CRUSTAL THICKNESS VARIATIONS AT VALLES MARINERIS, MARS;

F. Scott Anderson and Robert E. Grimm, Department of Geology, Arizona State University, Tempe, AZ 85287-1404; anderson@violetta.la.asu.edu.

Summary. The thicknesses of the crust and elastic lithosphere at Valles Marineris (VM) are constrained using the gravity and topography data sets of Goddard Mars Model-1 (GMM-1). Derived results useful for modeling formation of the rift include bounds on total extension and the minimum heat flow at the time of rifting. Regional crustal thickness lies between 45-60 km, pre-erosional extension between 10-25%, and heat flux is constrained to be > 50 mW/m^2. Under slow extension, the crustal thickness and heat flux results are consistent with early distributed faulting (wide rifting) forming the central parallel troughs.

Data and Methods. Our analysis used the GMM-1 50th degree and order spherical harmonic representations of free-air gravity and topography [1]. Typical half-wavelength resolution for these data sets is ~210 km, large enough to clearly observe a single broad anomaly for the central trough system. Examination of individual LOS orbits showed that GMM-1 had accounted for most of the gravity signal amplitude at VM. However, a local phase error is manifested as a 60 km offset of the gravity field to the NE. We correct for this error by comparing only the amplitudes of observed and predicted signals, rather than both amplitude and phase as in automated minimum-variance calculations. The observed anomaly, ~190 mgal, was taken to be the largest negative gravity signal in VM minus the average gravity value at the 4000 m contour. 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]. Assuming that the mantle is not exposed at the floor of VM, an independent constraint on minimum regional crustal thickness follows simply from isostatic considerations, without necessarily satisfying the gravity data. Increasing flexural compensation flattens perturbations on the moho, allowing a thinner regional crust.

Formal errors on the gravity and topography fields at VM are 70 mgal [1] and 1 km [4], respectively. We convert topography error into an equivalent gravity error by taking the predicted gravity difference between the original topography and the "erroneous" topography. The erroneous topography is calculated by stretching the topography 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 gravity is mitigated by compensation; therefore the gravity equivalent of the topography error varies continuously with assumed values of H and Te. Adding the variances from both gravity and topography yields a total error of ~80 mgal, which then provide error bounds on derived parameters such as H and Te.

Results. Acceptable combinations of Te and H are inversely related at VM (Fig. 1). As Te increases, short-wavelength surface features become flexurally compensated, requiring less compensation at the moho and producing more a negative net gravity anomaly. In order to match the observed anomaly, the crustal thickness must then be decreased to place the positive density contrast and gravity anomaly closer to the surface. Using the additional constraint of minimum crustal thickness, the best-fit values are H = 45-60 km and Te < 16 km; the errors allow the full range H = 33-80 km, Te < 27 km. In principle, these values should reflect the time of rifting, however, erosion has widened the central troughs by up to a factor of three [5] and has deposited several km of sediments in parts of the valley floors [6], thus allowing the possibility that the inferred Te is that of the time of isostatic adjustment to erosion. Because heat flow has likely decreased with time, the value of Te may be treated as a minimum at the time of rifting.

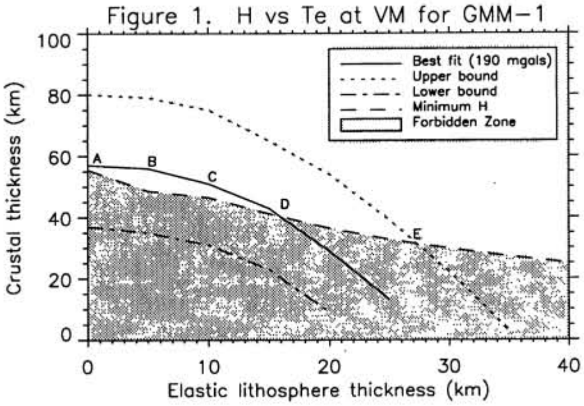
Figure 2 shows several N-S cross sections through the deepest part of the trough system (279° E) at the best-fit values of H and Te. These sections suggest that there can be no more than 10 km of crust beneath VM and, under the assumption that all crustal attenuation occurred by extension, constrain the maximum extension at this longitude to 300 km. Allowing for a threefold widening by erosion, this figure is reduced to 100 km. A minimum amount of erosion-corrected extension of 55 km follows from the maximum crustal thickness under the upper error bound. This range is comparable to previous estimates based on fault geometry [7].

Implications for the Formation of Valles Marineris. We previously applied a model for the evolution of lithospheric strength during rifting [8] to Valles Marineris [9]. This model predicts rift morphology as functions of extension rate, initial crustal thickness, and heat flow (q) (Fig. 3). Core complexes, characterized by very large amounts of extension, form under conditions of largest H and q. This mode may be rejected for Valles Marineris. Wide rifts form under intermediate H and q, wherein the uplifted strong upper mantle forces further extension to move outward. For low values of H and q, the upper mantle does not reach thermal equilibrium during rifting and so remains weak, allowing greater concentration of strain in a narrow rift. Valles Marineris shows geological characteristics of both wide and narrow rifts: multiple troughs at its center, and long, narrow, single troughs to the east and west. One possibility, consistent with timing relationships for the troughs [6], is that VM is an aborted wide rift, one that underwent a transition from wide to narrow as regional heat flow and/or strain rates fell [9].

The solutions for crustal thickness and heat flow derived from gravity lie largely within the wide rifting zone (Fig. 3), consistent with the location of the gravity observations over the multiple central troughs of VM. If erosional infilling has inflated the estimate of Te, it may be very difficult to achieve narrow rifting using this model. We conclude that the conceptual model of time-dependent lithospheric strength during rifting is consistent with independent constraints provided by gravity modeling. We will continue to test these data against other models, such as lithospheric necking, for the development of multiple troughs during rifting.

References. [1] Smith D.E. et al. (1993) *JGR 98*, 20871. [2] Turcotte D.L. and Schubert G. (1982) Geodynamics, John Wiley and Sons, New York. [3] Parker R.L. (1972), *GJRAS 31*, 447. [4] USGS Topographic Map of Mars: M 15M 0/90 2AT (1991). [5] Schultz, R.A. (1989) *MEVTV Workshop on Tectonic Features on Mars*, 47-48. [6] Lucchitta B.K. et al. (1994) *JGR 99*, 3783. [7] Schultz, R.A. (1991) *JGR 96*, 22777. [8] Buck, W.R. (1991) *JGR 96*, 20161. [9] Anderson F.S. and Grimm R.E. (1994) *LPSC XXV*, 29-30.

Figure 1. H vs Te at VM for GMM-1



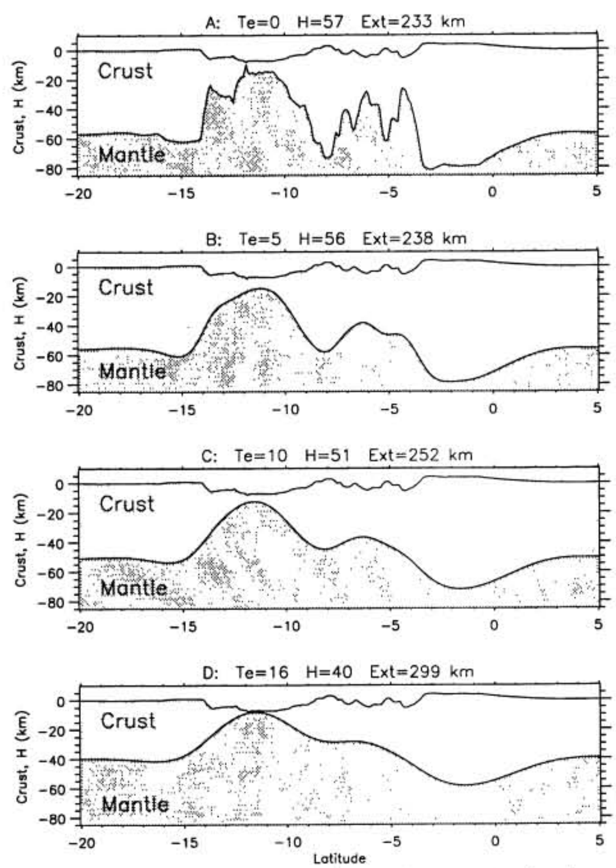


Figure 2. Cross Sections of Valles Marineris

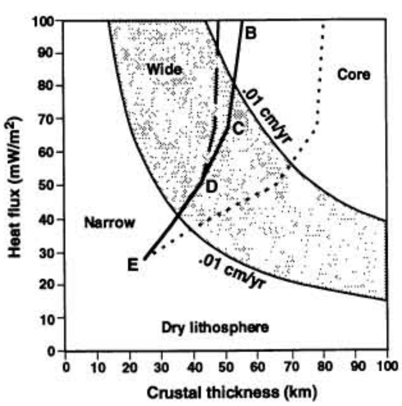


Figure 3. Constraints on rift model