MASS-WASTING SLOPE STREAKS IMAGED BY THE MARS ORBITER CAMERA. R. Sullivan[1], K. Edgett[2], M. Malin[2], P. Thomas[1], and J. Veverka[2], [1]CRSR, Cornell University, Ithaca, NY 14853, sullivan@cuspif.tn.cornell.edu, [2]Malin Space Science Systems, San Diego, CA.

Introduction: Narrow, fan-shaped dark streaks were observed on steep martian slopes in some of the highest resolution Viking Orbiter images. Several origins for dark slope streaks were proposed[1,2,3], but a conclusive explanation was not possible due to the limited resolution of the Viking images. The Mars Global Surveyor (MGS) Mars Orbital Camera (MOC) has obtained >22,000 high resolution images, many <5 m/pixel, since September, 1997, with the majority of these being returned since the mapping phase of the mission began in March, 1999. These images show innumerable examples of dark slope streaks distributed widely, but not uniformly, across the brighter equatorial regions, as well as individual details of features that were not visible in Viking Orbiter data. Initial assessments of these features with early MOC data generally confirmed previous characterizations from Viking images while showing important additional details from many new localities[4]. Here we report on observations made from new MOC images obtained since March 1999, which suggest a dust-based avalanche model is the most likely explanation for slope streak formation. Dark slope streaks (as well as much rarer bright slope streaks) represent one of the most widespread and easily recognized styles of mass-wasting currently affecting the martian surface. Edgett et al.[5] at this meeting presents evidence showing new dark streaks have formed since Viking and even during MGS missions, confirming earlier suppositions that darker streaks are younger, and fade (brighten) with time[2,3].

Morphology of dark slope streaks (Fig. 1): Streak margins are sharp even at MOC resolutions <2 m/pixel, but show no relief. The covering/uncovering layer responsible for creating the contrast must be extremely thin. Upslope ends of streaks are acute and provide no obvious clues relating streak location to potential sources of dark material (e.g., no obvious evidence for dark material outcrops at or near upslope ends). Downslope ends commonly are digitate in MOC images, which suggests a ground-hugging flow subject to deflection around minor topographic obstacles. The darkest slope streaks represent about 10% contrast with surrounding slope materials, and internal darkening is relatively uniform throughout each feature. In rare cases MOC images resolve hints of internal streak texture, including instances where subtle textural relief is continuous across streak margins as if minor preexisting slope roughness were "showing through" the dark streak interior, hardly disturbed by events involved in dark streak formation. Viking work and preliminary MOC analyses have concentrated on dark slope streaks, but rare bright slope streaks having the same general features except reversed contrast (i.e., they are brighter than surrounding slope materials) have been observed. Slope streak apexes are located subjacent to slightly more rugged and/or slightly steeper terrain in many cases, including immediately downslope of singular knobs (Fig. 2). Acute upslope ends suggest single-point origins for individual features. There are many examples of dark streaks descending in complex paths indicating mass-movement occurred outside a narrow range of likely angles of repose for granular materials. Slope streaks appear on a wide range of slope textures, from smooth and featureless to rougher aeolian or even heavily cratered slopes.

Discussion: The upslope-pointing triangular shape of slope streaks is distinctive, and differs from many terrestrial landslide scars that decrease in width (and depth) downslope and have crowns that are amphitheater-shaped, not pointed (e.g., [6]). However, laboratory experiments with glass beads on rough inclined planes indicate two styles of landslide scar occur, depending on the depth of the mobilized layer: (1) thick mobile layers create avalanche scars that narrow downslope and have rounded crowns that propagate upslope from the trigger point; (2) thin mobile layers form acute triangular scars expanding downslope ("pointing" upslope)[7]. Triangular, upslope-pointing scars are also characteristic of thin-skinned failures involving avalanches of dry, loose snow (Fig. 3). This style of snow avalanche occurs under cold, nearly windless conditions which retard metamorphism of new-fallen snow crystals and prevents inter-particle cohesion from developing[8]. Avalanches of loose, dry snow typically are triggered by simple rotational slip of <1 m^3 of snow, which then entrains a widening cross-section of mobilized snow traveling downslope, creating a very shallow triangular scar[9].

Two mass-wasting models differing in the average size of mobilized particles were proposed based on initial MOC analysis[4]. Both models create dark slope streaks by disturbing a brighter dusty mantle to partly reveal a darker substrate. The first model involves ejection/intercalation of a thin mantle of dust on an underlying debris flow, probably triggered where debris resides near its angle of repose. In this scenario a block strike or other trigger causes only minor downslope movement of individual debris elements, and the dust mantle is partially ejected into the atmosphere, is intercalated between the debris elements, and/or relatively dust-free faces of individual debris elements are exposed to view. Long downslope displacements of individual debris elements from the top to the bottom of the streak zone are not implied; individual displacements of only a small fraction of the streak length would be required to reduce dust and brightness. This model was favored on the basis of initial analyses, but additional observations from recent MOC images pose challenges. If downslope displacements of individual debris elements underlying the dust mantle are short, then average velocities must be very low and one would expect such movements to be restricted to slopes very near the angle of repose. This expectation is inconsistent with the wide range of gradients where dark and bright slope streaks are found, and with apparent changes in gradient along many individual streaks. Dark streaks are found on heavily cratered surfaces in some places, and this observation combined with indications that dark streak formation recurs on time scales similar to local dust deposition rates[5] requires that mass-movements involved in streak formation must be sufficiently non-destructive to preserve a relatively old, heavily cratered surface after many mass-movement cycles.

The model we favor involves dust avalanches following oversteepening of an airfall deposit. This idea supposes that dark slope streaks are scars from avalanches composed primarily of dust. Low angles of internal friction (typically 10-30 deg) for terrestrial loess and clay materials suggest that mass movement of low-cohesion martian dust material should be possible on slopes well below angles of repose for sand-sized and larger particles. If dust avalanches are responsible for the dark streaks, then the failed layer must be very thin, because levees, distal deposits, or margin relief of any kind have not been observed at only a few meters/pixel. Trial calculations applying an infinite slope analysis (e.g., [10]) indicate martian gravity, low presumed density of the airfall deposit, and limits to the depth of the failed layer require extremely low cohesive strength at time of failure, consistent with expectations for an airfall deposit of dust particles. Downslope digitate streak ends show little evidence that significant quantities of material accumulated at the downslope ends of slope streaks during their formation. Modeling is underway to determine if avalanche velocities and dynamics are sufficient to suspend dust during entrainment as the avalanche front moves downslope.

References: [1]Morris (1982) *JGR*, *87*, 1164-1178. [2]Ferguson and Lucchitta (1984) *NASA TM86246*, 188-190. [3]Williams (1991) *LPSC XXII*, 1509-1510. [4]Sullivan et al. (1999) *LPSC XXX*, #1809. [5]Edgett et al. (2000) *LPSC XXXI* #1058. [6]Crozier (1973) *Zeit. F. Geomorph.*, *17*, 78-101. [7]Daerr and Douady (1999) *Nature*, *399*, 241-243. [8]McClung and Schaerer (1993) *Avalanche Handbook*, 271 pp. [9]Perla (1980) in Colbeck, *Dynamics of Snow and Ice Masses*, 397-462. [10]Graham (1984) in Brunsden and Prior, *Slope Instability* 175-177.

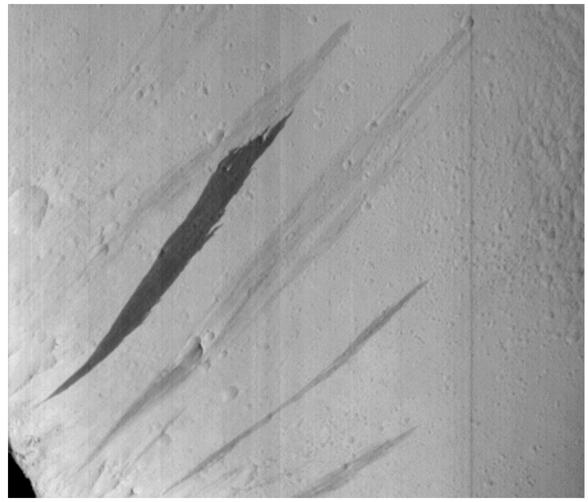

Fig. 1. Excerpt from MOC image M03-7769. Dark slope streak descending lower left to upper right near 25.3N, 143.7W. Darkest streak terminates against older, fainter streak, suggesting depletion of dust supply halted movement.

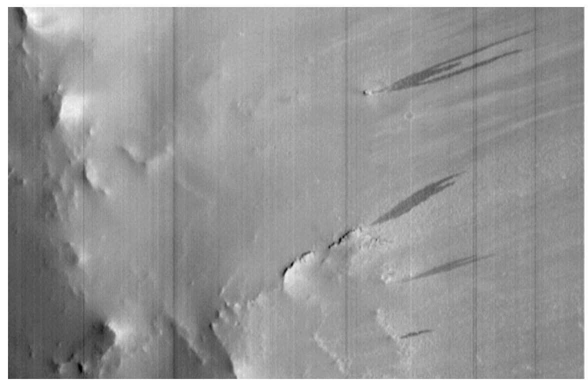

Fig. 2. Excerpt from MOC image M04-0072, showing slopes descending lower left to upper right near 7.6N,313.3W. Dark streak apexes commonly are located immediately subjacent to increased slope roughness or, as here, isolated knobs, presumably where triggering disturbances occur more frequently.

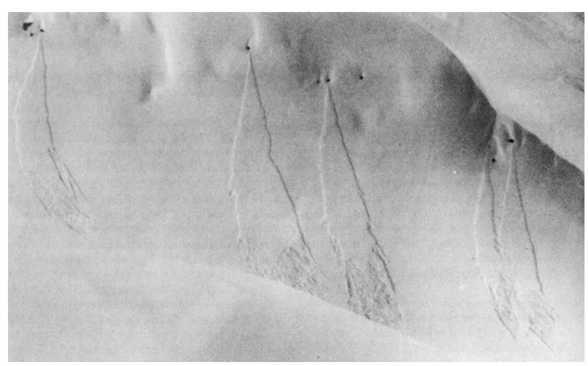

Fig. 3, after [8]. Glancing illumination highlights patterns created by five avalanches of dry, loose snow. Similarities with Martian slope streaks include fan-shaped patterns, acute apexes associated with knobs or increased roughness, and digitate downslope ends.