The Moon is one of the smaller terrestrial planetary bodies. However, heat transport by mantle convection must have played an important part during its early history. We present a thermal evolution model of the Moon that simulates axisymmetric mantle convection. The model assumes newtonian rheology determining the radial viscosity profile depending on the average radial temperature profile. Convection is heated internally by radioactive isotopes. The present day global average U abundance is assumed to be 30 ppb. The model considers a crust with a thickness of 60 km which is enriched in radioactive isotopes with respect to the mantle. The crustal U concentration is assumed to be 240 ppb. In addition to internal heating, a metallic core with a radius of 450 km containing 8 wt% sulfur is assumed whose initial temperature exceeds lower mantle temperatures by about 100 K. The existence of a similar core formed at high temperatures has been inferred from geochemical considerations [1].

The initial thermal state of the model implies that the differentiation into core and mantle as well as the formation of the crust following the crystallization of the early magma ocean have been completed. Therefore, the starting point of the model is chosen at 0.2 Gyr after formation of the Moon. The initial temperature profile comprises a cold thermal boundary layer close to the surface, a zone in the upper mantle corresponding to a solidified magma ocean where the average radial temperature profile is close to the solidus, an adiabatic profile in the lower mantle, and a hot thermal boundary layer at the core mantle boundary.

The cooling of the Moon results in the thickening of the lithosphere. Depending on the thickness of the initial magma ocean and the mantle abundance of radioactive isotopes the thickness of the thermal lithosphere increases to about 670 km at present while the elastic lithosphere thickness grows to about 380 km. Mantle convection dominates the heat transport in the lower mantle up to the present day and causes lower mantle temperatures to remain nearly constant in the range of about 1700 K to 1750 K. The initial hot thermal boundary layer causes upwelling mantle plumes early in lunar history. These plumes cause pressure release melting in the upper mantle at depths between about 250 km and 700 km, roughly corresponding to the source regions of mare lava. The duration of partial melting in the mantle depends strongly on the early lower mantle temperatures and the thickness of the primordial magma ocean. A further contributing factor is the internal radiogenic heating rate of the mantle. A magmatic activity period of at least 2 Gyr inferred from dating of surface mare units [2] requires early mantle temperatures close to the solidus throughout the whole mantle even if a present day Th concentration of 30 ppb in the mantle and corresponding U and K abundances are assumed to contribute to internal heating.

The remanent magnetization of lunar samples can be interpreted as evidence for a dynamo mechanism operating in an at least partially liquid metallic core [3]. Taking into account the ages of magnetized samples the dynamo was active only prior to 3 Gyr ago [4]. In our model the core cools during the first Gyr of lunar history until it has reached thermal equilibrium with the lower mantle. This heat loss causes thermal convection within the liquid core which in turn is able to drive a dynamo. After the early core cooling stage is terminated core temperatures are controlled by the thermal state of the lower mantle. Due to the thermostat effect of mantle convection lower mantle temperatures do not decrease significantly thereby causing core temperatures to remain in the range of about 1700 K to 1750 K. Thus, a core containing 8 wt% sulfur might remain entirely liquid during the 4.6 Gyr of lunar evolution. As no solid inner core is being formed and consequently neither the release of latent heat nor chemical convection are available as energy sources for the generation of a magnetic field the dynamo is shut off as soon as the early core cooling phase is finished.

References: