FORMATION OF MARS IMPACT CRATER RAMPARTS BY VOLATILE DEGASSING OF THE OVERLAND EJECTA FLOW. S. M. Baloga[1] and O.S. Barnouin-Jha[2], [1]Proxemy Research (14300 Gallant Fox Lane, Suite 225, Bowie, MD 20715. steve@proxemy.com; [2]Johns Hopkins APL, Baltimore, MD).

Introduction: The mechanical details of forming the distal ramparts of Mars impact craters remain enigmatic. Recently a new set of quantitative models of the ground-hugging overland ejecta flow appeared in the literature [1, 2]. These preliminary models consider very basic physical processes such as the conservation of ejecta flow volume and momentum and the role of boundary conditions at the entrance to the continuum flow regime. They differ from [3], who combined an ejecta production model with a wet Bingham model, which may not be valid to describe wet landslides and debris-flows [4].

The newer formulations [1,2] treat frictional resistance in an elementary way. These models are useful for estimating from observations of crater rampart topographies and dimensions, the basic character of the ejecta flow dynamics (e.g., whether vertical shear occurs at the base or throughout the flow [1]) and some of the flow parameters (e.g., emplacement times, flow velocities [2]). They also permit useful comparisons with the flow properties of other planar mass movements (e.g., debris flows, landslides [1]). However, the existing models do not clearly elucidate the role of volatiles in the rampart formation process and indeed it may be possible to produce ramparts with dry granular flows [1,4]. Either pre-impact target volatiles or some unique atmospheric process must play a presently unrecognized fundamental role either prior to or during the formation of rampart craters because rampart craters are not found on Mercury or the moon.

As one end-member of the wide-array of plausible mechanisms responsible for rampart formation, we propose an elementary transport model that considers the ejecta flow as two components, solids and a gas species derived from volatiles presumably in the target. Thus, we use two volume conservation equations as a model of the ejecta flow. They are made explicitly solvable partial differential equations by assuming a local volumetric flow rate that has been used in terrestrial mass flows (e.g., floods, debris flows, lahars) for many decades. Our adaptation of the flow rate model makes a simple choice for the dependence of the volumetric flow rate on the gas content.

Governing Equations: Here we assume that the solid component of the ejecta flow is conserved during transit. That is, there is no assimilation of pre-existing solids along the path of the flow or deposition. Thus the generic governing local conservation equation for the rock component in cylindrical coordinates is

$$\frac{\partial(hC_r)}{\partial t}+\frac{1}{r}\frac{\partial(ruhC_r)}{\partial r}=0 \qquad (1)$$

where $h=h(r,t)$, $C_r=C_r(r,t)$, u, r, and t are the thickness of the flow, the volume concentration of solids, the flow velocity and radial distance from the crater center and time, respectively. However, gas may be lost from the upper surface during transit so the conservation law takes the form

$$\frac{\partial(hC_g)}{\partial t}+\frac{1}{r}\frac{\partial(ruhC_g)}{\partial r}=-\nu C_g \qquad (2)$$

where ν is the exit velocity of the gas from the upper surface and $C_g = C_g(r,t)$ is the volume concentration of gas within the flow. Here we take ν as a constant. These equations cannot be solved explicitly without a prescription for the flow rate or an independent momentum equation [2].

As a prescription with a basis in terrestrial experience (e.g., [7, 8]), we would like to write an analog to

$$u=\sqrt{\frac{g\sin\theta h}{C}} \qquad (3)$$

for which there is a great deal of data on values of the flow resistance C for a wide variety of geologic mass flows in different settings. Values range over 3 orders of magnitude from about 0.0001 for very fluid mass flows to approximately 1 for dense debris flows [7,8]. Consequently we take

$$u=u(h)=u_o\sqrt{\frac{C_o}{C}h} \qquad (4)$$

A similar approach was taken in [1], except we considered both $u\sim h^{1/2}$ and $u\sim h$. The latter case represents a 'basal glide' where most of the flow shear is limited to a small region at the base and probably best describes long run-out landslides as well as 3-D granular flows. In [1], we showed that the basal glide provides profiles that resemble the observed ramparts. However, the $h^{1/2}$ version of our model did not include degassing effects.

Degassing effects are clearly plausible since Martian ejecta could be highly charged with gas at the entrance to the continuum flow regime, but as the flow loses gas,

particles begin to stick and the friction increases. Thus we take C to be proportional to the gas concentration to some power. Making the simplest choice we have

$$u = u(h) = u_o \frac{C_g}{C_{go}} \sqrt{\frac{h}{h_o}} \tag{5}$$

The governing equation for the solids with (5) becomes

$$\frac{\partial(hC_r)}{\partial t} + u_o C_{go}^{-1} h_o^{-1/2} \frac{1}{r} \frac{\partial(rh^{3/2} C_g C_r)}{\partial r} = 0 \tag{6}$$

The conservation of the gas species that is lost is given by

$$\frac{\partial(hC_g)}{\partial t} + u_o C_{go}^{-1} h_o^{-1/2} \frac{1}{r} \frac{\partial(rh^{3/2} C_g^2)}{\partial r} = -\nu C_g \tag{7}$$

These can be added to give

$$\frac{\partial h}{\partial t} + u_o C_{go}^{-1} h_o^{-1/2} \frac{1}{r} \frac{\partial(rh^{3/2} C_g)}{\partial r} = -\nu C_g \tag{8}$$

Theoretical Example. We have used the model above to illustrate typical ejecta flow thickness profiles for a range of different parameters. Here we assume that the continuum ejecta flow regime starts at a distance of 10 km from the center of a 20 km-diameter crater. We have taken the flow velocity and boundary flow depth to be 100 m/s and 30 m respectively, consistent with the recent results from a different model [2] of rampart emplacement. We start with a C value of 0.0025 and terminate the flow front when the velocity drops to about 1 m/s. The resulting thickness profiles are shown in Figure 1. With an initial gas content of 5%, the flow front thickness is somewhat higher than the upper limits of about 200 m reported in the literature. An initial gas content of 30% produces a thickness at the front consistent with typical rampart heights [1,2,5]. The overall shapes of these theoretical profiles correspond nicely to the MOLA profiles of single layer ejecta deposits in the literature [1,2,5], particularly with the radial narrowness of the prominent rampart.

Conclusions: The presence of a gaseous component in the ejecta flow that is lost during emplacement could be the factor that uniquely distinguishes the Mars rampart deposits from those of impact-generated deposits on other planetary surfaces. Our results show that the shape and dimensions of the deposits are sensitive to three factors: 1) the initial gas content, 2) the rate at which degassing occurs during emplacement, and 3) the final gas content when other processes (e.g., granular locking) finally terminate the forward advance of the flow.

The solutions of this mathematical model show that ramparts form naturally in cylindrical coordinates due to degassing while the ejecta flow is in transit. Moreover, the dimensions of typical rampart deposits are reproduced for flow resistance coefficients like those of catastrophic terrestrial mass flows. A very detailed comparison of model predictions and observed topographies and dimensions of rampart deposits will be required to establish whether degassing is an essential process in rampart formation or whether results from a host [1-4] of other models provide equally admissible explanations. Nevertheless, degassing during transit provides a simple and natural explanation for rampart formation that is consistent with the longstanding notion of a volatile requirement [6, 7] and features transport characteristics similar to terrestrial mass flow experience in planar geometries

References: [1] Barnouin-Jha et al., JGR 110, Issue E4, CiteID E04010, 2005 [2] Baloga et al., JGR, 110, Issue E10, CiteID E10001, 2005, [3] Ivanov, B., Solar System Research, V. 30, # 1, 43-58, 1996 [4] Wada and Barnouin-Jha, (submitted) MAPS, 2005 [5] Mouginis-Mark and Baloga, (submitted) MAPS, 2005 [6] Mouginis-Mark, Icarus, 45, 1981 [7] Schultz, JGR 97, 11,623-11,662, 1992. [7] Bulmer et al., JGR, 107, Issue E5, CiteID 5033. [8] Baloga and Bruno, JGR, 110, Issue E5, CiteID E05007 [2005] .

FIGURE 1: EJECTA FLOW THICKNESS PROFILE