THE INFLUENCE OF VARIABLE OXYGEN FUGACITY ON THE SOURCE DEPTHS FOR LUNAR HIGH-TITANIUM ULTRAMAFIC GLASSES. M. E. Guenther[1a], S. Brown Krein[1b] and T. L. Grove[1c], [1]Massachusetts Institute of Technology, Department of Earth, Atmospheric and Planetary Science, 77 Mass Ave, 02139, MA ([a]megang@mit.edu, [b]brownsm@mit.edu, [c]tlgrove@mit.edu).

Introduction: The lunar high-TiO_2 ultramafic glasses are among some of the most unusual magma compositions in the solar system [1], with TiO_2 contents ranging from 9–16.4 wt%. They erupted from high temperature explosive fire fountains and are ubiquitous in the lunar regolith samples collected at the Apollo landing sites. The ultramafic glasses are thought to represent remelting of Ti-rich cumulates that formed as a result of the chemical differentiation and solidification of a global magma ocean early in the Moon's history. Experimental studies of the lunar glass suites are needed to determine the temperatures and pressures of cumulate remelting, thereby constraining the pressure-temperature-compositional history of the lunar interior.

Previous experimental studies determined the high-pressure, high temperature near liquidus phase equilibria of the Apollo 14 Black (A14B) [2], Apollo 15 Red (A15R) [3], and the Apollo 17 Orange (A17O) [3] glasses. These suites have some of the highest TiO_2 abundances of the lunar ultramafic glasses, with 16.4, 13.8, and 9.0 wt. % TiO_2, respectively. Krawczynski and Grove [3] showed that the phase relations of lunar high- and moderate-Ti ultramafic glasses were very sensitive to the sample container used in experiments (iron vs. graphite capsules). Iron capsules fix oxygen fugacity (f_{O2}) at iron-wüstite- 2.1, (IW–2.1), and graphite capsules fix f_{O2} at IW + 2. These different f_{O2} conditions strongly influence the pressure and temperature of phase appearances. The major effect of decreasing oxygen fugacity is to stabilize olivine as the liquidus phase to higher pressures, moving the point on the liquidus cosaturated with olivine (oliv) and orthopyroxene (opx) to higher temperatures and pressures. This point, known as the multiple saturation point (MSP) is significant because it reflects the inferred depth and temperature of melt generation in the Moon.

Here we present redone and refined phase diagrams for the A14B, A15R, and A17O glasses in both iron and graphite capsules.

Experiments: We performed high-pressure (1.4–4.0 GPa), high temperature (1420–1590 °C) experiments in graphite and iron capsules using a piston cylinder [4]. The starting materials used were the same as those used in [2] and [3] for experiments on the A14B, A15R, and A17O glass compositions. The experimental procedures were similar to those described in [3,5]. Chemical analyses of the experimental run products were acquired using the JEOL JXA-8200 Superprobe, as described in [3,4].

Experimental Results: Figs. 1, 2, and 3 show the phase diagrams for the A17O, A15R, and A14B compositions in graphite and iron capsules. It is evident for all three compositions that the stability fields of olivine and pyroxene on the liquidus are expanded when f_{O2} is lower, and thus the MSPs for each glass occur at higher temperatures and pressures in iron capsules.

For the A17O glass, the oliv + opx MSP occurs at 2.5 GPa and 1530℃ in graphite capsules and a minimum of 3.3 GPa and ~1565℃ in iron capsules. The A15R MSP is at 1.3 GPa and 1350 ℃ in graphite capsules and 2.8 GPa and 1490℃ in iron capsules. Lastly, the A14B glass is multiply saturated with oliv + opx at 1.8 GPa and 1425℃ in graphite capsules and 4 GPa and 1530℃ in iron capsules.

Effects of f_{O2} and TiO_2 Content on Multiple Saturation Point: Initially, [3] proposed that the change in multiple saturation pressure between graphite and iron capsules (ΔMSP) could be most strongly influenced by melt TiO_2 content under changing f_{O2} conditions, since the valence state of titanium is dependent on f_{O2} conditions. Under the reducing conditions of the iron capsules, Ti^{4+} is likely being reduced to Ti^{3+}. This in turn affects melt speciation and makes the melt more olivine normative in iron capsules [3,5].

To further understand the role of titanium in the change in multiple saturation pressure, Brown and Grove [5] compared their experimentally determined MSPs for the intermediate Apollo 15 yellow glass in graphite and iron to the results of [3] and [6]. They found that the effect of TiO_2 content on ΔMSP was not a linear fit and instead suggested a fit dependent on both Fe and Ti content.

However, based on our new experimental results, we now suggest that melt TiO_2 content is the most important influence on ΔMSP. We find that the following linear regression has an R^2 = 0.95 with a root mean square error of 0.2 GPa:

$$\Delta MSP \text{ (GPa)} = 0.13x \text{ wt\% } TiO_2 - 0.1$$

Figure 4 summarizes the change in multiple saturation pressure as a function of TiO_2 content for these three high TiO_2 glasses and include the change in multiple saturation pressure found by [5] in the intermediate-TiO_2 Apollo 14 Yellow glass (A14Y, 4.5 wt. % TiO_2) and by Elkins-Tanton et al. [6] in the low TiO_2 Apollo 15 Green A glass (A15GA, 0.42 wt. % TiO_2).

References: [1] Delano J.W. (1980) *Lunar Planet. Sci. Conf. Proc. 11*, 251-288. [2] Wagner T. P. and Grove T. L. (1997) *GCA*, *51*, 1315–1327. [3] Krawczynski M. J. and Grove T. L. (2012) GCA, 79, 1-19 [4] Boyd J. R. and England J. L. (1960) *JGR 65*, 741-748. [5] Brown S. M. and Grove T.L. (2015) GCA, 171, 201- 215. [6] Elkins-Tanton L. T., Chatterjee N. and Grove T. L. (2003a) Meteorit. Planet. Sci. 38, 515–527.

Figure 4. Changes in the pressure of olivine + orthopyroxene multiple saturation for low, intermediate, and high - TiO_2 ultramafic glasses. The A15GA glass is estimated to have a ΔMSP = 0 GPa. All other ΔMSP are experimentally determined.

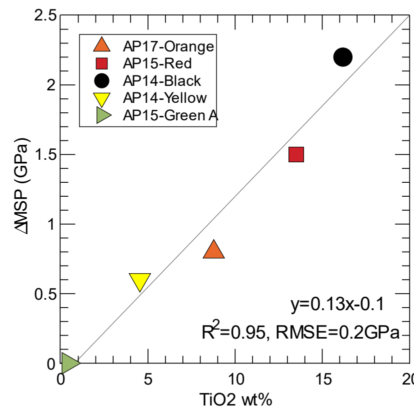

Fig 1. A17O phase relations in graphite and iron capsules. Gray boxes correspond to experiments performed by [3].

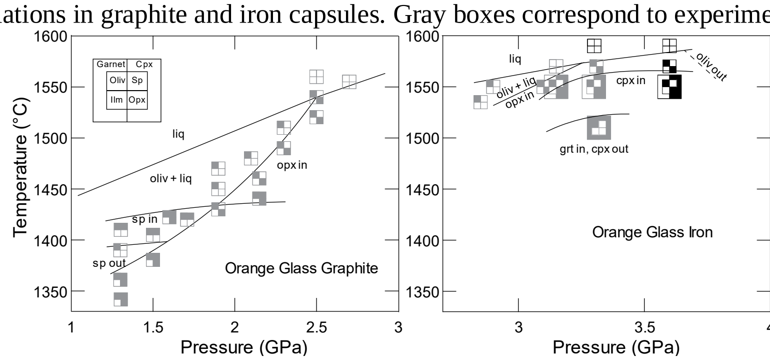

Fig 2. A15R phase relations in graphite and iron capsules. Gray boxes correspond to experiments performed by [3].

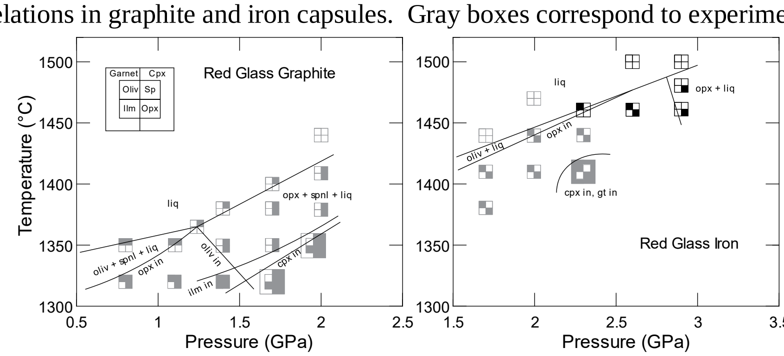

Fig 3. A14B phase relations in graphite and iron capsules. Gray boxes correspond to experiments performed by [2].