DISTRIBUTION, OCCURRENCE, AND DEGRADATION OF IMPACT MELT ASSOCIATED WITH SMALL LUNAR CRATERS.

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Introduction: Impact craters are ubiquitous on the surface of the Moon, and any future lunar surface activities will encounter impact-derived materials. Impact melts typically occur as thin veneers, sprays, ponds, sheets, or lava-like flows [e.g., 1-2]. The Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Cameras (NACs) provide sub-meter pixel scale details of impact products including melt flows [3-5], sprays, and ponds [6-8]. Here, we characterize the occurrence and distribution of impact melt deposits observed at simple craters, with a focus on craters <1 km in diameter (D). This work addresses the criteria for melt identification at small diameters, the factors responsible for the observed melt and its distribution, and the changes in observed melt with crater degradation.

Methods: More than 1600 fresh, randomly distributed impact craters (D<15km) were identified for study based on their maturity, albedo, presence of ejecta rays, and by visual inspection of LROC images. 30% of the craters are located in mare and 70% non-mare. Nearly 50% of these craters have been imaged with the NAC as of 1 Jan 2012 at incidence angles between 20° and 70°. One third of these craters have D≤1km. In some cases, NAC stereo pairs and derived-DEM products, created using the techniques of [9], are available. DEMs provide crater profiles, crater depths, and slopes of melt materials. Calibrated high sun NAC images in units of I/F [10] allow preliminary interpretations of reflectance differences between different crater materials in a single crater.

Results: *Occurrence and Distribution of Melt.* Floor materials include melt ponds that have flat or undulating surfaces similar to terrestrial lava lakes (Fig. 1). These ponds often have cracks due to compaction or cooling and, occasionally, collapse pits and scarps. In craters where less melt was created, the floors are often covered with a veneer of melt draped over boulders. Some craters appear to preserve patches of melt that lined that transient crater cavity [e.g., 11]. In some cases, crater walls preserve channels formed by melt flowing to the crater floor.

Exterior melt deposits include hard-rock veneers, melt flows, and melt ponds [1-2]. Melt veneers form nearest to the crater cavity, and can be identified by their concentric patterns of cracks. Impact melt flows have been observed within one crater diameter of impact craters as small as 3-km in diameter [1-5]. Many of the flows have one or more channels.

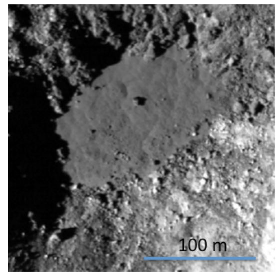

Figure 1: A fresh, smooth ~100 m melt pond in a 700-m crater (348.52° E, 15.54° N) exhibiting an undulatory surface texture. LROC NAC M135263272.

Effects of Crater Diameter. Some very small craters appear to have smooth ponds on their floors, including one 150-m crater, consistent with observations of [6]. At diameters ~400m, melt ponds and puddles become easier to recognize, and at D>700m interior melt deposits become more frequent. Collapse pits in melt ponds are observed, but rare, for craters D<2 km, and are similar to pits observed at craters D≥10 km [12]. Many of the floors, particularly those of craters >1 km, appear to be mantled by a fine particulate layer that partly obscures cooling and tension cracks.

Topographic Data. Depth-to-diameter ratios (d/D) of impact craters with and without melt are determined from NAC DEMs as they become available; we will continue to study relationships between d/D and volume of observed melt.

2a 2b

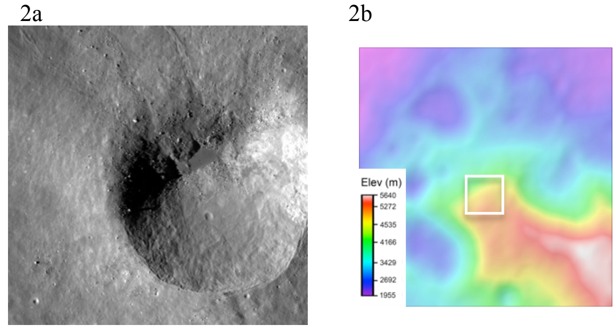

Figure 2a: 720-m crater with melt flows to the NW towards the lowest topography. NAC M135344703. **Figure 2b:** GLD100 [15] and hillshade illustrate that the crater in 2a impacted into the side of a ridge.

Local topographic features, such as a nearby crater (e.g., north of King crater [13-14]), can trap ejected melt. In this study, we observe an exterior melt pond to the east a 2.5-km crater where ejected melt coalesced in a local topographic low. The smallest crater with surviving exterior melt flows observed, thus far, is D~720m (Fig. 2). Melt flows in craters this small are correlated with extreme pre-existing topography, such as a steep crater wall. Melt is concentrated outside the lowest portion of the rim, consistent with observations of [2, 5].

Reflectance Variations. Melt ponds and sprays often have lower reflectance than surrounding materials, consistent with [1], but we find that reflectance can vary, both from crater to crater and sometimes within the same crater. In many of the freshest mare and highlands craters, the continuous ejecta appears as a bright blanket, with thin stringers or sprays of darker melt that extend from the crater floor up to 1 crater D away. Some albedo variations are derived from layers disturbed by the impact and exposed in crater walls, as in the case of a 1.8-km crater (Fig. 3). In this crater, dark material forms part of the ejecta resulting in an asymmetrical distribution of bright and dark ejecta. Dark material is also spread downslope through mass wasting.

Degradation. Many craters have experienced wall failures; in some cases it is difficult to determine if these failures occurred during crater modification (shortly after the impact) or much later through mass wasting. Crater modification and wall failure is generally believed to play only a minor role in the development of craters D<2 km [e.g., 16]. However, in several examples D>2 km, impact melt has embayed or flooded slumped wall materials implying that slumping occurred during the impact process, consistent with [16].

Granular debris flows, which often resemble melt flows, are common on steep walls of fresh craters of all sizes, consistent with [16-17]. Debris flows can be distinguished from melt flows and crusts based on their lack of cooling or tension cracks. Debris flows bury crater floors, emplace boulders, and mantle topography even in relatively fresh-appearing craters with bright ejecta rays, crisp rims, and smooth floors. The floors of older craters and most craters larger than a few kilometers have a mantled appearance.

Discussion: *Diameter Relationships.* Because melt volume is known to scale with crater diameter, at small diameter, the limited volume of melt produced should become choked with clasts [11]. Some low volume melt flows have a rubbly appearance, suggesting mixture with unmelted materials. Alternatively, many small (D<1 km) craters may be secondary impacts that did not generate enough melt to form a pond. NAC DEMs will be used to assess correlations between depth/Diameter ratio (thought to reflect primary or secondary craters) and volume of melt produced.

Emplacement Mechanisms. Smooth melt ponds, veneers, and flows often appear draped over other crater materials, suggesting deposition late in the cratering process, consistent with [1-2]. 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 [2,5,7]. Different types of impact melt associated with a single crater may suggest multiple generations of melt as in [7].

Degradation. In older craters, we observed smooth and flat-lying ponds that appear mantled with particulate materials -- either degraded impact melt, a composition not dominated by glass [e.g., 1], or a melt with a non-melt coating. These ponds can exhibit cracks indicating at least some melt. However, boulder tracks are observed on the surfaces of many of these floor materials, indicating at least a surficial layer of poorly consolidated materials, as expected of particulates settling from nearby impacts or mass wasting events. Dark melt sprays are only observed on the walls of the freshest craters, implying rapid degradation by meteorite impacts, regolith formation, and/or mass wasting of interior crater walls.

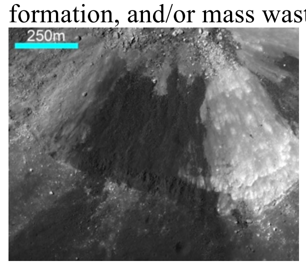

Figure 3: A pocket of dark, friable material exposed in the wall of a 1.8-km crater at 33.14°E, -11.80° contributes to asymmetric distribution of bright and dark ejecta. NAC M121993376.

Conclusions: NAC images have shown that, like larger craters, those with D≤1km often have interior melt ponds, veneers, and exterior melt flows that are deposited late in the impact process. However, not all craters of similar size display the same distribution and abundance of melt, which may be a result of factors such as target composition, impact velocity, pre-existing topography, and/or impact angle [6, 11]. NAC images show that even impact craters with bright ejecta rays, crisp rims, and smooth floors can have significant degradation due to subsequent nearby impacts and mass wasting events. Effects of degradation include rapid disaggregation of fine textures and melt sprays as well as burial and mantling of melt and floor materials.

Acknowledgements: The authors thank the members of the LROC Team for their assistance. **References:** [1]Howard and Wilshire (1975) J. Res. U.S. Geol. Surv. 3, p.237-251. [2]Hawke and Head (1977) in *Impact and Explosion Cratering*, p.889-912. [3]Hawke et al. (2010) LPSC #1611. [4]Hawke et al. (2011) LPSC#2347. [5]Denevi et al. (2012) Icarus, submitted. [6]Plescia and Cintala (2012) JGR, in press. [7]Bray et al. (2010) GRL 37: L21202. [8]Robinson et al. (2010) Space Sci. Rev. 150: 81-124. [9]Tran et al. (2010) LPSC#2515. [10]Robinson et al. (2011) LPSC#2511. [11]Cintala and Grieve (1998) Met. Plan. Sci. 33: 889-912. [12]Wagner et al. (2012) LPSC, this vol. [13]El-Baz (1972) in *Apollo 16: Prelim. Sci. Rep.*, p.29-62–29-70. [14]Ashley et al. (2011) LPSC #2437. [15]Scholten et al. (submitted) JGR. [16]Hawke and Head (1979) LPSC, p.510-512. [76]Basilevsky (1976) Proc. LPSC, p.1005-1020. [87]Barnouin et al. (2010) LPSC#1479.