GRAVITY OBSERVATIONS OF STRUCTURE IN VALLES MARINERIS, MARS. Walter S. Kiefer, Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058, kiefer@lpi.usra.edu, http://www.lpi.usra.edu/science/kiefer/home.html .

Introduction Valles Marineris is one of the most prominent tectonic structures on Mars. It is approximately 4000 km long [1] and up to 11 km deep [2]. Valles Marineris is oriented radial to the Tharsis volcanic province and formed primarily by normal faulting in an extensional rifting environment [3]. Detailed geologic mapping indicates that it formed primarily during the Early Hesperian [4], corresponding to deformation stages 2 and 3 in the deformation stratigraphy of Anderson et al. [5].

Gravity and topography observations provide clues that can help to constrain the mechanisms which produced Valles Marineris. Previous studies by McGovern et al. [6, 7] and by McKenzie et al. [8] used admittance modeling to constrain the compensation state of the region. McGovern et al. favored generally large elastic lithosphere thickness (T_E = 60-120 km) and either a very low surface density (around 2000 kg m^{-3}) or the presence of significant buried loads. McKenzie et al. favored a somewhat smaller elastic thickness, around 50 km, and a surface density of 2350 kg m^{-3}. The nearby Tharsis volcanic province has a basaltic composition corresponding to a higher crustal density (> 2800 kg m^{-3}), and layering in the Valles Marineris walls has been interpreted in terms of flood volcanism [9]. The very low surface densities inferred in some of these models pose significant challenges to our understanding of Valles Marineris, as they require either a very different crustal composition from Tharsis or a high porosity maintained throughout up to 11 km of exposed stratigraphy.

Method The admittance spectrum method used in past studies of Valles Marineris [6-8] is an excellent approach for defining the compensation state of a region. However, purely spectral models can not be used to define the amplitude and spatial distribution of possible buried loads or to assess the geologic causes of such loads. For this reason, my modeling approach [10, 11] uses a combination of both spectral domain calculations and spatial domain interpretation. I calculate the residual gravity anomaly after removing both the effects of the topography and of the best-fitting flexural compensation model, $R_{LM} = G_{LM} - F_L H_{LM}$. Here G_{LM} and H_{LM} are spherical harmonic expansions of the free-air gravity anomaly (model JGM95I, [12]) and topography [13] and F_L is a flexural response function calculated using thin-shell elastic flexure theory [14]. The residual anomaly, R_{LM}, is the part of the observed gravity anomaly that can not be explained by the topography and its compensating root. Thus, the residual anomaly represents either subsurface mass anomalies or regions where the surface density or compensation mechanism differs significantly from the assumed regional values. By mapping R_{LM} into the spatial domain, I can compare the residual anomaly with the known surface geology and make plausible inferences about the mass anomalies that produce the gravity signature.

Figure 1 shows an example of this approach, calculated assuming an elastic thickness of 60 km, a mantle density of 3400 kg m^{-3}, a crust density of 2900 kg m^{-3}, a mean crustal thickness of 50 km, Young's modulus of 10^{11} Pa, and Poisson's ratio of 0.25. Current gravity models for Mars have statistically useful signal up to about harmonic degree 72 [13], but terms above degree 60 are damped by constraints imposed in the inversion process [12]. Thus, Figure 1 conservatively includes only gravity and topography up to spherical harmonic degree 60, corresponding to a horizontal half-wavelength resolution of 180 km. Figure 1 shows that significant residual anomalies exist in several parts of Valles Marineris after removing the contribution of topography and its compensation. In this initial survey, I focus on three aspects of Valles Marineris.

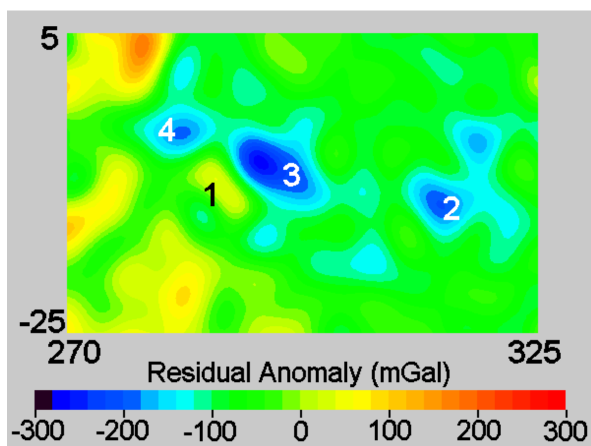

Figure 1: The residual gravity anomaly for the Valles Marineris region, 270 – 325 East, 25 South – 5 North, calculated using the parameter values in the text. Anomalies 1 to 4 are discussed in the text.

Dike Systems Mège and Masson [15] and McKenzie and Nimmo [16] proposed that normal faulting in the circum-Tharsis region, including Valles Marineris, occurs over subsurface dikes swarms. Dikes could contribute to the buried load inferred to exist in Valles Marineris [6]. The expected gravity signature of a dike depends on the density contrast between the dike material and the surrounding country rock. On Mars, surface lava flows are subject to vesicle formation due to volcanic outgassing and to impact brecciation. Both processes reduce the rock density relative to the density of intact bed rock of the same composition. Dikes forming at several km depth on Mars [17] would not be subject to either process and thus would be expected to be denser than the country rock, resulting in a positive gravity anomaly. If martian dike systems contain dense, cumulate minerals, as is observed in Hawaii [18], this would also contribute to a positive gravity anomaly. Of course, individual dikes would not be visible in the gravity field determined from orbit, but a broad swarm of dikes could produce a detectable signal.

In Figure 1, there is a weak positive gravity anomaly in Melas Chasma identified as anomaly 1. The anomaly is about 500 km along strike and has a peak amplitude of 40 mGal. Increasing the assumed elastic lithosphere thickness to 120 km increases the residual amplitude of anomaly 1 to 110 mGal but leaves the overall shape of the anomaly relatively unchanged. This anomaly is plausibly due to dense material in a subsurface dike swarm. The absence of similar anomalies to the east in Coprates Chasma and to the west in Ius Chasma may simply reflect the narrowness of these troughs and of any underlying dike swarm, which would therefore not be detectable from orbital altitude.

Capri Chasma Anomaly 2 in Figure 1 occurs in Capri Chasma, which connects Valles Marineris with the outflow channels to the east. Much of the floor of Capri Chasma is covered by chaos deposits [4], which are likely to be sedimentary and less dense than other portions of the crust. For a large but plausible density difference of 500 kg m^{-3} between normal crust and the sediments, the sedimentary layer would need to be about 10 km in thickness to explain the observed residual anomaly. This seems implausibly thick.

An interesting alternative explanation invokes lateral variations in the compensation state of Valles Marineris. Valles Marineris formed relatively early in martian history, at a time when volcanic activity in Tharsis was still significant. Thus, there might have been a significant gradient in heat flow and lithospheric thickness across Valles Marineris, ranging from high heat flow and thin lithosphere in the west to low heat flow and thick lithosphere in the east. Increasing the assumed elastic lithosphere thickness decreases the amplitude of residual anomaly 2, making it easier to explain the anomaly as a sedimentary structure. Quantitative trade-offs between the assumed lithospheric properties and the required sedimentary basin parameters are currently being assessed.

Northern Wall Rock Residual anomaly 3 occurs on the northern wall rock of Valles Marineris, north of Coprates Chasma and east of Candor and Ophir Chasma. Residual anomaly 4 is smaller in both size and amplitude and also occurs on northern wall rock to the north of Ius and Tithonium Chasma and to the west of Candor and Ophir Chasma. The negative residual anomaly requires that the crust in this region is significantly less dense than elsewhere, suggesting a possible difference in composition. However, the origin and significance of the density difference remains unclear.

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