MODEL FOR THE EMPLACEMENT OF THE OUTER EJECTA LAYER OF QUASI-MULTIPLE LAYER EJECTA CRATERS:

J. M. Boyce[1], Barlow[2], N. G., and Wilson[1] L., [1]Hawaii Institute of Geophysics and Planetology, Univ. HI, Honolulu, HI 96922, jboyce@higp.hawaii.edu, and lwilson@higp.hawaii.edu, [2]Dept. Physics and Astronomy, Northern AZ Univ., Flagstaff, AZ 86011-6011, Nadine.Barlow@nau.edu,

Introduction: Quasi-multiple layer ejecta (QMLE) craters are single or double- layer ejecta craters with an additional extensive outer thin layer which terminates in a sinuous "flame-like" edge. We [1] are currently conducting a global survey of the distributions of QMLE craters and modeling the emplacement of their outer ejecta layer as part of an on-going study. This abstract describes the work, to date, on the modeling aspects of this study.

Impact-Produced, Blast/thermal Pulse Model: Currently, the only well-developed model of the formation of the outer layer of these craters was proposed by [2]. They suggested that these distal features are not ejecta, but a duracrust-like layer produced as a result of an impact-produced, early-time, atmospheric blast/thermal pulse. This pulse generates extreme winds and lingering elevated temperatures that produce melting of subsurface volatiles that causes the formation of an erosion resistant armored surface.

However, because this model requires the generation of a substantial amount of water vapor to produce the blast/thermal pulse with the required characteristics, the example 10 km diameter crater (Lonar) used must form in a target that is composed of water or pure water ice (above a basalt substrate) with this layer being completely transformed to water vapor. While in itself this requirement is not unreasonable, the lack of geomorphic evidence in the crater cavity for the presence of this ice or water layer is troubling, as is the requirement that the surrounding surface be composed of regolith instead of the pure ice or water in which the crater hypothetically formed. These requirements are clearly inconsistent with the geology of surface of Mars in areas where these craters are found [3].

In addition, because the volumes of shocked materials and impact melt scales disproportionately with increasing transient cavity diameter [4], in order for impact craters to produce enough water vapor to generate the proposed blast/thermal pulse, impact craters ~ 0.6 of the diameter of the example crater [2] must form in targets composed entirely of pure ice or water. Hence, QMLE craters smaller than ~ 6 km diameter must not only impact targets made entirely of pure ice or water, but also acquire additional water vapor from elsewhere. This means that for craters smaller than ~ 6 km diameter the proposed mechanism generates insufficient water vapor, and hence, wind velocity and temperatures to produce QMLE craters. Furthermore, the blast/thermal effects calculated with this model are inconsistent with those predicted in a similar simulation by [5] that employed the same shock physics CTH hydrocode model [6]. Both simulations were for a similar size crater, formed in an ice-rich rock target, but the simulation of [5] employed a range of near surface pore ice (i.e., 0 to 100%) and failed to find the same blast/thermal effects as found by [2].

Pyroclastic Flow Model for QMLE Outer Layer Emplacement: Here, we outline an alternative model for emplacement of the QMLE outer layers. Our model suggests that these features are thin ejecta layers produced by the same mechanisms that allow the long run-out of the special type of terrestrial pyroclastic flow that crosses over tens of km of sea (e.g., the Koya flow in Japan that crossed over 30 km of sea) [7]. This model also offers an explanation of why these craters are found mainly in high-latitude regions and why they are relatively small. In our model, we assume that, to a first order, the physics of emplacement of some pyroclastic flows (those produced by volcanic explosions) and the outer layer of QMLE craters are similar because both likely owe their origin to collapse of an explosion column of hot silicate particles and gas.

It would be tempting to interpret the similarities in emplacement mechanisms and the similarities in some of the physical dimensions of these deposits [e.g., similar deposit aspect ratio of 10^{-4} to 10^{-5}, and run-out distances of tens of km; e.g., see 8, 9, 10, 11] as evidence that QMLE are just the impactite equivalent of a simple type of long run-out pyroclastic flow, but such an assumption would be in error. This is because of the role atmospheric pressure and density plays in the settling velocity of particles suspended in such gas/clast flows. The relatively low Martian atmospheric pressure and density dramatically increases the sedimentation rate of suspended particles in flows (i.e., of 2-3 orders of magnitude) causing any such Martian flow to quickly drop its solid load and halt. Hence, in general, long run-out pyroclastic-like flows are not possible on Mars without an additional mechanism that counterbalances the high particle settling rates.

However, the high-mobility of some terrestrial pyroclasts flows (i.e., those flows that crossed open seas) may not require a substantial atmosphere, but instead their flow is enhanced and sustained by steam arising from water/hot clast interactions [see 11]. We suggest that it is reasonable to expect that such enhanced mobility for gravity driven density flows (produced by collapse of debris from an ejecta vapor plume) is possible on Mars in high latitude regions covered by a meters-thick ice mantle [12] that could be a ready source of steam. As a first step in constructing a quantitative model to support and test this hypothesis for how QMLE outer ejecta layers may be emplaced based on this analog, we turn to the results of studies of the emplacement of sea-crossing pyroclastic flows.

In addition to field observations [e.g., see 13, 14, 15, 16], the behavior of pyroclastic flows that enter and cross water has been studied experimentally [17]. Based on these studies, it was found that, in addition to a wave formed as the flow pushed back the water during entry of the pyroclastic flow; an ash jet surge over the water and an ash cloud surge were generated. At the same time, course ash mixed into the water generated steam explosions consisting of back-dropping ash fountains and fine ash plumes rising by thermal convection. Remarkably, experiments show that the underwater mixing zone did not extend down to the bottom, but rather was confined along the surface [17]. The finer-grained load of the ash fountains contributed to the ash cloud surge, while the coarser sediment mixed with the water to form dense sediment plumes that rapidly fell to the bottom. Further explosions were generated from this along-surface mixing zone, with fountains throwing ash farther downstream. Subsequent explosions were commonly more vigorous than the ones closer to the entry location. In addition, experiments with shallower water showed that steam explosions extended further downstream, wet ash was ejected higher above the water, and ash fountains were even more strongly forward directed. The region across which the steam explosions occurred grew in length as long as the pyroclastic flow was maintained [17].

Experiments also showed that the ash-cloud surge initially decelerated away from shore. But as a strong explosive pulses began these pulses formed denser and faster ash-cloud surge-pulses that propagated to the front of the ash-cloud surge accelerating it. These explosions also generated waves that were sometimes larger than the initial entry wave. This indicates that this mechanism provides a powerful push forward for the surface flow.

For our model to be viable, this mechanism also must work on a Martian surface that is mantled by snow and ice. This requires that sufficient heat is transferred from the hot clasts to enough ice to rapidly transform it to steam generating strong explosive pulses that propagate the impactite equivalent of a forward-moving ash-cloud surge. While at this point formulation of our model is still a work in progress, we expect to address such issues as, for example, the grain-size distribution and temperature of the hot clasts, the mechanisms for mixing these hot clasts and ice, the transfer of heat during that mixing, the amounts of steam likely to be produced at various distances from the crater, and the distance to which the flow can be maintained.

References: [1] Barlow N. G. and Boyce J. M. (2011), *this meeting*; [2] Wrobel et al, (2006), *MAPS*, 41, 10, 1539-1550; [3] Tanaka et al., (2005), *JGR.*,108 (E4), 8043, doi:10.1029/2002JE001908; [4] Cintala M. and Grieve R.A.F. (1998) Meteor. Planet. Sci. 33, 889-912.; [5] Stewart et al., (2004) *Am. Inst. of Physics*, 1484-1487; [6] McGlaun et al., (1990), *Intl. J. Impact Eng*, 10, 351-360; [7] Ui et al., (1983), *EOS*, 64, 876; [8] Fisher RV., (1966), *Am. J. Sci.*, 264, 350-363; [9] Sparks R.S.J. et al. (1976) *J. Vol Geotherm Res.*, 7, 97-105; [10] Wilson C.J.N., (1995), *Philos. Trans. R. Soc. London, Ser.* A, 314, 229-310; [11] Dade W.B., (2003), JGR 108, B4, 2211; [12] Head et al., (2005), *Nature*, 426, 797-802; [13] Cas RAF, and Wright JV, (1991), *Bull Volcanol*, 53, 357-380; [15] Mandeville, et al., (1996), *Bull Volcanol* 57, 512-529; [16] Cary S. et al, (2000), *GSA Sp. Pap* 345, 1-14.; [17] Freundt A., (2003), *Bull Volcanol*, 65, 144-164.