MODELING AND PALEOMAGNETIC POLE POSITIONS FOR TWO MAGNETIC ANOMALIES IN THE NORTHERN POLAR REGION OF MARS.

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Introduction: By analogy with the terrestrial case, the most probable source of a steady magnetic field early in Mars' history is a former core dynamo. Consistent with this interpretation, thermal history models admit the possibility that a core dynamo could have existed early (during the first Gyr) of Mars' history (1,2). 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 formations. Assuming that the dynamo magnetic moment vector was roughly constant in orientation (aside from reversals), then it follows that the corresponding magnetic pole positions for anomaly sources of similar ages should ideally be in the same aerographic region(s). Thus, analysis of the MGS magnetometer data to infer bulk directions of magnetization of major anomaly sources could provide a direct test of the core dynamo hypothesis. Moreover, if the aerographic 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 (3).

In this paper, an analysis is presented of original MGS magnetometer data delivered as of June, 2000 to the Planetary Data System for general use by the planetary science community. These data were obtained during the period from May 28 to September 13, 1998 (MGS orbits 327 to 553) and are from a period in the MGS mission known as Science Phasing Orbits (SPO) 1 and 2. Data coverage is limited to the northern polar region (60° N to 90° N). Although two major medium-amplitude ($\sim$ 50 nT) anomalies have previously been mapped in this region (see Fig. 1 of ref. 4), the earlier mapping procedure involved averaging all available measurements over altitude (170 to 200 km). In the current work, only a selected subset of available data over a given region is used in order to avoid averaging over altitude. Source characteristics for the two major mapped anomalies are then investigated using a simplified, iterative forward modeling procedure. Limits on bulk magnetization intensities, directions of magnetization, and corresponding magnetic pole positions for a former magnetizing dipole centered in Mars are estimated for these two anomaly sources.

Analysis: An examination of the 226 orbits of MGS magnetometer data available for analysis at present (June, 2000) showed that the region north of 60° N latitude was covered multiple times at variable altitudes. It was therefore decided to divide the data set into subsets with each subset containing a sequence of orbits with single-altitude coverage as a function of position.

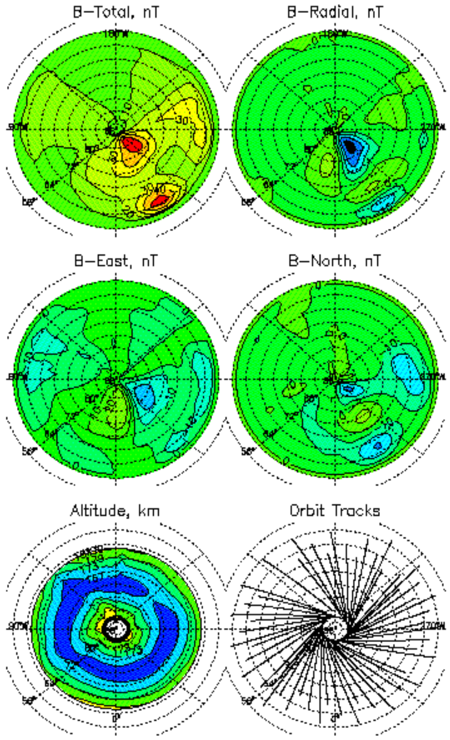

Figure 1:

One sequence of orbits (438 to 495; July 20 to August 17, 1998) was found to provide a general overview of the northern polar region from 60° N to 88°N. The resulting maps of the field magnitude, the radial, east, and north components, the spacecraft altitude, and orbit track locations are shown in Figure 1. The mean altitude structure (lower left plot) is nearly symmetric about the north pole with a minimum altitude of $\sim$ 163 km near 75° N. Two major anomalies are evident on the field magnitude plot (upper left of figure). The radial field component plot (upper right) agrees approximately with that published earlier by Acuña et al. (ref. 4). These anomalies, centered near 83° N, 32° E and near 65° N, 27° E, will be referred to hereafter as the northern and southern anomalies, respectively.

In order to investigate possible source characteristics for the northern and southern anomalies of Figure 1, we have employed an approximate, iterative forward modeling procedure (see, e.g., ref. 5). Since the two mapped anomalies are relatively isolated and are dominantly dipolar, we assume that a single source is responsible for each. For simplicity, two extreme endmember source model geometries were investigated: (1) a point dipole with moment amplitude **m** buried at a depth

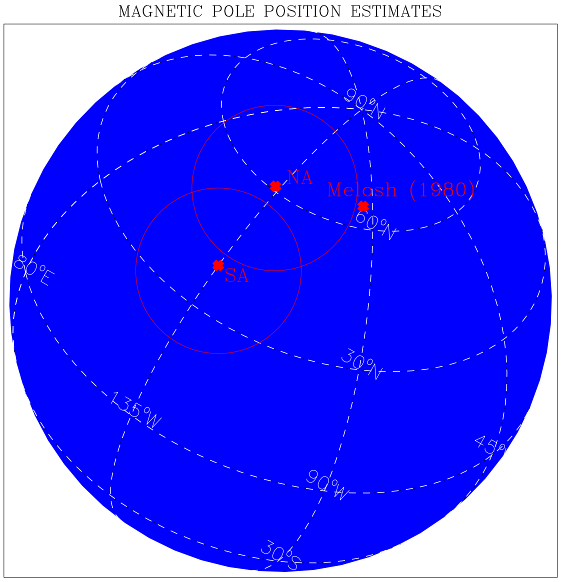

Figure 2:

d; and (2) a circular surface disk with dipole moment per unit area $\overline{m}$ and diameter D. An improved fit to the data could be obtained using more than one dipole or using a surface disk of arbitrary shape; however, for the purpose of the present first-order analysis, a single dipole or a circular disk is employed. The orientation of the dipole moment vector and that of the magnetization vector in the disk are both described by two angles, α and β. α is the angle between the local radial direction and the moment vector; β is the azimuth of the surface projection of the moment vector measured from the local eastward direction counterclockwise about the radial direction.

In the case of the southern anomaly, an optimal fit to the observed field was obtained for a location at 65° N, 27° E, direction angles $\alpha = 115^\circ \pm 20^\circ$, $\beta = 100^\circ \pm 20^\circ$, moment $\mathbf{m} = 2.4 \pm 0.4 \times 10^{19}$ G-cm^3; and depth $d = 160 \pm 40$ km. The corresponding south magnetic pole position is at approximately 40° N, 135° W. The north magnetic pole position is antipodal to this location and lies in the southern hemisphere. In the case of the northern anomaly, an optimal fit was obtained for a location at 83° N, 32° E, direction angles $\alpha = 160^\circ \pm 20^\circ$, $\beta = 100^\circ \pm 20^\circ$, moment $\mathbf{m} = 1.2 \pm 0.3 \times 10^{19}$ G-cm^3; and depth $d = 150 \pm 40$ km. The corresponding south magnetic pole position lies at approximately 61° N, 137° W.

Discussion: As noted in the Introduction, a significant aerographic clustering of paleomagnetic pole positions estimated for relatively isolated Martian magnetic anomalies would (a) add support to the core dynamo hypothesis for the origin of Martian paleomagnetism; and (b) provide a means of investigating past orientations of the rotational pole with respect to the planet. The south magnetic pole positions estimated above for the two northern polar anomalies analyzed here are plotted in Figure 2. (Since dynamo reversals are allowed, it is arbitrary whether the south or the north positions are plotted here.) While additional pole positions are needed to establish statistically a significant clustering, it is of interest that these two positions are in the same general aerographic region, i.e. in an area between Olympus Mons and the present rotational north pole. Moreover, as discussed below, it is of interest that this region is roughly near the location expected theoretically for the orientation of Mars prior to the formation of the Tharsis mass anomaly.

Polar wander on Mars associated with the formation of the Tharsis volcanic province and gravity anomaly has previously been discussed and investigated by several authors (6,7,8). 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. The reorientation is such that the axis of the maximum principal moment of inertia becomes aligned with the spin axis thereby yielding a minimum-energy rotational state. In particular, 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 very large 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 30° north of its present location, the rotational pole before the formation of Tharsis should be located near 60° N in the present aerographic 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. 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 most straightforward attempt to estimate the location of the former pole of Mars prior to the formation of the Tharsis region was reported by Melosh (7). His approach was to attempt to remove the Tharsis anomaly from the gravity field and recompute the ancient pole position from the remaining gravity anomalies. Specifically, the inertia tensor without the Tharsis anomaly was constructed and diagonalized to estimate the maximum principal moment orientation. Using an earlier gravity model, it was found that the removal of the Tharsis anomaly results in a shift of the pole by 25° in latitude to 95° W, 65° N. The location of this theoretically predicted position is indicated in Figure 2. Considering the errors associated with the anomaly modeling, the theoretical location is in marginally good agreement with the magnetic pole position locations.

References: (1) Stevenson, D. et al. (1983) *Icarus, 54*, 466; (2) Schubert, G., and T. Spohn (1990) *J. Geophys. Res., 95*, 14095; (3) Russell, C. T. (1987) in *Geomagnetism, Vol. 2*, (ed., J. A. Jacobs), p. 458, Academic Press, Orlando; (4) Acuña, M. et al. (1999) *Science, 284*, 790; (5) Hood, L. (1980) in *Proc. Lunar Planet. Sci. Conf. 11th*, 1879; (6) Mutch, T. et al. (1976) *The Geology of Mars*, Princeton Univ. Press, Princeton, N.J.; (7) Melosh, H. J. (1980) *Icarus, 44*, 745; (8) Willemann, R. J. (1984) *Icarus, 60*, 701.