NEW LARGE LATE HEAVY BOMBARDMENT IMPACT BASINS ON MARS REVEALED IN CRUSTAL THICKNESS DATA: CRATER RETENTION AGES AND IMPLICATIONS H. V. Frey, Geodynamics Branch, Goddard Space Flight Center, Greenbelt, MD 20771, Herbert.V.Frey@nasa.gov,

Summary: Crater retention ages of the 20 largest impact basins previously recognized on Mars suggest most formed in a relatively short time, perhaps in less than 200 million years. New crustal thickness data suggests there are several additional very large basins, some lying outside the areas affected by those already known. Crater retention ages for these newly identified basins are not significantly older than those already known, suggesting either the large diameter Late Heavy Bombardment on Mars was a relatively brief event or the record of previous large impacts was somehow erased, perhaps by the formation of a Borealis Basin.

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]. 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. The oldest known basin has N(300) = 6.67 and to date no large areas of Mars have been shown to be significantly older. 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 basins (Hellas, Argyre and Isidis), with most falling within an even narrower interval of 4.12-4.14 BYA [3].

The sharp peak in likely formation ages for the largest impact basins on Mars and the apparent lack of basins earlier than those known have 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, seem wrong: the lunar cataclysm occurred between 4.0 and 3.8 BYA. Martian ages are model ages based a number of assumptions [4], and this difference may well be within the uncertainty of the current Hartmann-Neukum chronology. In fact, 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 [3,9].

Are there large basins even older than those already known? Although it may be impossible to know if the absolute ages of the large martian basins correspond in time with the Terminal Lunar Cataclysm, it may be possible to determine if there are previously unrecognized large impacts significantly older than the ages already determined. The current inventory of large impacts actually occupies only about 35% of the surface area of Mars, leaving, in principle, a large area in which older basins might exist [9]. Older basins would likely be more subtle, less obvious than those already identified, obscured by both ejecta from the known basins and by other subsequent geologic processes. Perhaps the best hope of finding such ancient large structures is through use of improved crustal thickness data, which is now available in the form of the MarsCrust3 model [10]. Based on new gravity models from MRO, MarsCrust3 has improved signal-to-noise and horizontal resolution and has confirmed the existence of many of the Crustal Thin Areas (CTAs) larger than 300 km diameter which we previously recognized in an earlier crustal thickness model [11] and which were used to help determine the N(300) CRAs for the highlands and lowlands of Mars [1] and the 20 known very large basins [3].

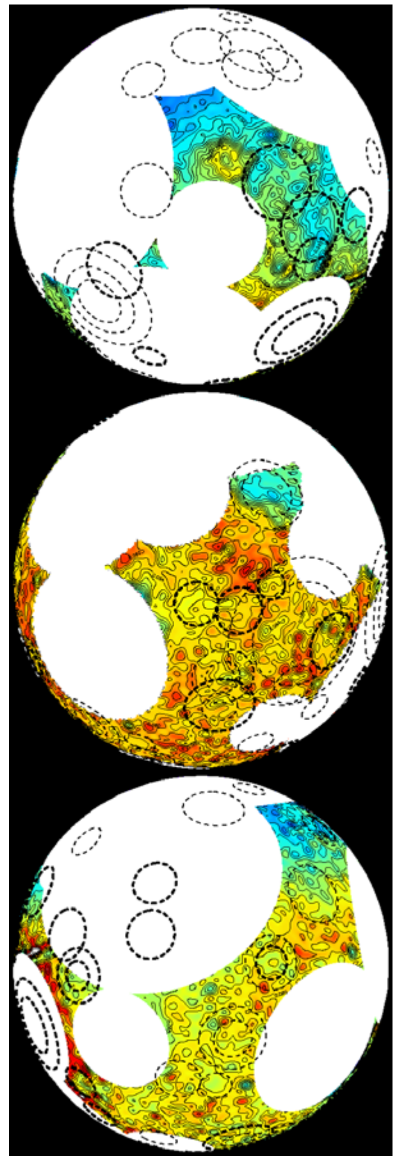

Figure 1. MarsCrust3 [10] centered at 30N, 120W (top), 30S, 240W (middle) and 30S, 0W (bottom). Thin crust shown by blues, thick crust by reds. Contour interval 4 km. White circles centered on known 20 largest impact basins out to 1.5 x basin diameter. Dashed circles are new CTAs found in MarsCrust3 [10]. Those overlying known basins must be younger than those basins, but those in the unblocked areas could be older.

We searched this new crustal thickness data for CTAs. Given the probable ancient age of the basins it is unlikely that complete circular thick rings corresponding to basin rims would survive intact. Most of the known large impact basins, including those identified [3] in earlier crustal thickness data [11], have discontinuous circular thick zones and are better characterized as sometimes piecemeal assemblages of circular arcs enclosing thinner crust. Younger basins have the more complete circular thick rings, as would be expected. A search for sectioned circular arcs in the new crustal thickness data revealed several dozen larger than 500 km diameter that were not recognized in previous searches for QCDs or CTAs [1,3]. Of these, some 10-11 are likely larger than 1000 km diameter and of these, some 7-8 seem to be very strong candidates for previously unrecognized large impact basins.

Crater retention ages of newly discovered basins. While some of these newly identified CTAs lie within the previously known large impact basins (Figure 1), and therefore must be younger than those basins, several lie outside the likely area of impact influence (here assumed to be 1.5 x Basin Diameter) and therefore have the potential to be older than basins identified earlier. We have concentrated on these and begun determining N(300) crater retention ages of these possibly older basins, counting superimposed QCDs and CTAs as we did previously [3] to determine ages of the 20 largest known impact basins. That is, initially we have used the old crustal thickness data to search for CTAS> 300 km in diameter to remain consistent with the ages we determined earlier. It is clear, however, that the new crustal thickness data [10] reveals even more such features [9] than were found in the old crustal thickness data [11]. We will determine the ages of all large diameter basin candidates using the new crustal thickness data.

Figure 2 shows preliminary ages for four new basins, all located in one of the largest areas possibly unaffected by the previously known large impacts (Figure 1, middle). These include a very large candidate with diameter ~ 2880 km. In general the N(300) CRAs (top) for the new basins (gray) are to the old side of the ages previously found (black); two of the four (N(300) ~ 7.78 and 8.90) are older than the oldest previously known (6.67). However, as shown in the bottom half of the figure, the inferred model absolute ages, using the conversion to the Hartmann-Neukum chronology previously adopted [3], suggests these are really not significantly older: the two oldest have model ages 4.236 and 4.252 BY compared with 4.218 BY for the Amenthes basin previously found. For the four new basins so far dated, there is no significant change in the spike-like character of the basin ages.

We note that, with the CRA to model absolute age conversion used, it would require an N(300) CRA of ~ 15 to yield an absolute model age greater than 4.3 BY.

Implications: If there are no basins significantly older than those already known and the new basins simply add to the sharpness of the spike-like character of the large diameter basin ages, two distinct possibilities need to be considered. It may be that the entire crust of Mars is indeed recording a short-lived large diameter impact "event" of the sort suggested by the Nice model [5,6]. Alternatively, it may be that some process has removed any record of earlier events. In principle this could be the combined effects of the more than 20 (perhaps more than 30) large basins, or it might be that slate was wiped clean by a single large impact such as Andrews-Hanna et al. [12] have suggested formed the martian dichotomy. If the latter, the CRAs of the oldest surviving basin would place a minimum age on that giant impact. At the present time, it appears that may have been N(300) ~ 9, or some 4.26 BY ago.

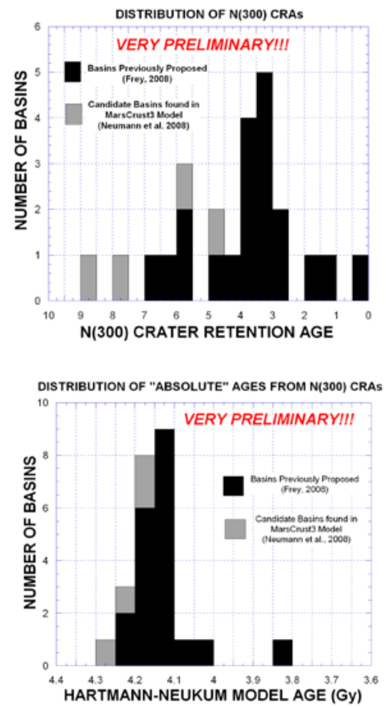

Figure 2. Distribution of N(300) CRAs (top) and model absolute ages (bottom) for previously known large impact basins (black) and four of the new basins found in MarsCrust3 data (gray). Even though two of the new basins are the oldest yet found, they are not significantly older in absolute model age and do not change the spike-like character of basin ages.

References. [1] Edgar, L.A. and H.V. Frey (2007) *Geophys. Res. Lett. (in press)*. [2] Frey, H.V. (2006), *JGR (Planets) 111*, E08S91,doi:10.1029/2005JE002449. [3] Frey, H.V. (2008) *GRL 35*, doi: 10.1029/2008GL033515. [4] Hartmann, W.K. and G. Neukum (2001) Space Sci. Rev., 96, 165-194. [5] Bottke, W.F. and H.F. Levison (2007) NAC Lunar Workshop, Tempe, AZ. (abstract). [6] Gomes, R., H.F. Levison, K. Tsiganis and A. Morbidelli (2005) *Nature 435*, 466-469. [7] Tera, F. D.A. Papanastassiou and G. J. Wasserburg (1974) *Earth Planet. Sci. Lett, 22*, 1-21. [8] Ryder, G., C. Koerbel and S.J. Mojzsis (2000) Origin of the Earth and Moon, (R.N. Canup and K. Righter, eds.), U. AZ Press, 475-492. [9] Frey, H.V. (2008) *Workshop on Early Solar System Bombardment*, LPI, November 2008. [10] Neumann G.A. et al. (2008) LPSC Abstract # 2167. [11] Neumann, G.A. et al. (2004) *JGR (Planets) 109*, E08002, doi: 10.1029/2004JE002262. [12] Andres-Hanna, J. et al. (2008) *Nature, 453*, 1212-1215.