EXPERIMENTAL CONSTRAINTS ON THE SOURCE REGIONS OF THE SHERGOTTITES AND GUSEV BASALTS. K. I. Hutchins[1], C. B. Agee[1] and D. S. Draper[1], [1]Institute of Meteoritics and Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM, 87111, karen@unm.edu.

Introduction: Rover data from rocks sampled at Gusev Crater [1] on Mars combined with data from the martian basaltic meteorites (shergottites) [2-9] suggest there are at least two distinct basalt source regions in the martian mantle. The shergottites display a marked depletion in aluminum, also expressed as superchondritic CaO/Al_2O_3. One way to achieve this ratio is to derive these basalts from a source region that formed through magma ocean crystallization with majoritic garnet (a high-pressure form of garnet) fractionation occurring early on during crystallization in order to impart a superchondritic CaO/Al_2O_3 ratio to the residual magma ocean liquid due to sequestration of aluminum by garnet deep in the magma ocean [10]. This ratio should remain comparatively unperturbed by subsequent crystallization of olivine and low-Ca pyroxene. Thus, a deep, global magma ocean will produce a differentiated mantle with superchondritic CaO/Al_2O_3.

Several recent studies support the idea that the modern martian crust and mantle may have been derived through differentiation and crystallization of a chondritic magma ocean in the planet's earliest history [10-14]. Basalts derived via melting of olivine- and orthopyroxene-rich upper mantle source rocks likely retain the CaO/Al_2O_3 value from their sources because these phases do not significantly fractionate Ca from Al. However, the Gusev samples exhibit a ratio that is close to chondritic. If the Gusev rocks are largely unaltered basaltic samples, then their CaO/Al_2O_3 values appear to be inconsistent with having been derived from a source region that formed via crystallization of a deep, global magma ocean, which should impose a uniform superchondritic value on the entire mantle. We propose that the shergottite parent liquids and Gusev basalts can be derived from separate and distinct regional, rather than global, magma seas that are produced through impact melting and/or from magma chambers that are produced by mantle plumes. The shergottite source region resulted from crystallization that originated deep in the mantle (~14 GPa or ~1200 km) where majoritic garnet fractionation occurred. The Gusev basalt source region resided at a shallower depth in the mantle (≤10 GPa or ≤800 km) where majoritic garnet is not stable. Our experimental results demonstrate that both the shergottite parent liquids and the Gusev basalts can be derived through igneous processing of a chondritic mantle and that a deep, global magma ocean with large scale differentiation is not required as a mechanism of formation.

Experimental Results: All experiments were conducted using a Walker-style multi-anvil press in the High Pressure Laboratory, Institute of Meteoritics, University of New Mexico. The starting materials were finely ground samples of the Farmville H4 ordinary chondrite (Mg# 80) obtained from the Institute of Meteoritics' Meteorite Collection. High-pressure experiments were carried out at 10 GPa and 1825ºC, 14 GPa and 2100ºC, and 17 GPa and 2250ºC. Each run was first raised to a superliquidus temperature (1900ºC, 2200ºC, and 2300ºC, respectively) for five minutes to ensure melting of all residual grains before dropping to the target temperature. All experiments were held at target conditions for one hour to allow enough time for the mineral phases to equilibrate. Runs were quenched by cutting power to the rhenium heater.

Figure 1 shows that our experiment at 14 GPa produced a melt (coexisting with majoritic garnet and low-Ca pyroxene) with a CaO/Al_2O_3 ratio of 1.3, which is consistent with the range of values (1.0 to 1.4) calculated for the liquids that have been proposed by previous authors as being parental to the shergottite meteorites [2-9]. Short-lived radiogenic isotopes indicate that the source regions of the shergottites formed at ~4.52 ± 0.02 Ga [13, 15-18]. Around 4 billion years later, the shergottite source region was partially melted, producing the shergottite parent liquids. These liquids rose to near surface conditions where olivine, and in some cases low-Ca pyroxene, fractionation occurred as the parent liquids resided in magma chambers and/or igneous intrusions, thus increasing the absolute concentrations of Al_2O_3 (and CaO) in the melt because olivine will not incorporate much Al (or Ca).

The experimental melts in Figure 1 represent the residual melt (after some amount of mineral fractionation) in a magma sea or magma chamber that crystallized into the source regions of the shergottites and Gusev basalts. The green arrows indicate how the absolute concentrations of Al_2O_3 (and CaO) will be higher in the parent liquids than the source regions due to the parent liquids undergoing low pressure olivine fractionation. The experimental melt produced at 10 GPa (coexisting with olivine and low-Ca pyroxene) has the correct CaO/Al_2O_3 ratio for the Gusev source region. The experimental melt produced at 17 GPa (coexisting with majoritic garnet) has a CaO/Al_2O_3 ratio that is substantially higher than that required for either the shergottite or Gusev source region.

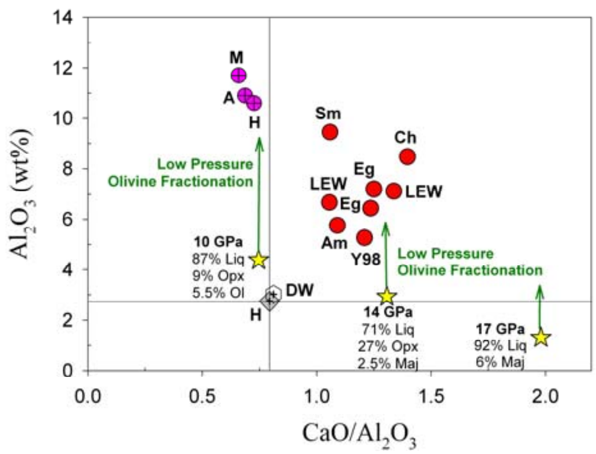

Figure 1. Comparison of experimental melts to the shergottite parent liquids and Gusev basalts in regards to Al_2O_3 content and CaO/Al_2O_3 ratio. Vertical and horizontal lines denote chondritic abundances. Experimental melts are represented by yellow stars. Green arrows show how the composition of the melts would change due to low pressure olivine fractionation. H (gray diamond) = H-chondrite starting composition. DW (white hexagon) = Dreibus-Wänke mantle composition [19]. Gusev basalts [1] (purple dots): A = Adirondack, H = Humphrey, M = Mazatzal. Shergottite parent liquids (red dots): Am = ALHA77005 parent [8], Ch = Chassigny parent [6], Eg = EETA79001 parent [2, 7], LEW = LEW88516 parent [5], Sm = Shergotty parent [9], Y98 = Yamato 980459 [3, 4].

Discussion: If Mars had a deep, global magma ocean in which majoritic garnet fractionation took place, then the resulting differentiated mantle, in its entirety, would have a superchondritic CaO/Al_2O_3 ratio due to the sequestration of aluminum by garnet deep in the magma ocean. However, the Gusev basalts have a roughly chondritic CaO/Al_2O_3 ratio. If these rocks are largely unaltered basaltic samples that were derived from a mantle with superchondritic CaO/Al_2O_3, then their source magma would need to have undergone a large amount of high-Ca pyroxene fractionation (at least ~17 wt%) in order to produce such a large decrease in the CaO/Al_2O_3 ratio (~0.5). However, removing this much high-Ca pyroxene results in concentrations of CaO in the residual melt that are much lower than those of the Gusev basalts. Additionally, if the parent liquids of the Gusev basalts were similar to primitive shergottites such as Yamato 980459 [3, 4], then high-Ca pyroxene would not be a near-liquidus phase and therefore such a process would not be plausible. Therefore, we prefer the alternate formation mechanisms of regional magma seas (Figure 2) and/or mantle plumes (Figure 3) rather than a global magma ocean. The extensive igneous processing that is evident in the shergottites [10, 13, 15-17] can take place within a deep, localized magma sea and/or a deep magma chamber. It is possible that the shergottite source region crystallized from a regional magma sea while the Gusev source region formed from a mantle plume.

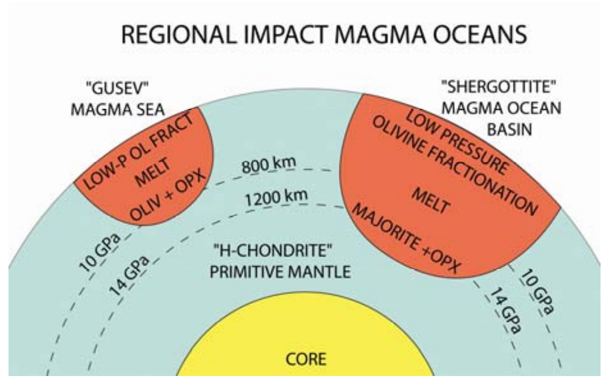

Figure 2. Schematic drawing (not to scale) depicting formation of the shergottites and Gusev basalts from regional magma oceans due to impact melting. In the shergottite source region, fractionation of majoritic garnet and low-Ca pyroxene occurs first, producing a superchondritic CaO/Al_2O_3 ratio in the residual melt. Later, low pressure olivine fractionation serves to boost the CaO and Al2O3 concentrations in the melt, as observed in both the shergottites and Gusev basalts. In the Gusev source region, the magma ocean does not reach deep enough for majoritic garnet to form. Olivine and low-Ca pyroxene fractionation occurs first, followed by a later event of low pressure olivine fractionation.

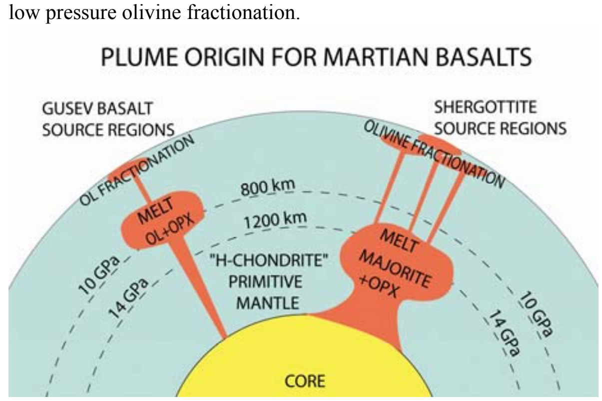

Figure 3. Schematic drawing (not to scale) depicting formation of the shergottites and Gusev basalts from mantle plumes. The same crystal fractionation processes occur in this model as with the regional magma oceans, only in this case the processes take place in magma chambers produced by mantle plumes.

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