STRUCTURE OF THE MARTIAN HIGHLANDS WITHOUT IMPACT BASINS AND VOLCANOES.

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Introduction: The Martian crust is unique amongst other terrestrial worlds. It is more evolved than the primary crusts of the Moon or Vesta, but less evolved than the crusts of the Earth and Venus which have long and complicated histories of crustal growth, erosion, and recycling. There is growing evidence that Mars may have once generated continental crust [1, 2]. The present structure of the Martian crust is dominated by a hemispheric dichotomy, several large impact basins (Hellas, Argyre, Isidis, Utopia), and large igneous provinces (Tharsis, Elysium). While previous studies have quantified the contributions of Tharsis to the crustal structure [3-5], no study has quantified the contributions from impact basins. In this study, we determine the crustal thickness of Mars before the formation of the largest impact and volcanic provinces. The reconstructed crustal thickness map provides new insight into the structure of the Martian crust and the origin of the dichotomy.

Methods: There are several methods for isolating, characterizing, and removing the signature of impact basins and volcanoes from the gravity fields, shapes, and crustal structures of planets [3–7]. In this study, we develop a method for removing these features from crustal thickness map [8–9]. We assume that impact basins are largely axisymmetric and reshaped the crust in a way that approximately conserved crustal mass. We assume that volcanoes are also axisymmetric, but did not assume that they conserved mass (as they may be sourced from deeper mantle reservoirs). In essence, we "re-filled" the impact basins, and removed the volume excess from volcanoes. Figure 1 shows an example of this procedure applied to Hellas.

Using this technique, we sequentially isolated and removed the axisymmetric crustal thickness structures associated with the four largest impact basins (Hellas Planitia, Argyre Planitia, Utopia Planitia, and Isidis Planitia), the Elysium Mons, the Tharsis rise, and the five largest individual volcanoes (Olympus Mons, Arsia Mons, Pavonis Mons, Ascraeus Mons, Alba Patera).

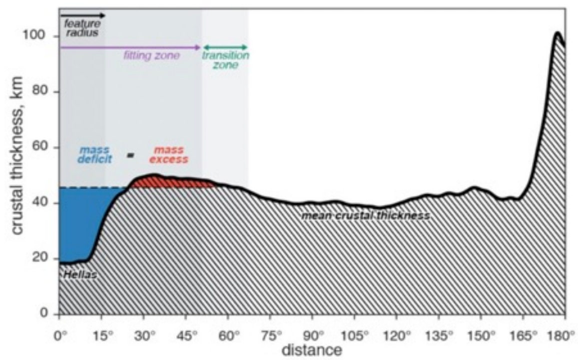

Figure 1. The radial crustal structure of Hellas Planitia. *Azimuthally-average crustal thickness about Hellas (solid black line with hatching beneath). The grey boxes delineate the fitting and transition zones used for finding the mass-conserving crustal reconstruction. The volume above the mass-conserving crustal thickness (dashed line) is equal to the volume below it.*

Early Mars without Impact Basins and Volcanoes: Figure 2 shows the crustal thickness of Mars with (b), and without (c), impact basins and volcanoes. This exercise reveals an early Mars with three distinct crustal components: one thinner than 35 km (similar to the present northern lowlands), one with a crustal thickness between 35 and 45 km (around Hellas, Argyre and south of Tharsis region) and another component thicker than 45 km restricted to region of Terra Cimmeria–Sirenum.

While impact basins contribute to the hemispheric dichotomy, they cannot completely explain the dichotomy. For example, the crustal volume in the southern highlands is roughly four times larger than the volume displaced by the formation of Hellas.

Cimmeria–Sirenum, a continental crust? This Cimmeria–Sirenum crustal block shares many of the geophysical and geochemical signatures of terrestrial continental crust: high topography, thick crust with lower density, strong magnetic anomalies and high abundances of incompatible elements. The Cimmeria–Sirenum crustal block coincides with the strongest crustal magnetic anomalies (Figure 2d) [10–13]. Cimmeria–Sirenum is associated with the lowest inferred crustal densities inferred in gravity analyses [9]. This region is the only place in the southern terrains with both enrichment in K and Th [16].

While felsic material has been previously identified in specific outcrops or Martian samples [14–16], our study identifies a regional scale crustal block (covering 10% of Mars) with geophysical and geochemical affinities with the terrestrial continental crust. Cimmeria–Sirenum could be analogous to cratons, formed by the accretion of smaller crustal nuclei [17]. Since this terrain is overprinted by Hellas, Argyre, and Tharsis, it is likely one of the oldest segments of the crust. This study opens the debate about the possibility of an early block tectonic and the plausible presence of early water allowing early crustal differentiation. The InSight mission will soon provide measurements about Mars's interior structure, which will be critical for testing this hypothesis and improving our understanding of Mars's crustal evolution.

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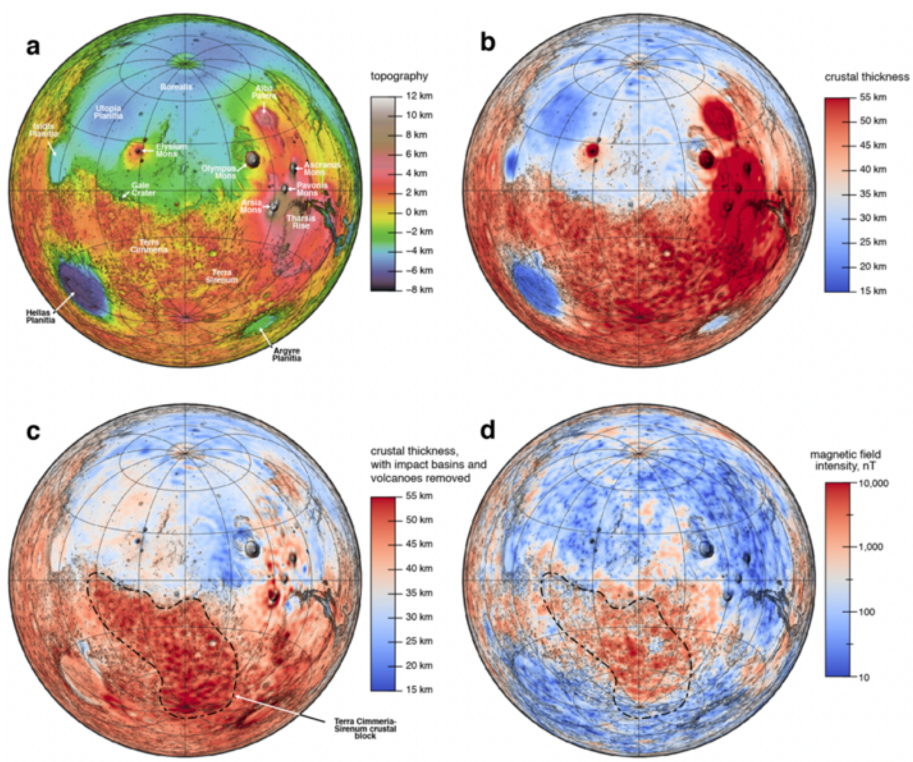

***Figure 2. Global view of the crustal structure of Mars. a**, MOLA topography of Mars with features of interest labelled. **b**, crustal thickness of Mars [7]. **c**, the crustal thickness of Mars after removing all the large impact basins and volcanic features. The Cimmeria–Sirenum crustal block is enclosed by a dash-dot line. **d**, magnetic field intensity, evaluated at the surface of Mars [13]. Maps are in Lambert azimuthal equal-area projection, centred on 0°E (left column) and 180°E (right column). Each map covers all of Mars except for a small region antipodal to the map centre. Maps are draped over present-day topography for reference. Grid lines are in increments of 30° of latitude and longitude.*