GRAVITY/TOPOGRAPHY ADMITTANCES AND LITHOSPHERIC EVOLUTION ON MARS: THE IMPORTANCE OF FINITE-AMPLITUDE TOPOGRAPHY. Patrick J. McGovern, *Lunar and Planetary Institute, Houston, TX 77058, mcgovern@lpi.usra.edu*, Sean C. Solomon, *Dept. of Terrestrial Magnetism, Carnegie Inst. of Washington, Washington, DC 20015*, David E. Smith, *NASA Goddard Space Flight Center, Greenbelt, MD 20771*, Maria T. Zuber, Gregory A. Neumann, *Dept. of Earth, Atmospheric, and Planetary Sciences, MIT, Cambridge, MA 02139*, James W. Head, *Dept. of Geol. Sci., Brown University, Providence, RI 02912*, Roger J. Phillips, *Dept. of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130*, Mark Simons, *Div. of Geological and Planetary Sciences, Caltech, Pasadena, CA 91125*.

Introduction. Gravity [1] and topography [2] data collected by the Mars Global Surveyor (MGS) spacecraft are of sufficient quality and resolution to yield new insights into the evolution of the surface and interior of Mars. We calculate gravity/topography ratios (admittances) and correlations in the spectral domain [3] and compare them to those predicted from models of lithospheric flexure in order to estimate the thickness of an elastic lithosphere (T_e) required to support the observed topographic load [4, 5]. In regions of extreme topographic relief on Mars (e.g., the Tharsis Rise and associated shield volcanoes), the mass-sheet (small-amplitude) approximation for calculation of gravity from topography is inadequate. A correction that accounts for finite-amplitude topography [6] tends to increase the amplitude of the predicted gravity signal. We implement this correction and explore the implications of localized admittances for the compensation of surface features and the thermal evolution of the planet.

Method. We calculate gravity/topography admittances and correlations using a spatio-spectral localization approach [3]. We localize within windows of fixed widths specified by harmonic degree l_{win} = 5, 10, or 15 (spatial diameters of 4000, 2000, or 1400 km, respectively). We generate gravity models using the observed topography as a surface load on a thin, spherical elastic shell [7]. Elastic lithosphere thickness T_e is varied; load density ρ_l and crustal density ρ_c are both set to 2900 kg/m^3 [4]. We also consider sublithospheric bottom loading, parameterized by the ratio f of bottom to top load magnitude [8]. We calculate localized admittances vs. spherical harmonic degree l for the observed topography and gravity fields and for models of lithospheric flexure (e.g., Fig. 1). Our estimates of T_e are most accurate for regions exhibiting small admittance fluctuations, small formal errors, and high correlations. Estimates of T_e cannot be obtained for regions with strongly-varying or negative admttances and negative or near-zero correlations, including the northern lowlands of Mars and the Argyre and Isidis impact basins.

Gravity from finite-amplitude topography. The method used to model gravity perturbations resulting from relief on density interfaces profoundly influences interpretations of MGS-derived gravity fields and admittances. Under the commonly used mass-sheet approximation, admittance spectra approach a constant value with increasing T_e (the "rigid limit"). At Olympus Mons, for instance, the nominal model yields a rigid-limit admittance that falls far short of the observed values (Fig. 1a). In order to match the observations, models with buried excess loads highly correlated with topography [9] or surface densities in excess of 3300 kg/m^3 [4] are required; the former would induce horizontal compressive edifice stresses inconsistent with observed broad volcanic effusion [10], and the latter works only over a limited waveband (see solid line in Fig. 1a).

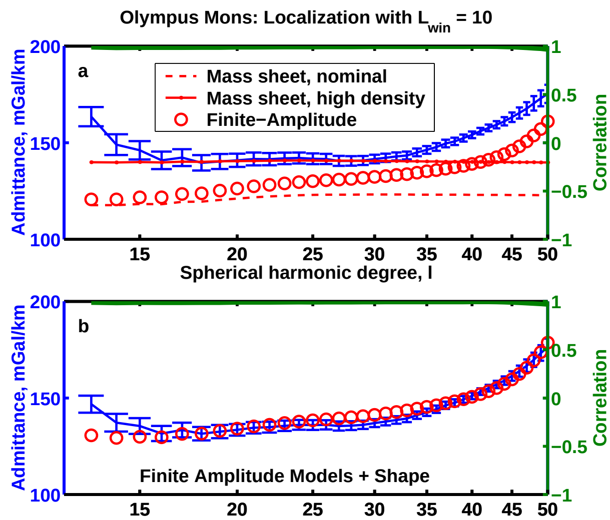

Fig. 1. Gravity/topography admittances, localized [3] with a 2000-km-diameter window. Left axis: admittances from MGS topography and gravity data (solid line with error bars), and admittances from MGS topography and modeled gravity from flexure model with T_e = 200 km (thin lines and circles). Right axis: correlation of MGS gravity with topography (thick solid line).

However, with a calculation of gravity from finite-amplitude topography [6], the resulting model admittance curves more closely match the observed curve in both magnitude and shape. The upturn at high l (circles, Fig. 1a) is caused by the increased attraction of the short-wavelength near-summit topography atop the longer-wavelength high of the Olympus Mons edifice. In order to account fully for this coupling of short and long wavelengths, the radii from the center of mass (collectively known as the planetary "shape") must be used instead of the equipotentially-referenced topography. If radius is used in place of topography, the nominal model (circles, Fig. 1b) and observed admittance curves match very closely. This correction will affect admittances for short-wavelength topography atop longer-wavelength highs (e.g., the Tharsis Montes and rise, and the southern hemisphere cratered uplands) and lows (the northern hemisphere lowlands and large basins). The planetary shape component of the correction will be greatest near the equator and at the poles, due to rotational flattening.

Olympus Mons and Tharsis Montes. Gravity/topography admittance spectra for the central Tharsis region are characterized by high magnitudes and low formal errors, dominated by

Feature	Age	T_e (km)	Subsurface loading
Tharsis shields	A	100–200	no
Domal rises	A-H	50–100	some
Valles Marineris	A-H	50–200	significant?
Highland plana	H	0–50	significant
Cratered uplands	N	0–20	variable

Table 1. Age, T_e estimate, and indication of subsurface loading for several regions of Mars amenable to analysis by admittance techniques. Letters A, H, and N refer to Amazonian, Hesperian, and Noachian epochs, respectively.

the strong signals from the large shield volcanoes [4]. Gravity/topography correlations are very nearly 1. Gravity models that employ the mass-sheet approximation are unable to match the observed admittance magnitudes (especially at short wavelengths; see Fig. 1a) without invoking unusually large densities [4] or dense buried loads [9]. When gravity models for the central Tharsis region are calculated with the finite-amplitude formalism, the resulting admittance spectra match observed spectra without resorting to peculiar loads. These models yield 100 $\leq T_e \leq$ 200 km.

Alba Patera and Elysium Rise. Localized admittance spectra at Alba Patera yield an excellent fit to T_e = 50–75 km. This result is consistent with estimates for T_e from a sill-inflation model for the construction of the edifice [11]. An admittance dropoff at high l may indicate short-wavelength intra- and sub-crustal intrusions that are uncorrelated with current topography [11]. The long-wavelength admittance spectrum at the Elysium Rise resembles that of Alba Patera, suggesting a similar evolution of both constructs [4, 11] as “domal rises” (Table 1). Best-fit T_e at the Elysium Rise is 50–100 km.

Valles Marineris. Coprates Chasma exhibits admittance and correlation spectra typical of the Valles Marineris. The admittance spectrum is flat, especially at short wavelengths (l > 25) and is not fit well by the nominal model with any particular value of T_e. The flatness of the spectrum suggests a largely uncompensated model, but with a reduced surface density (< 2500 kg/m^3) or a significant component of subsurface loading (f > 0.33) to match the admittance. The gravity/topography correlation is near unity over the entire waveband, consistent with either an uncompensated trough or subsurface compensation of a shape that closely corresponds to that of the trough. The latter may be accomplished though crustal thinning or intrusion of high-density dikes beneath the troughs.

Highland Plana. The Thaumasia Plateau region of southeastern Tharsis consists of broad volcanic plains (Syria, Solis, and Sinai Plana) ringed by rugged highlands (Claritas Fossae, the Thaumasia highlands, and the Coprates Rise); these units are mostly of Hesperian and Noachian age [12]. Admittance magnitudes in this region are typically smaller than those in volcano-dominated regions of Tharsis farther north. At Syria Planum, a 1400-km-diameter window yields a low-magnitude admittance spectrum and low correlation consistent with a substantial component of local subsurface loading. In Solis Planum, the 2000-km-diameter window yields high correlation and admittance values consistent with surface loading for $T_e \leq$ 50 km. The 1400-km-diameter window, however, results in reduced correlation and admittance magnitudes, also consistent with subsurface loading.

Southern cratered uplands. The admittance spectrum for the south rim of the Hellas impact basin is typical for the ancient (generally Noachian in age) southern highlands of Mars: small formal errors, high correlation, and a trend broadly consistent with compensation at $T_e <$ 20 km, approaching Airy isostasy in some regions. However, some southern highland regions (for example, parts of Noachis Terra and Terra Sirenum) exhibit correlations much less than 1, suggestive of a subsurface load component.

Discussion. The characteristics of localized admittance and correlation spectra for structures on Mars appear to be functions of age. The large shield volcanoes (Olympus Mons and the Tharsis Montes) with Amazonian-aged surfaces are characterized by high admittance magnitudes and correlations (Fig. 1a). The admittance spectra are consistent with loading at high T_e, indicating low heat flux from the martian mantle during edifice construction. If the troughs at Valles Marineris are uncompensated (as suggested by the admittance), they must have formed during an era of similarly low local mantle heat flux (e.g., low enough to yield T_e > 100 km). Pre-Amazonian volcanic constructs (Alba Patera) and plains (Syria and Solis Plana) tend to exhibit lower admittance magnitudes and correlations than the large shields. Such spectra are consistent with low to moderate T_e at time of loading and a significant component of subsurface loading uncorrelated with the current topography. The powerful “large shield” admittance signal (Fig. 1) dominates central Tharsis, obscuring the signal from earlier stages of the region’s evolution in a manner analogous to the way that the young lava flows emanating from the Tharsis Montes cover older geologic and tectonic features. In contrast, young shield volcanoes are absent on the broad Hesperian- and Noachian-aged lava plains of the Thaumasia plateau. Admittance and coherence spectra for this region thus likely reflect earlier stages of the planet’s history, when heat flux from the mantle was greater (and T_e was less) and subsurface loading contributed strongly to the gravity field (in contrast to the presumably surface-dominated gravity signal from the young shield volcanoes). The lowest T_e values are found for the cratered southern highlands of Mars, which are among the oldest surface terrains on the planet. In summary, predicted T_e values generally decrease with increasing surface age of feature, consistent with declining heat flux from the martian mantle.

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