THE INFLUENCE OF LOCAL THERMAL ANOMALIES ON LARGE IMPACT BASIN RELAXATION.

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Introduction: Lunar gravity data from orbital spacecraft have been used to identify several large impact basins with significant, positive free-air gravity anomalies, called mascons [e.g., 1]. Although it was postulated that this excess mass was a result of mare fill [e.g., 2], recent modeling of the basins that accounts for the effect of the mare suggests that several of these basins are supporting a mass load that is in excess of that which would be expected if they were in isostatic equilibrium [e.g., 3, 4]. The mechanisms that generated and preserve this state of superisostatic compensation are of particular interest because they are poorly understood.

The post-impact relaxation of large impact basins over geologic time is primarily the result of the viscoelastic response of the lithosphere to the stress field created by excavation of basin material at the time of impact. The viscous creep component of the relaxation is strongly temperature-dependent as well as being dependent on rock type. It is of interest therefore, to investigate the thermal conditions near the impact site at the time of the event and during its evolutionary lifetime, with attention to both the regional background and localized temperature fields. An important potential source of local thermal perturbation is the regional enhancement of incompatible radiogenic elements associated with the Procellarum KREEP Terrane (PKT) [5]. If the source of the PKT is a large unit that underlies the crust [6], the increased heat production from such a deposit may dramatically affect the relaxation of the basin.

In addition, a significant amount of the energy from the actual impact event is converted into heat via shock wave decompression, commonly referred to as impact heating. The resultant thermal anomaly is expressed as a core of high temperature and a radially decaying thermal perturbation beyond the core, that is elevated above the background field [7]. We investigate the contribution of this anomaly to the evolution of the isostatic compensation state and overall topographic relaxation, and compare the effects to those resulting from a subsurface KREEP layer.

Methods: We use the commercial finite element software MSC.Marc to analyze planar, axisymmetric viscoelastic relaxation [e.g., 8, 9] . Though this approach has a significantly greater computational cost compared to analytical models [e.g., 10], it has the advantage of accounting for viscosity structures that can vary both vertically and laterally, as well as temporally. The model is constructed with values representative of the thermomechanical post-modification stage of a large impact basin with a simulation time of 1 Gyr. Crustal thickness is generally an important parameter in viscoelastic relaxation of topography. Here, our preliminary models utilize a nominal crustal thickness of 60 km and an initially flat moho, though ongoing work utilizes a range of crustal thicknesses [e.g.,11] and initial compensation states. To investigate conditions of maximum relaxation, we use a Young's modulus of 10^{10} Pa for the crust and 10^{11} Pa for the mantle while recognizing actual variations in the parameter are less than have been modeled thus far. Basin sizes ranging from 400 km to 1200 km in diameter, roughly bracketing basins from Mendel-Rydberg to Imbrium in size, are simulated using two laterally varying thermal scenarios. Initial basin topographic relief, excepting a rim and ejecta, is implemented following [9], though with an initial depth:diameter of 0.01 consistent with [4]. The load provided by the mare fill is not simulated.

In the first case, we use a radiogenically heated background temperature gradient with a local KREEP anomaly represented by a 10 km-thick unit at the base of the crust, consistent with the thermal model of [5]. This layer is varied in radial extent from the center of the basin in order to characterize how lateral variations in the thermal perturbation affect the lithospheric response.

In the second case, the local thermal increase is provided by remnant heat from the basin-forming impact. Here, the background thermal fluxes are modeled as linear depth profiles, ranging from 25mW m^{-2} [e.g., 10] to an arbitrary upper bound of 100 mW m^{-2}, with a constant surface temperature of 253 K. Using this limited parameter range, we study the effects of an isothermal core of 0.1x and 0.05x the basin radius, which is located immediately under the surface at the center of the basin and is elevated above the background temperature by 300 K. This thermal anomaly is held at its maximum value for the duration of the simulation in order to provide an upper limit on the thermal effect.

For both cases we examine the surface topographic evolution over time by comparing vertical displacement of the center of the basin with the original apparent depth of the basin. Additionally, we calculate the degree of compensation of the basin (also at the center) in order to understand the evolution and preservation of basin compensation. Although the background temperature field for each case is computed differently (radiogenic for the KREEP investigation and linear approximation for the impact scenario), we enforce a minimum viscosity cutoff at 10^{21} Pa s for both scenarios in order to maintain tractable simulation times. Sensitivity tests of these models have shown that the degree of compensation after 1 Gyr is not substantively affected by this cutoff relative to lower minimum viscosities.

Preliminary Results and Observations: We first note that the full range of our modeled basin sizes achieves central-basin overcompensation in some, if not many, of the thermal test scenarios. Figure 1 shows the results of two test cases (models with no KREEP-enhanced heat production, and those where such a layer has a radius equal to the basin) for each of the basin sizes modeled. The latter scenario closely mimics the global one (not shown), but is much less computationally expensive and is therefore plotted below as a proxy for the more radially-extensive cases. In all cases, the presence of the KREEP layer drives the system more rapidly towards a compensated state. However, as the diameter of the basin increases, the added thermal energy inhibits the trend of these models towards overcompensation. We note that the development of an overcompensated state, as well as a reversal and subsequent decrease in compensation (as depicted by the inflection in the curves of Figure 1) has also been predicted by previous work using analytic modeling [12]. Further, we find that our results for models that have KREEP layers that extend to 1.5x the basin diameter are nearly identical to the "global" case (that is, extending to the outer edge of the model) in both rate and magnitude.

In regard to the extent of effects of impact heat, it appears for all cases modeled thus far that the temperature increase plays a small role in the evolution of the state of compensation. Rather, it is the choice of background temperature gradient that determines the relaxation behavior of each case. Only in the smallest basin size with a high background heat flux (100 mW m^{-2}) do we see any noticeable difference in final compensation state. It should be noted as well that in this model, the impact thermal anomaly is not allowed to diffuse into the surrounding material and thus is already considered to represent a generous environment for enhanced viscous relaxation. However, the spatial restriction of the isothermal cores simulated thus far may partially counteract the expected enhanced relaxation that the thermal anomaly may provided.

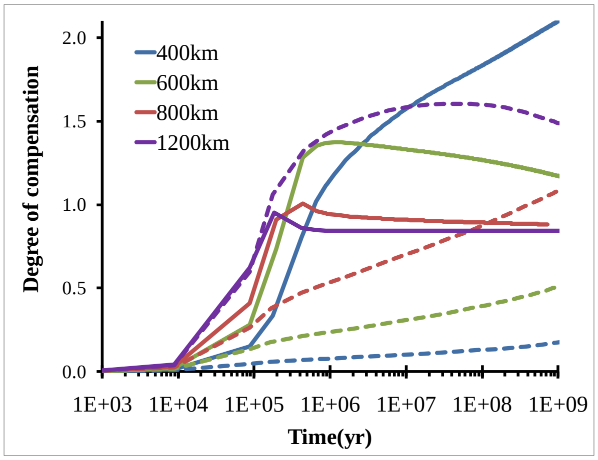

Figure 1. Comparison of the effect of a crustal-base KREEP deposit upon the degree of compensation of basins within the PKT. The solid lines represent the presence of a 10 km-thick KREEP layer with radius equal to that of the basin. The dashed lines represent the absence of the same.

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