A REACTIVE CRYSTALLIZATION MODEL FOR THE FORMATION OF POIKILITIC SHERGOTTITE METEORITES. J. K. Miura[1,2] and Y. Liang[1], [1]Brown University, Providence, RI, [2]California Institute of Technology, Pasadena, CA (jmiura@caltech.edu)

Introduction: Poikilitic shergottites are a subgroup of Martian meteorites characterized by two distinct regions: a poikilitic lithology with pyroxene oikocrysts enclosing olivine and chromite chadacrysts, and a non-poikilitic lithology with dominantly olivine, pyroxene, and maskelynite grains. These poikilitic shergottites are considered cumulate rocks crystallized at depth within the Martian crust, and represent relatively young mantle melting and surface volcanism from ~150-574 Ma [1,2].

Poikilitic textures similar to those observed in poikilitic shergottites, with olivine chadacrysts enclosed by clinopyroxene oikocrysts, have been observed in gabbros from the oceanic crust beneath mid-ocean ridges and ophiolites from around the world [3]. The clinopyroxene oikocrysts have high Mg# (86-91) and are interpreted to have formed at lower pressures due to their oikocrystic nature and equilibration with low-anorthite plagioclase. The high Mg# of the clinopyroxenes is attributed to equilibration of interstitial melts with cumulus olivine in the host rock, resulting in late-stage crystallization of high-Mg# clinopyroxene. This equilibration is facilitated by high Fe-Mg exchange between melts and olivine, which has been experimentally demonstrated [4]. These melt-rock reaction processes can be better understood and verified utilizing laboratory dissolution and crystallization experiments. Previous experiments have reproduced these textures for terrestrial compositions, with olivine chadacrysts in orthopyroxene and clinopyroxene oikocrysts [e.g. 5,6], motivating an experimental investigation of similar textures in poikilitic shergottites.

In this study, poikilitic textures similar to those observed in poikilitic shergottites were experimentally reproduced to determine whether the terrestrial melt-rock reaction formation mechanism for poikilitic textures could be applied at Martian magmatic conditions. Using terrestrial analog samples with compositions similar to those observed in lherzolitic shergottites, experiments were conducted to constrain possible temperature-pressure conditions and cooling histories needed to produce olivine chadacrysts enclosed by pyroxene oikocrysts. The experimental results support the possibility of this formation mechanism. This model of melt-rock reaction followed by crystallization (reactive crystallization) for poikilitic shergottites can further our understanding of the Martian interior and the igneous processes that can occur below the surface.

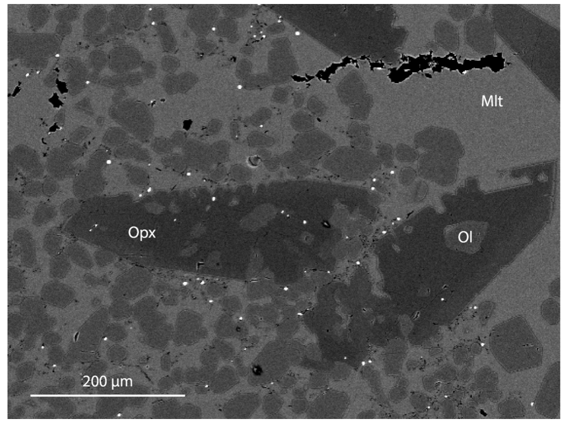

Fig. 1. Back-scattered electron (BSE) image of 1.0 GPa experiment. The experiment was run with a starting temperature of 1300ºC, and step cooled down to a temperature of 1200ºC. The experiment had a starting composition of 30% olivine and 70% basalt. Olivine chadacrysts are anhedral to subhedral; orthopyroxene oikocrysts are up to 500 µm in length, and are euhedral.

Methods: Experiments were conducted using a 19.1-mm piston cylinder apparatus at Brown University. The experiments utilized a layer of alkali-basaltic or basaltic-andesitic glass mixed with Fe-rich olivine crystals. This reaction couple was contained in a molybdenum capsule lined with graphite, which served as an inert buffer between the molybdenum and the silicates. The experiments were run at a variety of pressures and starting temperatures. The melt-olivine mixture was partially molten at starting run conditions. After 8 to 24 hours, the temperature of the experimental charges was decreased via step cooling. Pressures were allowed to drop due to thermal contraction as the temperatures decreased to replicate the geotherm. Once charges reached their final temperature, the temperature and pressure were maintained for at least 24 hours before quenching.

Quantitative chemical analyses and backscattered electron images were obtained using a Cameca SX100 electron microprobe at Brown University. The analytical conditions were an accelerating voltage of 15 kV and a beam current of 10-20 nA. A focused beam was utilized for the analysis of olivine, pyroxene, and oxides, while a 10 µm diffuse beam was used to analyze feldspar and glass. Natural and synthetic standards were used for calibration, and the data were calculated using the PAP correction procedures [7]. Compositions of cores and rims of selected mineral grains were analyzed, either as individual points or as line traverses. Rims were analyzed at least 3-5 µm from the grain boundary to avoid interference from adjacent phases. Analyses with anomalous totals (<98 or >102%) were discarded.

Results and Discussion: Two experiments produced textures similar to the poikilitic regions in poikilitic shergottites. One experiment was conducted at 1.5 GPa (Fig. 1a), while the other was conducted at 1.0 GPa (Fig. 1b). Both experiments sat at an intermediate temperature (1220ºC and 1200ºC) for a significant period of time (49 hours and 77 hours) before quenching, similar to how a rising magma from the Martian mantle would sit near the crust-mantle boundary or lithosphere-asthenosphere boundary for an extended period of time to grow orthopyroxene oikocrysts that enclose olivine, before rising to the surface. Experiments that did not include this intermediate temperature step did not produce poikilitic textures, suggesting that a magma that continuously rises from the mantle to the surface would not grow poikilitic textures by entraining olivine grains as it rises; an extended period of reactive crystallization at constant pressure and temperature is necessary.

To replace the glass in these samples similar to the nonpoikilitic textures observed in poikilitic shergottites, experiments were conducted with a similar cooling history, but cooling further to 1108ºC after holding the temperature at 1200ºC for 36 hours (Fig. 2). These experiments produced textures similar to poikilitic shergottites, with olivine, zoned orthopyroxene, clinopyroxene, and plagioclase with accessory ilmenite, but without the poikilitic textures previously synthesized, suggesting that the intermediate temperature needs to be held for longer to produce poikilitic textures.

The experimental results suggest that poikilitic textures similar to those observed in poikilitic shergottites may be produced at pressures between 10 and 15 kbar,

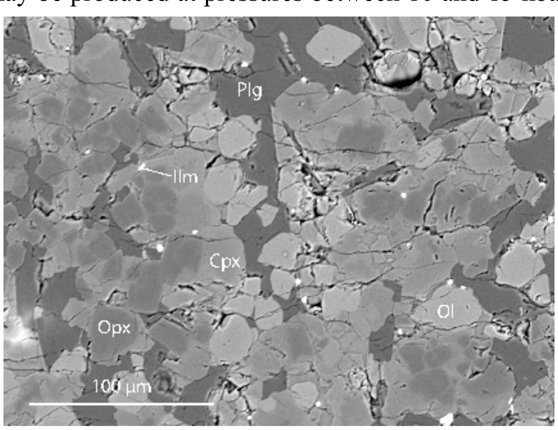

Fig. 2. Back-scattered electron (BSE) image of 1.0 GPa experiment with further cooling to produce nonpoikilitic textures. The experiment was run with a starting temperature of 1300ºC, and step cooled down to a temperature of 1200ºC, where it was held for 36 hours before further cooling to 1108ºC. The experiment had a starting composition of 30% olivine and 70% basalt

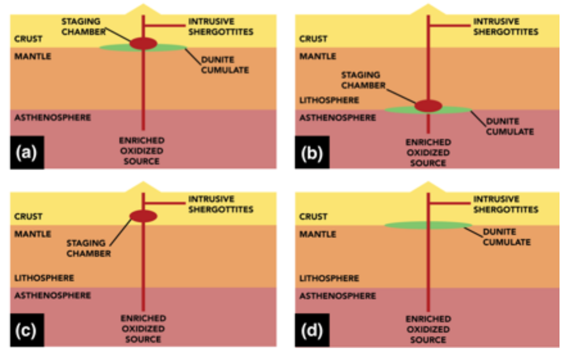

Fig. 3. Four scenarios for poikilitic texture growth in lherzolitic shergottite meteorites. (a) A rising magma pools at the crust-mantle boundary and reacts with a dunite layer before transport toward the surface. (b) A rising magma pools at the lithosphere-asthenosphere boundary and reacts with a dunite layer before transport toward the surface. (c) A rising magma pools at the crust-mantle boundary and crystallizes olivine out of the melt before transport toward the surface. (d) A magma rises continuously through a dunite layer toward the surface.

and with an extended intermediate temperature period following crystallization of orthopyroxene but prior to crystallization of clinopyroxene and plagioclase. This extended period provides the opportunity for reactive crystallization to occur between the basaltic melt and the olivine. Based on these results, we propose a model of reactive crystallization for the formation of poikilitic textures in lherzolitic shergottites, in which a rising mantle magma sits at either the crust-mantle boundary (Figure 3a) or the lithosphere-asthenosphere boundary (Figure 3b) boundary for an extended period of time. A layer of melt-bearing dunite at this boundary reacts with the basaltic melt, producing oikocrystic orthopyroxenes enclosing anhedral olivine grains, before these grains are brought near the surface. The interstitial melt then crystallizes the non-poikilitic textures observed in the lherzolitic shergottites. These results also indicate that a scenario in which a magma continuously rises through the mantle and crust through a dunite layer cannot produce these poikilitic textures (Figure 3d). This model for poikilitic texture growth is similar to that observed in oceanic gabbros and ophiolites, but with a different crystallization sequence (with orthopyroxene crystallizing before clinopyroxene in poikilitic shergottites).

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