

VAPOR PHASE EVOLUTION DURING SEQUENTIAL DEGASSING OF Cl-, F-, H₂O- AND S-BEARING LUNAR MAGMAS: INSIGHTS FROM TIME STUDIES G. Ustunisik¹, H. Nekvasil¹, D. H. Lindsley¹, and F. M. McCubbin², ¹Department of Geosciences, Stony Brook University, Stony Brook, NY 11794-2100, ²Institute of Meteoritics, University of New Mexico, MSC03-2050 Albuquerque, NM 87131 Gokce.Ustunisik@stonybrook.edu

Introduction: While the recent successes of several groups [1-4] in detecting measurable amounts of OH in lunar apatite has opened the door to a new paradigm of a much “wetter” lunar interior, they also raise the obvious question, “How wet is wet?” and, because of the importance of other volatiles such as F, Cl, and S, “What were the abundances of all important magmatic volatiles in the parental magma?”. The answers to these questions are not straightforward because of the potential that late-stage crystallization of apatite may have taken place after some amount of degassing of the magma. In fact, the mass balance calculations of [5-7] for the KREEP-bearing samples analyzed by [3] showed that apatites record a degassing process that resulted in both loss of magmatic volatiles and significant changes in the relative volatile contents of the residual liquids, which affected the composition of the apatites forming. [5-7] concluded that the first-order assumption of simple increases in volatile content during crystallization may result in greatly underestimated parental magma volatile contents and changes in relative volatile contents during degassing may have obscured the relative volatile abundances of the magmatic source regions.

In order to determine the potential for differential degassing of lunar magmas at shallow conditions, a process that can change both volatile abundances and relative proportions, and therefore, influence the composition of the late-formed apatite, [8] conducted a first set of degassing experiments. These experiments determined the absolute and relative changes in abundance of volatiles (Cl, F, OH, and S) in the melt during the ascent of a lunar magma from 100 km depth to the surface without crystallizing. Based on the initial and final values for volatiles (wt%), degassed samples with initially 2.2 and 2.5 wt% water lost 99-100% water, 89-84% Cl, 60-61% F, and 94-92% S. This percentage loss also affected the relative volatile contents of the melt with a strong decrease in water content and an increase in F:Cl ratio. In reflection of changes in melt volatile contents, hypothetical computed apatite compositions also showed a strong reduction in OH content and a decrease in Cl:F ratio. While computed apatites from the initial (undegassed) magma had 20% Cl, 48% F, and 32% OH, computed apatites from degassed melts showed 10% Cl, 90% F, and 0% OH.

Further degassing experiments [9] were designed as time studies to monitor the changes in relative volatile content during successive intervals of low pressure degassing (1, 4, and 6 hours) (Fig. 1).

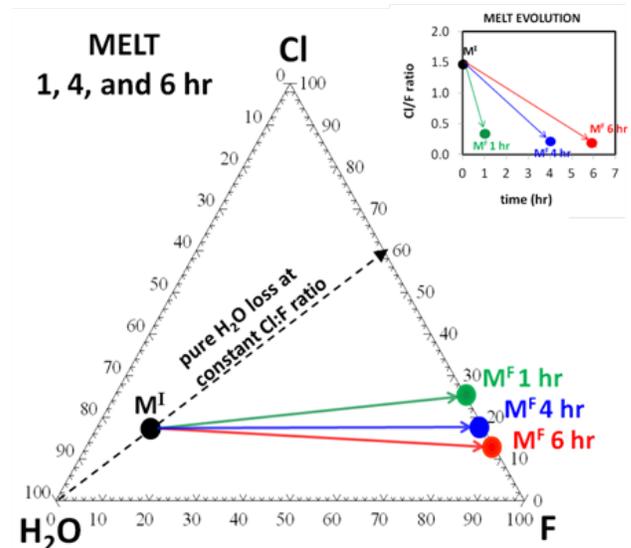


Figure 1. a. Ternary diagram showing relative abundances of the volatiles H₂O, Cl, and F in initial (M^I) melt and melts degassed for 1 hour (M^F1hr, green), 4 hour (M^F4hr, blue), and 6 hours (M^F6hr, red). **b.** Variation in melt Cl/F ratio with time.

Mass balance computations made it possible to access the changes in compositional nature of the gas exsolved over time (Fig. 2). The first vapor produced at the end of 1 hour degassing was water-rich; the successive vapor was dry and degassing was likely through the loss of metal chlorides and fluorides (Fig. 2).

However, these time study experiments started with the same initial magma and the vapor phase was computed by the change in volatile content of the melt from the initial to a final state for each time interval. In order to reduce uncertainty, we have now conducted experiments in which the partly degassed glass from the previous degassing step is used for the next degassing experiment.

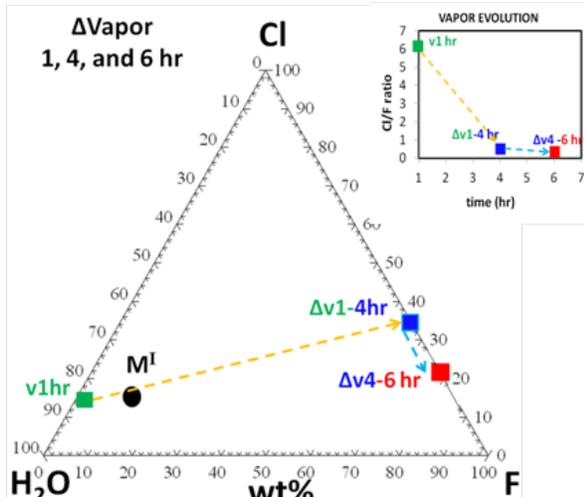


Figure 2. a. Ternary diagram for the relative volatile content of H₂O, Cl, and F in initial (M^I) melts and computed vapor composition lost at each time step. v1hr - computed vapor given off during the first hour of degassing; Δv1-4hr - computed vapor given off during degassing for another three hours; Δv4-6hr - computed vapor lost during degassing for yet an additional two hours. **b.** Changes in Cl/F ratio of the vapor during degassing along this path.

Experimental Design and Details: The new experiments are similar to those discussed by [8, 9] but were designed to monitor in more detail the changes in relative volatile content during sequential intervals of low pressure degassing by isolating the degassing stages through the use of partly degassed glass from a previous step for further degassing. This gives better access to the sequential changes in both melt and vapor composition. As before, a synthetic melt of 15043 with 0.5 wt% Cl, 0.5 wt% F, and 0.3 wt% S and 2.3 wt% was used. The final sample at the end of 1 hour degassing from experiments of [9] were placed in Fe⁰-capsules and inserted into a long silica tube. After evacuation, the tubes were sealed and suspended by a Pt-wire into a vertical furnace and heated above the liquidus T for an additional 3 hours and then quenched (thereby achieving a total degassing duration of 4 hours). Similarly, this degassed glass at the end of 4 hour is used for further degassing for 2 additional hours under the same conditions described above and quenched. Both the starting glasses and the final degassed glasses at the end of each subsequent degassing interval were analyzed optically as well as by electron microprobe (at the AMNH and UNM) and by micro-FTIR (for water) at SUNY Stony Brook. The results of these experiments and comparisons with previous mass balance calculations will be presented at the conference.

References: [1] McCubbin F.M. et al. (2010) *PNAS*, 107, 11223-11228. [2] Boyce J.W. et al. (2010) *Nature*, 466-469. [3] Greenwood J. P. (2010) *LPSC*, #2439. [4] McCubbin F.M. et al. (2010) *Am. Min.* 95 1141-1150. [5] Nekvasil H. et al. (2010) *AGU*, P41A05. [6] Nekvasil H. et al. (2011) *LPSC XLII*, 2240. [7] Nekvasil H. (2011) *A wet v. Dry Moon LPI*. [8] Ustunisik G. et al. (2011) *Am. Min.* 96 1650-1653. [9] Ustunisik G. et al. (2011) *A wet v. Dry Moon LPI*. [10] Sharp Z.D. et al. (2010) *Science* 329, 1050-1053.