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Buried impact basin distribution on Mars: Contributions from crustal thickness data

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[1] Crustal thickness data (derived from Mars Global Surveyor (MGS) gravity field and topographic data) exposes a number of circular thin areas (CTAs) that may represent deeply buried impact basins, which are often not visible in topography alone. A data set which combines quasi-circular depressions (QCDs) revealed by the Mars Orbiter Laser Altimeter (MOLA) on the MGS spacecraft with a population of non-QCD CTAs is a better estimate of the true crater retention ages of the buried surfaces of Mars. This study finds that all regions have older crater retention ages than previously thought based on QCDs alone. The highlands and lowlands appear to have the same basement crater retention age, but Tharsis is younger. **Citation:** Edgar, L. A., and H. V. Frey (2008), Buried impact basin distribution on Mars: Contributions from crustal thickness data, *Geophys. Res. Lett.*, *35*, L02201, doi:10.1029/2007GL031466.

1. Introduction

[2] Mars Orbiter Laser Altimeter (MOLA) data reveal a large number of quasi-circular depressions (QCDs) in both the highlands and lowlands of Mars, interpreted as buried impact basins [*Frey et al.*, 2002]. QCDs are roughly circular basins (>200 km), most of which lack visible structure in image data, but are revealed in high precision topographic data. QCDs are either "visible" (seen in image data, and having a very distinct circular feature in topography), or "buried" (generally not seen in image data but display a circular depression in topography). QCDs (both visible and buried) have been used to relatively date the age of several different regions in the Martian lowlands, as well as to compare the relatives ages of the highlands and lowlands [*Frey*, 2006]. *Frey* [2006] found that the density of QCDs appears to correlate with the topographic and physiographic dichotomy – more basins in the cratered southern highlands and fewer basins in the relatively smooth northern lowlands. Using N(200) crater retention ages (indicating the cumulative number of basins larger than the given diameter, 200 km, per million square kilometers), QCDs suggest that the highlands are older than the lowlands, though the lowlands are significantly older than previously thought using only visible basins [*Frey*, 2006]. However, we suggest that the ages based on QCDs are essentially minimum ages, because there may well be basins too deeply buried to have a signature in the topography alone.

[3] *Neumann et al.* [2004] developed a crustal thickness model derived from Mars Global Surveyor (MGS) gravity field and topography, which assumes a uniform crust/mantle density contrast and a given mean crustal thickness. Additional corrections were made for density anomalies associated with the polar caps, major volcanoes, and hydrostatic flattening of the core. Using an interactive software program called GRIDVIEW [*Roark et al.*, 2004] to analyze the crustal thickness model, we find a large number of circular thin areas (CTAs): roughly round areas of thinner crust surrounded by thicker crust (Figure 1). We suggest many of these CTAs are the signatures of buried impact basins. The total population of impact basins (a data set which combines QCDs and non-QCD CTAs) may produce a better estimate of the true crater retention ages of the buried surfaces of Mars.

2. Comparison of CTAs and QCDs

[4] In this study, GRIDVIEW was used to analyze the crustal thickness model, stretching the data in the same way that MOLA data was stretched to reveal QCDs. We searched for CTAs larger than 300 km in diameter, a constraint imposed by the low resolution of the crustal thickness model. The locations of these CTAs were compared the locations of previously identified QCDs (diameters >200 km) and a strong correlation was found in many cases. However, approximately half of the CTAs do not correspond to identified QCDs. We suggest that these CTAs represent more deeply buried impact basins while the CTAs with corresponding QCDs represent less deeply buried basins, as seen in Figure 2.

[5] However, there are several limitations in the current crustal thickness model. Due to the low resolution of the crustal thickness data, a CTA that looks like a single feature may actually be related to several smaller objects grouped close together. Also, the overlap with QCDs is not always perfect: sometimes CTAs appear to be "shifted" from the corresponding visible basins. Finally, the data is in spherical harmonic form, so some features, especially smaller ones, might be spurious. Yet the frequency and occurrence of CTAs is consistent with them being deeply buried impact basins. In areas of likely thicker cover (sparsely cratered terrain), there are more non-QCD CTAs than QCDs and cumulative frequency curves based on CTAs appear to follow the same trends as those based on QCDs. In some cases, CTAs with corresponding QCDs have been detected at diameters as small as 200 km, but given the spherical harmonic representations used for the gravity and topography data, we cut off consideration of circular features at

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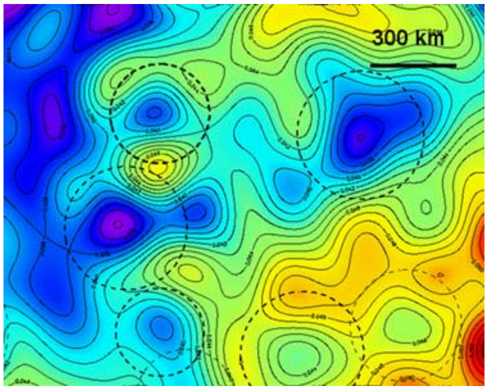

Figure 1. An example of circular thin areas (CTAs) >200 km in diameter, plotted in colored and contoured crustal thickness data. Red and orange colors reflect thicker crust, while blue indicates thinner crust [*Neumann et al.*, 2004]. Dashed rings represent likely CTAs. Thicker rings represent stronger crustal thickness signatures. Contour interval, 1 km. Approximate range, 20 km. Centered at (26, 320W).

300 km in crustal thickness (this is much coarser than the MOLA topography resolution, which makes possible the detection of QCD features smaller than 10 km). Care needs to be taken when counting CTAs as possible impact basins, but there does seem to be a significant population of CTAs that do not have corresponding QCDs, which may represent older, more deeply buried basins.

3. Observations

[6] Figure 3 shows the global distribution of likely impact basins larger than 300 km in diameter in the combined data set. CTAs with no corresponding QCD (new features uncovered in this study) are plotted as white rings. Initial observations reveal that in the highlands there are more CTAs with corresponding QCDs, but in the lowlands and Tharsis, there are more CTAs with no corresponding QCDs. This is consistent with the CTAs being more deeply buried impact basins. To quantify these results we examined (1) the percentage of buried basins that are non-QCD CTAs and (2) the ratio of non-QCD CTAs to previously discovered QCDs (Table 1). There is a far greater percentage of non-QCD CTAs in the lowlands than in the highlands (63% vs. 29%), probably reflecting the greater thickness of cover in the plains. There are relatively few non-QCD CTAs compared to previously discovered QCDs identified in the highlands (0.4:1) but the ratio in the lowlands is nearly 1.7:1. However, the relationship between the two types of features is practically 1:1 in Tharsis. The regions of thickest cover, the lowlands and Tharsis, have a larger percentage of non-QCD CTAs.

[7] Cumulative frequency curves for each region also reflect the addition of CTAs. The highlands, lowlands and Tharsis are all older than previously thought based on QCDs alone, and all regions are much older than previously thought based on visible impact craters alone (Figures 4, 5, and 6). In areas of deepest cover, such as the lowlands, the combined data set suggests that the lowlands are significantly older than previously thought based on QCDs (Figure 5). The comparison of all three regions in Figure 7 indicates that not only are all regions older, but the highlands and lowlands now appear to have the same basement age. The highland and lowland curves are nearly identical over a broad diameter range, from 1000 km down to 300 km. The curves visibly separate at very large diameters, but this may be due to the definition of some of the very large basins as either "highlands" or "lowlands," which is difficult for basins such as Chryse and Isidis, which are surrounded by highland crust but contain an area thought of as lowlands. The combined cumulative frequency curves plotted in Figure 7 also show that the Tharsis curve parallels that of the highlands and lowlands, but is lower at all diameters.

[8] We use N(300) crater retention ages, the cumulative number of basins larger than 300 km in diameter or greater per million square km, to compare the relative ages of the different regions. These are shown in Table 2 for the highlands, lowlands, and Tharsis regions, and compared with the N(300) age based only on QCDs. The N(300) crater retention ages derived from the cumulative frequency curves are the same for the highlands and lowlands, but Tharsis is significantly younger, as seen in Table 2. Table 2 also shows that the basement ages of these areas are older

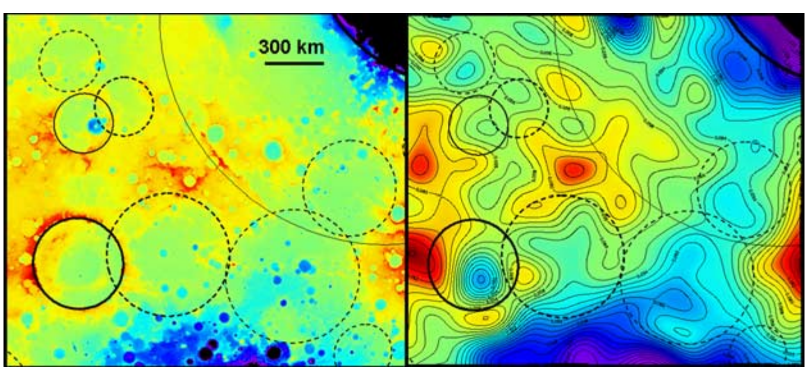

Figure 2. QCDs with signatures in crustal thickness data. (left) Previously mapped QCDs shown in colored topographic data from the highlands, just north of Hellas, centered at (−6, 295W). Solid black rings represent visible basins, dashed rings represent buried basins. (right) QCD locations are plotted on colored and contoured crustal thickness data, illustrating that previously mapped QCDs often have an expression in crustal thickness. Contour interval, 1 km. Approximate range, 30 km.

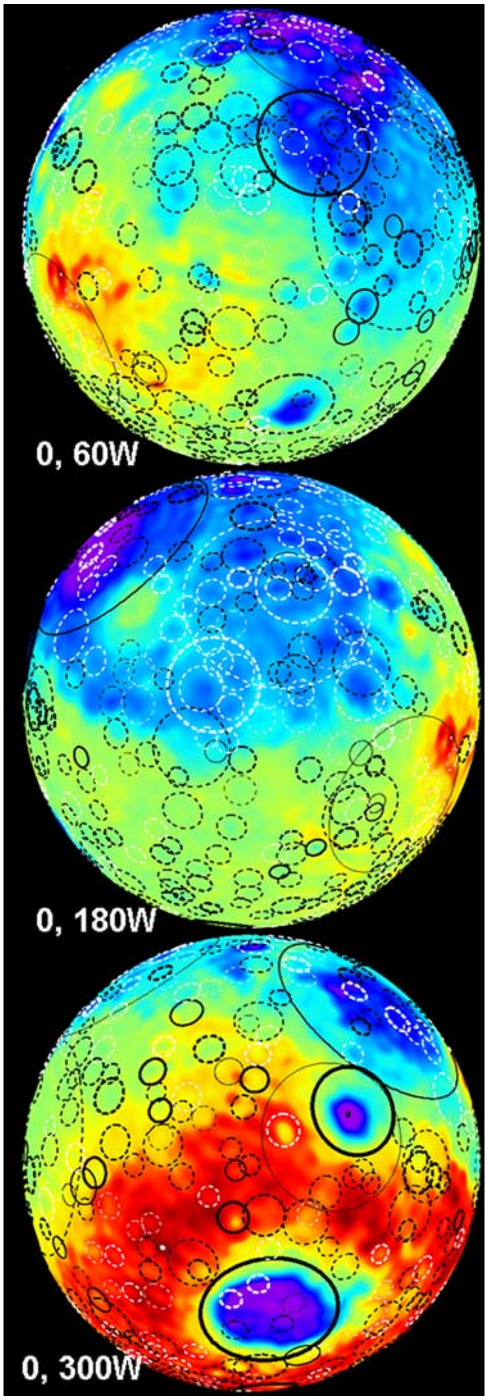

Figure 3. Global distribution of likely impact basins >300 km, plotted on crustal thickness. Equatorial views are shown at three different longitudes. Visible impact basins are plotted as solid rings, buried basins as dashed rings. QCDs identified in topography are plotted as black rings, while white rings represent CTAs with no corresponding QCD (new basins uncovered using the crustal thickness model). Red, regions of thicker crust. Blue, regions of thinner crust. Note the larger percentage of non-QCD CTAs in the lowlands compared to the highlands.

Table 1. Comparison of Non-QCD CTAs to QCDs

	Highlands	Lowlands	Tharsis
#Non-QCD CTAs	81	83	16
#QCDs	196	49	19
CTAs/(CTAs + QCDs)	.29	.63	.46
#CTAs/#QCDs	.41	1.69	.84

than was previously thought based on QCDs alone. Although we use N(300) crater retention ages, N(400) or N(500) would show the same result since the highland and lowland curves are nearly identical.

4. Discussion

[9] The ratios of non-QCD CTAs to QCDs suggest that in the highlands, many of the CTAs have already been identified as QCDs. However, in the lowlands and Tharsis, many new features are uncovered in crustal thickness data, most likely because these areas contain great thicknesses of burying material. There is a significant population of features suggested by the crustal thickness model which do not correspond with QCDs. These are likely older, more deeply buried basins.

[10] As indicated in Figure 7 and Table 2, the highlands and lowlands appear to have the same combined QCD + CTA crater retention age, but Tharsis is younger. All three regions have older ages than previously suggested by QCDs. However, it is important to consider if these regions might have reached crater saturation. At the small diameter end in Figure 7, both the highlands and lowlands appear to follow a −2 power-law trend, which may support the possibility that they have reached crater saturation [*Frey and Edgar*, 2007]. If this is true, we cannot really determine if the highlands and lowlands have the same crater retention age.

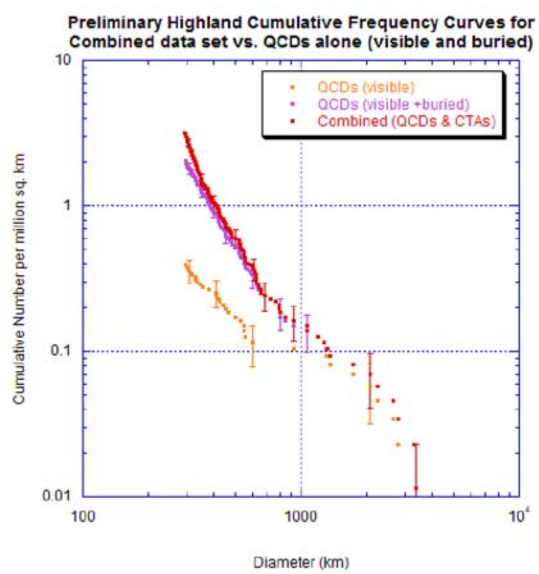

Figure 4. Cumulative frequency curves for the highlands based on visible QCDs (orange), all QCDs (visible + buried) (purple), and the combined data set of QCDs and CTAs (red). The combined curve suggests that the highlands are somewhat older than previously thought based on QCDs alone, and much older than previously thought using only visible impact craters.

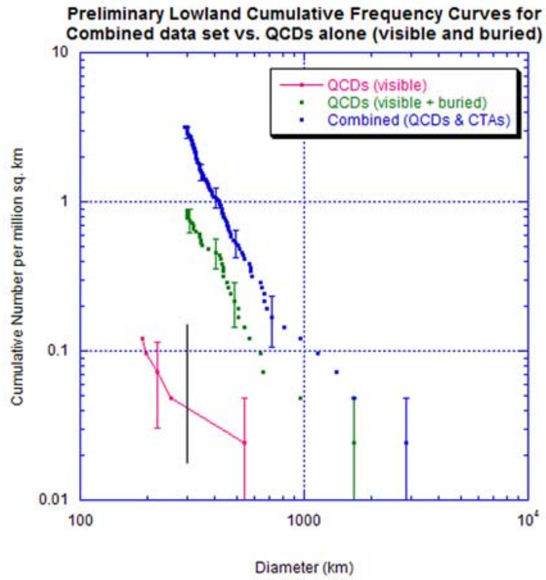

Figure 5. Cumulative frequency curves for the lowlands based on visible QCDs (pink), all QCDs (green), and the combined data set (blue). Only one visible QCD > 300 km is found in the lowlands, so the visible QCD curve is plotted with features as small as 200 km for perspective. The vertical black line shows the cut-off at 300 km. The combined curve suggests that the lowlands are significantly older than previously thought.

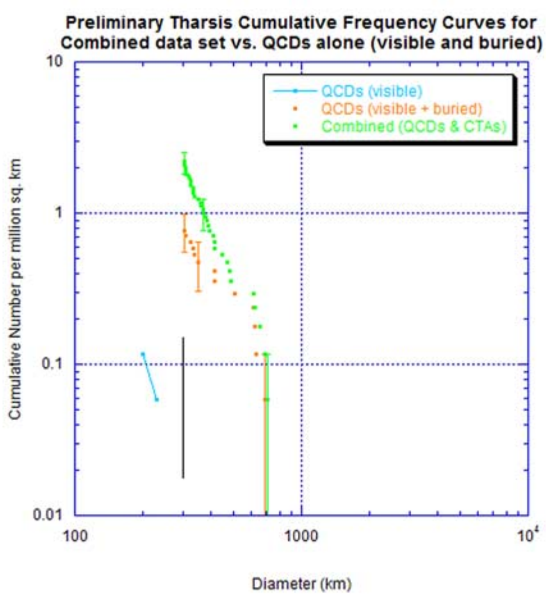

Figure 6. Cumulative frequency curves for Tharsis based on visible QCDs (light blue), all QCDs (orange), and the combined data set (light green). We find no visible QCDs > 300 km in Tharsis, but two small 200 km range basins are plotted for perspective (light blue). The combined curve suggests that Tharsis is older than previously thought based on QCDs alone.

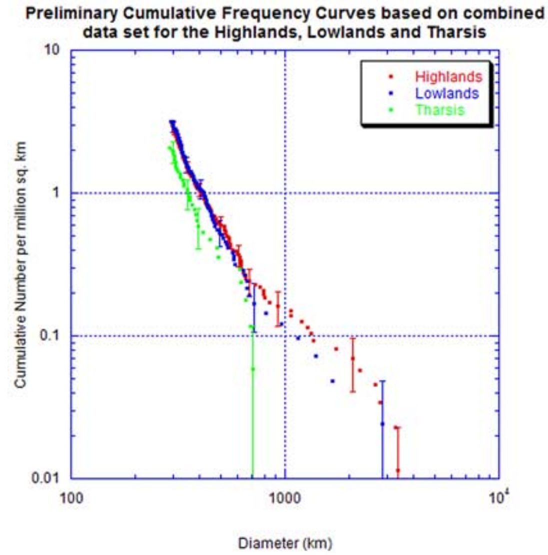

Figure 7. Cumulative frequency curves for the highlands, lowlands, and Tharsis based on the combined data set. The combined data set shows a similar age for the highlands and lowlands (shown in red and dark blue). The highland and lowland curves are nearly identical over a broad diameter range.

[11] If the highlands and lowlands do indeed have the same basement age, several important questions arise from this study. Future work should aim to address how and when the lowlands formed, how and when Tharsis formed, and the nature of the material filling the basins. It would also be interesting to look for regional variations in crater densities and the retention ages of the very large basins. We would also like to compare QCDs and CTAs with basins being discovered by radar, such as MARSIS [*Watters et al.*, 2006] or SHARAD, because the combination of these techniques is likely to produce the most complete inventory of buried basins.

[12] Additionally, upon completion of a new gravity map from the Mars Reconnaissance Orbiter, a new crustal thickness model should become available, and can be used to verify the CTAs at small diameters, and search for additional, even smaller basins.

5. Conclusions

[13] Since the ratio of non-QCD CTAs to QCDs is greatest in areas of thickest cover, and the CTAs follow a similar shape in the cumulative frequency curves as the QCDs, it is likely that they represent additional, more deeply buried, impact basins. This suggests that the ages previously determined for the highlands and lowlands based

Table 2. N(300) Crater Retention Ages for the Combined Data Set Vs. QCDs Alone

	QCDs Alone	QCDs and CTAs
Highlands	1.98	3.18
Lowlands	0.87	3.19
Tharsis	0.77	2.06

only on QCDs are too low, and the combined non-redundant data set is a better estimate of the true crater retention age of the (buried) surfaces of Mars. Based on the combined data set, all regions are older than previously thought using QCDs alone. Furthermore, the N(300) crater retention ages derived from the combined population are the same for the highlands and lowlands, but are significantly younger for Tharsis.

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