EXPLORING EARLY THARSIS: GRAVITY OBSERVATIONS OF RADIATING DIKE SYSTEMS IN THE THAUMASIA REGION OF MARS

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Introduction The Tharsis region of Mars is the dominant volcanic and tectonic province on the planet, with activity stretching from the earliest part of martian history to the present day. This work reports the first portion of a multi-year project that focuses on the earliest part of Tharsis history. Here, I use gravity and topography observations to constrain lithospheric and crustal structure in the Thaumasia region of Mars, which defines the southeastern margin of Tharsis. This region has long been recognized as an important early center for Tharsis tectonism [1,2]. Detailed geologic mapping indicates that much of this activity occurred in the Late Noachian and Early Hesperian [3-6]. This corresponds to extensional faulting predominantly in stages 1 and 2 and wrinkle ridge formation during stage 3 of the Anderson et al. [6] tectonic chronology. The pattern of positive gravity anomalies observed in this region suggests the presence of volcanic dikes both in the younger portions of Claritas Fossae and across much of Solis Planum.

Previous Geophysical Models Previous work typically favored a relatively thin elastic lithosphere in Thaumasia at the time that the major topography was emplaced. McGovern et al. modeled the admittance spectrum for a 2000 km wide region centered on Solis Planum and found best fit values of T_E=24-37 km for the elastic lithosphere thickness and 2900 kg m^{-3} for the surface load density [7]. Williams et al. found T_E < 20 km based on modeling of line-of-sight gravity profiles [8]. On a more local basis, models of rift flank uplift at Coracis Fossae indicate T_E = 10-13 km [9] and mechanical modeling of thrust fault scarps imply a seismic layer thickness of 21-35 km [10].

Results Prior work has demonstrated the utility of residual gravity anomaly maps, which remove the effects of both the surface topography and of the topography's compensating root from the free-air gravity anomaly [11, 12]. Assuming a reasonable estimate of the compensation mechanism is used, structures that are observed in a residual gravity anomaly map must be due to buried density anomalies and thus can be used to map sub-surface structure.

Figure 1 shows a residual gravity anomaly map for the study region, calculated assuming T_E=30 km, a surface load density of 2900 kg m^{-3} [7] and a mean crustal thickness of 50 km [13]. Results are shown to spherical harmonic degree 72 [14,15], which corresponds to a resolving wavelength of 300 km. The most prominent residual gravity anomalies in this study area are associated with Claritas Fossae, which contains numerous graben trending roughly North-South, radial to south-eastern Tharsis. However, the graben system is not uniformly associated with large amplitude gravity anomalies. The large anomalies occur on the eastern side of Claritas, which contains stage 2 and 3 faults [6] and which is mapped primarily as either Hesperian or Noachian-Hesperian, although some purely Noachian age units occur within the gravity high [5]. In contrast, the western graben, which are not associated with the gravity high, correspond to stage 1 faulting and occur exclusively in Noachian geologic units [5,6].

The positive residual gravity anomalies in Claritas require the presence of large volumes of high density material in the subsurface. Prior work has suggested that extension at many graben on Mars may be driven by emplacement of volcanic dikes, although there is not likely to be a one-to-one correspondence between graben and dikes [16-19]. If the magma that fills the dike is denser than the surrounding crust, as is observed in Hawaii [20], the dike will produce a positive gravity anomaly. Of course, individual dikes are not dectectable in orbital gravity data, but the aggregate effect of dike swarms is detectable. The peak amplitude of the residual anomaly in Claritas Fossae is weakly sensitive to the choice of elastic thickness, varying by 10 mGal for T_E between 20 and 40 km. The observed anomaly amplitudes can be easily reproduced by plausible values of igneous rock densities [11], particularly given that martian dike systems may be up to 20 km in vertical extent [21]. Assuming that the source for the dike intrusions is Tharsis volcanism, the absence of a gravity anomaly over the oldest (Stage 1) graben in western Claritas may indicate a chemical evolution in Tharsis towards denser lavas during the Late Noachian and Hesperian. Also, because the older dikes formed on thinner lithosphere, they may be more compensated, resulting in smaller gravity anomalies.

Many of the positive gravity anomalies in Figure 1 are somewhat elongated. The elongated directions of most of the positive anomalies (blue dashed lines in Figure 1) appear to radiate from a common center point in south-central Tharsis, suggesting a common origin for the various anomalies. Given the likelihood that gravity anomalies in both Claritas Fossae and on the floor of Valles Marineris are related to dikes [22], a common origin for all of these anomalies would imply the presence of dike swarms across much of Solis Planum. There is no topographic or tectonic evidence for dikes at the present-day surface in Solis Planum. However, the lava plains in Solis Planum (units Hsl1, Hsl2, Hsu, and Hr, [5]) are stratigraphically younger than the graben-related units (units Nf, HNf, and Hf) in Claritas Fossae. Perhaps evidence of dike emplacement in Solis Planum was simply obscured by later geologic activity.

This suggestion of wide-spread dike systems in Thaumasia might appear to conflict with previous admittance results, which concluded that there was little or no bottom loading evident in admittance spectra for Thaumasia [7,8]. In part, this is due to improvements in the resolution of the gravity field, which now includes relatively short wavelengths that were not reliably measured just a few years ago [14, 15]. Moreover, if the buried loads have a shallow origin (such as dikes), they still would act as loads on the top of the lithosphere and thus would not be detected as “bottom loads” in admittance spectrum modeling; bottom loads are emplaced at the base of the elastic lithosphere. Ongoing Doppler tracking of the Mars Reconnaissance Orbiter should improve the resolution of the spherical harmonic gravity field model and thus sharpen our view of these dike systems.

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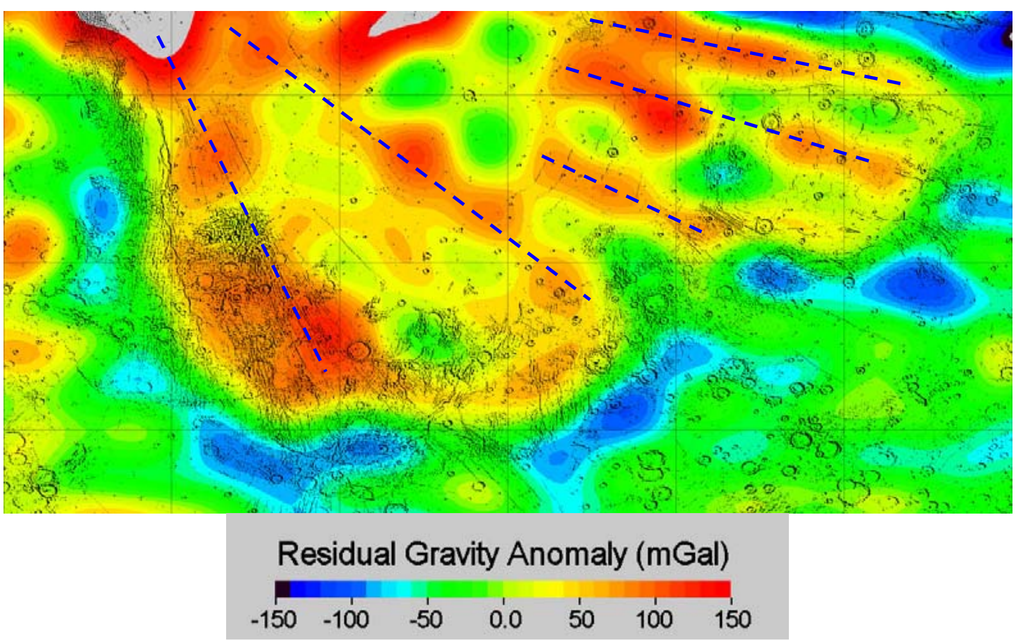

Figure 1. Residual gravity anomalies in Thaumasia, 15° – 45° South, 245° – 305° East. The underlying shaded relief image is a Viking MDIM mosaic, processed to emphasize shadowed regions such as fault scarps and impact crater rims. The blue dashed lines emphasize the common orientation of many of the positive anomalies radial to Tharsis. Simple cylindrical projection. The region shown is 3080 km across at map center (30° South). In order to emphasize the anomalies in the majority of the study region, the color bar is saturated at +150 mGal, which affects only anomalies between 15° and 17° South (shown in gray).