ALLUVIAL FANS ON DUNES IN KAISER CRATER SUGGEST NIVEO-AEOLIAN AND DENIVATION PROCESSES ON MARS. M.C. Bourke [1,2.] [1]Planetary Science Institute, 1700 E. Ft. Lowell, Tucson, Arizona 85719 [2]School of Geography, University of Oxford, Oxford, OX1 3TB, UK mbourke@psi.edu

Introduction: On Earth, cold region sand dunes often contain inter-bedded sand, snow, and ice (Fig. 1). These mixed deposits of wind-driven snow, sand, silt, vegetal debris, or other detritus have been termed *Niveo-aeolian* deposits [1]. These deposits are often coupled with features that are due to melting or sublimation of snow, called d*enivation* features [2]. Snow and ice may be incorporated into dunes on Mars in three ways. Diffusion of water vapour into pore spaces is the widely accepted mechanism for the accretion of premafrost ice [3]. Additional mechanisms may include the burial by sand of snow that has fallen on the dune surface or the synchronous transportation and deposition of snow, sand and ice. Both of these mechanisms have been reported for polar dunes on Earth [4, 5].

Niveo-aeolian deposits in polar deserts on Earth have unique morphologies and sedimentary structures that are generally not found in warm desert dunes. Recent analysis of MOC-scale data have found evidence for potential niveo-aeolian and denivation deposits in sand dunes on Mars [6].

Alluvial fans: Alluvial fans have distinctive geomorphological and sedimentologic characteristics that include: 1. semi-conical form and plano-convex cross profile; 2. limited radial length (≤12 km); 3. restricted association with high relief settings; 4. high depositional slopes; 5. typically rare and catastrophic water and sediment discharge; 6. non-channelized, unconfined and expansive water flows; 7. interbedded association with water-flow (fluid-gravity flow) and sediment-gravity flow facies; 8. predominance of upper flow-regime, planar bedded, water flow facies [7].

Fans on sand dunes: Although rare, fans have been observed on sand dunes. The following is a brief review of formative processes.

Dry grain flow features are common on aeolian dune avalanche faces. They form due to loading and localised oversteepening on the avalanche face [8, 9]. Typically, they initiate on mid-slope and their planform is rectilinear. Transport tends to end abruptly at the base of the slope. Laboratory experiments undertaken with hollow ceramic spheres, simulating Martian gravity, indicate that dry granular flows can form fan shaped deposits [10].

Wet grain flow on aeolain dunes can produce fan morphology similar to that observed on Kaiser Dune. Typically a combination of rainfall on an impermeable surface (caused by induration, freezing or vegetation) can trigger surface flow and erosion of dune sand. These fans have been reported for linear sand dunes in Niger [11, 12], Nebraska [13] and observed in the rock record [14].

Denivation fans are formed by the the melting of interbedded snow and ice in sand dunes and can form fans on the avalanche face. These fans are not well studied but are generally small scale features (~1 m long, < 1 m wide) [15, 16] (Fig. 2). They form distinctive fan shapes, convex-up with superimposed lobes.

Study Area: Kaiser Crater Dunefield is a small intracrater sand sea in the southern hemisphere of Mars (47.3°S 340.8°W). Kaiser Dune (Fig. 3) is located at the eastern, upwind margin of the dunefield. This dune is a candidate for the largest barchan dune in our solar system standing ~ 500 m tall, ~6.5 km wide and has an estimated volume of ~ 2.5 km^3 of sand.

Three types of flow features have been previously noted on martian sand dunes: *Type I are Gullies:* sourced in alcoves at or close to the dune crest, with long slightly sinuous and leveed channels, that terminate abruptly without well-developed debris aprons [17-19]. These are thought to be debris flows initiated by the melting of subsurface ice, snow packs or seasonal frost [18, 20, 17]. *Type II are Simple slides:* initiated at the dune crest, they are shallow, relatively straight, smaller scale with lobate termini. They are thought to be dry grain avalanches [21, 17, 18]. *Type III are Large slides:* They are poorly described features of unknown origin [Fig. 4 in 18]. Geomorphic mapping of the avalanche face of Kaiser Dune indicates a series of features that suggest alluvial transport of sand. Features described below fall into the Type III category and are proposed to be alluvial fans and coalesced alluvial fan sequences.

Geomorphic Observations of kaiser Dune Fans:

1. Flow features occur predominantly on the west-facing avalanche face of dunes in Kaiser crater.
2. On Kaiser Dune, Type I gullies dominate the northern end of the dune while Type III are concentrated at the southern end.
3. Features are initiated in alcoves with deep steep-walled channels at both the slope crest and lower down the dune flank
4. Multiple phases of activity are indicated by superimposing relationships of channels and fans.
5. Deposits extend beyong the footslope of the dune.
6. Deposits are fan-shaped

7. Fans appear to have formed by avulsing channel location and concomitant channel head incision at the apex.
8. Steep walls and bench formation indicate induration of dune sands.
9. The larger fan complex has a feeder channel length of ~500 m and a fan length of ~525 m. Total surface area of the fan is 183,757 m^2

Discussion and Conclusions: On Kaiser Dune there are examples of significant terminal deposits and multiple periods of activation. This represents a new class of flow features on martain dunes indicating a higher ratio of liquid to solid that potentially representing hyperconcentrated flow or fluvial processes rather than a debris flow model. Although there are several mechanisms by which fans may form on aeolian dunes this work favors the niveo-aeolian model. The model proposed here, invokes the encorporation of snow and ice crystals into the aggrading dune. Melting of snow and ice layers within the dune, exposed at the avalanche face supply liquid for the formation of the fan complexes. This mechanism is also relevant for the gullies (Type II) features and may also influence Type I feature formation.

Implications for Dune migration on Mars: There is little data available for the migration of cold desert dunes on Earth. Marin and Filion [22] established that the rate of sub-arctic dune migration is about 10 times lower than that established for Saharan dunes. Aerial photographs, satellite and LIDAR data were used to assess if the Victoria Valley sand dunes in Antartica have migrated since 1958 and to observe the influence of niveo-aeolian deposits and permafrost on dune morphology. Preliminary results indicate that the dunes have migrated, and that dune form has changed (principally by merging and limb extension) [23]. It is therefore likely that dunes on Mars may contain niveo-aeolian deposits and still have the potential to migrate.

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Reference

[1]A. Cailleux, in R. W. Fairbridge and J. Bourgeois, eds., 1978, pp. 501-503.[2]E. A. Koster, (1988) *Journal of Quaternary Science*, **3**, pp. 69-83.[3]M. T. Mellon and B. M. Jakosky, (1995) *Journal of Geophysical Research*, **100**, pp. 11,781-11,799.[4]P. E. Calkin and R. H. Rutford, (1974) *Geographical Review*, **64**, pp. 189-216. [5]C. McKenna Neuman, (1993) *Progress in Physical Geography*, **17**, pp. 137-155.[6]M. C. Bourke, (2004) *Eos Trans. Fall Meet. Suppl.*, **85**, pp. Abstract P21B-01.[7]J. G. McPherson and T. C. Blair, 1993, pp. K33-K41.[8]M. Tischner, *et al.*, (2000) *Journal of Sedimentary Research*, **71**, pp. 355-364.[9]R. S. Anderson, (1988) *Sedimentology*, **35**, pp. 175-188.[10]T. Shinbrot, *et al.*, (2004) *Proc. Natl. Acad. Sci U. S. A*, **101**, pp. 8542-8546.[11]M. R. Talbot and M. A. J. Williams, (1979) *Catena*, **6**, pp. 43-62.[12]M. R. Talbot and M. A. J. Williams, (1978) *Earth Surface Processes and Landforms*, **3**, pp. 107-113.[13]M. R. Sweeney and D. B. Loope, (2001) *Geomorphology*, **38**, pp. 31-46.[14]D. Loope, *et al.*, (1999) *The Journal of Geology*, **1097**, pp. 707-713.[15]E. A. Koster and J. W. A. Dijkmans, (1988) *Earth Surface Processes and Landforms*, **13**, pp. 153-170. [16]A. Cailleux, (1974) *Zeitschrift fur Geomorphologie*, **18**, pp. 437-459.[17]D. Reiss and R. Jaumann, (2003) *Geophysical Research Letters*, **30**, pp. doi:10.1029/2002GL016704.
[18]N. Mangold and F. Costard, (2003) *Journal of Geophysical Research*, **108**, pp. 5027.[19]F. Costard, *et al.*, (2002) *Science*, **295**, pp. 110-113.[20]H. Miyamoto, *et al.*, (2004) *Geophysical Research Letters*, **31**, pp. doi:10.1029/2004GL020313.[21]K. S. Edgett and M. C. Malin, (2000) *Journal of Geophysical Research*, **105**, pp. 1623-1650.[22]P. Marin and L. Filion, (1992) *Quaternary Research*, **38**, pp. 316-330.[23]M. C. Bourke, *et al.*, (in prep)

Figure 1. Niveo-aeolian deposits, Alaska. Photo courtsey E. Koster.

Figure 2. Alluvial fan on dune avalanche face [16]

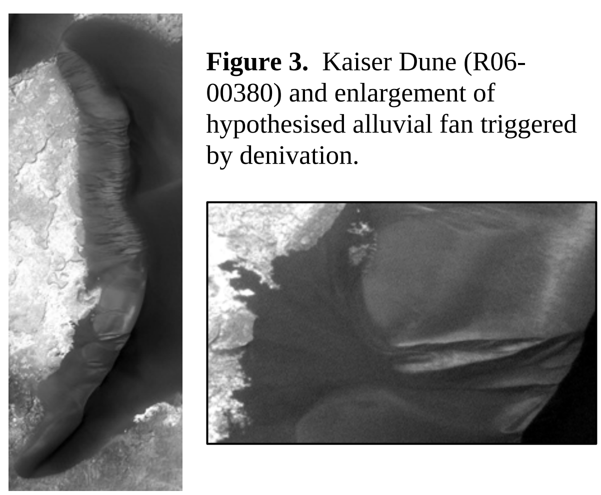

Figure 3. Kaiser Dune (R06-00380) and enlargement of hypothesised alluvial fan triggered by denivation.