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Duration and Extent of Lunar Volcanism: Comparison of 3D Convenction Models to Mare Basalt Ages

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It is widely accepted that lunar volcanism started before the emplacement of the mare fills ($\approx$3.1 – 3.9 Ga b.p.) and lasted for probably more than 3.0 Ga. While the early volcanic activity is relatively easy to understand from a thermal point of view, the late stages of volcanism are harder to explain, because a relatively small body like the Earth's Moon is expected to cool rapidly and any molten layer in the interior should solidify rather quickly. We present several thermal evolution models, in which we varied the boundary conditions at the model surface in order to evaluate the influence on the extent and lifetime of a molten layer in the lunar interior. There are several factors that control the thermal evolution of a planetary body, including the amount and distribution of radiogenic elements, crustal thickness, and the amount of kinetic energy introduced by meteorite impacts. In addition, because a porous megaregolith layer on the surface is ineffective in transporting heat from the interior to space, it leads to an insulation of the interior. Consequently, once this thermal lid is in place, it slows down the cooling rate significantly. In this paper we studied whether a thick megaregolith layer is sufficient enough to preserve the interior melt zone for long enough periods of time to serve as source regions for the young lava flows in Oceanus Procellarum. To investigate the influence of such an insulating layer we used a fully three-dimensional spherical shell convection code for the modelling of the lunar thermal history, where the viscosity depends on the azimuthally averaged temperature. We compare models with an inhomogeneous distribution of radioactive isotopes and a reduced thermal conductivity of the crust to a homogeneous reference model. In all our models, a partial melt zone formed nearly immediately after the simulation started (early in lunar

history), consistent with the identification of lunar cryptomare and early mare basalt volcanism on the Moon. With time, the initially global melt layer became increasingly disrupted by cold downwellings from the growing lithosphere. While the layer of partially molten material was global in the beginning, it became more local with ongoing time. Due to the characteristic thickening of the Moon's lithosphere the melt zone solidified from above. This suggests that the source regions of volcanic rock material proceeded to increasing depth with time. The rapid growth of a massive lithosphere kept the Moon's interior warm and prevented the melt zone from fast freezing. The lifetimes of the melt zones derived from our models are consistent with basalt ages obtained from crater chronology. We conclude that an insulating megaregolith layer is sufficient to prevent the interior from fast cooling, allowing for the thermal regime necessary for the production and eruption of young lava flows in Oceanus Procellarum.