EXPERIMENTAL SIMULATIONS OF LUNAR MAGMA OCEAN CRYSTALLIZATION: THE PLOT (BUT NOT THE CRUST) THICKENS. D. S. Draper[1], J. F. Rapp[1,2], S. M. Elardo[3], C. K. Shearer, Jr.[4], and C. R. Neal[5], [1]Astromaterials Res. and Expl. Sci. Div. and [2]Jacobs Technology – JETS, NASA JSC, 2101 NASA Pkwy, Houston TX 77058 (david.draper@nasa.gov), [3]Geophysical Lab., Carnegie Inst. of Wash., [4]Inst. of Meteoritics & Dept. Earth & Planetary Sci., Univ. of New Mexico, [5]Dept. Civil & Env. Eng. & Earth Sci., Univ. Notre Dame.

Introduction: Numerical models of differentiation of a global-scale lunar magma ocean (LMO) [1-3] have raised as many questions as they have answered. Recent orbital missions and sample studies have provided new context for a large range of lithologies, from the comparatively magnesian "purest anorthosite" reported by [4] to Si-rich domes [5] and spinel-rich clasts [6, 7] with widespread areal distributions. In addition, the GRAIL mission provided strong constraints on lunar crustal density and average thickness [8]. Can this increasingly complex geology be accounted for via the formation and evolution of the LMO? We have in recent years been conducting extensive sets of petrologic experiments designed to fully simulate LMO crystallization [9-13], which had not been attempted previously. Here we review the key results from these experiments, which show that LMO differentiation is more complex than initial models suggested. Several important features expected from LMO crystallization models have yet to be reproduced experimentally; combined modelling and experimental work by our group is ongoing.

Experimental Approach: We have simulated both equilibrium [9] and fractional crystallization [10-13] of two proposed LMO compositions, Taylor Whole Moon [TWM; 14] and Lunar Primitive Upper Mantle [LPUM; 15], under nominally anhydrous conditions. Relative to bulk Earth, these compositions have, respectively, either a ~50% refractory-element enrichment or no such enrichment. Equilibrium crystallization is duplicated by taking each bulk composition directly to successively shallower conditions, whereas fractional crystallization is simulated by iteratively synthesizing new starting materials with the composition of the prior run's liquid phase, mimicking removal of crystals.

Results and Inferences: Fig. 1 compares model results to those from our fractional experiments. Equilibrium runs (not shown) extending to 50% solidified produced ol + opx-dominated cumulate piles. Fractional runs produced greater volumes of monomineralic olivine and smaller volumes of orthopyroxene. Cr-spinel in TWM suppresses the onset of plagioclase, paradoxically producing *more* plag in the less aluminous LPUM and hence a thicker anorthositic crust of ~60km. Both produce thicker crust than the 34-43 km implied by GRAIL results. Sequestration of Al in pyroxene, aluminous phases, and/or in interstitial trapped liquid [2], could result in less plagioclase, resulting in crustal thickness closer to that implied by the GRAIL results.

The Path Forward: Our work indicates that LMO solidification is more complicated than anticipated. Reconciling these complexities may require some combination of a) better understanding of the role of trapped liquid; b) a hybrid process of equilibrium followed by fractional crystallization [1]; or c) that the LMO is shallower than "whole Moon," although the latter may lead to even more plag crystallization, hence even thicker crust, owing to its enhanced stability at low pressures.

References: [1] Snyder G. et al. (1992) *GCA* 56, 3809. [2] Elkins-Tanton L. et al. (2011) *EPSL* 304, 326. [3] Davenport J. et al. (2014) *LPSC* 45, #1111. [4] Ohtake M. et al. (2012) *Nat Geo.* 5, 384. [5] Joliff B. et al. (2011) *Nat. Geo.* 4, 566. [6] Gross J. et al. (2014) *Am. Min.* 99, 1849. [7] Prissell T. et al. (2014) *EPSL* 403, 144. [8] Wieczorek M. et al. (2013) Science 339, 671. [9] Elardo, S. et al. (2011), *GCA* 75, 3024. [10] Rapp J. & Draper D. (2012) *LPSC* 43, #2048. [11] Rapp J. & Draper D. (2013) *LPSC* 44, #2732. [12] Rapp J. & Draper D. (2014) *LPSC* 45, #1527. [13] Rapp J. & Draper D. (2016) *LPSC* 47, #2691. [14] Taylor, S. R. (1982) *Planetary Science, a Lunar Perspective*. [15] Longhi, J. (2006) *GCA* 70, 5919.

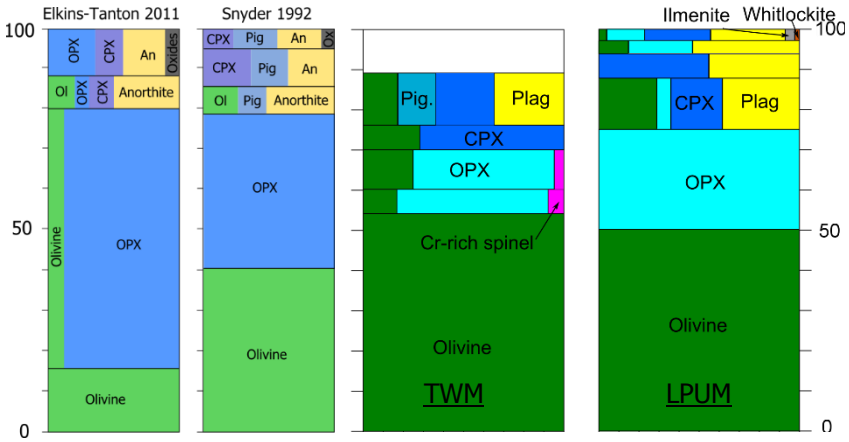

Fig. 1. Comparison of LMO cumulate lithologies from numerical models [1, 2] (left two columns) and from fractional crystallization of TWM and LPUM LMO bulk compositions (our work; white area = work ongoing). Width of mineral fields = modal abundance. Note significant mismatches between modelled and experimentally-derived LMO cumulate piles. Plagioclase in LPUM corresponds to ~60 km thick lunar crust. See text for discussion.