THE FORMATION OF THARSIS IN THE EARLY NOACHIAN: WHAT THE LINE-OF-SIGHT GRAVITY IS TELLING US.
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Introduction: Tharsis is a vast, complex topographic rise on Mars that has undergone protracted volcanic and tectonic activity spanning nearly the entirety of Mars' history [1]. The Thaumasia region that defines the southeastern most portion of Tharsis can been seen as being topographically coherent with the main central rise containing the Tharsis Montes (Ascraeus, Pavonis, and Arsia) [2,3]. This region is identified as an arcuate mountain belt, the Thaumasia Highlands, which extends southward from the region of the Tharsis Montes (containing Claritas Fossae) that then curves northeastward in a "scorpion tail" pattern to form a quasi-circular feature. The Thaumasia highlands, the oldest preserved portion of Tharsis, contains heavily cratered Noachian terrains that have survived resurfacing by younger volcanic flows presumably because of their high elevation. These mountains, standing 4-5 km above the surrounding cratered highlands, bound an interior plateau that includes Solis, Sinai, and Syria Planum [2]. Immediately adjacent to the Thaumasia Highlands in the surrounding cratered plains, a negative free-air gravity anomaly flanks the high standing topography (Figure 1). This gravity anomaly reveals a possible flexural trench created by the loading of the lithosphere by Thaumasia that has undergone subsequent burial by lava flows and debris.

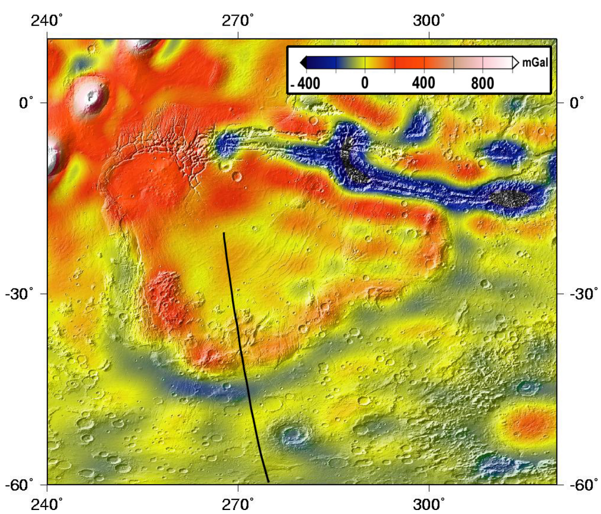

Figure 1. Free-air gravity anomaly (MGS75D). The negative gravity signal flanking the Thaumasia Highlands (blue) may indicate a buried trench. Line is the location of the acceleration profile plotted in figure 2.

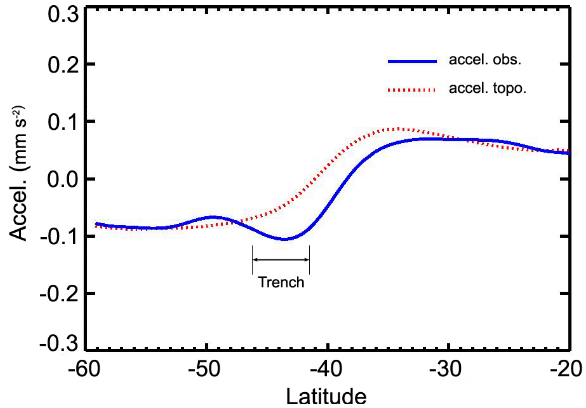

Figure 2. Observed los acceleration for MGS (blue) and expected acceleration derived from topography (red). Location of trench identified by MOLA topography and surface geology is shown. See figure 1 for the ground track of the profile.

Forward Model: Direct line-of-sight (LOS) spacecraft accelerations have been analyzed [see 4 and 5 for details] and confirm that the negative gravity anomaly associated with the Thaumasia Highlands observed in the spherical harmonically represented data is real and is not simply an artifact (i.e. ringing). An acceleration profile crossing the trench is shown in figure 2 along with the predicted acceleration that would result from the topography (see figure 1 for location of profile). The negative gravity anomaly is evident in the raw spacecraft acceleration and is not correlated with that expected from the topography.

We have employed a forward model to fit the flexural wavelength of the gravity signal generated by the buried trench and estimate the elastic thickness (T_e) to have been relatively thin (~ 20 km) at the time Thaumasia loaded the lithosphere. T_e can be regarded as the depth at which a planets interior becomes too weak to support stresses over geologic time scales (~10^8 yrs). This depth, being related to the inverse of the thermal gradient, implies the value of T_e increases with time as heat flow from the planet's interior diminishes [6]. As a result, T_e reflects the state of the lithosphere at the time of loading allowing temporal comparisons to be made on a regional basis [7]. The oldest features reflect a small flexural wavelength, as they are associated with young, thin lithosphere. Values of $T_e \leq 20$ km are observed in the most ancient portions of the Martian crust [7, 8] and are consistent with the Thaumasia Highlands having formed in the Early Noachian.

Admittance: From the LOS accelerations, we have derived the admittance, the transfer function between topography and gravity, for the southeast portion of Tharsis that encompasses Thaumasia. A best fit to the data yields a value for T_e of ~71 km (Figure 4) [see 9 for model description]. This higher value reflects more recent events, such as the formation of Valles Marineris or the continued subsidence of the Thaumasia plateau, which will dominate the regional admittance in which the signal of the buried trench is embedded. Even greater values of T_e, >100 km, have been observed northwest of Thaumasia where the large, younger shield volcanoes of the Tharsis Montes are located [e.g. 7, 8]. As T_e is presumed to increase with time, an evolutionary trend in Tharsis development is suggested with the earliest manifestation of Tharsis occurring in the southeast and progressing northwest. This is consistent with the surfaces ages of the mapped geologic units of Tharsis [10] that follow this same trend.

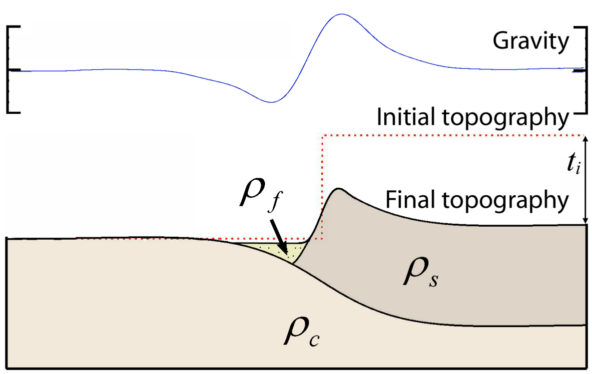

Figure 3. Cartoon depicting forward model with best-fit parameters: crust density ρ_c ~2900 kg m^{-3}, load density ρ_s ~3000 kg m^{-3}, fill density ρ_f,~1600 kg m^{-3}, initial plateau height t_i ~6 km), and elastic thickness T_e~20 km.

Conclusion: The gravity signal reveals a buried trench resulted from the formation of the Thaumasia plateau during the Early Noachian. The relatively thin T_e implied by the signal and the Noachain terrains preserved on the margin of the Thaumasia plateau indicate that the development of Tharsis was well underway in the Early Noachian. Further, T_e values from admittance indicate Tharsis development progressed toward the northwest through the Hesperian and Amazonian, consistent with the mapped geology which reflects the same trend [10]. This suggests there has been an alteration to the underlying convection since the Early Nochian resulting in a migration in volcanic activity away from Thaumasia and the preservation of Noachian terrains on the southeast margin.

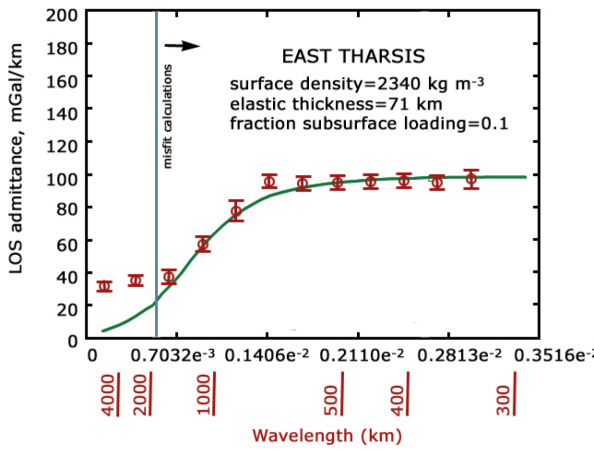

Figure 4. The LOS admittance for Thaumasia. Lat/Lon range of area used in obtaining the admittance is that of figure 1.

References: [1] Banerdt B. W. et al. (1992) in *Mars*, 249–297. [2] Smith D. E. et al. (1999) *Science*, *284*, 1495-1503. [3] Smith D. E. et al. (2001) *JGR*, *106*, 23,689-23,722. [4] McKenzie D. and Nimmo F. (*1997*) *Icarus*, *130*, 198-216. [5] McKenzie D. et al. (*2002*) *EPSL*, *195*, 1-16. [6] Solomon S. C. and Head J. W. (*1990*) *JGR*, *95*,11,073-11,083. [7] Zuber M. T. et al. (*2000*) *Science*, *287*, 1788-1793. [8] McGovern P. J. et al. (*2002*) *JGR*, *107*, doi: 10.1029/2002JE00-1854. [9] Nimmo F. (*2002*) *JGR*, *107*, doi:10.1029/2000JE001488. [10] Scott D. H. and Tanaka K. L. (*1986*) *USGS Misc. Inv. Series Map*, I-1082-A.