SLOPE STREAKS IN THE ANTARCTIC DRY VALLEYS: CHARACTERISTICS, CANDIDATE FORMATION MECHANISMS, AND IMPLICATIONS FOR SLOPE STREAK FORMATION IN THE MARTIAN ENVIRONMENT.

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Introduction: Slope streaks on Mars, first observed in Viking Orbiter images [1], were imaged in detail by MGS MOC [2,3], and have been observed to form and change over less than decadal time periods [3]. Typically displaying a low albedo relative to their surroundings, they show no detectable relief, are elongated downslope, usually <200 m in width, and usually extend for distances ranging from a few hundred meters to <2 km; length/width ratios range from ~5 to 30. They typically occur on steep slopes associated with massifs, escarpments and crater interior walls; no correlation with substrate of a particular age are seen. New streaks are typically the darkest, some relatively bright streaks are observed, and occasional brightness variations are observed within streaks; quantitative estimates of brightness contrast with local background are ~10% for dark streaks and ~2% for bright streaks. Streaks typically follow local topography closely, and often are digitate, or branch and fan in their distal (downhill) regions [2-8]. Streaks are not evenly distributed on Mars, occurring in some low latitude regions [4,5]; further, they occur exclusively in regions of low thermal inertia, steep slopes, and only where peak temperatures exceed 275 K; northernmost streaks form preferentially on warmer south-facing slopes [5]. Changes in slope streaks are observed only if the observation interval includes the warm season [5]; areas of most abundant slope streaks are positively correlated with GRS/NS elevated hydrogen levels [9,10]. These characteristics have led to a range of hypotheses for slope streak origin, including: 1) dry dust avalanches (with avalanching dust revealing the darker subsurface which then brightens with time as the avalanche scars are healed) [2,11], 2) dust avalanches controlled by wind [8], 3) wet debris flows [1], 4) both wet and dry debris flows [12], and 5) erosive fluvial processes from spring discharge, where melting is aided by hydrothermal activity or hypersaline aquifers [7,13].

Slope Streaks in the Antarctic Dry Valleys: The hyperarid, cold polar desert environment of the Antarctic Dry Valleys represents one of the most Mars-like temperature-precipitation environments on Earth [14,15]; the ADV are characterized by three major microenvironments, widespread permafrost, and extremely low, Mars-like erosion rates. There is currently no hydrothermal activity in the Dry Valleys region. Analysis of aerial photographs and satellite images of the South Fork of upper Wright Valley revealed the presence of streak-like features on the north-facing slopes of the valley wall (Fig. 1). These streaks typically display a low brightness relative to their surroundings, show no detectable relief, are elongated downslope, are usually <60 m in width, and extend for distances ranging from ~100-400 m; length/width ratios range from ~10 to 35. They occur on steep slopes $(10-30^0)$ associated with the southern wall of Wright Valley in colluvium derived from bedrock

scarps and massifs [15], which are exposed ~400-600 m above the valley floor. New streaks are typically the darkest, some relatively bright streaks are observed, and occasional brightness variations are observed within streak. Streaks follow local topography closely, are often digitate and branching distally, and show brightness differences related to variations in surface roughness at the meter scale. Slope streaks in South Fork (Fig. 1) occur exclusively on the warmer, equator-facing slopes.

Fig. 1. Slope Streaks in the ADV; Left: digitate streaks, image width 220 m; Right: parallel streaks and effect of local topography at lower left; image width 260 m. Slope is 20-30^0, top to bottom.

Field Observations: During the 2006-2007 austral summer (October-January) we made field observations of the South Fork slope streaks in an effort to understand their nature, mode of formation and evolution. Helicopter-based reconnaissance confirmed the basic observations made from the aerial photos and satellite images described above. A series of field traverses were conducted across the streaks, along the streaks and inter-streak areas to as high a level as safety would permit, and along outcrops and terrace at the top of the scarp.

Terrace, scarp and slope: About 500-600 m above the floor of the valley lies a 3 km long terrace that formed due to listric faulting of the northern portion of the Asgard Mountains [16]. Bedrock is generally continuously exposed at the top of the scarp, and is progressively covered with colluvium downslope. The topography of the bedrock scarp varies along strike, ranging from planar, near-vertical cliffs to alcove dominated sections; the latter collect windblown snow in the austral winter, some of which remains well into the austral summer.

Colluvium surface: Surface observations of the streak margins confirm the brightness change observed at other scales: the line of demarcation between dark streaks and brighter inter-streak areas is knife sharp at the cm scale. The top of the colluvium surface has undergone eolian deflation and is characterized by a desert pavement with ventifacts. There is no evidence for differences in grain size, surface textures, or rock types, between streak and inter-streak areas at the cm to m scale. No distal or lateral deposits of dust, sand, or other materials were found in association with the streak. No evidence of fluvial activity or overland flow of water was observed (e.g., channels, rills, sorting, or sedimentary structures). Streaks remain prominent despite active eolian deflation.

Color variation within streaks occurs and appears to be related to darkening of the finer-grained soil component of the deflated surface.

Colluvium subsurface: Soil pits were excavated in streak and between streak areas in order to assess whether the streaks had a three-dimensional (subsurface) manifestation. Observations and physical measurements were made in shallow and deep pits in the streak and interstreak areas, samples were taken for grain-size, lithology and mineralogy, and gravimetric water content analyses, and the depth to the ice table (where ice-cemented soils/colluvium are encountered) was measured. Excavation of shallow pits revealed that the most fundamental difference between the subsurface soils of the colluvium in the streak and inter-streak areas was a difference in their water content. Soils in the inter-streak areas were dry at visible scales at the surface and down toward the ice table. Soils in the streak areas were moist from the surface down to the top of the ice table in the colluvium; no other visible differences between streak and inter-streak areas were observed in the soils making up the colluvium (e.g., grain size, mineralogy, petrology, sorting, layering, depth to the ice table, etc.). Excavation of deeper pits confirmed these initial observations. Regional depth to the ice table is ~20-40 cm.

Mode of Origin of ADV Slope Streaks: On the basis of these observations, we conclude that the primary cause of the slope streaks is the presence of moisture in the streak areas at the surface and in the subsurface; streak geometry (fingering downslope) and analysis of colluvium adjacent and distal to the streaks indicates that the water is moving downslope and that the enhanced water content is derived from the upper parts of the scarp and terrace. We assessed three candidate sources of the water in our field investigations: 1) Subsurface aquifer groundwater sources from below the permafrost layer: We searched extensively for evidence of outcrop wettings or icings, springs, seeps, or other manifestations of the presence and release of deep groundwater; we found none; furthermore, excavations continuously revealed the top of the ice table at 20-40 cm, suggesting that permafrost was continuous in the area. 2) Local melting of the ice table: Could localized top-down insolation-related heating (downward migration of the melting geotherm) cause melting of the top of the ice table and downslope migration of water? Our field data (instruments/excavations) during the study period suggest that the current ice table is deep (~20-40 cm) and not significantly influenced by the seasonal thermal wave; however, we measured local melting at the top of the ice table, and this, and water vapor wicked to the surface and seasonally frozen, could contribute meltwater in the summer. 3) Melting of seasonal and perennial snowpack: The most obvious source of water in the streaks is from melting of the seasonal and perennial snow banks commonly found on scarps and in alcoves in the ADV [15]. Precipitated and wind-blown snow collects in these relatively protected areas in the austral winter, and lasts well into the austral summer, while adjacent, more exposed snow patches and cover undergo more rapid sublimation [15]. Along and within the terrace scarp, we observed patches of snow that remained on the surface and in the alcoves throughout the field season; snow was concentrated in the broad areas above the slope streaks (and not seen in adjacent areas where slope streaks were absent). In addition, individual slope streaks show a close correlation with individual alcoves.

On the basis of these observations, we interpret the mode of formation of these slope streaks as follows: Preferential accumulation of snow during the austral winter in specific environments in the scarp and on the terrace results in the preservation of snowpack into the austral summer; during austral summer, and in areas with favorable insolation geometries, melting takes place in the snowpack and the meltwater percolates into the dry substrate to the top of the ice table, where it then begins to migrate downslope. In areas of coarser colluvium (usually at the top of the slope) porosity is higher, and water travels downslope along the top of the ice table; when it reaches the finer-grained colluvium typical of the mid-to-lower slopes, pervasive grain-boundary contact causes "wicking" of the moisture traveling along the top of the ice table toward the surface, resulting in the wetting of the surface that produces the streak. Streaks widths and lengths appear to be determined by the width and thickness of the snowpack source, and the insolation geometry that permits melting. Diversions in course are caused by changes in slope orientation (mirrored in the ice table). Bright streaks occur adjacent to some dark streaks and appear to represent former dark streaks that have undergone desiccation; relative brightness may be related to salts deposited by the moisture.

Implications for slope streaks on Mars: Although the ADV represent one of the most Mars-like terrestrial environments [14,15], there are also substantial differences (e.g., atmospheric pressure and composition; abundance of water, etc.) and thus analogs must be assessed cautiously. Among the observations of Mars streaks that suggest that this mechanism should be seriously considered are: 1) similarities in characteristics, brightness, scales, slopes, aspect ratio, temporal behavior, and modes of occurrence; 2) distribution and geometry of occurrence suggesting a relation to solar insolation (low latitudes and northernmost streaks for preferentially on warmer south-facing slopes); 3) the observation that they occur only where peak temperatures exceed 275 K, and that changes occur only where there has been an intervening warm season, suggesting a potential role for the melting of surface snow and ice. We thus conclude that the surface-near surface melting and water migration origin of slope streaks interpreted from the ADV should be seriously considered as a mechanism for the origin of slope streaks on Mars.

References: [1] H. Ferguson & B. Lucchitta, NASA TM-86246, 188, 1984; [2] R. Sullivan et al., JGR, 106, 23607, 2001; [3] M. Malin and K. Edgett, JGR, 126, 23429, 2001; [4] M. Rifkin & J. Mustard, LPSC 32, 1698, 2001; [5] N. Schorghofer et al., GRL, 29, 2126, 2002; [6] O. Aharonson et al., JGR, 108, 5138, 2003; [7] J. Ferris et al., GRL, 29, 128, 2002; [8] D. Baratoux et al., Icarus, 183, 30, 2006; [9] W. Boynton et al., Science, 297, 81, 2002; [10] W. Feldman et al., Science, 297, 75, 2002; [11] A. Treiman & M. Louge, LPSC 35, 1323, 2004; [12] H. Miyamoto et al., JGR, 109, 2234, 2004; [13] T. Motazedian, LPSC 34, 1840, 2003; [14] V. Baker, Nature, 412. 228. 2001; [15] D. Marchant and J. Head, Icarus, in revision, 2006; [16] M. Isaac et al, Geol. Map 20, N.Z. Inst Geol., 1995.