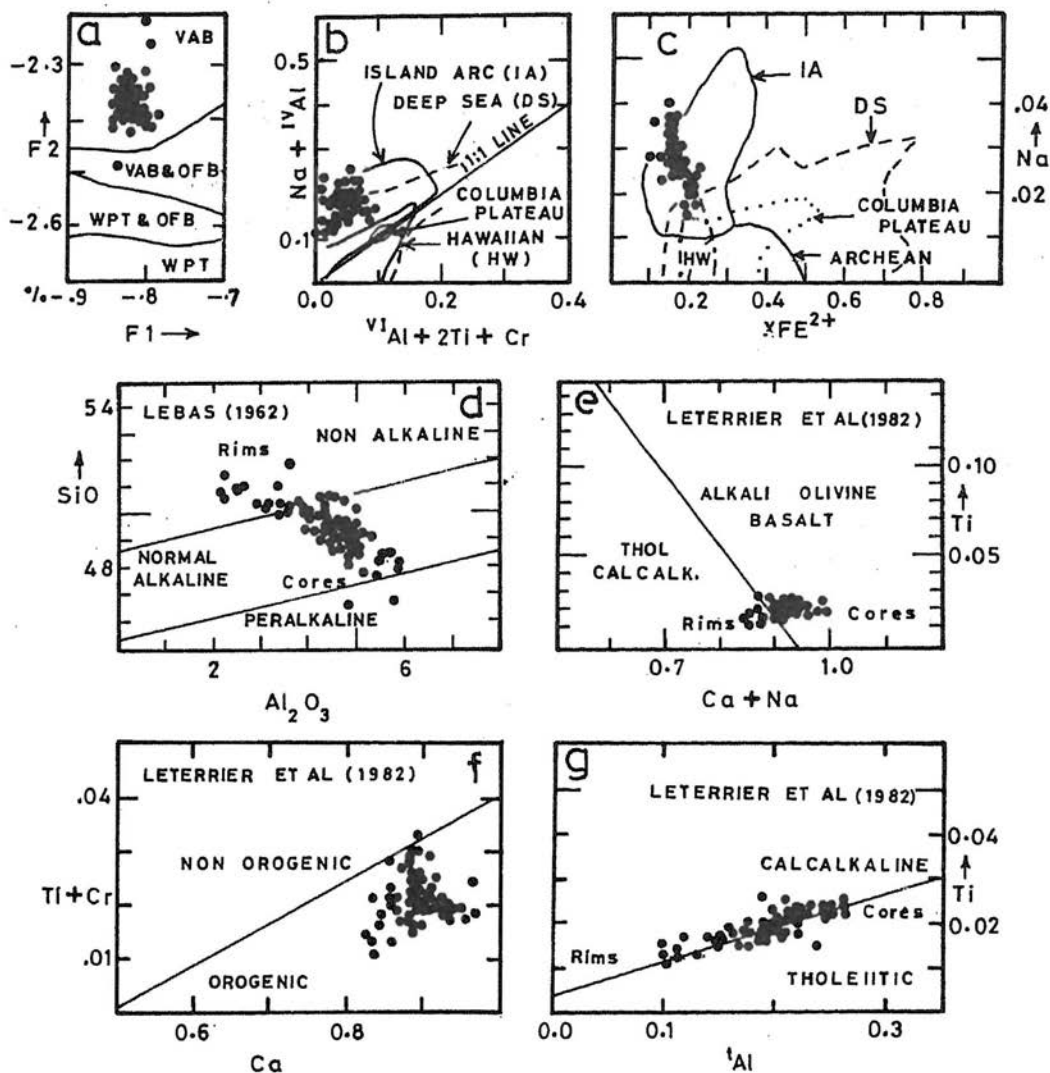


Fig. 8. Clinopyroxene from the Deosai volcanics plotted on: (a) F₁ vs F₂ discriminant analyses factors diagram of Nisbet & Pearce (1977); VAB = Volcanic Arc Basalt, OFB = Ocean Floor Basalt, WPT = Within-Plate Tholeiite. (b-c) Na + $ivAl$ vs $viAl + 2Ti + Cr$ and Na vs XFe^{2+} ($XFe^{2+} = Fe^{2+}/Fe^{2+} + Mg$) diagrams of Papike (1982), (d) SiO_2 vs Al_2O_3 plot of LeBas (1962) and (e-g) Ti vs Ca + Na, Ti + Cr vs Ca and Ti vs Al plots of Leterrier et al. (1982).

position of the primary magma type is an overall reflection of the source material, depth and the degree of partial melting together with the geometry of the subduction system. Alkaline rocks are also found frequently associated with anomalous environment such as hinge faults, fracture zones and back-arc basins in an island arc system (cf. Wilson, 1989). Keeping the geographical position of the Deosai (Dras) volcanics in the Kohistan-

Laddakh island arc (i.e., close to MMT; cf. Fig. 1) with a northward subduction along MMT, one would expect tholeiitic characters from these lavas. The alkaline characters and the positive correlation of Na with Ca shown by the Deosai clinopyroxene and the considerably wide spectrum of composition and affinity shown by the Dras volcanics, mentioned earlier (see also Honegger et al., 1982), however, indicate these lavas either to be part of an earlier island arc/back arc system or reflecting an anomalous (hinge fault or fracture zone) feature. Using the $^{40}\text{Ar}/^{39}\text{Ar}$ method and hornblende, an age of 125 ± 6 Ma has been determined for the Deosai volcanics. This is consistent with the previous dates determined on the basis of fauna associated with metasediments at Dras, mentioned earlier. It also shows that if the Deosai volcanics belong to an earlier island arc or back-arc regime (e.g. Dras island arc of Honegger et al., 1982) then such a tectonic regime probably ended or merged up with the Kohistan-Laddakh island-arc system.

CONCLUSIONS

1. Clinopyroxene in the Deosai volcanics crystallized from alkaline basaltic type of magma under highly variable pressure in a temperature range of 1100-1200°C.
2. The alkalinity of the magma decreased with increase in fractionation.
3. An overall core to margin substitution of $[\text{Ca}, \text{Na}]_{\text{M2}} [\text{Fe}^{3+}, \text{ivAl}, \text{Ti}]_{\text{M1}} [\text{Al}_2]_{\text{TO6}} = [\text{Mg}, \text{Fe}^{2+}]_{\text{M2}} [\text{Mg}, \text{Fe}^{2+}]_{\text{M1}} [\text{Si}_2]_{\text{TO6}}$ type was responsible for $\text{Wol} = (\text{En}-\text{Fs})$ type variation within the pyroxene quadrilateral as well as for the removal of OTHERS component by En+Fs along with fractionation. This substitution also reflects a decrease in alkalinity (i.e., Na decrease towards margins) of the magma along with fractionation.
4. The existence of tholeiitic, calcalkaline and alkaline rocks at Deosai, and Dras are possibly related to an earlier island arc/back-arc system or to an anomalous tectonic feature of the Kohistan-Laddakh island arc.

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