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Thermal evolution models of the Moon

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We present technical aspects and results of numerical convection models of the Moon, aiming to explain the longevity of lunar volcanism and the evolving depth of the partial melt zone.

Volcanism started early during the lunar evolution and has lasted probably for more than 3 Ga. The variation of titanium content in volcanic rocks suggests that the source region moved to greater depth over time. A high attenuation zone –a candidate for a partial melt zone- has been observed near the core-mantle boundary of the Moon.

The thermal conductivity of the Moon's crust is significantly reduced in comparison to the conductivity of the mantle due to its composition and porosity. Earlier thermal evolution models of the Moon have usually neglected the influence of the crustal thermal conductivity and simply used an average value of 4 W/mK for both the mantle and the crust. That resulted in fast cooling of the Moon and made it hard to explain the longevity of lunar volcanism. Parameterized convection models have shown that the cooling history differs significantly if the lower conductivity of the crust is taken into account. Higher interior temperatures for the Moon can be expected. A partial melt zone can be present in the mantle during most of the Moon's evolution, even at the present time.

We use a 3D spherical convection code to study the effects of reduced thermal conductivity near the surface, internal heating, viscosity level, partial melting and melt extraction on the thermal evolution of the Moon. Viscosity depends on the laterally averaged temperature and controls the thickness of the stagnant lid. Initial temperatures are in the partial melting range, and the melt zone survives longest just beneath the stagnant lid in all models. The melt layer is disrupted by cold downwellings that originate at the base of the stagnant lid.

Models with a low viscosity level show no significant thickening of the stagnant lid over 4.4 Ga of evolution. The partial melt zone mainly solidifies from the bottom. Melt extraction seems to be more important for the cooling of the mantle than thermal conduction through the stagnant lid. An insulating regolith layer might still be necessary to explain the survival of partial melt until today. In the model with the most cooling (constant conductivity, melt extraction), the partial melt zone does not survive until the present day. Less internal heating also decreases the longevity of the melt zone. However, the ability of melt to penetrate a stagnant lid is a major unknown.

If we assume a higher viscosity level, the stagnant lid thickens faster. This changes the evolution of the melt zone significantly and brings it better in line with the observational constraints. The top of the melt zone moves to greater depths and its bottom rises much slower during the model run.