

**EXPERIMENTAL SIMULATION OF MAGMATIC HYDROTHERMAL ACTIVITY ON MARS: I. HIGH TEMPERATURE ALTERATION IN THE PRESENCE OF A CL- AND S- ENRICHED FLUID.** H. Nekvasil<sup>1</sup>, G. Ustunisik<sup>1</sup>, F. M. McCubbin<sup>2</sup> and D. H. Lindsley<sup>1</sup>, <sup>1</sup>Department of Geosciences, Stony Brook University, Stony Brook, NY 11794-2100, Hanna.Nekvasil@stonybrook.edu, Gokce.Ustunisik@sunysb.edu, <sup>2</sup>Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Rd., NW, Washington, DC 20015, fmccubbin@ciw.edu

**Introduction:** Studies of mineral-hosted melt inclusions within the Chassigny [1] and MIL 03346 [2] martian meteorites have provided both evidence for and constraints on two types of magmatic fluids [3]. The first type, characteristic of water-rich systems, is associated with the production of phyllosilicates upon interaction with wallrocks and has been extensively studied in the hydrothermal literature (e.g., [4-8]). The second type, evidenced by melt inclusion assemblages in the nakhlite MIL 03346 is a Cl-rich, S-rich acidic aqueous solution that gives rise to jarosite-hematite assemblages upon oxidation [2]. Such fluids have enhanced transport potential and will be compositionally sensitive to the magma from which they exsolved as well as to the nature of the wallrock with which they interact. Without compositional constraints on such fluids, it is difficult to predict the nature of the alteration assemblages that should arise by interaction with wallrock. For these fluids, experimental simulation is needed and the experiments must be designed preferably using both realistic martian magmas as the source of the fluid and realistic martian wallrocks for fluid/rock interaction.

This abstract reports on the first results of high temperature experiments that simulate fluid-assisted metamorphism/metasomatism in order to provide information on the assemblages produced within the martian crust as Cl- and S-rich magmatic fluids exsolve during magma ascent and interact with a basaltic crust. They specifically simulate ascent and decompression of a Cl- and S-enriched magma residual to crystallization of a Backstay composition parental magma at the base of a 65 km thick crust, exsolution of fluid from this magma at ~35 km depth, and interaction of this fluid with a wallrock of Humphrey composition containing crystals of olivine, plagioclase, and pyroxene and glass.

**Experimental design:** The alteration experiments were designed as sandwich experiments in which the fluid source was placed between two slugs of simulated wallrock at either end of a 0.5" capsule within a thermal gradient such that the wallrock was at the cooler ends of the capsule. The ratio of wallrock to fluid source was kept low in order to maximize the fluid:rock ratio. *Fluid source.* The source of the fluid was a dry Cl-, F- and S-enriched variant of the liquid residual to crystallization of Backstay composition at 9.3 kbar. This composition was selected for the following

reasons: First, Backstay represents a composition of an actual observed martian lithology analyzed by the MER Spirit in the Columbia Hills of Gusev Crater [9] that has textural features consistent with a high probability of reflecting a melt composition. Second, there is evidence that melts similar to the Backstay composition have been trapped at the base of the Martian crust and undergone partial crystallization. This conclusion was based on the experiments of [10], who showed that a Backstay composition melt is a good analog to the type of melt that can lead to the production of a dunite such as the Chassigny dunite and its mineral-hosted melt inclusion assemblages if ponded at the base of an average martian crust. Third, there is evidence for a secondary Cl- and S- enrichment process in the melt interstitial to cumulus olivine in the Chassigny dunite (ascribed by [1] to fluid/melt exchange with hot upward percolating fluids from hotter deeper parts of the magmatic plumbing system), a process that was coupled with a decrease in magmatic water content. Mineralogical evidence points to this enrichment as having occurred after crystallization of olivine and high temperature pyroxenes, but before crystallization of kaersutite and feldspar [1]. The experiments of [10] pinpoint the composition of the melt at the stage just prior to enrichment (1050°C at 9.3 kbar). Furthermore, the porosity and permeability of a cumulus olivine pile makes it likely that this modified interstitial melt could have separated and ascended to shallower levels, as simulated by the experiments. Taken together these reasons make a Cl- and S- enriched evolved Backstay liquid a reasonable approach to a realistic martian magma composition.

*Wallrock.* The wallrock was chosen to be of Humphrey composition mainly because previous experimental work (e.g., [11, 12]) has shown that it produces the primary minerals upon cooling seen repeatedly in Martian basalts, olivine, orthopyroxene/pigeonite, and plagioclase. A Humphrey mixture with 1.5 wt% water (to provide some water to the system) was partly crystallized at 5 kbars in order to provide coherent slugs consisting of these mineral phases and hydrous glass.

**Experimental details:** Two experimental mixes were made from silicates and oxides for these experiments. The first was of the Humphrey composition used by [11]. This was ground in alcohol for 2 hours and dried. Water was syringed into the bottom of a

graphite-lined Pt capsule, and the dried mixture added on top to yield 1.5 wt% water. The capsule was welded shut and placed in a talc assembly, loaded into a piston-cylinder apparatus, melted at 1350 °C for 2 hours and crystallized at 1080 °C for two days at 5 kbars. This produced slugs of hydrous glass and well formed crystals of olivine, high-Ca orthopyroxene/low-Ca pigeonite, and plagioclase (Fig. 1). Rare radiating clusters of amphibole were also produced.

The second mixture was made of the evolved Backstay composition shown in Table 1 with MgCl<sub>2</sub>, MgF<sub>2</sub>, and CaSO<sub>4</sub> as the sources of Cl, F, and S, respectively. The silicates and oxides were ground in alcohol for two hours, the fluoride, chloride and sulfate were added last and ground by hand with a minimal amount of alcohol. The mixture was dried under vacuum at 150 °C.

**Table 1.** Evolved Backstay composition used as the fluid source.

SiO <sub>2</sub>	51.47
TiO <sub>2</sub>	1.09
Al <sub>2</sub> O <sub>3</sub>	16.75
FeO	9.94
MnO	0.12
MgO	3.10
CaO	6.05
Na <sub>2</sub> O	5.25
K <sub>2</sub> O	1.27
P <sub>2</sub> O <sub>5</sub>	1.78
Cl	1.88
F	0.38
Cr <sub>2</sub> O <sub>3</sub>	0.15
S	0.38

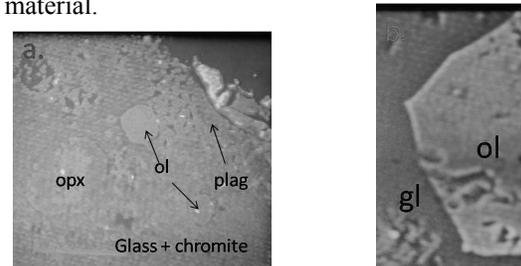
The alteration experiments were conducted in graphite-lined Co capsules, 0.5" in length, with a diameter of 0.25". A slug of partly crystallized Humphrey was placed at the bottom of the capsule, the center was packed with the composition of Table 1 and an additional slug was placed at the top. This yielded ~25 mg of wallrock and 300 mg of evolved Backstay, which made available ~4.5 mg Cl, 0.9 mg S, and 0.3 mg H<sub>2</sub>O for

reaction. The capsule was placed in a talc assembly, pressurized to 5 kbar in piston-cylinder apparatus and for the first experiment, heated to 680 °C at the thermocouple junction. This placed the center of the Backstay mixture at about 720 °C. The sample was reacted for 4 days. The capsules were then opened and prepared for optical and microprobe investigation.

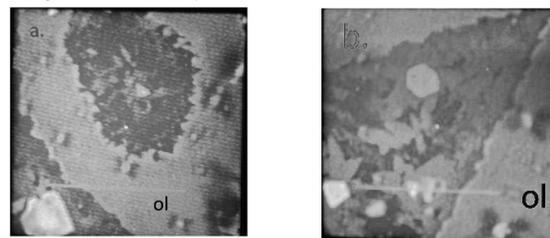
**Results:** The experiment at 680°C subjected the wallrock to amphibolite facies conditions and under these conditions there was extensive interaction. The boundaries of the wallrock slugs remained distinct, indicating the likelihood of solid-state transformation. The alteration assemblages produced had significantly greater Cl content, suggesting that the Backstay source became fluid-saturated and released a Cl-rich fluid that successfully travelled to the ends of the capsule.

The most volumetrically abundant mineral produced during the alteration was amphibole (Figs. 2, 3).

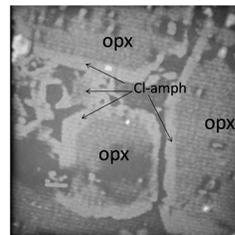
It grew primarily at the expense of the glass but also produced distinct rims around orthopyroxene. Olivine showed corroded edges and slight reverse zoning towards the edge. Plagioclase was notably absent in spite of having been present as euhedral laths in the starting material.



**Figure 1.** BSE image of unaltered Humphrey wallrock. **a.** Overview. Width of view: 65µm. **b.** Unreacted olivine grain. Height of view: 16 µm.



**Figure 2.** BSE images of Humphrey olivine after alteration showing corroded margins and felted mass of amphibole replacing glass. Wov: 16 µm



**Figure 3.** BSE image of amphibole rims on orthopyroxene after reaction. Wov:32 µm.

**Summary.** This feasibility study shows that alteration of a martian wallrock of Humphrey composition in the presence of a Cl- and S-enriched magma under amphibolite facies conditions in the mid-crust can be readily accomplished by exsolving magmatic fluids. These fluids would convert a basaltic wallrock to amphibolite and in the process destroy plagioclase, corrode olivine, and replace pyroxene with amphibole.

**References:** [1] McCubbin F. and Nekvasil H. (2008) *Am. Min.* 93, 676-684. [2] McCubbin F. M. et al. (2009) *Geochim. et Cosmochim. Acta*, 73, 4907-4917. [3] Nekvasil H et al. (2008) *LPSCXXXIX*, #1828. [4] Burnham C. W. (1979) In *Geochemistry of Hydrothermal Ore Deposits* 2<sup>nd</sup> Ed., 71-133. [5] Kilinc I. A. (1969) Ph.D. Dissertation, The Pennsylvania State University. [6] Kilinc I. A. and Burnham C. W. (1972) *Econ. Geol.* 67, 231-235. [7] Holland, H.D. (1972) *Econ. Geol.* 67, 281-301. [8] Webster J. D. and Mandeville C. W. (2007) *Rev. Mineral. Geochem.* 65, 313-362. [9] McSween H. Y. et al. (2006) *J. Geophys. Res.*, 111, E09S91. [10] Nekvasil H. et al. (2009) *Meteoritics & Planet. Sci.*, 44, 853-869. [11] McCubbin F.M. et al. (2008) *J. Geophys. Res.*, 113, doi:10.1029/2008JE003165. [12] Nekvasil H. et al. (2009) *AGU Publ.*, Toronto, Canada.