

**HYDROTHERMAL ALTERATION MINERALOGY OF HOME PLATE: THERMOCHEMICAL CONSTRAINTS FOR THEIR FORMATION CONDITIONS.** J. Filiberto<sup>1</sup> and S. P. Schwenzer<sup>2,3,1</sup> Rice University, Department of Earth Science, MS-126, 6100 Main St, Houston, TX 77005; Justin.Filiberto@rice.edu. <sup>2</sup>The Open University, CEPSAR, Walton Hall, Milton Keynes, MK7 6AA, UK; s.p.schwenzer@open.ac.uk, <sup>3</sup>Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058, USA.

Home Plate is a plateau in the Columbia Hills of Gusev Crater [1]. It is a layered sequence of clastic rocks with alkali basaltic composition. Based on stratigraphy, structure, sedimentology, mineralogy, and bulk chemistry it is interpreted as pyroclastic deposit and thought to be extensively hydrothermally altered [1-5]. The hydrothermal alteration is presumed to be of high and low temperature nature. In order to better understand the conditions (P,T,X) of hydrothermal alteration for the Home Plate region we have calculated the hydrothermal alteration mineralogy of Fastball, a primitive basalt from the Home Plate sequence, and compared these results to the mineralogy of the area.

**Home Plate alteration mineralogy:** The MER Spirit has investigated the igneous and alteration mineralogy and chemistry of Home Plate. Home Plate contains significant amounts of igneous olivine, pyroxene, and magnetite with small amounts of hematite and nanophase oxides. Surrounding Home Plate are deposits rich in goethite, hematite and Fe-sulfates with one location possibly containing pyrite/marcasite. These have been interpreted as acid sulfate fumarolic and/or hydrothermal system deposits related to the Home Plate pyroclastic deposit [5]. However, if indeed Columbia Hills were part of the central uplift of Gusev [6], it could be related to impact-generated hydrothermal activity. Bulk chemical data support the assumption of high and low temperature aqueous alteration. Elements more susceptible to alteration show correlations with mineralogy and stratigraphic position [4].

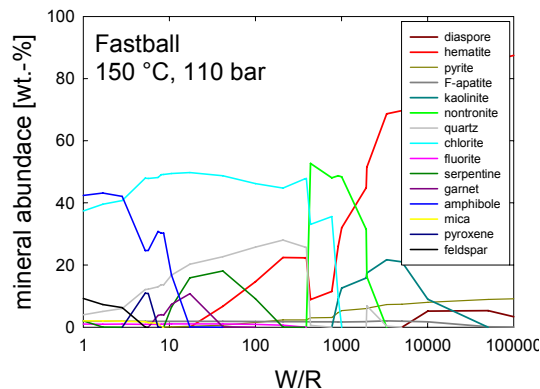
**Modeling background and input parameters.** Thermochemical modeling to understand formation conditions of minerals has been applied to various Martian processes (e.g., weathering [7], jarosite [8] and methane [9,10] formation, and Martian volcanic [11,12] and impact-generated [13] hydrothermal systems). For this study, we use CHILLER [14] to evaluate mineral assemblages that are likely to form from the Martian rock Fastball in contact with a diluted fluid [see 13]. To explore different stages of the hydrothermal system we calculated mineral assemblages at three temperatures (13, 150 and 300°C), P=110 bar, and water to rock (W/R) ratios from 100,000 to 1. We chose Fastball because 1) it has recently been shown to represent a primitive basaltic composition [15] and 2) it has the least amount of Cl and SO<sub>3</sub> of all of the Home Plate basalts suggesting it is the least altered composition [1]. We set the oxygen fugacity to 2 log units below

the QFM oxygen fugacity buffer equivalent to ~10% of FeO<sub>T</sub> as Fe<sub>2</sub>O<sub>3</sub> and added 0.3 % of F and Cl as CaF<sub>2</sub> and CaCl<sub>2</sub>, respectively. These values are consistent with average values for the SNC meteorites and unaltered Gusev Basalts [16-18]. CO<sub>2</sub> was set to 0.2x10<sup>-4</sup> mole HCO<sub>3</sub><sup>-</sup> in the brine.

**Results: Alteration mineralogy:** Alteration at 300 °C can be grouped in three main alteration assemblages: high W/R cause magnetite to form. At the highest W/R, when ion activities of all species are low, only magnetite and few % of diaspore precipitate. If the activity of Si-containing species is high enough (W/R < ~20,000), chlorite and serpentine form. At intermediate W/R chlorite dominates the assemblage; magnetite is not stable, but quartz forms. The dominating minerals are chlorite and serpentine. At low W/R, chlorite and serpentine dominate the assemblage accompanied by a range of silicates (feldspar, pyroxene, epidote).

If the system cools to 150 °C (Fig. 1), a different alteration assemblage forms. At high W/R, a very diluted fluid precipitates hematite, diaspore and eventually kaolinite. At intermediate W/R nontronite and kaolinite or chlorite dominate the precipitated minerals. Serpentine occurs in a small, intermediate W/R range only; and at very low W/R the silicate assemblage is amphibole, chlorite, feldspar quartz and pyroxene. If the system continues to cool to < 20°C the stable alteration assemblage would be nontronite–chlorite–goethite in the high and intermediate W/R range. At low W/R chlorite, amphibole, zeolite and quartz form.

Models with higher CO<sub>2</sub> contents are ongoing and based on previous results [11,19] should produce carbonates on the expense of oxides and silicates.



**Figure 1.** Example of modeling results. Lines represent alteration minerals as calculated dependent on water/rock (W/R) for 150 °C and at a depth of 1 km ( $P = 110$  bar).

**Brine composition:** The alteration minerals are in equilibrium with a brine (Tab. 1) that subsequently can get separated from the minerals, move to shallower levels in the crust, and cool. Depending on cooling or evaporation conditions those brines have the potential to form between 0.2 and 0.5 g silica and up to 0.2 g FeS<sub>2</sub> per kg of brine. The amount precipitated from this brine can be illustrated with two examples: a) Wiesbaden, one of the most famous German spas, is built on a tectonic hydrothermal system, which discharges ~1.3x10<sup>6</sup> m<sup>3</sup> fluid/year [20]; b) the theoretical discharge of a 100 km diameter crater on Mars over the life time of its hydrothermal system (300,000 years) [21] is calculated as 2.9x10<sup>3</sup> km<sup>3</sup> [22]. The former volume would precipitate 2.6 to 5.6x10<sup>8</sup> g silica and up to 2.6x10<sup>8</sup> g FeS<sub>2</sub> per year from the Fastball brine and the latter would result in the deposition of ~ 0.6x10<sup>15</sup> to 1.5x10<sup>15</sup> g silica and up to 0.6x10<sup>15</sup> g FeS<sub>2</sub> in 300,000 y.

**Table 1.** Brine compositions in equilibrium with Fastball alteration mineralogy. Selected ions, SiO<sub>2</sub> (aq), and S(tot) from all S-species; all in moles.

species	300 °C	300 °C	150 °C	150 °C
	W/R 1000	W/R 1	W/R 1000	W/R 1
Al <sup>3+</sup>	0.9x10 <sup>-4</sup>	0.2x10 <sup>-2</sup>	0.2x10 <sup>-4</sup>	0.7x10 <sup>-6</sup>
Ca <sup>2+</sup>	0.3x10 <sup>-2</sup>	0.1x10 <sup>-2</sup>	0.3x10 <sup>-2</sup>	0.2x10 <sup>-5</sup>
Mg <sup>2+</sup>	0.2x10 <sup>-1</sup>	0.9x10 <sup>-7</sup>	0.2x10 <sup>-1</sup>	0.3x10 <sup>-8</sup>
Fe <sup>2+</sup>	0.8x10 <sup>-2</sup>	0.9x10 <sup>-7</sup>	0.4x10 <sup>-2</sup>	0.2x10 <sup>-7</sup>
K <sup>+</sup>	0.5x10 <sup>-4</sup>	0.2x10 <sup>-1</sup>	0.5x10 <sup>-4</sup>	0.2x10 <sup>-2</sup>
Na <sup>+</sup>	0.8x10 <sup>-3</sup>	0.2x10 <sup>0</sup>	0.8x10 <sup>-3</sup>	0.3x10 <sup>0</sup>
SiO <sub>2</sub> (aq)	0.3x10 <sup>-2</sup>	0.9x10 <sup>-2</sup>	0.6x10 <sup>-2</sup>	0.6x10 <sup>-2</sup>
S (total)	0.3x10 <sup>-2</sup>	0.3x10 <sup>-2</sup>	0.2x10 <sup>-2</sup>	0.1x10 <sup>-1</sup>

**Comparison with Previous Results:** Our model results show similarities and differences to model results obtained from other Martian rock compositions. Comparing our results at 150 °C to alteration obtained from the Martian meteorite Shergotty [12], shows that chlorite and amphibole are formed in both models. However, our Fastball result is dominated by nontronite with chlorite and hematite at W/R of 1000, where the model of Shergotty [12] is dominated by chlorite and amphibole with quartz and prehnite. At W/R of 1, the differences are smaller and both models mainly show chlorite, amphibole, quartz and feldspar. Comparing Fastball to a more mafic lithology (Iherzolitic shergottite LEW88516, [13]), shows that both host rocks produce a nontronite–hematite–chlorite assemblage at W/R of 1000. At W/R of 1, serpentine–chlorite–amphibole dominates the LEW88516 alteration mineralogy, while an amphibole–chlorite–feldspar assemblage is formed by the Fastball host rock. One main difference of the models of this study to the previously investigated rock compositions is the presence of F and Cl in the Fastball host rock compositions. This

causes the apatite to be fluor-apatite. More importantly, fluorite is formed at intermediate and low temperatures and intermediate and low W/R. Although present as a minor phase only, the detection of fluorite in alteration mineral assemblages could give insights into the open question of the fluorine content of the original magmatic rock and the hydrothermal fluid.

**Implications:** We can now compare our model results and Home Plate alteration mineralogy to place constraints on T and W/R ranges for alteration. Home Plate is dominated by igneous minerals (olivine, pyroxene, and magnetite) with small amounts of alteration minerals (hematite and nanophase oxides), while areas surrounding Home Plate contain goethite, hematite and Fe-sulfates with one location possibly containing pyrite/marcasite. In the models, hematite dominates the alteration assemblage at relatively high W/R at 150°C, but is generally produced at W/R above 10. Goethite only forms at low temperature and W/R above 40 with a maximum around 100 and again around 100,000. Pyrite is produced at all temperatures but only at relatively high W/R. These results imply intermediate to high W/R and low to intermediate temperatures during alteration of the Home Plate region. Additional acidic brine, while not strictly excluded, is not required to form many of the observed phases. For future exploration, our results emphasize that the observation of assemblages is critically important to understand mineral formation conditions and that minor phases such as fluorite can give valuable insights into host rock chemistry and alteration conditions.

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