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Formation of impact basins on the moon - insights from numerical modeling, gravity and remote sensing data

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Abstract

The surface of the Moon was shaped by large-scale impact basins. The formation of impact basins is influenced by target properties and most obviously by the size, composition (mass), and velocity of the impactor. Beside the surface expression (crater morphology) as the most obvious outcome of an impact event also the gravity field, local petrography and thermal structure have been influenced by these events ([2], [10]). Satellite gravity data from GRAIL-mission and topography datasets from LOLA-instruments provide further insights and additional constraints on the formation mechanism, crater morphology, crustal structure and ejecta thickness. Previous numerical modeling studies use different kinetic energies - based on impactor diameter, velocity, and/or mass - to match either gravity or ejecta thickness data. In this study, we aim at the development of a new numerical model that satisfies both observational constraints, including the ejecta distribution and subsurface structure based on the gravity data. In addition, we will quantify the deposition of ejecta and the production and distribution of impact melt. The resulting, improved model for Orientale will be the basis for studying all basins on the Moon.

1. Introduction

In previous studies lunar impact basins have been investigated (e.g. [2], [5], [6], [9]) to obtain a better understanding of the formation and subsequent evolution as a function of varying target conditions. Satellite data sets can be used for different approaches to get insights into the Moons interior: Gravity data from GRAIL were used for developing a crustal thickness model [7] and high-resolution topography data from LOLA leads to investigate the impact ejecta thicknesses on the Moons surface [9]. In this study, we use the Orientale basin as the benchmark for further systematic numerical modeling studies of all impact basins on the Moon. A formation model of Orientale has been developed taking the ejecta distribution into account [9]. The simulation predicts an impactor of 100 km in diameter and a velocity of 12 km/s. Alternatively, the study of Johnson et. al [3] focuses on the subsurface structure, especially in the area of the ring of Orientale. In this model, the kinetic energy is only half of the impact energy according to the model of Zhu et. al [9] and corresponds to an impactor diameter of 74 km. A lower kinetic energy results in a smaller transient crater and, thus, a smaller amount of ejected material, which results in a thinner ejecta blanket in the vicinity of Orientale.

2. Method

We use the iSALE2D shock physics code ([1], [8]) to simulate the formation of large basins. We consider Orientale Basin as a test case, using parameters from previous simulations ([6], [9]). The crust consists of gabbroic anorthosite, mantle and projectile of dunite. As Orientale is located at the boundary of the lunar highlands, we considered a 40 km and 60 km thick relatively cold crust [9]. As observational constraints we use topographic data from LOLA and Bouguer gravity from GRAIL. Furthermore, a crustal thickness model [7] is used in our model.

3. Results

In a first step we have modeled the formation of the Orientale basin consistent with observational constraints such as the present day morphometry, the gravity field, and the thickness of the ejecta deposits as a function of distance from the crater center. Our model confirms that a 100 km diameter body impacting the lunar surface at 12 km/s formed the Orientale basin [9]. The alternative model [3] with a 74 km diameter impactor has a significantly smaller transient crater and the ejecta thickness distribution does not match the observed decrease along with the distance.

Fig.1 shows a cross section through the 100 km-diameter-impactor model running from the crater center up to a radial distance of 600 km. Fig. 1(a) presents the Bouguer gravity profiles from the model (g_{model}) and the measurements from GRAIL (g_{GRAIL}). From Fig. 1(a), we find that the Bouguer gravity reaches its maximum in the center of the crater caused by mantle material that was uplifted close to the surface during the basin forming process. Low mantle densities in the craters center correspond to high temperatures in the upwelling mantle (Fig. 1(b)-(c)). The low-density crustal layer can explain lower Bouguer anomalies at distances > 350 km. The general trend of calculated Bouguer anomalies follows the shape of the GRAIL measurements. The red and green lines in Fig. 1(b)-(c) show observed topography data and the crustal thickness model based on GRAIL data. The crustal thickness model agrees with our model for distances > 350 km, where relatively little deformation occurs during the impact. However, in the central part our model significantly deviates from the crustal thickness model [7].

4. Figures

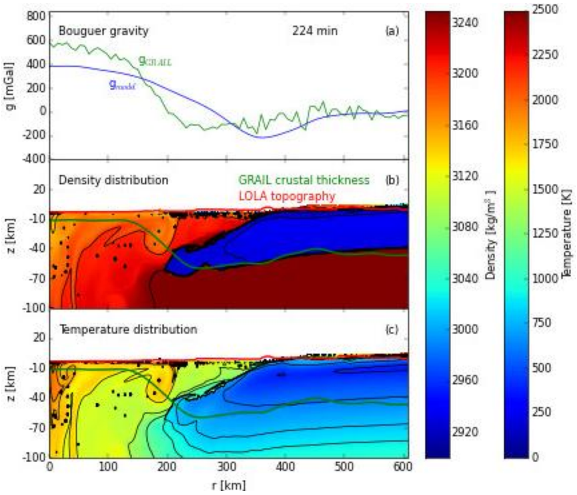

Figure 1: Profile through the Mare Orientale. (a): Bouguer gravity anomalies (b): Density distribution and (c): Temperature distribution in the target material. r: Distance from the crater center.

5. Conclusion

We consider the amount of ejecta as the best measure of transient crater size and, thus, impact energy, which rules out the low-impact-energy model. Better agreement with the gravity data for the higher-impact-energy model may be achieved by adjusting other target properties. By a extensive suite of models we will test the effect of a range of target parameters to minimize the discrepancy between model and observation constraints. In addition we will determine the thermodynamic conditions in the target material and quantify the emplacement of ejecta.

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