CRUSTAL EVOLUTION OF THE PROTONILUS MENSAE AREA, MARS.

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Despite research by numerous geologists and geophysicists, the age and origin of the martian crustal dichotomy remain uncertain. Models for the origin of this dichotomy involve single or multiple impact, mantle megaplumes, primordial crustal asymmetry, and plate tectonics [1 - 10]. Most of these models imply a Noachian age for the dichotomy. A major problem common to all genetic models is the difficulty separating the features resulting from the primary cause for the dichotomy from features due to younger faulting, impact cratering, volcanism, deposition, and erosion.

The boundary between northern lowlands and southern highlands (the dichotomy boundary) approximates a small circle that ranges in latitude from about -10^0 in Elysium Planitia to about $+45^0$ north of Arabia Terra. For much of its length the boundary is characterized by relatively steep scarps separating highland plateau to the south from lowland plains to the north, generally with a complex transition zone on the lowland side of these scarps [11]. These scarps are almost certainly due to normal faulting. The type fretted terrain [12], which defines the boundary in north-central Arabia Terra, also is characterized by scarps but has undergone a more complex history of faulting and dissection [13]. In some places, notably in the Acidalia Planitia region, the dichotomy boundary is gradational. In the Tharsis region the boundary is obscured by younger volcanics.

The present study concerns the segment of dichotomy boundary between about 50^0E and 90^0E (310^0-270^0W), within the Ismenius Lacus and Cassius quadrangles. This site was chosen because: 1) within part of the site the boundary is a single well defined scarp ~2.5 km high, 2) parallel to this scarp are several grabens, which support an extensional origin for the boundary scarp, and which also provide a means to estimate strain, 3) erosion appears not to be extreme, 4) the geology and structural history allow constraining the age of the boundary scarp, and 5) there are areal correlations among topography, geology, remanent magnetism, and gravity anomalies. The combination of tractable geology with magnetic and gravity data provides a rare opportunity to infer the evolution of the crust and mantle along the highland/lowland boundary.

Terrains within the study site may be divided into three structural blocks based on surface morphology and elevation. From southwest to northeast these are: 1) highland plateau, 2) lowland bench, and 3) lowland plains [14]. The highland plateau block is within the large region Arabia Terra, which is somewhat anomalous because it is topographically lower than most highland areas despite its highland crater population. The highland plateau has been resurfaced following accumulation of most of its large craters. The crater age of the highland plateau is Early Noachian; the age for craters younger than the resurfacing event is Middle Noachian. High resolution THEMIS and MOC images indicate that resurfacing was accomplished at least in part by deposition of a layer of material that is thin enough to permit the rims of older craters larger than a few km in diameter to show through as inliers. Thus the post-resurfacing crater age is interpreted to be the age of the material deposited on the highland basement.

The boundary between the highland plateau and the lowland bench is a fault or zone of faults. The lowland bench is 2-3 km lower than the highland plateau, and is characterized by an abundance of knobby inliers projecting through a younger layer of smooth plains material. Some of these knobs clearly define circles that are inferred to be structurally disrupted crater rims ("knob ghosts"). A count of all craters and knob ghosts yields a Late Noachian age. However, the presence of the knob ghosts indicates that the basement surface under the lowland bench has experienced greater structural disruption than the basement of the highland plateau where rims of large, ancient craters, although degraded, have not been dissected into rings of knobs. The basement of the lowland bench also is partially covered by plains material that is similar to the material underlying the lowland plains block Thus it is very likely that the age of the basement beneath the lowland bench is similar to the age of the basement beneath the highland plateau; that is, Early Noachian. This is consistent with the basement age determined for the entire lowland using all craters visible in images plus "Quasi-Circular Depressions" (QCD's) visible only in MOLA digital terrain models [15].

Is it possible that the scarp separating highland plateau from lowland bench is erosional rather than structural? The highland plateau and lowland bench have similar basement ages. It is not possible for the scarp to be older than these basement ages because it could not have survived formation of the craters yielding these basement ages. If the scarp formed by erosion after the cratering of the highland plateau and lowland bench basement, then on the order of the scarp height (2.5 km) of material must have been removed over what is now the lowland bench. This depth of erosion would have completely destroyed the rims of all of the craters used to date the lowland bench basement. It thus appears to be impossible to create the current topography within the Protonilus Mensae area by extensive erosion alone.

The boundary between the lowland bench and the lowland plains is characterized by the abrupt loss of the knobs that are so abundant on the lowland bench. This boundary is parallel to and about 400 km NE of the scarp that separates highland plateau and lowland bench. The loss of the knobby topography along this boundary is most likely due to an increase in thickness of smooth plains material, resulting in complete burial of the knobs in the lowland plains block. The abruptness of this loss of knobby topography suggests that the lowland bench/lowland plains boundary is a fault, down on the NE [14]. There is no topographic signature of this fault other than the loss of knobby topography, indicating that its fault scarp has been completely destroyed or buried. The minimum vertical displacement needed to completely bury the knobs of the lowland bench block is about one kilometer; the actual displacement is probably greater but is not constrained. Poorly defined ridges that are similar to wrinkle ridges occur in the lowland plains block. These ridges are locally parallel to the dichotomy boundary. The age of the smooth surface material in the lowland plains block is Late Hesperian [11,14]. The smooth plains material surrounding the knobs on the lowland bench is continuous with the plains material in the lowland plains block, and thus also is inferred to be Late Hesperian.

Both the dichotomy boundary scarp separating highland plateau from lowland bench, and the buried fault separating lowland bench from lowland plains cut basement rocks of Early Noachian age. The boundary scarp also cuts the Middle Noachian resurfacing material of the highland plateau. Thus the old age limit for faulting in this area is Middle Noachian. The smooth plains material underlying the lowland plains is also present as a thin veneer on the lowland bench. This plains material embays the boundary scarp in places, and it buries the buried fault, indicating that the young age limit for faulting in this area is Late Hesperian. The relative age range Middle Noachian-Late Hesperian is interpreted to correspond to an age range in years of 3.9-3.1 Ga [16]. The old limit is only 140 Ma younger than the young age limit for lowland basement as determined using QCD's [17].

The dichotomy boundary scarp and the scarps bordering the grabens that are present SW of the boundary scarp have slopes in the range 13-21^0; thus, as we would expect, these scarps are degraded from the presumed ~60^0 slope of a pristine normal fault scarp. Using MOLA altimetry profiles and assuming 60^0 fault dips, the extensional strain in the immediate vicinity of the dichotomy boundary scarp is determined to be ~3.5%

The lowland bench block is part of an extensive transitional zone between highland and lowland. Lowland bench crater ages determined in this study are completely consistent with crater ages determined for this entire transitional zone [11]. Furthermore, the old age limit on dichotomy boundary faulting in the Amenthes area [18] is similar to or perhaps slightly younger than the old limit in this study area. Thus the present morphology of the dichotomy boundary for segments characterized by scarps is due to faulting between Middle Noachian and Late Hesperian. The remanent magnetic field and gravity anomalies correlate with the morphology and structure of the dichotomy boundary zone in the Protonilus Mensae area, providing an excellent opportunity to model the crust and upper mantle where there are relatively robust geological constraints. The geology and topography of the study site are consistent with either the creation of the dichotomy by faulting between Middle Noachian and Late Hesperian, or with an earlier creation followed by crustal-scale processes that were responsible for the faulting. We currently are exploring the latter possibility.

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