ARE MARTIAN CRUSTAL MAGNETIC ANOMALIES AND VALLEY NETWORKS CONCENTRATED AT LOW PALEOLATITUDES?

Lon L. Hood[1] and Keith P. Harrison[2], [1]Lunar and Planetary Lab, University of Arizona, Tucson, Arizona 85721 (lon@lpl.arizona.edu), , [2]Southwest Research Institute, Boulder, Colorado 80309.

Introduction: A broad spatial correlation between the Mars crustal magnetic field and the distribution of valley networks has previously been reported [1, 2]. Several possible explanations involving magmatic intrusions, hydrothermal alteration of the adjacent crust, and surface discharge of water have been suggested [2, 3]. In this paper, we investigate whether the distributions of both magnetic anomalies and valley networks may have been preferentially concentrated at low paleolatitudes. Such a concentration would be expected if melting of water ice and snow was a stronger source of surface valley erosion in the tropics and if hydrothermal alteration of crustal rocks played an important role in producing the unusually strong martian magnetic anomalies.

Paleopoles and Paleoequators: Recently, forward modeling of relatively isolated magnetic anomalies has been carried out by several groups for the purpose of estimating the location of the paleopole during the earliest few hundred million years (Myr) of Mars history when a core dynamo existed [e.g., 4, 5, 6, 7]. The analysis consists of estimating bulk directions of magnetization for individual sources and calculating the corresponding paleomagnetic pole location, assuming a dipolar core dynamo centered in the planet. Under the further assumption that the dynamo dipole moment vector was roughly aligned with the rotation axis (as is true for the Earth and most presently existing planetary dynamos), the paleomagnetic pole location is essentially identical to the estimated paleopole location.

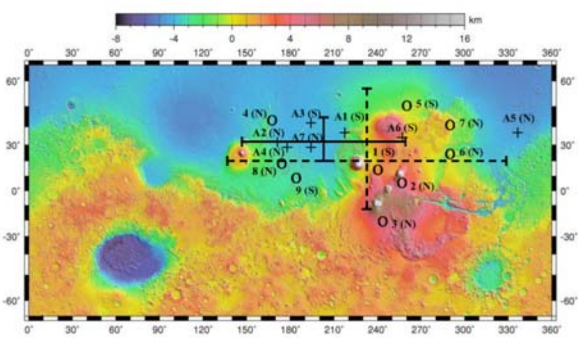

Figure 1. Paleomagnetic pole positions estimated by modeling of martian crustal magnetic anomalies. The crosses and solid line error bars refer to the analysis of ref. 7 while the circles and dashed error bars refer to the analysis of ref. 6. (MOLA topography)

As shown in Figure 1, the results of two recent modeling analyses [6, 7] indicate that the paleomagnetic pole in the Northern Hemisphere during the core dynamo epoch was significantly displaced from its present location. Within the 2σ error limits, the paleopole locations inferred by these two separate analyses are in agreement. In the following, we consider specifically the results of ref. 7 (crosses and solid error bars in Figure 1) which were obtained from modeling of seven relatively strong and isolated anomalies. The estimated paleopole position is $34^o \pm 10^o$ N, $202^o \pm 58^o$ E.

In addition to paleomagnetic evidence for displaced paleopoles during the early history of Mars, a number of authors have suggested geologic evidence for polar reorientations. In particular, based on an earlier suggestion by R. S. Saunders, Mutch et al. [8] originally proposed that the presence of furrowed terrain (now referred to as valley networks) in an approximate great circle around Mars tilted by 15^o to the equator could represent geologic evidence for planetary reorientation. They argued that the development of this terrain was controlled by fluvial and meteorological processes that would have been symmetric about the former equator. Their estimated pole position was at 75^o N, 250^o E. This position would be representative of the period when valley networks dominantly formed, i.e., middle to late Noachian. Melosh [9] later investigated theoretically the pole position prior to the formation of Tharsis by calculating the residual moment of inertia tensor resulting from a removal of the Tharsis gravity anomaly. Although significant errors are associated with such an approach, the calculated pole position (65^o N, 265^o E) was in reasonable agreement with that estimated from the furrowed terrain (valley network) distribution.

Comparison of Paleopoles, Paleoquators, Valley Networks, and Crustal Magnetic Fields: Shown in Figure 2a is the distribution of valley networks (superposed on MOLA topography) as mapped originally by M. Carr [10]. Although modified by the formation of Tharsis [11] and the Northern Lowlands, the valley distribution tends to follow an approximate great circle tilted relative to the equator as pointed out earlier [8]. Shown in Figure 2b is a superposition of a crustal magnetic field map [7] onto the valley network distribution. Also plotted in this figure are the locations of six paleoequators corresponding to the A1, A2, A3, A4, A6, and A7 paleomagnetic poles shown in Figure 1 (thin continuous lines) and the mean of these paleo-equators (heavy dark line). As seen in the figure, the magnetic field distribution also tends to follow a meandering band encircling the planet. The mean tilt angle relative to the equator (~ 45^o) is somewhat greater than that of the valley network distribution (~15^o – 30^o). The mean paleomagnetic equator also tends to follow the distribution of magnetic anomalies. This is especially true when the possible modification of the distribution associated with the formation of the Northern Lowlands is considered.

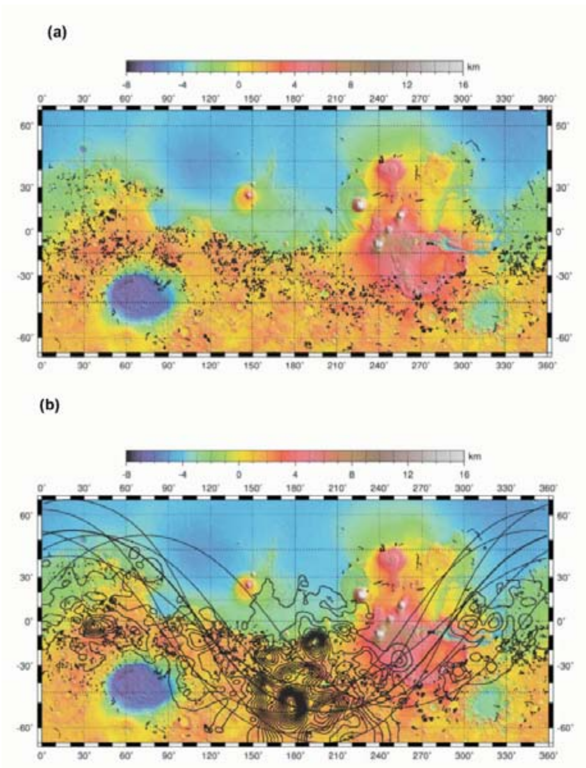

Figure 2. Comparison of (a) valley network distribution and (b) magnetic field distribution with paleo-equators superposed. (MOLA topography)

In order to objectively compare the paleopoles and paleoequators that are predicted by the hypothesis considered here, Figure 3 shows the results of a statistical calculation. Plotted in Figure 3a is the standard deviation (km) of the latitudinal displacements of valley networks from the paleoequator corresponding to a given assumed paleopole location. Red indicates the most probable paleopole location. Figure 3b shows a similar calculation but for the latitudinal displacements of high-field bins (i.e., bins for which the field magnitude is greater than the mean value of 14.5 nT at the mapping altitude of about 400 km) from the paleo-equator corresponding to a given paleopole location. The most probable paleopole location based on the magnetic field data (~ 67^{o}N, 201^{o}E) is near to that estimated from the directional data. The valley network data yield a most probable paleopole location at ~ 75^{o}N, 222^{o}E, which is near to that estimated originally by ref. 8.

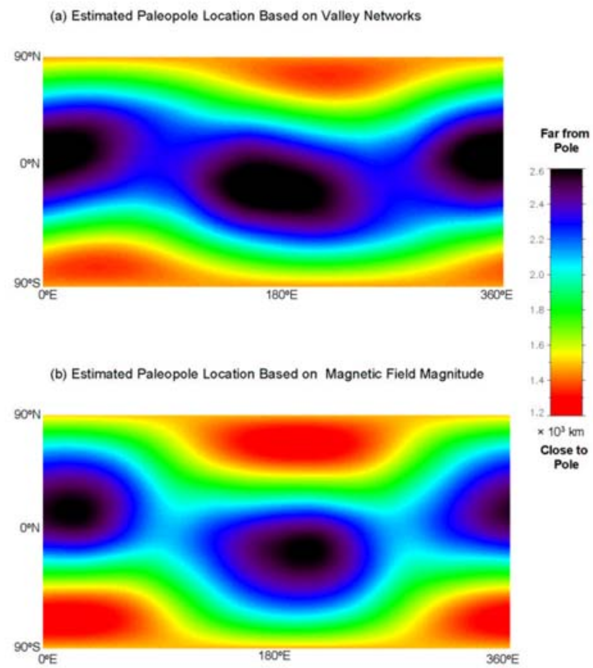

Figure 3. See the text.

Conclusions: The mean paleomagnetic equator calculated from the clustered paleomagnetic pole positions of ref. 7 tends to follow the distributions of both valley networks and magnetic fields. The paleopole may have been located at a lower latitude during the core dynamo epoch than during the period when most of the valley networks formed.

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