MODEL FOR THE EMPLACEMENT OF THE OUTER EJECTA LAYER OF LOW-ASPECT-RATIO LAYER EJECTA CRATERS BY TURBUENT FLOW.

J. M. Boyce[1], N. G. Barlow[2], and L. Wilson[3], [1]Hawaii Institute of Geophysics and Planetology, University of Hawai'i, Honolulu, HI 96822, (jboyce@higp.hawaii.edu), [2]Department of Physics and Astonomy, Northern Arizona University, Flagstaff, AZ. 86011, [3] Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, U.K.

Introduction: Our study of low-aspect-ratio layer ejecta (LARLE) craters on Mars combines morphometric analysis [1] and modeling of emplacement mechanisms for the enigmatic outer ejecta layer. These ejecta layers are characterized by their long runout distances, nearly uniform thinnesses (< ~5 m), feathery shape of their outer edges, with long, narrow jet-like prominences of ejecta (both reminiscent of turbulent flow), and their fine-grain composition suggested by the THEMIS nighttime images of these deposits. Here, we discuss our preliminary findings on the emplacement mechanism of this outer ejecta layer of these craters.

Background: In contrast to the mechanism proposed here [1, 2], Wrobel et al. [3] proposed that this ejecta layer is a “duricrust-like” erosion-resistant surface produced by extreme winds, lingering high temperatures, and water vapor from the impacts that melted near-surface volatiles and caused them to migrate upward through the regolith. This model is inconsistent with the geology of the impact sites [4], requiring each LARLE crater to form in a place capped by a thick surface layer of pure ice or water. In the case of their example, (Lonar Crater ~11.5 km dia.), the target must be basaltic rock capped by a ½ km layer of water or pure ice. This upper water/ice layer must be completely vaporized by the impact in order to provide the required volume of water vapor. In addition, in this model [3], scaling relationships (crater size to volume of impact melt and vapor [5]) require that LARLE craters < ~ 0.5 the size of Lonar Crater must not only form in a target of water or pure water ice, but also include additional vapor added (from an unspecified source) to produce enough water vapor to generate the proposed blast/thermal pulse. Furthermore, the effects found by [3] are inconsistent with those found by [6] in a similar simulation that employed the same shock physics CTH hydrocode [7]. The simulations of [6] were for similar sized craters formed in targets composed of ice-rich rock, and employing a range of near-surface pore ice (i.e., 0-100%).

Suspension-Driven Gravity Current Model: The unique physical characteristics of the outer ejecta layers of LARLE craters suggests that they are emplaced by a different flow mechanism than other ejecta layered deposits found around Martian Craters. We also suggest that these characteristic imply that these outer ejecta layers are fine-grain ejecta emplaced as a radially spreading, suspension-driven, dilute gravity current produced by the collapse of an ejecta column [see 8]. This emplacement mechanism is similar to that proposed for pyroclastic flows that originate from eruption column collapse [9, also see 10], some of which are low-aspect ratio (average deposit thickness to average run-out distance) ignimbrites (LARI) whose aspect ratio (*AR*) is 10^{-4} or less. This mechanism also is similar to that of the emplacement of the thin, lobate deposits of fine-grain ejecta deposited around Schooner nuclear test crater (Fig 1). This extensive ejecta layer of Schooner was deposited by sedimentation from a dust-laden, turbulent, gravity-driven base-surge produced by collapse of the explosion column [e.g., 11]. The development of this thin deposit may have been enhanced because of subsurface detonation in a target composed of alluvium that may have contained >10 % water [11].

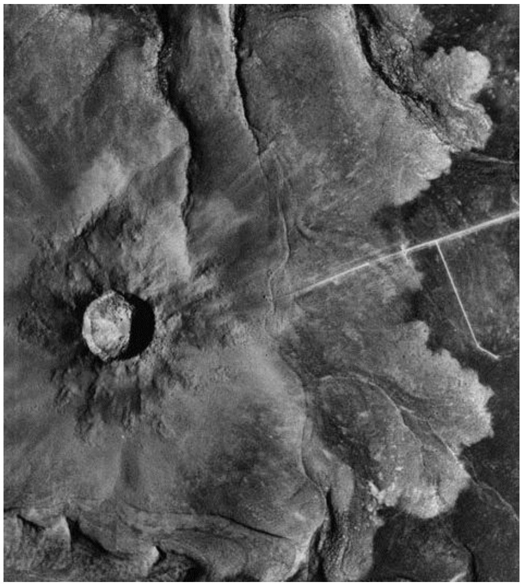

Figure 5. *Arial Photo of Schooner crater (375 m dia.) at the Nevada Test Site taken shortly after formation. This photo show light, thin (~ < 1 m), lobate, fine-grain ejecta extending outward for over 12 R.* [from 12]. *This deposit has an AR of ~2.23 x* 10^{-4}.

To test the reasonableness of our hypothesis, we employ the numerical model of Dade and Huppert [13, 14] for the emplacement of LARI to predict the run-out distance of the outer ejecta layer of Lonar Crater, and an unnamed 4.2 km dia. crater (crater 2) at 44.3º S., 139.3º E. We compare the predicted values with the actual run-out distances. Dade and Huppert [13] derived vertically averaged equations that govern the evolution of a dilute gravity current that spreads radially, where volume release is instantaneous, and the currents progressively loses the driving force associated with its density owing to particle fallout. We selected this flow model to use for our test because it 1) has been used to predict, with reasonable accuracy, the run-out distances of terrestrial LARI flows, 2) it uses the same mechanism that produced deposits around Schooner crater, and 3) the physical characteristics of LARLE outer ejecta layers are consistent wih those expected to be produced by operation of this mechanisms.

The measured average run-out distances (L) of the outer ejecta layers of Lonar, and crater 2, respectively, are ~ 60 km, and 45 km (from the crater center) and, average thicknesses are ~5 m and ~3 m (based on MOLA DEM), resulting in *AR*s of 8.3×10^{-5}, and 6.6×10^{-5}. Dade [14] simplified the equations of [13] for the characteristic scales of length L and time T of emplacement of fine particles by a turbulent, gravity current driven by a deposit–forming suspension. These are given by:

$$L = (64\, F^2/\lambda^3)^{1/8}\ \{\gamma\, g\, V_s{}^3/(w_s\, C_o)^2\}^{1/8}$$

and

$$T = [(4\, \lambda\, L^4)/\ (F^2\, \gamma\, g\, V_s)]^{1/2},$$

where g is the acceleration due to gravity, V_s is the initial volume (56.5 km^3 for Lonar and 31.5 km^3 for crater 2), w_s and γ are, respectively, the characteristic fall speed and dimensionless relative excess density of individual particles in the flow, F is the Froude number (assumed to be unity here [14]), and λ is the geometric aspect of the deposit in plan (π for radially expanding flows), C_o is the initial concentration of solids in a parent flow, given by $C_o = 8\ (\lambda\ V_s{}^3)/(A^4\, d)^{1/2}$ {C_o is ~ 4.7×10^{-2} for Lonar, and ~ 2.9×10^{-2} for Crater 2}, where A is the areal extent {A ~ 1.13×10^4 km^2 for Lonar and ~ 6.2×10^3 km^2 for Crater 2}, and d is the characteristic diameter of individual particles (~ 1 mm) [14].

We have solved these equations (with adjusted values for Martian conditions) and calculate that L for Lonar is ~ 59.7 km, T ~ 1071 s, and an average flow speed (U_{av}) of 56 m s^{-1}, L for crater 2 is ~ 44.8 km, T = 476 s, and U_{av} = 94.5 m s^{-1}. These numbers compare well to the actual values of L for Lonar ejecta and crater 2, and also to values of T and U_{av} for terrestrial LARI of similar size [14]; e.g., Koya (L = 60 km, T = 1137 s, U_{av} = 53 m s^{-1}) and Taupo (L = 80 km, T = 1180 s, U_{av} = 68 m s^{-1}), both with $AR = 2 \times 10^{-5}$. These findings suggest that the dimensions of the outer ejecta layers of LARLE craters are consistent with emplacement as dilute, turbulent, suspension-driven gravity currents composed of fine-grain clasts similar to those proposed for LARI [13, 14].

In addition, we suggest that these ejecta deposits may initially be warm enough to cause substantial melting of near-surface ice in the regolith, especially in the high-latitudes where ice may be nearly at the surface. Such melting may result in cementation of near-surface materials, and formation of a duricrust as suggested by [3]. The mechanism may explain the pedestal craters found in the same regions as the LARLE craters [1]. The elevated temperature of this ejecta is suggested by the initial temperature of some ejecta deposits (~ 750 ºC for the fallout suevite at Ries Crater [15]) and temperatures of long run-out (10s of km) LARI flows that are hot enough at their termini to incinerate organic materials.

Conclusions: Our preliminary results suggest that the outer ejecta layer of LARLE craters may be fine-grain ejecta deposited from a dilute, suspension-driven, gravity current produced by collapse of the ejecta column. This is similar to the emplacement mechanism proposed for LARI deposits, and for the thin, but continuous, dust deposits around Schooner crater. We find that, to first order, equations derived to predict the dimensions of LARI flows; also predict the run-out distance of our two Martian LARLE test craters. This suggests that the emplacement of the long run-out outer ejecta layer of LARLE crater is by a fluid mechanical mechanism that, while straight-forward, also is likely to be different than that of the other ejecta layers (e.g., suspension verse granular flow).

References: [1] Barlow N. G. and Boyce J. M. (2012) *this meeting*. [2] Boyce J. M. et al. (2008) *LPS XXXIX*, Abstract #1164. [3] Wrobel K. E. et al. (2006) *MAPS*, *41*, (10), 1539-1550. [4] Tanaka K. et al. (2005) *JGR*, *108*, (E4), 8043, doi:10.1029/2002 JE001908. [5] Cintala M. and Grieve R. (1998) *MAPS*, *33*, 889-912. [6] Stewart S. et al. (2004) In: Shock Compression of Condensed Matter-2003 *Am. Inst. Phys.*, 1484-1487. [7] McGlaun J. et al. (1990) *Intl. J. Impact Eng.*, *10*, 351-360. [8] Meyer C. et al. (2011) *Bull. GSA*, *123*, (11-12), 2312-2319. [9] Barnouin-Jha O. and Schultz P. (1996) *JGR.*, *101*, 21099-21115; [10] Fisher R. (1966) *Am. J. Sci.*, *264*, 350-363.; [11] Nordyke, M., and Willianson, M. (1965) *PNE-242F*, 103 p.; [12] Roddy, D. (1971), *USGS, Geol. Guide for Apollo 15 Field Trip to the NV Test Site*; [13] Dade W. and Huppert H. (1995) *Nature*, *381*, 509-510. [14] Dade W. (2003*) JGR*, *108*, B4, 2211. [15] Engelhardt W. v. et al. (1995) *Meteoritics,* 30, 279-293.