EFFECTS OF INCIDENCE ANGLE ON CRATER COUNTING. 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 because 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) and Wide Angle Camera (WAC) images, in conjunction with Apollo Metric images, provide a rich dataset at high-resolution to examine the effects of incidence angle on crater measurements. A key issue to address is whether the small crater slope and rollover in cumulative frequency 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, and more craters would be detected at higher incidence [3,4]. 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 [5] 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. Furthermore, studying the effects of resolution on consistent identification of craters at different incidence, and at the same geographic location, is now possible at several scales using the LROC NAC and WAC images.

Method: Expanding previous work [specifically 2,6], we digitized craters in Mare Serenitatis in LROC WAC monochrome mosaics at 100 m/pixel. We created mosaics of images obtained at 66° incidence (66°i) and 46°i for our study. We then selected an area surrounding the Apollo 11 landing site in LROC NAC images where there was overlapping coverage and resampled the images to 0.70 m/pixel. The Apollo 11 landing site in Mare Tranquillitatis had the most repeat coverage at different illuminations of the Apollo and Luna landing mare sites. NAC images of the Apollo 11 landing site have incidence angles of 82°i (M116161085R) and 64°i (M150368601R). The high incidence of the 82°i image creates substantial shadows in the largest craters; we identified these regions of shadow and removed them from the count area to better represent the crater density of the visible surface. Obvious secondary craters were excluded from the measurements. We disregard craters that are less than 5 pixels in diameter; thus, the lower limit for identifying craters is 500 m in WAC images and 3.5 m in NAC images.

Results and Discussion: *LROC WAC:* We initially selected three 400 km^2 areas at 66°i to characterize craters at diameters >500 m to several km. Cumulative crater frequencies for these measurements largely deviate from one another, representing the differences in crater density and sizes for these three areas. To obtain better statistics, we expanded the measurement area to 40,000 km^2. For craters ≤2 km in diameter, the 66°i measurements are always greater than those at 46°i. This result is consistent with the observation that more craters are identified and recorded with larger diameters at higher incidence angles.

LROC NAC: We selected a 2.09 km^2 area centered on the Apollo 11 lunar module descent stage (0.67°N, 23.47°E). Consistent with previous work [2,6] and the WAC statistics, more craters are identified with larger diameters at higher incidence. NAC images provide the means to observe the production functions and apparent equilibrium populations. We estimate apparent crater equilibrium diameter, D_{eq}, as ~200 m at 82°i and ~170 m at 64°i, a trend similar to the findings in Wilcox et al. [2]. Model ages were derived from the production population for both incidences, using the CraterStats software [7]. The 82°i model age of 3.61 Ga for this region is consistent with published crater counts [8] and Apollo 11 rock samples [reported in 8]. However, the 64°i model age of 3.48 Ga is anomalously young, which reflects the smaller diameters digitized and is consistent with Wilcox et al. [2].

Conclusions: Crater measurments at several resolution scales show that incidence angle affects consistent identification of craters and will affect the small crater population counts and crater equilibrium diameter estimate for a count area. Lower incidence images provide anomalously young model ages for a region because at lower incidence, fewer craters are identified. The craters measured in lower incidence images have smaller measured diameters than those measured at higher incidence. This trend is consistent between different study areas, different resolutions, and amongst different individuals, and is also consistent with Wilcox et al. [2]. Furthermore, the NAC crater measurements show the small crater population (<300 m diameter) and may be used to estimate equilibrium crater diameter. LROC WAC images may be used to characterize subtle differences in crater distribution resulting from illumination at larger diameters (>500 m to several km).

Future Work: Future work will examine the Apollo 11 landing site over a broader range of incidence angles to further characterize the small crater population. Additional regions in Mare Serenitatis will be identified over a broader range of incidence angles at WAC scale to continue studying the affects of illumination on crater distribution at larger diameters. Furthermore, examining small crater populations at the meter scale is highly relevant to impact melt studies. Accurate crater counts, with well-defined errors, will extend the lunar chronology function to these young cratered surfaces.

References: [1] L.A. Soderblom (1970) *JGR*, 75, 2655. [2] B.B. Wilcox et al. (2005) *MAPS*, 40, 695. [3] L.A. Soderblom (1972) *NASA Special Paper #289,* 25-87. [4] R.A. Young (1975) *Proc. Lunar Sci. Conf. 6th*, 2645. [5] V.R. Oberbeck (2008) *MAPS*, 43, 815. [6] L.R. Ostrach et al. (2011) *LPSC 42nd*, abst. 1202. [7] G.G. Michael and G. Neukum (2010) *EPSL*, 294, 223. [8] H. Hiesinger et al. (2000) *JGR*, 105(E12), 29239.

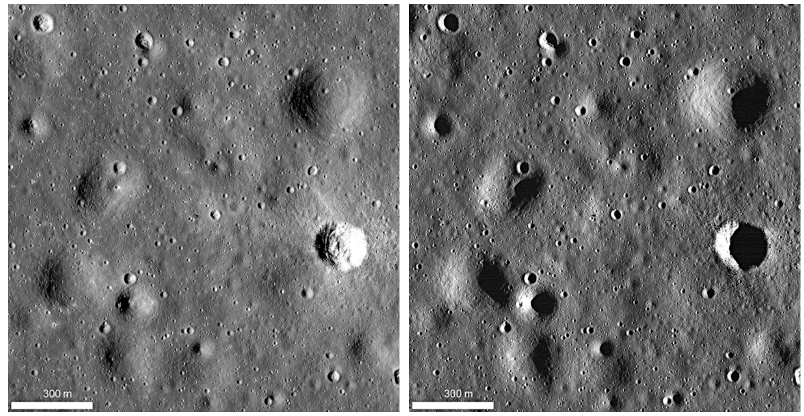

Figure 1: The Apollo 11 landing site; lunar module descent stage is approximately centered. All LROC NAC images of the landing site we chose were slewed, which affects the coregistration. To lessen these misalignments between images, we tied the location of the descent stage in the 64°i image to that in the 82°i image, using the 82°i image as a control because it has the smaller slew. Images M150368601R (64°i, azimuth west; left) and M116161085R (82°i, azimuth east; right) were resampled to 0.70 m/pixel [NASA/GSFC/ASU].

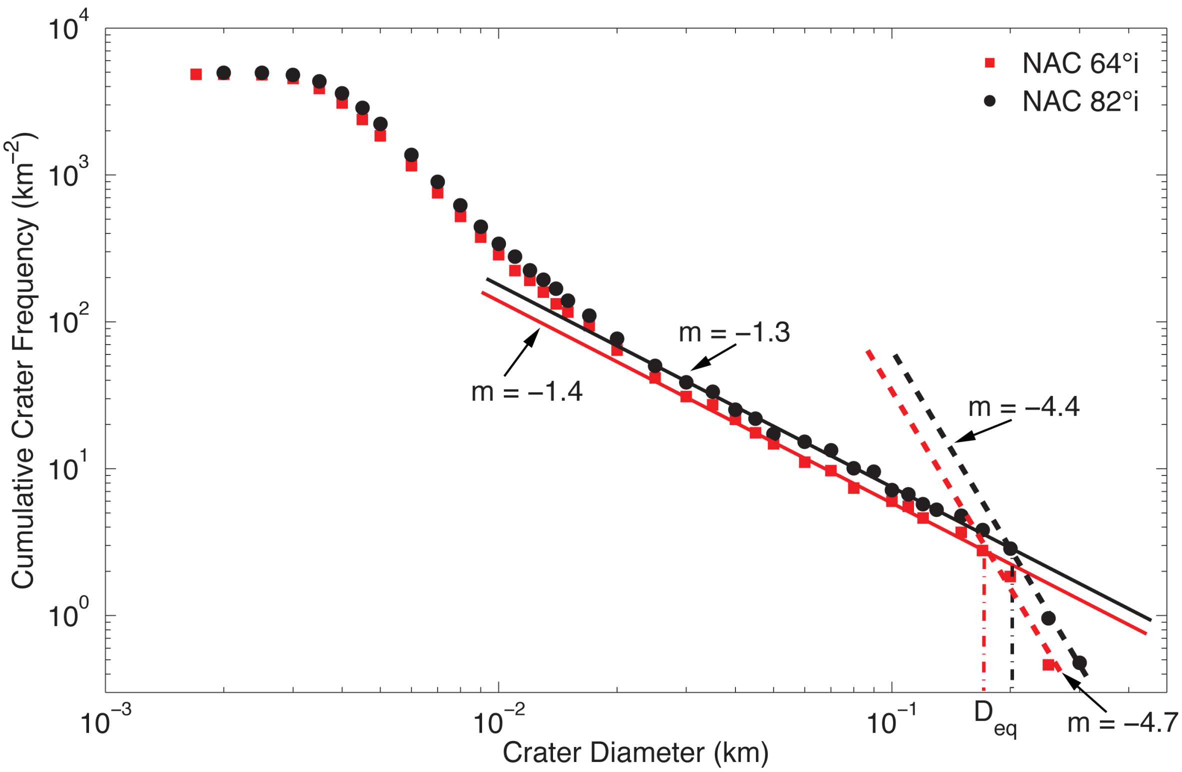

Figure 2: Cumulative crater frequencies for 82°i and 64°i NAC images of the Apollo 11 landing site. More craters are identified with larger diameters at higher incidence. We estimate apparent crater equilibrium diameter, D_{eq}, as ~200 m at 82°i and ~170 m at 64°i, a trend similar to the findings in Wilcox *et al.* [2].