IMPACT CONSTRAINTS ON THE AGE AND ORIGIN OF THE CRUSTAL DICHOTOMY ON MARS.

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Introduction: MOLA data have revealed a large population of "Quasi-Circular Depressions" (QCDs) with little or no visible expression in image data. These likely buried impact basins [1,2] have important implications for the age of the lowland crust, how that compares with original highland crust, and when and how the crustal dichotomy may have formed [3-6]. The buried lowlands are of Early Noachian age, likely slightly younger than the buried highlands but older than the exposed (visible) highland surface. A depopulation of large visible basins at diameters 800 to 1300 km suggests some global scale event early in martian history, maybe related to the formation of the lowlands and/or the development of Tharsis. A suggested early disappearance of the global magnetic field can be placed within a temporal sequence of formation of the very largest impact basins. The global field appears to have disappeared at about the time the lowlands formed. It seems likely the topographic crustal dichotomy was produced very early in martian history by processes which operated very quickly. This and the preservation of large relic impact basins in the northern hemisphere, which themselves can account for the lowland topopgraphy, suggest that large impacts played the major role in the origin Mars' fundamental crustal feature.

QCDs > 200 km Diameter: Figure 1 shows polar views of QCDs > 200 km diameter. Features of this size, which number >500, are difficult to bury completely (rim heights 1-1.5 km, depths ~4 km [7]) and therefore might be expected to survive over all of martian history. This is also a size appropriate for comparison with gravity and magnetic anomalies [8-11].

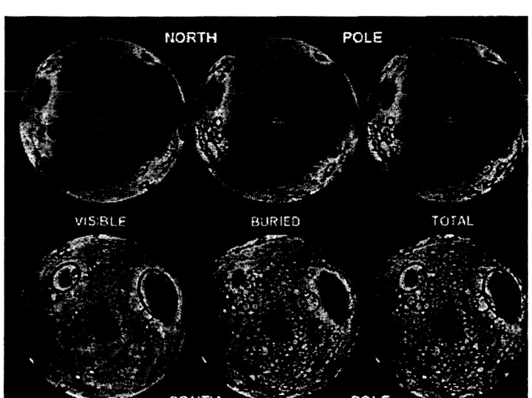

Figure 1: Polar views of visible, buried and total (= visible + buried) QCDs > 200 km diameter. Note the larger number of buried basins in both hemispheres, and the larger total number in the south.

In both highlands and lowlands the buried population is always much greater than the visible population. There is a significant number of very large basins (D>1000km), equally divided between the two hemispheres, including two Utopia-size buried highland features. One is near but not identical to an earlier proposed "Daedalia Basin" [12,13] and the other centered near 4N, 16W. This "Ares" basin may have influenced early fluvial drainage through the Uzboi-Ladon-Arden Valles and Margaritifer-Iani Chaos depressions.

Cumulative Frequency Curves and Crater Retention Ages: A small (~10) population of very large basins (D=1300-3000km) follow a –2 power law slope on the log-log cumulative frequency plots. At D < ~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. The relative positions of the lowland and highland curves indicate the buried lowland crust is slightly younger than the original (now buried) highland crust, consistent with our earlier result [2]. By direct comparison with the oldest exposed surface units on Mars (Nh_1, SE of Hellas [3,4]), the buried lowland crust is Early Noachian in age [14].

At intermediate diameters (1300 to about 800 km) the global visible population falls off the –2 slope before recovering at smaller diameters. This depletion of intermediate size basins may be the signature of some global-scale event very early in martian history. Candidates include formation of the slightly younger lowland crust (i.e., the formation of the topographic crustal dichotomy), and the growth of Tharsis (or both), both of which could have removed pre-existing intermediate-size basins.

Implications for the Age and Origin of the Crustal Dichotomy: Unless there is some way to preserve the large population of Early Noachian (now buried) impact craters while lowering the crust in the northern third of Mars, it appears the lowland crust not only formed in the Early Noachian but also became low during that time [2,14]. The slight crater age difference (which could be a very short absolute time interval), does suggest the lowlands formed after the highlands were in place and preserving craters. It may be hard to form the lowlands by endogenic processes in the short time available. Most mechanisms suggested [15-17] have a relatively late formation of the lowlands. Even if degree one convection does occur, it appears to take hundreds of millions of years to become established, even with extreme viscosity gradients [17]. How much longer, and by what exact means, the crust then becomes low, is generally discussed in only vague terms. In contrast, three large "lowland-making" QCDs (Utopia, Acidalia and Chryse) do account for most of the lowland topography and offer a simple impact mechanism for the early formation of a topographic dichotomy on Mars [18].

Comparison with Magnetic Anomalies: We compared the distribution of QCDs (both buried and visible) with the distribution of magnetic anomalies [9,10,19-21]. Only the two oldest very large basins, Daedalia and Ares, have prominent anomalies lying within their main rings. Daedalia and Ares likely predate the disappearance of the global magnetic field. The "lowland-making" basins Utopia, Acidalia and Chryse have only a few moderate amplitude anomalies within their main rings, and are of intermediate age between Ares and the younger Hellas, Argyre and Isidis basins (see below). The demise of the global magnetic field may have been at about the time of formation of these "lowland-making" basins.

A Chronology of Major Events in the Early History of Mars: We used the cumulative number of basins larger than 200 km diameter per million square km [N(200)] to place the large diameter basins in a relative chronology [6, 18, 22]. The N(200) relative crater retention ages can be converted into "absolute ages" [22,23] using the Hartmann-Neukum (H&N) model chronology [24]. This is uncertain by at least a factor 2 [25]. We use Tanaka's [26] 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], etc.) to N(200) ages assuming a -2 power law. Hartmann and Neukum [24] give a model absolute age for each of these epoch boundaries. 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): a linear extrapolation from the EN/MN and MN/LN points and the unlikely case that the origin of Mars at 4.6 BYA is the upper limit.

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 an additional pre-Noachian crater saturation caveat, 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. This is also close to the time when the global magnetic field died, based on which basins do and do not have anomalies within their main rings. It may be that the two events, formation of the fundamental crustal dichotomy and the demise of the global magnetic field, are related.

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
-8.5	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. The buried lowland crust is Early Noachian in age and the lowlands likely formed by processes that operated relatively quickly. In a Hartmann-Neukum model chronology, a crustal dichotomy produced by large "lowland-making" impact basins formed by 4.12 +/- 0.08 BYA and the global magnetic field died at about or slightly before the same time (4.15 +/- 0.08 BYA).

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