**INVESTIGATING THE FORMATION OF RAMPARTS AT FLUIDIZED EJECTA ON MARS USING A GRANULAR FLOW MODEL.** K. Wada[1] and O. S. Barnouin[1,2], [1]Planetary Exploration Research Center, Chiba Institute of Technology, Japan (wada@perc.it-chiba.ac.jp), [2]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD.

**Introduction:** Ejecta deposits of Martian craters show evidence for extensive surface flow not typically seen at other craters on the Moon and Mercury. The exact mechanism for why such surface flow occurs remains unclear, but it must be indicating some unique surface environmental condition. Typically fluidizing agents such as water or an atmosphere have been proposed to be responsible for the formation of these deposits [e.g., 1-5].

Simple granular flows can explain a wide range of flow features at landslides including their long run-out distance and lineaments, without necessarily invoking any volatiles [e.g., 6]. They might also explain fluidized deposits, with their long run-out, circumferential lineaments, thin deposit layers, and ramparts, also without necessarily invoking any volatiles or an atmosphere. In order to investigate simple granular flow models for such ejecta deposition, we use the three dimensional distinct element method (DEM)[7]. This method calculates the motion of each individual ejecta grain, taking into account mechanical interactions between grains. Our initial study [8] showed that the surface condition is important: smooth plains with a low coefficient of friction, or readily erodible plains can produce long run-out ejecta flow. Such smooth or readily erodible martian surfaces could be the result of sedimentary processes associated with large amounts of water that existed on Mars.

While our initial model showed that ejecta surface flow was fairly easy to achieve, it possessed too many simplifications that did not permit the formation of ramparts at the distal end of the ejecta deposits. One of the obvious simplification was that all the grains in our model were true spheres without any rolling resistance. As a consequence, grains kept rolling on flat surfaces even if the surface had a finite friction [8]. A necessary condition to make a rampart is that the distal ejecta must stop advancing. In the DEM, this implies giving the ejecta grains rolling resistance that reflects their natural angularity. This study, thus, investigates how giving ejecta grains rolling resistance in the DEM might generate ramparts, and impact the overall emplacement and flow of granular ejecta.

**Numerical method and settings:** In our DEM model, the mechanical interaction forces and torques between spherical grains in contact (and the floor) are expressed by the Voigt-model, which consists of a spring and dash-pot pair, in both normal and tangential directions. The spring gives elastic forces based on the Hertzian elastic contact theory. The dash-pot expresses energy dissipation during contact to realize energy dissipation with a given coefficient of restitution $e$. For the tangential direction, a friction slider is introduced to express Coulomb's friction law with a given coefficient of friction $\mu$. In this study, we introduce a rolling resistance between grains (and also the floor), which models the difficulty of rolling due to the grain angularity given by a torque $M_r = -\xi F_n$, where $F_n$ is the normal force and $\xi$ is the rolling displacement between grains (and the floor) in contact. We assume $\xi$ has a critical value $\xi_{crit} = R d_{crit}$, where $R$ is the grain radius and $d_{crit}$ is the dimensionless parameter. When $\xi$ becomes over $\xi_{crit}$, rolling resistance is reset to 0 and the energy stored in the rolling mode is dissipated. As $d_{crit}$ expresses the limit of rolling distance compared to the grain size, it is considered to be a measure of the grain angularity.

As an initial condition of our DEM calculations, we consider a 5-degree wedge of an ejecta curtain composed of 2958 grains with a radius of 35 m, each traveling on ballistic paths prior to deposition (Fig. 1). This initial condition was obtained by using the ejecta scaling relationship [9], assuming a transient crater with a radius of $\sim 5$ km (see [8] for details). We will present additional results using a more sophisticated initial conditions tied to the interior of the crater using Z-model [10], and many more ejecta grains. The latter may have equally important consequences during ejecta emplacement. Since this study focuses on the influence of rolling resistance of ejecta grains, we fix the surface condition as a smooth plain with a given $\mu_w$. We also fix $e = 0.4$, which does not strongly affect the results [8].

**Results:** Figure 2 shows examples of the final deposition of ejecta with $d_{crit} = 0.5$ and 0, respectively. The influence of rolling resistance can be seen in the morphology of final ejecta deposition. The thickness of deposited ejecta with $d_{crit} = 0.5$ is larger than that without rolling resistance. This is caused by the fact that rolling resistance prevent ejecta grains from rolling and moving far away. However, we cannot clearly see rampart-like morphology even for the case of $d_{crit} = 0.5$.

The rolling resistance affects the ejecta flow and its energy dissipation. Figure 3 shows the velocity profiles, in which the velocity of each ejecta grain is plotted as a function of the height in the flow. Since the slope of the profile reflects the degree of shear motion in the flow, a steeper slope indicates less energy dissipated. The slope

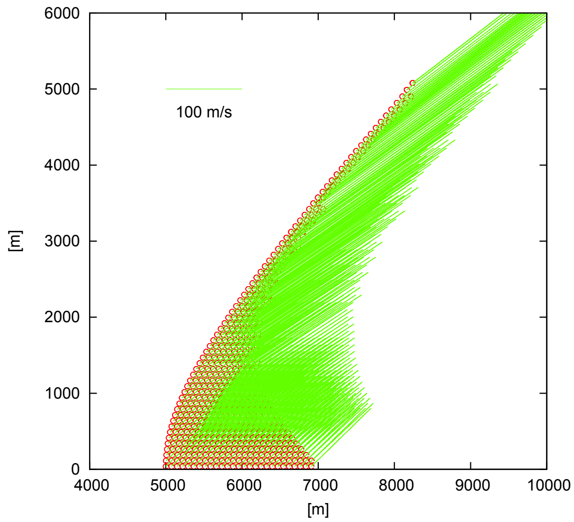


Figure 1: Side view of an initial condition of ejecta grains with their velocity vectors. The horizontal scale indicates the distance from an impact point.

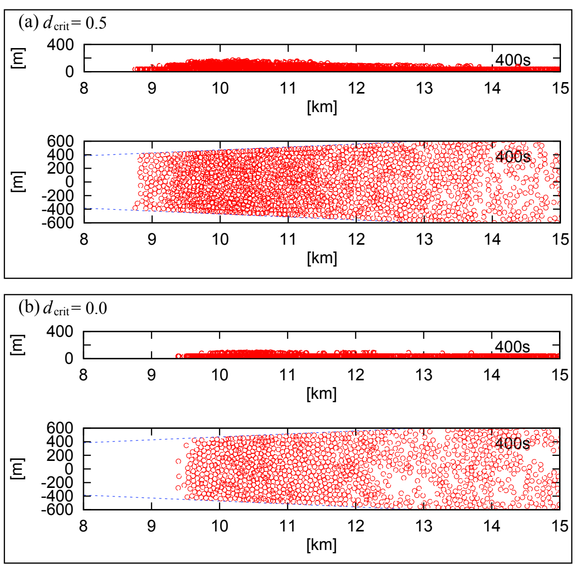


Figure 2: Side views and top views of deposited ejecta (400 sec after the start of the calculation) for the cases of (a) $d_{crit} = 0.5$ and (b) $d_{crit} = 0$. The coefficients of friction are $\mu = \mu_w = 0.5$.

for $d_{crit} = 0.5$ is shallower than that for no rolling resistance. This means that much more energy is dissipated when $d_{crit} = 0.5$, causing the ejecta motion to stop sooner, leading to a thicker near-rim ejecta deposit.

**Discussion and summary:** By introducing rolling resistance in our granular flow model, we have succeeded in stopping ejecta motion effectively. However, we have

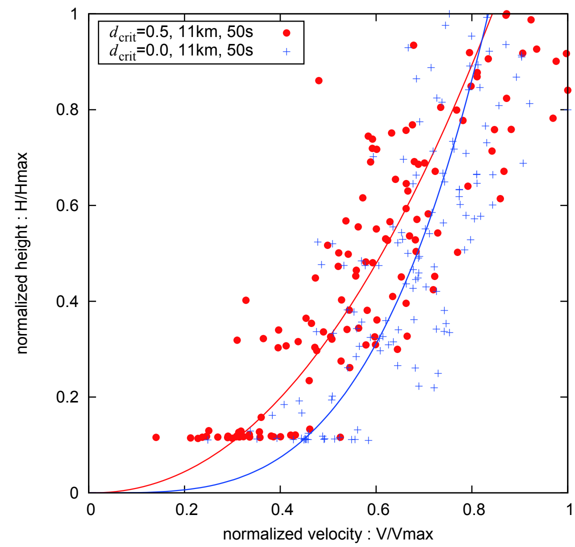


Figure 3: Velocity profiles of ejecta flow for the cases of $d_{crit} = 0.5$ (red circles) and $d_{crit} = 0$ (blue crosses). Both profiles are taken in a horizontal region of 11 km $\pm 100$ m, 50 sec after the start of the calculations. Fitting curves are also shown.

not yet succeeded in making an obvious rampart. This may be due to other simplification of our model such as the small number of grains considered, and their fairly large size. Secondary cratering of the surface material and their subsequent flow might also play a role. Further studies will explore all these factors, including direct comparisons of the DEM model relative to the new Ejecta Emplacement Simulator (see [11]).

**References:**

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