CORRELATIONS OF MARTIAN CRUSTAL MAGNETIC FIELDS WITH VALLEY NETWORKS, PHYLLOSILICATE EXPOSURES, AND VOLCANIC CONSTRUCTS: IMPLICATIONS FOR MAGNETIC SOURCES AND DYNAMO HISTORY

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Introduction. A broad spatial correlation between strong martian crustal magnetic fields and the valley networks, which are indicative of surface water erosion, has previously been reported [1,2]. A correlation of at least one martian crustal field anomaly with a volcanic construct, Apollinaris Patera (A.P.), has also been reported [3]. In this paper, we report initial evidence for a correlation of phyllosilicate exposures identified to date using Mars Express OMEGA data with strong crustal fields and valley networks in the Noachian southern highlands. We also report evidence for a correlation of weaker magnetic anomalies with a volcanic plateau adjacent to A.P. Possible implications for the sources of martian crustal magnetic fields and for the duration of the martian dynamo are discussed.

Phyllosilicate Exposure Correlations: The distribution of phyllosilicates has previously been investigated using data from the OMEGA imaging spectrometer on Mars Express [4,5]. Global mapping showed that phyllosilicates are widespread and associated with a range of geomorphic features, but are typically restricted to localized regions exposed in small areas by erosion or excavation. The specific locations of probable exposures that have been verified to date are plotted as red symbols in Figure 1. Two separate statistical methods were applied to investigate whether the distribution of phyllosilicate exposures correlates significantly with the crustal field strength and with the distribution of major valley networks. When the 60°S to 60°N latitude range is considered and divided into 96 15° lat. × 30° longitude cells, both methods (binomial test and normalized occurrence rates) yield evidence for significant correlations with magnetic fields and valley networks. If cells dominated by the Northern Lowlands or the Tharsis topographic high are excluded from the analysis, normalized rates of cells containing both phyllosilicate exposures and either strong crustal fields or valley networks still exceed 1.2, which is significant at the 10% level.

As can be seen from a visual inspection of Figure 1, the significant normalized occurrence rates of phylosilicates with magnetic fields and valley networks in the southern Noachian highlands reflects an inhomogeneous distribution of all three. If strong fields and valley networks had been homogeneously distributed there, normalized rates near unity would have been obtained. The significantly higher-than-unity rates are mainly caused by a relative absence of all three southwest of Hellas and southeast of Argyre.

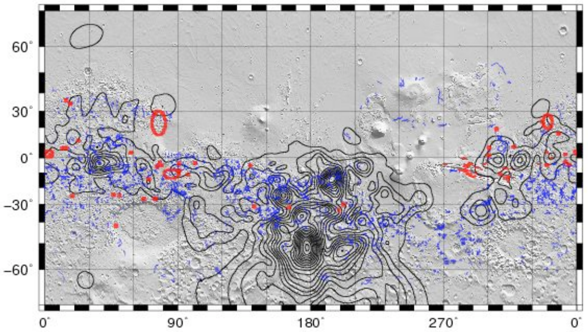

Figure 1. Comparison of the distributions of martian crustal fields at ~ 400 km altitude (black contours; C.I.: 10 nT; [6]), major valley networks (short blue lines; [7]), and phyllosilicate exposures (red; after [5]).

Implications for Strong Magnetic Sources: The observed positive correlation between exposed phyllosilicates and both crustal magnetic fields and valley networks in the Noachian highlands adds further evidence that the strongest crustal magnetization occurred primarily while liquid water was present in the martian upper crust. This correlation therefore provides further support for models in which hydrothermal processes played an important role in producing the strongest martian crustal magnetization [2,6]. The source of the water could have been from above (precipitation) or below (mantle outgassing) [8]. However, the correlation of crustal fields with valley networks suggests a primary source from above. Also, the inhomogeneous distribution of crustal fields, valley networks, and phyllosilicates in the southern Noachian highlands evident from Figure 1 is less easily explained by a mantle outgassing source, which would presumably have been uniformly distributed. Such an inhomogeneous distribution can, however, be explained by a surface precipitation water source. Specifically, the relative absence of all three southwest of Hellas and southeast of Argyre may be a consequence of the location of these regions at high paleolatitudes where liquid surface water would have been less stable [9].

The production in magnetic source regions of magnetite, which is the most efficient remanence carrier, could have occurred in the presence of magmatic heat through hydrothermal chemical processes such as serpentinization. Recently, evidence has been obtained from MRO CRISM data for the presence of serpentine minerals in the Nili Fossae phyllosilicate exposure region near the Isidis basin (B. Ehlmann, private communication, Dec., 2008). This evidence confirms that serpentinization occurred in at least some regions. The maximum depth of hydrothermally formed source regions can be estimated as ~ 20-25 km (based on theoretical permeability estimates that account for impact fracturing of the upper crust) while the lateral extent of strong source regions is in the range of ~ 200-650 km [9,10]. Geologic evidence suggests that magmatic intrusions occurred commonly in the upper crust during the Noachian. If these intrusions occurred in the form of dikes and/or dendritic conduits over large lateral regions during time periods less than the dynamo reversal time scale, then magnetic source regions with the required dimensions could be accounted for.

Correlations of Crustal Fields With Volcanic Units. Using MGS MAG aerobraking data, it has previously been shown that a magnetic anomaly is closely associated with the A. P. volcanic construct [3]. Forward modeling using a near-surface disk source indicates that the horizontal scale size of the source is about twice as large as the surface diameter of the construct. Although detailed modeling of the A. P. gravity anomaly has not yet been carried out, gravity models for several other constructs (e.g., Tyrrhena Patera and Hadriaca Patera) have yielded source diameters that were also several times larger than those of the surface constructs [11]. Because the gravity modeling inferred high-density, buried material beneath each volcano, it was argued that this material was probably dense cumulate minerals in extinct magma chambers. Therefore, if future work shows that the inferred scale size and location of the magnetic anomaly source are similar to those inferred from gravity modeling, then a possible source may be the extinct magma chamber.

Figure 2 plots the field magnitude in nT at the mapping altitude (~ 380 - 400 km) over A. P. and vicinity, produced using methods described in [9]. Anomalies are generally weak north of the dichotomy boundary but become stronger south of the boundary near 20°S. On the eastern half of the map, centered roughly on the dichotomy boundary, a broad anomaly correlates approximately with a large-scale volcanic plateau that adjoins the A. P. construct on its southwestern side. The contours protrude to the southwest over the construct itself, consistent with a separate magnetization source at this location, as previously found [3]. The plateau unit is mapped as part of the Medusae Fossae Formation (MFF) and has an Amazonian surface age. The MFF most probably consists of pyroclastic flow deposits several km thick originating at one or more vents that may now be buried [12].

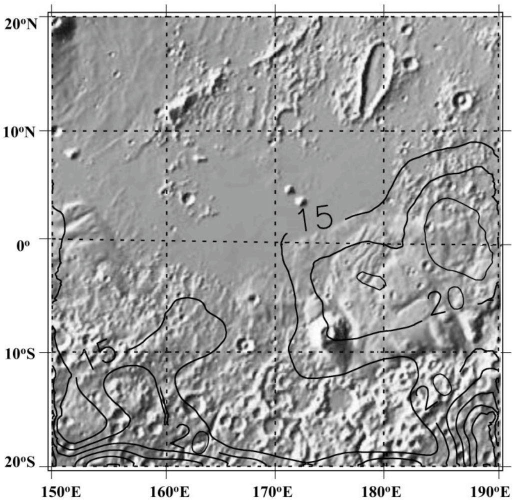

Figure 2. Magnetic field intensity (nT) at ~ 400 km altitude over Apollinaris Patera and vicinity.

Implications for Dynamo Duration. The formation of strong martian magnetic source regions apparently ceased during the Noachian [13]. If hydrothermal processes were involved in their formation, this cessation could have been caused by either a decline of the magnetizing field intensity (end of the dynamo) or by a decline of the effective crustal susceptibility to magnetization (e.g., reduced abundance of upper crustal water). Magnetic anomalies associated with young (surface age) volcanic units favors the latter explanation. This evidence together with uncertainties in the interpretation of demagnetization signatures of the youngest martian basins allows the possibility that the dynamo may have persisted beyond the Noachian.

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