The Minimum Confidential Diameter For Crater Counts. Yichen Wang[1] and Zhiyong Xiao[1, 2], [1]Planetary Science Institute, China University of Geosciences (Wuhan)(ycwang@cug.edu.cn; zyxiao@cug.edu.cn); [2] Space Science Institute, Macau University of Science and Technology.

Introduction: Statistic of impact craters is the major tool used in dating planetary surfaces [1]. Imagery data are normally used in collecting craters, so that the pixel resolution of images affects the diameter range larger than which craters can be confidentially recognized and completely collected. The minimum confidential diameter for crater statistics (D_{min}) is crucial since craters with rim-to-rim diameter (D) less than D_{min} do not represent the entire observable crater population. This issue is especially important now, since more and more sub-meter-scale high-resolution images have recently been acquired for the Moon, Mars and other bodies, so that craters less than ~100 m in diameters are frequently used to estimate model ages for small and young geological units. Without in-situ samples, such applications are perhaps the only method to study the temporal relation of recent and small scale geologic events, e.g., the duration of lunar endogenic activity [2,3,4]. To ensure better statistics, craters with diameters that equal only several pixels are included [5]. However, D_{min} sets limits for the completeness of the crater population collected, rendering the derived ages questionable. Previous studies have used personal-chosen D_{min} in crater counts, e.g., 3, 5, or 10 pixels [e.g., 6]. So far, there is no standard for defining D_{min}.

Here we set up a standard for defining D_{min} of crater counts that are based on optical images [7]. We are approaching this goal using two methods: (1) using crater rim-to-rim diameters derived from digital terrain models (i.e., DTM) as benchmarks to compare the observed crater size-frequency distribution (i.e., SFD) based on images that have different pixel resolutions; (2) study the observable crater SFD on a same geological unit using the same image but with different down-sampled pixel scales.

Method and data: We selected a series of different counting areas that have stratigraphic ages ranging from the oldest to the youngest on the Moon for this study. Monochrome images obtained by the Kaguya Terrain Camera (TC; ~7 m/pixel) [8], the Lunar Reconnaissance Orbiter Camera Narrow Angle Camera (LROC NAC; 0.5–2 m/pixel) and Wide Angle Camera (LROC WAC; 100 m/pixel) [9] are used to compare crater SFD at different diameter ranges. DTM constructed from LROC NAC stereo pairs are used to derive the actual rim-to-rim diameters.

For each of the geological units selected, craters on the same counting area are repeatedly collected using exactly the same dataset that has been down-sampled to different pixel scales. Craters larger than 3 pixels were exhaustedly searched using CraterTools [10] during the counts. The counts were performed by the same individual so that the recognition criteria of crater counts were not biased for different counting areas or datasets. The SFD for the crater counts are compared using a Gaussian kernel density estimator and the error bars with bootstrap process [11]. For each of the counting area, the density ratio of the crater SFDs is derived, and the maximum density ratio (i.e., $\Delta\rho_{max}$) is evaluated. D_{min} is selected as the diameter at which the density ratio equals 1 within error bars, i.e., for a given counting area, crater counts based on different pixel-scales are identical with each other at $D \geq D_{min}$. Notably, to avoid the other possible difficulties raised from the quality of datasets or counting areas, we used images with solar incidence angle of 60°–70° and select counting areas following the standard routine [12].

Results: We noticed that craters less than ~10 pixels are mostly affected by the pixel resolution of images used in the crater counts (Figure 1).

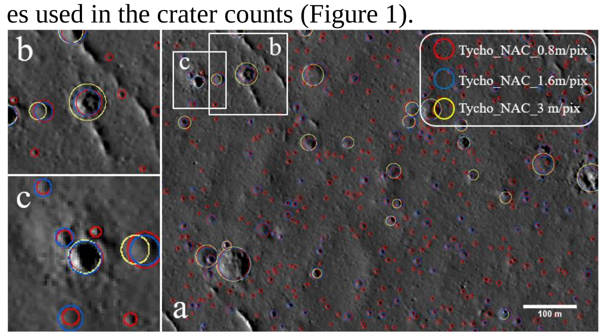

Figure 1. a) Spatial distribution of same crater population but with differential pixel resolutions in Tycho test area. b) Overestimate of crater sizes. c) Incomplete recognition.

The resolution of LROC NAC DTMs is normally ≥4 times that of the NAC images used, i.e., >2 m [13]. They cannot precisely reveal the topography of raised crater rims for D<100 m craters, especially for relatively degraded ones (Figure 2). Therefore, DTM cannot be used to serve as benchmarks of locating the actual crater rims.

This study suggests that for a given crater population, pixel scales of imagery data can cause ≤1.5 times difference in the crater density, and most of the crater density difference is restricted at pixels less than ~10 times, except for the most heavily cratered areas on the Moon. Figure 3 shows three of the cases studied. For the Tycho crater, a crater population formed in the melt pools on the southeastern crater rim is studied using the same NAC image but with different resolutions (0.8 m/pixel versus 1.6 m/pixel and 3 m/pixel). Crater SFD ratio comparison reveals that the two crater SFDs have a maximum density difference of ~1.25 times, and they are unique at *D*>=10 pixels of the down-sampled image. For the counting area at the south of the Rümker Mount, the two SFDs of the same crater population that are collected based on images with 7 m/pixel versus 28 m/pixel exhibits a maximum density difference of ~1.5 times, and they are identical at *D*>~230 m, i.e., ~8.2 times of the down-sampled pixel scale. For one of the most heavily cratered lunar highland, the same population collected based on the same WAC image dataset but with different pixel scales (100 m/pixel versus 300 m/pixel) shows almost no density difference at *D*>3–5 pixels of the down-sampled images.

Discussion and Conclusion: Our systematic study suggests that 10 pixels can be regarded as the reliable confidential diameter for completeness of crater counts, and collecting crater populations at less than 5 pixels could yield less than a decreased density of ~2.5 times. Incomplete recognition and overestimate of crater sizes caused by resolution difference lead to such discrepancy of SFDs (Figure 3).

It appears that crater counts on the lunar highland are less affected by pixel scales of the base images used, since D_{min} is ~5 pixel sizes of the down-sampled image (Figure 3f). The smaller D_{min} on the lunar highland has been verified by three other counting areas. On average, impact craters on the lunar highland are more degraded craters on average compared with those formed on post-3.8 billion years old terrains. It appears that the net effect of incomplete recognition and imprecise measuring is less affected on the highly mottled lunar highland.

Other factors would also cause and increase the difference of SFDs when using different kinds of data. A same crater population in Tycho melt pools exhibits a maximum density difference of ~3 times with NAC and TC data in this study. Similar difference is also found by Xiao and Strom in 2012 [2].

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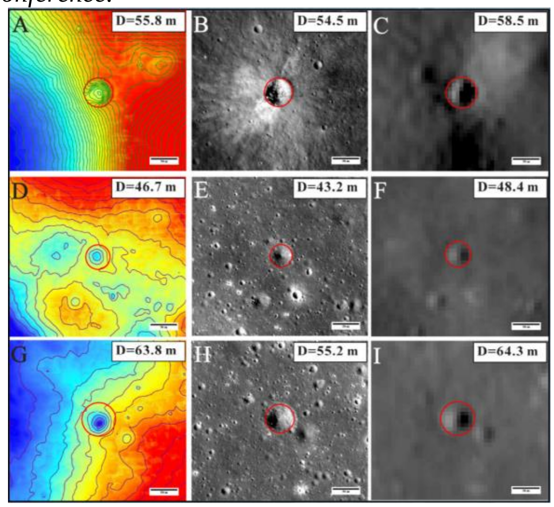

Figure 2. Crater diameter comparison based on LROC NAC DTM, NAC, and TC monochromes.

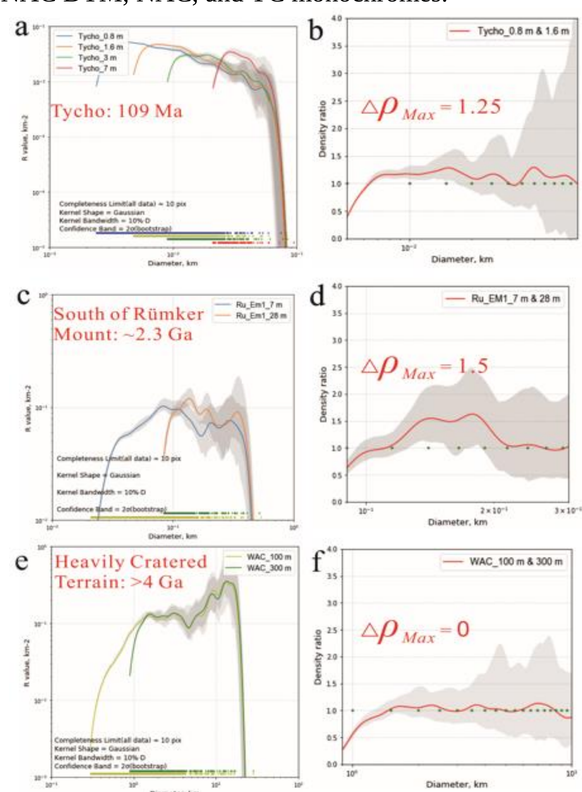

Figure 3. Crater SFDs observed at the Tycho crater, the Rümker Mount and Highland Terrain in NAC, TC and WAC with different resolutions (a,c,e) and the density ratio of corresponding SFDs (b,d,f).