PREVIOUSLY UNRECOGNIZED LARGE LUNAR IMPACT BASINS REVEALED BY TOPOGRAPHIC DATA H. V.

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Summary: Lunar topographic data reveal a significant population of large impact basins not previously recognized by standard photogeologic mapping. We find at least 92 impact basins $\geq$ 300 km diameter, compared with 45 previously cataloged. This has implications for the Late Heavy Bombardment on the Moon and use of the Moon as a standard for crater retention ages throughout the solar system.

Introduction: The discovery of a large population of apparently buried impact craters on Mars, revealed as Quasi-Circular Depressions (QCDs) in Mars Orbiting Laser Altimeter (MOLA) data [1,2,3] and as Circular Thin Areas (CTAs) [4] in crustal thickness model data [5] leads to the obvious question: are there unrecognized impact features on the Moon and other bodies in the solar system? Early analysis of Clementine topography revealed several large impact basins not previously known [6,7], so the answer certainly is "Yes." How large a population of previously undetected impact basins, their size frequency distribution, and how much these added craters and basins will change ideas about the early cratering history and Late Heavy Bombardment on the Moon remains to be determined. Lunar Orbiter Laser Altimeter (LOLA) data [8] will be able to address these issues. As a prelude, we searched the state-of-the-art global topographic grid for the Moon, the Unified Lunar Control Net (ULCN) [9] for evidence of large impact features not previously recognized by photogeologic mapping, as summarized by Wilhelms [10].

Candidate Impact Basins: We searched for circular depressions by stretching colored versions of gridded topography, plotting contours and profiles to reveal detailed structure, and fitting circles to the often subtle features found. This was done using interactive GRIDVIEW software [11] developed for analysis of MOLA data which revealed buried basins on Mars [1,2]. We identified all roughly circular features $\geq$ 300 km diameter, a limit set partially by the global coverage and resolution of the ULCN and partly by the compilation of Wilhelms [10]. We then compared our candidate basins with Wilhelms' list.

Most of the basins suggested by Wilhelms have prominent topographic structure in good agreement with the basin rings derived from photogeology. There are important exceptions. Most notable is the lack of a topographic depression associated with the suggested Tranquilitatis basin [10]. Tranquilitatis is a local topographic high. We also found cases where topography strongly suggests the presence of a basin but the Wilhelms center is offset and/or the diameter is significantly different from that suggested by topography. More interesting, there appear to be a large number of basins that were not identified by photogeology. Figure 1 shows several examples. In the vicinity of the Wilhelms-identified Freundlich-Sharonov (F-S) and Korolev (K) basins on the lunar farside are a number of well-defined circular depressions with strong basin-like character. Though the total relief of these basins is not as great as that of Korolev, the circular nature is just as obvious, and multi-ring structure like that of Korolev may be present in the topography. Note we suggest

multi-ring structure for Freundlich-Sharonov in contrast to the single ring suggested by Wilhelms (1987).
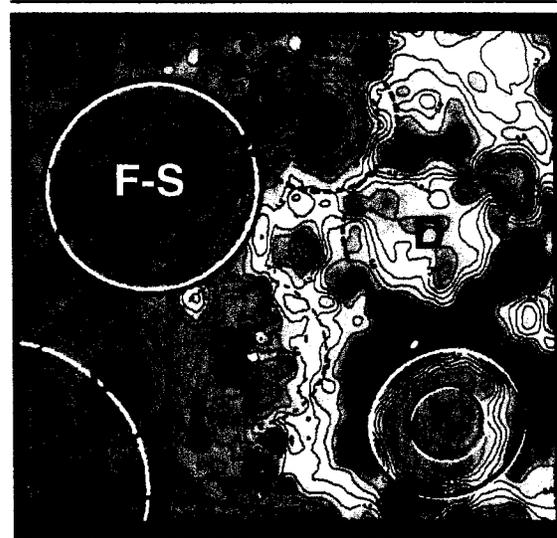

Figure 1. Portion of the lunar farside at 10N, 172W. Color is stretched ULCN topography. Contour interval 400 m. Basins identified by Wilhelms [10] shown as white circles: K=Korolev (440 km) and F-S = Freundlich-Sharonov (600 km). These have strong expression in the topography (solid black circles). The diameter suggested by the topography is in good agreement with Wilhelms" diameters, though F-S may have more rings than he suggested. Basins $\geq$ 300 km diameter not recognized by Wilhelms but suggested by topography (dashed black circles) include several Korolev-size features (at D) and a less obvious feature at P.

We find at least 92 circular topographic lows in the ULCN topography $\geq$ 300 km in diameter, compared with 45 basins listed by Wilhelms. Topography supports the center and main ring diameter of many of Wilhelms' basins, but ten (10) on his list have no basin-like topographic character, and ten (10) others have a different diameter or center. Figure 2 shows direct comparison of basins determined by us from ULCN topography with those listed by Wilhelms [10].

Spudis et al. [6] identified several candidate new basins from the Clementine altimetry alone. Some of these were also described by Zuber et al. [7.] Spudis and co-workers (unpublished data) also searched the ULCN topography and found "lots of new basins, especially on the farside" (Spudis, private communication), as well as some differences in both diameters and ring assignments as well. There seems little doubt that a population of previously unrecognized, at least large, lunar basins does indeed exist.

Figure 3 shows cumulative frequency curves for basins $\geq$ 300 km diameter from the Wilhelms [10] inventory and the population suggested by our examination of the ULCN. Wilhelm's largest basin is his "probable or possible" Procellarum, but the topography does not support such a feature, as
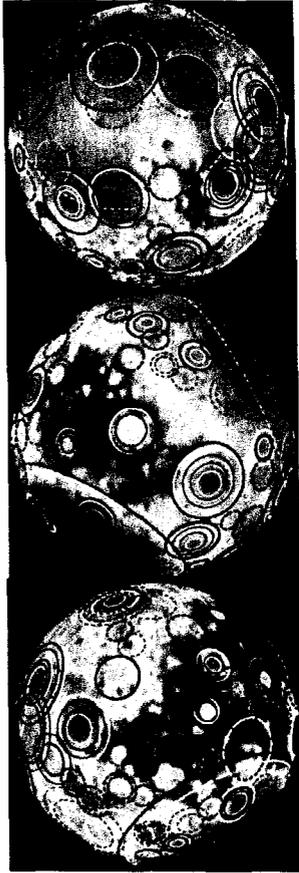
Figure 2. Equatorial views of the ULCN topography at three longitudes (0, 120 and 240W). Blues = lows, reds = highs. Wilhelms' basins ≥ 300 km shown as white circles. His "Probable or possible basins" shown as thinner white lines. Black circles show our mapping of Wilhelms' basins derived from ULCN topography, which sometimes suggests different ring assignments and reveals the existence of many basins not previously recognized by photogeologic mapping (dashed black circles). We find at least 92 large basins compared with the 45 listed in [10].
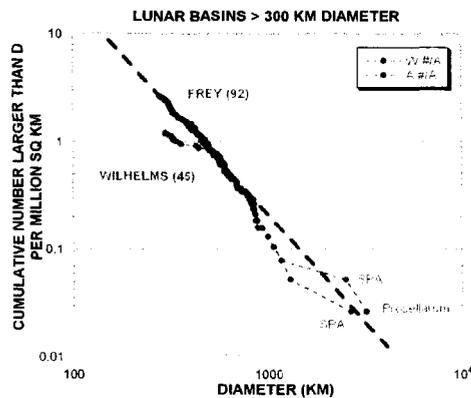

Figure 3. Cumulative frequency curves for impact basins ≥ 300 km diameter from Wilhelms [9] based on traditional photogeologic mapping (red) and our mapping based on the ULCN topography (blue). The curves are very similar from 1200 km down to about 500 km diameter, but at smaller diameters Wilhelm's inventory has far fewer features than we find in the topography. Dashed line is a -2 power law.

others have also found [6,7; Spudis 2007, private communication]. Our diameter for SPA (South Pole-Aitken) is slightly larger than given by Wilhelms. Over the diameter range 1200

down to about 500 km the two curves are virtually identical, though we see no evidence for Wilhelm's Australe and our diameter for Keeler-Heaviside is significantly smaller than given by Wilhelm's. Both curves closely follow a -2 power law (dashed line) from 800 to 500 km. For D < 500 km, the topographically-derived basins still follow the -2 power law trend, but Wilhelms' basins fall off rapidly. Photogeologic mapping apparently misses many of the smaller features, perhaps because of poor pre-Clementine lighting and/or burial by ejecta. Note that although the Mendel-Rydberg basin, first reported by Hartmann and Kuiper (1962), can be seen despite being blanketed by Orientale ejecta, it is even more prominent in topographic data [6, 7; this work].

Discussion: The total population of large impact basins on the Moon appears to be significantly greater than the previously recognized "visible" (photogeologically-determined) population. The rapid fall-off of Wilhelms' lunar basins at D<500 km suggests observational problems; non-uniform and generally poor lighting conditions for available pre-Clementine imagery is a likely cause (Spudis, 2007, private communication). The total population of large basins may be even larger than suggested here based on the ULCN, as its limited resolution means it cannot reveal very low relief (< few hundred meters) features. If significant differences between image-based and topography-derived crater counts also exist at much smaller diameters (if there is a substantial population of previously unrecognized small impact craters and basins on the Moon) then the current crater frequency estimates [12] are too low and the early lunar impact rate was likely (much?) higher than previously thought. This has important implications for using the Moon as a basis for estimating impact rates on other planets, and also on the lunar history – including the Late Heavy Bombardment.

Conclusions: A large number of large basins not previously recognized by photogeologic mapping exist on the Moon, which are revealed by the current relatively low resolution gridded lunar topographic data. Previously unrecognized craters of much smaller diameter will likely be revealed by high quality altimetry from LOLA. A more complete inventory of the actual cratering record on the Moon should then be possible, which will have important implications not only for the history of the Moon, but for using the Moon as a standard for crater retention ages on other planets.

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