APPLICATION OF A TWO-PYROXENE THERMOMETER; D. J. Andersen and D. H. Lindsley, Dept. of Earth and Space Sciences, State Univ. of New York, Stony Brook, N. Y. 11794

To apply experimental data obtained for the quad pyroxenes ($Fe_2Si_2O_6$-$Mg_2Si_2O_6$-$CaMgSi_2O_6$-$CaFeSi_2O_6$) to natural samples for purposes of geothermometry, one must consider the effects that minor elements (Fe^{3+}, Ti, Al, Cr, Na), which enter into the pyroxene as coupled substitutions, may have on the Ca distribution between a low-Ca and high-Ca pyroxene. Pyroxenes from the lunar highlands are probably the best natural samples to test a two-pyroxene thermometer because the minor element contents are much lower than those from many terrestrial rocks. In addition, one avoids the problem of the oxidation state of Fe (assumed to be all Fe^{2+}), although in the lunar pyroxenes, Ti and Cr may have variable oxidation states and even the stoichiometry of the pyroxene may be questionable [1].

In order to apply the two-pyroxene thermometer of [2], it is necessary to try to correct for any effect that the minor elements may have on the Ca distribution. Based on the analysis of correlation coefficients of mineral formulas for terrestrial pyroxenes from granulites, we have devised a correction scheme for re-casting the pyroxenes into components that yield appropriate proportions of Wo, En, and Fs. Because the minor-element compositions of these highland pyroxenes vary from site to site, probably reflecting the bulk compositional differences of the sites [3], we hope eventually to be able to separate the effects of bulk-rock composition versus crystal-chemical constraints in determining the extent of minor-element substitution in these pyroxenes. However, the exact correction scheme is relatively unimportant in view of the low amounts of minor elements in most highland pyroxenes.

The minor-element components are calculated as follows: (1) Al and Si fill the tetrahedral site, the excess Al going into the octahedral site; any tetrahedral deficiency is ignored (${}^{IV}Al + Si \leq 2$). (2) Na and the R^{3+} cations (${}^{VI}Al$ and Cr^{3+}) are combined to form $NaR^{3+}Si_2O_6$. (3) The remaining Na (if any) is combined with Ti^{4+} and ${}^{IV}Al$ to form $NaTiAlSiO_6$. (Since the Na contents are quite low in lunar rocks, the $NaR^{3+}Si_2O_6$ component is minor, and the $NaTiAlSiO_6$ component is rarely encountered.) (4) The remaining Ti is then combined with ${}^{IV}Al$ for $R^{2+}TiAl_2O_6$; and finally (5) the remaining ${}^{IV}Al$ and R^{3+} cations are combined to form $R^{2+}R^{3+}AlSiO_6$. For augites the R^{2+} cation is Ca, and for low-Ca (opx) pyroxenes the R^{2+} cation is Fe^{2+} and Mg taken in proportions equal to the Fe/(Fe+Mg) and Mg/(Fe+Mg) ratios, respectively. This procedure is supported by the experiments of [4] on aluminous, Fe-free pyroxenes. Projection of their compositions from $CaAlSiAlO_6$ for cpx and from $MgAlSiAlO_6$ for opx yield results comparable to those of Al-free experiments. The Wo, En, and Fs ratios are then calculated from the remaining Ca, Mg, and Fe. This scheme has the effect of minimizing the Wo content for augites and of maximizing the Wo content for the low-Ca pyroxene.

Applications: As a test of the two-pyroxene thermometer, we applied it to the Adirondack pyroxene pairs of [5]. Most augites and their coexisting opx give mutually consistent temperatures (corrected for pressure) in the range 500-550°C, much lower than the temperatures predicted from Fe-Ti oxide and two-feldspar thermometry. We suggest that these temperatures may well be real and may represent effective blocking temperatures for diffusion of Ca (on the scale of electron probe microanalysis) during the slow cooling of the Adirondack terrane. A re-examination of the Adirondack pyroxenes for evidence of granule-exsolution would seem appropriate.

Compositions of host-lamellae pairs from 67075 (an anorthositic breccia) have been reported by [6,7] (Fig. 1). While the range of temperature is somewhat greater than one would like, there is a fairly good correlation between

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the two temperatures, although it appears that temperatures derived for the host phase (regardless of type) tend to be higher than those obtained from the included lamellae (Fig. 1). This suggests that there may be exsolution lamellae in the host that cannot be optically distinguished.

Other host-lamellae pairs are listed in Table 1, and likewise show higher host-temperatures than lamellae-temperatures. The one exception is 14321 [8]. Sample 77215 shows fairly consistent temperatures derived from the exsolution features (average T = 850° ± 30°C), with higher temperatures derived from the host (955° ± 40°C; the host with a T > 1100°C is probably due to grain overlap).

Conclusions: We conclude that successful application of the two-pyroxene thermometer will require the same meticulous attention to reconstruction of lamellar and granule exsolution textures as is often necessary for Fe-Ti oxide and two-feldspar thermometry [9].

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Table 1. Temperatures derived from host-lamellae pairs.

Sample	Wo	En	Fs	T(°C)	Type
14321	44.7	48.7	6.6	740	host
[8]	2.4	82.0	15.6	950	lam.
76255,61	2.5	62.9	34.6	800	host
[10]	43.3	42.2	14.5	730	lam.
62236,12	2.3	63.7	34.0	780	host
[17]	44.1	42.7	13.2	690	bleb
77215	3.6	66.6	29.8	990	host
[12]	41.7	44.7	13.6	860	blebs
77215	3.2	66.7	30.1	920	host
[12]	42.2	44.9	12.9	810	hachur
77215	3.2	66.8	30.0	920	host
[12]	41.9	44.6	13.5	840	septum
77215	3.7	66.0	30.3	990	host
[12]	41.0	45.0	14.0	890	planar
77215	4.6	66.7	28.7	>1100	host
[12]	41.7	45.8	12.5	860	bleb

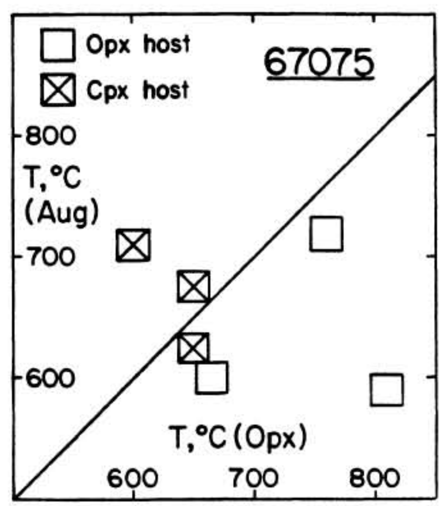

Fig. 1. *Temperatures derived by applying [2] to analyses of exsolved pyroxene pairs from 67075.*