PARALLEL MODELING OF THE APOLLINARIS PATERA MAGNETIC AND GRAVITY ANOMALIES. Lon L. Hood, Lunar and Planetary Laboratory, University of Arizona , 1629 E. University Blvd., Tucson, AZ 85721, lon@lpl.arizona.edu; Walter S. Kiefer, Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX, 77058, kiefer@lpi.usra.edu; Benoit Langlais, Université de Nantes, Laboratoire de Planétologie et Géodynamique; and CNRS, UMR 6112, Nantes, F-44000, France.

Introduction: Crustal magnetic fields on Mars are unusually strong – several orders of magnitude stronger than lunar fields and roughly one order of magnitude stronger than terrestrial crustal fields at a given altitude. Although it is generally accepted that a former core dynamo provided the magnetizing field, the processes that led to such intense crustal magnetism at Mars and the identities of the sources remain only partly understood [1].

Several lines of evidence suggest that the strong field sources may consist primarily of Fe-rich basaltic intrusions and extrusions in the upper martian crust. First, it is well established that martian basaltic rocks are enriched in FeO (~17 wt%) compared to terrestrial basalts (typically 8-10 wt%). Recent laboratory experiments show that synthesized basalts that are similarly enriched in FeO can yield high magnetization intensities (up to ~ 50 A/m in a 50 μT applied field) if they formed in a sufficiently oxidizing environment [2,3]. For such a high magnetization intensity, a total thickness of ~14 km and a width of ~200 km would be sufficient to produce crustal fields of the required maximum strength (~1000 nT at 100 km altitude). Successive volcanic lava flows and/or intrusions with individual thicknesses less than a few km (to promote rapid cooling and single domain magnetite formation) could then explain the formation of large-scale magnetic sources [4,5].

Second, despite the high (~400 km) Mars Global Surveyor (MGS) mapping altitude, there have been several reports of possible correlations of orbital anomalies with volcanic constructs, i.e., Hadriaca Patera based on MGS electron reflectometer data [6] and Apollinaris Patera based on MGS magnetometer data [7]. Both of these constructs are much older than the Amazonian-aged constructs that populate the Tharsis region where thermal demagnetization has dominated since the end of the dynamo [8,9]. But they are still significantly younger than the large basins (e.g., Hellas, Argyre) that have been clearly shock demagnetized [10]. These correlations have therefore raised questions about whether the Mars dynamo may have persisted into (or been restarted in) the late Noachian / early Hesperian. On the other hand, it may be alternately hypothesized that a ``proto-Hadriaca'' or ``proto-Apollinaris'' magmatic intrusion in the deep crust dating from the early Noachian is actually re-

sponsible for the observed anomaly at each site and was incompletely thermally demagnetized by the magmatic events that formed the visible volcanoes [6].

In this paper, we report more detailed modeling of the Apollinaris Patera (A.P.) magnetic anomaly supplemented by initial modeling of the co-located A. P. gravity anomaly. The magnetic anomaly modeling is mainly intended to investigate whether a secondary concentration of magnetization exists at the construct itself (needed to eliminate the pre-existing early Noachian source hypothesis). The gravity anomaly modeling is intended to investigate whether a significant buried load (in addition to the edifice topography) is implied. Such a buried load may consist of a solidified cumulate chamber, which could also potentially be the primary source of the magnetic anomaly.

Magnetic Anomaly Data and Modeling: A. P. is well suited for magnetic modeling because it is located in a geologically less complex area just north of the dichotomy boundary and is some distance (> 10°) away from stronger anomalies in the southern Noachian highlands. In addition, several low-altitude orbit tracks from the aerobraking phase of the MGS mission fortunately pass very close to the construct. Two of these tracks have similar altitudes at closest approach (~122 and ~117 km) and are less than a degree of longitude apart, allowing a consistency check. A broad anomaly with amplitude near 200 nT is present on both passes with maximum amplitude occurring near 9° S, close to the southern edge of the caldera. Since the effective resolution of these passes is roughly equal to the altitude (120 km or ~2°), the anomaly location is not significantly different from that of the construct.

For the special case of a relatively isolated, dominantly dipolar field anomaly, iterative forward model calculations can yield reasonable estimates for quantities that are of geophysical interest [11,12]. Even for a dominantly dipolar anomaly, however, a large number of source region models is possible ranging from a point dipole buried deep within the crust to a thin, uniformly magnetized surficial layer, all of which would yield nearly identical fields at the spacecraft altitude if their directions of magnetization are consistent. But there is one constraint that can be applied: Sources deeper than some maximum depth can be ruled out because temperatures at those depths would have exceeded the Curie temperature for plausible magnetic minerals during Mars history. According to [1], the

maximum allowed depth is ~ 50 km for magnetite. For comparison, Mars crustal field sources have estimated horizontal scale sizes in the range of ~ 200 – 600 km [11,12]. Therefore, a source model consisting of a relatively thin (< 50 km thick) near-surface layer is more plausible than one consisting of a point dipole, which must be at a depth comparable to the surface layer diameter.

Based on the above arguments, the available low-altitude MGS MAG data near A.P. was modeled assuming a source consisting of one or more uniformly magnetized circular disks (vertical cylinders) at a shallow depth. An iterative forward method [13] was then applied in which the source parameters are adjusted until a minimum rms deviation is obtained between the model field components and corresponding observed quantities along the original orbit tracks (see the appendix of [11]). Figure 1 shows the approximate surface locations and sizes of the best-fitting disks for a two-disk model. As seen in the figure, the first disk (A) is centered near the main construct but with a scale size several times larger than the construct (radius 180 ± 30 km). The second disk (B) is centered not far from the caldera although its radius is not well determined: 60 ± 60 km, which allows models ranging from a point dipole to a 120 km radius disk. Nevertheless, the reduction in the rms deviation when a second disk is added (from 60 to 47 nT) is larger than the estimated noise level of 10 nT, indicating that a second disk significantly improves the fit.

The main characteristic of the anomaly that favors a central concentration of magnetization is the ``sharpness'' of the radial and north field maxima on the two closest low-altitude orbit tracks. The directional results of the modeling yield a paleomagnetic pole position in the N.H. near 66°N, 228°E, consistent with that obtained using a single dipole model by [7]. Overall, these results indicate magnetization acquisition at a later time during the main magmatic event that produced the construct, a conclusion that is difficult to reconcile with absence of the dynamo during the late Noachian / early Hesperian.

Gravity Anomaly Data and Modeling: A pronounced free-air gravity anomaly is associated with A.P. (see, e.g., [7]). The gravity anomaly has a scale size comparable to that of the main inferred magnetic source (Figure 1). We have examined a more recent, higher-resolution gravity model (MRO95A) from the Mars Reconnaissance Orbiter mission [14] up to spherical harmonic degree 85. Although most of the free air anomaly is due to the edifice topography, a significant buried load is apparently required as well, similar to that inferred at Syrtis Major and interpreted

in terms of a solidified cumulate chamber [15]. A cumulate mineral layer (assuming an olivine/pyroxene composition) with a thickness of several km is indicated. Detailed modeling using sources consisting of one or more vertical cylinders is in progress. This should allow a direct comparison to the magnetic modeling results and an evaluation of whether the magnetic and gravity sources could be coincident.
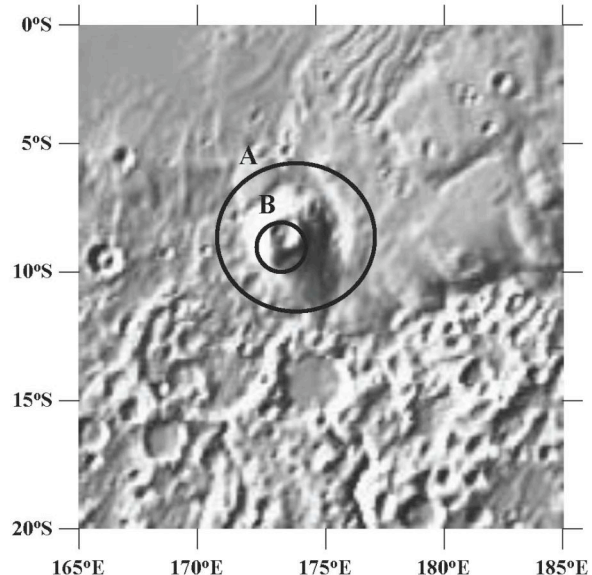

Figure 1. Approximate surface locations and sizes of the two vertical cylinder magnetic sources that yielded a minimum rms deviation from the low-altitude MGS MAG data (see the text).

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