BURIED IMPACT BASINS AND THE EARLIEST HISTORY OF MARS. H. V. Frey, Geodynamics Branch, Goddard Space Flight Center, Greenbelt, MD 20771, Herbert.V.Frey@nasa.gov.

Introduction: The "Quasi-Circular Depressions" (QCDs) seen in MOLA data which have little or no visible appearance in image data have been interpreted as buried impact basins on Mars [1,2]. These have important implications for the age of the lowland crust, what mechanisms could produce the crustal dichotomy, and the existence of crust older than the oldest observed surface units on Mars [3,4]. A global survey of large QCDs using high resolution MOLA data now available [5,6] has provided further details of the earliest history of Mars. The lowlands are of Early Noachian age, slightly younger than the buried highlands and definitely older than the exposed 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.

QCDs > 200 km Diameter: Figure 1 shows polar views of QCDs > 200 km diameter. The diameter cutoff for this global survey was motivated by several factors: (a) the total number found (~560) was tractable; (b) features of this size 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; and (c) this is an appropriate size for comparison with other data such as the distribution of gravity and magnetic anomalies [8-10].

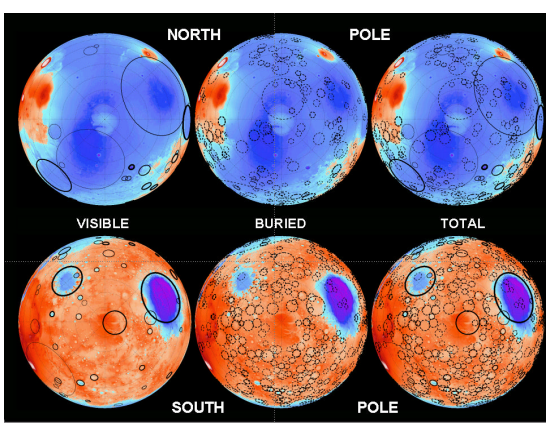

Figure 1: Polar views of visible, buried and total (= visible + buried) QCDs > 200 km diameter. Note the larger number of buried basins in both hemispheres, and the larger total number in the south.

The buried population is much greater than the visible population in both the northern lowlands and in the southern 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).

There is a significant population of very large basins (D>1000km), equally divided between the two hemispheres, including two Utopia-size buried features. One is near but not identical to an earlier proposed "Daedalia Basin" [11,12] and the other centered near 4N, 16W. This "Ares" basin has independent support. The Uzboi-Ladon-Arden Valles through Margaritifer-Iani Chaos depressions form a nearly continuous northward channel system that is radial down toward the exact center of the Ares Basin. Ares Vallis itself drains exactly radially away from this center NW into Chryse.

Cumulative Frequency Curves and Crater Retention Ages: Global and separated highland/lowland cumulative frequency curves show similar characteristics. 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. 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. On a regional basis, the total lowland population for D<600 km lies <u>above</u> the visible highland population, but <u>below</u> the buried (and total) highland population. This suggests that globally the buried lowland crust is slightly younger than the original (now buried) highland crust.

This is consistent with our earlier result that the buried lowlands were older than the visible highlands in the extended "Arabia" area [2] and that, based on 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 [13].

At intermediate diameters (1300 to about 800 km) the global visible population of falls off the –2 slope before recovering at smaller diameters. The visible and total populations of the highlands have 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. Candidates are the formation of the slightly younger lowlands, and the

growth of Tharsis, 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 [2,13]. The slight crater age difference (which could be a very short absolsute 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 shosrt time available. Most mechanisms suggested [14-16] 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 [16]. Three large "lowland-making" QCDs (Utopia, Acidalia and Chryse) do not account for all the lowland area of Mars, but are responsible for much of it and provide a simple mechanism for the early formation of a topographic dichotomy on Mars [7].

Comparison with Magnetic Anomalies: We compared the distribution of QCDs (both buried and visible) with the distribution of magnetic anomalies, both modeled [17,18] and directly observed [9,10]. As shown in Figure 2, most of the very large basins do not have prominent magnetic anomalies lying within

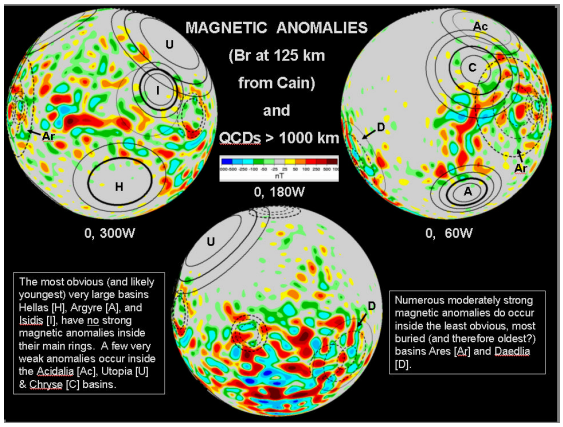

Figure 2. Crustal magnetic anomalies from Cain [11] with QCDs > 1000 km diameter superimposed. Note only Daedalia [D] and Ares [Ar] have prominent anomalies lying inside their main (darker) rings. These two may have formed when the global magnetic field was still present.

their main ring, as had been previously suggested for the Hellas and Argyre Basins [9,19]. This is also true for many of the less obvious large basins detected in this study, and consistent with earlier suggestions that these basins may have formed after the global dynamo died [9,19]. But two very large basins, Daedalia and Ares, do have prominent anomalies lying within their main rings (Figure 2). These two are also the oldest of the population, based on their much more subdued nature and larger number of superimposed smaller basins. Daedalia and Ares likely predate the disappearance of the global magnetic field. The "lowland-making" basins Utopia, Acidalia and Chryse have a few moderate amplitude anomalies within their main ring, and based on superposed smaller basins appear to be of intermediate age between Ares and the younger Hellas, Argyre and Isidis basins (see below).

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 3). The highland total N(200) age is [4.53]. The very ancient Ares Basin is slightly older [3.98] than the buried highland surface [3.89]. The three basins which contribute most to the topography of the lowlands ("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.

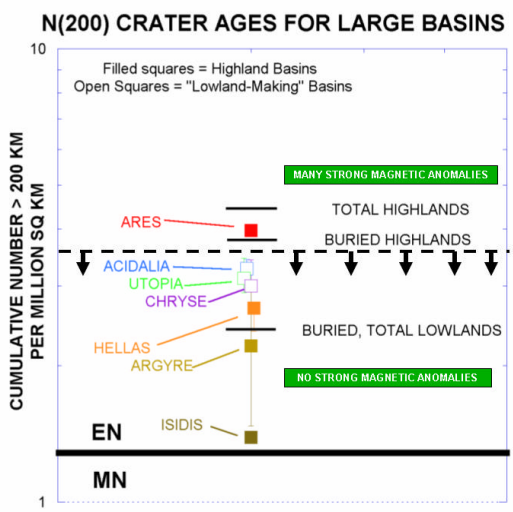

Figure 3: Possible chronology of early events in martian history, including formation of major impact basins before and after presence of global magnetic field, based on crater retention ages for D>200 km.

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 powerlaw. Extending this to D=200 gives an N(200) age of ~ 6-8, significantly older than the buried and total highlands. This probably represents the oldest N(200) age that can be estimated, but is not oldest age on Mars. There must be still older crust if the oldest large basins are preserved as recognizeable structures (see discussion below).

The relative basin sequence is fairly secure and consistent with regional ages based on counts of superimposed impact basins. The line dividing the magnetic field/no-magnetic field eras is less so. We place it at N(200) ~ 3.5, before 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 [9,19]. If some process other than impact demagnetized the crust [e.g., 20], then this line could be substantially lower in Figure 3 and later in martian history.

The scheme described above is a relative chronology, loosely constrained by cumulative frequency data for QCDs of large size. It does not, except through modeling studies, provide information on absolute ages or dates for major events. Buried impact basins do provide some information on the limitations on our ability to estimate absolute ages, as described below.

Pre-Noachian Crust?: The "Early Noachian" (EN) used in geologic mapping [21-23] is undefined at the early end, but it is often assumed in absolute chronologies [24,25] to extend back to 4.6 BYA. This assumption was explored by searching for evidence of buried impact basins, [3,4] in the largest occurrences of Early Noachian terrain. If such basins exist, they indicate crust which must pre-date the surface units mapped as the oldest on Mars, and those units must then be less than 4.6 BY old. We show that such older basins and crust do indeed exist. Also a number of Noachian terrains on Mars appear to have a common total (visible + buried) crater retention age. This might be either the age of an original (planet-wide?) crust of Mars, or may indicate crater saturation.

Buried Basins near Hellas and Isidis: The two largest occurrences of EN materials on Mars are the basin rim materials of Hellas (Nh_1, about 1.2 million sq. km) and Isidis (Npl_1, about 0.6 million sq km). We searched MOLA data for Quasi-Circular Depressions (QCDs) >25 km diameter in the Hellas [3,4] and >15 km in the Isidis [4,26] areas, and found a significant population of QCDs not visible on images that we assume are buried impact basins. Cumulative frequency curve shape supports this assumption.

The total (cumulative) population near Hellas is about 1.6 times the visible population [3,4]. Isidis [4,26] shows a total population about 3-3.5 times the visible population over the same diameter range. Our counts suggest Isidis rim material is younger than Hellas rim material in terms of visible crater populations, but has a larger buried population. The total cumulative populations for Hellas and Isidis rim materials are similar, implying a common age older than the Early Noachian visible crater retention age.

Total Populations Compared: Figure 4 compares these total populations with other Noachian units, including MN Npl_1 near Hellas and a very large "Arabia" area (~17 million sq km, average MN age) used previously for comparison with our lowland study [2]. Because of its very large area, the "Arabia" statistics are very good, and the "Arabia" total population closely follows a –2 power law over the entire diameter range 50-500 km. Over a more limited range where their smaller area statistics are also good, the total population curves for EN terrain at Isidis and for EN and MN terrain at Hellas closely overlap and follow the same –2 slope as for "Arabia". In all three regions, despite radically different sampling areas, the total crater retention age is similar.

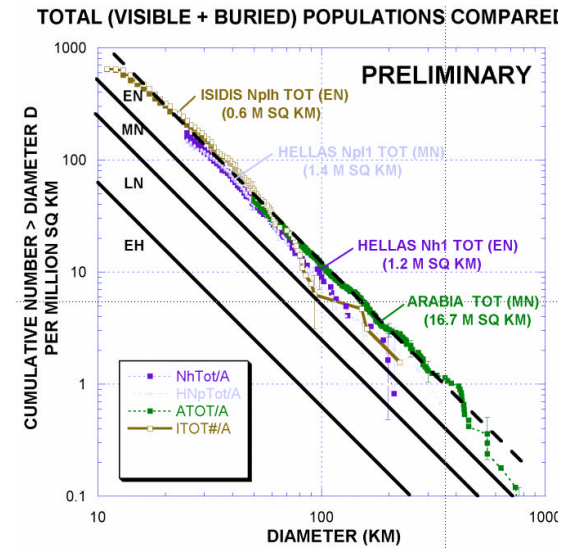

Figure 4: Cumulative frequency curves for total populations in Early and Middle Noachian terrains. See text for details. Note common crater retention age for all areas where good statistics permit comparison.

Similar total crater retention ages could suggest either (a) a common age for the underlying surface which, if not the age of the primordial crust on Mars, is certainly older than the surface units mapped as Early Noachian, or (b) crater saturation [4,26]. To

test the second of these we show in Figure 5 the same total population data in an incremental frequency plot and compare it with curves of martian ages from [25].

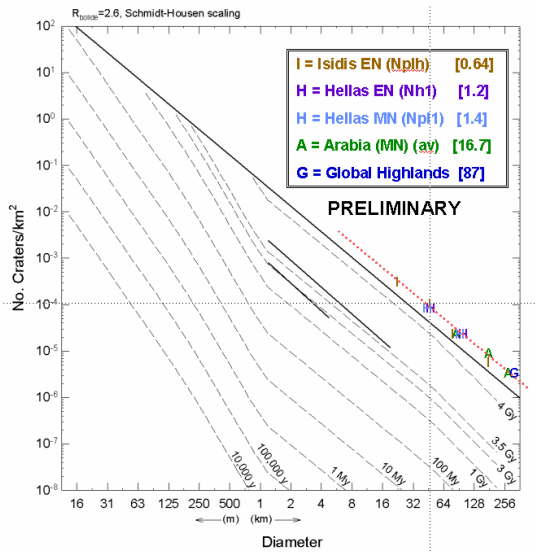

Figure 5: Incremental frequency curves for total populations for several Noachian terrains. All plot on a line (red dots) parallel to but slightly above the saturation line. Curves from [10].

Over the diameter ranges for which we have data the total population points define a straight line (red in Figure 5) which parallels a saturation curve, but lies above it. However, the curves in Figure 5 depend on a number of model assumptions, especially the scaling factor R. The absolute ages shown are probably accurate to a factor 2 [27]. Note our data does lie within a factor 2 of the saturation line in Figure 5. The total population data shown here may well indicate saturation in the underlying crust [13,26]. It is interesting to speculate that data such as presented here, if supported by similar results from other Noachian terrains around Mars, might be used to "calibrate" the model curves.

Conclusions: Buried impact basins on Mars provide evidence that: (1) The buried lowland crust is Early Noachian in age, slightly younger than the buried highlands but definitely older than the exposed highland surface. This constrains the mechanisms by which the crustal dichotomy formed and favors those which operate very early and very quickly. Impact processes may have been the cause of the lowlying topography in many areas. (2) Very large visible basins show a depopulation (relative to a -2 power law) at intermediate diameters (1300 down to about 800 km) that may be the signature of some early global scale event. The formation of the lowlands or Tharsis (or both) are obvious candidates. (3) While most very large impact basins have few or no strong magnetic anomalies inside their main rings, the two oldest (based on superposed smaller basins) do have prominent anomalies, suggesting they formed before the global magnetic field died. Weak anomalies in the "lowland-making" basins may indicate partial remagnetization in a dying field following formation of these intermediate age basins. (4) The oldest visible surface units are not the oldest crust and cannot date from 4.6 billion years ago. There is a "pre-Noachian" history recorded by buried basins found underlying the oldest visible terrains on Mars. (5) A number of old terrains appear to have similar total population crater retention ages, which could be a common-age earlier crust or could indicate saturation cratering.

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