POLAR WANDERING ON MARS?

K. F. Sprenke[1] and L. L. Baker[1], [1]University of Idaho (College of Mines and Earth Resources, University of Idaho, Moscow, Idaho 83843 ksprenke@uidaho.edu lbaker@uidaho.edu)

Introduction: Magnetic anomalies due to unknown features in the martian crust were observed by the Mars Global Surveyor (MGS) during relatively low altitude aerobraking and science phasing orbits in 1997 and 1998 [1, 2]. A correlation of the anomalies with the ancient cratered terrain of the martian highlands, particularly in the Terra Sirenum and Terra Cimmeria regions was noted. There, field intensities exceeding 1500 nT were measured at altitudes of near 100 km. The presence of these large anomalies over the ancient crust and their absence over younger terrain revealed that Mars, devoid of a global field at present, must have had an internal active dynamo in its ancient past. This hypothesis supports models of a hot early Mars immediately after accretion, followed by rapid cooling and crust formation [3, 4]. If the ancient dynamo operated for several hundred million years after accretion, sufficient time would have been available for the ancient iron-rich crust to have formed and to have acquired a remanent magnetization through thermal, chemical, or depositional processes. This remanent magnetization, if undisturbed by reheating or reworking, would retain information on the direction and magnitude of the ancient dipole field [1].

Analytical models of the extended magnetic sources in the Terra Sirenum and Terra Cimmeria region and their implications were recently presented [5]. It was noted that the polarities of the crustal magnetic anomalies were organized in extensive quasi-parallel east-west trending lineations from 1000 km to as long as 2000 km. Their quantitative analyses used four representative tracks of the MGS observations acquired from orbits with periapses near the 180°W longitude meridian to explore models of crustal magnetization consistent with the observations. They noted that intense positive radial features were separated by equally intense negative radial features, suggestive, in the authors' opinion, of bands of crustal remanent magnetization of alternating sign. They interpreted the alternating magnetization to be suggestive of sea-floor spreading, or less likely, regional folding.

For this paper, we have re-modeled the data presented by [5]. In contrast to these authors, we claim that the martian magnetic anomalies can be explained in a simple manner by remanent magnetization of crustal rocks which formed in the presence of an ancient areocentric dipole field of constant polarity. Our model requires no polarity reversals of the martian magnetic field. If true, this hypothesis has implications for rock magnetization, paleomagnetic poles, and polar wandering on Mars

Method: The procedure we followed was similar to that outlined by [5] for their analysis of the same data. The sources of the magnetic anomalies in the Terra Sirenum and Terra Cimmerria regions were assumed to be represented by a group of 40 uniformly magnetized horizontal slabs, 100 km in width, 30 km in depth, infinitely extended in the east-west direction. The number and width of slabs used was more or less arbitrary; the more used, the closer the details of the anomalies can be matched.

The magnetic field of each horizontal slab was computed using conventional formulae [6]. Readers unfamiliar with magnetic modeling should note that uniform magnetization of a single slab produces both positive and negative magnetic anomalies. It is not necessary to reverse the polarity of the magnetization of the source to produce anomalies of alternating sign.

For each profile, the horizontal and vertical components of the observed field were fit to a crustal model consisting of 40 uniformly magnetized slabs, each characterized by a volume magnetization. The direction of magnetization was constrained by the paleomagnetic inclination and paleomagnetic declination for assumed trial paleomagnetic pole positions. Some 600 trial pole positions at 10° spacings around the globe were modeled. For each assumed paleopole position, a non-negative least squares procedure was used to find a distribution of positive magnetizations that fit the observations in a least-squares sense, and an RMS error was calculated. As in all potential field inverse procedures, the results depend on the assumptions in the model; they are by no means unique. They show no more than a consistency between the observations and the model assumptions

Results: Although the RMS residuals are of the order of 90 nT, the fits are satisfying considering the simplicity of the model. The physical dimensions and volume magnetizations of the sources are , without doubt, much more complex then as modeled. Nonetheless, the results indicate that the magnetic anomalies along these tracks are consistent with a martian axial dipole field of constant polarity. Reversals in the direction of magnetization are not required to explain the magnetic anomalies on Mars. The crustal magnetizations required by this model, assuming a 30 km thick crust, range from zero in some slabs to as high as 70 A/m in others. Thinner or thicker crust will produce correspondingly higher or lower intensities of magnetization.

A contour plot of the RMS errors for trial paleomagnetic pole positions on Mars (Fig. 1) indicates that the lowest residuals occur along a sub-equatorial belt centered about 20^{o} S latitude at 0^{o} longitude. Paleomagnetic poles anywhere along this belt all produce a reasonably good fit with the observations

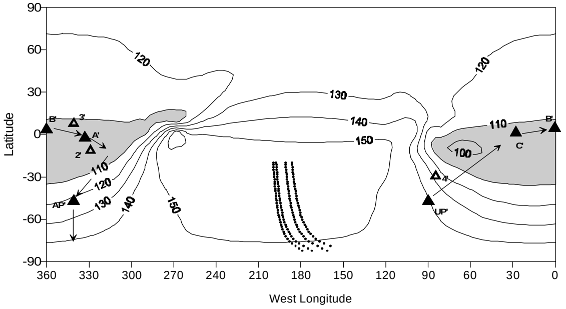

Fig 1.

Discussion: On Earth, numerous archeomagnetic studies have shown that paleomagnetic poles cluster about the rotational poles. This has led to the geocentric axial dipole hypothesis, which states that the Earth's geomagnetic field has been predominantly dipolar, and when averaged over sufficient time, the dipole field was centered at the center of the Earth and the axis of the dipole coincided with the rotational axis of the Earth. If we can therefore suggest an areocentric dipole hypothesis, then the possible paleomagnetic pole positions shown on Fig. 1 may represent possible locations of ancient martian rotational poles.

Mars has long been considered a likely planet for true polar wander, a reorientation of an entire planetary surface with respect to its rotational axis. True polar wander is thought to result from changes in the inertia tensor as a result of internal mass redistribution. [7] and [8] suggested that the rotational pole of Mars may have moved as a result of the rise of Tharsis. [9] suggested that the Coprates Trough assemblage provides evidence of tensile stresses developed by polar wandering on Mars, although [10] argue against this. The record of grazing impacts has been used to locate possible ancient orbital pole points [11]. Geomorphic studies have shown that regions of mantled and layered terrain near the martian equator are similar to present polar deposits, providing additional proposed ancient paleopole locations [12]. Assuming that Terra Sirenum and Terra Cimmerium have not moved relative to the rest of the planetary surface, our paleomagnetic pole locations appear to provide independent evidence for polar wandering on Mars through at least 50^{o} of arc.

A proposed wandering path [12] for the south pole of Mars is shown on Fig. 1. The solid triangles represent pole positions based largely on geomorphic evidence; the open triangles represent possible pole positions based on grazing impacts. The better fitting paleomagnetic pole positions (gray areas) in the equatorial regions near the prime meridian agree remarkably well with the Schultz and Lutz model for polar wandering. The best-fit paleomagnetic south pole position along the polar wandering path is near 45oE, 15^{o} S, southeast of C'. This ancient pole corresponds to the chaotic terrains of eastern Valles Marineris, and at the antipode, to the southeast slope of Elysium Mons, not far from the very old and heavily eroded deposits south of Elysium Planitia. The timing of a rotational pole at this position would be somewhat earlier than the stable position of C' proposed by Schultz and Lutz, but nonetheless consistent with the emplacement of the highly magnetized rocks of the ancient cratered highlands, including Terra Cimmeria and Terra Sirenum.

Another good fit between the paleomagnetic data and the geomorphic data occurs southeast of Schiaparelli Crater near 2' just south of the Schultz and Lutz proposed stable pole at A'. However, this stable pole position is thought by Schultz and Lutz to have been contemporaneous with the development of the Tharsis fracture system and the beginning of Arsia Mons, and thus would seem to be too young to be related to the highly magnetized rocks in Terra Cimmeria and Terra Sirenum.

References: [1] Acuña, M. H. and 19 colleagues, (1998). Science 279: 1676-1680. [2] Acuña, M. H. and 12 colleagues, (1999). Science 284, 790-793. [3] Pepin, R. O. and Carr, M. H., (1992) In Mars, pp. 147-183. Univ. of Arizona Press, Tucson. [4] Schubert, G., Solomon, S. C., Turcotte, D. L., Drake, M. J., and Sleep, N. H., (1992) In Mars, pp. 147-183. Univ. of Arizona Press, Tucson. [5] Connerney, J. E. P., Acuña, M. H., Wasilewski, P. J., Ness, N. F., Reme, H., Mazelle, C., Vignes, D., Lin, R. P., Mitchell, D. L., and Cloutier, P. A., (1999) Science 284, 794-798. [6] Heiland, C. R., (1940). Geophysical exploration. Xiii. Prentice-Hall, New York. [7] Ward, W. R., Burns, J. A. and Toon, O. B., (1979J. Geophys. Res. 84, 243-259. [8] Melosh, H. J., (1980 Icarus 44, 745-751. [9] McAdoo, D. C. and Burns J. A., (1975). Sci. Lett. 25, 347-354. [10] Grimm, R. E. and Solomon, S. C., (1986) Icarus 65, 110-121. [11] Schultz, P. H. and Lutz-Garihan, A. B., (1982). J. Geophys. Res. Suppl. 87, A84 - A96.[12] Schultz, P. H. and Lutz, A. B., (1988) Icarus 73, 91-141.