THE EFFECTS OF IMPACTOR AND TARGET PROPERTIES ON THE FORMATION OF BASIN STRUCTURES ON THE MOON. T. Lompa¹ and K. Wünnemann², ¹Museum für Naturkunde Berlin (Invalidenstr. 43, 10115 Berlin, tomke.lompa@mfn.berlin), ²Museum für Naturkunde Berlin (Invalidenstr. 43, 10115 Berlin, kai.wuennemann@mfn.berlin).

Introduction: The prominent large impact basins on the Moon are remnants of the late accretion phase. To improve our understanding on how these basins formed we investigate the effect of impactor and target properties on the formation process. In our study, target properties are defined by the thermal state, composition and crustal thickness. Impactor properties are given by mass, velocity and, size. Previous studies (e.g. [2], [7], [9], [5]) revealed that especially thermal conditions in the target have a large influence to the material behavior and therefore affect the crater formation process. Our study support these results and we provide a more systematic and qualitative analysis of the relationship between the target temperature, solidus, strength, and the resulting basin structure. We use gravity data from GRAIL mission to constrain our models. We can show that the pre-impact thermal structure influences the shape (amplitude/width) of the modeled gravity signature. Based on this we can draw first conclusions from 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.

Method: We use the iSALE2D shock physics code to simulate the formation of large basins ([1],[8]). For our study, we varied target properties (strength as a function of pressure) with respect to the temperature profiles ([5], [6],[9]). We use thermal profiles, solidus and liquidus as a function of pressure (depth) that are based on thermal evolution models ([5],[6],[7]). Besides the temperature profile the solidus is particularly important as the difference between temperature and solidus defines how much material is thermally softened (decrease in strength). The strength is the ruling parameter influencing e.g. the mantle uplift. The model includes the ANEOS equation of state of basalt (crustal material) and gabbro (mantle material) and the rock strength model. The cell size in the simulations is 1.5 km x 1.5 km.

Model constraints: Remote sensing data from LOLA provide information about the topography and can be supplemented by gravity data from the Gravity Recovery and Interior Laboratory (GRAIL) spacecraft [10] which provide detailed information about the deep structure of lunar basins. Previous studies have shown that positive Bouguer gravity anomalies result from mantle uplift [4]. It was noticed that the amount of uplift, the extent of crustal thinning, and the crustal thickening close to the mantle uplift, strongly depend on the thermal state of the Moon at the time of impact [5]. These observational data are used as constraints for a systematic modeling study, where we investigate how varying target conditions as a consequence of different thermal profiles affect observable parameters of the basins.

Results: Yield strength in the target material is a parameter that is sensitive to temperature changes. Figure 1 shows that yield strength of warm material is shifted to lower values compared to material with a colder temperature profile (dashed blue and red lines). Below a depth of approximately 60 km (mantle regime) the differences in yield strength are large. This leads to the assumption that it is mostly the thermally softened behavior of mantle material that influence the crater formation process. Figure 2 shows the effect of the usage of a cold and a warm thermal profile in our simulations. In case of the warm target the mantle is exposed at the surface of the impact basin. In the other case (cold target) there remains a crustal cap in the crater center.

The geometry of the internal structure, and, therefore, the density distribution inside the basin contribute to the amplitude of the gravity field. Dense mantle material close to the surface increases the Bouguer gravity signal, whereas a less dense crustal cap lowers the amplitude of the gravity field.

Figure 3 shows the density distributions and calculated Bouguer gravity signals (blue) corresponding to the cold and warm target simulations as discussed above. The green curve represents the gravity data from the GRAIL mission for the Orientale basin. The calculated gravity signal from the simulation using a warmer target (right column) approximates the observed gravity data better than the modeled gravity signature from the cold target simulation (left column). The crustal cap and the exposed mantle are the prominent features that influence the amplitude as well as the width of the gravity signal.

Summary and Outlook: Our study shows that final crater morphologies are sensitive to the thermal state of target material and, thus, yield strength. This is important for the study of basin formation during the cooling of an initially hot Moon (4.5 Ga) to a relatively cold Moon (3.5 Ga), when the main basin formation era ended.
During our ongoing work, we will have a closer look to the relationship between gravity signal, thermal properties, and impactor characteristics. In addition it has to be taken into account that the present-day observations have been altered through long-term processes and one has to be careful taken such present day observational data as constraints for the formation models. For example, the gravity signal we can derive from our models is related to a fresh impact basin, whereas the GRAIL gravity measurements represent the subsurface mass distribution that has been subject to long-term isostatic relaxation processes [3]. Taking this process into account will be subject of future work.


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Figure 1: Yield strength (dashed lines) as a function of temperature in the target (solid lines).

Figure 2: The figure shows two sections of the final basin structure of numerical models (v=17km/s, L=70km) depending on thermal target conditions (warm/cold target). Green colors indicate crustal material, blue color mantle material. The final basin having a cold pre-impact target is covered by a crustal cap in the center of impact basin, whereas mantle is exposed after impacting warm target material. Models with a cold target material also show thickened crustal slabs, dipping towards the crater center. Yield strength (dashed lines) as a function of temperature in the target (solid lines).

Figure 3: The upper frame shows the observed (blue) and modeled gravity anomalies for the cold (left) and warm (right) target. Below, the corresponding density structures are shown. The last row presents again the final basin structure as already shown in Figure 2. Depending on the preimpact thermal state of the target, the gravity response of the models (blue line) vary (bouguer correction density is 2940 kg/m³).