THE RELATIONSHIP BETWEEN DEBRIS FLOW AND ENHANCED RADAR CIRCULAR POLARIZATINO RATIO VALUES IN LUNAR SECONDARY CRATER CLUSTERS. K. S. Martin-Wells,[1] D. B. Campbell,[1] B. A. Campbell,[2] and L. M. Carter,[3] [1]Cornell University, 514 Space Sciences Building, Ithaca, NY 14853 (kassiew@astro.cornell.edu), [2]Center for Earth and Planetary Studies, National Air and Space Museum, [3]NASA Goddard Spaceflight Center.

Introduction: Identifying secondary craters in remote datasets is critical to constraining ages based on counts of small-diameter craters. Recent work has shown that Copernican-aged lunar secondary craters are sometimes associated with streaks of enhanced radar circular polarization ratio (CPR) compared to surrounding terrains.[1] Enhanced radar CPR indicates roughness on the radar wavelength scale; however, the cause of this roughness in relation to the secondary cratering process is not well understood. Here, we examine the origin of these CPR features by comparing 13-cm Arecibo-Green Bank Telescope (GBT) radar maps to Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) and Narrow Angle Camera (NAC) images.

Observations: Targets for investigation were chosen on the basis of well-preserved secondary crater clusters. As one of the largest young craters on the Moon, Tycho (D=86 km) crater's secondary network best suits this criteria. Secondary clusters were identified based on their morphology. Craters in secondary clusters exhibit shallow floors, elliptical planforms, and are sometimes recognizable by unique chevron-shaped or "herringbone" dunes flanking their rims, pointing back in the direction of the parent crater.[2] Secondary crater clusters are also known for the distinctive area of "disturbed" terrain which often occurs downrange from the craters themselves.[2] This region is characterized by v-shaped ridges and grooves, reminiscent of the herringbone dunes, and is sometimes also referred to as "braided" or "textured."[2]

Two groupings of secondary crater clusters were chosen for examination based on the clear nature of their secondary morphology and the presence of enhanced radar CPR values. The first grouping is on the northern part of the floor of Clavius crater (henceforth: Clavius region) and the second to the south-east of Lilius crater (henceforth: Lilius region). These regions are south-south-east of Tycho crater, at distances of several hundred kilometers.

For each of these regions, the areas of enhanced CPR begin in narrow regions at the head of the crater clusters, broadening laterally as they extend downrange. WAC mosaic coverage of these regions reveals that the enhanced CPR regions are spatially correlated with the disturbed terrains as well as the secondary craters themselves (Figure 1).

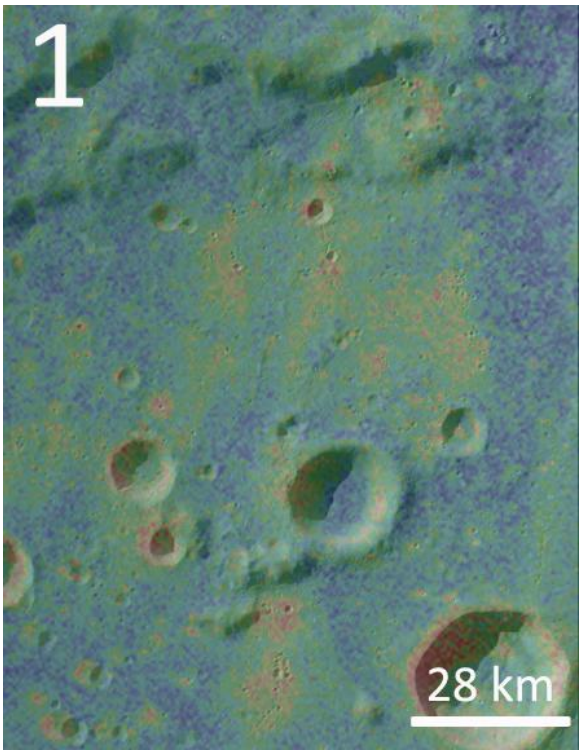

Figure 1: LROC WAC image M119956789M of Clavius crater, overlaid with a 13-cm Arecibo-GBT radar CPR map. High CPR regions, shown in red and yellow, are correlated with Tycho secondary craters.

NAC image products were used to better constrain the morphology in the areas of enhanced CPR, particularly the disturbed terrains. Surprisingly, the most common characteristic revealed was the presence of very smooth material (lacking boulders on the 1-10m scale) in the inter-crater regions and disturbed terrains. Blocks on the 1-10m scale were sometimes observed, but only in isolated patches, typically on the steep interior slopes of secondary crater walls. Although smooth units were typically darker than these blocky units, the numerous contacts between the two terrains revealed that the smooth units almost always post-date the block-rich deposits. Ages of the smooth terrains derived from counts of small, fresh craters are consistent with that of Tycho crater or younger.

Flow morphologies were observed associated with many of the smooth terrains. The smooth material

breaches multiple secondary crater rims and appears to have been deflected by local topographic obstacles. In some cases, boulders extrude from or are partially buried by these smooth flows, as if they had been entrained and transported before deposition in their current locations.

We propose that these smooth units are the result of debris flows initiated by the formation of the secondary craters. Block-rich material ejected from the secondary craters was swept downrange by the flows and partially buried by a thin layer of smooth material. This buried, block-rich material could produce the enhanced 13-cm CPR features observed in these regions.

In order to assess whether or not such flows are typical, we revisited Tycho secondary clusters investigated by other workers. Lucchitta (1977) used Apollo panoramic camera photographs to investigate Tycho secondary craters near the Apollo 17 landing site and other regions, among them Ptolemeaus crater.[2] Comparing the original panoramic images of these clusters to WAC and NAC products, we observed many similarities between the morphologies described by Lucchitta (1977) and those observed in the Clavius and Lilius regions.

Tycho secondary craters in NAC product M106690695 (of the Apollo 17 landing site) appear very shallow, with irregular, almost scalloped, planforms. These morphologies are consistent with observations of secondary craters in the Clavius and Lilius regions, where degraded, irregular planforms were common. The pattern of extensive smooth terrains broken by "islands" of block-rich material observed at Lilius and Clavius is also repeated here. Smooth, dark material, lacking in 1-10m sized blocks, fills the inter-crater regions of these clusters and breaches secondary crater rims.

Similarly, NAC image M106870568 of a Tycho secondary cluster near Ptolemeaus crater shows evidence of flow deposition of smooth, dark material (Figure 2). These smooth units appear to have been deflected by local topographic obstacles, as observed in the Lilius and Clavius regions.

Summary: LROC NAC images reveal that smooth units with flow morphology are common in areas of enhanced radar CPR associated with Tycho secondary crater clusters. Evidence of such flows was observed in Tycho secondary clusters at Lilius, Clavius, Ptolemeaus, and near the Apollo 17 landing site. Isolated patches of block-rich terrain were also observed in these regions, often superposed by the smooth deposits. Considering the frequent correlation of these features, we propose that the enhanced radar CPR signatures observed at Tycho secondary crater clusters are a result of sub-surface scattering off of block-rich material ejected from secondary craters and carried downrange by debris flows initiated during secondary formation.

References:

[1] Wells, K. S. et al. (2010) *J. Geophys. Res., 115*, E06008. [2] Lucchitta, B. K. (1977) *Icarus, 30*, 08-96.

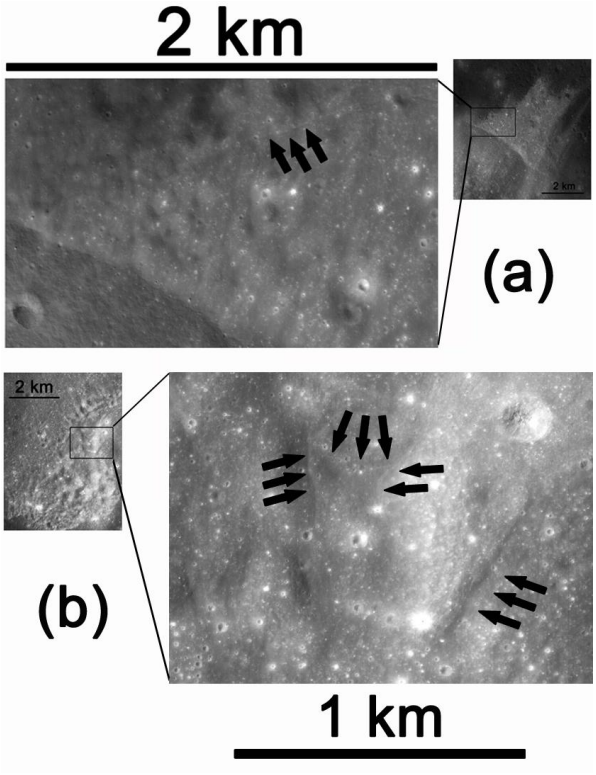

Figure 2: (a) View of the light mantle near the Apollo 17 landing site in LROC NAC image M106690695 (left eye). Lucchitta (1977) attributed the light mantle to Tycho secondary craters in the area.[2] (b) NAC image M106870568 (left eye) of a Tycho secondary cluster identified by Lucchitta (1977) near the rim of Ptolemeaus crater. At the full NAC resolutions (1.55m/pixel and 1.08m/pixel, respectively) both (a) and (b) show signs of debris flow, particularly deflection of smooth material around topographic obstacles. The dark arrows indicate flow margins. In (b), especially, these boundaries reveal deflection of the smooth material around ridges and mounds. Similar flow morphologies are observed in Tycho secondary clusters in the Clavius and Lilius regions.