Experimental Investigation of the Depth of Origin for the Apollo 15 Red Glass: evidence for a f_{O2} Control on Olivine-Opx Multiple Saturation. T. L. Grove[1], M. J. Krawczynski[1], and E. Medard[1], Department of Earth, Atmospheric, and Planetary Science; Massachusetts Institute of Technology; Building 54-1220; 77 Massachusetts Ave, 02139; (email: tlgrove@mit.edu, kraw@mit.edu, emedard@mit.edu)

Introduction: The Apollo 15 Red Glass represents one of the extreme high-Ti (HiTi) compositions (13.8 wt % TiO_2) in the spectrum of ultramafic glasses returned from the moon. The HiTi ultramafic glasses provide a sample of the lunar mantle processes that led to the melting of magma ocean cumulates nearly one billion years after the magma ocean solidified. Constraints on the depth, temperature, and melting processes that led to the origin of this HiTi glass are crucial for understanding the nature of magma ocean processes. The high amount of TiO_2 and FeO in this magma makes the phase relations more sensitive to changes in the oxidation state of the source region.

Delano [1] investigated the high-pressure phase relations of the Apollo 15 Red Glass (15R) using Fe-metal capsules, and determined the olivine+low-Ca pyroxene multiple saturation point at about 2.4 GPa. However we have found slightly different phase relations due primarily to longer run times, allowing kinetically sluggish reactions to reach equilibrium and varying oxygen fugacity.

Oxygen Fugacity Control: A starting material of synthetic 15R glass powder was prepared and conditioned in a gas mixing furnace at 1 atm at the iron-wüstite buffer for 24 hours. The conditioned powder was then run at high pressure and temperature in Fe-metal and graphite capsules. The metal capsules buffer the experiments at approximately IW-2.

The f_{O2} inside the graphite capsules was measured using two independent methods. One method uses the oxybarometer of Ballhaus et al. [2], and utilizes coexisting olivine+opx+spinel+liquid to yield a f_{O2} of IW+0.5 to IW+1. The other method employed the equilibrium between a 15R glass and a FePt alloy. This equilibrium can be used to calculate fugacity and yields a f_{O2} of IW+1.2 [3, 4].

Fe-metal Capsule Experiments: 15R glass, in Fe-metal capsules, is multiply saturated with olivine and low-Ca pyroxene at 2.0 GPa (Fig 1). This is 0.4 GPa lower than that originally reported by [1], however due to possible systematic offsets between laboratories as well as uncertainties in the pressure calibrations (+/- 0.05 GPa); the multiple saturation points are very similar. The difference in pressure of multiple saturation may be explained by the short run times of Delano [1], in which low-Ca pyroxene may not have had enough time to nucleate, where it is close to the limits of its stability. Spinel saturates at 40 ºC below the liquidus near the multiple saturation point, at least 10-20 °C before ilmenite.

A major difference between the phase relations presented here and those of [1] is the appearance of garnet relatively near the multiple saturation points, where Delano had ilmenite but no aluminous phase. It is most likely that the short experimental durations of Delano (1-2 hrs) were insufficient to nucleate garnet, even though it is a stable phase.

Graphite Capsule Experiments: Experiments run in graphite capsules show spinel as the liquidus phase for all pressures investigated. A much lower pressure for olivine+low-Ca pyroxene multiple saturation of 1.25 GPa is also found. It is inferred that the change in multiple saturation point is due mainly to the higher oxygen fugacity in the graphite capsules. The ΔP of ~0.75 GPa represents a shift in depth generation of approximately 140 km.

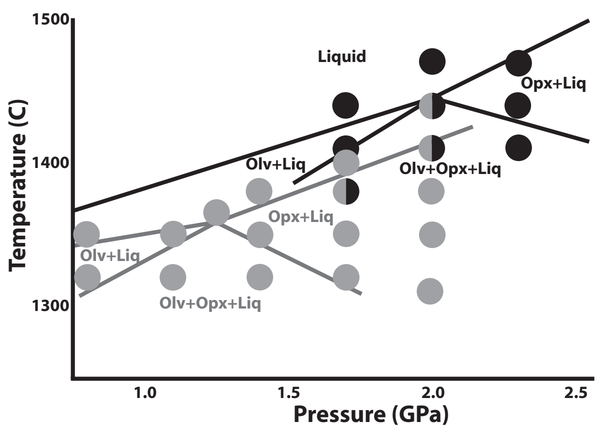

Fig 1: P-T diagram showing the location of experiments and simplified phase diagram. Black circles represent Fe-metal capsule runs, and grey represent graphite capsules. Half filled circles are conditions where both type of capsules were used.

Thus to understand the depth of origin for the 15R glass it is critical to know the f_{O2} of the lunar interior. Estimates of lunar f_{O2} values have varied between IW+0.2 to IW-2. Original estimates for the Apollo 17 orange glass yielded estimates of about IW-2 [5]. This large range in f_{O2} would correspond to ~100 km difference in the depth of origin for the HiTi ultramafic glasses (no estimates of f_{O2} are available for the 15R glass, so we make the assumption that 17O glass is representative). Recent estimates for the f_{O2} of the Apollo 17 orange glass indicate a fugacity of IW-0.6 (M. Nicholis pers. comm.). Using this as an estimate for the f_{O2} of the 15R source region and interpolating from our end member f_{O2} experiments, yields a multiple saturation point of about 1.6 GPa.

Comparison to Other HiTi Glasses: The new data on the 15R glass are in good agreement with phase equilibria of the Apollo 14 black glass (TiO_2 ~16.4 wt %) [6] and the Apollo 17 orange glass (TiO_2 ~9.1 wt %) [7]. All of the HiTi glasses appear to have similar olivine+low-Ca pyroxene multiple saturation points. This suggests that the glasses may have originated at similar depths and conditions, although different TiO_2 contents suggest different amounts of assimilation and or mixing. These results also have a bearing on the role of cumulate overturn and mantle diapirism that have been devised in part to account for the extremely deep multiple saturation depths initially reported for the red [1] and orange glasses [8]

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