A Common Depth of Origin for Lunar High-Ti Glasses. M. J. Krawczynski and T. L. Grove, Department of Earth, Atmospheric, and Planetary Science; Massachusetts Institute of Technology; Building 54-1212; 77 Massachusetts Ave, 02139; (email: kraw@mit.edu, tlgrove@mit.edu)

Introduction: Pristine lunar picritic glasses and mare basalts have been used to infer information about the structure and composition of the lunar interior. Of particular interest is the depth of origin for the high-Ti (HiTi) glasses, and their relationship to the low-Ti (LoTi) ultramafic glasses that together define the compositional extremes of the ultramafic glass suite. We present new phase equilibria results on the Apollo 17 orange glass (17O), and show that the multiple saturation (with olivine+low-Ca pyroxene) of HiTi glasses are sensitive to the oxidation state of the system. This abstract focuses on the importance of fO2 of the Moon in future considerations of the composition and structure of the Moon from mare basalts.

Experimental Methods: A series of experiments are being carried out in a piston cylinder apparatus, using a starting material similar to the 17O glass composition of Delano [1]. The starting material is conditioned at one atmosphere in a gas mixing furnace while held at the IW-buffer for 24 hours. Experiments are run at high pressure and temperature contained in graphite capsules. The original experiments conducted by Green et al. [2] on a similar composition were done in Fe-metal capsules, which buffer the experiment at lower fO2 than the graphite runs.

Phase Equilibria on the Apollo 17 Orange Glass: Preliminary results from experiments suggest that there is a multiple saturation point with olivine+low-Ca pyroxene in the vicinity of 1.4 GPa (fig 1). This is significantly lower than the 2.3 GPa multiple saturation point of Green et al. [2]. However the run times for these graphite capsule experiments are much longer (8-16 hrs) than the run times of Green et al. [2] (5-60 mins). The longer duration runs allow for slower react-ing phases to reach equilibrium with the melt. Another difference is the fO2 of our experiments [3], which were carried out in graphite as opposed to Fe-metal capsules. Our results on the 17O glass are consistent with results for the Apollo 15 red glass (15R) [3] and the Apollo 14 black glass (14B) [4] in that the multiple saturation point is much shallower than that obtained in the more reducing environment imposed by using Fe-metal cap-sules.

Ilmenite does not appear to be a liquidus phase at pressures up to 1.7 GPa, which is similar to other HiTi glasses [5, 4, 3] as well as the previous studies of the orange glass itself [2].

Comparison with Other HiTi Basalts: The inverse trend of TiO2 content and increasing pressure of multiple saturation, as observed by Wagner and Grove [4] is no longer valid for the lunar ultramafic glasses, because the experiments used to constrain multiple saturation of the HiTi glasses were done at different oxygen fugacities. When experiments at the same fO2 are compared (fig 2), it is clear that the HiTi glasses all have about the same depth of origin (~1.4 +/-0.15 GPa at IW+1). Because the fO2 of the source region for the HiTi basalts is likely more reducing than that imposed by the graphite capsules, which is approximately IW+1 [3], the multiple saturation points may be slightly deeper than in fig 2, but the effect should be similar for all glasses. Thus, if we assume that the fO2 of the source regions are the same for all of the HiTi glass magmas, they originate from about the same depth in the Moon. The multiple saturation depth of the HiTi glasses is also consistently shallower than the LoTi ultramafic glasses (fig 2).

Implications for Lunar Interior Structure: The existence of a single depth of origin for the HiTi glasses is not unrealistic, and indicates that there is a depth/temperature regime that allows HiTi magmas to be sampled. In the cumulate overturn hypothesis for HiTi magma generation [9], sinking Ti-rich cumulates interact with other magma ocean cumulate residues and undergo remelting. Agee [10] found using high pressure studies of 14B glass that there is a density inversion between 0.7 and 2.0 GPa (dependent on the
Olv/Opx ratio and the Fo and En contents of the saturating minerals) where the 14B liquid becomes denser than the surrounding mantle. The common depth of origin for the HiTi basalts could be explained by the correspondence of this density inversion to a depth when the melts become positively buoyant and can therefore ascend to the lunar surface.

This correspondence of depth of origin for the HiTi glasses to the pressure at which they become less dense than their surrounding mantle is strong evidence in support of a cumulate overturn model. The implications are that the HiTi hybridized source may have been present over a range of depths in the lunar interior, but it could only be sampled as ultramafic glass eruptions when the melts were generated above a critical depth. Furthermore, at greater depths any melts that were produced would sink into the lunar interior. Thus, it is not necessary to have the HiTi melts be entrained by rising diapirs of lunar mantle, a method that has been evoked to reconcile the eruption of the HiTi glasses [11] which would be negatively buoyant using the higher multiple saturation points of Green et al. [2].

![Diagram](https://example.com/diagram.png)

**Fig 2**: Plot of TiO$_2$ wt % in the glass v. pressure of olivine – low-Ca pyroxene multiple saturation for the ultramafic glasses (done in graphite capsules). Values taken from: 17VLT [6], 15ggA [7], 14 VLT [8], 14B [4], 15R [3].

**References:**
3. Grove T.L. et al. (this meeting).  