Effect of Cl on Near-Liquidus Crystallization of Olivine-Phyric Shergottite NWA 6234: Implication for Volatile-Induced Melting of the Mantle. B. J. Farcy [1] and J. Filiberto[1]; (1) Department of Geology, Southern Illinois University – Carbondale, 1259 Lincoln Dr, Carbondale IL 62901, USA
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Introduction: Martian magmas and the Martian interior are thought to be rich in chlorine compared with their terrestrial counterparts, based on comparisons of the chlorine concentration of SNC meteorites, the Martian crust, and terrestrial basalts [1, 3, 7, 8, 9]. Using the K/Cl ratio of the Martain surface from Gamma Ray Spectrometry data, the Cl concentration of the Martian mantle has been estimated to be ~ 390 ppm [8]. When compared to the terrestrial mantle, concentration of ~1 ppm for depleted sources [6] and ~30 ppm for enriched sources [6], the Martian mantle is almost an order of magnitude more enriched in Cl than the Earth's mantle. This higher mantle Cl concentration has potentially lead to Martian magmatism that is significantly more concentrated in Cl than typical terrestrial basalts. Therefore, we have conducted near-liquidus crystallization experiments on a Martian basalt, olivine-phyric shergottite NWA 6234, with varying Cl concentrations in order to investigate how Cl affects the liquidus temperature and the mineral phases that crystallize.

Sample: Olivine-phyric shergottite NWA 6234 is a relatively unaltered Martian basalt that represents a magma composition [5]. A textural analysis of NWA 6234 shows olivine grains in a finer grained matrix of pigeonite and maskelynite, along with other excessory minerals such as ilmenite, spinel, titanomagnitite, apatite, and iron sulfide [5]. A crystallization age of ~180 My has been determined from a Re-Os isochron plotted for trace element isotopes [5]. Analysis of apatite grains of NWA 6234 show a Cl content of 3.9 wt. % for individual apatite grains, which yields a total volatile composition ratio (Cl+F:OH) of ~0.4: ~0.6 [6]. This is consistent with Cl-rich apatite and amphibole commonly found in other SNC meteorites [reference needed here] and suggests that the parental magma to NWA 6234 is enriched in Cl similar to other Martian magmas.

Methods: Experiments were performed using a Quickpress piston cylinder apparatus at Southern Illinois University, Carbondale. A synthetic basalt was made based on the bulk composition of olivine-phyric shergottite NWA 6234, and was then doped with varying amounts of AgCl equivalent to 0 - 4 wt. % Cl. The synthetic basalt with added Cl was placed in a graphite capsule, with MgO spacers and encased in a $BaCO_3$ sleeve. The entire assembly capsule was brought to 12 Kb of pressure, then gradually reduced to 10 Kb of pressure during the initial temperature increase. This pressure was the kept constant throughout experimental runs. The synthetic basalt was melted at a temperature above the liquidus (~1440 ^{o}C) for 1 hour, then left to crystallize at varying temperatures (1320-1430 ^{o}C) for 2 hours, before being quenched by cutting power to the assembly. The graphite capsules, which contained the sample, were cut and mounted on a petrographic thin section, and visually examined for their crystal and glass content using a petrographic microscope. Electron microprobe analyses of the run products are forthcoming.

Results: The liquidus temperature for the NWA 6234 plus varying wt% Cl was calculated to be between the sample with the lowest temperature that contained contained all glass and no crystals and the highest temperature experiment that contained glass and crystals. A regression through the liquidus for each wt% chlorine was calculated to investigate how chlorine depresses the liquidus [fig.1]. At 0 wt% chlorine the liquidus temperature is 1430 ^{o}C and with 4 wt% Chlorine the liquidus temperature is at 1375 ^{o}C. Based on the trend of these inferred liquidi, the liquidus of the synthetic basalt decreases with increasing wt. % Cl with a slope of 13.

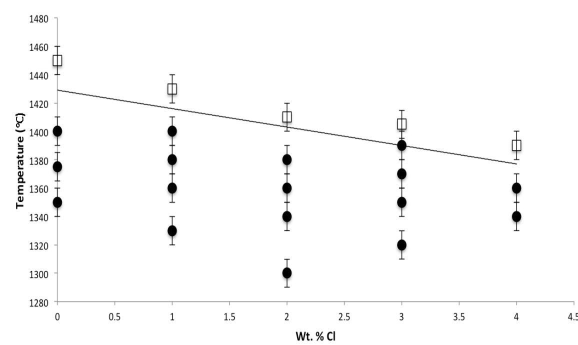

Fig. 1 Observed liquidus temperature (ΔT (^{o}C)) versus increasing volatile content (wt. % Cl) of a basaltic melt of starting bulk composition of olivine-phyric shergottite NWA 6234. Black circles represent experiments with Ol (± Opx) + liquid, and white squares represent experiments with pure liquid. Wt. % Cl is from the added AgCl to the synthetic basalt.

This is also shown by the ΔT plot, which shows the change in inferred liquidus temperature compared to wt. % Cl [fig. 2]. The liquidus ΔT was calculated by using the experimentally determined liquidus for 0 wt. % Cl (1430 ^{o}C), and subtracting the liquidus temperature of subsequent sample Cl contents from this temperature. As with fig. 1, this trend shows that the change in liquidus temperature decreases with increasing wt. % Cl. This observation is more consistent with findings from [6] than [4], as the curve of liquidus depression falls just above that of [6] for the basalt with lower Al and higher Si.

The plot of the ΔT of the liquidus shows that the degree of liquidus depression can be calculated using the following equation:

$$\Delta T\ (^{o}C) = -0.339 \text{ x } (\text{wt\% Cl in basalt})^2 + 14.92 \text{ x } (\text{wt\% Cl in basalt}) + 1.397$$

where ΔT (^{o}C) is the change in liquidus temperature of Cl-bearing basalt compared to Cl-free basalt.

Discussion: [6] showed that the effect of Cl on liquidus depression is dependent on the bulk composition, and Cl has more of an effect on magmas with higher Al and lower Si. We can compare our results to those of two different bulk compositions; one with higher Si and intermediate Al, and one with intermediate Si and higher Al. The curve of the ΔT plot [fig. 2] falls above experiments completed by [6], but below previous experiments by [4]. The difference in regression curves between these three studies is dependent on bulk silicate composition of the material being tested.

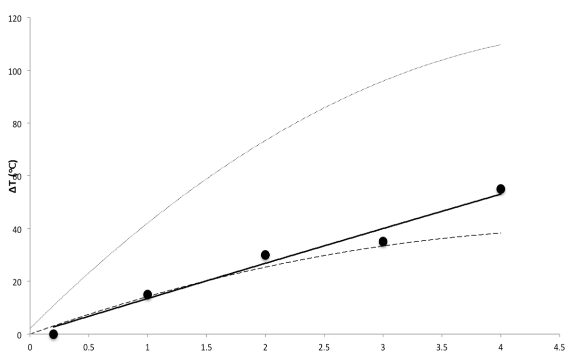

Fig. 2 Calculated liquidus depression (ΔT (^{o}C)) versus increasing volatile content (wt. % Cl) of a basaltic melt of starting bulk composition of Olivine-phyric shergottite NWA 6234. The three regression curves are from Filiberto et al. 2012 (dotted line), Filiberto et al. 2014 (dashed line), and this study (solid line). Liquidus depression (ΔT (^{o}C)) was calculated using the liquidus temperature of a volatile-free basalt of the starting bulk composition, and the liquidus temperature of a volatile-bearing basalt of the same composition.

[4] used a SiO_2-poor, FeO_T-rich, MgO-poor, Al_2O_3-rich basalt for the starting composition, whereas [6] used a more SiO_2-rich, Al_2O_3-poor composition. The results of this study seem to support the assertion that liquidus depression is affected by bulk silicate composition, because NWA 6234 has the lowest Al_2O_3 content compared to the bulk silicate composition used in the previous two studies. NWA 6234 also has a lower SiO_2 content than the two other bulk compositions plotted in fig. 2, which suggests that while Al_2O_3 has more of an effect on liquidus depression in the presence of Cl than SiO_2, the differences in regression curves could be due to varying FeO_T, MgO, and total alkalis as well.

Conclusions: Experiments done in this study, as well as in previous studies, show that Cl depresses the liquidus temperature in basaltic melts, with a dependence on the bulk composition of the melt. Using the wt. % Cl content of 1.4 wt %, which is the estimated lower limit concentration of a Martian magma produced from low-degree partial melting, we calculate a liquidus depression of 19 ^{o}C for this melt. This is compared to the upper limit for the typical Cl content of terrestrial ocean island basalts (OIBs) of 1,145 ppm. A melt of this Cl concentration would show a liquidus depression of 2 ^{o}C. Therefore, the addition of Cl to a Martian mantle melt would have lead to the observed liquidus depression and subsequent magmatism that produced the SNC meteorites.

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