MARS WITHOUT THARSIS; *M.T. Zuber*[1,2], *D.E. Smith*[2], and *J.W. Robbins*[3], [1]Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, MD 21218, [2]Laboratory for Terrestrial Physics, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, [3]Hughes-STX Corporation, Greenbelt, MD 20770.

The significant power in the Martian gravity field due to the Tharsis rise may mask or modify gravitational signatures that contain subtle but important information on martian geophysical processes. In order to isolate gravitational signals in regional areas where the field is affected by Tharsis as well to investigate characteristics of the global field, we have developed a technique to "remove" Tharsis from the martian gravity field. Removing Tharsis facilitates analysis of various geophysical problems relevant to the structure and evolution of Mars.

The Martian Gravity Field. We utilized the GMM-1 (Goddard Mars Model-1) gravitational field [1], a spherical harmonic model derived from S-Band tracking observations from the Mariner 9 and Viking 1 and 2 orbiters. This field is complete to degree and order 50 with a corresponding (half wavelength) spatial resolution of 200-300 km where the data permit. In this model the gravitational potential at spacecraft altitude is represented in spherical harmonic form as

$$V_M(r,\theta,\phi) = \frac{GM_M}{r} + \frac{GM_M}{r}\sum_{l=2}^{N}\sum_{m=0}^{l}\left(\frac{r_M}{r}\right)^l \overline{P}_{lm}(\sin\varphi)(\overline{C}_{lm}\cos m\lambda + \overline{S}_{lm}\sin m\lambda) \qquad (1)$$

where, r is the radial distance from the center of mass of Mars to the spacecraft, ø and λ are the areocentric latitude and longitude of the spacecraft, r_M is the mean radius of the reference ellipsoid of Mars, GM_M is the product of the gravitational constant and mass of Mars, $\overline{P}_{lm}$ are the normalized associated Legendre functions of degree l and order m, $\overline{C}_{lm}$ and $\overline{S}_{lm}$ are the normalized spherical harmonic coefficients which were estimated using the tracking observations, and N is the maximum degree representing the size (or resolution) of the field. The gravitational force due to Mars which acts on the spacecraft corresponds to the gradient of the potential, V_M.

Defining Tharsis. We assumed that to first order Tharsis can be considered an axisymmetric gravitational signal. It is then possible to define Tharsis by low degree spherical harmonic zonal coefficients ($\overline{C}_{lm}$ where m=0), which have no longitude dependence. We determined the size and center of Tharsis by plotting the GMM-1 geoid for progressively increasing degrees and orders. On the basis of visual inspection we chose to characterize Tharsis by a sixth degree zonal field. Our two prime reasons for this were: (1) Higher degree fields began to introduce complexitites in the geoid that may not be a consequence of the primary Tharsis signature; and (2) Higher degree fields moved the center of Tharsis, presumably due to the influence of regional-scale structure. Examination of the sixth degree and order geoid in the region yielded a center of Tharsis of (lon=-111.67°E, lat=5.67°N). In determining the center of Tharsis, we assumed that there is a 5% non-hydrostatic component to the flattening of Mars.

Removing Tharsis. We removed Tharsis from the GMM-1 field by: (1) Rotating the non-hydrostatic component of the GMM-1 field to the center of Tharsis and recalculating the spherical harmonic coefficients of the gravity field in the new coordinate system with the z-axis through the center of Tharsis; (2) Putting all the zonal harmonic coefficients of the gravitational potential up through degree six in the new coordinate system to zero; (3) Rotating the new field back to the original coordinate system and recalculating the spherical harmonic coefficients to yield the gravitational potential for Mars without Tharsis. We repeated this process several times for varying amounts of non-hydrostatic $C_{2,0}$ ranging from 0% to 20%.

In practice, we performed the finite rotations of the spherical harmonics using the formalism of Goldstein [2]. The method is based on a decomposition of an arbitrary rotation of a coordinate system D, into five elementary rotations of the form

$$D = A_\gamma B^{-1} A_\beta B A_\alpha \qquad (2)$$

where A_α, A_β, and A_γ represent polar axis rotations, and B and B^{-1} are 90^o rotations about a fixed equatorial axis whose effect on the spherical harmonics is described by a set of pre-computed weighting coefficients.

MARS WITHOUT THARSIS: Zuber, M.T. et al.

Interpretation of New Field. Preliminary analysis of the Mars Without Tharsis field has allowed us to address the following issues relevant to the geophysics of Mars:

(1) *Axial Asymmetry of Tharsis:* The large-scale gravitational signature after the axisymmetric component of Tharsis is removed provides a measure of the deviation of Tharsis from axisymmetry. We find Tharsis displays a significant non-axisymmetric component. The deviation from axisymmetry that we observe holds for other plausible values of the percent hydrostatic $C_{2,0}$ removed, which indicates that complex or multiple mechanisms contribute to the long wavelength geoid and gravity signature of Mars, of which a notable fraction is associated with Tharsis.

(2) *Flattening/Moment of Inertia:* When Tharsis is removed, the dynamical flattening ($C_{2,0}$) of Mars is reduced by approximately 5% for a fully hydrostatic $C_{2,0}$ to approximately 10% for $C_{2,0}$ that is 80% hydrostatic. The resulting moment of inertia factor C/Ma^2, ranges from 0.368 to 0.361 for that range, in agreement with most [3, 4] though not all [5] previous estimates. In addition, for the Mars Without Tharsis field we find the axis of symmetry of the new gravity field has moved approximately 1° in the direction of Tharsis for removal of 5% non-hydrostatic $C_{2,0}$. This polar motion occurs due to the removal of "material" from the Tharsis bulge.

(3) *Elysium:* We find that the geoid signature of the Elysium Province is "contaminated" by the "Tharsis" contribution to the field. Removal of Tharsis causes a reduction of 40 m in the maximum geoid in this region for a 5% non-hydrostatic $C_{2,0}$. This observation indicates that the long wavelength zonal field is not representative of Tharsis alone; in fact our analysis quantifies the relative contributions of Elysium, Tharsis, and other areas to Mars' long wavelength global gravity field.

(4) *Other Regional Structures:* Removal of Tharsis clarifies the signatures of important regional structures such as Alba Patera and the Valles Marineris, especially in the geoid. The Olympus Mons volcano, on the western slope of Tharsis, now displays distinct gravitational "moats" surrounding the volcano on both the "uphill" and "downhill" flanks. Isolation of the Olympus Mons gravitational signature facilitates calculation of the elastic thickness of the lithosphere via the predicted gravity associated with flexure due to the volcanic load [6].

Summary. Our analysis indicates that the removal of Tharsis from the martian gravity field facilitates analysis of certain questions relevant to the global and regional geophysics of Mars. This method of analysis may also have value if applied to other planetary potential fields that contain global-scale signatures that may be considered axisymmetric to first order, due to, for example, mantle plumes or large impact basins.

References: [1] Smith D.E. et al. (1993) *JGR 98*, 20,871. [2] Goldstein J.D. (1984) *JGR, 89,* 4413. [3] Kaula, W.M. (1979) *GRL, 6,* 194. [4] Kaula W.M. et al. (1989) *GRL, 16,* 1333. [5] Bills B.G. (1989) *GRL, 16,* 385. [6] Kiefer W.S. et al. (1995) *LPSC XXVI,* this volume.