

THE EFFECT OF DEGASSING OF A Cl-RICH, OH-POOR LUNAR MAGMA ON THE NATURE OF VAPOR DEPOSITS AND RESIDUAL MAGMA CHEMISTRY AND MINERALOGY. N.J. DiFrancesco¹, H. Nekvasil¹ and D.H. Lindsley¹. ¹Stony Brook University Department of Geosciences, Stony Brook, NY 11794. Nicholas.difrancesco@stonybrook.edu

Introduction: Analysis of lunar basalts and breccias has demonstrated that their parental magmas may have contained abundant volatiles [1,2]. Evidence of chlorine, specifically, is found in magmatic mineral phases (e.g., apatite and scapolite) of mare and highlands basalts [3]. While dissolved in the melt at depth, chlorine has the ability to change the properties of a magma, such as its liquidus temperature and viscosity [4]. However, Cl-rich magmas ascending rapidly may boil at or near the surface due to Cl-oversaturation. Cl is not lost as Cl₂ gas but rather complexes with cations. In terrestrial H₂O-rich systems, Cl loss is mainly as HCl. In water-poor melts, other cations will be scavenged from the liquid by the vapor phase and could precipitate with Cl as halides onto the lunar surface (e.g., halite, sylvite, lawrencite) as well as oxides. Perhaps the best examples of likely vapor deposits from the Moon are coatings on Apollo 66095, better known as “Rusty Rock” [5] and on pyroclastic glass beads [6]. Importantly, the loss of specific cations to the vapor phase has the potential to alter the chemistry of the degassing magma which can have an effect on the ultimate mineralogy the rock.

This investigation of magmatic degassing of Cl from a lunar melt has two major goals: to characterize the solids deposited from a vapor phase exsolved from a Cl-rich, OH-poor melt, and to determine the change in composition of the magma as a result of degassing at low pressure and how that affects the mineralogy formed from the magmatic residue.

Methods: In order to reliably simulate the compositional effects of magma degassing, it is important to use a reasonable lunar analog material (as a source of the cations) and to replicate magmatic conditions (e.g., pressure, temperature, and fO₂) that exist at the lunar surface. KREEP basalts are particularly appropriate analogs in that they contain components of liquids residual to the LMO and are considered rich in volatile and incompatible elements such as Cl [7].

KREEP basalt 72275 was selected as a starting composition [8], to which 2 wt.% Cl was added (Table 1). A mix was synthesized using the reagents oxides, silicates, Fe metal, and hematite (in the proportions required to have all iron as FeO in the starting composition), as well as MgCl₂ as a source of chlorine. This mix was homogenized in alcohol, dried at 800°C (with an oxygen getter at 500°C) to drive off any water, then placed in a Fe metal capsule, and melted at 0.5 GPa to

simulate magma generation at depth. The charge was rapidly quenched to a glass, which was recovered, crushed, and used as the starting material for degassing experiments. An iron capsule was employed during the glass synthesis in an attempt to constrain the fO₂ of the system to near the IW buffer, similar to the redox state of lunar basalts [9].

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Cl	Cr ₂ O ₃
Starting Glass	47.23	1.52	13.40	14.61	0.07	10.11	9.75	0.28	0.24	0.39	1.94	0.45
Apollo 72275	46.99	1.37	13.22	14.68	0.16	9.79	10.28	0.28	0.24	0.58	1.96	0.45

Table 1: Composition of Apollo 72275 with added Cl and EMPA of source glass used in experiments. Compositions normalized to 100 wt%.

Crushed glass was loaded into freshly reduced Fe⁰ capsules, and each was placed inside a ~30cm long silica glass tube, which was then evacuated and sealed shut. Each tube was heated in a vertically-oriented furnace at several temperatures (above the solidus temperature) for 8-72 hours with the sample at the hotspot to allow the source to degas into the overlying “head space” of the tube. After this time period, the tube was removed from the furnace and allowed to cool in the air. The silica glass tube was inspected for any breeches to ensure the system remained closed. Once the integrity of the tube was confirmed, it was opened and the contents were recovered.

The source capsule was removed for EMPA of the glasses and minerals that crystallized from the magma. Vapor-deposited minerals on the interior of the upper walls of the glass tube were analyzed by SEM and EDAX for morphological and compositional information. The bulk chemistry of these vapor deposits from some experiments were also quantified by ICP-OES to determine the cations that were transported from the melt by the vapor phase.

Finally, a set of equilibrium crystallization experiments were carried out with the same starting material at 0.5 GPa for similar temperatures as the low pressure degassing experiments. These experiments were meant to compare the differences between the magma crystallizing at depth, while retaining Cl, and at the surface after losing it.

Results: Several distinct crystal forms were noted in the crystalline vapor deposits (Fig. 1); these crystals were large enough to be clearly visible by naked eye. The phases were dominated by halide salts such as

halite, sylvite and an iron-chloride phase that appears to be lawrencite. Iron oxides were also present.

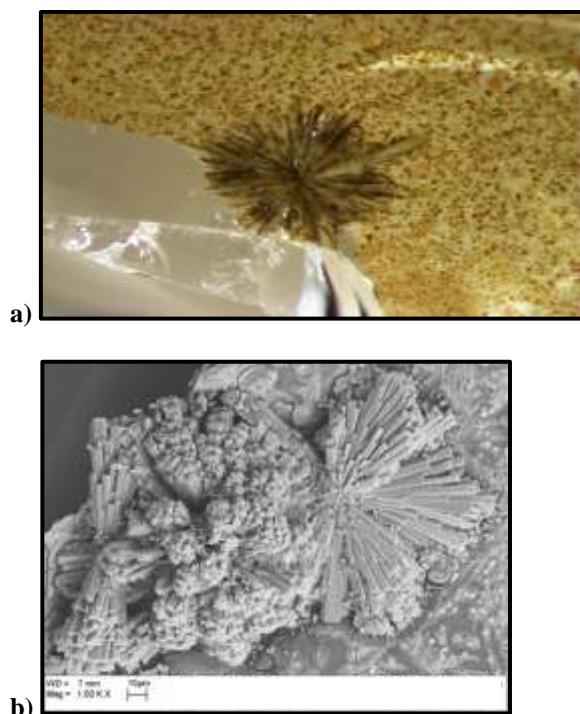


Figure 1: a) Photograph showing a large Fe-Cl crystal cluster surrounded by smaller halite crystallites that were deposited on the walls of the silica tubes containing experiments. Field of view is approximately 1 cm. b) Electron photomicrograph of a similar Fe-Cl crystal, field of view is approximately 200 microns.

Bulk composition of the cations in the vapor deposits from several experiments were determined through ICP-OES (Table 2). While this technique precluded the analysis of anions such as Cl and O, it is understood that Na, K and (some) Fe was deposited as Cl-complexes on the walls of the tubes containing the degassing charges.

	K	Na	Fe
K2013	5.52	4.77	89.70
K2014	4.48	4.16	91.36
K2015	6.17	7.05	86.79

Table 2: Composition of cations in vapor deposits from 3 different degassing experiments. Data are from solution ICP-OES, with totals normalized to 100%.

A comparison between the source magma crystallized at pressure and at low pressure during degassing demonstrates major differences in both the chemistry (Table 3) and mineralogy of the final assemblages. In both cases, the material left behind consisted of glass and crystals dominated by pyroxene. Both the glass

and pyroxenes formed at low pressure were more magnesian than those produced at higher pressure and similar T, despite the higher crystallinity for the same temperature at low pressure (due to the rise in solidus T as the magma degassed). Without degassing, this higher crystallinity would have driven both melt and pyroxene to lower Mg#. [Importantly, this effect was noted utilizing identical capsule and starting material]. The higher Mg# in the degassed melt relative to the undegassed higher pressure melt (Table 3) is driven by the significant loss of Fe to the vapor. Table 3 also shows the expected (e.g., Keller and McKay 1993) scrubbing of alkalis from the melt by the vapor phase. [Abundances of other cations are affected by renormalization of totals after vapor loss, and crystallization of pyroxene of different compositions.]

T (°C)	P (Kb)	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Cr ₂ O ₃	Cl
1200	0	53.44	2.17	14.13	11.02	0.02	7.67	10.83	0.09	0.01	0.21	0.38	0.00
1150	0	53.54	2.27	14.18	10.94	0.02	7.52	10.91	0.07	0.01	0.14	0.38	0.00
1200	5	45.15	1.41	13.72	17.89	0.11	8.50	10.32	0.31	0.20	0.30	0.38	1.69
1160	5	45.63	1.52	14.70	16.49	0.09	6.88	11.52	0.33	0.22	0.49	0.30	1.84

Table 3: EMPA of residual liquids (glasses) from crystallization of mafic phases at 0 and 0.5 GPa. Totals are normalized to 100% With Cl.

Discussion: Vapor transport at the lunar surface has been documented for some time [9]. Deposits produced from vapor phases in our experiments are mainly Fe chlorides and oxides, with halite and sylvite-similar to what has been observed in lunar samples.

Upon vapor exsolution, Cl is capable of stripping a magma of alkalis leaving behind a residual magma compositionally with higher An#. Cl-loss also greatly impacted Fe-loss; this was compounded by Fe loss that resulted in Fe-oxide vapor deposits, both of which results in a significant net increase in Mg# of the melt.

These results suggest that a significant magmatic Cl budget may result in major compositional changes in a lava without preserving much trace of the degassing process. This complicates the recognition of the characteristics of a magma source region assessed for example through multiple-saturation experiments of an observed surface lava composition.

References: [1]Wänke et al. 1970 LPSC. [2]McCubbin et al. 2015 Am.Min. [3] McCubbin et al GCA 2011. [4]Filiberto and Treiman 2009 Chem. Geol.[5] Shearer et al. GCA 2014. [6] Renggli et al. 2016 LPSC. [7]Sharp et al. 2010 Science. [8]Blanchard et al. Moon 1975. [9]Haggerty 1978 GRL. [10] Keller and McKay 1993 Science.

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