AN OVERVIEW OF LITHOSPHERIC FLEXURE ON MARS: IMPLICATIONS OF INITIAL MOLA OBSERVATIONS.

Sean C. Solomon[1], Catherine L. Johnson[1], Patrick J. McGovern[1], Oded Aharonson[2], W. Bruce Banerdt[3], James W. Head[4], Roger J. Phillips[5], David E. Smith[6], and Maria T. Zuber [2], [1]Dept. of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, N.W., Washington, DC 20015 (scs@dtm.ciw.edu), [2]Dept. of Earth, Atmospheric, and Planetary Sciences, M.I.T., Cambridge, MA 02139; [3]Jet Propulsion Laboratory, Pasadena, CA 91109; [4]Dept. of Geological Sciences, Brown University, Providence, RI 02192; [5]Dept. of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130; [6]NASA Goddard Space Flight Center, Greenbelt, MD 20771.

Introduction. The thickness of the elastic lithosphere on a planet is a measure of the reciprocal of the vertical thermal gradient in the lithosphere, and thus of interior heat flow [1]. Most commonly the lithosphere thickness is estimated from the flexural deflection of the lithosphere in response to loading, but for Mars that methodology has been hindered by the lack of accurate topographic information of sufficient horizontal resolution. Instead the earliest estimates of the thickness of the elastic lithosphere on Mars were derived from the radial distances of circumferential graben inferred to be the result of flexural stresses near axisymmetric loads [2], or from the absence of such graben around a known load [3]. A few other estimates have been obtained from limited harmonic topography and gravity [4,5].

The Mars Orbiter Laser Altimeter (MOLA) [6] on board the Mars Global Surveyor (MGS) spacecraft has provided the first high-resolution altimetry measurements from Martian orbit. A number of profiles cross features expected to exert a significant load on the Martian lithosphere. In this paper we discuss the implications of the new altimetry for assessing the thickness of the elastic lithosphere and its spatial and temporal evolution on Mars.

Large Volcanoes. Elastic thickness estimates of 20-50 km have been derived from the radial distances to circumferential graben for five volcanic constructs on Mars: Ascraeus, Pavonis, Arsia and Elysium Montes and Alba Patera [2]. In addition, the elastic lithospheric thickness beneath Olympus Mons has variously been held to be at least 150 km from the absence of circumferential graben [2,3] and 25-50 km on the basis of harmonic topography and gravity [4,5]. Two MOLA profiles (MGS orbits 24 and 33) cross three of these large volcanoes: Olympus Mons, Arsia Mons, and Alba Patera. A detailed assessment of those profiles in terms of volcano evolution and lithospheric flexure is given elsewhere [7], so only a summary of the principal findings needs mention here.

The profile across the western flank of Olympus Mons (MGS orbit 24) displays relative topographic lows immediately outward of the volcanic edifice, and a reasonable working hypothesis is that these lows reflect subsidence arising from the loading and flexure of the Martian lithosphere by the volcano. The quantitative estimation of the flexural strength of the lithosphere from the topographic profiles outward of the volcano, however, is problematic. There are two relative topographic highs north of the edifice; the nearest (centered about 600 km from the volcano center) consists of highly disrupted aureole deposits and the more distal (centered about 1200 km from the volcanic center) is older (Noachian) terrain including the densely fractured Acheron Fossae region [8]. If the more distal rise is flexural in origin, then a thickness of 75-100 km for the underlying elastic lithosphere is implied and the loading history of Olympus Mons may extend back to the Noachian era [7]. To the south of the Olympus Mons edifice, the nearest relative topographic high (centered about 800 km from the volcano center) occurs within the Medusae Fossae Formation, interpreted to be pyroclastic or aeolian deposits [8]. If this high is flexural in origin, an elastic lithosphere about 40 km thick is implied [7].

The two new estimates for elastic lithosphere thickness are in disagreement, but they lie within the range of previous estimates. Testing the hypothesis that the candidate flexural features have been correctly identified and reconciling these disparate estimates for lithospheric thickness will require further topographic data and an integration with geological unit history and gravity.

The altimetric profiles of Arsia Mons and Alba Patera (MGS orbit 33) lack discernible signatures of lithospheric flexure, despite the fact that both volcanoes display prominent gravity anomalies [9,10] and should thus exert significant lithospheric loads. This result implies that any flexural depression around each volcano, at least along the azimuths sampled by the single altimeter pass, must be filled by some combination of volcanic flows and landslide material from the edifice [7].

Isidis Basin. The Isidis basin is the only large impact basin on Mars known to be associated with a lunar-like mascon [9,10]. A fit to the radial distances of circumferential graben indicates that the elastic lithosphere was at least 120 km thick at the time of loading [2]. One MOLA profile (MGS orbit 34) crossed the basin. While no flexural signature is apparent in the altimetry, the elevations and relief are similar to those available prior to MGS, a consequence of high-quality Earth-based radar measurements of regional topography [11,12]. Thus there is no basis for inferring an elastic lithosphere thickness different from the previous estimate, at least pending improved altimetric coverage and an improved regional gravity field.

North Polar Deposits. Another load on the Martian lithosphere of significant horizontal extent but poorly known magnitude is that imparted by the north polar deposits. The north polar region is the site of a positive free air anomaly [13]; the average thickness of the polar deposits has been estimated to be at least 2 km [14], and the thickness may be as great as 5 km [4]. From the mean thickness and the gravity anomaly, a density of 1 g/cm^3 has been estimated [13], but that estimate has a large uncertainty.

A number of the MOLA passes reached within about 10° of latitude of the north pole; two (MGS orbits 22 and 31) of the profiles most suggestive of flexure are shown in Figure 1. Also shown in the figure are the southern limits along these profiles of polar layered deposits (including residual ice), linear dune material, and debris mantle material [15]; the latter two units, while not formally part of the polar layered terrain, may contribute to the distal portions of the lithospheric load.

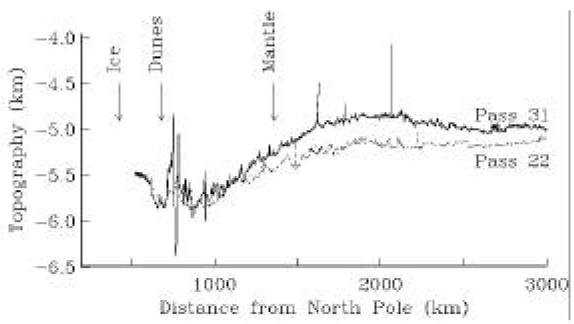

Figure 1. MOLA topographic profiles for passes 31 and 22, plotted versus distance from the pole. The southern limits of polar layered deposits (including residual ice), linear dune material, and debris mantle material are indicated.

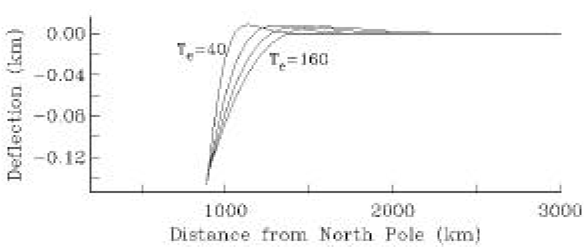

Figure 2. Deflection due to loading by a cylindrical cap of height 1 km, density 1 g/cm^3, and radius 15° for elastic lithosphere thicknesses of 40, 80, 120, and 160 km.

Comparison flexure profiles for a simple load model (a vertical cap or cylinder of uniform thickness and 15° radius) are shown in Figure 2. The model profile is strongly dependent on the radius of the load and on the lithospheric thickness. Deflection scales linearly with load amplitude, and results for different load radii are similar to those shown but with a corresponding radial shift in the deflection curves. Comparison to observed profiles suggests that a flexural interpretation is viable as long as the elastic lithosphere is thick (120 km or greater) and significant components of the polar load are contributed by the dune and debris mantle materials. Improved estimates will be possible from simultaneous inversions of all near-polar profiles and non-axisymmetric load models permissive of variations in latitudinal extent of load units.

Discussion. The new estimates of the thickness of the Martian lithosphere can be converted in turn into estimates of lithospheric thermal gradient and heat flow at the time of loading, given flow laws and thermal conductivity values for crustal and mantle material [1]. The preliminary lower bound on lithospheric thickness (120 km) suggested by a flexural interpretation of profiles southward of the northern polar deposits is consistent with a modern global heat flux [1] for the planet of about 20 mW/m^2, an estimate that includes the distinct thermal conductivities of crustal and mantle material and a mean thickness of the high northern latitude crust of 30-50 km. This heat flux is in line with the mantle heat production expected on the basis of SNC meteorite compositions [16,17]. A greater heat flux, 25-35 mW/m^2, is implied by a 40-100 km elastic lithosphere thickness beneath Olympus Mons. Such a higher heat flow is to be expected on the basis of the realtively high magmatic flux of the Tharsis region and the potentially older era represented by the flexural signature.

MOLA data to be collected while MGS is in the science phasing orbit and during the subsequent global mapping phase promise to improve substantially our information on lithospheric flexure and heat flux on Mars.

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