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The South-Pole Aitken basin formation and its effects on the melting activity in the lunar mantle

Sebastiano Padovan (1), Doris Breuer (1), Lukas Manske (2), Elena Martellato (2), Ana-Catalina Plesa (1), Thomas Ruedas (1,2), Sabrina Schwinger (1), and Nicola Tosi (1,3)
(1) Institute of Planetary Research, German Aerospace Center (DLR), Berlin, Germany, (2) Museum für Naturkunde, Berlin, Germany (3) Technische Universität, Berlin, Germany (sebastiano.padovan@dlr.de)

Abstract

Several large lunar impact basins have basaltic infillings, indicating a possible causal link between impacts and subsequent volcanic eruptions [1]. However, the majority of lunar basalts are located in the nearside, in a region known as the Procellarum-KREEP terrane (PKT), an observation explained by invoking the presence of a layer enriched in heat producing elements below or within the crust in the PKT region [2]. Furthermore, the South-Pole Aitken basin (SPA), the largest lunar basin, lacks any significant basaltic infilling. We perform thermal evolution simulations of the Moon that include the effects of the formation of the SPA, and show that any volcanic activity following the formation of a large impact basin depends on the interaction of the impact-induced thermal perturbation with the underlying mantle convection.

1. Introduction

Many large impact basins on the nearside of the Moon are filled with volcanic material that has been emplaced after (in a geological sense) the basins' formation. Thus, these volcanic infillings are not solidified impact melt. This observation led to the hypothesis that large impacts may induce long-term volcanism (e.g., [1]). The causal link between impacts and volcanic activity has been criticised on the basis of numerical models and statistical arguments [3]. However, a recent investigation of the effects of large impacts on the volcanic activity in the mantle of Mercury showed that it is possible to reproduce the observed properties (volume and time of emplacement) of the volcanic infillings of young large basins on the surface of the planet by an impact-induced modification of the melting activity in the mantle [4]. We apply the model developed in [4] to investigate how the formation of large impacts on the Moon may induce and/or modify volcanic activity in the lunar mantle.

2. Methods

2.1. Mantle convection: GAIA

We simulate the thermal evolution of the Moon using the GAIA convection code [5]. We adopt a setup where heat producing elements (HPE) are distributed homogeneously in the mantle and are enriched in the crust (enrichment factor $\Lambda \simeq 15$) and in the KREEP layer ($\Lambda \simeq 350$), a $\sim$ 10-km-thick layer placed under or within the crust in a 40 to 80 degree-wide spherical cap corresponding to the location of the PKT. We track melt production as a function of time and location in order to compare the results with the inferred volume and emplacement history of lunar volcanic units (e.g., [6, 7]). The thermal perturbations caused by large impacts are simulated with iSALE.

2.2. Basin formation: iSALE

Impact simulations are performed with the iSALE shock physics code (e.g., [8]). We assume a 40 km basaltic crust overlying a dunite mantle and an iron core. We use the ANEOS equation of state to describe the thermodynamic behaviour of materials. The mechanical response of the basaltic crust and the dunite mantle under deformation is described by a pressure- and damage-dependent strength model [9], while for the iron core we use the von Mises strength model, more suitable for ductile materials. We also include the Acoustic Fluidization model (e.g., [10]), a transient weakening mechanism required to explain fluid-like behaviour of matter during crater collapse.

3. Results

The adopted distribution of the HPE induces melting activity in the nearside lasting more than a billion years. The stagnant lid, the cold upper layer of the mantle that does not participate in convective motions,

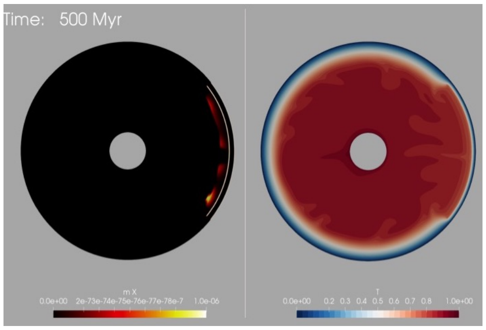

Figure 1: Melting (left) and temperature (right) fields at $t = 500$ Myr in a simulation of the lunar thermal evolution without impacts. The KREEP layer is identified with the thin white line on the right side of the melting field. Color units are dimensionless.

is thinner where the KREEP layer is located. Correspondingly, hot convecting material can reach temperatures locally in excess of the solidus and generate melt (Figure 1). This configuration is consistent with the observation that volcanic provinces are observed mostly on the nearside of the Moon [2].

The 2500-km-wide South-Pole Aitken basin is the largest basin on the Moon. It is located on the farside and shows almost no sign of volcanic activity following its formation, unlike basins on the nearside like Imbrium. We simulated an impact forming an SPA-sized basin and tracked convection and melting activity under the newly formed basin. When the impact occurs away from the KREEP layer the impact-induced thermal perturbation locally thins the stagnant lid, but without producing any post-impact long-term melting activity. This result is a direct consequence of the location of the enriched KREEP layer in our model, which focuses most of the mantle melting activity on the near side.

4. Summary and Conclusions

We investigated the thermal evolution of the Moon in the presence of a layer enriched in heat producing elements (KREEP layer) located under the crust on the nearside. The resulting melting activity is localised on the nearside, consistent with the presence there of the most extensive volcanic units, as already noted in [2]. The formation of an SPA-sized basin does not induce any long-term melting activity in the mantle, as long as it occurs far from the KREEP layer. These results are consistent with the lack of large volcanic units in the SPA basin and support the interpretation of volcanic infillings of large basins as the result of an interaction of the impact-induced thermal anomaly with the convective activity in the mantle [4].

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