IMPACT MELT AND WATER RELEASE AT TOOTING CRATER, MARS.

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Introduction: Morphological attributes of geologically young and well-preserved impact craters have been studied in detail with High Resolution Imaging Science Experiment (HiRISE) [1, 2]. We present here some specific details of these features within the pristine example of Tooting crater. Tooting crater is ~29 km in diameter, is located at 23.4°N, 207.5°E, and is classified as a multi-layered ejecta crater [3]. Inspection of 30 THEMIS VIS images of Tooting that were collected up to the end of 2006 [4] reveals that there is a total of 13 superposed impact craters ≥ 54 m on the ejecta blanket, which has an area of ~8,120 km^2. Using the 2004 iteration of the Martian crater-count isochron [5; Table 2], gives an age for Tooting crater that is <2 Myrs, but see [6] for an alternative viewpoint.

Tooting crater formed on virtually flat lava flows within Amazonis Planitia [4] where there appears to have been no major topographic features prior to the impact. The depth of the crater and the thickness of the ejecta blanket can therefore be determined by subtracting the appropriate elevation of the surrounding landscape (-3,872 m) from the individual MOLA measurements. The measured depth of Tooting crater below average rim crest is 1,690 m for northern floor, and 1,881 m for southern floor. Garvin and Frawley [7] established the relationship $d = 0.25\ D^{0.49}$, where d is the depth and D the diameter, both in kilometers, for 98 of the most unmodified Martian craters. Using this relationship, Tooting crater should have a depth of 1,302 m, but in reality it is ~1.3 times deeper on the northern floor and ~1.4 times deeper on the southern floor, than predicted by [7] for this diameter.

The large depth/diameter ratio indicates that Tooting crater most likely has significantly less in-fill material than is typical for Martian craters of this size. The low number of superposed impact craters also implies a young age. Both of these attributes suggest that Tooting crater is an ideal example of a fresh crater where high-resolution imaging may reveal details of the original morphology of a large impact crater on Mars.

HiRISE observations: HiRISE samples the Martian surface in the visible and near-infrared at a scale of 25 – 31 cm/pixel [1, 8]. Three areas of Tooting crater have been imaged by HiRISE to date, including a north-south stereo pair over the central part of the cavity, a stereo pair over the western rim and ejecta, and a single image over the rampart and distal edge of the NNW ejecta. Here we select several sub-scenes from these HiRISE data (Fig. 1) to investigate some of the remarkably fresh attributes of Tooting crater in more detail.

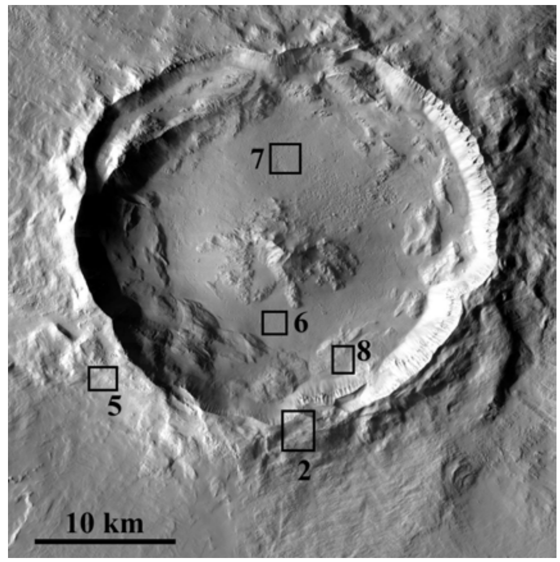

Fig. 1: THEMIS VIS mosaic of Tooting crater. Boxes mark the locations of HiRISE images used in other figures.

Impact melt-bearing deposits in Tooting: Sheet flows, lava flow-like flows, and ponded materials have been identified in geologically young and well-preserved craters including Tooting [1, 2]. A kilometer-scale area bearing the smooth, sheet flows can be seen on the southern rim of Tooting (Fig. 2). This material is relatively smooth, but there are numerous flow features that appear to be concentrated on the steeper slopes. Several distinct flow units can be identified, of which the examples shown in Figs. 3 and 4 are representative. The stratigraphy of the flow in Fig. 3 is very informative, with the 50 m-wide flow having traveled towards the crater floor across a smooth, fractured surface that presumably formed prior to the emplacement of the flow. Both of these features may represent two melt-bearing occurrences that were emplaced at different times during the modification stage. Impact melt maintains a high temperature and low viscosity post-emplacement (e.g., [9]), allowing movement of melt-rich after the cessation of the modification. This would generally give the appearance of multiple melt-bearing flow events. Note the crenulated surface texture of the flow and the absence of debris at the distal end of the lobe, which suggests that the basal unit was quite coherent during lobe emplacement. The flows shown in Fig.4 also cross smooth, fractured ground.

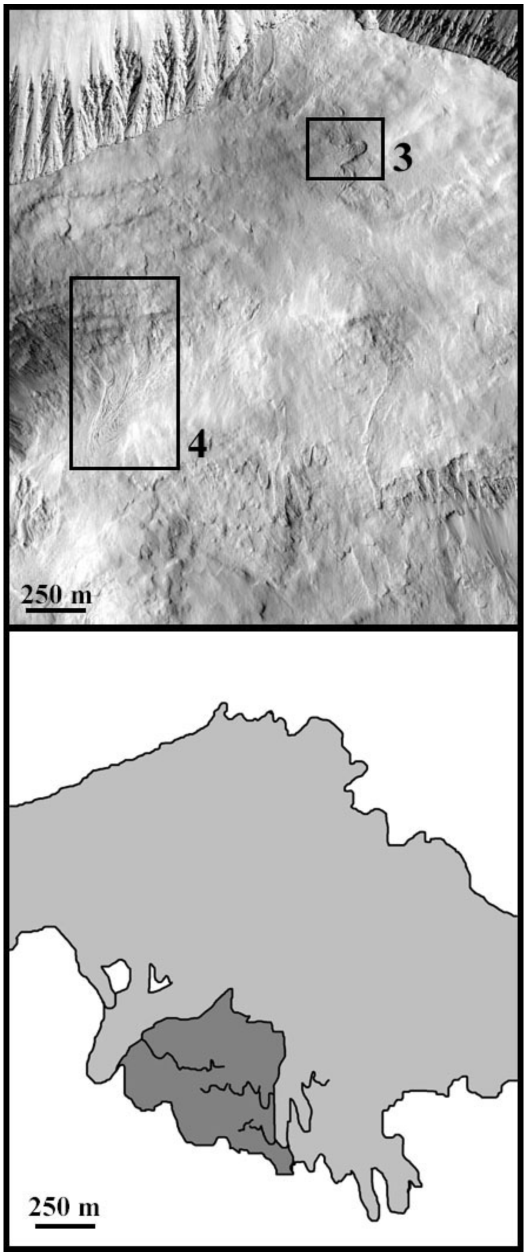

Fig. 2: (Top): HiRISE view of sheet flow materials on the southern rim of Tooting crater. Location of Figs. 3 and 4 are shown. (Bottom): Distribution of flow units interpreted here to be impact melt. This material is similar to fluid lava that has been erupted in a fire fountain and drains back into the vent, but in this instance there is no evidence of a volcanic vent existing at the rim crest of the crater.

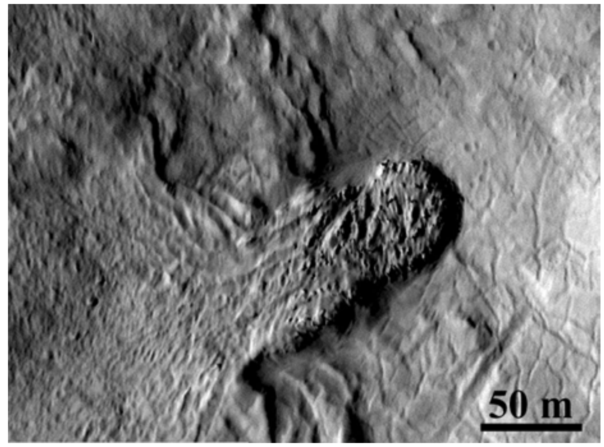

Fig. 3: HiRISE view of lobate flow on the southern rim of Tooting crater. Direction of flow is towards the top right. Note the fractured ground at top right.

Fig. 4: HiRISE view of lobate flows, interpreted here to be impact melt flows. The source area is at the top of the image, and several small lobes merge to form flows with transverse festoon ridges on their surfaces.

The lava flow-like feature on the SW rim (Fig. 5) has several characteristics in common with volume-limited lava flows. For instance, there is a central channel with pahoehoe-like ropes, levees along each side of the channel, and a broad lobate distal margin. This is similar to a lava-flow like features on lunar crater rim crests [10] and one other such flow that was first identified in HiRISE image PSP_002118_1510 of Zumba crater [2].

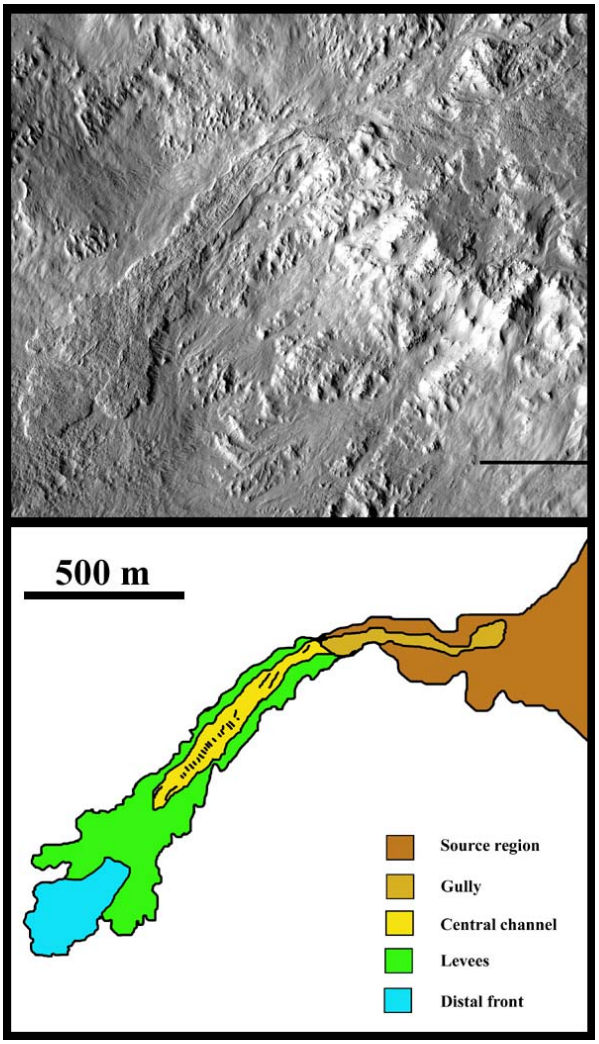

Fig. 5: HiRISE view (top) and geomorphic sketch (bottom) of lobate flow on SW outer rim that is very likely to be a flow of impact melt. Direction of flow is from top right to bottom left.

Two types of ponded melt materials can be seen on the floor, inner wall, and ejecta blanket of Tooting crater: fractured [2, 4] and pitted [2]. On the southern part of the crater floor, pervasive fractures can be seen (Fig. 6). These fractured ponded materials were previously interpreted as possible impact melt using MOC images [4]. Furthermore, the cracks were recently interpreted [2] as cooling-contraction cracks, which is consistent with an impact melt origin. Pitted materials can be seen predominately on the northern floor (Fig. 7) with diameters generally between 100 to 200 m. These pits have a variety of shapes (i.e., they are not all circular) but a common attribute is that there are no raised rims and no ejecta surrounding them. In addition, they appear to coalesce and not destroy one another. These attributes indicate that the pits do not have an explosive origin. A collapse mode of formation seems likely. HiRISE reveals that both pits and fracturing occur within the same unit (Fig. 7), which has been observed at other crater examples and suggests that both of these materials may represent impact melts with varying components of melt, lithics and volatiles (i.e., spanning coherent impact melt, melt breccias and suevites) [2].

With respect to impact melt occurrences on the ejecta blanket of Tooting, sheet flows and fractured materials dominate the proximal ejecta blanket to the south, while pitted materials appear to be more abundant on the remainder of the proximal ejecta blanket and even extend beyond the distal edges of the ejecta rampart. These distributions appear to be consistent with the impact-direction of the bollide that created Tooting [4], but additional coverage by, and mapping with, HiRISE is required to say definitively if this is truly the case.

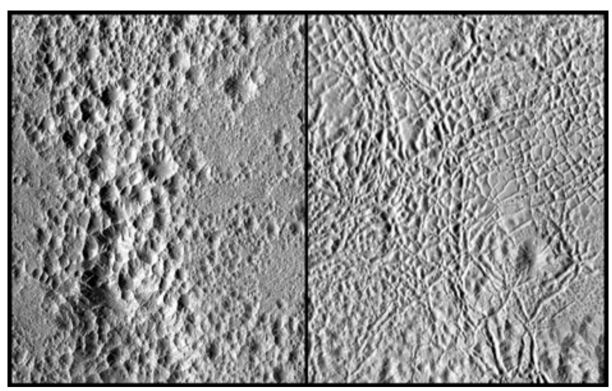

Fig. 6 (left): HiRISE view of pits on northern part of crater floor, which also occur on the lower flanks of the central uplift. Note the absence of raised rims, and the fact that many of these craters are not circular. Image width is 1.5 km. Fig. 7 (right): HiRISE view of fractures on southern part of crater floor. The pits at lower right appear to be similar to the examples shown in Fig. 6, suggesting that the material at this location can locally collapse. Image width is 1.5 km.

Dewatering of the impact melt-bearing lithologies: Not all of the flow features on the rim of Tooting crater are suggestive of impact melt. Some features bear a resemblance to surface run-off features that were first identified in Mojave Crater [11] and recently recognized in Tooting and other fresh craters [12]. Figure 8 illustrates numerous channels on the southern inner wall of the crater. The dendritic nature of these tributaries, suggests that they were fed by a broad area of fluid release that then coalesced into several larger flows (arrows). Several streamlined islands can be found in this area. Sources for some of these features can be traced back to the ponded materials on the crater wall and ejecta blanket of Tooting. This has also been observed at several craters, including Mojave [2].

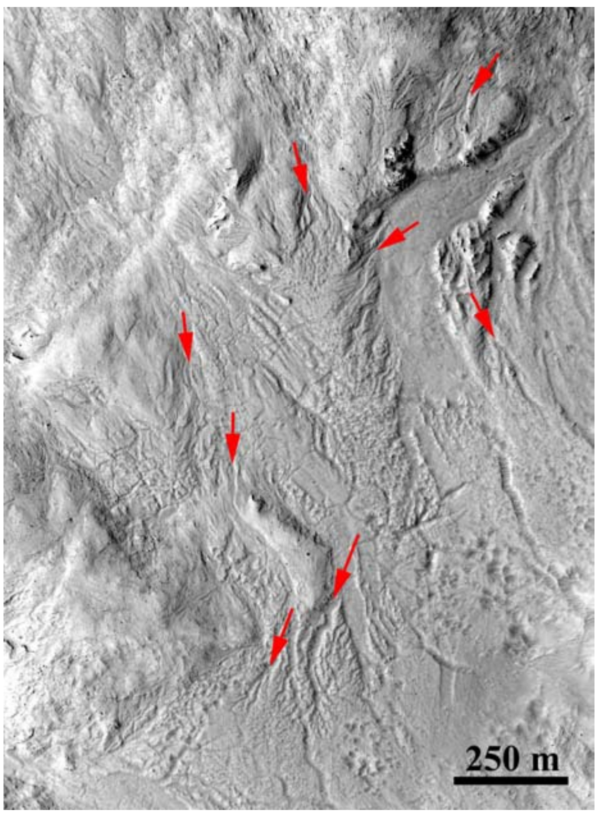

Fig. 8: HiRISE view of tributaries (arrowed) on inner southern rim. No flow lobes are present at the distal ends of the tributaries, indicating that they are not impact melt flows. Direction of flow is towards the top of the image.

Summary and Conclusions: The identification of impact melt within any large (>15 km diameter) crater on Mars is of potential significance. Our observations of melt deposits on the rim of Tooting crater (Figs. 2 - 5) and other craters (see [2]) suggest that extensive melt sheets were created on Mars despite two factors that were once referenced for explaining the previous lack of observations of melt: (1) the lower impact velocities ([e.g., [13]) and (2) the volatile-rich nature of the Martian subsurface (e.g., [14]).

The observation that there was significant amounts of hot rock created during the cratering process has relevance for the idea that hydrothermal systems may have once existed within some large craters that became flooded with water soon after their formation because of the large volume of (relatively) hot rock that could have persisted on the crater floor for extended periods of time [15, 16], perhaps as much as ~70,000 years [17].

References: [1] McEwen A. S. et al. (2007) Submitted to *Science*. [2] Tornabene L. L. et al. (2007) this meeting. [3] Barlow N. G. et al. (2000) *JGR* 105: 26,733 - 26,738. [4] Mouginis-Mark P. J. and H. Garbeil (2007) *Meteoritics & Planet. Sci., in press.* [5] Hartmann W. K. (2005) *Icarus* 174: 294 – 320. [6] McEwen A. S. et al. (2005). *Icarus* 176: 351 – 381. [7] Garvin J. B., and J. J. Frawley (1998) *Geophys. Res. Letts* 25: 4405 – 4408. [8] McEwen A. S. et al. (2007) *LPS XXXVIII*, abs #2031. [9] Osinski, G. R. (2004) *EPSL* 226: 529 – 543. [10] Howard, K. A. and H. G. Wilshire (1975). *U. S. Geol. Surv*. 3: 237 – 251. [11] Williams et al. (2004), *LPSC XXXV*, 1415. [12] Tornabene, L. L. et al. (2007) *LPS XXXVIII*, abs. #2215. [13] Steel D. I. (1998) *Planet. Space Sci*. 46: 473 – 478. [14] Kieffer S. W. and C. H. Simonds C. H. (1980) *Revs. Geophys. Space Phys.* 18: 143 – 181. [15] Newsom H. E. et al., (2001) *Astrobiology* 1: 78 – 88. [16] Rathbun J. A. and S. W. Squyres (2002) *Icarus* 157: 362 – 372. [17] Abramov, O. and D. A. Kring (2005). *JGR* 110: E12S09, doi:10.1029/2005JE002453.

Figures: The HiRISE image segments for Figs. 2, 3, 4, 6, 7, and 8 come from frame PSP_001538_2035. Fig. 5 is a segment of frame PSP_002646_2035.