MARS CRUSTAL DICHOTOMY: LARGE LOWLAND IMPACT BASINS MAY HAVE FORMED IN PRE- THINNED CRUST
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Summary: Crater retention ages of large impact basins on Mars suggest most formed in a relatively short time, perhaps in less than 200 million years. Large basins in the lowlands have thinner central regions than similar size basins in the highlands. Large lowland impact basins, which we previously suggested might explain the low topography and thin crust of the northern part of Mars, may have formed in crust already thinned by yet earlier processes.

Introduction: Crater retention ages (CRAs) for the 20 largest impact basins on Mars (D> 1000 km) based on superimposed large visible or buried Quasi-Circular Depressions and even more deeply buried impacts revealed as Crustal Thin Areas [1] suggest that most of the basins formed in a relatively short period of time [2,3]. As shown in Figure 1, N(300) CRAs for 65% of the large basins lie between 2.5 and 5.0 [3], and 50% of the population have CRAs between 2.5 and 4.0. This narrower range includes all the basins now in the lowlands and Tharsis regions of Mars. Conversion to the Hartmann-Neukum model chronology [4] suggests an absolute age of 4.10 to 4.25 BYA for all but the three youngest (Hellas, Argyre and Isidis) (see Figure 2), with most (including all those in the lowlands) falling within an even narrower interval of 4.12-4.14 BYA.

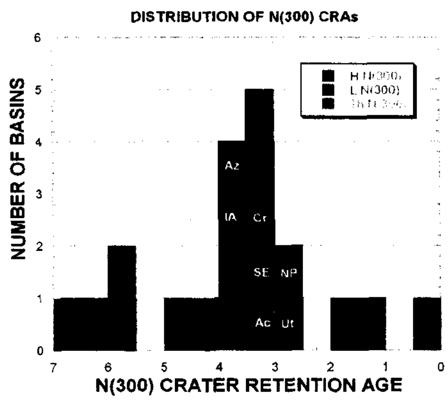


Figure 1. Distribution of N(300) Crater Retention Ages CRAs) for the 20 largest impact basin on Mars. The strong peak in the middle contains over half of the population, 3 of the 4 largest basins, and all those in the lowlands (blue) and Tharsis (green) regions. Highland basins (red) have a broader range of ages. If the CRAs are equivalent to formation ages, > 50% of the population may have formed in a relatively short time.

Conversion to the Hartmann-Neukum model chronology [4] (averaging where the authors differ) suggests an absolute age of 4.10 to 4.25 BYA for all but the three youngest basins (Hellas, Argyre and Isidis) (see Figure 2), with most (including all those in the lowlands) falling within an even narrower interval of 4.12-4.14 BYA.

The sharp peak in likely formation ages for the largest impact basins on Mars has several important implications. It suggests the possibility of a cataclysmic Late Heavy Bombardment (LHB) on Mars. The short time is consistent the NICE model [5, 6] and a "terminal lunar cataclysm" [7, 8]. The absolute ages, however, are wrong: the lunar cataclysm occurred between 4.0 and 3.8 BYA. Martian ages are model ages based a number of assumptions [4]. If the peak shown in Figure 2 is part of an inner solar system event, it may be that the martian chronology can be corrected by pinning this peak to the ~3.9 BYA cataclysm on the Moon.

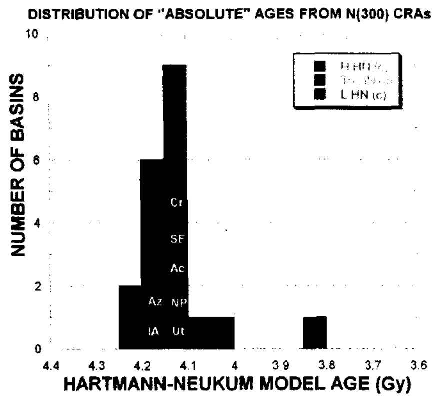


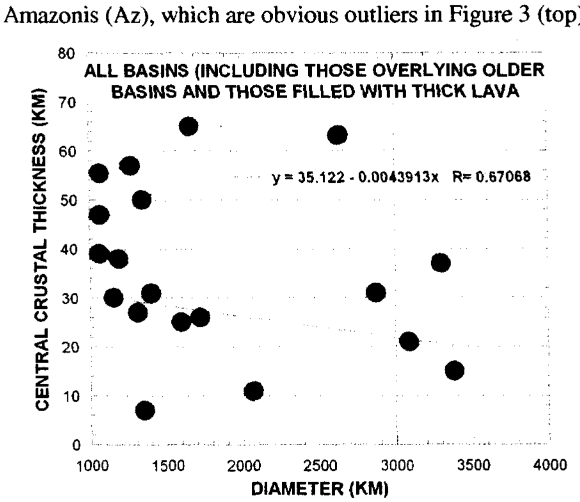
Figure 2. . Histogram of model absolute ages for large basins. Color code same as in Figure 1. Bin size 50 MY. The basin ages are sharply peaked between 4.1 and 4.2 BYA. All the lowland and Tharsis basins lie in this bin.

The apparent lack of large basins earlier than those shown, if real, suggests the impacts may have been very tightly confined in time, permitting a ~400 MY period before 4 BYA during which planet-sterilizing impacts did not occur [3]. This may support the idea of a "cool early Earth" [9] during which Earth (and Mars?) may have been more habitable than during the 4.0-3.8 BYA LHB interval.

The martian global magnetic field apparently died during the peak in impact basin ages [10]. Whether this was cause (due to many very large impacts in a short period of time) or coincidence is still TBD (see companion abstracts by James et al. and by Lillis et al., this meeting).

The ages of lowland basins are even more sharply peaked in time than are highland basins. We previously suggested [2,3] this might support the idea that large impact basins could explain the formation of the lowland portion of the martian crustal dichotomy [11,12]. Large impacts would produce both low topography and thin crust, which characterize the northern third of Mars compared to the cratered highlands. But, as shown below, the short time interval implied for the formation of all the large basins creates a problem with this scenario.

Crustal thickness of large basins. Figure 3 shows average model [13] crustal thickness for large basin central regions for all the basins (top) and for those in the narrow peak interval before Hellas formation not overlying already formed basins and not having large accumulation of volcanics (bottom). Basins forming on already formed basins may have unusually thin crust. For example, Isidis (Is) formed on the likely already thinned crust of the Scopolus and Utopia basins. Other cases include Hematite (Hm) on Ares and Inside Amazonis (IA) on Amazonis. Basins with thick accumulation of lava include Daedalia (Da), Solis (So) and possibly Amazonis (Az), which are obvious outliers in Figure 3 (top).



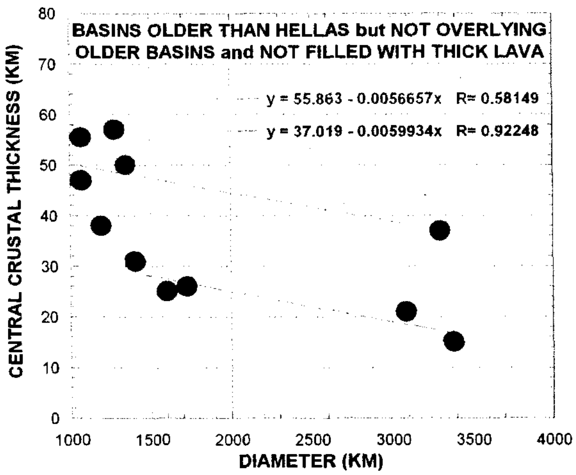


Figure 3: Crustal thickness at basin center vs basin diameter. Color code same as Figure 1. Top: all basins. Bottom: basins older than Hellas not overlying yet older basins and not having thick accumulations of lava. Thickness of crust in basin center decreases with increasing diameter, but lowlands basins have thinner crust than do highland basins of similar size, especially at large diameters.

Larger basins have thinner central crust, as would be expected. Both the highlands and lowlands follow remarkably similar linear trends (Figure 3, bottom), though these are strongly weighted by the largest basins. Lowland basin crust is systematically thinner for the same size basin. This is especially obvious for the largest two basins, both about 3000 km in diameter. Ares (Ar) has a central thickness of about 37 km while Utopia (Ut) has a central thickness of about 15 km. Acidalia (Ac), the next largest lowland basin, has a similar difference from Ares so there is no reason to believe that Utopia is anomalous in its thin central crust.

Discussion: If the model absolute ages of the two largest basins are correct, Utopia formed only 56 million years after Ares. It seems unlikely there would be substantial change in the target crustal thickness over this brief interval. If both impacts thinned the crust by similar amounts (given their similar diameters), and later basin filling was minor compared to the post-impact crustal thickness, then the difference in central thicknesses may imply the lowland crust was already thinner when Utopia formed than was the crust where Ares formed 56 million years before. This could explain the systematic difference (~20 km) for lowland basins compared to their highland counterparts: perhaps the northern third of Mars had crust already thinner than the southern highlands at the time the large basins formed. A simplistic extrapolation of the curves in Figure 3 (bottom) to zero basin diameter suggests the lowland pre-impact thickness might have been ~35 km and the highland thickness more like ~55 km.

If true, the large lowland basins were not the sole and perhaps not even the primary cause of thinner lowland crust: they only contributed to further thinning and defining the detailed topography of the lowlands. If so, at least one early manifestation of a crustal dichotomy (thinner crust in the northern hemisphere) may have predated the formation of the large lowland basins. The cause of such "pre-thinning" prior to the intense LHB remains to be determined: we note that both endogenic (degree-1 mantle convection [15]) and exogenic causes (a single giant impact [16,17]) are still invoked as they have been in the past [18,19,20].

Conclusions: The possible short (~56 MY) period of time between two very large impacts that produced 3000 km wide basins of very different central crustal thicknesses in the highlands (Ares, 37 km) and lowlands (Utopia, 15 km) may require that crust was "pre-thinned" prior to the formation of large lowland basins. If so, some aspect of the crustal dichotomy existed prior to the cataclysmic Late Heavy Bombardment on Mars, which, if part of an inner solar system wide event, likely occurred over ~200 million years ~ 3.9 BYA.

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