DYNAMICS OF FLUIDIZED EJECTA BLANKETS ON MARS; B.A.Ivanov[1], B.C.Murray[2] and A.S.Yen[2]; [1]Institute for Dynamics of Geospheres, Russian Academy of Sciences, Moscow, 117979, [2]California Institute of Technology, 170-25, Pasadena, 91125.

We report the preliminary results of a study of fluidized ejecta blankets (FEBs) with rampart or convex termini around Martian impact craters. A numerical model was developed which suggests "dynamic" and "quasi-static" stages of ejecta emplacement. Turbulent versus laminar flow regimes are discussed. Viking Orbiter images were used to constrain ejecta flow velocities and subsequently to estimate cohesion and viscosity using a Bingham model. Comparisons between Martian ejecta flows and terrestrial rock avalanches and lahars are described. The final goal of the project is to better constrain the volatile content in the upper layers of the Martian crust.

The primary deposition process. The general scenario of ejecta depositing around an impact crater is formulated using the well-known Z-model of cratering [1,2]. The ejected debris flies along ballistic trajectories forming a "plume" in the shape of an inverted cone; this debris moves as a cloud of particles, not as a continuous sheet. The slowest particles are the first to be deposited on the uplifted rim of the crater, and the collective motion of the ejecta layer begins only after deposition of the material. The falling particles may disrupt the target surface and involve some of the ground material in the collective motion [3].

Flow models. We have evaluated several analytical and numerical models of the FEB's motion. The final radial extent of the FEB in our models is controlled by dissipation of the initial kinetic energy of the blanket (just after deposition). The dissipation mechanisms tested were turbulent and linear viscosity as well as finite cohesion. All of the ejecta is assumed to be at the surface when the outward flow begins, and the initial velocity is assumed to be the horizontal velocity of ejecta near the crater rim: $v_0 \approx \mathrm{sqrt}\{(2/15)*g*R\}$. For craters from 5 to 50 km in diameter, the initial flow velocity is approximately 30 to 100 m/s, respectively.

The linear viscosity model. The MAC numerical code [5], which calculates flows of Newtonian viscous fluids, was used to evaluate flow characteristics. The ejecta blanket is assumed to be an annular ring with a thickness that decreases as the inverse cube of the distance from the crater center. Although this model cannot calculate the final radius of the FEB (a viscous fluid in a gravity field will spread to infinity), it does reveal two distinct stages of the flow: (1) The dynamic stage where the inertia of the material is very important and (2) the late quasi-static stage where the flow spreads like a volcanic lava flow. The FEB for a 5-km crater has a model derived viscosity of 20 m^2/s and flows in the dynamic regime to a diameter of 15 km over several minutes. During the subsequent quasi-static stage, it takes ≈5 hours to increase the diameter from 15 to 20 km (velocity is a function of flow thickness). The material parameters may change over this long time period; models with time dependent material properties will be considered in the future. Further study will also indicate whether we can distinguish between dynamic and quasi-static deposits.

These MAC calculations also show that in the dynamic regime of a purely laminar flow, it is difficult to achieve a ratio of Rej (the final outer FEB radius) to R (the crater radius) larger than 3. For a laminar, dynamic flow, Rej/R is proportional to (viscosity)**(-1/8) for a constant R, therefore, an increase of Rej/R from 2 to 3.5 implies a two order of magnitude reduction in viscosity. For larger Rej/R values in the dynamic regime, the viscosity may be low enough to have a turbulent flow just after ejecta deposition.

The Bingham model. The final radius of the FEB is derived from the Bingham mechanical model: Plastic behavior under some threshold shear stress and a viscous fluid above the threshold (e.g., [4]). Bingham parameters have been estimated for avalanches and lahars on the slopes of Mount St. Helens [6], and we've constructed a similar model for the FEBs. In contrast to [6], FEBs flow on a horizontal surface, using the initial kinetic energy and the potential energy derived from its thickness. In our analytical model, the fluidized ejecta flow is a flat disk of constant volume spreading out from the crater rim, and the dissipation factors used in [6] are included. Some of the resulting parameters indicate that the FEB's flow is turbulent. In a strict sense, however, the term "turbulent flow" is only valid for continuous media. The ejecta from impacts is a collection of fragments with some size-frequency distribution and may contain some volatiles (Mars and Earth). The so-called Bagnold debris flow [7] may mimic the turbulent fluid flow: In both cases the shear stress is proportional to the square of the shear strain rate [8]. Depending on the chosen parameters, the model shows that the flow will have different velocity decays with distance. Constraints from Viking Orbiter images have been used to refine the model parameters.

Observations from Viking Orbiter images I. We have found and analyzed 15 situations in the Viking Orbiter images where the ejecta flow either overran or did not overrun older craters. The estimated heights of these obstacles were used to derive lower or upper limits of the flow velocities. The resulting model values of cohesion (2000 to 10,000 Pa) and viscosity (1 to 100 m^2/s) have been compared with the same parameters for Mount St. Helens (MSH) rock avalanches and lahars calculated in [6]. This comparison shows that model derived cohesion and viscosity range between values derived in [6] for MSH rock avalanches (10,000 Pa, 200 m^2/s) and lahars (500 to 1000 Pa, about 1.5 m^2/s). Longer flows ($Rej/R \approx 6$) have parameters close to terrestrial lahars while shorter runouts are more like rock avalanches. Values of these parameters are model dependent and may change for more sophisticated models.

Observations from Viking Orbiter images II. Another source of observational constraints is from the morphology of the FEBs surfaces. A subset of multiple-lobe FEBs exhibit radial striations extending from the crater rim to at least the edge of the inner ejecta lobe. A lahar-like flow could be responsible for this morphology. We discuss two possible scenarios: (1) The inner lobe may be deposited within the turbulent zone close to the rim; eddies help to sort the fragments, and the finer debris flows out to form the outer lobe. In this case, the striations are regions of shear and form when the flow in the inner lobe becomes laminar before the motion ceases. (2) The outer lobe flows over the earlier inner lobe deposits [9]; large rocks and boulders can be carried by the lower viscosity lahar-like flow thus creating the radial striations on the inner lobe. Further investigations will yield additional observational constraints on the FEB's deposition mode.

Conclusions

- Fluidized ejecta blankets may be formed as a dynamic, laminar flow only if $Rej/R < \sim 3$; this regime operates over several minutes. An alternative is slow viscous spreading to $Rej/R >> 3$ over the course of several hours.
- For $Rej/R > \sim 3$, turbulent flow is predicted by our model.
- The preliminary dynamic model results for $4 < Rej/R < 6$ show that in terms of effective cohesion and viscosity, Martian FEBs may be similar to some terrestrial lahars.
- In future work, we hope to be able to distinguish between deposits of turbulent and laminar flows in Martian FEBs. A better understanding of the radial striations may help constrain the FEB's mode of emplacement.

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