CUMULATE MANTLE DYNAMIC RESPONSE TO MAGMA OCEAN COOLING RATE. C.- E. Boukaré[1], E.M. Parmentier[1], S.W. Parman[1], [1]Department of Earth, Environmental and Planetary Sciences, Brown University, 02912 Providence, RI (charles-edouard_boukare@brown.edu).

Summary: Magma ocean (MO) fractional crystallization has been proposed to generate gravitationally unstable Fe-Mg chemical stratification capable of driving solid-state mantle overturn [1]. Fractional solidification and overturn hypothesis, while only an ideal limiting case, can explain important geochemical features of both the Moon and Mars. Recent models of MO cumulate dynamics have shown that cumulate overturn can occur during MO solidification if the cumulate viscosity is low enough or the time of solidification is long enough [e.g., 2,3]. Nevertheless, these models do not consider (1) the effect of retained melt on cumulate viscosity and (2) substantial variation in the rate of solidification during MO solidification. Here, we investigate the issue of the cumulate compaction during MO solidification. We show that the cooling rate of the magma ocean affects the amount and distribution of retained melt in the cumulate layers. The retained melt controls the viscosity of the cumulates and the effective chemical partitioning between the residual magma ocean and the cumulate.

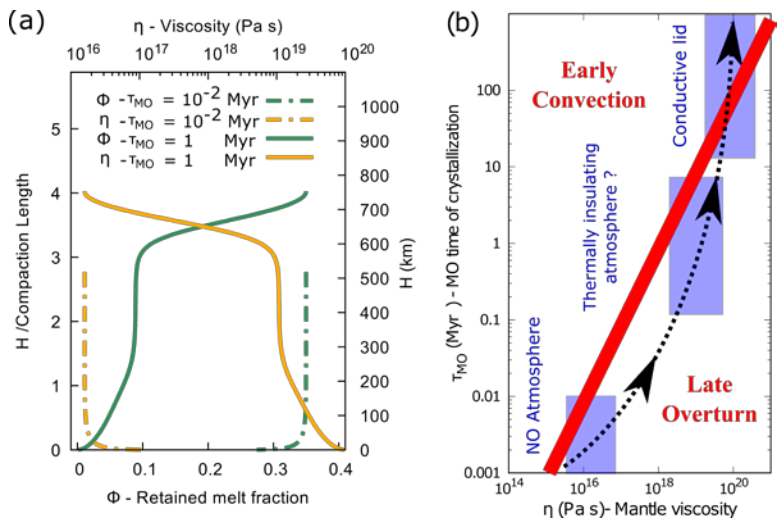

Figure 1 : Cumulate compaction during MO solidification (scaled to the lunar magma ocean). The cumulate viscosity, η, evolves as its retained melt fraction is expected to respond to changes in the MO time of solidification, τ_{MO}. This would affect the timing of cumulate overturn that is governed by η and τ_{MO} [3]. **(a)** Retained melt fraction profile (green) and corresponding cumulate viscosity (orange) assuming $\eta(\phi) = \eta_{ref}\,\mathrm{Exp}(-25\phi)$ [5]. For τ_{MO} =10^{-2} Myr, the cumulate does not have time to compact. Melt fraction remains at the RCMF, 35 %. For τ_{MO} = 1 Myr, the melt fraction profile tends to a steady-state that depends on the rate of crystal deposition [4] that is here reduced to $v_{sed} = H/\tau_{MO}$. **(b)** In the η- τ_{MO} space, the regimes of late overturn and early convection are delimited by the solid red line. For the Moon, this study suggests that the increase of cumulate viscosity might prevent early convection in the cumulate. Compaction of the cumulate that expels melt back into the MO would have interesting implications on the petrological evolution of the MO.

Model: We consider an ideal case where a liquid layer lies above a viscous cumulates that contains interstitial melt. As solidification proceeds, layers of small but finite thickness are deposited at the top of the cumulate pile at a rheological critical melt fraction (RCMF) of ~ 35-40%. of melt. As the melt is buoyant in the cumulate, it tends to rise upwards towards the residual magma ocean by percolation limited by cumulate compaction. We solve the compaction problem in 1D in the cumulate layers in a similar approach as the one proposed by [4]. The main parameters that govern the dynamics are: the compaction length δ, the segregation flux of reference S_{ref} and the crystal sedimentation velocity, v_{sed}. If v_{sed} exceeds a critical value [6], (v_c ~ S_{ref}), the cumulates layers cannot compact during crystal deposition. If v_{sed} remains below this critical value, the cumulate layers compact. In this case, lower v_{sed} results in lower retained melt fraction. Here, v_{sed} is assumed to reflect perfectly the time of MO solidification : $v_{sed} = H/\tau_{MO}$. We investigate three timescales of MO solidification that approximate MO cooling by pure black-body radiation (τ_{MO} =10^{-2} Myr), thermal radiation inhibited by an opaque atmosphere (τ_{MO} = 1 Myr) or MO cooling through a conductive lid (τ_{MO} = 100 Myr). For the Moon, these preliminary results suggest that the cumulate should not overturn during the early stages of MO solidification when solidification is fast ($\tau_{MO} < 10^{-2}$ Myr). Even though the cumulate viscosity is relatively low (about 10^{16} Pa s). Asumming that a decrease in the MO cooling rate implies a decrease of v_{sed}, the cumulate would compact and expel melt as the MO cooling rate drops due to the formation of the plagioclase-rich conductive lid.

References: [1] Hess and Parmentier (1995) *EPSL 134*, 510-514. [2] Maurice *et al.*, (2017), *JGR Planets 122*, 577-598 [3] Boukaré *et al.*, (2018), EPSL, in revision. [4] Shirley (1986) J. Geol. 94, 795-809. [5] Hirth *et al.*, (1995) *JGR Solid Earth 100*, 15441 – 15449.