HIGH PRESSURE PHASE EQUILIBRIUM INVESTIGATION OF THE HOME PLATE PYROCLASTIC BASALT FASTBALL AND APPLICATION TO MELTING IN THE MARTIAN MANTLE. J. Filiberto, R. Dasgupta, W. S. Kiefer and A.H. Treiman. Department of Earth Science, MS-126, Rice University, 6100 Main Street, Houston, TX 77019 Justin.Filiberto@rice.edu. Lunar and Planetary Institute, 3600 Bay Area Blvd, Houston, TX 77058.

Introduction: Until recently, the SNC meteorites represented the only source of information about martian igneous processes [1]. This changed with the Mars Exploration Rovers which have analyzed basalts on the surface of Mars in both Gusev Crater and Meridiani Planum. These basalts are thought to be much older than the basaltic SNC meteorites [2] and have significantly different bulk chemistry [3-5]. Recent experimental works have explored some of these compositions to determine if they could represent mantle-derived melts [6-7] and have attempted to connect these surface basalt compositions with the cumulative SNC meteorites through crystallization [8-9]. To complement these models, we have experimentally investigated the near-liquidus phase equilibria of the Fastball basalt, analyzed at Home Plate (Gusev Crater), to test if it represents a primitive mantle derived melt.

Home Plate: Home Plate is a plateau in the Columbia Hills of Gusev Crater [10]. It is a layered sequence of clastic rocks with alkali basaltic composition, and has experienced some aqueous alteration [10-11]. The outcrop is mostly basaltic glass with lesser pyroxene, olivine, plagioclase, nanophase Fe-oxide, and magnetite (from Mössbauer and Miniature Thermal Emission Spectroscopy) [10, 12]. Based on stratigraphy, structure, sedimentology, mineralogy, and bulk chemistry it is thought to represent a pyroclastic deposit [10, 13]. Pyroclastic deposits on the Moon typically represent magmatic liquids [14-15], therefore we have assumed that Fastball is a liquid composition and experimentally investigated the melting phase relations of the bulk composition at pressure. We chose the Fastball composition because 1) it has the highest Mg# of all of the Homeplate rocks suggesting it is the most likely to represent a primitive magma [10] and 2) it has relatively low abundances of Cl and SO3 suggesting that it is not extensively altered [10].

Inverse Experiments: Near-liquidus phase relations can determine whether or not a basalt is a mantle derived liquid. If a magma is co-saturated at a single pressure (P) and temperature (T) with expected mantle minerals (olivine + orthopyroxene ± cpx ± plagioclase/spinel/garnet) of appropriate chemical compositions, that magma could reasonably represent a mantle-derived melt [16]. This approach has been previously applied to martian samples: meteorites Yamato 980459 [17] and NWA 1068 [18] and to the Gusev Crater Adirondack-class basalts [6-7]. We apply the same approach here to determine whether the Homeplate-class pyroclastic basalts are mantle derived liquids.

Experimental technique: The starting Fastball composition was made from a mixture of oxides and carbonates, fired at 1400° C at 1 atm to ensure homogeneity and to drive-off volatiles, and stored in a desiccator. Experiments were conducted in an end-loaded piston-cylinder apparatus using graphite capsules, BaCO3 sleeves, and crushable MgO spacers. All the assembly parts were dried at 300-1000 °C to minimize water contamination. Temperature was measured with a W5%Re/W26%Re thermocouple. Samples were pressurized and then rapidly heated to temperature where they remained for 19-24 hours. Experimental run products were analyzed using a Cameca SX-100 electron microprobe at NASA JSC for major element abundances.

Results: Figure 1 shows the liquidus P-T results for the Fastball composition. The liquidus T increases from 1425-1450 °C at 1.1 GPa to 1450-1470 °C at 1.5 GPa. Experiments at ≤1.3 GPa have olivine (Fo76) on the liquidus whereas at 1.5 GPa, opx (En77Wo3) is the liquidus phase. This suggests that near ~1.4 GPa there is a multiple saturation with both olivine and orthopyroxene on the liquidus.

Discussion: If Fastball is a mantle derived melt, then the compositions of its olivine and pyroxene at the multiple saturation condition should be those of the martian mantle. The composition of olivine (Fo76) and opx (En77Wo3) near the multiple-saturation point are close to those found for the Dreibus-Wänke model mantle composition (at similar P, T) [19-20]. The mul-

Figure 1. Experimentally determined near-liquidus phase relations for synthetic Fastball composition.
multiple saturation point of Fastball also lies well above the solidus for the Dreibus-Wänke composition, which suggests that the Fastball basalt represents a finite extent of melting with average melting conditions of \( \sim 1.4 \text{GPa} \) and \( 1450^\circ \text{C} \).

Making reasonable assumptions about crust density (2900 kg m\(^{-3}\)), crust thickness (50 km) [21], and mantle density (3400 kg m\(^{-3}\)) [22], the multiple saturation pressure of 1.4 GPa corresponds to a depth of 120 km in the martian mantle. If magma extraction in Mars is a batch process, the multiple saturation point determined suggests that the martian thermal lithosphere extends to \( \sim 120 \) km depth. However, if the melting of the martian mantle is a polybaric, near-fractional process, the multiple saturation may represent the average depth of melt extraction [16], somewhat deeper than the lithosphere-asthenosphere boundary. If the latter is more appropriate, the depth of 120 km is an upper bound for the lithosphere-asthenosphere transition beneath Home Plate plateau.

If Fastball represents a primary mantle-derived magma, we can use Ti partitioning to estimate the plausible mantle melt fraction required to produce the Fastball composition. For this calculation, we assume: batch or a fractional melting; a mantle of the Dreibus-Wänke composition [23], and a bulk partition coefficient, \( D_{\text{melt/mantle}}^{\text{Ti}} \), of 0.03-0.07 (based on the experimentally determined mantle mineralogy and partitioning [19-20]). This yields a melt of fraction 13-17 wt.% for Fastball. If Fastball represents an average, aggregate melt and if we assume a melt production rate of 10%/1 GPa as estimated for mid-oceanic ridge basalt generation on Earth [24], we would expect the one-dimensional melting interval to be 3.4-2.7 GPa, i.e., 290-230 km long column. If the multiple saturation point determined in this study roughly coincides with the mean pressure of melting column, then this predicts the top of the melting column to be at the surface or even extend to negative pressure. However, this is inconsistent with the estimated crustal thickness of Mars and rules out any presence of mantle lithosphere. Hence we predict that melt production in the martian mantle was more likely a batch process, with extraction of melt from the source region at the base of \( \sim 120 \) km thick lithosphere.

The olivine + opx + melt multiple saturation for Fastball, at \( \sim 1450^\circ \text{C} \) and \( \sim 1.4 \) GPa, also constrains the potential temperature of the martian mantle. The multiple saturation temperature of 1450°C corresponds to an average thermal gradient of 12.5°C/km through the thermal lithosphere of Mars. This gradient is relevant for the time of Gusev volcanism \( \sim 3.65 \) Ga [2] (Early Hesperian). Based on gravity modeling of elastic flexure, the lithospheric thermal gradients in other Hesperian age units on Mars are estimated to be 6-14°C/km [25], in excellent agreement with the value derived here. For a mantle adiabat of 0.18°C/km [26], the multiple saturation temperature and pressure correspond to a maximum mantle potential temperature (the temperature adiabatically extrapolated to zero pressure) of 1430 °C (assuming a relatively dry mantle).

This potential temperature is similar to the upper-bound of mantle potential temperatures estimated for present-day terrestrial mid-ocean ridges (1315-1450°C; [27-29]) but not as extreme as estimates for terrestrial oceanic islands (1450-1600°C; [28-30]). However, Gusev basalts are 3.65 b.y. old [2] and if we compare our estimate of ancient martian mantle potential temperature with the terrestrial mantle potential temperature based on archear komatitites (1550-1700°C [31]), we observe that the martian mantle was actually colder than the terrestrial mantle at the same point of time. Colder mantle temperature of Mars compared to the Earth’s mantle of similar age is consistent with cooling of a planetary body of a smaller size.