THE INFLUENCE OF VARIABLE OXYGEN FUGACITY ON THE SOURCE DEPTHS FOR LUNAR HIGH-TITANIUM ULTRAMAFIC GLASSES. M. E. Guenther\textsuperscript{a}, S. Brown Krein\textsuperscript{b} and T. L. Grove\textsuperscript{c},
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Introduction: The lunar high-TiO\textsubscript{2} ultramafic glasses are among some of the most unusual magma compositions in the solar system [1], with TiO\textsubscript{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\textsubscript{2} abundances of the lunar ultramafic glasses, with 16.4, 13.8, and 9.0 wt. % TiO\textsubscript{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 ($f_{O_2}$) at iron-wüstite- 2.1, (IW=2.1), and graphite capsules fix $f_{O_2}$ at IW + 2. These different $f_{O_2}$ 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 $f_{O_2}$ 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°C in graphite capsules and a minimum of 3.3 GPa and ~1565°C in iron capsules. The A15R MSP is at 1.3 GPa and 1350 °C in graphite capsules and 2.8 GPa and 1490°C in iron capsules. Lastly, the A14B glass is multiply saturated with oliv + opx at 1.8 GPa and 1425°C in graphite capsules and 4 GPa and 1530°C in iron capsules.

Effects of $f_{O_2}$ and TiO\textsubscript{2} Content on Multiple Saturation Point: Initially, [3] proposed that the change in multiple saturation pressure between graphite and iron capsules ($\Delta$MSP) could be most strongly influenced by melt TiO\textsubscript{2} content under changing $f_{O_2}$ conditions, since the valence state of titanium is dependent on $f_{O_2}$ conditions. Under the reducing conditions of the iron capsules, Ti\textsuperscript{4+} is likely being reduced to Ti\textsuperscript{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\textsubscript{2} content on $\Delta$MSP 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\textsubscript{2} content is the most important influence on $\Delta$MSP. We find that the following linear regression has an R\textsuperscript{2} = 0.95 with a root mean square error of 0.2 GPa:

$$\Delta\text{MSP (GPa)} = 0.13x \text{ wt\% TiO}_2 - 0.1$$

Figure 4 summarizes the change in multiple saturation pressure as a function of TiO\textsubscript{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$_2$).


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 $\Delta$MSP = 0 GPa. All other $\Delta$MSP are experimentally determined.