CRUSTAL AND LITHOSPHERIC STRUCTURE OF MARTIAN IMPACT BASINS.
L. Cris Mauldin and Robert E. Grimm, Department of Geology, Arizona State University, Tempe, AZ 85287-1404; email: cris@violetta.la.asu.edu.

Summary. Gravity anomalies from the Goddard Mars Model-1 over the largest impact basins on Mars are consistent with nearly complete isostatic compensation of the original basins. However, thickening of the elastic lithosphere with time can be demonstrated from the isostatic response to later basin infill. Isidis basin in particular shows a marked positive free-air anomaly, indicating development of a thick (>100 km) elastic lithosphere to flexurally support 2-4 km of volcanic load within several hundred million years of basin formation. The best-fit thickness of highland crust surrounding Hellas is ~80 km. The gravity data are consistent with 50-100% complete excavation of the crust during formation of the Hellas basin.

Data and Methods. The large basins Hellas and Isidis are well resolved in the GMM-1 50th degree and order spherical harmonic representations of the free-air gravity and topography [1]. However, local phase errors preclude accurate comparison of gravity and topography by automatic minimum variance techniques; therefore we compared only the basin rim-to-center amplitudes of the observed and predicted signals. Assuming that the observed topography is supported by crustal thickness variations and/or lithospheric strength, we calculate combinations of regional crustal thickness H and elastic lithosphere thickness Te that produce the observed gravity anomaly. The calculations employ standard wavenumber domain techniques [2], modified for finite-amplitude topography using an infinite series expansion [3]. We allow for basin infill by assuming the original basin to have a flat floor of 60% of the observed basin diameter. The fill was added from the observed surface fill down to the flat floor, thus depth is a free parameter. Te is allowed to vary between the times of basin formation and filling. Assuming that the mantle is not directly exposed on the present floors of the impact basins, independent constraints on minimum regional crustal thickness follow simply from isostatic considerations, without necessarily satisfying the gravity data.

Formal errors on the gravity and topography fields for both Hellas and Isidis are ~70 mgal [1] and 1-1.5 km [4], respectively. We calculate the gravity equivalent of the topography error as the predicted gravity difference between the original topography and "erroneous" topography stretched by ±1 km from the original local minimum and maximum values. This is the worst-case spatial structure for the topography error, thus ensuring that our error bounds are conservative. In practice, the effect of the topography error on predicted gravity is mitigated by compensation; therefore the gravity equivalent of the topography error varies continuously with assumed values of H and Te but is ~30-40 mgal. Adding the variances from both gravity and topography yields a total error ~80 mgal, which then provide error bounds on derived parameters such as H and Te.

Hellas is the largest impact structure on Mars (D=2000 km); its depth and gravity anomaly are ~7.6 km and ~125 mgal in GMM-1. The formation of the basin occurred in the early Noachian with eolian, volcanic, and flood deposits 2-3 km thick emplaced until the end of the Hesperian [5,6].

The minimum initial crustal thickness Hmin for Hellas is fairly constant, ~50 km, nearly independent of Te, as changes in the long-wavelength basin topography with varying Te do not cause large changes in moho relief. However, the gravity is more sensitive to changes in Te, as shown by the inverse correlation of H and Te. Best-fit values are H = 55-80 km and Te < 30 km; a range of H = 55-100 km and Te < 45 km is allowed by the errors in the data. The close proximity of the best-fit solutions and the line of minimum crustal thickness suggests that the Hellas impact excavated nearly all, if not all, of the crust. This is expected if the present topographic boundary of the basin was the excavation cavity, as excavation depth ~ D/20 [7, including correction for collapse enlargement], or ~100 km. Buried inner rings might indicate a smaller excavation cavity and lesser excavation.

The gravity anomaly is insensitive to differences in density of the basin infill between 2.0 and 3.0 g/cm³; therefore we cannot distinguish high-density lavas from low-density aeolian deposits. We cannot rigorously define an upper bound to the fill because thicknesses > 3 km cannot be accurately added to the original perturbed surfaces in the wavenumber domain. Nonetheless, the best-fit fill thicknesses modeled here are in good agreement with geological observations [6].

Isidis is a 1200-km diameter early Noachian basin that has been embayed by Amazonian lavas from the northeast [5]; its post-embayment depth is 4 km. A flexural response to earlier loading during the Hesperian is manifested by circumferential grabens of that age [8]. The strong positive gravity anomaly of 200 mgal over the basin is analogous to lunar mascons. Because of the anticorrelation of gravity and topography, tradeoff curves for H vs Te as a function of fill thickness have a positive slope (Fig. 2). The mascon is so immense that the models require Te at the time of basin formation to be small and Te at the time of infilling to be large. This, and the constraint of Hmin = 27-35 km, requires the fill thickness to be > 2 km. Because Isidis is smaller than Hellas and
shows more variation in topography, the density of the fill does change the tradeoff between $H$ and $T_e$. Fig. 2 further shows that fill greater than 4 km can require unreasonably large crustal thicknesses. We expect $H=80$ km in the highlands around Hellas and so $H$ should be less at Isidis, which is at the highland-lowland transition. At the time of volcanic infill, $T_e > 50$ km assuming the thickest fill, and was most likely $>100$ km. This result is in agreement with earlier estimates of $T_e$ based on the distances of graben formed in response to the volcanic load [8].

**Conclusion.** A substantial increase in $T_e$ at Isidis over several hundred m.y. is required by the gravity data; Hellas is also consistent with a smaller amount of lithospheric thickening but does not require it. The large $T_e$ at Isidis, comparatively early in Martian history, may be the result of unpertrubed cooling and thickening of the lithosphere after the impact, away from later volcanic centers that display smaller $T_e$. It may also require the presence of strong mantle immediately beneath the load, where basin formation resulted in extreme crustal attenuation. The lithospheric thicknesses at the time of basin formation for both basins are comparatively small, so we cannot distinguish whether basin isostatic adjustment was sensitive to the "normal" geological lithosphere determined largely by planetary heat flow or to a "transient" lithosphere determined by the local physical parameters during transient cavity collapse. Modeling of transient cavity collapse and the mechanisms of basin isostatic adjustment are the subjects of future investigation by us.


Figure 1. Combinations of crustal thickness $H$, elastic lithospheric thickness $T_e$, and basin infill allowed by gravity and topography for Hellas Planitia. For models with basin fill, $T_e$ applies to time of filling. Figure 2: As Fig. 1, for Isidis Planitia.