

New Views of Lunar Magma Oceanography. The Importance of Melt Properties on Forming Primordial Lunar Crust. Charles K. Shearer, Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico 87131.

Introduction: Models for the formation of the lunar ferroan anorthosite (FAN) crust are based on the concept that during crystallization, the lunar magma ocean (LMO) reached plagioclase saturation, the plagioclase was less dense than the Fe-rich LMO resulting in plagioclase flotation, and the plagioclase efficiently separated from its coexisting melt to produce FANs with limited interstitial liquid capable of crystallizing mafic silicates (1 to 20% mafic silicates with Mg#=70-40). Based on initial age measurements on the FANs, this primordial event was considered to have occurred fairly early (~4.5 Ga). In the late 1970s, thermal and chemical evolution of the LMO and crustal formation were explored by Solomon and Longhi in a series of manuscripts that they referred to as Magma Oceanography [1,2]. Numerous interpretive issues have been identified that potentially complicate this conceptual model for the LMO. For example, Walker and Hayes [3] illustrated that as a plagioclase saturated LMO melt changed composition the capability for plagioclase to float would also change. In addition, Elkins-Tanton et al. [4] suggested that large-scale plagioclase flotation may be nearly impossible because high crystal fractions create networks in the evolving LMO that decrease the efficiency of plagioclase separation and flotation. This not only has ramifications for plagioclase flotation, but also the removal of intercumulus melt to produce the relatively pure FANs (99% plagioclase). Another potential complication is the abundance of “H₂O” in the LMO and its influence on melt properties and plagioclase flotation. Over the last decade, the abundance of H-species in the lunar interior and its role in lunar processes has been debated. Numerous studies have identified H-components in lunar glasses and phosphates [e.g., 5] suggesting a more hydrous lunar interior and LMO. On the other hand, Sharpe et al. [6] suggested lower concentrations in the lunar mantle and that H₂ was a dominant hydrogen species. Additional studies have explored the potential role of water during the LMO event. Hui et al. [7] measured “water” in plagioclase from a FAN and concluded that the LMO may have contained ~320 ppm “water” and that during its crystallization the “water” content may have reached 1.4 wt%. At this relatively high “water” content of the LMO, [3] suggested that the field of plagioclase flotation would disappear. A follow-on study of other FANs was unable to detect an H-component in the plagioclase [8]. Elkins-Tanton and Grove [9] examined the ramifications of “water” in the LMO.

They concluded that H-species in the LMO increased during crystallization, the H-species were dominated by H₂, and that the H-species content of the lunar interior (and the LMO) was closer to the lower range suggested by [6]. More recent isotopic data suggest an important episode of FAN crystallization occurred between 4.31 to 4.36 Ga [10]. If correct, this appears to be inconsistent with a very early LMO event.

Discussion: Evolving LMO compositions have been empirically and experimentally determined assuming different bulk LMO composition and degrees of fractional and equilibrium crystallization [e.g., 11, 12]. In all of these models, the LMO will evolve from the onset of plagioclase saturation through plagioclase crystallization (along the pyroxene-plagioclase boundary). These changes in LMO composition will significantly influence the density, viscosity, and structure of the evolving LMO. The earlier studies of [3] illustrated the potential roles of melt composition and H₂O in plagioclase flotation in the LMO. Dygert et al. [13] measured the viscosity of a late-stage, plagioclase-saturated LMO melt composition. Their results indicated that this melt composition is less viscous than many other lunar basaltic compositions and given this viscosity the compaction of flotation cumulates would reduce the volume of intercumulus melt to less than 2% [14]. Using empirical relations among melt composition, “water”, viscosity, and density, we are examining the interplay among these variables during the formation of plagioclase flotation cumulates from the LMO and the cumulates ability to remove intercumulus melt through compaction. These evolving melt properties will be linked to the Mg# and proportion of mafic silicates in FANs. Direct measurements of melt properties of these LMO compositions will follow.

References: [1] Solomon & Longhi (1977) 8th LPSC Proceedings 583-599. [2] Longhi (1977) 8th LPSC Proceedings 601-621. [3] Walker & Hays (1977) *Geology*, 5(7), 425-428. [4] Elkins-Tanton et al. (2003) *MAPS* 38, 1753-1771. [5] Saal et al. (2008) *Nature* 454(7201), 192-195. [6] Sharp et al. (2010) *Science*, 329(5995), 1050-1053. [7] Hui et al. (2013) *Nature Geoscience* 6(3), 177-180. [8] Mosenfelder et al. (2017) 48th LPSC abstract # 2473. [9] Elkins-Tanton & Grove (2011) *EPSL* 307(1), 173-179. [10] Shearer et al. (2015) *Am. Mineral.* 100, 294-325. [11] Snyder et al. (1992) *GCA* 56, 3809-3823. [12] Elardo et al. (2011) *GCA* 75(11), 3024-3045. [13] Dygert et al. (2017) 48th LPSC abstract # 2421. [14] Piskorz & Stevenson (2014) 239, 238-243.