

MIXING OF MELTS OF COMPOSITIONALLY DISTINCT SOURCE REGIONS CAN EXPLAIN THE WITHIN- AND BETWEEN-SUITE COMPOSITIONALLY VARIABILITY OF THE LUNAR ULTRAMAFIC GLASSES: EXPERIMENTS AND MODELS. S. M. Brown and T. L. Grove, ¹Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, brownsm@mit.edu, ²Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, tlgrove@mit.edu.

Introduction: Explaining the origin of the lunar volcanic ultramafic glasses has remained an outstanding problem in lunar science. The challenge is generating the observed negative correlation between CaO and TiO₂ of the most-primitive compositions in each of the 25 lunar ultramafic glass suites (compositions at which olivine fractionation is calculated, Figure 2). No models or experiments have been able to quantitatively reproduce the observed trends. The best models for the formation of lunar ultramafic glasses, so far, are: 1) melting of variably hybridized LMO cumulates (e.g., [1][2][3], and references therein), or 2) by mixing of melts of compositionally distinct source regions with simultaneous olivine fractionation (e.g., [4][5][6][7]). Mixing of melts can take many forms, such as a deeper melt mixing with a shallower melt, or two melts mixing at the same depth (see Fig. 9 from [7]) and typically includes the process of assimilation. For example, the assimilation process modeled by [8] assumes that the assimilating source is near to its solidus temperature and so is effectively the same as a deeper melt mixing with a shallower melt.

Major element within-suite compositional variations of the Apollo 14, 15 and 17 yellow glasses and the Apollo 15 green glasses are inconsistent with a (1) partial melting, or fractional crystallization, origin [5][6][7]. In the mixing of melts model (2), melts of olivine and orthopyroxene cumulates mix with either different melts of olivine and orthopyroxene cumulates and KREEP (e.g., [5]), or melts of clinopyroxene and ilmenite cumulates and KREEP [7].

Furthermore, our new analysis of the invaluable dataset from [9] indicates that the compositional variation in all high titanium (orange, red, and black) glasses is also inconsistent with a partial melting, or fractional crystallization, origin (Figure 2). Because mixing successfully explains the compositional variations of at least some of the ultramafic glasses [5][7], it could explain the variations of the other glass suites. Hence, in this study we are testing the magma mixing model (2) by iterating between quantifying the end member mixing compositions and proportions (e.g., HT* and R3* in Figure 2) needed to generate the compositional variability of all 25 glass groups, and comparing to preexisting and new experimental data on the range of potential cumulate primary melt compositions.

Experiments: The compositions of lunar magma ocean cumulate melts, hybridized or not, with or without trapped liquids, have never been fully experimentally studied. There has only been one previous intentional experimental study of melting a clinopyroxene and ilmenite lunar magma ocean cumulate [3], and only one published study of melting a hybridized cumulate [10]. Both studies concluded that their experiments could not reproduce the lunar ultramafic glasses, due to the aforementioned CaO - TiO₂ trend and difficulties matching other trends (Figure 2). However, neither study considered the full potential of mixing of cumulate melts as a potential important process in generating the ultramafic glasses, which would relax the constraints on generating specific trends of primary magmas.

With mixing of cumulate remelts in mind, we are currently conducting high pressure phase equilibrium experiments melting lunar magma ocean cumulates over a range of pressures and temperatures. A series of cumulate compositions, guided by the recent experiments by [11], that span the late stages of lunar magma ocean solidification have been selected for investigation. Here we present the first results of the experimental melting of a late-stage cumulate layer (Trapped5) composed of 78% clinopyroxene, 11% ilmenite, 5% trapped plagioclase, 1% trapped silica, and 5% trapped melt (Figure 1). At this point in magma ocean solidification, the residual magma ocean has an Mg # (molar MgO / (MgO + FeO)) = 0.10. The Trapped5 bulk composition is similar to that used by [3] but has slightly less TiO₂, less FeO, and more CaO.

Results: We have found that the concentration of titanium in our experimental melts increases with increasing pressure (Figure 2). It is worth noting that these results appear to be in conflict with the results of the ilmenite saturation study of [12]. We have also confirmed this trend in experiments by [3], which they do discuss but do not consider a primary cause of the differences between lunar ultramafic glass groups. However, in a model of mixing of cumulate remelts such a trend is very significant. For example, this pressure effect could explain the required variability in the high-titanium end member mixing component evident from the within- and between-suite compositional variability of all ultramafic glasses. Further, our initial

results suggest that higher pressures are required to explain the natural data, which provides evidence for lunar mantle overturn and could potentially constrain the extent of overturn.

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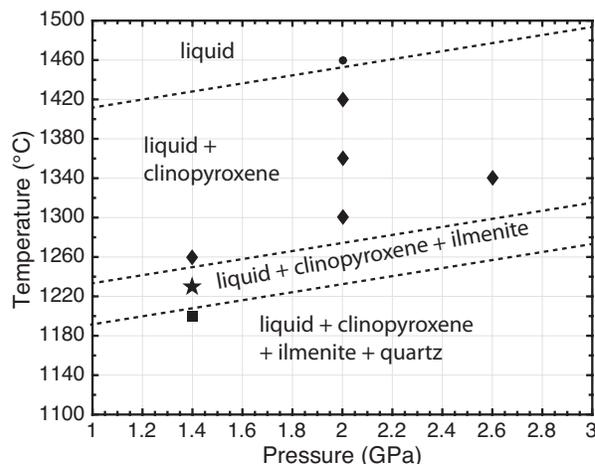


Figure 1: Phase diagram of melting experiments on the Trapped5 lunar magma ocean cumulate composition.

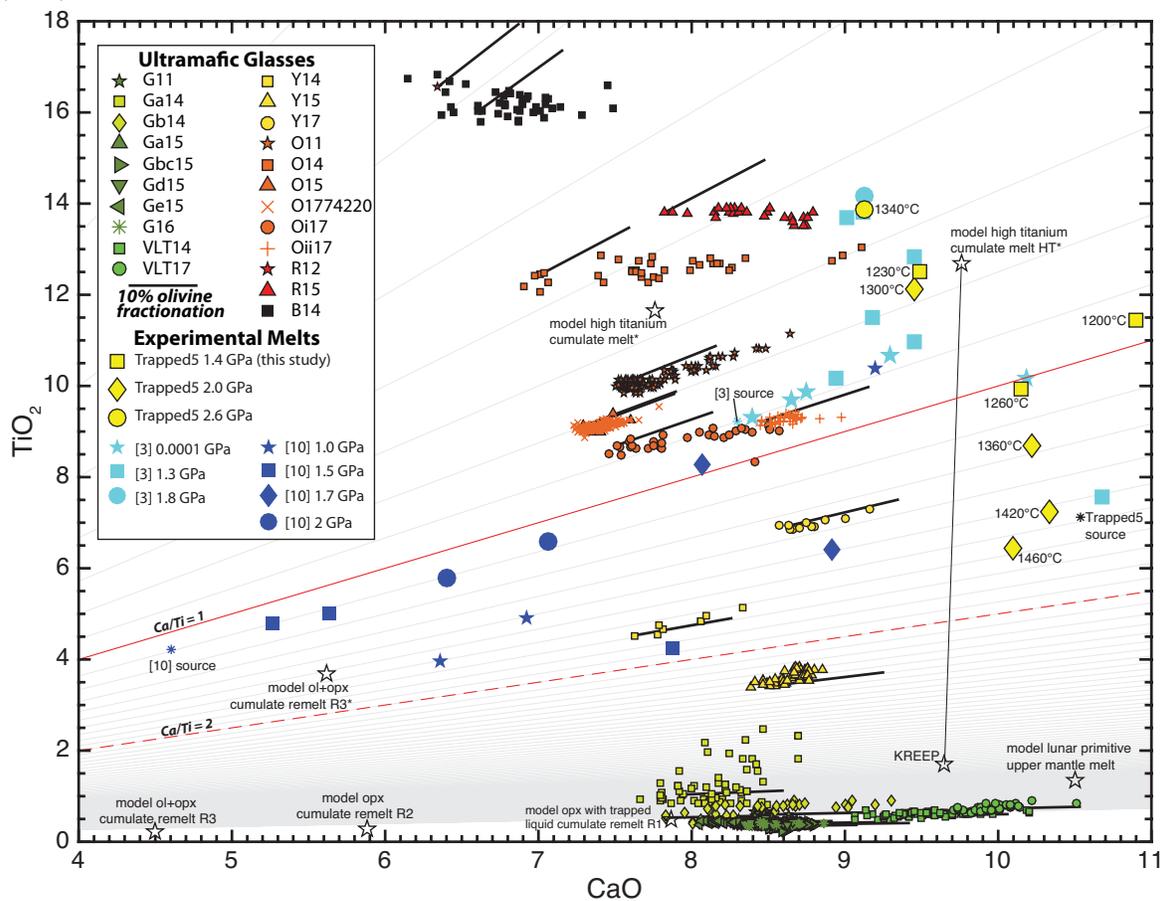


Figure 2: Compositional variability exhibited by the lunar ultramafic glasses shown with modeled and experimental cumulate remelt compositions. Glass data is from [9], modeled cumulate remelt compositions (black unfilled stars) are from [13] [14] [6] [7]. Cumulate melt titanium content increases with pressure at similar melt fractions and equilibrium mineral phases.