AN IMPROVED MODEL OF THE CRUSTAL STRUCTURE OF MARS. M. T. Zuber[1,2], G.A. Neumann[1,2], P. J. McGovern[3], M. A. Wieczorek[4], F. G. Lemoine[2], and D. E. Smith[2] [1]Department of Earth, Atmospheric and Planetary Sciences, MIT, Cambridge, MA 02139; zuber@mit.edu. [2]Laboratory for Terrestrial Physics, NASA/Goddard Space Flight Center, Greenbelt, MD 20771. [3]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058. [4]Département de Géophysique Spatiale et Planétaire, UMR7096, Institut de Physique du Globe de Paris, France.

Introduction: The first reliable model of the structure of the crust and upper mantle of Mars from remote observations [1] was produced using data from the Mars Orbiter Laser Altimeter (MOLA) and the Radio Science investigation of Mars Global Surveyor (MGS). That model assumed a uniform crustal density and solved for the global variations in crustal thickness using a gravity field derived from preliminary MGS tracking [2]. In that study, spherical harmonic potential coefficients were derived to degree and order 80, but crustal structure was interpreted cautiously to degree 60, or 360 km wavelength, owing to the presence of noise. Tracking normal equations have since been generated to degree 75 [3], to degree 80 (supplemented by altimetric crossovers) [4], and recently to degree 90 [5], using new constants for the orientation of the spin pole and the rotation rate of Mars provided by the IAU2000 rotation model [7, 8]. Gravity models now incorporate tracking data coverage from the Primary and Extended MGS missions and the early phases of the Mars Odyssey mission. In the present study we exploit these advances in gravity modeling to present a refined crustal inversion, which we also interpret in the context of Mars' internal structure and thermal evolution.

Comparison to Previous Model. Our initial crustal thickness model [1] varied from a minimum of 3 km to a maximum of 92 km thickness, with the northern lowlands characterized by a relatively uniform 35-km-thick crust.. When averaged over the globe, the crust was 43.5 km thick (not 50 km as stated therein) owing to the flattening of polar topography.

Unlike the Earth and Moon, the depth of crustal interfaces is not known from seismic observations, so absolute measurements were constrained by two considerations. First, the amplitude of crust-mantle deflections beneath the Isidis basin did not permit a significantly shallower crust-mantle density interface (Moho). Second, crustal thickness significantly greater than 50 km was deemed unlikely, as any dichotomy would have been removed by crustal flow during Mars' early thermal history [1].

Our latest crustal thickness model assumes constant crustal density constrained by SNC meteorites and takes into account the lower density of the polar ice caps [9], the higher density of the Tharsis volcanoes [10], and the flattening of the core-mantle boundary [7, 11]. The residual anomaly is filtered and inverted as in [12] for an inferred Moho shape with a power-law behavior that matches that of the surface. The resulting map resolves thickness variations at wavelengths of 300 km or shorter.

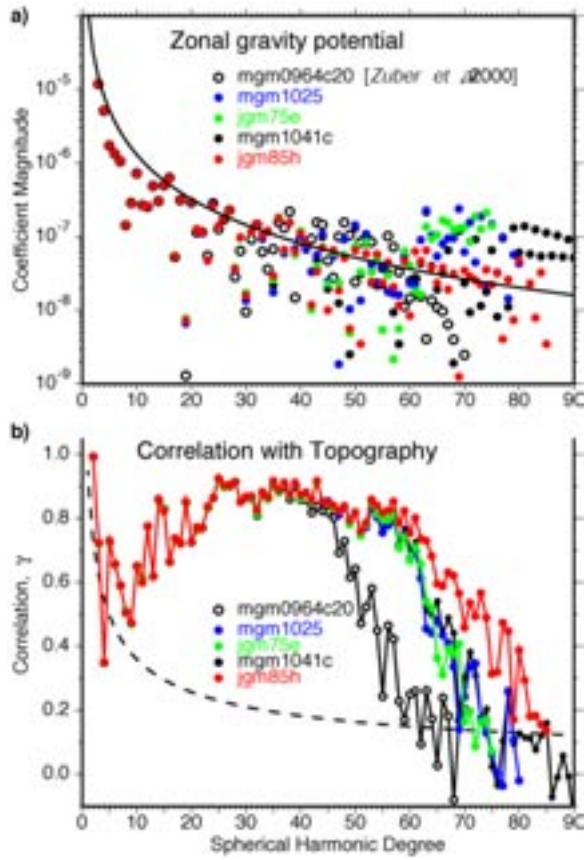

Fig. 1. **(a)** Zonal gravity coefficient magnitudes compared to Kaula's rule for recent MGS gravity field solutions.Coefficients diverge from a power law starting at about degree 40. **(b)** Correlation of gravity fields with topography. Dashed curve shows 95\% confidence level of positive correlation.

Gravity Model Improvements. Gravity models obtained primarily from MGS and historical tracking [2, 3, 4] are constrained by an empirical power law

known as Kaula's rule [8]. Gravity fields estimated from tracking equations use an l^{-2} power law constraint to minimize the covariance of the solution, reducing noise but also reducing the resolution of the gravity signal at high degrees. The zonal coefficient magnitudes in recent JPL and GSFC solutions often exceeded Kaula by an order of magnitude at high degrees (Fig. 1a), while earlier MGS fields such as mgm0964c20, which was used in [1], were necessarily overconstrained.

The formal coefficient uncertainty in the gravity model used in the present study (JGM85H02) is less than the signal up to degree 72. While the unconstrained coefficient uncertainty of MGM1025 is less than the (constrained) coefficient magnitude up to degree 62, the divergence of zonal coefficients starting at degree 40 among the most recent models suggests caution in interpreting the coefficients at higher degrees.

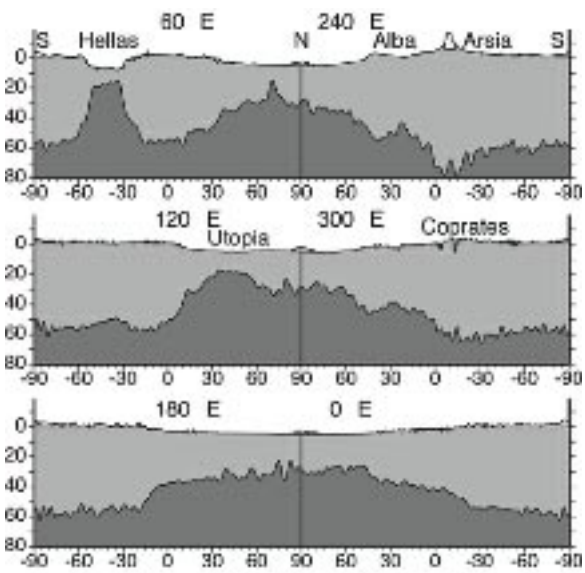

Fig. 2. Profiles of crustal structure along three great circles showing the pole-to pole variations along longitudinal transects. Regions at the poles and through Arsia Mons assigned a local density anomaly are shown in lighter shades.

The degree correlation of gravity with topography or coherence (γ) should approach unity at short wavelengths since such gravity anomalies arise mainly from very localized surface loads such as volcanoes. Fig 1b shows a high correlation for all fields up to degree 50, declining at higher degrees, where noise power becomes relatively stronger than signal. Above degree 60, γ>0.15 is significant at a 95\% confidence level. Beyond degree 60, JGM85H02 is more sensitive to topographically induced anomalies than all other fields considered, and $\gamma \geq 0.15$ persists up to degree 85.

Marcsrust2. Our new model, marscrust2 [13], constrains the mean crustal thickness of Mars to be >45 km. The model shows a contrast in thickness between 32 km in the north and 58 km in the south. As for the Moon, giant impacts remove most of the crust beneath the basins, replacing crustal material by uplifted mantle. Adopting a value of 45 km, the model thickness of the crust varies from approximately 5-100 km, with the thinnest crust (still) at the center of the Isidis basin.

Interpretation. The crustal structure is, to first order, characterized by a degree 1 structure that is several times larger than any higher degree harmonic component. The hemispheric dichotomy is revealed as a distinction between two terranes, with a modal crustal thickness of 32 km in the north and 58 km in the south. The Tharsis rise and Hellas annulus represent the strongest components in the degree 2 crustal thickness structure.

A simple pole-to-pole slope, *i.e.,* degree 1 offset between the center of figure and center of mass, would produce a uniform distribution of thickness between two extremes. The crustal structure we have inferred provides a better fit to a bimodal distribution with a degree-1 component and other shorter wavelength complexities. The presence of a 58-km crustal thickness peak suggests a single mechanism for highland crustal formation, with modification by the Hellas impact, followed by additional construction of Tharsis.

The largest surviving lowland impact (Utopia) appears to have postdated the formation of the crustal dichotomy. Its variations of crustal thickness are preserved, making it unlikely that the northern crust was originally thick, and thinned by internal processes following the Utopia impact.

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