THE THARSIS REGION OF MARS: NEW INSIGHTS FROM MAGNETIC FIELD OBSERVATIONS. C. L. Johnson[1] and R. J. Phillips[2], [1]Institute for Geophysics and Planetary Physics, Scripps Institution of Oceanography, 9500 Gilman Drive, La Jolla, CA 92093-0225 (johnson@igpp.ucsd.edu), [2]Dept. of Earth and Planetary Sciences, Washington University, Campus Box 1169, One Brookings Drive, St. Louis, MO 63130 (phillips@wustite.wustl.edu)

Introduction: The Tharsis volcanic province dominates the western hemisphere of Mars. The regional topography comprises a long-wavelength rise of several kilometers elevation. Superposed on this are the Tharsis Montes, Olympus Mons and Alba Patera. To the southeast, the Tharsis rise includes Solis, Syria and Sinai Planae, bounded by Valles Marineris, Claritas Fossae, and the Coprates rise. The region also dominates the gravity field of the western hemisphere, with typical free air anomalies of several hundred milligals, and a peak free air anomaly greater than 1000 milligals over Olympus Mons.

Tectonic deformation is pervasive throughout the Tharsis region and provides constraints on the history of uplift and/or loading and/or volcanic construction. There have been several major episodes of radial fracturing from the Noachian onwards [1,2,3,4]. Concentric contractional deformation of mid-Noachian units of the Coprates Rise and South Tharsis ridge belt has been reported [5]. Additional information on the earliest history of Tharsis is provided by observations of concentric extensional fractures in the oldest (early Noachian) units of Claritas Fossae [6,7,8]. Later concentric contractional deformation – the Hesperian ridged plains (type locale: Lunae Planum) – is of a fundamentally different wavelgnth and amplitude than the above-mentioned contractional deformation in the South Tharsis Ridge belt and the Coprates Rise.

Here we focus on new constraints for models for the origin and evolution of Tharsis, provided by Mars Global Surveyor (MGS) magnetic field data. Magnetic field observations are compared with the geology and topography of the region. Given that it is unlikely that a global magnetic field persisted beyond the late Noachian [10], we investigate end-member scenarios for thermal demagnetization of pre-existing, or early-Tharsis, magnetized Noachian crust. Specifically, we test whether observed distributions of magnetic field amplitude over surface units of Amazonian, Hesperian and Noachian age, are consistent with reasonable bounds on the extent of crustal thermal demagnetization during the construction of Tharsis. Implications for the relative timing of the cessation of a Mars dynamo and the earliest history of Tharsis are discussed. The magnetic field observations are integrated with constraints from tectonics, gravity and topography and a revised scenario for the evolution of Tharsis presented.

Previous Models for Tharsis Formation: A variety of models for the formation of Tharsis have been proposed, and predicted gravity, topography and tectonic stresses compared with available observations. These models include dynamic support of topography by a large mantle plume [11,12]; regional uplift due to underplating of crustal material derived from the northern hemisphere [13]; uplift due to solely mantle anomalies - thermal and/or compositional [14], and including crustal thickening by intrusion [6]; flexural loading due to volcanic construction [2, 15, 16]. There are several difficulties associated with plume models. Single-plume structures are difficult to achieve in numerical convection models, and the required maintenance of persistent plume for the 4 Ga history of Tharsis [15] is problematic. Furthermore, the lack of sensitivity in geoid kernels at appropriate mantle depths [17], means that less than ten per cent of the present-day geoid can be attributed to an upper mantle plume. Support of the Tharsis rise solely by mantle thermal and compositional anomalies are not favored since it requires the maintenance of large lateral variations in density over billions of years. Present-day gravity and topography is consistent with flexural loading and crustal thickening at Tharsis [15,16, 18]. Estimates for lithospheric thickness in the region are variable and range from 70 - 150 km [19,20], nonetheless they are consistent with current flexural support of much of the Tharsis topography.

Magnetic Field: *Observations.* MGS magnetic field data provide critical new constraints on the history of crustal evolution in the Tharsis region. Here we discuss the altitude-normalized (200 km altitude) radial magnetic field anomalies (B_r) of Purucker et al. [21]. Investigations of other magnetic field data sets and global magnetic field models (refs) are underway. Figure 1 shows a simplified version of the geological map of the western hemisphere of Mars [22] and of B_r, each draped over MGS-derived topography [23].

Anomalies of over 50 nT amplitude are observed above the 8-km-high early Noachian basement complex at Claritis fossae (unit Nb, Scott and Tanaka [21]). Similar magnitude anomalies are seen above the Nf units of Nectaris Fossae [21]. In contrast, no magnetic

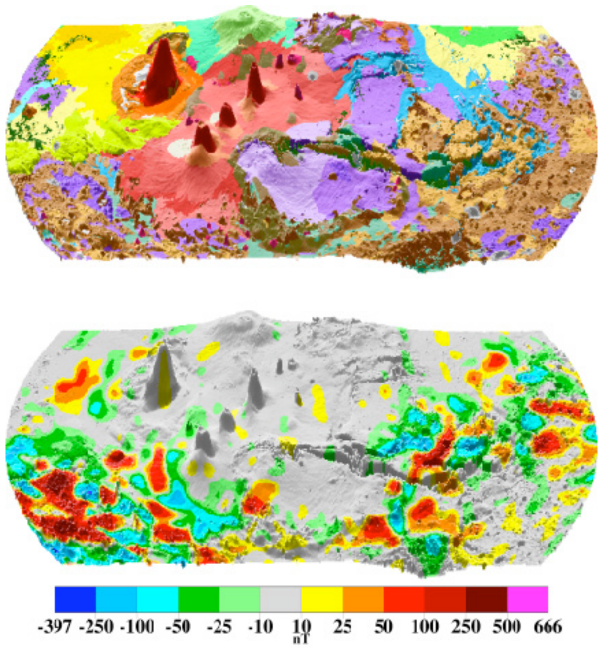

Figure 1. Drape of geological map (upper figure) and B_r (lower figure) over MOLA topography for the region bounded by –180°E, 0°E, 45°S, 45°N. Geological map is a simplified version of that in [22]. Noachian units are denoted by brown colors, Hesperian units by purple, blue and green colors, and Amazonian units by red, orange and yellow and white colors. The color bar gives the scale for B_r in nT [21].

field anomalies are associated with the Noachian units (Nf) of Tempe Fossae and Ceraunius Fossae. Negligible anomalies are observed over Sinai Planum, Syria Planum, Solis Planum and western Valles Marineris. Anomalies at the eastern edge of the Terra Cimmeria region are associated with deformed Noachian terrain south-west (Nplr, Npl1) of Daedalia Planum. Significant, though lower amplitude, anomalies are observed at eastern Daedalia Planum which rises to elevations of about 4 km above the planetary mean. The surface units here are Amazonian in age. Finally, magnetic anomalies are observed over a small area on the lowermost western flanks of Olympus Mons. The surface units here are also Amazonian.

Inspection of Figure 1 suggests, on average, decreasing magnetic field anomaly amplitude with decreasing surface unit age. Figure 2 shows magnetic anomaly distributions over units of Amazonian, Hesperian and Noachian age. The region examined extends from 45°S to 45°N and from 180°W to 0°E. Similar patterns of results were obtained when various smaller areas within Tharsis were analyzed. Magnetic anomaly amplitudes of less than 5nT were excluded as being at the limit of accuracy of the magnetometer. The distributions show significant anomalies over units of all ages. The peak anomaly, mean anomaly and variance of the distributions decrease with decreasing surface unit age. Values of B_r over Noachian surface units can be large, but do not approach the several hundred nano-Tesla anomalies of the Terra Cimmeria region. Kolmogorov-Smirnov tests [24] indicate that the Amazonian, Hesperian and Noachian cumulative distribution functions are statistically significantly different.

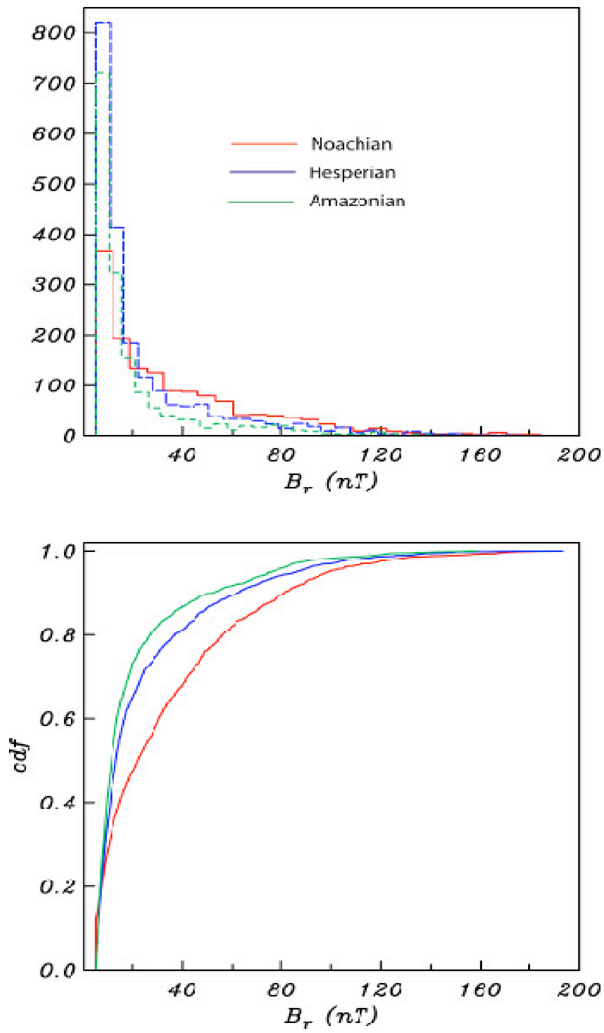

Figure 2: Histograms (upper) and empirical cumulative distribution functions for the absolute value of B_r over Amazonian (green), Hesperian (blue) and Noachian (red) surface units. Values of B_r less than 5 nT are excluded (see text). There are 1423, 2089 and 1619 observations of B_r over Noachian, Hesperian, Amazonian units. Noachian, Hesperian and Amazonian distributions have mean values of 37.5 nT, 24.6 nT, and 20.7 nT respectively.

Implications Some of the oldest and highest exposed Noachian terrain in the Tharsis region exhibits significant magnetic anomalies, indicating long-lived crustal magnetizations. This provides important constraints on the thermal regime of the magnetization source region. The retention of significant magnetization at Claritas Fossae means that models for uplift/construction in that region must allow a significant depth extent of the magnetization source region to remain below the appropriate Curie temperature. Uplift (inferred structurally [6,7,8]) may be the result solely of crustal thickening by magmatic intrusion, irrespective of the source of early mantle buoyancy in the region. Crust below the young Amazonian units of Daedalia Planum is magnetized, but less strongly so, suggesting that burial of older basement units by volcanics has reduced, but not removed, the remnant magnetism. The basement below the Tharsis Montes is not magnetized. The fracture system associated with Tempe Fossae has been proposed to underly the Tharsis Montes. Since Tempe Fossae exhibits no magnetic signature, it is possible that the crust beneath the Tharsis Mons was never magnetized. Two scenarios consistent with the presence of high-elevation magnetic anomalies are: (1) Anomalies in these regions reflect pre-Tharsis Noachian basement, that has been uplifted during the construction of Tharsis, (2) Crustal magnetization was acquired during the early stages of formation of Tharsis, as intruded and extruded crust cooled through the Curie temperature of the magnetic carrier. Scenario 1 would not require the presence of a global magnetic field during the formation of Tharsis, scenario 2 requires a global magnetic field at least during the early stages of Tharsis construction.

Effect of Thermal Demagnetization: We have investigated two 1-D end-member scenarios for thermal demagnetization of a magnetic source layer. We assume that the crust in the Tharsis region prior to the formation of Tharsis was strongly magnetic, and had a thickness of 40 – 50 km [22, 25]. Furthermore we assume uniform magnetization of the crust, and a Curie temperature of 580°C (typical of single domain magnetite). Emplacement of surface lava flows heat the underlying crust, and the maximum depth to the Curie isotherm scales linearly with the flow thickness [26]. For 1-km thick flows, only the upper few hundred meters of the underlying crust are raised above the Curie temperature. Thus volcanic extrusions after the cessation of a dynamo will only have a small demagnetization effect on the underlying crust, unless the magnetic carriers are strongly concentrated upwards.

In the second calculation we use the results of the nominal thermal model of Hauck and Phillips [25] to estimate the temperature gradient in the martian lithosphere at ~ 4 Ga. We assume the base of the magnetic source region (crust) is initially at the Curie temperature. Persistent intrusions and underplating of crustal material are permitted, such that the temperature at the base of the crust is held close to its melting temperature. This provides a crude upper limit on the vertical extent of demagnetization of the crust due to intrusions. In this case, the lower 50% of the crust is raised above the Curie temperature. In practice this model would correspond to a requirement of continuous intrusions over a 100 Myr period.

From these preliminary calculations it is clear that it is possible retain significant magnetization signatures during the construction of Tharsis. We will investigate trade-offs between magnetization distribution, volcanic construction and the resulting crustal thermal anomalies.

Evolution of Tharsis: Integration of the magnetic field observations with constraints from gravity and topography are consistent with the following scenario for the formation and evolution of Tharsis. In the early Noachian thermal (and possibly compositional) buoyancy produced uplift, partial melting and deep intrusion. This is consistent with exposed oldest Noachian units being pre-existing crust, not volcanic construct. Deformation of these units produced the observed extensional fracture [7,8,9]. Whether the magnetized Noachian crust is primarily pre-existing basement or early Tharsis construct is unknown. Further information regarding the relative timing of the waning and cessation of a martian dynamo and the earliest phase of Tharsis construction is needed. By the mid-late Noachian Tharsis topography was supported by a combination of membrane and bending stresses from loading, and crustal thickening [2, 16, 18]. This transition explains the circumferential ridges and radial extensional faulting at Tharsis, the present-day gravity and topography, valley network orientations and the reduction in magnetic field anomalies over younger surface units.

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