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How do impactor and target properties affect the formation of basin structures on the Moon?

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Abstract

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 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. Based on these we will obtain a much better understanding on how the thermal evolution of the Moon is related to the changes in the formation of basins.

1. Introduction

Remnants of the late accretion phase are given by the most prominent features on the Moon, the large impact basins. For a better understanding of this important and violent phase of the evolution of planets we investigate the formation of impact basins. In previous studies lunar impact basins have been investigated (e.g. [2], [6], [8], [4]) to obtain a better understanding of the formation and subsequent evolution as a function of varying impactor properties, and, thus varying kinetic impact energy, and target conditions. Target conditions at the time of impact are described by lunar thermal gradient, crustal thickness and composition. 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 [9] which provide detailed information about the deep structure of lunar basins. Previous studies have shown that positive Bouguer gravity anomalies results from mantle uplift [3]. 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 [4].
Here we present results of a systematic modeling study, where we investigate how varying target conditions as a consequence of different thermal profiles affect observable parameters of the basins.

2. Method

We use the iSALE2D shock physics code to simulate the formation of large basins ([1], [7]). For our study, we varied target properties (strength as a function of pressure) with respect to the temperature profiles ([4], [5], [8]).
We use thermal profiles, solidus and liquidus as a function of pressure (depth) that are based on thermal evolution models ([4],[5],[6]). 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.

3. 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 ca. 60 km (mantle regime) the differences in yield strength are large. That leads to the assumption that the behavior of mantle material will mostly influence the crater formation process. In figure 2 we see the results of using a cold (left) and a warm (right) thermal profile in our simulations. The mantle is exposed at the surface of the impact basin (warm target), while there is still a crustal cap in the crater center when we use a cold thermal profile.

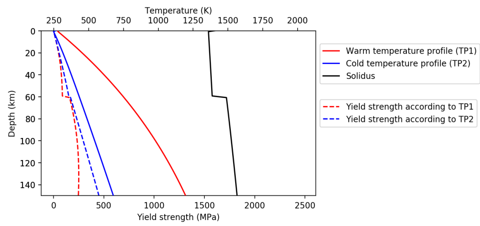

Figure 1: Yield strength (dashed red and blue lines) depend on thermal conditions in the target (red and blue solid curves). The temperature difference between the solidus (black line) to the warm temperature profile is smaller, therefore the yield strength of warmer material is smaller and the material is weaker. Using a cold thermal profile target material is stronger.

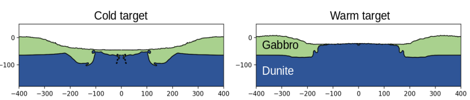

Figure 2: A crustal cap covers the center of impact basin (cold target, left), whereas mantle is exposed after impacting a warm target (right).

4. 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.

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 observable parameters 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. Taking these process into account will be subject of future work.

Acknowledgements

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