CONSTRAINTS ON THE EVOLUTION OF THE DICHOTOMY BOUNDARY AT 50-90E. S. E. Smrekar[1], C. A. Raymond[1], A. Dimitriou[2,3], and G. E. McGill[2], [1] Jet Propulsion Laboratory (California Institute of Technology, MS 183-501, 4800 Oak Grove Dr, Pasadena CA, 91109; ssmrekar@jpl.nasa.gov), [2]SLR Alaska (2525 Blueberry Road, Suite 206, Anchorage, AK 99503, adimitriou@slrcorp.com) [3]Univ. Massachusetts, Amherst (gmcgill@eclogite.geo.umass.edu).

Introduction: The global dichotomy is a fundamental feature of Mars. It marks the boundary between the highly cratered, older southern highlands, and the northern plains. Recent analysis of buried craters in the northern lowlands confirms the long held suspicion that they are comparable in age to the southern highlands, but with surficial deposits of younger material [1,2]. A variety of exogenic and endogenic models have been proposed for the origin of the dichotomy, including multiple impacts [3], plate tectonics [4], and degree one convection produced by core formation [5-7], a plume under the lowlands [8], or a plume under the highlands [9]. New gravity and topography data from the Mars Global Surveyor (MGS) Mission favor endogenic processes [1].

In this study we examine MGS topography, gravity and magnetic field data to constrain the tectonic history of the dichotomy in the region 30-60N and 50-90E (see Figure 1), which encompasses portions of the Ismenius Lacus quadrangle. The dichotomy formed very early in the history of Mars and has undergone extensive modification by impact cratering, erosion, and faulting. This history must be carefully interpreted in order to reconstruct the original nature of the dichotomy boundary and ultimately discriminate between models of origin. In the study area boundary-parallel faults are well preserved, and may be the result of gravitational relaxation. The geologic history has been examined in detail, including estimates of volumes of material eroded [10]. Further, it is one of the few regions where there is a correlation between the free air gravity, magnetic anomalies, and the geology. This allows us to constrain subsurface faulting beneath the lowlands fill material. In addition to being an excellent location to unravel the complex history of the dichotomy, this area preserves the transition from a highly magnetized highlands crust to an unmagnetized or slightly magnetized lowlands crust.

Analysis: *Structural geology*. The dichotomy boundary in the study is highly dissected by normal faults that parallel the boundary. In addition to the obvious normal faults, Dimitriou [11] mapped a NW-trending buried fault or monocline in the lowlands parallel to the dichotomy boundary. The fault location was identified based on the abrupt disappearance of inliers of older, partially embayed material marking a transition from smooth to very smooth plains materials. Dimitriou interpreted this transition as evidence of a structural bench, approximately 400 km wide, possibly down dropped from the original plateau height.

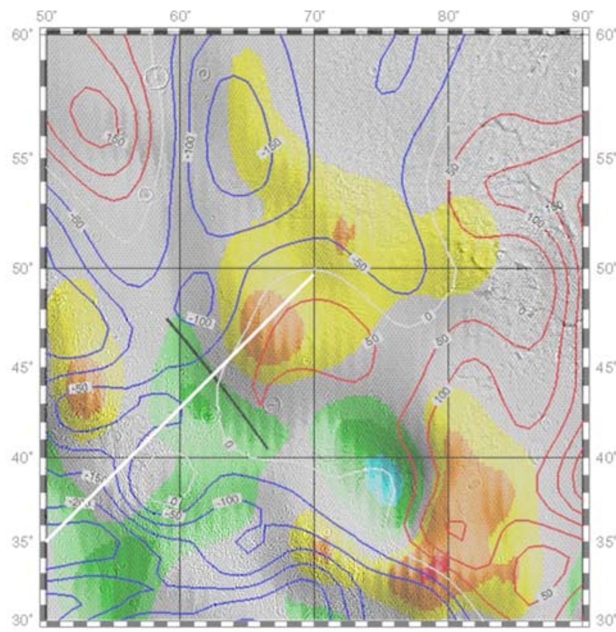

Figure 1. Viking imagery is a shown as the gray-scale background. The vertical component of the crustal magnetic field from the map of Purucker et al. [3] is shown in color, with negative values in blue [-100 to –50 nT], light green [-50 to –25 nT], and dark green [-25 to –10 nT] and positive values in yellow [10-25 nT], orange [25-50 nT], and red [50-100 nT]. The buried fault [11] is shown as a black line. The white line indicates the position of a magnetic profile (see Figure 3). The Bouguer gravity derived from MGS75D is shown as 50 mgal contours, with blue contours indicating negative anomalies, white lines the 0 contour, and red lines the positive anomalies.

Examination of MOLA topographic profiles across this area, as well as gridded data, shows that there is a break in slope at the location of the buried fault and confirms the transition from knobby to smooth terrain. The region between the fault and the steep edge of the dichotomy boundary is approximately 500 km across and has no appreciable slope. This supports the interpretation of the boundary as a fault, and is consistent with the shelf representing a fault block. One question is whether the block was originally part of the highlands and then down dropped or eroded down to its present level, or if it was always low and thus topographically part of the lowlands. This question could help constrain the timing of the formation of the dichotomy scarp and will be examined further using crater counts.

Gravity and Magnetic Fields. In this study area, the pattern of magnetic anomalies is generally correlated with both the Bouguer and the free air gravity field (Figure 1). Interestingly, the location of the proposed buried fault coincides with a polarity boundary in the magnetic field and is parallel to the contours of the gravity field (see Figure 1). Note that the map of Purucker et al. [12] represents the radial magnetic field only. Thus the actual location of highs and lows in the vector magnetic field may be shifted somewhat. The observed correlation between the gravity and magnetic fields indicates that the magnetic field variations are associated with changes in density.

The amplitude of the magnetic field in this area indicates a bulk magnetization contrast much lower than in the highly magnetized Terrae Sirenum/Cimmeria region of the southern highlands. This implies either a thinner magnetic source layer of equivalent magnetic intensity, or a lower intensity of magnetization than in the areas of strong magnetic fields, or both.

Admittance studies provide constraints on the compensation mechanism in the region. Isostatic compensation would indicate that the area is currently being supported by density differences at depth. Flexural compensation reflects the thickness of the elastic lithosphere at the time when loading occurred, most likely when either the dichotomy formed or when the fault scarps formed. Admittance models show a good fit to the data for a crustal thickness value of 20 km and an elastic thickness of 10 km. This elastic thickness value is close to 0 km, which would indicate an isostatic compensation mechanism. This estimate of the elastic thickness is in good agreement with estimates from other areas of the southern highlands [13], but lower than the value found for a large region of the southern highlands [14] . We will carry out an error analysis to determine whether or not a zero value of elastic thickness is a reasonable, suggesting an isostatic compensation mechanism.

As a first step towards placing constraints on the subsurface structure, we calculate the isostatic anomaly from the Bouguer gravity. This approach assumes that the gravity anomalies that are left once the density variations due to both the topography and the crust are removed are due to variations in crustal thickness. We examined various crustal layer thicknesses, assuming a density difference of 600 kg/m^3 between the crust and mantle. For the 20 km average crustal thickness obtained from the admittance studies, we obtain crustal thickness variations of +8 km under the highlands, and –2 in the lowlands along a line perpendicular to the fault (see Figure 2). If a thicker (thinner) crustal layer is used, either larger (smaller) variations in crustal thickness or larger (smaller) density contrasts are needed to match the observed anomalies.

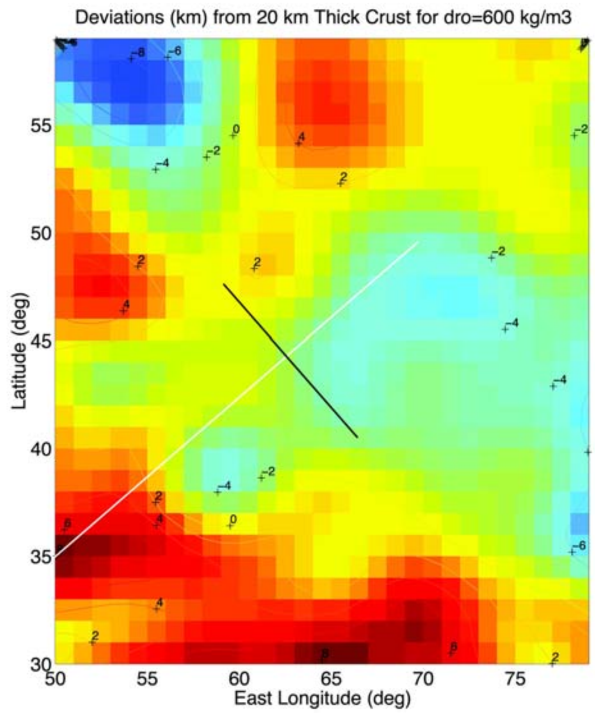

Figure 2. The Bouguer anomaly resulting from removing the gravitational contribution of the topography and a 20 km thick crust. Remaining variations in the gravity field are represented as variations in the thickness of the crust in km. Light blue regions indicate 2-4 km of crustal thinning, red areas are 2-4 km of crustal thickening, and dark red areas have 6-8 km of crustal thickening. The white line indicates the location of the modeled magnetic field profile. The black line shows the position of the buried fault.

Modeling of the magnetic field across the fault offers additional insight into the subsurface structure. A series of crustal zones or blocks with coherent magnetization are used to model the observed magnetic field (Figure 3). Note that the sign and intensity of the magnetization is constant in all of the blocks. The changes in amplitude of the predicted field are a result of the thickness and spacing of the various blocks. The tops of the blocks are located at the surface defined by MOLA data, and reflect the 3 km drop across the scarp that bounds the dichotomy. An intensity of 20 A/m, consistent with the high magnetic intensity in Terra Sirnum, is used for all blocks in this thin crust model. Using a lower intensity would result in thicker crust Estimated variations in crustal thickness across the dichotomy boundary from the Bouguer anomaly give an increase of +2-8, 0, -2, 0, and –2 km under the highland plateau, the edge of the plateau, the topographic shelf, the buried fault, and the plains to the north, respectively. The modeled variations in the thickness of a magnetic layer parallel the decrease in thickness from the plateau out to the buried fault. However, in the plains, the gravity suggests a thinned crustal layer where the magnetic field model has a thicker layer. The apparent thinning of the crust in the plains may be at least partly attributed to low-density fill material. This possibility will be further investigated.

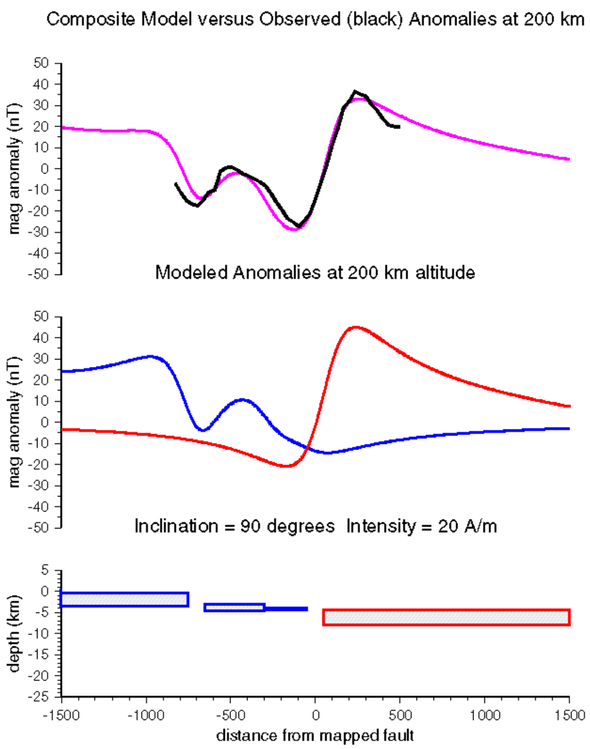

Figure 3. Variations in the thickness of a layer magnetized crust that fit the observed magnetic field. The black line indicates the observed field along a profile perpendicular to the buried fault, starting in the highlands on the left, crossing the buried fault in the center, and continuing out into the plains. The end points of the profile are 50E, 35N and 70E, 49.5N. The pink line is the predicted magnetic field. The magnetic field predicted by different crustal blocks is shown in the center plot. The blue line indicates the field produced by the blocks shown in blue and the red line corresponds to the red block in the plains.

First, modeling indicates that breaks in the magnetization of the crust at both the steep topographic boundary of the dichotomy and the location of the buried fault are required in order to match the magnetic field. The crust could lose its coherent magnetization by being disrupted by faulting, subsequent hydrothermal circulation, erosion, or a combination of these factors. Second, modeling has shown that crust with a single polarity across the dichotomy and into the plains can match the observed signal. North of the dichotomy boundary, the edge effect of a continuous source layer underlying the northern lowlands, or a discrete block can explain the observed signature. Thus the magnetic field signature alone cannot be used to infer a difference in the origin of the crust across the buried fault.

Results and Discussion: The correlation of the observed tectonic features with the gravity and magnetic fields in this region offer an unusual opportunity to constrain both the thickness and depth of the magnetic layer and the detailed geologic history of the dichotomy. The topographic shelf is interpreted as having been dropped by 1.4 km from the original level of the plateau [11]. We cannot directly estimate the displacement on the buried fault and thus simply assume that it is comparable to the displacement (~1.4 km) across the dichotomy boundary. The magnetized layer appears to be shallow enough to be affected by this faulting. Analysis of the Bouguer gravity and magnetic data together support a near surface layer. The low estimate of the thickness of the crust from admittance modeling is also consistent. Both the admittance modeling and modeling of the Bouguer anomaly indicate that the crust cannot be much thicker than 20 km. Modeling of variations in the magnetic field is consistent with a magnetized layer that is thinner than inferred within the southern highlands. This result is in contrast to the estimated 30-50 km thick magnetized layer in Terrae Sirenum and Cimmeria [15,16] .

The necessity for gaps in the magnetized crust at the dichotomy scarp and at the buried fault indicate demagnetization of the crust via extensive disruption of the crust or hydrothermal alteration by enhanced flow of fluids along the faults. The later mechanism has been suggested as means of demagnetizing the plains region and major basins [17]. Tectonic effects must be considered when interpreting other observed changes in the magnetic field.

Our initial results suggest that the magnetized layer underlying the plains differs from the layer beneath the highlands and the topographic shelf. Under the plains, the thickness of the crust suggested by modeling the gravity data decreases, while the magnetic layer thickness appears to increase. This corroborates the interpretation that the topographic shelf was originally part of the highlands. It also suggests that the magnetic layer either has a greater susceptibility or a larger thickness than the magnetic layer under the neighboring highlands. This could imply a different formation mechanism, mineralogy, or modification history. Further modeling of this layer and nearby magnetized plains regions will provide further information on this puzzle.

Understanding the details of the change in the magnetization of the crust from the highlands to the lowlands in this one area, where there are numerous constraints, may shed light on overall differences between the generally highly-magnetized highlands and lowlands, which typically have little to no magnetization. The lack of correlation of gravity and magnetic data in most regions of Mars may be due to a higher level of subsequent mechanical or thermal modification. Alternatively, variability in the magnetic layer may not have corresponding changes in density; conversely, density differences in a deeper layer would have smaller associated anomalies.

Prior studies have place bounds on the global crustal thickness and rates of relaxation of the dichotomy boundary [2,18]. Final results of this study will provide important constraints for modeling the evolution of the dichotomy boundary in this area. Timing and location of fault formation, final thickness of the crust, and the initial elastic thickness are key constraints for models of plateau relaxation. The goal of such models is to distinguish between models for the formation of the dichotomy by constraining the thermal and rheologic changes across the boundary with time. Another goal of the study is to determine whether hydrothermal (chemical) demagnetization or thermal demagnetization of the plains is more plausible. Future work will include crater counts to constrain the timing of the formation of the topographic shelf and error analysis of lithospheric parameters derived from gravity and magnetic models.

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