Abstract # 1382

A TIMESCALE FOR MAJOR EVENTS IN EARLY MARS CRUSTAL EVOLUTION H. V. Frey, Geodynamics Branch, Goddard Space Flight Center, Greenbelt, MD 20771, Herbert.V.Frey@nasa.gov.

Summary: The population of visible and buried impact basins > 200 km diameter revealed by high resolution gridded MOLA data and the cumulative frequency curves derived for these provide a basis for a chronology of major events in early martian history. The relative chronology can be given in terms of N(200) crater retention ages; "absolute ages" can be assigned using the Hartmann-Neukum (H&N) model chronology. In terms of billions of H&N years, the crustal dichotomy formed by large impact basins at 4.12 +/- 0.08 BYA [N(200) = 3.0-3.2] and the global magnetic field died at about or slightly before the same time (4.15 +/- 0.08 BYA) [N(200) = 3.5]. In this chronology, the buried lowlands are ~120 my younger than the buried highlands), ~160 my younger than the highlands overall and ~340 my younger than the oldest crater retention surface we see, defined by the largest impact basins.

Introduction: The total population of visible and buried impact basins on Mars provides a basis for determining the crater retention age of the highlands and buried lowlands, as well as the relative sequence and crater retention age of the very largest impact basins. We use the large size population of all Quasi-Circular Depressions [1,2] (QCDs) > 200 km diameter [3,4,5] revealed by MOLA because: (a) the total number found was tractable (~560); (b) features of this size are difficult to bury completely (rim heights 1-1.5 km, depths ~4 km [6]) and therefore might be expected to survive over all of martian history; and (c) this is an appropriate size for comparison with other data such as the distribution of gravity and magnetic anomalies (see below and accompanying abstract). The buried population is much greater than the visible population in both the lowlands and the highlands. The density of all (visible+buried) basins is also much greater in the highlands than in the lowlands, by roughly a factor 4 (much larger than their areal ratio). Finally, there is a population of very large basins (D>1000km) which is equally divided between the two hemispheres. This includes two Utopia-size buried features in the highlands, one near but not identical to an earlier proposed Daedalia basin [7,8] and the other centered near 4N, 16W which we call the Ares Basin and which appears to have controlled early fluvial drainage through the Uzboi-Ladon-Arden Valles through Margaritifer-Iani Chaos.

Cumulative Frequency Curves and Crater Retention Ages: There is a small (~10) population of very large basins (D=1300-3000km) which follow a –2 power law slope on the log-log cumulative frequency plots. This may represent the oldest detectable surface on Mars [3]; later we use a -2 power law extrapolation of this to give an N(200) age for this surface. At diameters smaller than ~500 km the total populations in both highlands and lowlands again follow a –2 slope; for the planet-wide visible population this is the same slope as for the very large diameter basins. On a regional basis, the total population for D<600 km for the lowlands lies <u>above</u> the visible highland population, but **below** the buried (and also below the total) highland population in the cumulative frequency plot. This suggests the lowland crust is somewhat younger than the highland crust, as we have previously suggested [2,3,4].

At intermediate diameters (1200 down to about 600km) the global visible population of basins falls off the –2 slope before recovering at smaller diameters. The visible and total population of the highlands has a similar depletion, but the buried population in the highlands does not. We speculate that this depletion of intermediate size basins is the signature of some global-scale event very early in martian history, such as the formation of the slightly younger lowlands and/or the growth of Tharsis [3,4,5].

Comparison with Magnetic Anomalies: We compared the distribution of QCDs with the distribution of magnetic anomalies [3,4], both modeled [9,10, 11] and directly observed [12,13]. Most very large basins do not have prominent magnetic anomalies lying within their main ring, as had been previously suggested for the obvious Hellas and Argyre Basins [12,14]. But the two very large highland basins, Daedalia and Ares, <u>do</u> have prominent anomalies lying within their main rings. These two are the oldest of the population, based on their very subdued nature and the large number of superimposed smaller basins, and may predate the disappearance of the global magnetic field [3,4].

A Chronology of Major Events in the Early History of Mars: We use the cumulative number of basins larger than 200 km diameter per million square km [N(200)] to place the large diameter basins in a chronology (Figure 1). The highland total N(200) age is [4.53]. The ancient Ares Basin is slightly older [3.98] than the buried highland surface [3.89]. The three basins which contribute most to the lowland topography ("lowland-making" basins Acidalia, Utopia, and Chryse), are all older [N(200) ~ 3.12-3.27] than the buried and total lowland crust [2.39-2.47], as they should be. Argyre [2.21] and Isidis [1.39] formed after the lowland crust, but Hellas [2.68] may have formed before.

Another age of interest in this chronology can be derived by extrapolation from the largest impact basins, which, before the depopulation at D<1300 km, roughly follow a -2 power law. Extending this to D=200 gives an N(200) age of ~ 8.5, significantly older than the buried and total highlands. This probably represents the oldest N(200) age that can be estimated, but is not the oldest age on Mars. There must be still older crust if the oldest large basins are preserved as recognizable structures (see discussion below).

The relative basin sequence is fairly secure and consistent with regional ages based on counts of superimposed impact basins [2,4]. The line dividing the magnetic field/no-magnetic field eras is less so. We place it at N(200) ~ 3.5, just before or perhaps about the same time as the formation of the "lowland-making" basins. The few weak anomalies in Utopia, Acidalia and Chryse may represent partial remagnetization of the crust in a dying field following formation of these intermediate age basins. This is an extension of the idea that basins without anomalies formed after the field disappeared [12,14].

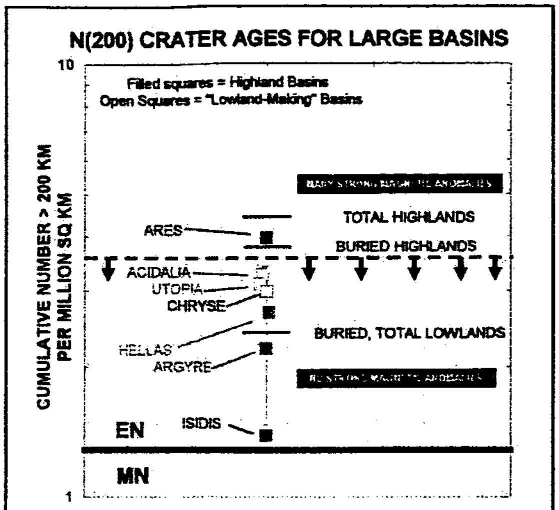

Figure 1: Possible chronology of early events in martian history, including formation of major impact basins before and after presence of global magnetic field, based on crater retention ages for D>200 km.

"Absolute Ages" and Major Events in Martian History: We can convert the N(200) relative crater retention ages into "absolute ages" using the Hartmann-Neukum model chronology [15]. This is uncertain by at least a factor 2 [16]. We use Tanaka's [17] crater counts at small diameters (2, 5, 16 km) to convert his N(16) ages for major epoch boundaries (Early Noachian/Middle Noachian [EN/MN], Middle Noachian/Late Noachian [MN/LN], etc.) to N(200) ages assuming a -2 power law. Note this is consistent with the cumulative frequency curves discussed above. Hartmann and Neukum [15] provide an absolute age for each of these epoch boundaries based on their model chronology. Thus we can plot a graph of H&N age versus N(200) age with points for the EN/MN and MN/LN. We consider two cases for the H&N value for the earliest age we find, extrapolated from the large basin population (D>1300 km diameter): the lower boundary on this is a linear extrapolation from the EN/MN and MN/LN points and the upper boundary is the unlikely case where the extrapolated age corresponds to the origin of Mars at 4.6 BYA.

Table 1 shows the resulting N(200) and "absolute ages" in billions of Hartmann-Neukum years for major events in martian history. With the factor of 2 and additional pre-Noachian uncertainty caveat, the total highlands have an absolute age of 4.10-4.33 BY. The buried highlands are slightly younger (4.08-4.27) than the Ares Basin (4.09-4.28), and distinctly older than the buried lowlands at 4.01-4.11 BY. These buried lowlands are slightly younger than the "lowland-making" basins Utopia, Acidalia and Chryse at 4.04-4.20 BY, as they should be. We take this to be the age of the formation of the crustal dichotomy. Based on the very low number of magnetic anomalies in these "lowland-making" basins, the near absence of such anomalies in still younger basins like Hellas, Isidis and Argyre (4.02-4.14, 4.00-4.07 and 3.92 BY respectively), and the assumption that this implies the global magnetic field had died by the time these basins had formed [12,14], we set the turn-off of the global field at N(200) ~ 3.5, or 4.07-4.23 BYA.

Table 1. A Proposed N(200) Time-Line for the Early Crustal Evolution of Mars

N(200)	Feature	Event	Epoch	H/N Age
~0.1	Visible Lowlands		EH	3.65
0.16	EH / LN BOUNDARY		EH/LN	3.70
~0.6	Visible Highlands		LN/MN	3.79
0.64	LN / MN BOUNDARY		LN/MN	3.80
1.28	MN / EN BOUNDARY		MN/EN	3.92
~1.3	Isidis	Impact	EN	3.92
~2.2	Argyre	Impact	EN	4.00-4.07
~2.5	Buried Lowlands		EN	4.01-4.11
~2.7	Hellas	Impact	EN	4.02-4.14
3.0-3.2	Chryse, Utopia, Acidalia	Lowlands formed?		4.04-4.20
~3.5?		Core Field Dies?		4.07-4.23
~3.8	Buried Highlands		pre-N	4.08-4.27
~4.0	Ares	Impact	pre-N	4.09-4.28
~4.5	Total Highlands		pre-N	4.10-4.33
~6.5	Large Basin Highlands (ext)	Impacts	pre-N	4.20-4.60

Conclusions: The (visible and buried) large diameter crater population suggest the buried lowlands are slightly younger than the buried highlands, but significantly older than the exposed highland surface. Formation of the lowlands may have caused a depletion in the intermediate size global population of visible basins. Buried basins outnumber visible basins for all diameters < 500 km, implying a significant hidden but recoverable early history for Mars. Very large basins appear to have separable crater retention ages and the existence or absence of magnetic anomalies in their interiors may suggest that the oldest large basins formed before the magnetic field died. In a Hartmann-Neukum model chronology, the crustal dichotomy formed by large impact basins occurred at 4.12 +/- 0.08 BYA and the global magnetic field died at about or slightly before the same time (4.15 +/- 0.08 BYA).

References. [1] Frey, H. et al., GRL 26, 1657-1660, 1999. [2] Frey, H. et al., GRL 29, 10.1029 /2001 GL013832, 2002. [3] Frey, H.V. Frey, 6th Intern. Coll. On Mars, abstract # 3104, 2003. [4] Frey, H. et al., LPSC 34 abstract #1848, 2003. [5] Frey, H., GSA Fall 2002 Meeting paper 26-3, 2002. [6] Garvin, J.B. et al. LPSC 33, abstract 1255, 2002. [7] Craddock, R.A. et al., JGR 95, 10729-10741, 1990. [8] Schultz, R. A. and H.V. Frey, JGR 95, 14,175-14,189,1990. [9] Purucker, M.E. et al., GRL 27, 2449-2452, 2000. [10] Cain, J. unpublished data, 2001. [11] Langlais, B. et al., in press, JGR, 2003. [12] Acuna, M.H., et al., Science 284, 790-793, 1999. [13] Connerney, J.E.P. et al., GRL 28, 4015-4018, 2001. [14] Hood, L.L. et al., LPSC abstract #1125, 2003. [15] Hartmann, W.K. and G. Neukum, Space Sci. Rev., 96, 1-30, 2001. [16] Hartmann, W.K., personal communication, 2002. [17] Tanaka, K. L et al., Chap. 11 in *Mars*, Kieffer et al. (ed.), 1992.