LUNAR BASIN FORMATION – CONSTRAINING NUMERICAL MODELS WITH GRAVITY DATA. T. Lompa[1,2], D. Wahl[3], J. Oberst[3,4] and K. Wünnemann[1,2], [1]Museum für Naturkunde Berlin, Invalidenstr. 43, 10115 Berlin, Germany, tomke.lompa@mfn.berlin, [2]Freie Universität Berlin - Institute of Geological Sciences, Malteserstr. 74-100, 12249 Berlin, Germany. [3]Technische Universität Berlin, Institute of Geodesy and Geoinformation Science, Straße des 17. Juni 135, 10623 Berlin, Germany, daniel.wahl@tu-berlin.de, [4]German Aerospace Center, Institute of Planetary Research, Rutherfordstr. 2, 12489 Berlin, Germany.

Introduction: Large impact basins on the Moon are thought to be remnants of the late accretion phase. To better understand how basin size and the corresponding gravity signature are related to the impactor size, we investigate how thermal properties of the target affect the basin formation process. Previous studies (e.g. [1], [2], [3], [4]) revealed that the temperature dependent rheology of crust and mantle rocks significantly affects the crater formation process and the resulting size and gravity signature of a basin. Here we present a more systematic and quantitative analysis of the relationship between the target temperature, which is related to the age of a basin, and the resulting basin morphometry and the gravity signal.

We use gravity data from the GRAIL mission (e.g. [5], [6]) as constraints for a suite of numerical models of basin formation where we varied the impactor size and the target temperature as a function of depth.

In turn, our models allow for drawing preliminary conclusions from the observed gravity data to the thermal pre-impact target conditions. These findings lead to a much better understanding on how the thermal evolution of the Moon is related to changes in the formation of basins and how gravity data can be used to analyze basin morphometry.

Methods: *Modeling of basin formation.* We carried out a systematic numerical modeling study of basin formation using iSALE2D shock physics code and the ANEOS ([7], [8], [9], [10]).

The target is composed of a 40 km basaltic crust on top of a dunitic mantle. We varied the diameter of the dunitic impactor between 20 km and 100 km. All models are resolved by 25 CPPR (cells per projectile radius). We consider vertical impacts only and set the speed of the impactor in all models to 13 km/s, which corresponds to the vertical component of a 45° impact assuming an average impact velocity on the Moon of 19 km/s.

We use temperature profiles from thermal evolution models [11], which allow for linking our models with basin ages [12], and solidus/liquidus temperatures as a function of pressure (depth) [11]. As case studies we chose the basins Orientale (not shown here) (ca. 3.8 Ga [12]), Hertzsprung (ca. 4.0 Ga [12]), and Korolev (not shown here) (ca. 4.1 Ga [12]). As a reference for the warmest Moon we also ran simulations for ages of 4.4 Ga. In total we conducted 36 numerical models of basin formation (4 thermal profiles x 9 impactor diameters = 36 models).

Observed Bouguer anomalies. By combining the most recent GRAIL gravity model GL1500E [6] (corresponding to a spatial resolution of about 3.6 km) with LOLA derived topography [13], and individually set bulk densities for different regions of the upper highland crust [14], we obtained a highly resolved Bouguer gravity field.

Modeled Bouguer anomalies. We use two approaches to calculate Bouguer anomalies from the basin formation models by considering (1) the actual density distribution from the model, or (2) constant densities in both crust and mantle. The latter may be understood as a simple approach to mimic the density matter after long-term cooling. The shape of the Bouguer signal can be used to detect the crust-mantle boundary. Using constant densities in crust and mantle is useful to verify the geometry of the model.

Results: *The effect of varying thermal conditions.* We determined the diameter of the central uplift (DCU) for all 36 models depending on the temperature profiles and plotted them against the impactor diameters (Fig. 1). The results show that for impactors smaller than 50 km DCU values for a fixed impactor size but different thermal profiles are very similar. For impactors larger than 50 km the DCU values increase for “hotter” profiles at constant impactor size.

Case study: Combination of numerical simulations and gravity data. For the model of the formation of Hertzsprung basin (Fig. 2) we used the thermal profile [11] corresponding to the age of 4.0 Ga [12]. Figure 2 shows the results of our best-fit model assuming an impactor size of 50 km.

Depending on the two different approaches to derive the Bouguer Anomaly from our models (see Methods-section above) we obtain very different gravity signatures. Using the actual density distribution from our model (method 1), which reflects the state right after the basin was formed results in a gravity profile (red curve) that is significantly below the observed data (green). This is because mantle rocks have been significantly heated or molten and due to thermal expansion have relatively low densities in comparison to their initial densities. Assuming the pre-impact (cold) densities results in a much higher amplitude of the gravity signature (blue), which is more similar to the observed curve (green).

The shift between the observed and calculated gravity can be eliminated by adjusting Bouguer correction densities, initial crustal, and mantle densities. Note, that we do not account for long-term isostatic adjustments and approximate only the effect of cooling here. The two gravity profiles from formation models (red, blue) show that the position of the minimum (x=180 km (Fig. 2)) and the overall trend of the signal between minimum and the outside of the basin are comparable to the measured gravity. The positions of the minima roughly correlate with the position of the thickest part of the crust. Thus, for a DCU of about 500-600 km, models with impactor diameters in range of 70-90 km approximate the observed basin morphology (Fig. 1).

Conclusion: Our results generally agree with previous studies [4] in terms of the importance of the thermal state of the target material. Final crater morphologies are sensitive to the thermal conditions in the target material. In our study, temperature effects are visible in simulations with impactors larger than 50 km.

The best fit model for Hertzsprung basin show that the long-term cooling causing compaction of thermally expanded rocks is important and changes the gravity signature significantly. In addition, isostatic relaxation processes, not considered here, further modify the initial gravity signature over time, which may explain the remaining deviation between models and observed data. The correlation between DCU and the position of the minimum in gravity (diameter of gravity) is a powerful tool to predict impactor diameters without extensive modeling studies.

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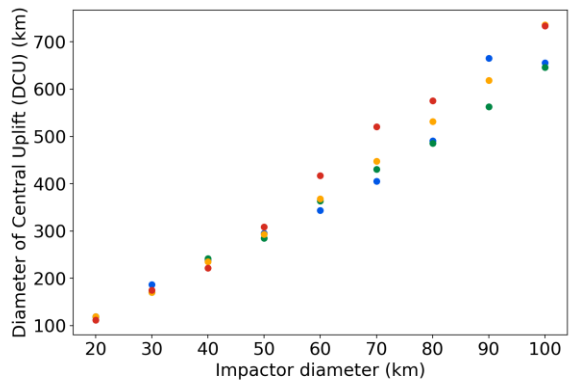

Fig. 1: Diameter of the central uplift is related to impactor diameters and thermal state of the target. The colors of the dots indicate used thermal profiles (blue: cold, red: hot).

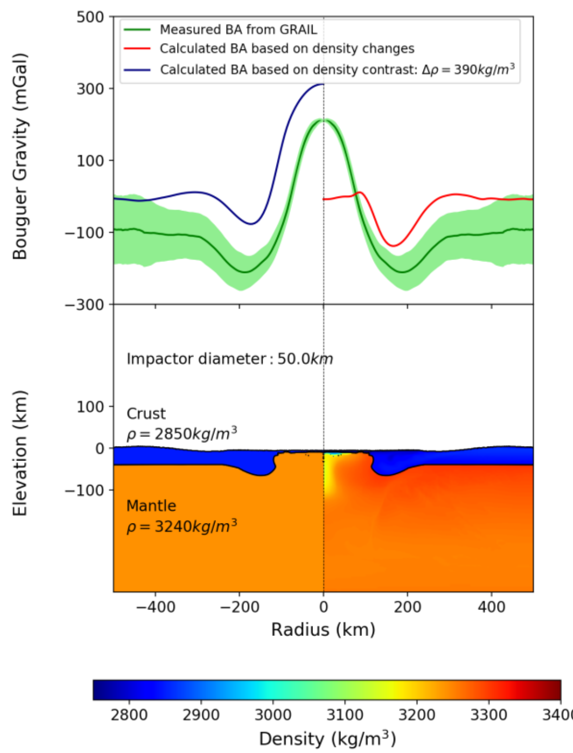

Fig. 2: Profile through the Hertzsprung Basin using an impactor of L=50 km. Observed gravity (green) compared to gravity response of the model (blue, red). Left panels show results using constant densities in crust (2850 kg/m³) and mantle (3240 kg/m³), right plots refer to varying densities in the target.