SEEING THE INVISIBLE: A HISTORY AND PERSPECTIVE ON SEARCHING FOR BURIED IMPACT CRATERS

H.V. Frey, Planetary Geodynamics Lab, Goddard Space Flight Center, Greenbelt, MD 20771, Herbert.V.Frey@nasa.gov .

Summary: Topographic and crustal thickness data provide evidence for buried impact craters and basins on Mars and the Moon that cannot be easily "seen" in image data. We summarize efforts to not only detect such features but to rate them based on the strength and character of their signatures, along with difficulties and advantages of such studies.

Buried Impact Craters on Mars: The first indication that a substantial population of "not visible" impact craters existed on Mars came from studies of Mars Orbiter Laser Altimeter (MOLA) data [1,2]. Suggested by early profile data and later by gridded data, the 450 km wide "MOLA Hole" was the first large "Quasi-Circular Depression" (QCD) revealed in topographic data. Subsequent investigation of the early MOLA gridded data demonstrated a large population of QCDs in the Northern Lowlands of Mars [2], which suggested those Lowlands were ancient and not recent despite the low density of craters exposed at the surface.

Figure 1 shows a classic example of QCDs that are not visible in image data but very obvious in MOLA topography.

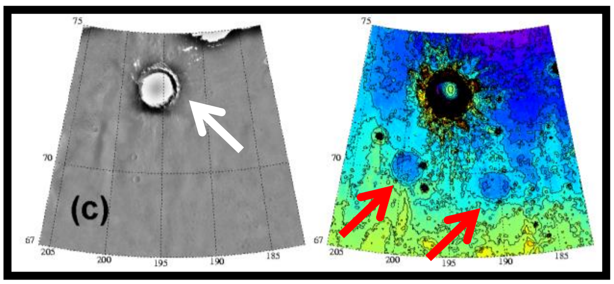

Figure 1. Image data (left) and stretched MOLA topographic data (right) for an area in the northern lowlands of Mars near the 80 km wide crater Korolev (white arrow). Low elevations shown in blues. Note the two closed circular depressions visible in the MOLA data south of Korolev (red arrows) that are not visible in the image data. From [2].

Recognizing that Mars had many ways to hide impact craters even to the point that no relic topographic expression might remain, we explored the use of model crustal thickness data [3] to reveal more deeply buried impact features. We identified numerous Circular Thin Areas (CTAs), many of which also corresponded to QCDs [4] and used these to determine the N(300) crater retention ages of the Lowlands, Highlands and Tharsis areas of Mars. The cumulative frequency curves for the Lowlands and Highlands are virtually indistinguishable, but Tharsis appears to be younger [4].

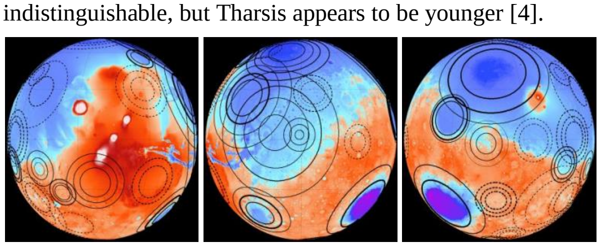

Figure 2. Distribution of 31 candidate basins on Mars >1000 km superimposed on MOLA topography. Reds = high, blues = low elevations for hemispheres centered at 120W (left), 0W (middle) and 240 W (right). From [7] and [9].

Topography and crustal thickness data were also used to search for previously unknown very large impact basins on Mars. Early results suggested 20 candidates > 1000 km across [5] but later study using more recent crustal thickness models [6] pushed this up to ~30 [7], as shown in Figure 2 above. These include a very large Utopia-sized feature in the ancient cratered terrain of Mars. Early CRAs on these basins indicted they mostly formed in a relatively brief period of time [5,8], a result that more recent work has confirmed [9].

Lunar Basins. We applied the same kind of approach to the Moon [10], using early Clemintine lunar topographic [11] and crustal thickness data [12], finding a large number of candidate impact basins > 300 km diameter beyond those generally recognized from photogeology [13]. More recent and much higher quality and resolution topographic data from LOLA demonstrated that some 25% of these candidates were not likely [14], but also provided evidence for additional candidates whose subdued nature could never have been revealed by the Clementine data [15]. Figure 3 shows an example of how clustered small craters could explain the low resolution QCD previously seen in ULCN data. Likewise, improved crustal thickness models [16] showed more CTAs than previously found, and, with the most recent GRAIL data [17], this inventory has been improved even further.

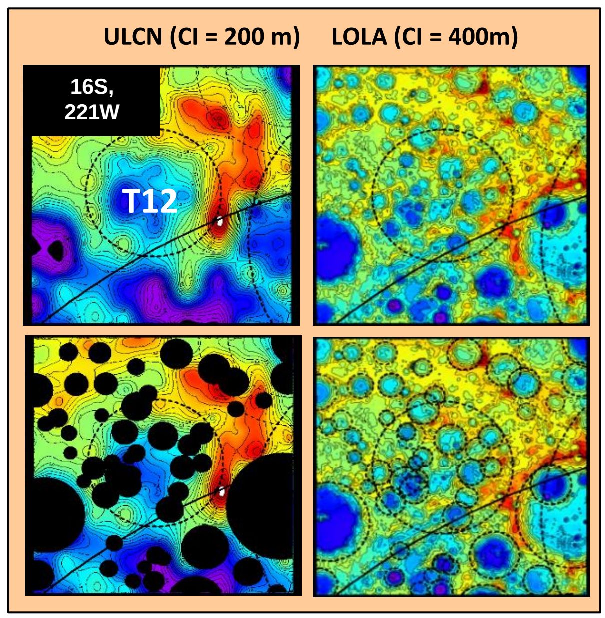

Figure 3. LOLA data (right) show that what looked like a single large QCD (T12 above left) in Clementine-era ULCN data (left panels) [10] can be explained as clusters of smaller craters as revealed in LRO/LOLA data (right panels). Lower panels show craters >~35 km mapped from LOLA data. Lower left superimposes these on the ULCN data. Note differences in countour intervals.From [15].

That QCDs and CTAs are likely expressions of not-always-visible impact craters and basins is supported by the fact that visible craters and basins generally do have such signatures. That does not mean that all QCDs or CTAs really are impact features. We prefer to consider QCDs and CTAs as candidate craters or basins except where image data makes that distinction unnecessary. And because these signatures can vary greatly in their strength character, we have developed a rating scheme for them.

Rating Candidate Basins. Candidate basins are scored or rated on the strength of their topographic (QCD) and crustal thickness (CTA) signatures. This provides a relative measure of the confidence placed in the identification of the candidate basin. The criteria used are the circularity of the signature and the contrast of the central topography or crustal thickness compared with the surrounding area. Figure 4 shows Topographic Expression (TE) and Crustal Thickness Expression (CTE) scores for an area on the far side of the Moon near Freundlich-Sharanov and Korolev [18], and explains the rating system.

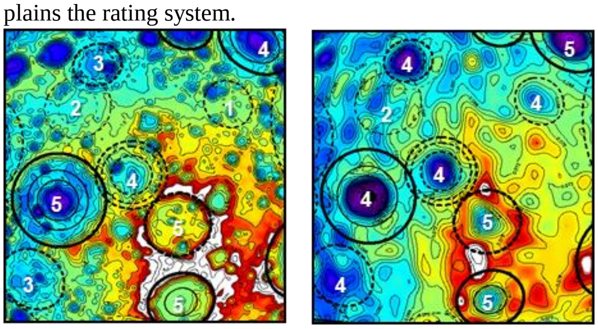

Figure 4. Smoothed LOLA topography (Left, CI = 300 m) and model crustal thickness (Right, CI = 3 km) for an area on the lunar farside. Blue colors are areas of low elevations or thin crust, reds are higher elevations or thicker crust. Numbers are Topographic Expression (TE) Scores (Left) or Crustal Thickness Expression (CTE) Scores (Right), both on a scale of 0-5. These are added together to give a single Summary Score (SS) with a range of 0-10. Note that a candidate basin can have a very low TE score (1 in the example in the upper right) but a high CTE score (4). Figure from [18].

Figure 5 shows N(50) Crater Retention Ages for inventories with different Summary Scores (SS) [18]. The original inventory started with 90 candidates. Those with SS< 3 were eliminated immediately. Subsets of this “Full Inventory” can then be selected based on Summary Score. If the full SS>3 are taken, the inventory has 73 candidates. If a more restrictive case of SS>5 is used, the inventory is reduced to 43.

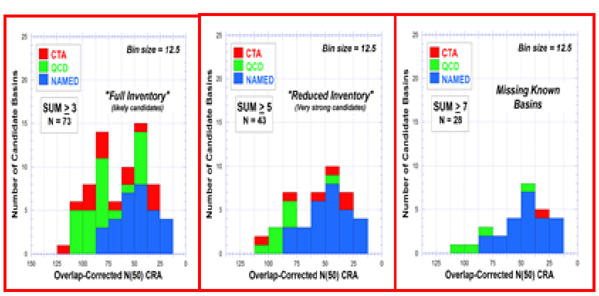

Figure 5. Distribution of N(50) CRAs for inventories with progressively higher cutoffs in Summary Scores. Colors indicate how candidates were first identified. Going to a very highe SS cutoff removes known basins. The “Full Inventory” of SS>3 may have some weak candidates. From [19].

Problems and Promises of Finding the Buried Population. There are complications in using QCDs and CTAs to identify candidate buried craters and basins. While topographic data for both Mars and the Moon is adequate to identify QCDs even smaller than those we have generally studied, burial (especially on Mars) can be thorough enough that no relict topographic signature is preserved for craters below some limiting size. This actually produces useful information on the burial, as discussed below. In regions of very high crater density, overlap may make recognition of QCDs even more difficult in topographic data than in image data.

Gravity data for Mars limits the ability to use CTA signatures to those > ~250-300 km [9]. Recent GRAIL data makes this much less a problem for lunar crustal thickness models. For lower resolution CTAs, the principle difficulty is knowing where to draw the diameter of the candidate if that lacks supporting topographic information.

Recovering the buried population of impact craters has several important advantages. The most obvious is that, by counting these as well as visible craters, it is possible to obtain a more reliable crater retention age for the crust as opposed to just the surface, important in areas of significant resurfacing. Second, the size distribution of buried craters provides information on the burial: the smallest buried crater sets a limit on the minimum thickness of material required to completely obscure even smaller craters in topographic data. This can be used, for example, to identify variations in sediment thickness, as we recently did for the Chryse Basin [20].

Conclusion: Topographic and crustal thickness data provide evidence for buried impact craters and basins on Mars and the Moon that cannot be easily “seen” in image data. These buried features provide important information on the likely true age of the crust (as opposed to just the surface) and the nature and history of resurfacing.

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