Preliminary Study of Olivine Melt Inclusions of Apollo 12 and 14 Basalts.

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Introduction: Characteristics of parental magmas of lunar basalts are pivotal to our understanding of magma evolution and source characteristics. Melt inclusions represent small parcels of silicate melt that have been trapped by growing crystals and thus provide information of the magma at the time of mineral crystallization [1]. Since olivine is one of the first crystallized minerals in basaltic magmas, contained melt inclusions potentially are able to provide some geochemical characteristics of parental magmas. However, such inclusions are often devitrified, which makes it difficult to decipher their compositions. Homogenization of polycrystalline melt inclusions can be performed before electron probe microanalysis of these inclusions (e.g., [2, 3]). However, this process can alter the chemical composition of the inclusion if the temperature is not properly controlled [1, 3]. In this study, a different approach has been applied to the analysis of melt inclusions. We used defocused beam electron microprobe analysis to obtain the bulk major element composition of melt inclusions. The melt inclusion compositions will allow the parental melt composition of each basalt suite to be investigated along with obtaining a better idea of the mantle source region.

Analytical Methods: Eight Apollo 14 high-Al basalts were analyzed from breccia 14321 (Group A: ,1473; ,1605; ,1480; Group B: ,1271; ,1594; ,1260; Group C: ,9080; ,9057), four Apollo 12 olivine basalts (12004,137; 12015,29; 12020,57; 12020,14) and two Apollo 12 ilmenite basalts (12005,44; 12008,65) for this study. Petrographic observations show that all samples contain melt inclusions in olivine phenocrysts. Most of the inclusions are polycrystalline while only a few of small inclusions are glassy (Fig. 1).

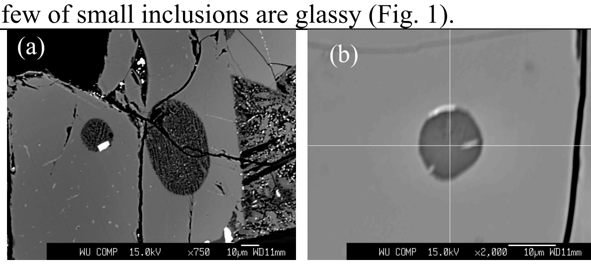

Fig. 1. Backscattered electron (BSE) images of melt inclusions: (a) polycrystalline melt inclusions in 14321,1473 (Group A high-Al basalt); (b) glassy melt inclusion in 12008,65 (ilmenite basalt).

The thin sections were carbon coated, and then analyzed using a JOEL JXA-8200 electron microprobe equipped with five wavelength-dispersive spectrometers, and a JOEL (e2vGresham) silicon-drift energy-dispersive spectrometer. X-ray correction was performed using the CITZAF correction software [4]. Operating conditions were 15 kV voltage and 25 nA current, using a defocused beam (the diameter was as large as possible for melt inclusions without encroaching on the host olivine) with typical count times of 30 s on peak and 20 s on background. The primary standards of a 10 element analytical setup both melt inclusion and olivine were: Na, Si: Amelia albite; Mg: Shankland forsterite (synthetic); Al: Alaska anorthite; K: Madagascar orthoclase; Ca: Gates wollastonite; Ti: synthetic TiO_2; Cr: synthetic Cr_2O_3; Mn: synthetic Mn_2SiO_4; Fe: synthetic fayalite. During the run, primary standards were checked against each other, and Kakanui hornblende and other standards were used as secondary standards to check the calibration. The measurements were quantified using the Armstrong Phi-Rho-Z algorithm coupled with Henke and Heinrich mass absorption coefficients.

Table 1. Range of measured concentrations of major elements in melt inclusion and whole rock.

	Melt inclusion		Whole rock	
Apollo 12 (olivine basalt and ilmenite basalt)				
	Ol basalt	Ilm basalt	Ol basalt	Ilm basalt
SiO_2	45-62.4	48.7-62.8	42.2-45	41.6-42.8
Al_2O_3	8.7-24	12.7-16.9	7.3-8.6	5.3-8
FeO	3.7-13.3	4.2-14.4	20.2-22	21.9-22.3
MgO	2-5.4	1.3-3.5	11-16.1	12.3-20
CaO	11.6-17.4	11.3-16.2	8.5-9.9	6.3-9
Apollo 14 (high-Al basalt)				
SiO_2	47.9-71.6		42.8-49.4	
Al_2O_3	7.6-23		11.1-13.8	
FeO	3.5-14.5		14-20.1	
MgO	1.6-10.4		7.4-12.1	
CaO	7.9-19		10.1-11.6	

Results and Discussions: Major element compositions of analyzed melt inclusions are significantly different from the whole rock compositions of each group of basalts. Electron microprobe data show that most melt inclusions contain substantially higher SiO_2, Al_2O_3 and CaO but lower FeO and MgO concentrations compared to the whole rock compositions [5-10] (Table 1, Fig. 2a). However, Mg/(Mg+Fe) ratios in melt inclusions overlap with those of whole rock (Fig. 2a). This implies that significant FeO and MgO loss and hence SiO_2, Al_2O_3 and CaO enrichemnet in the melt inclusion through olivine crystallization on the wall of the melt inclusion [3, 11]. In contrast to our direct measurements, Bombardieri et al. [2] showed that some homogenized melt inclusions had higher FeO concentrations compared to whole rock FeO contents. This difference indicates that homogenizing melt inclusions in the laboratory may incoporate components from the host olivine (i.e., overheating the melt inclusions).

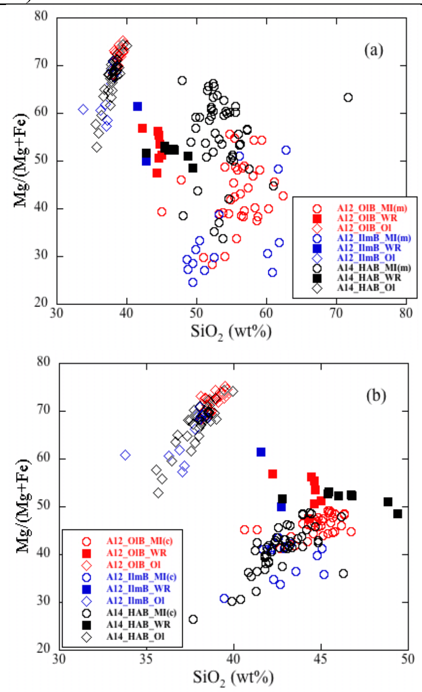

Fig. 2. Measured (a) and corrected (b) compositions of olivine hosted melt inclusions from Apollo 12 and 14 basalts. Whole-rock data and olivine data are plotted for comparison.

The effects of FeO and MgO loss were corrected using *Petrolog3* [12] based on the compositions of host olivine crystals. Corrected compositions of melt inclusions are comparable with whole rock compositions (Fig. 2b). Mg/(Mg+Fe) ratios in melt inclusions are generally lower than those of whole rock. This suggests that these melt inclusions may not represent the parental melts. Furthermore, the positive relationship between Mg/(Mg+Fe) and SiO_2 may reflect the co-crystallization of pyroxene at the time the melt was trapped in growing olivine crystals (Fig. 2b). Positive relationships between Mg/(Mg+Fe) and Al_2O_3, and to a lesser extent with CaO and TiO_2 also indicate that crystallization of spinel and/or Ca-rich plagioclase has affected these melt inclusions (Fig. 3).

Future Study: The main goal of this study is to use composition of melt inclusion to infer parental melt composition. The major elements suggest that the magma was saturated with several phases at the time of incorporation into the olivine crystals. This is further investigated with trace element abundances using laser-ablation inductively coupled plasma mass spectrometry (LA-ICPMS) to compare with whole rock data. Use of trace element ratios will further define melt evolution and source characteristics.

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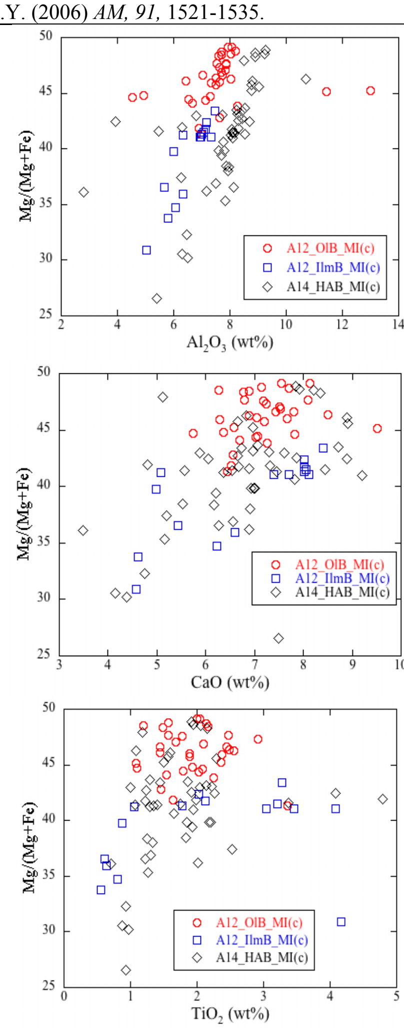

Fig. 3. Corrected compositions of olivine hosted melt inclusions from Apollo 12 and 14 basalts.