CARBON DIOXIDE ICE SUBLIMATION: AN AGENT OF CONTEMPORARY MARTIAN SURFACE FEATURE FORMATION. L. Mc Keown[1], M. C. Bourke[1,2] and J. N. McElwaine[2], [1]Trinity College Dublin (College Green, Dublin 2, Ireland mckeowla@tcd.ie), [2]Planetary Science Institute (1700 E Fort Lowell Rd # 106, Tucson, AZ 85719, USA, bourkem4@tcd.ie, mcelwainejim@gmail.com).

Introduction: Carbon dioxide is Mars' primary atmospheric constituent [1] and is an active and dynamic driver of Martian surface evolution. Kieffer's hypothesis that gas venting from beneath seasonally deposited south polar CO_2 slabs modifies the Martian landscape [2], spearheaded an advent of CO_2 modelling. In a climate in which it is difficult to sustain liquid water, the agency of sublimation in the form of the CO_2 block hypothesis [3], cryoventing [4] and basal sublimation-driven debris flows [5] is now recognized as a plausible architect of many contemporary features. These include the dendritic araneiform terrain of the south polar cryptic region, sand furrows and linear gullies. However, there is a dearth of empirical evidence to support CO_2 conceptual models. Here we present the results of a suite of laboratory experiments undertaken to understand the interaction between subliming CO_2 ice blocks and porous substrate. We test the CO_2 block hypothesis, which asserts that subliming CO_2 ice blocks may form linear gully pits [3]. We find that subliming CO_2 can mobilize grains to form features which may be analogous in morphology to those on Martian dunes. We present (1) pits and (2) furrows, formed via CO_2 sublimation, providing compelling evidence that CO_2 may be responsible for Martian features previously linked with water [7]. Based on a survey of Proctor and Russell Crater dunes, we present a new hypothesis for detached pit formation at linear gully termini.

Methods:

Laboratory Experiments. A low - humidity chamber was constructed in a constant temperature ($\Delta T \approx 1$ K) environment. An experimental chamber with a trap door was filled with silica beads and 'dessicating' CO_2 ice blocks were used for dehumidification purposes. This avoided water ice deposition onto the ~ - 80ºC CO_2 ice block which could hamper heat transfer and erase surface microtopography.

Guyson Honite Glass Beads of four grain diameter ranges (4-45 µm, 45-90 µm, 75-150 µm and 160-212 µm) were poured into the chamber for four separate experimental trials. Grain sizes finer than aeolian dune grains were chosen to account for the disparity in gravity and atmospheric pressure between Earth and Mars. We propose that coarser grains would be mobilised in a similar manner under Martian conditions.

Once relative humidity decreased below 10%, the trap door was opened and a CO_2 ice block of average mass 790g was either placed or slid onto the bed. The chamber was immediately re-sealed and the block was allowed to sublime during each experimental trial.

The resultant geomorphic feature in each case was imaged at overlapping angles. Images were then fed into Agisoft Photoscan, using Structure from Motion to generate a DEM and corresponding orthophoto of each feature (0.1 mm/pixel). Feature dimensions were then measured in ArcGIS using the DEM data.

HiRISE DTM Analysis. Linear gully pits in Proctor and Russell Crater DTM's were surveyed. The dimensions of terminal pits and their surrounding detached pits were recorded along with slopes and corresponding channel widths using ArcGIS.

Results:

Pit Formation. Pits (Fig. 1a) analogous in morphology to Martian linear gully pits (Fig. 1d,e) were observed following each experimental trial. These were characterized by depressions in the substrate which increased in depth with decreasing grain size. Levées and vent apertures were identified in most cases, which were also observed on levées bounding Russell crater linear gully channels. The Leidenfrost Effect [8], whereby a liquid or solid makes thermal contact with a surface at a temperature far beyond its boiling or sublimation point, caused each block to levitate on a cushion of vapor. The force of this escaping gas pushed grains from beneath the block to the side forming levées. These increased in height with decreasing grain size.

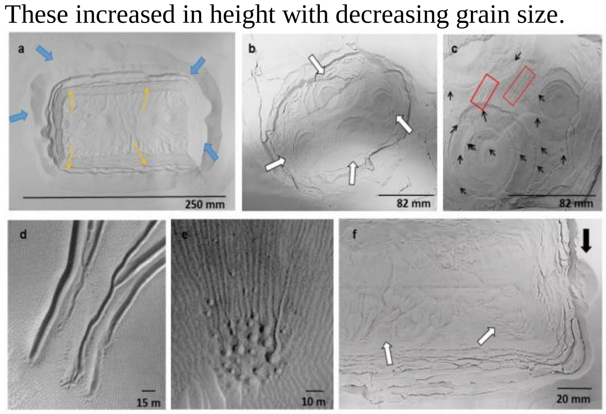

Fig. 1: (a) Pit, levées (blue) and slumps (yellow) formed on 45-90 µm bed. **(b)** Main and collapsed (white) pits on 4-45 µm bed. **(c)** Impact pits (black), linear strings (red) **(d)** Russell Crater attached and detached linear gully pits **(e)** Proctor Crater attached and detached 'tadpole' pits **(f)** Furrows (white), vent (black) on 4-45 µm bed.

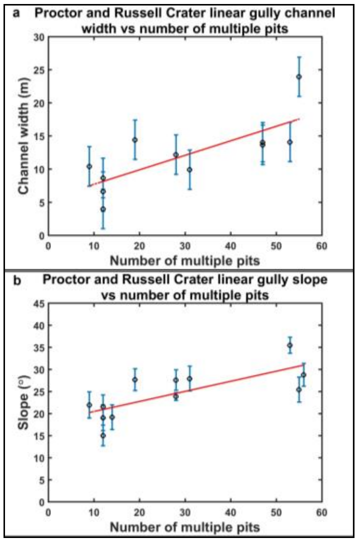

Fig. 2: Plots showing increase of number of multiple pits surrounding linear gully terminal pits with **(a)** channel width and **(b)** slope.

Furrow Formation. Furrows were observed on pit floors. These were formed by pressurized gas escaping through interstices between the rough block topography and the bed surface. Furrow abundance increased with decreasing grain size and network type was independent from grain size. Dendritic and curvilinear furrow networks were both observed on the 4-45 µm bed pit floor while only linear patterns resulted from a second trial of block placement on a 4-45 µm bed.

Impact Pits and Detached Linear Gully Pits. Rapid initial sublimation dynamics resulted when a block was slid onto the bed surface. Particularly in the 4-45 µm grain case, grains were mobilized on top of the block, and the block burrowed into the bed. Jets of CO_2 gas within which grain clusters were entrained, escaped from the subsurface. On return to the steady surface, these clusters formed ubiquitous impact pits with raised rims. Endogenic collapsed pits formed by the evacuation of the space from which gas jets emerged.

Discussion:

Our experiments indicate three pit formation modes – in particular, the formation of detached impact pits by clustering in granular jets. We suggest that detached pits at linear gully termini are formed by a similar process whereby CO_2 blocks experience maximum drag force at dune termini and entrain grains within subliming gas. A greater abundance of detached pits are formed for blocks of greater surface area and hence more CO_2 undergoing sublimation. On return impact, grain clusters form smaller, shallower pits detached from the main terminal pit. This is supported by our finding that the number of multiple detached pits surrounding linear gully termini in Russell and Proctor Crater increases with channel slope and width.

Furrows were formed by subliming CO_2 gas under low humidity conditions in the laboratory for the first time. Larger – scale furrows analogous in morphology have been identified on Martian polar dunes [6]. These were proposed to form through cryoventing, or the erosive action of pressurized CO_2 gas escaping through conduits between aeolian sediment and surficial CO_2 ice [4]. With appropriate scaling, our results provide empirical evidence to support this model. The concurrence of different furrow network types on substrate of the same grain size suggests that factors such as proximity of furrow source to vents, mass of overlying ice and thermal contact play a significant role in furrow patterning. These results may have implications for the recent distinction between furrows in the northern hemisphere and dendritic troughs of the southern hemisphere [9].

Our observations, though engendered by the sublimation of smaller scale CO_2 blocks, are of great significance in the validation of Kieffer's hypothesis and thus, many CO_2 hypothesis variants for contemporary Martian features. Our results verify that CO_2 venting involves an energy sufficient to mobilize grains on top of ice. Our study has delivered pioneering empirical laboratory results which show morphologies generated by the interaction between subliming CO_2 ice and porous substrate. These may be analogous to (1) linear gully pits and (2) furrows; active features observed to form in the current Martian climate. This research provides compelling evidence that Mars is subject to a unique geomorphic process unlike any we see on Earth.

References:

[1] Nier, A. *et al.* Composition and structure of the martian atmosphere: preliminary results from viking 1. *Science* **193,** 786–788 (1976). [2] Kieffer, H. H., Christensen, P. R. & Titus, T. N. CO_2 jets formed by sublimation beneath translucent slab ice in Mars' seasonal south polar ice cap. *Nature* **442,** 793–796 (2006). [3] Diniega, S. *et al.* A new dry hypothesis for the formation of martian linear gullies. *Icarus* **225,** 526–537 (2013). [4] Bourke, M. C. The formation of sand furrows by cryo-venting on Martian dunes. *Lunar Planet. Sci. Conf.* **44,** 1387 (2013). [5] Pilorget, C. & Forget, F. Formation of gullies on Mars by debris flows triggered by CO2 sublimation. *Nat. Geosci.* **9,** 65–69 (2015). [6] Bourke, M. C. & Cranford, A. Seasonal formation of furrows on polar dunes. *Fifth Mars Polar Sci. Conf.* 6059 (2011). [7] Costard, F. Formation of Recent Martian Debris Flows by Melting of Near-Surface Ground Ice at High Obliquity. *Science* **295,** 110–113 (2002). [8] Leidenfrost, J. G. De Aquae Communis Nonnullis Qualitatibus Tractatus. *Dusibg. Ovenius* (1756). [9] Portyankina, G., Hansen, C. J. & Aye, K.-M. Present-day erosion of Martian polar terrain by the seasonal CO2 jets. *Icarus* (2016).