TOPOGRAPHY OF 20-KM DIAMETER CRATERS ON THE MOON. R. V. Wagner, M. S. Robinson, E. J. Speyerer, and P. Mahanti. School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-3603 (rvwagner@asu.edu).

Introduction: The Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) routinely acquires high resolution (50 to 200 cm pixel scales) stereo pairs from adjacent orbits through spacecraft slews; parallax angles are typically >20°, and the local incidence angle is between 40° and 65° [**1**]. These observations are reduced to digital elevation models (DEM) using a combination of ISIS (USGS) and SOCET Set (BAE Systems) to pixel scales of 2 to 4 meters. Absolute control is obtained by tying stereo models to Lunar Orbiter Laser Altimeter (LOLA) profiles using cross-over analysis spacecraft position kernels [**2**]. Topography near the poles is well characterized by LOLA, with sampling as small as 5 m [**3**]. A key goal of this study is to characterize the topography of 20-km diameter impact craters. Typically we observe the upper 50% of interior walls of Copernican aged examples (~20 km diameter (D)) to have average slopes near 36°, with slopes locally above 40° not uncommon. Lower on the walls slopes tend to be 20 to 25° until they sharply intersect the crater floor. From these new data we can also estimate the angle of repose (angle at which granular material will fail or begin to move) for mare and highland materials. This angle is dependent on the coefficient of friction of the material dominantly controlled by particle characteristics: 1) increasing friction increases angle of repose, 2) increasing particle roughness increases angle of repose, 3) increasing particle size decreases angle of repose, 4) angle of repose is independent of gravity. The last point has recently been challenged with experiments performed in aircraft induced low g experiments [**4**].

Data Analysis: Slope and elevation measurements for this study come from NAC DEM mosaics of Giordano Bruno (21.4 km D), Moore F (23.6 km D), Larmor Q (19.3 x 23.2 km D), and Lichtenberg (19.3 km D) craters (listed in order of increasing age). To reduce stereo correlation noise the DEMs were downsampled to 5 m/px by averaging (effective increase of SNR ~2.5). We also used a LOLA-derived DTM (5 m sampling) to characterize the topography of Shackleton crater (20.7-km diameter Imbrian aged crater [**5**]) to investigate crater slope degradation with age. Slope maps for all five craters were computed using a 15x15 m baseline.

Summary of Key Craters:

Giordano Bruno (Figure 1A): Much of the upper walls have average slopes 35±4°. On the north and west slopes, the upper third exhibits slopes generally above 30°. Below that level, the slopes decrease to ~25°, and lobate slumps are common. To the south-southeast the wall maintains a slope of 36° all the way to the floor, a face of over 2500 m! The floor is very rough, superposed with smooth, ponded impact melt deposits. Lobate faced slumps are often found on the lower slope regime where slopes are ~25°. The lobate terminations of the slumps are typically 35° (**Fig. 3**). A large coherent block (4.5 km wide), that slumped 1500 m, dominates the NE portion of the crater wall.

Moore F (Figure 1B): The upper half of the north and south walls is very similar to Giordano Bruno's steep slope regime (>35°). The lower north and east walls show similar lobate slumping to Giordano Bruno, while the lower south wall exhibits a single large collapse. The upper and lower boundaries of the walls are just as sharp as Giordano Bruno, except for the southern collapse materials. No NAC stereo data is yet available for the western third of the crater, or the upper east wall. The floor is very rough, and similar to Giordano Bruno, holds smooth impact melt deposits in topographic lows.

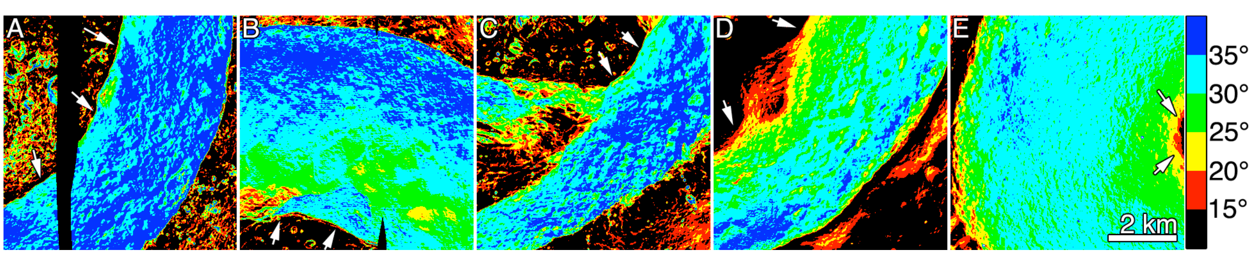

Figure 1: Slope maps of steep wall slopes from the five 20km craters described above: **(A)** Giordano Bruno **(B)** Moore F **(C)** Larmor Q **(D)** Lichtenberg **(E)** Shackleton. Arrows mark the boundary between crater wall and floor.

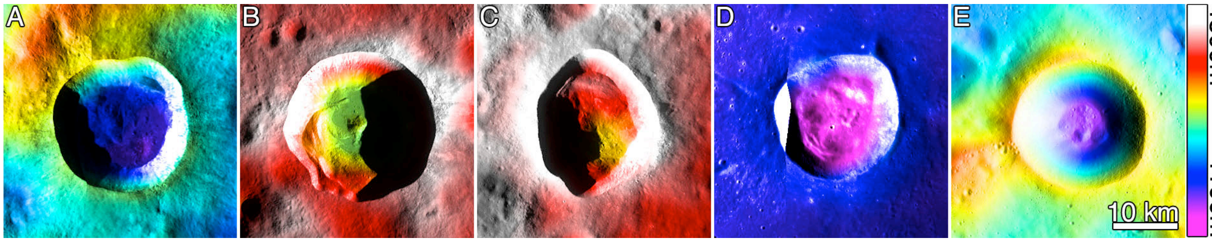

Figure 2: Elevation maps of the five 20km craters described above: **(A)** Giordano Bruno. **(B)** Moore F. **(C)** Larmor Q. **(D)** Lichtenberg. **(E)** Shackleton.

Larmor Q (Figure 1C): This crater is unusual relative to the other four due to its elliptical plan and large slump blocks covering much of the floor. However, it shows similar steep wall slopes, generally around 30-35°, except for a section of the southeast wall which frequently exceeds 35°. The top of the wall forms a sharp boundary with the surrounding terrain. The interface between the wall and floor is often rounded, although this determination is complicated by the large slumps on the floor.

Lichtenberg (Figure 1D): The upper half of the south and west walls average 32° slopes, while the rest of the crater wall slopes average 28°. The upper and lower extremes of the walls grade into the level floor and surrounding terrain over the course of a few hundred meters. The floor is fairly smooth. Lictenberg is proposed to be of Eratosthenian age (>1.7 by [6]).

Shackleton (Figure 1E): The average wall slope is 31°, and very rarely exceeds 35°. Both top and bottom of the walls show a gentle change in slope from the 35° wall to the nearly-flat floor over the course of over a kilometer. The floor is fairly smooth.

Lobes: Lobate slumps generally form on 25° slopes, and the fronts of the lobes average 32° slopes. and are found only in the younger examples (Giordano Bruno, Moore F, and a few in Lamor Q).

Discussion: Interior wall slopes of 36° degrees are common within 20-km diameter Copernican craters. Slopes significantly greater than 36° are associated with blocky outcrops and not granular material. Termination lobes of slump materials on shallower slopes within these same craters are also commonly 36°. Thus we infer that the angle of repose for dry granular material on the Moon is 36° for both highland and mare targets. This angle is consistent with small and angular grains and the long held rule that angle or repose is independent of g. Not surprisingly we observe that older craters exhibit shallower slopes (i.e. Shackeleton) likely due to relentless macro- and micrometeorite bombardment over time.

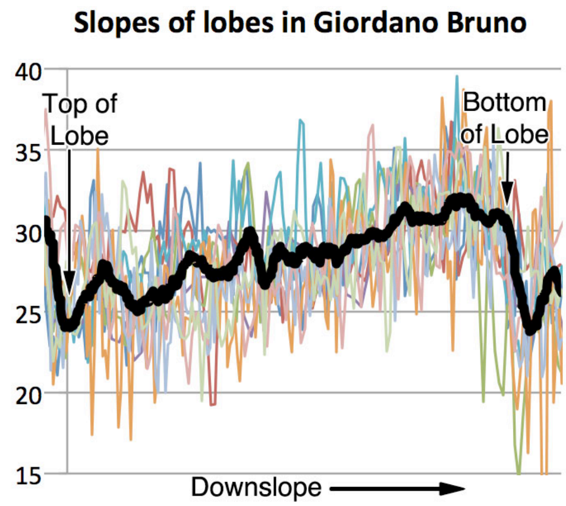

Figure 3: Averaged slope profiles of nine lobate slumps in Giordano Bruno. Colored lines are individual lobe profiles, scaled to start and end at the same points. Black line is average slope.

References: [1] Robinson et al. (2010) *Space Sci. Rev*. DOI: 10.1007/s11214-010-9634-2 [2] Burns et al. (2012) *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*., XXXIX-B4, 483-488. [3] Smith et al. (2010) *GRL* 37, L18204, DOI: 10.1029/2010GL043751. [4] Kleinhans, M.G. et al., *JGR*, 116, DOI: 10.1029/2011JE003865. [5] Spudis et al. (2008) *GRL*, 35, DOI: 10.1029/2008GL034468 [6] Hawke et al (2004) Icarus l70, 1-16, DOI: 10.1016/j.icarus.2004.02.013.