IMPACT MELT PROPERTIES AND CHARACTERISTICS AS OBSERVED WITH THE LROC NARROW ANGLE CAMERAS.

J. D. Stopar[1] B. W. Denevi[2], M. S. Robinson[1], B. R. Hawke[3], S. J. Lawrence[1], and S. Koeber[1] [1]SESE, Arizona State University, Tempe, AZ, [2]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, [3]Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI.

Introduction: Impact craters are ubiquitous on the surface of the Moon, and any future lunar surface activities will encounter the products of impacts. Therefore, the new views of impact craters provided by the Lunar Reconnaissance Orbiter (LRO) suite of science instruments will play a key role in characterizing and utilizing surface materials. The Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Cameras (NACs) provides sub-meter pixel scale insights into the products and distribution of glassy melt products including impact melt flows and sprays [1-3] and impact melt ponds [4-5]. The physical properties and dynamics within these materials can be inferred from these images [3,5]. Impact melts can occur as thin veneers, ponds, sheets, or lava-like flows [e.g., 6-7]. Here we present new LROC NAC images of fresh impact melt materials and characterize the different types of impact melt deposits observed from meter to kilometer scale craters, with a focus on sub-kilometer craters.

Methods: More than 800 fresh, randomly distributed impact craters (D<15km) were identified for study based on their Clementine maturity parameter, albedo, presence of ejecta rays, radar properties, and by visual inspection of LROC images. About 20% of these craters have been imaged with the NAC. A pair of NAC images provides ~0.5 m/pixel scale at 50-km altitude with a combined swath width of 5 km and length of 26 km [8]. For craters greater than a few kilometers in diameter, more than one NAC image pair is required for complete coverage. Melt flows and ponds were digitized using ArcGIS for spatial analysis and, when combined with the LROC Wide Angle Camera (WAC)-derived Digital Elevation Model (DEM), topographic analysis. Limited NAC DEMs are currently available.

Results and Discussion: Sub-meter detail of diverse impact melt materials are well preserved in many fresh impact craters. At least two types of impact deposits have thus far been identified based on morphology and reflectance: 1) a lower reflectance and smooth material (LSM), and 2) deposits of moderate to higher reflectance and often rubblier material (MRM) (Fig. 1). The LSM is interpreted to be impact melt and is typically found near the crater rim, in the crater, and occasionally as thin stringers, or rays, up to roughly one crater radius in length. The MRM typically extends over a larger area and in some cases displays flow lobes similar in form to low-viscosity terrestrial lava flows. In other cases, MRM can be difficult to distinguish from granular ejecta. Therefore, MRM could be a mix of melt and non-melt ejecta. We cannot yet rule out that the flow forms are a granular material deposited in a fluidized manner. Further study will investigate the relationship between these melt types, target material, impact dynamics, melt volumes, and underlying slope and topography to address the distribution of these two types of melt and their most likely composition.

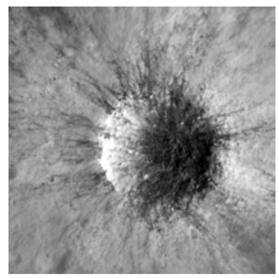

Figure 1: 480 m fresh impact crater (161.25° E, 16.26° N) with low reflectance stringers (interpreted as melt rich) apparently superposed on a higher reflectance veneer.

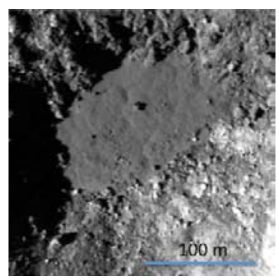

Figure 2: A fresh, smooth ~100 m LSM melt pond in a 700-m crater (348.52° E, 15.54° N) exhibiting an undulatory surface texture. This pond is too small to have cooling cracks.

Melt Ponds. In this study, impact melt ponds have thus far been unambiguously detected in craters with diameters as small as ~450 m, and [4] identified impact melt ponds in the bottoms of craters with diameters as small as ~200 m. Melt ponds often have variable albedo, both from crater to crater and sometimes within the same crater. LSM ponds typically appear fresh, with no superposed craters from later impacts, have smooth and undulatory surfaces, and often have cooling cracks (Fig. 2). MRM floor deposits occur as flat-lying, hummocks, or mounds, implying that there may be different types of MRM associated with impact craters. Smaller craters with interior MRMs generally do not display cooling cracks. Craters with MRMs more frequently have superposed craters, suggesting that some MRM craters are older than those with LSM (Fig. 3). Many of the radar-bright craters of [9] are correlated with large blocks mixed with melt on the floors of craters (Fig. 4). Future work will investigate why some craters have more boulders than melt on the floor.

Melt Veneers. Impact melt veneers occur in many fresh craters but are seen very clearly in several oblique craters with asymmetric ejecta distributions. In these craters, the LSM melt veneer coats the interior of the crater on the side opposite the most prominent LSM exterior melt (Fig. 5), consistent with an oblique impact [e.g., 6-7]. Some craters have deposits of MRM that also resemble melt veneers, but it is not clear whether or not these materials are composed, at least in part, of melted ejecta. They may also be granular “flows” particularly on the interior slopes of crater walls [e.g., 4] (Fig. 6).

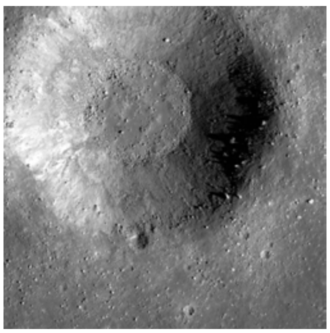

Figure 3: A 940 m crater (62.7°E, 12.9°N) with MRM floor deposits. A crater superposed on the rim and less visible ejecta rays suggest that this crater is less fresh those in Figs. 1, 2, 4, and 5.

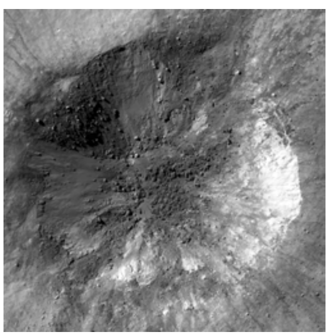

Figure 4: A fresh 1.4 km radar-bright impact crater (17.23° E, 33.72° S) with large boulders on crater interior and floor mixed with extensive LSM melt.

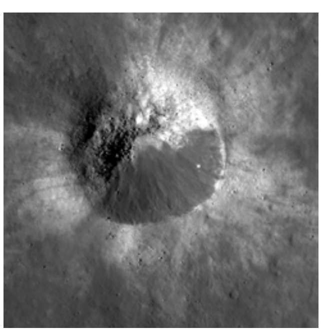

Figure 5: A fresh 550 m crater (336.01° E, 15.53° N) with asymmetric melt distribution. A thin veneer coats the interior crater wall opposite the LSM ejecta to the NW, suggesting an oblique impact.

Melt Flows. Impact melt flows have been identified within one crater diameter of impact craters as small as 3-km in diameter [1-4, 6-7]. Given that the volumes of impact melts are expected to scale with the size of the crater [10], it is perhaps surprising that craters this small can produce sufficient melt to form flows. [7] found a correlation between impact melt flows and craters with asymmetric melt distribution, in some cases, likely due to topographic controls on melt coalescence, and this finding is now supported by [3]. Impact melt flows sometimes entrain rubbly ejecta materials along their flow margins, implying that these flows of melt occurred after the deposition of rubbly ejecta, consistent with previous models [6,11]. Many of the flows have channels.

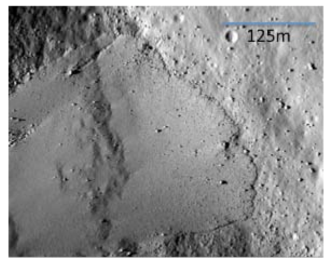

Figure 6: Probable debris flow, but possibly melt, covering part of MRM floor deposits in a 12.4 km crater (354.78° E, 3.22° S).

Discussion and Summary: Characterization of the types and morphologies of impact melt and ejecta materials is useful in the characterization of future exploration sites. Observations from the NAC images have shown that impact melt products are more extensive than previously thought and can be found beyond 1 crater radius [e.g., 4,12]. Impact melts can be used to infer the properties of the target material [e.g., 8], and can be used to infer freshness of an impact crater. Different types of impact melt associated with a single crater may suggest multiple generations of melt as in [5]. Small mare and highlands craters allow investigation of the influence of target material and strength on the development and distribution of impact melt and interior deposit morphology. NAC images show that even relatively fresh impact craters can have significant degradation due to mass wasting.

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References: [1] Hawke, B. R., et al. (2010) LPSC #1611. [2] Hawke, B. R., et al. (2011) LPSC #2347. [3] Denevi, B. W., et al. (in prep). [4] Plescia, J. B., et al. (2011) LPSC #2033. [5] Bray, V. J., et al. (2010) GRL 37: L21202. [6] Howard, K. and Wilshire, H. (1975) J. Res. U.S. Geol. Surv. 3, p. 237-251. [7] Hawke, B. R. and Head, J. (1977) in *Impact and Explosion Cratering*, p. 889-912. [8] Robinson, M. S., et al. (2010) Space Sci. Rev. 150: 81-124. [9] Thompson, T., et al. (1981) Icarus 46: 201-225. [10] Cintala, M. and Grieve, R. (1998) Met. Plan. Sci. 33: 889-912. [11] El-Baz, F. (1972) in *Apollo 16: Prelim. Sci. Rep.*, p. 29-62 – 29-70. [12] Robinson, M. S., et al. (2011) LPSC #2511.