EXPLORING THE PEAK-RING TO MULTIRING BASIN TRANSITION ON THE MOON. E. Bjonnes\textsuperscript{1}, B. C. Johnson\textsuperscript{1}, and J. C. Andrews-Hanna\textsuperscript{2}. \textsuperscript{1}Department of Earth, Environmental, and Planetary Sciences, Brown University, 324 Brook St, Providence, RI 02912, USA. \textsuperscript{2}Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA. (Emily.Bjonnes@brown.edu).

Introduction: The formation of impact basins played a dominant role in the evolution of ancient planetary crusts. Despite their importance, the formation of large basins, and especially the transition from peak-ring to multiring basin morphologies, is poorly understood. The prevalence of impact craters on the Moon and wealth of geophysical data present an opportunity to better understand basin formation and the peak-ring to multiring basin transition. Hertzsprung Basin, the smallest basin classified as a multiring basin on the Moon, has a distinct inner depression and 3 rings at 256 km, 408 km, and 571 km diameter \cite{1}. Freundlich-Sharonov, the largest identified peak-ring basin, is slightly smaller with a peak-ring at 200 km and an outer ring at 582 km diameter \cite{1,2}. We consider both basins to be at the transition between peak-ring and multiring basins. The intermediate ring of Hertzsprung is much lower in relief than the inner or outer rings, unlike the intermediate rings of well-developed multiring basins. A similar intermediate ring in Freundlich-Sharonov could have been obscured by the large craters within the basin. In high-resolution crustal thickness models \cite{1}, both basins show a cap of crustal material in the center of the basin, with the cap of Hertzsprung being thicker than that of Freundlich-Sharonov (Figure 1). Hertzsprung also shows a bench-like structure in the crust-mantle morphology, defined by a step-like geometry of the crustal thickness profile (yellow star) which is not observed in Freundlich-Sharonov or in larger multiring basins. This difference in crust-mantle shape raises the question of whether bench development is related to the transition from peak-ring to multiring basins, and what accounts for the difference between Freundlich-Sharonov and Hertzsprung basins. Here we simulate lunar basin formation to understand how pre-impact conditions affect basin formation and the transition between peak-ring basin and multiring basins, with a focus on the bench structure of Hertzsprung and reproducing the crustal caps of both basins.

Methods: We model impact crater formation on the Moon using the shock-physics hydrocode iSALE-2D \cite{3-7}. Our models consist of a dunite impactor hitting a granitic crust overlying a dunite mantle, testing crustal thicknesses between 30-60 km and lithospheric thermal gradients from 10-20 K/km. All models had 1 km resolution and an impactor diameter of 40 km. We are testing a variety of crustal thicknesses and thermal gradients due to the range of appropriate values from GRAIL data and previous modeling studies \cite{2,8-10}.

We evaluated our models on the development of a bench structure as seen in panel B of Figure 1. The thickness in the basin center is also considered as a secondary criteria to distinguish between Freundlich-Sharonov-like and Hertzsprung-like basins, in conjunction with the development of lithospheric faults where a fault is defined as a continuous, traceable bend in tracer lines.

Preliminary Results: The development of the bench morphology in crust-mantle structure depends on lithospheric thermal gradient, with lower thermal gradients making the development of the bench structure more likely. Simulations with a lithospheric thermal gradient of 15 K/km and crustal thicknesses of 30-50 km produce the bench structure in the crust-mantle interface. This result is consistent with the observation that Hertzsprung has a younger crater retention age than...
Freundlich-Sharonov [2, 3], and presumably formed in crust with a lower thermal gradient.

We found that having a thicker pre-impact crustal thickness increases the amount of crust in the inner basin at the end of the simulation, and a pre-impact crustal thickness of at least 50 km is needed to reproduce the crustal thickness on the crater floor. Increasing the thermal gradient also increases the amount of crustal cover of the final basin floor because material is weaker at higher temperatures and is able to move farther inward during crater collapse, consistent with [2, 10].

For crustal thickness of 30, 40, and 50 km with thermal gradient of 15 K/km, we observe at least 2 lithospheric cutting faults, indicating agreement with the multiring classification of Hertzsprung. Additionally, the bench structure is consistently associated with a possible fault in the crust, suggesting a relationship between ring faults and the bench morphology. In these models, the bench-like structure appears to be a result of a more gently dipping (~35°) fault intersecting the edge of the mantle uplift, in comparison to the steeper ring faults intersecting the crust-mantle interface outside of the mantle uplift. Simulations with 50 km crustal thickness and 20 K/km thermal gradient do not develop the bench structure and consequently are a better match to Freundlich-Sharonov basin.

**Discussion:** We are currently classifying simulations as Hertzsprung-like or Freundlich-Sharonov-like based on the presence or lack of a bench structure and crustal cap. More work is needed to ensure that factors such as ring spacing and bench location are also satisfying observational constraints. These preliminary simulations suggest that to successfully model either Freundlich-Sharonov-like or Hertzsprung-like basins, there is a balance to strike between the lithospheric thermal gradient and pre-impact crustal thickness; models need enough crustal thickness to reproduce the crustal cap in the basin center, but too thick of a crust layer inhibits the formation of the bench structure. Increasing the thermal gradient prohibits the development of the bench structure and also results in fewer ring faults, two factors that are more consistent with Freundlich-Sharonov-type basins.

**Conclusions and Future Work:** The factors governing which type of basin forms at transitional sizes remain poorly understood. Hertzsprung and Freundlich-Sharonov basins, similar in size and location on the Moon, give a valuable opportunity to test how various planetary conditions can affect multiring and peak-ring basin formation. Here we have begun to understand how crustal thickness and thermal gradient affect crater development, and future work will look closely at how the bench structure relates to inner ring fault formation.

![Figure 2: Comparisons of numerical simulations with 50 km thick crust with 15 K/km thermal gradient (A) and 20 K/km (B). The lower thermal gradient of panel A shows a bench structure development around 100 km radial distance, but this feature is not present in simulations with higher thermal gradients.](image)

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**References:**