MODELING OF MAJOR MARTIAN MAGNETIC ANOMALIES: FURTHER EVIDENCE FOR POLAR REORIENTATIONS DURING THE NOACHIAN. L. L. Hood, C. N. Young, *Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721-0092, USA, (lon@lpl.arizona.edu)*, N. C. Richmond, *Department of Geography, University of Liverpool, Liverpool U.K.*.

Introduction. If the magnetization of major crustal anomaly sources on Mars was due to the presence of a former core dynamo, then the bulk directions of magnetization of these sources should reflect the orientation of the planetary magnetic field at the times of their formation. Assuming that the former core dynamo field was dominantly dipolar and that the orientation of the moment vector was roughly constant (aside from reversals), then it follows that the corresponding magnetic pole positions for anomaly sources of similar ages should ideally be in the same areographic region(s). Thus, analysis of the MGS magnetometer data to infer bulk directions of magnetization of major anomaly sources can provide a direct test of the core dynamo hypothesis. Moreover, if the areographic region(s) in which former magnetic pole positions are found is displaced significantly from the present rotational polar zone, this displacement could represent evidence for reorientation of the planet relative to its spin axis ("polar wandering"). The latter application assumes that the former dynamo moment vector was approximately aligned with the planetary rotation vector, a condition that is met for most observed planetary fields including that of the Earth (e.g., ref. 1). A knowledge of Martian paleopole locations is useful for a number of applications including assigning the basic climatic regime (polar, temperate, tropical) experienced by ancient terranes. The latter property may be useful in evaluating where conditions were most favorable for the development of microscopic life forms during the early history of the planet.

We have previously mapped and modeled two relatively isolated, medium-amplitude anomalies (field magnitudes > 50 nT at 170 km altitude) in the northern polar region (2). Results generally support the feasibility of estimating the approximate bulk directions of magnetization of relatively isolated Martian crustal field sources. The south paleomagnetic pole positions corresponding to the two mapped anomalies were both located in a region between Olympus Mons and the present north rotational pole (approximately 215^{o}E, 30^o-60^{o}N). Arkani-Hamed (3) reported initial modeling of 10 relatively isolated, small anomalies to infer paleomagnetic pole locations. His estimated paleopoles were located mostly within a circle of radius 30 degrees centered at 230°E, 25°N. Both north and south magnetic poles were mapped in this region implying reversals of the former core dynamo. Recently, J. Phillips (4) has reported estimation of Martian magnetization vectors and corresponding pole positions from Helbig analysis, an independent technique that has been tested on terrestrial anomalies. His analysis of the n = 90 Martian magnetic field model of Cain et al. (5) showed that most of the stronger sources have pole positions within a circle of radius 50 degrees centered at 195°E, 50°N. This region agrees approximately with that inferred previously from analysis of the northern polar anomalies (2) and from the analysis of 10 anomalies by Arkani-Hamed (3). However, Phillips (4) also found that a smaller number of strongly magnetized sources have pole positions that cluster within a circle of radius 40 degrees centered at 290°E, 5°N. The latter cluster was suggested to represent either a secondary pole position or a preferred transition path during field reversals.

In this paper, we report further quantitative modeling of major, relatively isolated Martian magnetic anomalies for the primary purpose of estimating bulk directions of magnetization and corresponding paleomagnetic pole locations. Modeling of these anomalies is considered to be most reliable because of larger signal-to-noise ratios on the field maps.

Modeling Method and Results. We report here results of approximate, iterative forward modeling calculations applied to investigate possible anomaly source characteristics using methods previously described in ref. 2. These results extend and refine preliminary modeling analyses reported earlier (6). The data employed are the direct vector magnetometer measurements acquired at the MGS mapping altitude (380 - 420 km) along approximately 2800 orbital trajectories occurring during 1999 (7). These original orbital trajectories were first re-ordered according to equatorial crossing longitude and were then visually edited and quadratically detrended to minimize contributions from external magnetic field disturbances. Model fields are calculated along the same orbital trajectories and both the model fields and the observed fields are filtered two-dimensionally using the same algorithms. Comparison of the resulting observed and model field maps at the spacecraft altitude then allows source properties to be adjusted iteratively until a fitting parameter evaluated along the orbit trajectories near the anomaly maximum reaches a minimum. In this analysis, we assume that each relatively isolated anomaly source can be represented by one or more uniformly magnetized circular plates located at the (assumed spherical) planetary surface. The modeling procedure estimates the location(s) of the plate(s), their radii, their intensities of magnetization per unit area and their bulk directions of magnetization. The thicknesses of the plates and their mean depths are not constrained by the analysis. For each anomaly, all plates are assumed to be magnetized in the same direction. In some cases, only a single circular plate was required to represent the source. In other cases for which the anomaly in the field magnitude was elongated, more than one plate was used.

Figure 1 indicates the locations of five relatively strong but isolated anomalies (labeled A2 to A6) that have been modeled to date. One of these anomalies (A4) has previously been modeled by Arkani-Hamed (3) with very similar results. To our knowledge, the other four anomalies have not previously been investigated using forward modeling techniques.

Figure 2 shows the locations and polarities of the magnetic pole positions for these five anomalies. In addition, the pole position corresponding to one of the northern polar anomalies investigated previously (2) is also shown (A1 located at 65°N, 27°E). Modeling of the other northern polar anomaly (that

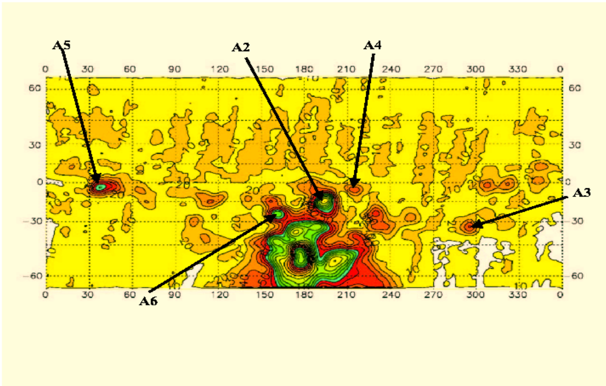

Figure 1:

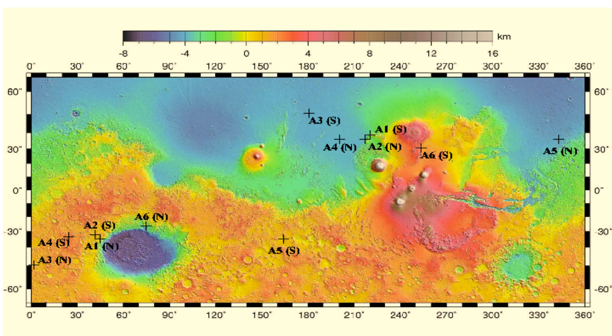

Figure 2:

at 83°N, 32°E) is considered to be less reliable because of its location near the north pole where data are sparse and ionospheric disturbances are larger.

Five of the six anomalies have pole positions that are clustered in one Northern Hemispheric region centered northwest of Olympus Mons at approximately 210°E, 40°N. This region compares favorably with that estimated previously (2,3,4). Both north and south polarities are found in agreement with ref. 3. However, one anomaly (A5 located at 4°S, 37°E) has a distinctly different pole location. Repeated modeling for a variety of source geometries confirms that this pole position is significantly displaced from the main cluster centered northwest of Olympus Mons. It lies close to the secondary cluster of pole positions found in ref. 4. This result is therefore supportive of the existence of a second pole position or a preferred transition path during reversals. Further analysis of additional anomalies is in progress to confirm this provisional inference.

Discussion. Geophysical evidence exists for significant surface mass redistributions during the Noachian epoch (e.g., the formation of the Tharsis gravity anomaly). Consequently, there is reason to suspect that significant reorientations of the Martian rotation vector relative to the planet may have occurred (e.g., ref. 8). Although the rotation axis of a planet remains fixed in space by angular momentum conservation, any process that alters the internal distribution of mass will cause the planet to reorient itself with respect to that axis. Reorientations are such that the new axis of maximum principal moment of inertia becomes aligned with the spin axis thereby yielding a minimum-energy rotational state. The addition of excess mass to a planetary surface will tend to reorient the planet such that the mass excess is moved toward the equator. The internal volcanic processes that led to the formation of the Tharsis gravity anomaly would therefore have led to such polar wander unless Tharsis coincidentally formed on the rotational equator. For example, if Tharsis had originally formed at a latitude of 30° N, the rotational pole before its formation should have been located near 60° N in the present areographic coordinate system. If Tharsis is represented as a simple point mass on the surface of a rigid sphere, the reorientation would be exactly 30° southward with no change in longitude. Melosh (9) estimated that a simple removal of the Tharsis gravity anomaly would result in a shift of the pole by 25° in latitude to 265°E, 65°N. In reality, the gravity anomaly distribution prior to the formation of Tharsis is not precisely known and other effects (e.g., oblateness of an elastic lithosphere) may have tended to oppose the polar reorientation. Hence, the actual polar shift may have been more complex than this.

The current data indicate a primary location for the Martian paleopole during the early Noachian (prior to the formation of Tharsis and the demagnetized major basins) near 210°E, 40°N with an error circle of approximately 30° radius. This implies significantly displaced climatic regimes during this early period when atmospheric conditions may have been most conducive to the origination of microscopic organisms.

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