CO_2 SUBLIMATION IN MARTIAN GULLIES: INFLUENCE OF SLOPE ANGLE AND GRAIN SIZE ON SEDIMENT MOVEMENT.
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Introduction: Every spring, the solid CO_2 ice deposited over the martian high latitudes sublimates [1]. Several unusual surface features, including dark spots and flows on sand dunes [2], as well as recent activity in martian gullies [3], have been associated with this sublimation. However, the exact mechanism by which CO_2 sublimation moves sediment is not fully understood, and this understanding is required to validate the CO_2 hypothesis. Here we present the results of the first ever laboratory simulations of this process under martian conditions, showing that significant quantities of loose sediment can be transported, and examine the influence of slope and regolith grain size as process controls [4,5].

Approach: We performed 26 experimental runs at initial slope angles from 10°–30°, with coarse sand (594 µm mean dia.), fine sand (168 µm mean dia.) and JSC Mars-1 martian regolith simulant. The runs were conducted in the Mars Environmental Simulation chamber at The Open University, allowing control of the atmospheric composition and pressure. The model slopes were formed inside a box (~30 cm long, 23 cm wide, 12 cm deep) cooled with liquid nitrogen, Fig. 1.

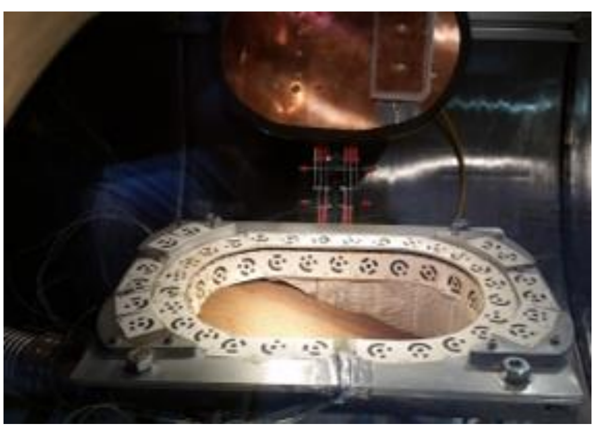

Fig. 1. Cooling box inside the Mars Environmental Simulation chamber. Slope is JSC Mars-1 at ~17.5°. Coded photogrammetric markers, for developing 3-dimensional surface models, encircle the slope. The lid (at top) shielded the slope from radiant heat during the cooling and frost condensation procedures. CO_2 gas was introduced through the foam diffuser at the front (right in image) of the lid during condensation.

After cooling, CO_2 gas was introduced over the slope, which condensed as frost on/in the surface. Finally, the chamber pressure was reduced to ~5 mbar and the slope heated radiantly from above. Stereo video of surface activity was recorded for photogrammetric analysis, allowing determination of slope-angles, displacement volumes, and rates [4,5].

Results: Table 1 lists the minimum slope angle at which each of four movement types (discrete flow, creep, gas entrainment, grain tumbling) were observed.

Table 1. Minimum slope angle required for granular movement by type.

Regolith simulant	Discrete flow	Creep	Gas entrainment	Grain tumbling
Fine sand	31°	29°	30°	None
JSC Mars-1	14.5°	11.5°	15.5	None
Coarse sand	33°	31°	None	31°

JSC Mars-1 was the most active of the three sediments tested, as evidenced by the correspondingly low observed angles. Coarse sand, in contrast, was the least active. Although sediment movement was observed for coarse sand, the displaced volumes were of the same order as the estimated photogrammetric noise. Coarse sand was the only sediment to display tumbling movements of individual sediment grains (~1 grain dia. displacements). Coarse sand was also the only sediment for which gas entrainment of fine grains was not observed. Fig. 2 illustrates the two forms of entrainment observed. Pitting was most frequent and extensive at the toe of the slope, where deposition over-topped surface CO_2 ice accumulations. Fan-shaped deposits of fine-grained sediment on the upslope box sides where only observed for JSC Mars-1 at slope angles below 20°.

Fig. 2. Gas entrainment features. (Left) Pitting due to sublimation of CO_2 ice buried by deposition. JSC Mars-1 initially near angle of repose. (Right) Fan-shaped deposits on box sides due to rapid escape of subsurface CO_2 gas. JSC Mars-1 at 20° initial slope.

Of the four movement types, only discrete flow and creep produced significant volumes of sediment transport. For JSC Mars-1, creep was not observed in six runs where discrete flows were present. Creep, without discrete flows, was observed in one run for JSC Mars-1 (11° initial angle; Fig. 3), one run for fine sand (at 30°) and coarse sand (34°). While additional work is needed to quantitatively assess the relative productivity of creep and discrete flows, the two mechanisms appear to displace comparable volumes of sediment.

Mass wasting of fine sand slopes was only present at angles near the angle of repose (Table 1). However, displaced volumes were comparable to those of JSC Mars-1 (82 cm^3 mean erosion for a surface area of 473 cm^2) [4].

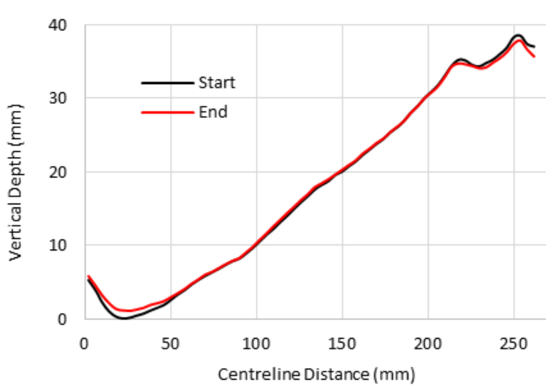

Fig. 3. Long-profile change due to creep. JSC Mars-1 at 11° initial slope angle.

Sylvest et al. [5] proposed that the observed mass wasting is caused by the reduction of the internal friction angle due to increased intergranular pressure, resulting from the sublimation of CO_2 ice. We developed a one-dimensional model, solving the continuity equations for energy and CO_2, while balancing downslope gravitational acceleration against Coulomb friction [4]. Solutions of this model using parameters consistent with our experiments were in agreement with the experimental results. Under Mars gravity, the model predicts that mass wasting could be triggered by this process at slope angles lower than those tested experimentally. The model also reveals that the increased activity range of JSC Mars-1 in comparison to the other sediments tested, may be due to the presence of fines, which lower the permeability of the simulant [4].

Conclusions: Four movement types were identified: discrete flows, creep, gas entrainment and grain tumbling. Movement type was controlled by initial slope angle and regolith type. Substantial mass wasting was only observed for discrete flows and creep. Volumes of mass wasting were comparable for fine sand and JSC Mars-1; however, significant movement was constrained to angles near the angle of repose for fine sand, while the minimum productive angle JSC Mars-1 was just under 17°. Measured volumes of mass wasting for coarse sand were minimal - on the order of the estimated photogrammetric noise.

Physical modelling confirmed the hypothesis that mass wasting was triggered by increased interpore pressure due to the sublimation of ice within the sediment. The model, combined with vertical temperature profiles from our experiments, reveals that CO_2 ice did condense in the subsurface, and that the quantity and distribution of that ice is vital to understanding the role of CO_2 sublimation in sediment transport [4].

We find that mass wasting, triggered by CO_2 sublimation, could play a role in some of the on-going changes observed in mid-latitude gullies and linear dune gullies on Mars. Creep, induced by CO_2 sublimation, could provide an alternate genetic mechanism for lobate features, often found in association with martian gullies [4].

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