THE FORMATION OF MARTIAN DUNE GULLIES BY DRY ICE: FIELD EXPERIMENTS Jim McElwaine[1,2], Serina Diniega[3], Candice Hansen[1], Mary Bourke[1,4] and Joanne Nield[5]. [1]Planetary Science Institute, Tucson, USA, (jmcelwaine@psi.edu), [2]Durham University, UK, [3]JPL, Pasadena, USA, [4]Trinity College Dublin, Ireland, [5]University of Southampton, UK.

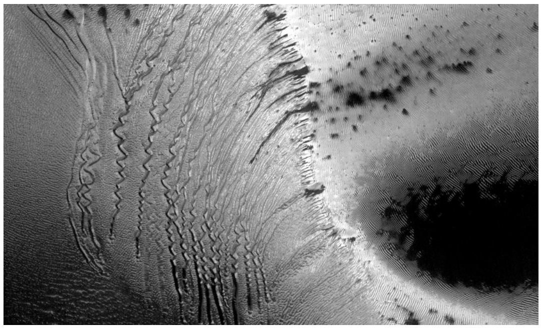

Figure 1: Zig-Zag gullies in a Dune Field in Kaiser crater, HiRISE PSP_010749_1325

Introduction Long, narrow grooves found on the slopes of martian sand dunes were first reported by Mangold et al. [1] and are most likely the result of large blocks of dry ice (figure. 1. Imaging by the Mars Orbiter Camera (MOC) on the Mars Global Surveyor and the High Resolution Imaging Science Experiment (HiRISE) on the Mars Reconnaissance Orbiter has demonstrated that these *linear gullies* are found within many dune fields and on sandy crater walls within the mid-latitudes on pole-facing slopes [2, 3]. These slopes typically range from 7 to 12° (well below the angle at which a dry granular material is expected to flow [4, 5, 3]), but the gully alcoves and grooves appear to originate within the steeper upper slope [can be $> 25°$; 4]. Over the past six Mars years, HiRISE images show that existing grooves have elongated and new grooves have formed at the start of each spring, demonstrating that these features are active in the present-day Martian climate.

The dry ice block hypothesis is consistent with the observed morphology, location, and current activity: that blocks of carbon dioxide ice break from over-steepened cornices as sublimation processes destabilize the surface in the spring, and these blocks move downslope, carving out levéed grooves of relatively uniform width and forming terminal pits.

Fieldwork: To test this hypothesis, we have performed experiments at two dune fields, Grand Falls in Arizona and Coral Pink in Utah. Dry ice blocks were released and on a variety of slopes and their positions

Figure 2: Setup on a falling dune at Grand Falls. Two high resolution video cameras, two calibration targets and a Terrestrial Laser Scanner are visible.

Figure 3: Ripples are gradually smoothed out by the repeated passing of the CO_2 blocks.

tracked in three dimensions using video cameras. In addition Terrestrial laser scanning was used to create digital terrain models and to map the changing morphology of the surface (figure 2). The data is combined to produce trajectory data for each block measured as arc length down the thalweg as a function of time. The results show that steady movement is possible on slopes of as little as five degrees.

Modelling: A model for the levitation of CO_2 blocks was developed in [6]. The flow of CO_2 gas within the sand bed is given by Darcy's law. The heat flux is calculated by solving a heat diffusion equation which have the result that, with Martian parameters, a block will levitate when

$$t < t^* \frac{H}{R} = \frac{H}{R} \left(\frac{\pi \mu h}{4gke\rho_s \rho} \right)^2 = 2.9 \frac{H}{R}\,\mathrm{s},$$

where ρ_s is the bulk density of sand, c is the heat capacity and κ_s is the thermal conductivity of sand. Thus even blocks of high aspect ratio (H/R) can levitate for a few seconds. The extended model had the same basic equations for heat flow and CO_2 flow, but when the block is levitating the heat flux will be much lower. Conduction now takes places through a combination of solid conduction and gas phase conduction with a linear transition depending on the CO_2 pressure relative to the solid pressure. The temperature boundary condition under the block then becomes

$$h = \frac{T_{z=0} - T_s}{r} \left[\kappa_s + \frac{p_{z=0}}{H\rho_s g} \frac{T_{z=0} - T_s}{r} (\kappa_g - \kappa_s) \right],$$

where κ_g is the thermal conductivity of CO_2. This heat flux under the block now depends on the position, since the pressure is spatially varying and a numerical solution is required. As the block moves it also encounters fresh sand which is hotter enhancing the mobility.

Finally there is an equation for the motion of the block. It is driven down the slope by gravity $mg \sin\theta$ and resisted by a frictional force proportional to the blocks weight minus the supporting CO_2 pressure. Finally there is a *form* drag due to ploughing like interactions with surface roughness. Taking s to be the coordinate down the thalweg (steepest descent slope) the equation of motion is

$$m\ddot{s} = mg\sin\theta - \mu(mg\cos\theta - F) - \tfrac{1}{2}\rho_s R r \dot{s}^2,$$

where F is the CO_2 pressure integrated under the block, C is a drag coefficient width and r a roughness length characterising the surface. The surface roughness r depends on the initial condition of the sand surface and then develops as blocks are released and remodel the surface. If there are initially ripples the surface roughness is high and reduces over time (figure 3). If the surface is initially smooth the blocks induce surface undulations similar to washboard road or moguls (figure 4).

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Figure 4: The initially smooth surface develops a *wahboard* pattern after multiple passings.

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