RHEOLOGY OF LUNAR IMPACT MELT FLOWS. J. B. Plescia[1] and S. M. Baloga[2], [1]Applied Physics Laboratory, Johns Hopkins University, Laurel MD 20723 (jeffrey.plescia@jhuapl.edu), [2]Proxemy Research, Gaithersburg, MD 20882.

Introduction: Impact melt is a common product of the impact cratering process with the amount of the melt being proportional to the energy of the event [1-5]. For simple craters, the melt typically occurs as coatings around the rim, small ponds on the floor, and flows extending away from the rim (Fig. 1). For larger complex craters, significant pools of melt form on the crater floor surrounding the central uplift, melt pools are perched on the faulted rim blocks and flows may extend downslope beyond the rim.

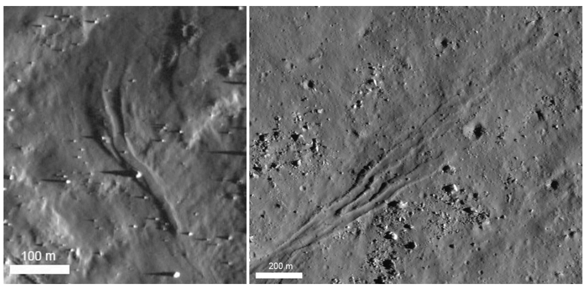

Fig. 1. Impact melt flows at Giordano Bruno (left) and unnamed 9 km crater (right). LROC images M1124290784L; M178453332L.

Analysis of the impact melts provides insight into several aspects of the cratering process. The composition of the impact melt reflects the average composition of the target material. The distribution of the melt beyond the crater rim provides insight into the dynamics of ejection and deposition of material during cratering, particularly at the end of the process. The morphology and morphometry of the melt flows on the crater exterior and on slopes within the crater provide information about the physical properties of the melt (temperature, rheology).

Analysis of Lunar Melts: Since impact melt flows are silicate liquids, they behave similar to lava flows (Fig. 1) and thus models of lava flow rheology [7-18] can be used to understand the rheology of impact melt flows. An extensive amount of research on volcanic lava-flow rheology has been applied to terrestrial and planetary lava flows with later models examining different aspects of the flow eruption and characteristics. Keszthelyi [15-16] recently reviewed the applicability and limitations of the different approaches to the modeling of lava flows and suggested that flow thickness is the most diagnostic property of the rheology of a lava flow. Similar to a lava flow, an impact melt flow will cool by radiation from its initial temperature to its solidus (and eventually to ambient). Estimates of radiative cooling impact flows on the Moon [16, 19] suggest the time-scale for solidification would be similar to that for a lava flow, that is hours to days (depending on volume). Flows having an anorthositic composition would cool significantly more slowly than melt flow having a basaltic composition. Entrainment of "cold" debris into the melt flow will also influence both the viscosity and the cooling history.

The basic morphometric parameters that are used to derive flow rheology are illustrated in Fig. 2 and include flow thickness (H), overall flow width (w_f), channel width, levee width (w_b), and substrate slope (θ). Flow length can also be measured, but such values are often minimum values as the upstream portion of melt flow can be truncated at the crater rim or buried by younger materials. Data to provide these parameters were derived from LROC NAC and LROC derived DEM data.

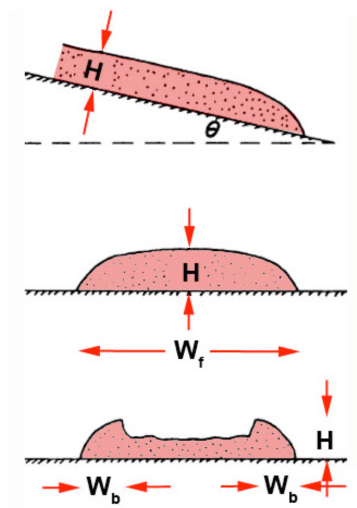

Fig. 2. Morphometric parameters of a melt flow (modified from Moore et al. 1978).

Lava Flow Rheology: Relatively little work has been done on the rheology of observed lunar impact melt flows. Several studies have examined the morphology and distribution of melt material and noted that the flow morphology indicates that the material was a viscous fluid [e.g., 4-6, 20] but these studies did not specifically consider the rheology.

We have examined impact melt flows at several craters including Giordano Bruno, Byrgius, Das G, Gibbs, Korolev X, Lichtenberg, Lowell, Mandelshtam, Meshcherskly NE, Necho, Oday M, Pavlov, Pierazzo, Steno, Tycho and several unnamed craters.

The flows at both Giordano Bruno and an unnamed 9 km diameter crater (13.5°N, 234°E) exhibit similar morphologic changes down flow. They begin as channelized flows with well-developed levees and then change into open tabular flows. The different morphologies along different portions of the flow allows for the rheology to be estimated using different combinations of parameters, that are in part independent of each other.

The flow at Giordano Bruno occurs on the south rim. It is relatively narrow (~50 m), some 350 m long; the slope of the underlying surface 4.2°. The yield strength is of the order 1-2 x 10^2 Pa. At the unnamed 9 km crater, a broad melt flow occurs on the northeast rim. The flow begins as a broad flow (~150 m wide) with levees and then divides into two independent flows having well-formed levees. The slope is relatively steep at 14.4°. The flows are about 60-70 m wide, levees are 15-20 m wide, the central channel is 2 m deep and the flow is about 8-10 m thick. Estimates of the yield strength are 0.8-1.1 x 10^4 Pa.

For comparison, we assumed a density of 2640 kg m^{-3}. Denevi et al. [22] also assumed a density of 2640 kg m^{-3} based on the composition of a highlands soil (61221) whereas Moore et al. [21] used 2500 and 3000 kg m^{-3}. All other things being equal, the difference in density results in about a 10% variation in the rheology. While the models do not consider the flow temperature, the temperature of the impact melt will also control how far it flows and its morphology. An impact melt could be superheated, well above its liquidus temperature [23] with a corresponding lower density.

Hulme [7] examined a large melt flow on the northern rim of Tycho; he interpreted the melt as a lava flow. Assuming a viscosity of 10^6 Pa s, a yield strength of 1.7 x 10^4 Pa was estimated with a flow rate of 750 m^3 sec^{-1}, taking ~20 days to be emplaced. Moore et al. [21] examined impact melt flows at King, Aristarchus and Necho craters. They estimated yield strengths of 2.4 x 10^4, 1.9 x 10^4 and ~1 to 3 x 10^4 Pa, respectively. Denevi et al. [22] examined two melt flows at Mandel'shtam F, and determined average yield strengths of 4.6 to 6.0 x 10^3 Pa.

Discussions: The yield strengths estimated here for Bruno and 9 km crater differ from earlier studies by as much as two orders of magnitude. Estimates based on LRO data are lower than older studies. However, is it not clear if this difference is real or an artifact of the lower resolution of the data used in the older studies. Qualitatively, it appears the data are better behaved on the steep slopes. This may result from the fact that minor slope variations represent a smaller fractional change than on a shallow slope, thus reducing "noise." Similarly, flows on steeper slopes (all other aspects held constant) would have greater momentum and would be less influenced by the minor surface slope changes and roughness. It is interesting to note that the flow at Giordano Bruno, the largest crater, has the lowest yield strength.

Conclusions: LRO high-resolution imaging and DEM data allow for detailed studies of impact melt rheology. Studies of melt flow rheology provide critical information about aspects of cratering mechanics specifically energy partitioning amount fracturing, melting and vaporization. Data to date suggest a considerable range of rheologic properties. This range may be a function of insufficient data or it may be revealing significant difference in cratering energy. Varying impact angles impart different amounts of energy into the target. Depending upon the total energy of the event and the impact geometry, resulting melt temperatures can vary considerably.

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