THE RELATIONSHIP BETWEEN VOLATILE ELEMENT ABUNDANCES AND IRON MASS TRANSFER IN LUNAR VOLCANIC AND IMPACT VAPORS.

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Introduction. The highly volatile elements (e.g. H, C, S, Cl) released during lunar volcanism provide important insights into the bulk volatile composition of the Moon. Once erupted, some fraction of the species containing these elements may have migrated to the poles where they could have become sequestered in shadowed cold traps such as those found near the lunar South pole. The volatiles trapped in the lunar South pole are of great interest to the upcoming Artemis missions, and one major objective is to sample some of those materials. Volcanic vapor deposits in the polar regions may also be supplemented by volatiles from both exogenous sources (i.e. comets) and other endogenous sources (i.e. remobilization of lunar volatiles by impact). Characterizing these endogenous sources is challenging because the highly volatile elements often leave little trace behind in the rocks themselves, which are inherently refractory by nature.

Minerals found on vug, vesicle, or fracture surfaces of some lunar rocks have characteristics consistent with phases formed via direct deposition from a vapor, as opposed to crystallization from a liquid or via solid state decomposition. One common vapor-deposited species is metallic Fe, typically observed as subhedral to euhedral crystals found on vug or vesicle walls in mare basalts and on select breccia clast surfaces in regolith soil samples returned from the Moon [1-4]. A particularly striking example is seen below in Fig. 1, where numerous Fe crystals are deposited onto the wall of a vug in Apollo 17 basalt sample 71036.

![Fig. 1: Euhedral Fe crystals (lighter colored crystals) observed on the walls of a vug in Apollo sample 71036.](image)

Euhedral Fe crystals are not very common in Apollo breccia samples, though this may be from the limited number of systematic searches that have been performed. However, when Fe crystals are found, they can occur in extremely high abundance. For example, lunar soil sample 15402 which was specifically selected because of its numerous Fe crystals, was found to have a class with 477 euhedral Fe crystals in a 570 x 570 µm area [4].

What struck us as interesting about this was not only that it takes a large amount of Fe to make these crystal-rich deposits, but also that these crystal-rich deposits are not ubiquitous, and therefore they must be controlled by some aspect of their depositional conditions. Since those conditions are inherently difficult to investigate and are critically interesting, we used thermochemical modeling as a tool to examine the relationship between vapor-deposited Fe and various intensive and extensive parameters. We assumed that a high abundance of Fe in the vapor is required to form these crystals, thus the mass of Fe in the vapor was used to determine the plausibility of the vapor-deposited, euhedral Fe crystals observed in Apollo samples.

Model Parameters. All models were calculated at a pressure of 0.01 bar from 100 to 2500 K using the Gibbs energy minimization module within HSC Chemistry™ (Metso Outotec). Our model used an input composition calculated from measured bulk chemistries of proxy samples of Apollo basalt 71036 (71035, 71036, 71037, and 71055 all came from the same boulder on the rim of Steno Crater), while varying the abundances of volatile elements Cl, S, C, and H. Equilibrium was calculated between 17 mineral phases and over 1000 vapor species (liquid species were ignored). To ensure accurate speciation, mineral phases and species were selected based on known lunar mineral compositions and simple phase diagrams were calculated to verify the correct phase change temperatures.

Preliminary Results. Temperature. As expected, increasing temperature (T) results in an increase in the mass of Fe in the vapor phase. Fig. 2 shows that changing temperatures from 500 K < T < 2500 K results in an increase in the mass transport of by ~10^10. This effect is most easily seen at low temperatures (T < 1000 K), where the Fe mass transport changes with T re-
Regardless of volatile content. The pronounced decrease in Fe mass transport at T below the approximate range of basalt solidus temperatures likely explains the conversion of various Fe-bearing vapor species into Fe solid. As the hot, Fe-rich vapor traveled across cooled or partially-cooled rock, the conditions for vapor deposited Fe crystals may have been favorable, resulting in a steep decrease in the abundance of Fe in the vapor. In the case of the generation of the initial igneous vapor at high T and the maximum Fe carried, the range of temperatures is considerably more limited, perhaps only a few hundred degrees. Above 1500 K, the effect of increasing T is lower than at low T; sometimes even zero or slightly decreasing Fe in the vapor.

**Fig. 2:** Mass of Fe in the vapor phase while changing the abundance of all volatile elements simultaneously.

Volatile. Fig. 3 shows the mass of Fe in the vapor at various T while the abundances of Cl, S, C, or H are varied. The volatile elements held constant in each chart represent the approximate abundance in Apollo 17 mare basalts determined by the Lunar Sourcebook [5]. Cl has the greatest individual impact on the mass transport of Fe, where the range of Cl contents in lunar glasses results in a variation of ~10^7 in Fe mass transport. The mass of Fe in the vapor is not as strongly influenced by the abundance of S, C, or H.

**Discussion.** Based on the proposed model, if a deposit is found to be particularly rich in Fe crystals, then the vapors that created those deposits were likely Cl-rich.

This leads to two testable hypotheses:

1. Investigate Cl-rich basalts to determine if there are more vug- or vesicle-hosted Fe crystals than in Cl-poor basalts.

2. Investigate if Cl-rich breccias have more Fe crystals than Cl-poor breccias.

**Fig. 3:** The mass of Fe in the vapor phase when increasing the abundance of various volatile elements from 1 to 1000 g, with other volatile elements held constant at the estimated values for Apollo 17 Mare Basalts [5]. A) Varying Cl, B) varying S, C) varying C, D) varying H.