EFFECTS OF INCIDENCE ANGLE ON CRATER COUNTING OBSERVATIONS. L. R. Ostrach[1], M. S. Robinson[1], B. W. Denevi[2], P. C. Thomas[3], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, [2]Applied Physics Laboratory, Johns Hopkins, Laurel, MD, [3]Center for Radiophysics and Space Research, Cornell University, Ithaca, NY. Contact: lostrach@asu.edu.

Introduction: Determining the equilibrium crater diameter for a crater population is important for accurately estimating regolith depth as the equilibrium diameter represents the steady-state between the formation of new craters and the removal of older craters [1]. The Lunar Reconnaissance Orbiter Camera Narrow Angle Camera (LROC NAC), in addition to scanned Apollo Metric images, provides a rich dataset at high-resolution to examine the effects of incidence angle on digitizing craters. A key issue to address is whether the small crater slope and rollover observed in Wilcox et al. [2] are representative of the equilibrium crater population or whether these observations are due to resolution limits of the images, insufficient count area, or shadow effects (e.g., loss of small craters in the shadows of larger craters).

Background: Wilcox et al. [2] hypothesized that the number of craters identified in an image is dependent on incidence angle, an idea first proposed by Young [3]. Using scanned Lunar Orbiter and Apollo Metric images, Wilcox et al. [2] showed that for three different young mare regions, fewer craters were visible at lower incidence angles (measured from the surface normal) and proposed that illumination influences equilibrium diameter estimates. Oberbeck [4] disputed this hypothesis as well as the presence of an equilibrium crater population in the data from Wilcox et al. [2], suggesting that a sharp kink, versus a gradual rollover, in the cumulative histogram is necessary to define the equilibrium crater population.

Method: Testing the hypothesis that incidence angle affects crater counts [2], we chose four Apollo Metric images of the same area with different incidence angles to examine the effects of resolution on apparent equilibrium diameter. We selected a 100 km^2 area centered at 27.3°N, 18.2°W in Mare Imbrium east of Lambert crater (**Fig. 1**) with images acquired at 87°, 82°, 71°, and 50° incidence angles. There are no obvious secondary crater chains in the count area. We resampled the images to 10 m/pixel and employed three individuals to count craters. We disregard craters that are less than 5 pixels in diameter. Thus, the lower limit for identifying craters in these images is 50 m.

To test if the observed rollover in the cumulative histograms is due to resolution effects or to the observation of the equilibrium crater population, we used higher resolution LROC NAC images taken over a range of incidence angles. For our first comparison we chose a subscene of a commissioning phase NAC image (56° incidence) covering a section of the Metric count area. We resampled the NAC frame to 2 m/pixel and chose a 4 km^2 area. This method focused on the small crater population visible at the NAC scale.

Results: *Apollo Metric images:* At the largest diameters (greater than 200 – 300 m), the cumulative histograms at each illumination are similar; all have a production function slope at or near -4.1 and the different observers counted the same, or very similar, cumulative numbers of craters in each diameter bin. Results from Apollo Metric crater counts for the 82° incidence angle image are the most consistent between different observers and we find a production function slope of -4.1 and an apparent equilibrium diameter of 200 m. However, the small crater trends (less than 150 m diameter) vary significantly among observations at different illuminations. The small crater function slopes are not consistent between different illuminations and the variation between cumulative crater counts in different diameter bins is quite large (**Table 1**). Furthermore, the estimated apparent equilibrium diameters may shift toward larger diameters at lower incidence angles; for the 87° incidence image, the equilibrium diameter is estimated to be ~150 m whereas the apparent equilibrium diameter is 256 m in the 50° incidence image. This observation, however, is opposite to the findings of Wilcox et al. [2], where equilibrium diameter estimates increased with increasing incidence likely resulting from an increase in visible craters, and thus requires additional study (e.g., revising estimation methods, considering a larger count area, using higher resolution data). The cumulative histograms for the four Apollo Metric frames exhibit the effects of different incidence angles on reliably counting craters.

LROC NAC: The deviation observed between counts at the small crater diameters in the Apollo Metric images provide an opportunity to use the LROC NAC images to more accurately count the smallest population of craters visible in the metric images. The resolution of the resampled NAC subscene allowed us to count craters 10 m in diameter or larger. Similar to the Metric AS15-M-2461 (50° incidence), the freshest and biggest craters are the most visible in the NAC image (56° incidence). Thus far, the 50 - 140 m diameter bins in the cumulative histograms of the NAC count overlap the Metric counts and provide a means of comparison at these diameters (**Table 1, Fig. 2**). The NAC counts presently do not agree well with the Metrics. These counts should lie between the 50° and 71° Metric counts, but there is a large difference at the 100 m scale that requires further study. The NAC subscene (4 km^2) may be too small to adequately assess the small crater population and/or quantitatively compare these data to the Metric counts (100 km^2).

Discussion and Conclusions: Our work thus far is consistent with the hypothesis from Wilcox et al. [2], that illumination angle affects reliable identification of craters on a mare surface. In the Apollo Metric images, we attribute some of the deviation of the crater trends to the effects of incidence angle on crater detection. At crater diameters greater than ~300 m, we find similar production functions, an observation consistent with our identification of these large craters in all four illuminations. However, the small crater trends vary significantly among observations at different illuminations. Although we have a single count for a small area from the LROC NAC image, this count extends to crater sizes of 10 m in diameter, allowing observations of what may be the small crater equilibrium population. Several of the larger diameter bins in the NAC counts overlap the smaller diameter bins in the Apollo Metric counts. These results suggest that we may be observing the small crater population, but additional examination of NAC images at different incidences is necessary.

Future Work: Examination of a region of repeat LROC NAC coverage at different incidence angles (e.g., Apollo landing sites or Constellation Regions of Interest) is necessary to conclusively determine whether the rollover observed by Wilcox et al. [2] and in our Apollo Metric counts represents the small crater equilibrium. Furthermore, we will attempt to characterize the subtle differences in crater distribution related to illumination at larger diameters (>500 m to several km diameter), by identifying several regions of different sizes in central Mare Serenitatis for crater counting.

References: [1] L. A. Soderblom (1970) *JGR*, 75, 2655. [2] B. B. Wilcox et al. (2005) *Meteoritics & Plan. Sci.*, 40, 695. [3] R. A. Young (1975) *Proc. Lunar Sci. Conf. 6th*, 2645. [4] V. R. Oberbeck (2008) *Meteoritics & Plan. Sci.*, 43, 815.

Table 1: Cumulative distribution comparison at the small crater diameters between four Apollo Metrics (100 km^2 area) and one NAC (4 km^2 area).

D (km)	1010 (87°i)	1152 (82°i)	1835 (71°i)	2461 (50°i)	NAC (56°i)
0.05	69.10 ± 0.831	53.72 ± 0.733	28.95 ± 0.538	8.09 ± 0.284	12.00 ± 1.732
0.06	47.90 ± 0.692	40.79 ± 0.639	24.81 ± 0.498	7.69 ± 0.277	8.00 ± 1.414
0.07	35.00 ± 0.592	29.93 ± 0.547	19.29 ± 0.439	6.82 ± 0.261	4.75 ± 1.090
0.08	25.80 ± 0.508	22.42 ± 0.474	15.22 ± 0.390	5.71 ± 0.239	3.75 ± 0.968
0.09	19.50 ± 0.442	17.39 ± 0.417	12.24 ± 0.350	4.91 ± 0.222	3.50 ± 0.935
0.1	14.70 ± 0.383	14.00 ± 0.374	10.01 ± 0.316	4.42 ± 0.210	2.75 ± 0.829

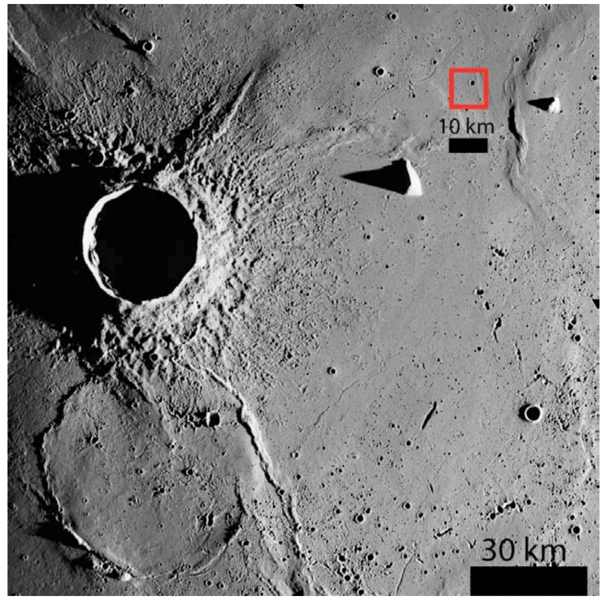

Fig. 1: Red box (27.3°N, 18.2°W) is the count region for the Metrics. NAC subscene (4 km^2) is within the box. Metric image AS15-M-1010, 87° incidence, Lambert crater to left (30 km diameter) north is up, illumination from the right [NASA/JSC/ASU].

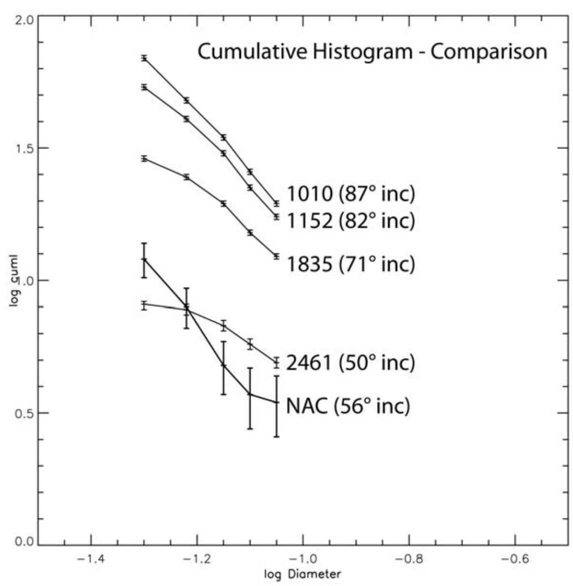

Fig. 2: Compartive cumulative histograms for Apollo Metrics and NAC subscene, derived from Table 1. Craters with <50 m diameter are disregarded due to the resolution threshold. The plotted bins overlap between the Metric and NAC datasets, providing a means of comparison between counts at these diameters. The NAC count does not follow the Metric count trends, which may reflect a too-small count area.