VISCOSITY STRUCTURE OF MERCURY AND IMPLICATIONS FOR SUPPORT OF THE NORTHERN RISE. Peter B. James[1], Maria T. Zuber[1], and Roger J. Phillips[2]. [1]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139 (pjames@mit.edu); [2]Planetary Science Directorate, Southwest Research Institute, Boulder, CO 80302.

Introduction: The shallowness of Mercury's core-mantle boundary [1] is unique among the terrestrial planets and has a number of implications for dynamic flow in the mantle. A thinner mantle will in theory reduce the amplitude of geoid undulations associated with dynamic topography. It is perhaps surprising, then, that MESSENGER has observed large ratios of geoid to topography [1]. We can use these observations to identify the mantle viscosity profiles compatible with dynamic topography. As an alternative to dynamic compensation, we also explore plausible configurations of partially compensated flexural loading and the implications for surface observables.

The ratio of geoid to topography is especially large at the northern rise (68°N, 33°E), a broad topographic swell within the northern smooth plains [2]. A number of models have been proposed for the formation of this feature [3], each of which has implications for the present compensation mechanism. We model the northern rise using both dynamic topography and flexure scenarios.

Observations: The HgM002 gravity field [1] provides a characterization of Mercury's geoid to spherical harmonic degree and order 20 in the northern hemisphere, and the corresponding long-wavelength topography in the northern hemisphere has been well-constrained by Mercury Laser Altimeter (MLA) data [3]. The northern rise dominates both the geoid and topography in the 8-12 degree band, with a geoid amplitude of ~60 m and an altitude of ~1000 m, respectively (Figure 1). The structure of the crust and mantle has been constrained with gravity and topography, and a mean crustal thickness of ~50 km is currently favored [1]. Models of internal structure [1, 4] constrained by Earth-based radar [5] and the gravitational field [1] place the outer radius of the liquid outer core at a depth of about 400 km and favor the existence of a high-density layer, plausibly composed of solid FeS, above the liquid outer core.

Topography must be supported with some combination of isostatic compensation, dynamic loading, and lithospheric stresses. Each of these support mechanisms is associated with a transform function that maps topography to geoid height. In the case of Airy crustal compensation this transform can be expressed as a degree-dependent ratio:

$$Z_l = \frac{N_{lm}}{H_{lm}} = \frac{4\pi\rho_c R^3}{M(2l+1)}\left(1-\left(\frac{R-D}{D}\right)^l\right) \quad \textbf{(1)}$$

where N is the geoid height, H is topography, M and R are Mercury's mass and radius, D is apparent depth of compensation, and l is spherical harmonic degree.

An assumed crustal density of 3200 kg m^{-3} derived from MESSENGER orbital geochemical remote sensing [6] and a mean crustal thickness of 50 km yields Z_{10}^{Airy} = 0.016, which is much lower than the observed ratio of 0.06 at the northern rise. Other shallow compensation mechanisms such as Pratt isostasy result in similarly modest geoid-to-topography ratios. To explain the northern rise geoid will require invoking compensation deeper in the mantle or support of the rise by lithospheric stresses.

Dynamic topography: One class of models for northern rise topography is support by buoyant dynamic loading or by the flexural remnant of such a load. The gravity and topography resulting from a dynamic load at a particular depth in the mantle can be calculated by propagating a no-slip surface boundary condition and a free slip boundary condition at 400 km depth through a viscous sphere [7]. A number of kernels come out of this analysis, with two of particular interest: the ratio of geoid height to topography, and the magnitude of surface deformation scaled by the driving load. Both of these kernels are dependent on the viscosity profile of the mantle, so we explored the effects of possible vertical viscosity profiles (Figure 2). Since topography associated with the northern rise is focused in a relatively narrow band in wavenumber domain we can simplify our analysis by considering solely the kernels for spherical harmonic degree 10.

The results in Figure 2 show that an isoviscous mantle requires a deep-seated load in order to reproduce the observed admittance. A step-wise decrease in viscosity with depth brings the modeled load slightly closer to the surface. However, the observed admittance is inconsistent with any viscosity increase in the lower mantle.

Alternatives to dynamic topography: In the absence of pure isostatic or dynamic compensation it is possible to model topographic support as a combination of crustal thickening and elastic stresses in the lithosphere. A modification of equation (1) shows that uncompensated topography is associated with an admittance of Z_{10}^{uncomp} = 0.084 for degree 10; this is somewhat larger than the geoid-to-topography ratio at the northern rise, so the superposition of a lowadmittance mechanism such as crustal thickening is necessary. This combination can be represented as a system of two equations:

$$N_{lm} - N_{lm}^{topography} = N_{lm}^{moho} \quad \textbf{(2)}$$

$$H_{lm} = H_{lm}^{crustal} + H_{lm}^{flexure} \quad \textbf{(3)}$$

Here, $H_{lm}^{flexure}$ is a degree-dependent term that takes into account bending and membrane stresses [8]. The first of these equations can be solved independently to find crustal thickness, and then the second can be used to determine an arbitrary distribution of flexure.

A mean crustal thickness of 50 km [cf. 1] is used and inversions are performed with a Young's modulus range of E=[10^{10}-10^{11}] Pa and an elastic thickness range T_e=[30-100] km. By inverting equations (2) and (3) we find ~6 km of crustal thickening under the northern rise and 3-200 m of downward flexure from a previously undeformed state. For volcanic surfaces formed on the flanks of the northern rise prior to flexure, this model predicts radial slopes of 0-0.09° relative to the geoid. If pre-flexure topography was supported at a compensation depth of 50 km, then the geoid over the northern rise would have grown by $\Delta N \cong$ 50 m; this scenario produces slopes of 0.05-0.14° relative to the present-day geoid. In contrast, volcanic surfaces formed before a dynamic topography event would have slopes closer to those of long-wavelength topography (up to ~0.5° in the opposite direction). These conflicting slope predictions can be compared with crater floor tilt measurements from MLA [3, 9, 10].

Conclusions: Dynamic support of the northern rise is plausible only for certain mantle viscosity structures. In particular, dynamic topography is inconsistent with a high-viscosity lower mantle. However, other more complex models involving compositionally stratified convection or an elastic lithosphere still need to be evaluated. As an alternative to dynamic topography, a flexure scenario was evaluated, but volcanic construction with mantle residuum contributions [12] also requires evaluation. Both dynamic and flexural models of northern rise topography make predictions of crater floor tilts that can be tested with MLA measurements.

References: [1] Smith D. E. et al. (2012) *Science*, submitted. [2] Head J. W. et al. (2011) *Science*, 333, 1853. [3] Zuber M. T. et al. (2012) *Science,* submitted. [4] Hauck, S. A., II et al. (2012) *LPS, 43,* this mtg. [5] Margot J.-L. et al. (2007) *Science, 316,* 710. [6] Nittler L. R. et al. (2011) *Science, 333,* 1847. [7] Hager B. H. et al. (1985) *Nature, 313,* 541. [8] Turcotte D. L. et al. (1981) *JGR, 86,* 3951. [9] Klimczak C. et al. (2011) *GSA Ann. Meeting,* 142-10. [10] Balcerski J. A. et al. (2012) *LPS, 43*, this mtg. [11] Dickson J. L. (2012) *LPS, 43,* this mtg.

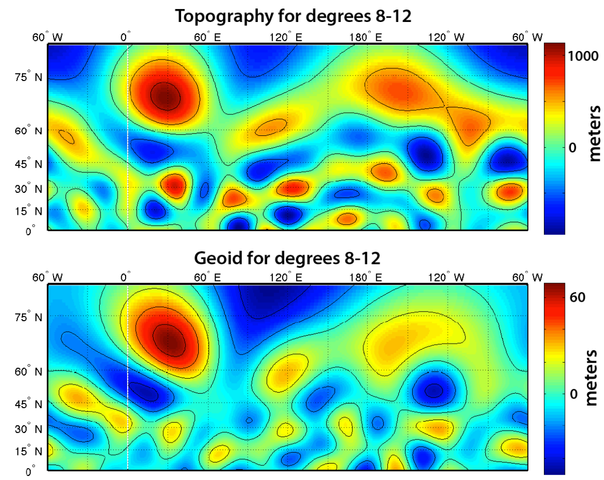

Figure 1. Northern hemisphere topography and geoid for a spherical harmonic bandpass between degrees 8 and 12 (Mercator projections).

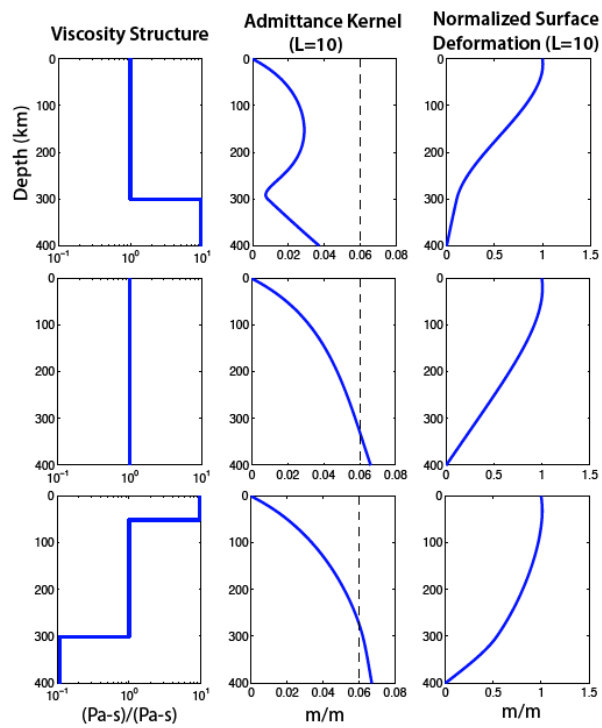

Figure 2. Dynamic topography models for three viscosity structures: a high-viscosity lower mantle (top row), an iso-viscous shell (middle row), and viscosity that decreases with depth (bottom row). Units for viscosity, admittance, and surface deformation are non-dimensional. Depth in the middle and right columns corresponds to load source depth.