

THE VOLATILE CONTENTS (CO₂, H₂O, F, S, Cl) OF THE LUNAR PICRITIC GLASSES. A. E. Saal¹, E. H. Hauri², M. J. Rutherford¹ and R. F. Cooper¹. ¹Department of Geological Sciences, Brown University, 324 Brook St., Box 1846, Providence, RI, 02912. ²Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, NW Washington, DC 20015.

Introduction: Studies of volatile elements in magmatic systems have particular importance, because volatiles influence mantle melting, magma crystallization and volcanic eruption, and their abundances and spatial distribution provide important constraints on models for the thermal and chemical evolution of the Moon's interior. Most of the geochemical inferences about the deepest section of the moon have been based on studies of the most primitive melts erupted on the Moon's surface, the lunar volcanic glasses [1]. The assumption that lunar magmas are anhydrous is based on 1) the accepted model of lunar formation from a giant impact [2], which would cause the depletion in volatiles, specially water; and 2) the previously applied analytical techniques having high detection limits, which were not able to constrain the volatile contents (e.g. H₂O) of the picritic glasses [3]. However, there exists indirect evidence that volatile elements might have played a role in the generation of the lunar volcanic glasses. The association of a fire-fountain mechanism of eruption with condensation and enrichment of volatile elements on the surface of the lunar volcanic glasses suggests the existence of a deep mantle source comparatively enriched in volatiles. The implication that follows this view is that, contrary to prevailing ideas, the bulk Moon is not uniformly depleted in highly volatile elements.

In this abstract using state-of-the-art analytical techniques we report the magmatic volatile contents of individual lunar picritic glasses from the Apollo 15 and 17 landing sites.

Samples and Analytical Techniques: The green and red glasses (sample 15427,41) and orange glasses (sample 74220,864) from Apollo 15 and 17 landing sites respectively, were chosen for this study. The glass spherules range in size from 100-700 μm and were individually selected and mounted in indium. The abundances of volatiles dissolved in the interior of the lunar picritic glasses were measured by SIMS using a Cameca IMS6F at DTM, Carnegie Institution of Washington, employing methods recently developed for the microanalysis of trace amounts of H₂O, CO₂, F, S, Cl in glasses and nominally anhydrous minerals [4-6]. A typical 10-min SIMS measurement for volatile abundances is made on a singly polished specimen using a Cs⁺ primary beam (~14 nA accelerated to 10 kv) with collection of negatively charged secondary ions. We used a 10 μm primary beam rastered at 25 μm, which

results in a 35 μm crater. We pre-sputter for 3-5 min prior to analysis, during this time, we monitored secondary ion images of ¹²C, ¹⁷OH, ¹⁹F, ³²S and ³⁵Cl projected on the channel plate. This procedure helped avoid inclusions and cracks, which appear as bright features on the projected image (especially ¹²C image), and dendritic crystals (dark shapes on ³²S image). After each beam spot was carefully examined a field aperture was inserted to permit transmission of ions only from the central 10 μm of the 35 μm crater (i.e., always 25 μm away from the crater edge) thus avoiding transmission of ions from the edge of the sputter crater and the surface of the sample. Counting times were 10 s for ¹²C and 5 s for all other elements. Pressure in the ion probe sample chamber was ~6x10⁻¹⁰ torr during the analyses. The samples was placed in the ion probe sample chamber for ~12 h before analysis; this approach allowed the best detection limits for H₂O. Detection limits (~ 6 ppm H₂O and CO₂, ~0.09 ppm F, ~0.27 ppm S, ~ 0.03 ppm Cl by weight) were determined by the repeated analysis of synthetic forsterite (0.4 ppm H₂O as determined by FTIR) located on each sample mount. Calibrations for H₂O were verified for glasses and nominally anhydrous mineral standards prior to each analytical session; abundances for the other volatile elements (CO₂, F, S, Cl) were calculated from the calibrations performed on glass standards. SIMS calibrations are regressions of ion probe signals compared to known concentrations. The ion probe signal is normally taken as the intensity ratio of two elements, one being the element of interest and the other a matrix element common to many phases. In this study, standard volatile concentrations are plotted against measured volatile/³⁰Si ratios. This provides a robust analysis, which is little influenced by primary beam fluctuations or by ionization efficiency changes owing to matrix effects [6].

Results: All volcanic picritic glasses have CO₂ below or within the 2σ standard deviation of the detection limit for our runs (6 ppm CO₂) and will not be considered further. The volatile contents after background correction have the following ranges: 4-46 ppm (±2 ppm 2σ) for H₂O; 4-40 ppm (±0.2 ppm 2σ) for F; 115-576 ppm (±3 ppm 2σ) for S; and 0.06-2 ppm (±0.03 ppm 2σ) for Cl. An outstanding feature of the data are the strong correlations between H₂O contents and those of other volatiles (F, Cl and S) shown in Table 1. Such correlations indicate that the measured

H₂O contents cannot be produced by solar wind implantation of H⁺ followed by diffusion within the spherule, but rather suggest that all the volatiles represent magmatic contents, which were subsequently affected by degassing processes. Furthermore, there seems to be a clear distinction between the volatile contents of the different groups of picritic glasses, consistent with their distinctive major and trace element compositions[1]. The data suggests significant differences in either the volatile content of their mantle source material, and/or their mechanism of degassing and eruption.

Lunar magmas are generally believed to have been produced by melting of cumulates at depth [1]; however the source of the heat required for the generation of the primitive melts is not clear. The presence of volatiles in the lunar glasses, suggesting a non-trivial volatile content in their melt-source region, may provide a possible solution to this problem, as the presence of water in lowering the melting temperature of silicate rocks is well known.

Conclusions: We reported new volatile contents (CO₂, H₂O, F, S, Cl) for the lunar picritic glasses, which by virtue of SIMS analysis provide improved detection limits by almost an order of magnitude. To our knowledge this is the first definitive confirmation of the presence of “magmatic” H₂O in primitive lunar basalts. Our results suggest that, contrary to the prevailing ideas, the bulk Moon is not uniformly depleted in highly volatile elements, and the presence of water in particular must be included to constrain models for the thermal and chemical evolution of the Moon’s interior.

Table 1: Correlation matrix for volatiles contents in green glasses from Apollo 15 landing site.

	H ₂ O ppm	F ppm	S ppm	Cl ppm
H ₂ O ppm	1.0000			
F ppm	0.9333	1.0000		
S ppm	0.8845	0.8683	1.0000	
Cl ppm	0.9560	0.9797	0.8897	1.0000

References:

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