IMPLICATIONS OF A MUCH LARGER POPULATION OF BURIED IMPACT BASINS ON MARS AS REVEALED BY CRUSTAL THICKNESS ANOMALIES

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Summary: Crustal thickness data show Circular Thin Areas (CTAs), some of which correspond to Quasi-Circular Depressions previously mapped from MOLA data, but many of which do not. The non-QCD CTAs likely represent additional, more deeply buried impact basins, suggesting the buried population is even greater than previously estimated. Based on combined QCD and non-QCD CTA populations, the lowlands and highlands have the same older N(300) crater retention age. Tharsis is younger and may not be simply thick volumes of volcanics superimposed on an older crust. The N(300) crater retention age of very large basins, extrapolated from D> 1000 km using a -2 power law, is about the same as that found for the highlands and lowlands at N(300). This may indicate a planet-wide "cataclysm" that reset the surface ages everywhere on Mars.

Introduction: As described in a companion abstract [1], stretching crustal thickness model [2] data reveal a very large number of Circular Thin Areas (CTAs) larger than about 300 km diameter and ranging up to several thousand km diameter. Some of these correspond to Quasi-Circular Depressions previously mapped from MOLA data [3], but many do not [1,4]. These non-QCD CTAs likely represent additional, more deeply buried impact basins, suggesting the buried population is even greater than previously estimated. Support for CTAs being buried impacts comes from the correspondence with many QCDs, CTA cumulative frequency curves that are similar to those for QCDs, including visible impact basins, and a larger ratio of non-QCD CTAs to QCDs in the lowlands and Tharsis than in the highlands [1].

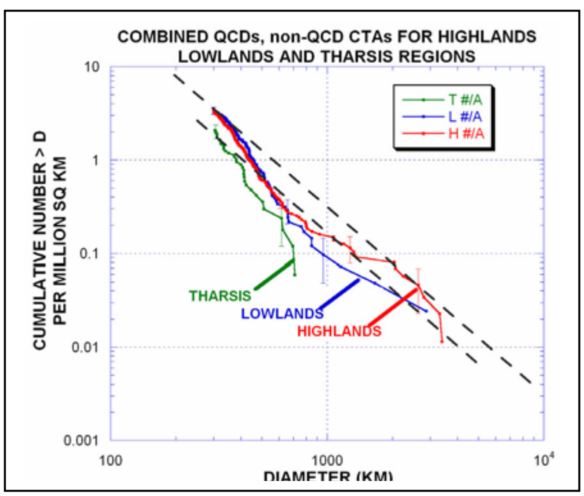

Figure 1. Cumulative frequency curves based on the combined QCD + non-QCD CTA population of impact basins for the Highlands, Lowlands and Tharsis regions of Mars.

Figure 1 shows cumulative frequency curves for the combined QCD+non-QCD CTA population for the highlands, lowlands and Tharsis region of Mars. The highland and lowland curves have a large diameter population which in the case of the highlands falls off below about 2000 km. At diameters < 800 km the two curves are essentially identical within their errors, and both yield an N(300) crater retention age of about 3.4. The overall shapes of these curves is similar to that previously seen for the QCDs alone [3], but the density of craters in both areas is now greater at the smaller diameters, dramatically so for the lowlands.

The Tharsis curve parallels that of the highlands and lowlands for D<700 km, but lacks the large diameter population seen in the highlands and lowlands. Instead the Tharsis curve falls off as would be expected for very small numbers of basins. This is unlikely to be due to simple burial, as larger features are more difficult to bury, and may have important implications for the nature of Tharsis (see below). Tharsis is clearly younger than the highlands and lowlands, with a cumulative crater retention age N(300) of about 2.1.

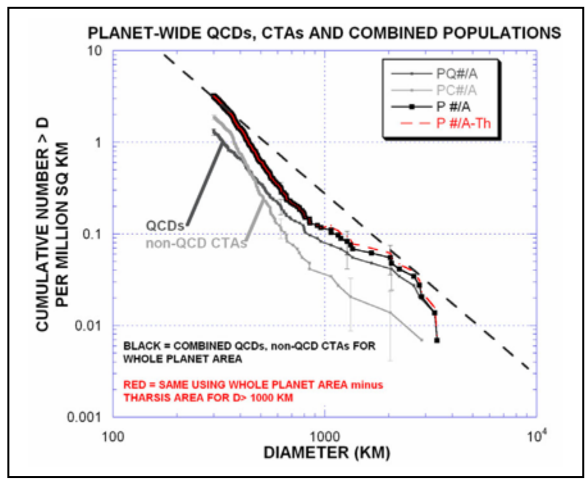

Figure 2. Whole planet cumulative frequency curves for QCDs, non-QCD CTAs and the combined population. The red curve has reduced the normalizing area for the largest basins (D>1000) because no large basins are seen in Tharsis (Figure 1). Note the same -2 powerlaw curve fits both the large and small diameter portions of the combined curve, as is the case for the highlands in Figure 1.

Figure 2 shows the cumulative frequency curves for the QCDs, the non-QCD CTAs, and the combined population for the planet as a whole. The red points show an adjustment for the lack of large basins in Tharsis: in this curve the cumulative number of basins > 1000 km diameter were normalized by an area which was the planetary area minus the area of Tharsis. For smaller basins, the entire planet area was used for the combined curve, as it was for the QCD and non-QCD CTA curve. At large diameters QCDs make up most of the contribution to the combined curve, as would be expected since features this large are difficult to bury. A few large diameter non-QCD CTAs were identified [1], but it is only at smaller diameters where non-QCD CTAs begin to dominate the combined population. In Figure 2 the cross-over occurs at about 430 km. Features larger than this tend to be preserved in most areas, but smaller features rapidly become hard to recognized topographically in areas of thick cover.

The overall shape of the combined curve in Figure 2 is similar to that of the highland curve in Figure 1 (not surprising since the highlands make up 60% of the planet), showing the drop off at diameters < 2000 km and the eventual recovery to the common -2 powerlaw which fits the large diameter end. We previously suggested, based on the similar character of the QCD cumulative frequency curves, that this may represent a major resurfacing of Mars by some global-scale event, perhaps the formation of the lowlands [3]. Because they both lie along the same -2 trend, an extrapolated N(300) age for the very large basins in Figure 1 and 2 is nearly the same as the N(300) crater retention age for the highlands (and lowlands) as a whole. In fact, the N(300) crater retention age is slightly greater, 3.55 versus about 3.43, though this is within the uncertainty of these determinations.

Below we discuss the implications of this apparently much larger population of buried impact basins than were revealed by MOLA topography alone.

Absolute Ages: Model absolute ages can be derived from the N(300) crater retention ages, using the same procedure previously employed for the large QCD study [3]. The N(300) ages for the highlands and lowlands, based on the combined population of QCDs and non-QCD CTAs, are 4.38 Gy, compared with 4.24 and 4.08 Gy based on QCDs alone. The large diameter basin age, extrapolated to N(300) as in Figures 1 and 2, is about 4.40 Gy, slightly older than the highland and lowland surfaces. This is about the same as previously determined from QCDs alone, since really large features are hard to bury completely. In this chronology, Tharsis is about 140 MY younger than the highlands and lowlands but still older than previously thought: about 4.24 Gy based on the combined population including non-QCD CTAs, compared with an earlier estimate of 3.97 Gy. Thus the additional buried basins inferred from the crustal thickness data have, in the Hartmann-Neukum chronology used, resulted in an increase in the age of the highlands by 140 MY, of the lowlands by 300 MY and of Tharsis by 270 MY.

Implications for Early Mars Evolution: Cumulative frequency curves based on the combined QCD and non-QCD CTA population suggest the lowlands and highlands have the same N(300) crater retention age, and this is significantly older than estimates based on QCDs alone. It appears the two largest regions on Mars have retained a crater record dating from the same time period, and this is about the same age (maybe a trifle younger) as would be determined from the largest impact basins (extrapolated to N(300). While it is clear there must have been crust older than that in which the largest basins formed, the recoverable record appears to date from after the time defined by these largest basins. It may be the formation of the largest basins reset the clocks not only for the crust which they impacted, but also for the rest of the surface of Mars. Since that time both the highlands and lowlands have accumulated the same combined population of impacts, though in the lowlands (and Tharsis) many of these were more deeply buried than in the highlands. If individual N(300) ages for the largest basins (work in progress) shows they all formed in a short period of time, it may be there was a martian equivalent of the proposed lunar cataclysm [4]. Dynamical arguments [5] might then be able to constrain the absolute age of such an event to the time it occurred on the Moon. However, it is also possible that the common -2 powerlaw and similar N(300) ages represent a saturation effect, creating a wall beyond which crater retention data cannot penetrate (see below).

If the age of the highlands and lowlands is in fact the same, and roughly that given by the absolute chronology above, then the lowlands formed only 220 MY after Mars itself. This is a very short period of time, and may be the maximum allowed, since the ages derived here are likely minimum ages (see below). This may prove a very restrictive constraint on proposed endogenic mechanisms for creating the lowlands. We note that the extrapolated N(300) crater retention age for the largest impact basins is a trifle older than that for the lowlands, suggesting many of them formed a few tens of millions of years earlier, though this is within the noise of these determinations. Individual N(300) crater retention ages should shed light on whether large lowland basins are in fact older than the average lowland surface, and therefore might be the mechanism by which the lowlands formed.

The N(300) ages for the highlands and lowlands may not represent the actual age of those surfaces. It is possible there are still additional buried basins not revealed by the crustal thickness model and the MOLA topography. All ages based on buried basins should be regarded as minimum ages. In addition, it is possible that impact saturation has occurred. We previously noted that the large diameter and small diameter portions of the highland and lowland (and planet-wide) cumulative frequency curves lie on nearly the same -2 power law slope (Figures 1 and 2). This could in principle mean that both the large and small diameter populations have approached or achieved saturation, and the common N(300) age is in fact a minimum age for these surfaces.

Implications for Tharsis: Tharsis is younger than the highlands and lowlands and may not be simply thick volumes of volcanics superimposed on ancient highland crust. The apparent lack of very large basins in Tharsis (Figure 1) suggests the Tharsis basement may in fact be younger and formed after the "resetting" of the highland and lowland basement ages. Lack of large basins is unlikely to be due to simple burial, as larger features are more difficult to bury, and the highlands and lowlands both show an increase in the cumulative density toward larger diameters. If there are in fact no very large (> 1000km diameter) impact basins in Tharsis, it may indicate that Tharsis basement itself is younger than the apparently common-age basement of the highlands and lowlands, and formed well after the ancient highland (and lowland) crust.

References. [1] Edgar, L.A. and H. V .Frey, H., LPSC 38 (this volume, 2007). [2] Neumann, G. A. et al., JGR (Planets), 109, E08002, doi : 10.1029/2004JE002262 (2004). [3] Frey, H.V., JGR (Planets) 111, E08S91, doi:10.1029/2005JE002449 (2006) [4] Tera, F. et al., EPSL 22, 1 (1974). [5] Bottke, W. personal communication (2006).