GEOLOGIC AND TOPOGRAPHIC CONSTRAINTS ON THE ORIGIN AND DEVELOPMENT OF THE MARTIAN CRUSTAL DICHOTOMY: WHAT THEY DO AND DON'T REQUIRE Herbert Frey, Geodynamics Branch, Goddard Space Flight Center, Greenbelt, MD 20771 and Richard A. Schultz, Mackay School of Mines, University of Nevada, Reno, NV 89557.

***Introduction***

There is still considerable debate about how and when the fundamental crustal dichtomy of Mars originated [1,2]. Below we review topographic and geologic constraints on the origin and development of the crustal dichotomy in eastern Mars, with emphasis on separating what these constraints actually *require* as opposed to imply.

***Impact Basins and the Crustal Dichotomy***

Most workers now agree that large impact basins are responsible for many of the details of the lowland topography of eastern Mars. The outer rings of the Utopia [3] and Elysium [4] Basins coincide with much of the highland/lowland boundary. The change in boundary trend at 230-240$^{o}$W is better marked by the rings of the two separate basins than by any single circular ring [5]. A 1000 km wide "South of Hephaestus" Basin [6] overlaps the Utopia and Elysium Basins between 230 and 240$^{o}$W, and may be responsible for the topographic structure of this part of the transition zone. The Isidis Basin overlaps and therefore post-dates the Utopia Basin which itself post-dates the Elysium Basin [1]. Much of the lowland topography lies within these two very large impact basins. The coincidence of physiography and impact basins strongly implies (but does not require) a causal connection. Because the basins so intimately associated with the highland/lowland transition zone and northern lowlands date from the earliest impact history of Mars, some form of early crustal dichotomy (lowland topography, thinned crust) has been present on Mars throughout its history.

***Fracturing and Resurfacing of the Transition Zone***

McGill and Dimitriou [2] summarize the evidence that the crustal dichotomy boundary has not moved far from its [early] original position. But the boundary and adjacent regions have experienced important modification. Episodes of fracturing in the Late Noachian and Early Hesperian first created "knobby terrain" and secondly created conditions for the extensive erosion that led to development of "fretted terrain" [2,7]. Most of the knobby terrain on Mars lies along or within the highland/lowland boundary, i.e., within the area influenced by formation of the Utopia and Elysium Basins. McGill and Dimitriou [2] argued for a late (Early Hesperian?) internal (or endogenic) origin for the dichotomy, suggesting the fracturing implies a late thinning of the crust north of the boundary. The evidence really indicates only a lowering of the existing (already low) topography and provides no real constraint on the cause.

Resurfacing events across the dichotomy boundary have common crater retention ages [8]. Widespread resurfacing occurred at the time of Lunae Planum ridged plains formation (Lunae Planum Age) in the Cratered Terrain (CT), Transition Zone (TZ) and Smooth Plains (SP), at the same Late Noachian/Early Hesperian time when fracturing [7] occured [8]. The size of depopulated craters indicate greater resurfacing within the TZ and SP than in the adjacent CT; this is easily explained if the TZ and SP regions were already lower than the CT [8]. An earlier Middle Noachian (Pre-Lunae Planum Age) resurfacing also affected the CT and some portions of the TZ. Greater depopulation in the TZ implies pre-existing topographic differences [8]. A lower elevation northward from the highlands existed, therefore, from the Middle or Early Noachian and persisted through the Hesperian into the Amazonian, where still later (Post-Lunae Planum Age) resurfacing events became increasingly important.

It is possible to estimate the maximum thickness of materials overlying each crater retention surface [9]. Model-dependent thicknesses for the Middle Noachian resurfacing show a general increase from CT through TZ into SP. This is consistent with pre-existing lower topography northward toward the interiors of the Utopia and Elysium Basins. The Lunae Planum Age resurfacing materials show the same general trend, with even greater thicknesses (200-300 vs 150-200m) in the TZ and SP. By contrast, this resurfacing in CT had less material (85-110m) than the earlier event (125-145m). Elevations of the TZ and SP areas apparently decreased from the Middle Noachian (Pre-Lunae Planum Age) to the Late Noachian/Early Hesperian (Lunae Planum Age) resurfacing. Thickness of Post-Lunae Planum Age resurfacing (Late Hesperian-Amazonian) materials were overall greater everywhere, with substantially more material in the SP (460-485m) and TZ (~250-315m) than in the higher CT (205m). In summary: (a) Significant topographic differences between the CT/TZ/SP already existed by the Middle Noachian resurfacing. (b) These differences increased from the Middle Noachian through the Late Noachian/Early Hesperian (Lunae Planum) to the Late Hesperian-Amazonian resurfacing.

***Surface (and Subsurface) Topography***

It is often said the highland/lowland boundary is scarp-like. This is an over-generalization. N-S profiles in the Amenthes-Aeolis region, oriented toward the centers of the Elysium and Utopia impact basins clearly show the boundary is mostly ***not*** scarp-like. Regional slopes are low, averaging about 0.25°. At 230-240°W, the TZ lies outside the rings of the Utopia and Elysium Basins but appears to be controlled by the smaller "South of Hephaestus" Basin. The 1.5° (2 km drop over 75 km) slope here is the greatest across the boundary, and may be related to this smaller basin. Slopes up to 0.5° occur at some places within the CT or TZ, but overall the gradients suggest more a gentle downwarp than the steep scarp often described.

More interesting is the observation that the decrease in elevation northwards across the boundary generally begins *not* at the CT/TZ border, but within the cratered terrain. Gradients may steepen at the CT/TZ boundary, but 2 to 3.5 km of height are ***first*** lost within CT. The broader scale regional topography is also a gentle downwarping to the north, affecting not just the TZ but also the CT 500 to 1000 km *south* of the CT/TZ boundary. This is consistent with late subsidence of impact basin topography, with long-wavelength flexure extending beyond the original basin rims [10, 11]. These observations suggest: (a) Development of the geomorphic boundary zone (TZ) was controlled more by local topography (impact basin rims?) than by regional topography, and (b) the regional downwarp was separate from (and subsequent to) the initial geomorphic boundary development.

***Discussion***

To accept the existence of the very large Utopia and Elysium Basins is to accept the existence of some form of crustal dichotomy (thin crust, low elevation) from earliest martian history. The association of the Utopia and Elysium Basins and their rings with the current topographic lowland and highland/lowland boundary suggests a causal connection between the original and present-day crustal dichotomy on Mars.

But simple impact structure by itself cannot account for the present-day differences between the northern lowlands and cratered highlands. The lowland is broader than the Utopia and Elysium impact basins, affecting areas of cratered terrain outside the basin rings and present-day geomorphic dichotomy boundary. There is good evidence for prolonged or repeated subsidence of the basins and even downwarping of the areas outside the basins, probably due to loading. Although the topographic dichotomy and geomorphic dichotomy are not exactly the same, they are almost certainly related, probably through the long term evolution of large, overlapping impact basins. The combination of basin relaxation, thermal cooling and subsidence, likely volcanic flooding and loading and later downwarping may well explain the present-day crustal dichotomy and other structures in eastern Mars [1].

REFERENCES: [1] Frey, H. and R.A. Schultz, J. Geophys. Res. 95, 14,203-14,213, 1990. [2] McGill, G. E. and A. M. Dimitriou, J. Geophys. Res. 95, 12,595-12,605, 1990. [3] McGill, G.E.. J. Geophys. Res. 94, 2753-2759, 1989. [4] Schultz, P. H., Lunar Planet. Sci. XV, 728-729, 1984. [5] Schultz, R. A. and H. V. Frey, J. Geophys. Res. 95, 14,175-14,189, 1990. [6] Schultz, P. H., R. A. Schultz and J. L. Rogers, J. Geophys. Res., 86, 9803-9820, 1982. [7] Maxwell, T. A. and G. E. McGill, Proceed. Lunar Planet. Sci. Conf. 18th, 701-711, 1988. [8] Frey, H., A. M. Semeniuk, J. A. Semeniuk and S. Tokarcik. Proceed. Lunar Planet. Sci. Conf. 18th, 679-699, 1988. [9] Frey, H. and T. D. Grant, J. Geophys. Res., 95, 14,249-14,263, 1990. [10] Bratt, S. R., S. C. Solomon and J. W. Head, J. Geophys. Res. 90, 12,415-12,433, 1985. [11] Wichman, R. W. and P. H. Schultz. J. Geophys. Res. 94, 17333-17357, 1989.