ACTIVE-LAYER DRAINAGE WITHOUT SURFACE EROSION: TIME-LAPSE PHOTOGRAPHY OF ANTARCTIC SLOPE LINEAE AND IMPLICATIONS FOR THE FLOW OF WATER ON MARS.

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Introduction: Conditions are such on present-day Mars that at certain locations at certain times of year, liquid water should be capable of existing for short amounts of time [1, 2]. The best evidence that this is indeed true comes from the recent discovery in the southern mid-latitudes of "Recurring slope lineae" (RSL) [3], low-albedo streaks with no apparent topographic signature that advance down very steep slopes in austral spring and fade when temperatures fall. Found on relatively warm equator-facing slopes, the recurrence of these features at times when surface temperatures approach 0°C promotes liquid water (perhaps with some salt component) as the most likely substance that would produce this downslope darkening [4].

Identical features are found on the equator-facing wall of the South Fork of Upper Wright Valley in the McMurdo Dry Valleys of Antarctica (Fig. 1). Initial field observations in 2006-2007 [4-5] showed that the features in South Fork are low-albedo due to increased moisture content. Water flows downslope along the base of the ~20-cm thick active layer of colluvium that superposes the ice-cement table and wicks to the surface when sufficient moisture is available and the host material is more fine-grained. Of the various potential sources, melting of annual alcove-snow appears to be the most significant. This drainage appears to be transporting significant amounts of salt, based upon evaporites discovered at the distal margins of the lineae. The lineae trend downslope towards Don Juan Pond, the saltiest body of water on the planet.

Don Juan Pond is a shallow pond (~10 cm) that measures ~300 m from east to west (+/- 100 m depending on level of infilling) and is nearly saturated with $CaCl_2$, such that it rarely freezes in Austral winter, when temperatures descend to -50°C. Hosting a relatively rich ecosystem despite such harsh conditions [7], it has been used as a potential analog for what a contemporary pond on Mars might be like [8]. While the pond is fed by seasonal surface runoff to the west, drillers from the Dry Valley Drilling Project claimed to have tapped a shallow aquifer (3-4 m depth) that would be another potential source [9]. The pond's ecologic sensitivity makes detailed in-situ measurements and sampling difficult, and its curious proximity to the slope lineae [5] has never been fully accounted for.

In this contribution, through synchronized soil-moisture measurements and long-duration, high-frequency time-lapse photography, we argue that (1) the Antarctic linea are seasonally active akin to their counterparts on Mars; (2) flow within the active layer extends further downslope than does the surface expression of the lineae; and (3) this active layer flow is part of a near-surface drainage network that does not erode the surface but contributes to the infilling of Don Juan Pond and could contribute to its unparalleled salinity.

Methods: In December of 2009, a soil moisture probe was installed 1m within the contact of the lineae, and a matching probe was installed at the same station but 1m outside of the lineae (Fig. 1). Continuous measurements were recorded for nearly a calendar year, capturing peak activity in the 2009-2010 summer season and the onset of activity in the spring 2010-2011 season. Meanwhile, a Canon A590 camera was stationed across the valley atop the Dais and programmed to acquire one image every 5 minutes through the warmest part of the season, from late November until late January, totaling ~16,000 images. The scene was framed to capture both the most prominent lineae and the entire extent of Don Juan Pond. Software was written at Brown University to synchronize the soil moisture data with the time-lapse photography.

Results: Like the RSL on Mars, activity within the lineae is initiated in austral spring and, at this point in the season, is directly correlated with both the diurnal and seasonal temperature fluctuation of the soil (Fig. 2). Melting of in-situ ice begins in late October, while the temperature is still very low (-15°C), and continues through November.

In late spring and early summer, however, periods of warmth above the melting point are followed ~1 week later by significant increases in moisture detection on the lineae, with no corresponding increase off the lineae (Fig. 2). In the austral summer of 2010, this cycle appers twice, and is indicative less of in-situ ice and more of transport of meltwater from upslope, replenishing the moisture content in the lineae. By early February, temperatures decrease again, shutting off moisture supply to the lineae.

Orbital observations from the IKONOS camera show that lineae advance and recede over the course of several years (Fig. 1), but during the 2009-2010 field season, the lineae did not advance or recede in planform extent, based upon our time-lapse observations. Yet lineae geometry only reveals where water wicks to the surface, not the full extent of flow within the active layer. During December of 2009, when soil moisture activity within the lineae was increasing, we documented clear infilling of Don Juan Pond from the east, which is the direction of the lineae (Fig. 3).

Discussion: The slope lineae of South Fork and the recently discovered RSL of Mars [3] share several important properties: (1) Each feature represents downslope darkening with no apparent erosion of surface material; (2) Each feature initiates activity in mid-spring, when the surface temperature approaches the melting point of water or a liquid brine; (3) Each feature is no longer active when temperatures at the surface fall well below freezing. While the Antarctic lineae persist through multiple seasons and Mars RSL fade and then recur, this is consistent with the contrasting stability regimes of the two planets, where Antarctica is far more capable of retaining near-surface moisture as ice through austral winter, compared to Mars. As such, we believe that the RSL on Mars are likely to form in much the same way.

If this is correct, then RSL on Mars may represent the surface expression of a far more significant ongoing drainage system on steep-slopes in the mid-latitudes. Our time-lapse observations of infilling of Don Juan Pond from its eastern margin suggest that lineae-related flow extends beyond the extent of the lineae, and may just be one component of an extensive near-surface fluvial network. Don Juan Pond represents a closed drainage basin for all active layer-related flow from this portion of South Fork. Soil moisture measurements along the thalweg of South Fork to the east of Don Juan Pond in the austral summer of 2010-

2011 also revealed transport of water downslope in the direction of the pond. Depending on active layer thickness, slope geometry, volume of source material, and specific microclimatic conditions, we hypothesize that similar near-surface drainage processes with negligible erosional capacity is a viable hypothesis for activity on contemporary Mars.

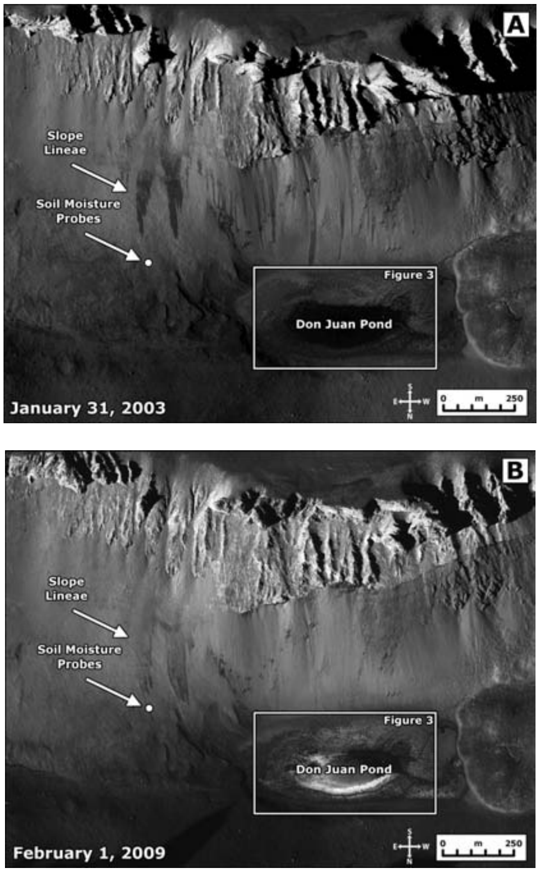

Figure 1. (A) IKONOS orbital image from 2003 of the Don Juan Pond region of the South Fork of Upper Wright Valley, Antarctica. Low-albedo slope lineae are observed on the warmer equator-facing slope. (B) IKONOS orbital image from 2009. The most prominent eastern lineae have advanced further downslope, while those directly above Don Juan Pond have faded.

References: [1] Haberle, R.M. et al. (2001) *JGR*, 106, 23317-23326. [2] Hecht, M. (2002) *Icarus*, 156, 373. [3] McEwen et al. (2011) *Science*, 333, 740-743. [4] Kreslavsky, M.A. and Head, J.W. (2009) *Icarus*, 201, 517-527. [5] Head et al. (2007) 10th ISAES, 177. [6] Head, J.W. et al. (2007) *7th Mars*, 3114. [7] Siegel, B.Z., et al. (1979) *Nature*, 280, 828-829. [8] Burt, D.M. and Knauth, L.P. (2003) *JGR*, 108, doi: 10.1029/2002JE001862. [9] Cartwright et al. (1974) DVDP Bul. 3, 75-91.

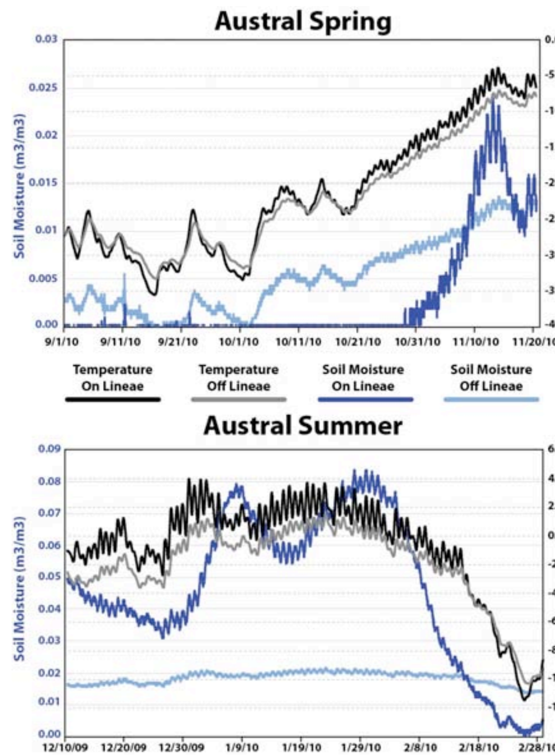

Figure 2. Temperature and soil moisture measurements on and off slope lineae in austral spring and austral summer. Initial soil moisture readings in spring appear to reflect in-situ melting of ice, while summer readings appear to show transport of water from upslope.

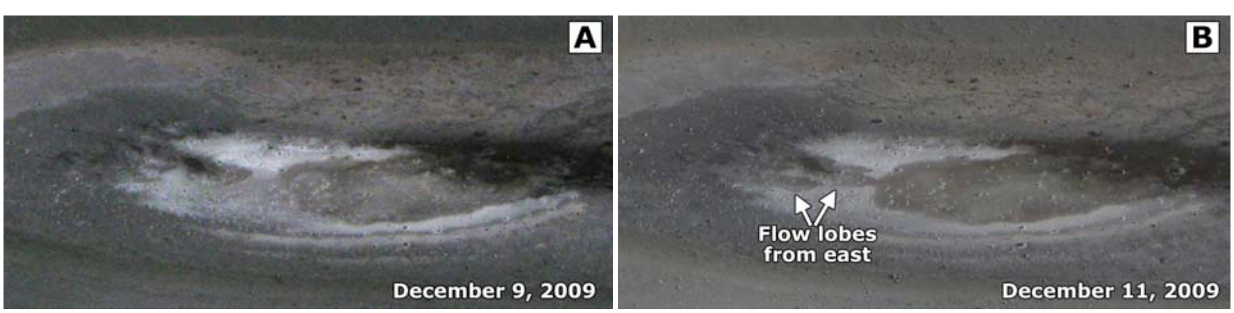

Figure 3. Time-lapse images of Don Juan Pond as water begins to drain into the pond from the east. Each image taken at ~20:00.