

MARTIAN CRUSTAL DICHOTOMY: INTERPLAY BETWEEN EXOGENIC ORIGIN AND LATER ENDOGENIC EVOLUTION Herbert Frey, Geodynamics Branch, Goddard Space Flight Center, Greenbelt, MD 20771.

Introduction

Too often the problem of how and when the martian crustal dichotomy came about is cast in terms of "endogenic *or* exogenic" origin. Early models approached this from one of two extremes: early mantle convection causing sub-crustal erosion and thinning [1], or thinning due to a mega-impact event [2]. In both models the dichotomy formed very early in martian history. A similar early origin due multiple large (but not giant) impacts was proposed [3], but recent arguments for an internal origin have the formation of the dichotomy much later [4]. Most recently the longer term evolution of large overlapping basins has been considered [5], which may account not only for the topographic and crustal dichotomy, but provide a reasonable model for a related origin of Elysium (and Tharsis?)-type tectono-volcanic complexes. In a sense the models have come full circle. What is new is the possible connection between exogenic (impacts) and endogenic processes (uplift, volcanism and loading, cooling and subsidence, perhaps changes in convective patterns), and that coupling between surface evolution and internal evolution may be improved by the ability of impacts to pre-condition the lithosphere. Below we emphasize that an exogenic origin of an early crustal dichotomy on Mars still requires endogenic evolution to account for present-day crustal properties, and raise the question whether very large impacts may affect deeper internal processes.

Internal Models for the Crustal Dichotomy

Early attempts to relate the origin of the fundamental crustal differences between the cratered highlands and northern lowlands to the growth of Tharsis through unusual mantle convection [1] have largely been discarded. More recently McGill and Dimitriou [4] suggested a late (Early Hesperian?) origin for the dichotomy by crustal thinning due to a mantle plume or single-cell convection. They require either late core formation or other processes to hold off major thermal and dynamic events until the Late Noachian/Early Hesperian, at which time significant fracturing of the crustal dichotomy boundary zone occurred. It could be argued that the crustal dichotomy had to predate the fracturing of its boundary zone, and the evidence may only imply a late change to the (already low) Utopia lowland. Schubert et al. [6] point out that any formation of the crustal dichotomy by mantle convection would have to be very early in martian history, since a degree=1 convective system (which they find hard to produce) requires a core much smaller than is thought to exist on Mars [7]. Thus the necessary form of mantle convection probably existed (if ever) only during core formation, which must have been early on Mars [8]. This leaves open the question whether less specialized mantle convection (plumes?) may have contributed to the longer term evolution of the dichotomy.

Impact Basins and the Crustal Dichotomy

The largest impact basins on Mars are in the region of the northern lowlands and the Tharsis and Elysium tectono-volcanic complexes [9]. There is now agreement that such impact basins are intimately related to at least the details of the northern lowland topography [3,4,5]. For example, the outer rings of the Utopia [10] and Elysium [11] Basins coincide with much of the *geomorphic* highland/lowland boundary in eastern Mars [5,9]. Because these basins 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*. However, the modern-day topographic dichotomy is not identical with the geomorphic or physiographic dichotomy [12]. The lowland is broader than the impact basins: the northward decrease in elevation begins not at the geomorphic boundary but within the cratered terrain 500-1000 km south of the boundary [12], and has a character which suggests gentle downwarping. Thus the dichotomy probably evolved over time, as might be expected from the long-term evolution of two very large overlapping impact basins [5].

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Evidence for long-term evolution of the lowland, including its effect on modification of the highland/lowland boundary, has been described elsewhere [4,5,12,13,14]. The fracturing that occurred along the dichotomy boundary [14] may be related to late thinning and subsidence of the lowland [4,5,12]. McGill [10] argues for a persisting depression at the site of the Utopia Basin. Early elevation differences increasing over time are probably required to explain the resurfacing along the dichotomy boundary [12,13]. Long-term cooling and volcanic loading of early impact basins would lead to subsidence and perhaps long-wavelength downwarping [5,15,16], consistent with the observation that the topographic dichotomy is larger than the physiographic dichotomy [12]. Overall the picture is one of continued or repeated subsidence of the early impact-related topographic lows, with endogenic processes (volcanism, subsidence, flexure) an important part of the longer-term development of the northern lowlands.

Discussion

Some form of early crustal dichotomy (thin crust, low elevation) must have existed on Mars from its earliest history, due to large and overlapping impacts [3,5,12]. But this early impact dichotomy is not identical to the present dichotomy. Evolution of large impact basins may account for much of the subsequent development and explain many of the observed crustal properties. What is not clear is whether that development was coupled to deeper processes, and whether impacts served to focus or concentrate such processes or to pre-condition the lithosphere so that already existing processes could more easily express themselves.

Large impacts will clearly thin the crust (and lithosphere) and concentrate heat in the sub-impact mantle. Isostatic response to basin formation will displace the mantle upwards and concentrate isotherms toward the surface. But for basins as large as Utopia or Elysium (nearly one quarter the circumference of Mars), will this deposition of heat and vertical uplift affect deeper processes? Could mantle convection consisting of a few to a dozen plumes [6] take advantage of the changes in the thermal boundary layer? Would the more rapid heat loss through the thinned basin lithosphere (aided by convective cooling and isotherm uplift) ultimately lead to focusing of mantle plumes in such regions, and perhaps therefore to prolonged uplift and volcanic construction such as may have built Elysium or Tharsis [5,17]? Would enhanced crustal thinning occur in adjacent regions as part of the downwelling return flow? Would this combine with volcanic loading and subsidence to help keep the lowlands low?

To date the modeling to answer these questions has not been done. Reasonable constraints now exist, based on the scenario that large overlapping impacts were originally responsible for forming an early crustal dichotomy. Modeling the details of the upper mantle response to such impacts, and how this couples to likely early whole mantle conditions, could provide important insight not only into how the surface and interior coupled in the early history of Mars, but also into how the crustal dichotomy evolved over time from its original impact-related form and what role (if any) deeper processes played in the development of this dichotomy and the other major features of the martian crust (Tharsis, Elysium).

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