LUNAR CRATER FORMS ON MELT SHEETS - ORIGINS AND IMPLICATIONS FOR SELF-SECONDARY CRATERING AND CHRONOLOGY.

J. B. Plescia[1], [1]The Johns Hopkins University, Applied Physics Laboratory, Laurel MD.

Introduction: Numerous circular crater-like forms occur on impact melt (Fig. 1) at many Copernican-age craters. For brevity, these features are referred to here as ***palimpsests***. These features are morphologically and morphometrically different from typical impact craters on both melt and ejecta at the same crater. The palimpsests are interpreted to be the result of impact into unsolidified impact melt and thus occurred during the deposition of melt and ejecta. Their presence indicates self-secondary cratering. Here we examine the morphology and morphometry at Tycho and suggest a mechanism of formation and implications using LROC Narrow Angle Camera (NAC) images [1] and NAC Digital Elevation Models (DEM) [2].

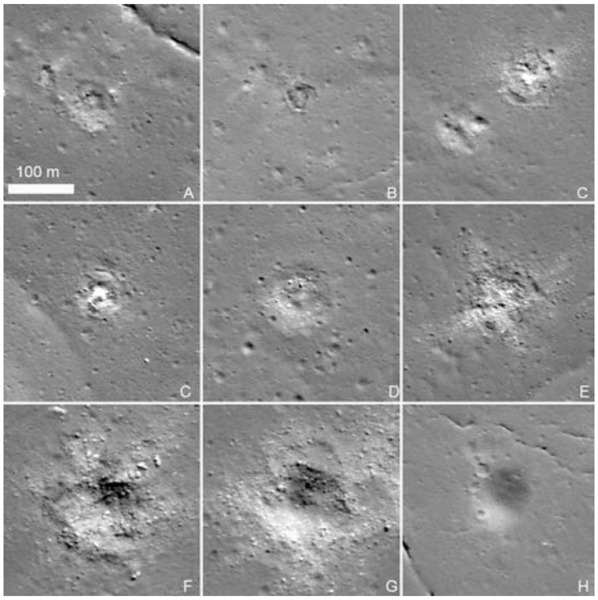

Figure 1. Crater-form features on Tycho impact melt. Panels A-F: shallow circular features with unusual morphology; G-H: impact craters with rocky ejecta; I: circular depression. LROC NAC images.

Craters on Melt Surfaces: Impact melt surfaces exhibit a range of crater-form features (Fig. 1). Some have raised rims, a bowl-shape interior, and well-defined (often rocky) ejecta. These are most reasonably interpreted as classical impacts into solid target materials. A second category is circular features with a morphology different from typical impact craters - the palimpsests. Palimpsests often exhibit a shallow floor, central mound, low rim, and lobate margins. Well-defined ejecta is typically absent, although in some a few cases blocky ejecta is observed. Features with this type of morphology are only observed on impact melt materials and not on adjacent clastic ejecta or surfaces with thin veneers of impact melt. A final feature observed on the melt surfaces is a circular depressions that lacks a raised rim or ejecta (Fig. 1, H).

Morphometric Data: Using NAC DEMS [2] morphometric data were compiled for impact craters, palimpsests and depressions on the melt, melt-coated, and ejecta materials at Tycho crater. Fig. 2 illustrates the rim to floor depth vs. rim-rim diameter values. Data are plotted in three groups based on the morphology: typical impact craters (black), palimpsests (red), and depressions (green). All of the data plot below the depth-diameter relation of Pike [3], although the slope of the data is parallel. However, the analysis of Pike [3] was for much larger craters and his analysis may not be applicable to these diameters. Mahanti et al. [4] examined the depth-diameter relation for craters of size examined here. The overall population of this data has a steeper slope than defined by [4].

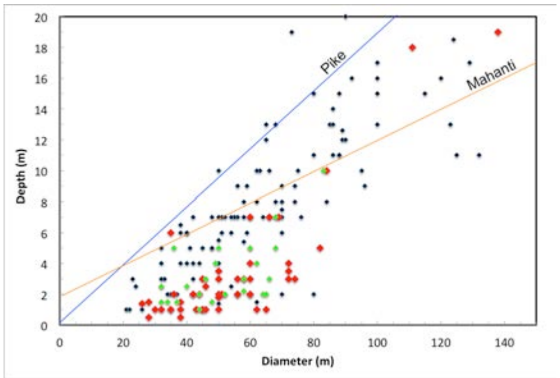

Figure 2. Depth-diameter relations of craters on melt material. Blue dots: impact craters; red dots: melt features; green dots: depressions. Solid lines denote the relations proposed by [3] and [4].

These data (for Tycho) indicate the depth/diameter ratio for small impact craters is 0.12 on melt material; and 0.06 for the palimpsests. Palimpsests are more shallow than impact craters at a given diameter, consistent with the visual impression. The steepest portion of inner crater wall slope was also measured. For impact craters, the interior wall slopes average 21° whereas the slopes for the palimpsests average 9°.

Origin: What is the origin of the palimpsests? They are confined to areas where impact melt has ponded; they do not occur on clastic ejecta or areas where clastic ejecta has only a melt veneer. This suggests some aspect of the melt controls their formation.

There are no features on terrestrial volcanic ponds that might serve as analogs for the palimpsests.

Palimpsests are similar to small-diameter mare craters: craters with central mounds, pits, or flat floors. Such morphology results from the presence of a weak layer (regolith) over a strong layer (basalt) [5-8]. If the palimpsest morphology resulted from similar target structure, central mound and pit dimensions can be used to estimate the regolith thickness [9, 5-6]. These palimpsests would indicate variable regolith thickness with an average of ~6 m. For a surface having the age of Tycho (108 Ma), a 6 m regolith is unlikely.

An alternative model is that palimpsests represent impacts into melt material that has not solidified. Palimpsest morphology is similar to that of experimental impacts into viscous targets [10-12] (Fig. 3). Details of the morphology of such experimental craters are a function of the target viscosity, impact energy and impact angle. For the palimpsests, impacts would have occurred immediately after melt emplacement (*t* = sec. - min.), before it solidified. The range of morphologies observed at Tycho probably reflect variations in the impact energy as the time-scale of formation is short compared with the time-scale of melt solidification.

Figure 3. Experimental 25-cm-diameter crater with 1 cm central mound produced by impact into clay slurry (from [12]).

Discussion: Several studies of Copernican-age craters [13-15] have noted that the crater frequency and slope of the cumulative size-frequency distribution differ across the continuous ejecta and that crater frequencies are always lower on melt than on ejecta. This is not a new observation, but rather dates to the 1960s.

Shoemaker et al. [16] argued that the differences were the result of self-secondary cratering in which ejected material reimpacted the surface during the cratering process. The interpretation that the palimpsests are the result of impact into unsolidified melt supports the idea that self-secondary cratering occurs. It is unlikely that so many primary impacts would have occurred before the melt solidified.

Self-secondary cratering has implications for cratering chronology. The sine qua non of cratering chronology is that the surface has zero craters at the time of formation. If a variable number of craters are present on the surface immediately after formation, it will indicate an excessive age and make the use of the crater (e.g., Copernicus, Tycho) problematic for constraining / calibrating the lunar impact flux.

Conclusions: The geologic setting, distribution, morphology and morphometry of palimpsests indicate they are impact features formed in impact-melt before the melt solidified. Thus, the target had a relatively low viscosity (compared with solid-rock). The melt lacked the strength to preserve long-wavelength topography (bowl-shape). Short-wavelength features (rim, central mound) are preserved. Material ejected from the interior forms lobate ejecta around the crater.

The presence palimpsests on impact melt indicates that they formed during the emplacement of melt associated with the primary crater. Palimpsests are interpreted to be self-secondary craters formed by material ejected at high-angle during the cratering event which re-impacted the surface. Such self-secondaries suggests that the basic tenet of crater chronology - that a surface has zero craters at the time of formation - may not apply to surfaces associated with impact craters.

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