Problem in Crater Counting by Small Craters-----Peeking at the Geologic History of Crater Alphonsus.

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Introduction: Small craters have been used to date small-area surfaces assuming that the craters are dominated by primary impacts. However, the small crater population on the Moon (less than 1km in diameter) are both primary and secondary craters. Distant secondaries produced by high-velocity ejecta fragments are more circular and may be less clustered than the adjacent bigger secondaries, and can therefore be difficult to be distinguished from the primaries [1].

Secondaries cannot be used for age dating because they are not uniformly distributed and they result from primary impacts over a wide range in ages. Therefore, the crater densities can vary appreciably from area to area even though the areas are geologically the same age. However, the popular assumption has been that primaries are most abundant on planetary surfaces in the solar system, and that most small craters originated from independent random impact events appropriate for dating the surfaces [2]. Most researchers assume that secondaries are in the form of clusters and chains that are easily excluded from the crater counts. We have tried to eliminate such craters in our counts.

To test the plausibility of age dating by counting small craters, the small crater population in Alphonsus and the adjacent Mare Nubium was counted on small areas of the same or different geological units using images of different resolutions from the Narrow Angle Camera of Lunar Reconnaissance Orbiter Camera (LROC NAC, 0.5 to 2 m/pix) and the Terrain Camera of Kaguya (Kaguya TC, ~10m/pixel). The counted area's crater densities were compared with each other to determine if the relative ages matched the geology of the region counted. If the resulting crater densities are reliable indicators of relative age then the calculated crater density from the two sets of images should be consistent.

Plotting Method Used: The "Relative" plot method of displaying the crater size/frequency distributions is used throughout this paper. The "Relative" or R plot was devised to better show the size distribution of craters, and crater number densities for determining relative ages [3, 4, 5].

Comparisons of the Crater Counts: The R-Plot of the crater counts from the higher resolution LROC images and the Kaguya images are shown in Fig. 1. The crater size range from LROC images is from 3-30m in diameter while that of Kaguya is from 50 to 1000m in diameter. There are major discrepancies between the relative ages based on the crater counts between the two data sets and those based on geologic relations. In the LROC data, the east crater floor is younger than the west crater floor while the east Dark Halo Craters (DHCs) are older than the west DHCs. In the crater curves plotted from Kaguya, however, the DHCs and the crater floors are almost the same age, which conflicts with the fact that the DHCs are obviously younger than the crater floor.

Despite the discrepancy in geological relations for a same counting area, there are major gaps between the curves plotted from LROC and Kaguya images. The gaps are R-Values between the 30-50m crater size bins. For some geological units, such as the 'Mare Nubium Bright Area' and the crater floor areas, the changes in the slope of the curves from LROC and Kaguya are relatively 'moderate', so it might be possible to regard the curves in LROC as an extending of the curves in Kaguya. However, in some other units, such as the DHCs and central ridge, the curves can not be a direct link-up.

Furthermore, the LROC curves of both the east and west of the crater floor and those of the Mare Nubium units are relatively flat. However, in the other LROC curves such as those of the DHCs and central ridges, the slopes are about p=-4. In contrast, the Kaguya curves of the Mare Nubium units seem to have slopes smaller than differential -2 while the others have slopes near -3.

Secondaries on planetary surfaces typically have a differential -4 slope because curves tend to turn up at smaller size bins [4]. As suggested by former research [1, 5, and 6], craters less than 1km on lunar surface can be dominated by secondaries. However, only several curves plotted from both the LROC and Kaguya images have obvious characteristic of secondaries.

Possible Reasons for Problems in Counting Small Craters: Alphonsus is an old crater which must have been influenced by the bombardment of numerous secondaries from later large impacts since its formation. Even though we have tried to eliminate obvious secondaries in clusters and chains, secondaries in the counting areas are almost certainly abundant, especially degraded secondaries. It is probable that the crater counts in our areas are contaminated with numerous secondaries. If the secondaries are evenly distributed across the counted areas then two data sets should be consistent but they are not.

We conclude that the reason for the discrepancies between the R-Plot results is due to density differences of secondaries in the counted areas. We conclude that:

1. The densities of secondaries on different geologic units are not the same. As shown by the slopes of the curves (Fig. 1), some of them are obviously dominated by secondaries, while others are mixtures of secondaries and primaries.

2. For one geologic region of equal age, as shown by the gaps between the curves of a same area, the percentage of secondaries in the counted craters from LROC and Kaguya is not the same.

References: [1] McEwen A. S. and Bierhaus E. B., (2006), *Annu. Rev. Earth Planet. Sci.*, 34:535–67. [2] Neukum G, B. A. Ivanov, W. K. Hartmann, (2001), *Space Sci. Rev.*, 96, 55–86. [3] Crater Analysis Techniques Working Group (1979), *Icarus*, 37, 467-474. [4] Strom R.G., Renu Malhotra, Takashi Ito, et al.(2005), **Science**, 309, 1847-1850. [5] Strom R.G., Chapman C. R., Merline., et al., (2008), *Science*, 321, 79-81. [6] Bierhaus E. B., Chapman C. R. and Merline W. J., (2005), (Nature), 437, 1125-1127.

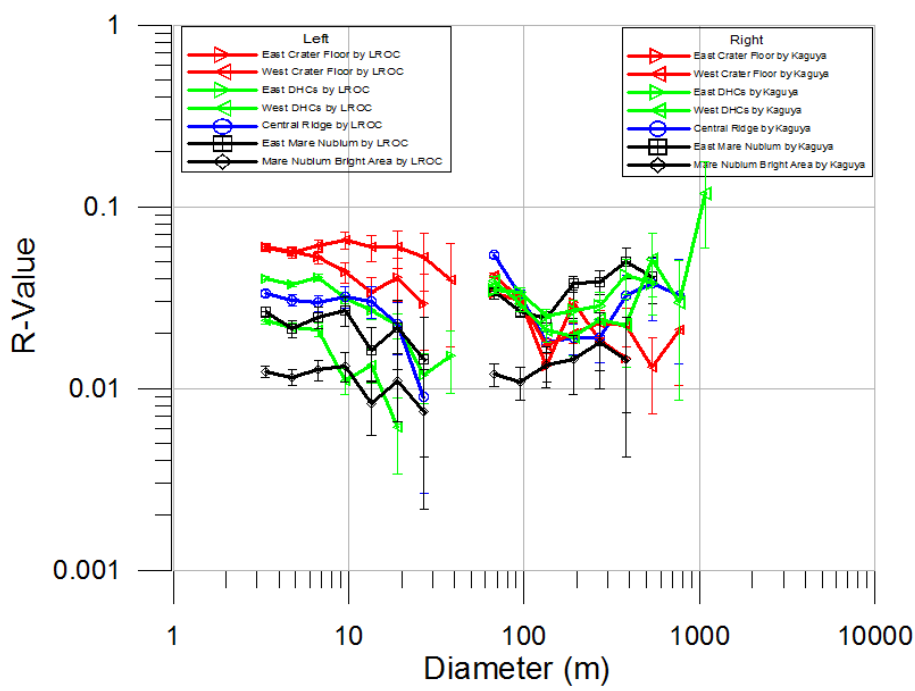

Fig. 1 Contrast of the R-Plot results for several geologic units in the area of Alphonsus by the LROC and Kaguya images. Curves at smaller diameter range are the results from LROC while the curves at right side are those from Kaguya TC.