**THE FORMATION OF THARSIS: WHAT THE LINE-OF-SIGHT DATA IS TELLING US.** J.-P. Williams[1], F. Nimmo[2], and W. B. Moore[3], [1]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, jpierre@gps.caltech.edu, [2]Department of Earth Sciences, University of California, Santa Cruz, CA 95064, [3]Department of Earth and Space Sciences, University of California, Los Angeles, CA 90095,

**Introduction:** Tharsis is a vast, complex topographic rise on Mars extending over 30 million square kilometers that dominates the western hemisphere of Mars. The region has been the locus of large-scale volcanism that has endured for the entirety of the planet's history, resulting in pervasive fracturing of the crust from lithospheric loading by the voluminous intrusive and extrusive magmatic deposits [1,2,3,4].

In this study, we present results from analysis of line-of-sight (LOS) spacecraft acceleration profiles from the Radio Science Experiment of the Mars Global Surveyor (MGS) for the primary purpose of estimating the effective elastic thickness ($T_e$) for various regions of Tharsis. This is done using two approaches: 1) best-fitting individual LOS profiles that cross the Thaumasia Highlands with a forward model, and 2) determining admittances from LOS profiles for various regions of Tharsis and fitting them with theoretical curves. The value of $T_e$ reflects the thermal state of the lithosphere at the time topographic loads are emplaced allowing temporal comparisons of features and crustal provinces to be made (e.g. [2]). The values derived in this study are used to infer the evolution of Tharsis over its ~4.5 billion year history.

**Thaumasia:** The Thaumasia region, the southeastern portion of Tharsis, is a volcanic plateau bounded by an arcuate mountain belt, the Thaumasia Highlands, which extends southward from the region of the Tharsis Montes that then curves northeastward to form a quasi-circular feature [5]. The Thaumasia Highlands, the oldest preserved portion of Tharsis [1], contains heavily cratered Noachian terrains that have survived resurfacing by younger volcanic flows presumably because of their high elevation. 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 load emplaced on the lithosphere by the formation of Thaumasia that has undergone subsequent burial [6].

We model the flexural response of the lithosphere to the emplacement of the volcanic plateau, represented by a disk load, to estimate $T_e$ at the time the Thaumasia Highlands formed. The model balances the initial applied load with buoyant, elastic, and membrane forces, and the LOS acceleration for a given MGS orbit is calculated from the resulting configuration of the topography and Moho. The disk thickness, disk density, and effective elastic thickness, are varied to achieve a best-fit with observed LOS accelerations profiles using ground tracks transecting the Thaumasia Highlands (Figure 2).

We find the Thaumasia Highlands to be near-isostatic with $T_e$ < 20 km. Similar values are observed in Early Noachian terrains of the Southern Highlands [7], consistent with the Thaumasia Highlands having formed in the Early Noachian.

**The Admittance of Tharsis:** Estimates of the admittance, the transfer function between topography and gravity, are used to constrain values of $T_e$, the surface density $\rho_s$, and the ratio of bottom to top loading $F$ with a best-fit theoretical admittance curve (see [8] and [9] for model description). Three study areas were analyzed: Thaumasia (240° to 320° E and -60° to 5° N), Olympus Mons (–5º to 45º N and 190º to 250º), and the western half of Tharsis (200° to 290° E and -20° to 45° N) selected to incorporate the largely Amazonian surface ages that are observed there [1]. The results are shown in Table 1.

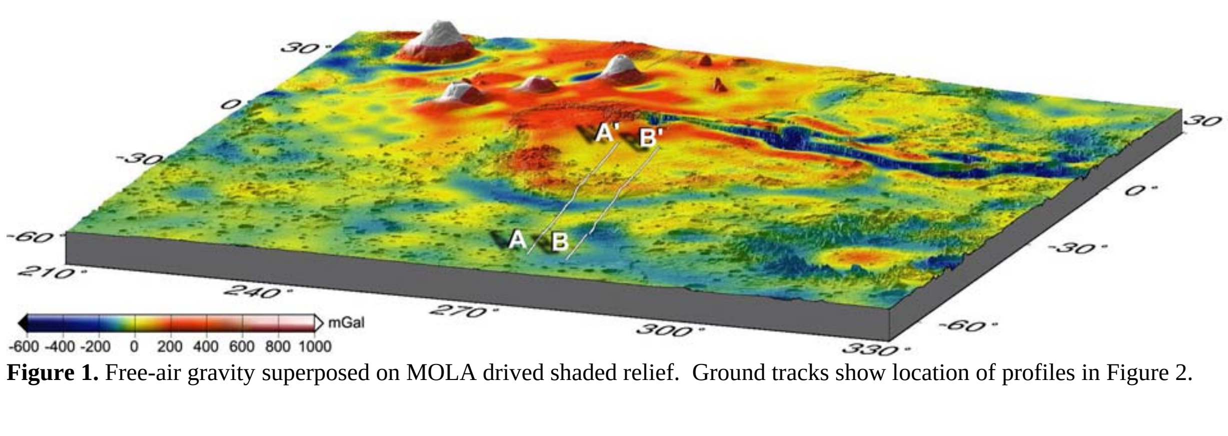


**Figure 1.** Free-air gravity superposed on MOLA drived shaded relief. Ground tracks show location of profiles in Figure 2.

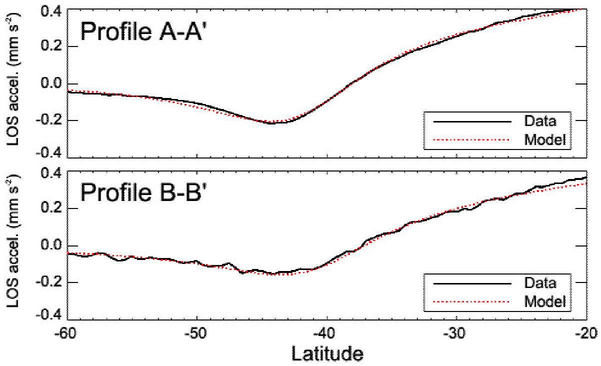


**Figure 2.** Observed and modeled LOS profiles across the Thaumasia Highlands. See Figure 1 for locations.

**Discussion:** Tharsis has experienced volcanic-tectonic activity throughout the entirety of its history, however, the bulk of the topographic configuration of Tharsis appears to have been largely in place by the end of the Noachian [4, 10, 11]. The surface ages of Tharsis reflect a migration in volcanic activity from the east (Thaumasia region), where surface ages are primarily Noachain and Hesperian, to the west (Tharsis Montes and Olympus Mons), where surface ages are predominantly Amazonian.

Estimates of $T_e$ for the Thaumasia Highlands, the oldest preserved potion of Tharsis, support this observation as near-isostatic values were obtained. The admittance of the entirety of Thaumasia however, yields $T_e$ = 72 km. This is likely due to the admittance signal being dominated by younger (Late-Noachian to Hesperian) features that are prevalent in the northern portion of Thaumasia, for example: Valles Marineris, Syria Planum, and widespread Hesperian ridge basalts that cover much of the Thaumasia Plateau. In addition, continued thermal subsidence of the plateau, after the initial flexural signal of the Thaumasia Highlands was established, may contribute to a larger $T_e$ signal in the admittance.

Olympus Mons, the western-most, and apparently youngest feature in Tharsis, reflects a large $T_e$, 111 km. The admittance of west Tharsis, including not only Olympus Mons but also the other large shield volcanoes of the Tharsis Montes, yields a $T_e$ = 39 km. This result initially seems at odds with the predominantly Amazonian surface ages of the region. However, the volcanoes are short wavelength features superposed upon the long wavelength bulge of Tharsis that was in place during the Noachian. The admittance signal likely reflects a dilution from multiple topographic sources spanning a multitude of formational ages.

The densities obtained reflect a systematic change across Tharsis that is consistent with the surface age migration. The lowest surface densities are found in Thaumasia, 2410 kg m$^{-3}$, and the highest densities are in west Tharsis, 3200 kg m$^{-3}$. The near-surface terrains of Thaumasia are either more porous from impacts during heavy bombardment and/or comprised in part of lower density sediments. The higher densities of west Tharsis are consistent with the densities of the SNC meteorites [12] (basalts and ultramafic cumulates) and reflect a younger, less altered surface layer.

These observations suggest that the apparent migration of volcanism across Tharsis observed in the surface ages from east to west is due to initial widespread volcanism with progressively greater confinement of the volcanism to the western margin of Tharsis. The pattern of volcanism also transitioned from voluminous large wavelength scale (1000's km) plateau building in the Noachian, to small wavelength scale (100's km) shield building by the Amazonian, perhaps reflecting the changing response of the lithosphere to volcanic loads [13, 14]. This is consistent with high heat flow early in the planet's history with a rapid decline by the end of the Noachian (e.g. [15]). This conclusion, bolstered by the fact that bottom loading was found not to be of any significance (Table 1), supports the paradigm of Tharsis being largely a constructional feature resulting from external loading by volcanics at or near the surface.

TABLE 1. SUMMARY OF ADMITTANCE RESULTS[a]

| Region | $T_e$ (km) | $\rho_s$ (g•cm$^{-3}$) | $F$[c] |
|---|---|---|---|
| Thaumasia[b] | 72 | 2410 | 0.0 |
| West Tharsis | 39 | 3200 | 0.0 |
| Olympus Mons | 111 | 3090 | 0.0 |

[a] Crust thickness is held fixed at 50 km.
[b] Model uses two-layered crust. Upper crust thickness fixed at 3 km and the lower crust density 2900 kg m$^{-3}$.
[c] Ratio of bottom to top loading, $F$ = 0 is top loading only.

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