K_2O-RICH MELT FROM THE MARTIAN MANTLE? C.A. Goodrich[1], A.H. Treiman[2], J. Filiberto[3], J. Gross[4] and M.J. Jercinovic[5]. [1]Planetary Science Institute, 1700 E. Ft. Lowell, Tucson, AZ 85719 USA (cgoodrich@psi.edu). [2]Lunar and Planetary Institute, Houston, TX 77058 USA. [3]Southern Illinois University, Dept. of Geology, Carbondale, IL 62901 USA. [4]Dept. Earth and Planetary Sciences, American Museum of Natural History, NY, NY 10024 USA. [5]Dept. of Geosciences, University of Massachusetts, Amherst, MA 01003 USA.

Introduction: Nakhlites are clinopyroxenites, interpreted to be olivine-augite cumulates that formed in flows or shallow intrusions of basaltic magma on Mars [1]. There are at least 15 proposed compositions for the Nakhla (or nakhlite) parent magma (NPM), derived by a variety of methods [2-14]. A striking feature of these compositions is that the one derived by [4] from melt inclusions in olivine, NK93 (and variants [15]) has ~3-10× higher K_2O and K_2O/Na_2O than those derived by other methods. High K_2O in the NPM would have significant implications for the mantle source [3,16,17]. Therefore, we began an investigation [15] to determine whether the high K_2O content of NK93 is a real property of the melt trapped in olivine, and if so, whether it is also a property of the NPM.

K_2O could be overestimated due to 1) boundary layer effects [18-20], 2) the unequal density effect in spread beam analysis [21,22], or 3) unrepresentative sectioning. In [15], we used P-mapping of host crystals to evaluate boundary layer effects, and began using "grid analyses" to test the accuracy of spread beam analyses. We have continued this investigation, establishing robust analytical procedures and analyzing many more inclusions.

Samples and Methods: We identified 31 melt inclusions in olivine in 9 sections of Nakhla. We obtained petrographic data and phase compositions from all of these, and bulk compositions (by grid analysis) from 14. We used the Zeiss EVO 50 XVP SEM and Cameca SX-50 EMP at U. Mass. and the Cameca SX-50 and SX-100 EMP at U. AZ.

EMPA conditions (15KeV, 8-10 nA, 5-20 sec count times, 2-μm beam) were established to minimize alkali loss and beam damage in glasses and other "fragile" phases. All analyses were carried out on freshly re-polished samples. A grid analysis consisted of setting up a rectangular grid of points covering the inclusion and running an automated routine to analyse each point using standard WDS procedures. Grid spacings ranged from 2 to 9 μm; time per grid ranged from ~8 to 70 hours. Bulk compositions were calculated from each grid by averaging all analyses after eliminating olivine.

Petrography and Mineral Compositions: The inclusions range in apparent size (maximum diameter) from ~25 to ~450 μm. All inclusions <180 μm have a simple texture and phase assemblage, in which augite occurs as a rim around the inclusion and in the interior as skeletal/dendritic crystals with interstitial glass (Fig. 1a). Minor phases are chromite, Fe-Ti oxide(s), Fe-sulfide, and phosphates. Glasses contain ~2-7% K_2O and ~2-8% Na_2O, with various K/Na ratios.
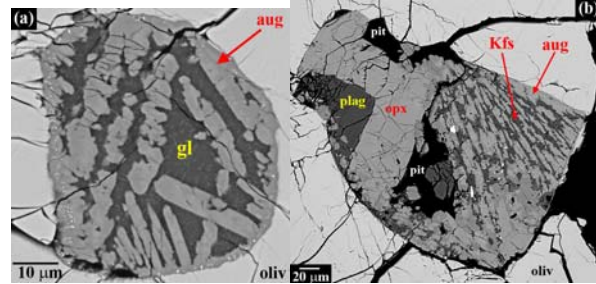
Fig. 1. (a) small melt inclusion in olivine (oliv), with simple texture and phase assemblage of mainly augite (aug) + glass (gl). (b) larger inclusion with more complex assemblage; opx = orthopyroxene; Kfs=alkali feldspar; plag=plagioclase.

All larger inclusions have more complex textures and phase assemblages (Fig. 1b), including large euhedra or massive crystals of opx (Wo 3-5), and either alkali feldspar (Or ~40-92), plagioclase feldspar (Ab 52-68) or both. One inclusion contains an ~100 μm patch of scapolite, which has not been reported in a martian meteorite. It contains 3.6% Cl and has the formula $(Na_{2.6}K_{0.3}Ca_{0.8}Fe_{0.1})_{3.9}(Si_{8.4}Al_{3.6})_{12}Cl_{0.93}$.

Inclusions found to have large amounts of "iddingsite" [23-26] were excluded from further study.

Bulk Compositions: Bulk compositions of 12 melt inclusions showed (in wt.%) SiO_2=50-57, Al_2O_3=5.4-10.3, CaO=10.9-15.1, Na_2O=0.7-2.1, K_2O=0.5-3.0 and Cl=0.1-0.2. K_2O and Na_2O contents for 5 inclusions analyzed by [4] are very similar to those reported by [4]. There appears to be a correlation of inclusion size with bulk K_2O and Na_2O, which is related to increasing concentrations of these elements in glasses or feldspars. There are no other correlations. Average bulk compositions for 5 large, complex vs. 7 small, simple inclusions are not significantly different, except possibly in K_2O (1.9 vs. 1.4 wt%).

Discussion: The range in apparent inclusion size is unlikely to be due entirely to unrepresentative sectioning, and there appear to be significant differences in texture and phase assemblage between "large" and "small" inclusions. Also, P-maps of two host crystals showed large inclusions located in core regions and small inclusions in outer zones [15].

Nevertheless, bulk compositions provide no evidence for more than one population. The difference in texture and phase assemblage could be due to differences in disequilibrium crystallization sequence [27]. The apparent correlation of alkalis with size is intriguing, but we cannot explain it at this point. We take the average of all inclusion bulk compositions to represent the melt trapped in olivine (Table 1, column 1).

Table1	1	2	3	4	5
	avg (12) bulk incl.	TM in Fo 53*	TM in Fo 40*	MIM [14]	TM in aug.[14]
SiO_2	52.2	47.3	46.6	47.0	48.4
TiO_2	1.1	0.83	0.82		1.8
Al_2O_3	8.0	6.3	6.2	7.3	8.0
Cr_2O_3	0.12	0.11	0.11	0.01	0.08
FeO	15.0	26.4	29.5	26.9	22.2
MgO	6.9	5.9	3.7	5.1	4.4
MnO	0.32	0.44	0.43	0.52	0.46
CaO	12.6	10.0	9.7	9.9	11.0
K_2O	**1.6**	**1.3**	**1.3**	**0.68**	**1.2**
Na_2O	1.3	1.0	1.0	2.0	1.8
P_2O_5	0.73	0.59	0.59	0.5	0.44

* K_D (Fe/Mg) = 0.35 [29].

The primary trapped melt (TM) is reconstructed from the average bulk inclusion by addition of wall olivine and adjustment of Fe/Mg to equilibrium with the olivine at the time of trapping [28]. The amount of wall olivine is constrained to a minimum of ~20 wt.% by the requirement of olivine-saturation. If we assume (like most workers) that the primary olivine was Fo ~53, we derive a TM (Table 1, column 2) that is similar to NK93" [4,15], with slightly lower alkalis.

The K_2O content of this TM is still 2-4× higher than in NPMs derived by other methods [2,3,13,14]. [15] argued that this is unlikely to be due to boundary layer effects, and the observed correlation of K_2O with inclusion size supports this. Results of grid analyses show that there is little overestimation of alkalis in the spread beam analyses of [4]. The observation of high K_2O in almost all the inclusions indicates that it is not due to unrepresentative sectioning. **We conclude that the melt trapped in olivine in Nakhla was unusually K_2O-rich compared to other martian magmas.**

Origin of K_2O-Rich Melt in Nakhla Olivine: The melt trapped in olivine in Nakhla is too K_2O-rich to have led to nakhlite bulk compositions [1] through simple accumulation of augite and/or olivine. It may be a late melt, rather than the parent magma, if olivine was not a cumulus phase. In this case, the TM could have been in equilibrium with the present olivine composition Fo ~40 (Table 1, column 3). [14]

interpreted the olivine in MIL 03346 as a late phase, and derived the parent magma MIM (Table 1, column 4). If such a scenario applies to Nakhla, then MIM should evolve to the TM in olivine through crystallization of augite. It is readily seen from Table 1 that this cannot be the case. MIM and TM are, in fact, very similar (especially SiO_2 and CaO) in all respects except alkalis. A very high degree of crystallization of MIM would be required to increase its K_2O content to the level of TM, which would drastically change its SiO_2, CaO and Al_2O_3 contents.

The olivine (except outermost rims) may be "xenolithic," either entrained or as phenocrysts in an admixed magma. In either case, it is difficult to imagine a scenario that explains why the parent melt of the olivine was so similar to either the parent melt of the augite or the mixed melt in all except alkalis.

The least model-dependent method for deriving the parent melt of the augite in nakhlites is to use the melt inclusions in augite. Two studies [11,12] have attempted to do this by experimental rehomogenization. Both produced a confusing range of compositions, which may partly be due to experimental difficulties [11,12]. [14] derived a TM from 5 melt inclusions in augite in MIL 03346 using methods similar to those here. A striking feature of that composition (Table 1, column 5) is high K_2O, similar to that of TM in olivine. We suggest that melt inclusions in augite in other nakhlites should be similarly investigated. If the TM in both olivine and augite was K_2O-rich, then perhaps the nakhlite parent magma was K_2O-rich. In that case, the question would be why bulk nakhlites are not.

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