

THE CRUSTAL STRUCTURE OF ORIENTALE AND IMPLICATIONS FOR BASIN FORMATION. J. C. Andrews-Hanna¹ and S. T. Stewart², ¹Department of Geophysics, Colorado School of Mines, Golden, CO, jca-hanna@mines.edu, ²Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA, sstewart@eps.harvard.edu

Introduction. The topography [1] and gravity [2] of the Moon are dominated by the signatures of impact basins and the mascon gravity anomalies contained within. A method of generating higher resolution crustal thickness models by utilizing the symmetry of the basins is here presented, providing a refined view of the subsurface structure of the basins, with a focus on Orientale. The crustal structure is compared with results from CTH numerical models of basin formation [3]. The implications of the crustal structure for the origin of the super-isostatic mantle plugs observed beneath a number of lunar basins are then considered. These basins possess mascon gravity anomalies in excess of that which can be accounted for by the mare loading in the basin interiors [4]. It is shown that the super-isostatic state of the basin floors is a result of the flexural uplift of an annulus of sub-isostatic thickened crust surrounding the basins.

Basin crustal structure: Methodology. Previous studies used gravity and topography data to generate global crustal thickness models for the Moon [5], which were then analyzed to investigate the structure of individual basins [6]. These crustal thickness models were limited by the amplification of the short-wavelength noise in the gravity data during the downward continuation to the Moho depth, requiring aggressive tapering for a stable global solution. However, when analyzing a feature with a natural symmetry axis, such as an impact basin with radial symmetry, the uncertainty in the mean profiles (represented by the standard error on the mean) is greatly reduced by averaging around the symmetry axis. This results in mean gravity and topography profiles of improved accuracy.

The averaged gravity and topography profiles can be used to generate crustal thickness models for the basins using the standard technique [5], at higher resolution than can reliably be done on a global basis. Both the quality of the gravity data and the departures from radial symmetry vary greatly from basin to basin, thus it is necessary to choose the optimal spherical filter to apply in the downward continuation. This filter is chosen using the *a priori* geologic expectation that the uplifted mantle plug below the basin should have a flat roof, resembling the flat floor of the basins themselves. A simple \cos^2 taper of constant width is applied for a series of models, while the degree at which filtering commences is shifted to higher degrees for successive models. The optimal filter is that which minimizes the RMS gradient of the Moho beneath the basin floor.

Basin crustal structure: Results. The azimuthally averaged gravity and topography over Orientale was

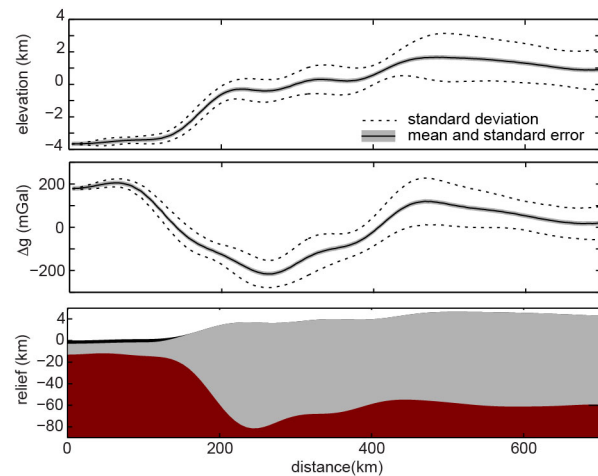


Figure 1. Azimuthally averaged profiles of the topography (top) and gravity (middle) over the Orientale basin. The crustal structure model (bottom) includes the mare basalt (black), anorthositic crust (gray), and mantle (red). The surface relief in the bottom panel is stretched by a factor of 5 relative to the Moho relief.

used to generate a crustal structure model (Figure 1). Orientale is underlain by a quasi-cylindrical mantle plug, which is surrounded by an annulus of thickened crust. This crustal thickening occurs at the Moho rather than at the surface, resulting in strongly sub-isostatic crust within this annulus. This sub-isostatic crustal thickening is responsible for the pronounced negative gravity ring surrounding many of the mascon basins. A similar crustal thickening is predicted by the CTH numerical simulations, resulting from the overturned flap of ejecta (Figure 2).

Origin of super-isostatic mantle plugs. The excess positive gravity anomalies beneath many basins indicate a super-isostatic uplift of the mantle plug below the basin. Previous studies interpreted this to result from the instantaneous rebound of the basin floor in the moments after the impact, which overshoots and is arrested in a super-isostatic position [6]. However, new CTH models predict that the basin floor should be sub-isostatic rather than super-isostatic in the moments following the impact, as shown by the difference between the topography and that predicted for a state of isostasy (the isostatic anomaly; Figure 2). However, this will rapidly relax to an isostatic state because of the thermal anomaly resulting from shock heating and excavation of the lithosphere (Figure 2). Using nominal rheological parameters [3], the CTH models predict the thickened crust outside the basin to be even more strongly sub-isostatic, though an investigation of a

broad parameter range is needed. This region experiences little impact-induced heating, and the lithosphere is thickened as a result of the effect of the ejecta both thickening the crust and increasing the overburden on and therefore the frictional strength of the underlying lithosphere. Thus this sub-isostatic thickened crust will be an enduring feature of the post-impact structure.

We propose that the isostatic rise of the annulus of thickened crust outside the basin drives a flexural uplift of the basin floor, resulting in a super-isostatic basin floor surrounded by a sub-isostatic annulus. We test this hypothesis using spherical harmonic thin shell loading models [7] to represent the loading and flexure of an initially isostatic basin after applying either (Figure 3a-b) a super-isostatic uplift of the mantle, or (Figure 3c) a sub-isostatic annulus of thickened crust. In each case, the initial isostatic basin topography was iterated such that the final topography would match the observed topography of Orientale. For models a and b, the super-isostatic uplift of the basin floor was tuned to match the observed gravity anomaly for lithosphere thicknesses of 40 km and 75 km, respectively. For the 75 km thick lithosphere, the models greatly under-predicted the magnitude of the negative anomaly outside of the basin. The 40 km-thick lithosphere model was able to approximately match both the positive anomaly inside the basin and the negative anomaly outside the basin, but this could only be done if the initial super-isostatic basin floor was uplifted and arrested above the level of the surrounding surface, which is not a likely outcome of the basin excavation. For model c, the annulus of thickened crust was set to match the observed crustal thickening surrounding Orientale. This model closely matches both the positive anomaly within the basin and the negative anomaly surrounding it. The initial state of model c is also most consistent with the final state of the CTH models. These results demonstrate that the super-isostatic mantle plugs beneath many lunar basins are best explained as a result of flexural uplift of the annulus of sub-isostatic thickened crust outside the basin.

In order for the flexural uplift of the annulus to result in a super-isostatic mantle plug below the basin, the lithosphere thickening below the basin floor must occur on a timescale faster than or comparable to the timescale for flexural uplift of the annulus. A simple scaling of post-glacial rebound timescales on Earth to the lower gravity and higher mantle viscosity for the Moon suggest uplift timescales of order 10 Myr, allowing growth of an elastic lithosphere 10's of km thick.

Conclusions. High-resolution models of the crustal structure of lunar impact basins reveal cylindrical mantle uplifts below the basin floor, surrounded by an annulus of sub-isostatic thickened crust. Flexural uplift of this annulus would have uplifted the basin floor, explaining the origin of mascon gravity anomalies in

excess of that predicted from the mare load in the basin interiors. These results shed light on the state of the basins shortly after formation, supporting the existence of a sub-isostatic annulus of thickened crust.

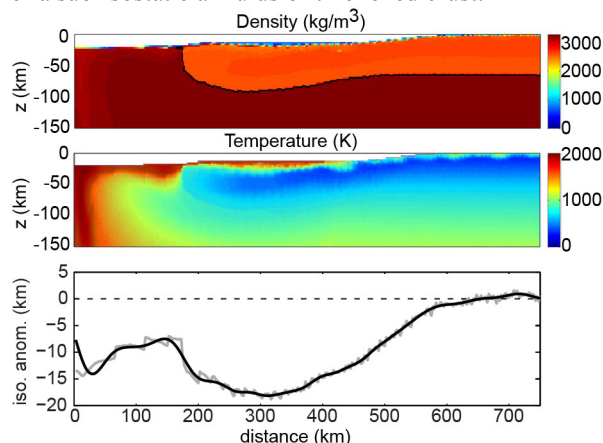


Figure 2. Fresh radial distribution of density (top) and temperature (middle) from a nominal hydrocode simulation of an Orientale-scale event [3]. The isostatic anomaly (bottom) shows both the basin floor and the annulus of thickened crust to be strongly sub-isostatic.

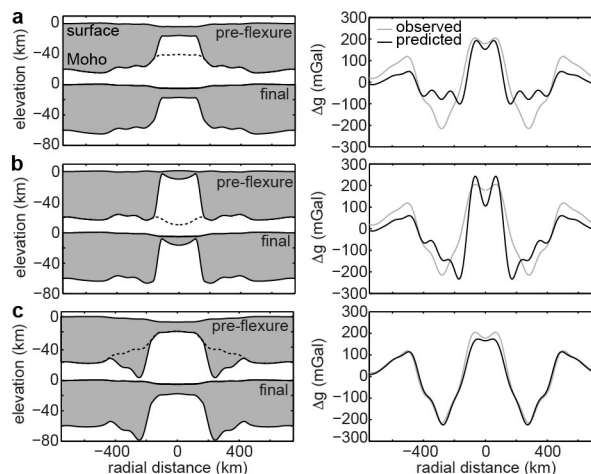


Figure 3. Model structure (left) and predicted gravity anomaly (right) for flexural models of Orientale. Model a assumes a super-isostatic Moho uplift beneath an otherwise isostatic basin with a lithosphere thickness of 75 km; model b is similar but with a lithosphere thickness of 40 km; model c assumes a sub-isostatic annulus of thickened crust surrounding an otherwise isostatic basin and a 90 km lithosphere. The dashed lines represent the level of the isostatic Moho.

References.

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