THE CRUSTAL DICHOTOMY OF MARS: GEOLOGICAL CONSTRAINTS AND TESTING OF GEOPHYSICAL MODELS. R. P. Irwin III and T. R. Watters, Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, MRC 315, 6th St. at Independence Ave. SW, Washington D.C. 20013-7012, irwinr@si.edu, watterst@si.edu.

Introduction: The crustal dichotomy remains among the fundamental unexplained features of Mars. Proposed models for the development of asymmetric crustal thickness, topography, and morphology between the southern and northern hemispheres include exogenic (one or more giant impacts) [1–4] and endogenic (long-wavelength mantle overturn [5–9] or plate tectonics [10,11]) mechanisms. Other papers describe possible erosional and tectonic modifications to the crustal dichotomy boundary (hereafter, "boundary") [e.g., 12–18]. Both classes of geophysical mechanisms and many analyses of modifications suffer from poor empirical validation and contrary observations in the geologic record. Here we use morphological and geophysical data from the boundary region to evaluate published models of the crustal dichotomy and constrain future modeling efforts.

Geologic Constraints on Timing and Process: The geomorphology of the boundary region provides important constraints on the age and origin of the crustal dichotomy.

Cratered terrain. Most of the decline in crustal thickness and topography that defines the boundary occurs within Noachian cratered terrain. Heavily cratered surfaces of Early to Middle Noachian age decline to the north in the Cimmeria, Sirenum, Arabia, Sabaea, and Margaritifer Terrae regions [19,20]. Characteristics of degraded impact craters and valley networks on these slopes indicate no substantial tilting, flexure, or related tectonic extension after the time of emplacement (Fig. 1). 1) The crustal dichotomy is isostatically compensated, whereas Early Noachian and younger impact-related and volcanic loads are not [e.g., 5,21]. 2) Degraded craters of Middle to Late Noachian age have eroded but otherwise intact rims, so little to no lithospheric flexure and relaxation occurred after these impacts. 3) Floor deposits within these craters, which accumulated until sometime around the Noachian/Hesperian transition, are flat and have not been tilted northward or faulted in ways predicted by models of contemporary lithospheric flexure and relaxation [17,18]. 4) The planes defined by rim crests of fresh impact craters incline subparallel to the boundary slope, whereas the interior cavities are vertical, as found at fresh craters within Hellas or other precursor slopes [22]. 5) Late Noachian valley networks follow the steepest topographic gradients, whereas post-Noachian tilting would yield a discrepancy between valley courses and modern slopes. These observations contradict endogenic models for dichotomy formation during or after the Middle to Late Noachian.

Fretted and knobby terrains. The transition zone of fretted and knobby terrains formed in Late Noachian to Early Hesperian time in rocks of Late Noachian age [e.g., 19,20,23]. As such, fretted terrain development is not contemporary with the origin of the crustal dichotomy. Characteristics of fretted terrains suggest origin by structurally controlled erosion of the surface or subsurface, in rocks that may have been particularly susceptible [12–14]. 1) Unidirectional crustal extension does not explain the complex and generally orthogonal planform of fretted valleys. 2) Enclosed, collinear depressions are often separated by undissected surfaces, restricting the possible crustal extension. 3) No offset of marker beds or crater rims, or rotation of fault blocks is observed. 4) Tectonic processes do not explain the gradation from mesas to rounded knobs with distance from the intact cratered terrain. 5) Relaxation due to lateral crustal flow should occur primarily within the first 100 Myr after the dichotomy forms, with the most significant flow along sections of the boundary with highest relief [18], which is inconsistent with the preservation of high-standing, Early Noachian cratered slopes along most of the boundary.

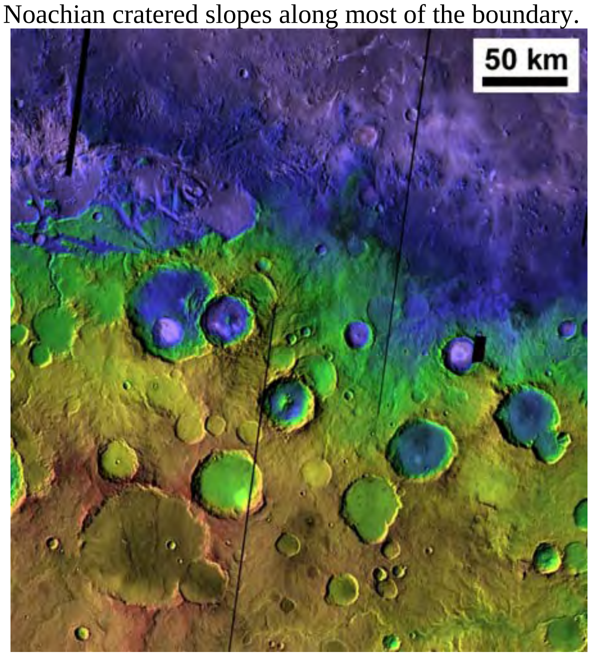

Figure 1. The cratered slope of the crustal dichotomy boundary in Terra Cimmeria (9.2°S, 154.5°E).

Exogenic Models: The giant-impact hypotheses for origin of the northern lowlands fail several empirical tests. 1) Most of the lowlands lack topographic basins, impact structures, and gravity anomalies predicted by the models [21], and it is unclear how both the gravitational and topographic signatures of large impacts would be simultaneously removed. 2) Topographic embayments expected from multiple impacts along the boundary are not found over most of its length [24]. 3) Recognized younger basins do not fully explain deviations of the boundary from the great circle predicted by the single giant impact model [24]. 4) Lunar analogs and impact theory show that adjacent impacts yield inter-basin highlands, not a wholesale lowering of a surface [24]. 5) Gravity and topography data show no crustal thickening from ejecta deposition or uplift along the boundary [8,21]. 6) The statistical likelihood that multiple large impacts would be concentrated in the lowlands is low [24]. 7) One impact crater at a specified diameter is an invalid basis for extrapolating an entire population [24], which was used as the original basis for the multiple large impact model [2]. 8) The Ares, Daedalia, and Acidalia impacts of Frey [4] and the Elysium feature of Frey and Schultz [3] are equivocal interpretations that provide no constructive support for the multiple-large-impact model. No quantitative models have addressed these challenges to the impact hypotheses. One or more giant impacts cannot explain the crustal dichotomy without relying on supporting endogenic and/or rapid erosional processes that have not been elucidated theoretically or validated by the geologic record.

Endogenic Models: The primary issues faced by endogenic models are time requirements and lack of corroborating evidence in the geologic record.

Plate tectonics. Both proposed scenarios involving plate tectonics have terminated around the Noachian/Hesperian transition due to the slow rate of the process [10,11]. The crustal dichotomy formed in the Early Noachian Epoch, however, and left no obvious topographic, mineralogical, or gravitational signature of plate tectonics along the boundary. Denudation rates in Noachian Mars (constrained by impact crater modification to the order of ~1 m/Myr [25]) were inadequate to remove landforms of this scale, so any substantial convective overturn is restricted to very early in the Noachian.

Degree-1 mantle overturn. Mantle convection driven by thermal or density contrasts must produce the crustal dichotomy in the time available (a few hundred Myr) and predict the size and shape of the lowlands and Arabia Terra. To date, quantitative models in this subclass [9,26] have not fully addressed these requirements.

Constraints on Future Modeling: 1) The processes that formed the crustal dichotomy culminated in the Early Noachian Epoch and may have been restricted to the first few tens to hundreds of Myr of Martian history [27]. All diagnostic features not found in the geologic record must have been small enough for Noachian erosion to completely remove them (note that Early Noachian, degraded impact basins of a few hundred km in diameter are still evident in topography [4]). The specific amount of time available to form the crustal dichotomy depends on the cratering rate and how it declined over time; a late impact cataclysm [e.g., 28] would allow more time for endogenic processes to operate within constraints set by the cratering record. Fretted terrain is not relevant to the origin of the crustal dichotomy. 2) The dichotomy is attributable to rapid endogenic processes that may have been related to the origin of the crust, rather than a later modification of an initially uniform crust. Future modeling efforts should explore the possible implications of processes related to early crustal formation.

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