MASS-MOVEMENT CONSIDERATIONS FOR DARK SLOPE STREAKS IMAGED BY THE MARS ORBITER CAMERA R. Sullivan[1], I. Daubar[1], L. Fenton[2], M. Malin[3], J. Veverka[1], [1]CRSR, Space Sciences Building, Cornell University, Ithaca NY 14853, sullivan@cuspif.tn.cornell.edu, [2]CIT, MS 150-21, Pasadena, CA 91125, [3]Malin Space Science Systems, San Diego, CA 92121-0148.

Introduction. Dark slope streaks initially were observed in the best Viking Orbiter images, but resolution limitations did not allow a definitive interpretation. Morris[1] interpreted the dark streaks on slopes within the Olympus Mons aureole as debris weathered from dark block inclusions within pyroclastic deposits. Ferguson and Lucchitta[2] surveyed all Viking Orbiter images <100m/pixel for dark slope streaks and their associations with geologic unit, latitude/longitude, albedo, and thermal inertia, and measured streak dimensions where resolution permitted. These authors found associations of dark slope streaks only with areas of high albedo and low thermal inertia, suggesting that fine surface particles were required. They concluded dark slope streaks most likely were stains from wet debris flows (perhaps involving brines) where aquifers intercepted slope faces. Williams[4], employing another survey of high resolution Viking Orbiter images[5], confirmed earlier observations[2] of dark slope streak character but proposed a mass-wasting origin in which disturbance of a dust mantle by mobile materials created a darker, dust-deficient scar. Very high resolution images (<10 m/pixel) from the Mars Orbiter Camera (MOC) aboard the Mars Global Surveyor spacecraft show details of dark slope streaks not observable with Viking Orbiter data. While characterizations previously recorded from Viking images are generally confirmed, we find the interpretation of Williams[4] to be most consistent with the MOC observations, and present two models that elaborate on his suggestion.

Morphology of dark slope streaks. Many steep slopes are not obviously rock faces and exhibit narrow dark streaks that follow local gradients and appear sensitive to downslope obstacles [Fig. 1]. Upslope ends of these streaks are acute. Widths increase gradually downslope, in many cases reaching relatively constant maximum widths well before half-length. Downslope ends are commonly digitate. Margins are sharp, even at resolutions of a few m/pixel. Internal darkening is relatively uniform throughout each feature, and features show a range of brightnesses probably correlated with relative age and the rate of dust accumulation. Dark streak margins show no detectable relief, even at resolutions of a few m/pixel.

Model 1: Ejection/intercalation of dust during disturbance of debris at the angle of repose. A dark streak might mark a zone where dust-mantled debris has been disturbed, e.g. following a block strike from disaggregation higher up the slope. In this scenario the 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. RS observed cirques near Ouray, CO, where late summer mass-wasting and talus adjustments were readily heard: crackling made by individual rocks tumbling down steep rock faces were followed immediately by sustained rumbling of short gravel/debris runs triggered by the strike of the initial rock falls. Similar events on dust-covered slopes on Mars could result in partial ejection or intercalation of a dust mantle wherever loose debris elements are set into motion. Long downslope displacements of individual debris elements from the top to the bottom of the streak zone are not required. Even elements moving only far enough to roll over several times would result in reduced dust and brightness, although typical peak momentum of debris elements is probably considerably greater than this because some dark streaks deflect around or overtop obstacles.

Model 2: Dust avalanches from oversteepening of an airfall deposit. A second, simpler idea supposes that dark slope streaks are scars of avalanches composed primarily of dust. In this scenario airfall dust deposits build up on steep slopes until avalanches of the accumulated dust layer are triggered, perhaps by simple oversteepening, and the weak dusty layer fails downslope under its own weight. 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.

Combination of ideas (1) and (2) is also possible. A strong density gradient is expected in the near-subsurface of an airfall dust deposit, and might be sufficiently tractive near its base to move loose materials with larger particles underneath the airfall buildup.

Discussion. If dust avalanches are responsible for the dark streaks (model 2), then the failed layer must be very thin, because levees, distal deposits, or margin relief of any kind has not been observed at resolutions typically only a few m/pixel. For this situation an infinite slope analysis is appropriate (e.g., [5]), and trials indicate martian gravity, low presumed density of the airfall deposit, and shallowness of the failed layer require extremely low cohesion at time of failure, consistent with expectations for an airfall deposit of dust particles.

There are some problems with this idea. The areal extent and continuity of a typical dark streak is large compared with an assumed thinness (unresolved, even in MOC images) of a potentially mobile dust layer. This puts demanding requirements on the mechanical continuity and strength for such a sliding layer and/or the individual elements that compose it, because lateral stresses sufficient for layer failure had to be transmitted through these materials somehow from the top to the bottom of the slope streak and across its width for mass-movement and streak creation to be completed. This represents a problem for a compressible, low-cohesion airfall deposit, even if it is partly indurated. Slab failure in the trigger area of terrestrial snow avalanches is well-documented (e.g., [6]), but in these cases substantial mobile material remains as a ground-hugging flow to form piles of mobilized snow at the distal end of the avalanche scar and even as levees along the scar margins. Analogous features are not observed with the martian dark slope streaks in MOC images. Lack of observed slide deposits implies most of the dusty mantle within the streak zone was ejected into the atmosphere, which seems contradictory with the need for transmitting lateral stresses from the trigger point through a mobile dusty mantle to create the streak zone via layer-failure as in model (2). One way around this is if layer failure propagated upward, with materials upslope of the trigger zone being successively undermined as the failure zone expanded upslope. However, acute upslope ends and digitate downslope ends of dark slope streaks seen in MOC images indicate motion was triggered at the top and propagated downslope.

Model (1) involves short movements within long slide areas of coarser debris near its angle of repose, and appears to have fewer problems. Model (1) requires that streaks form only on dust-coated debris near the angle of repose; examination of released MOLA profiles that coincide with observed dark streak slope localities in MOC images suggests that this requirement is met. These debris aprons probably represent thick talus[7]. A thinner debris layer as part of a Richter slope[8] is also a possibility (although debris on Richter slopes is not restricted to the angle of repose[9]). The "binary" nature of the model (either individual debris elements move or not, disturbing their dust mantle or not) seems consistent with crisp streak margins, uniformly dark streak interiors, and close correspondence of streaks with local gradient. In this model lateral stresses for affecting the entire dark streak area are transmitted via momentum transfer from one debris element to the next (not via mantling dust particles, as in the second model).

The streaks also resemble many slope markings seen elsewhere by MOC that are more confidently identified as having been produced by loose debris controlled by the angle of repose. In these places steep, smooth slope units (sometimes with subtle relief parallel to local gradient) occur immediately subjacent to even steeper rockfaces. The smooth slope units are probably composed of or covered with debris derived from disintegrating rockfaces immediately above. On these units narrow albedo contrasts coincide closely with local gradients, revealing the paths of debris elements mass-wasting downslope.

Summary. We conclude that dark streak formation on martian slopes is fundamentally similar to small mass-movements that have occurred on debris-covered steep slopes elsewhere on Mars; distinctive dark streak features result where small mass-movements occur in the presence of a thin, potentially mobile dust mantle. They cannot be easily interpreted as a dark fluid stain or float moving downslope from a point source.

Figure 1. Dark slope streaks observed by MOC, orbit 24, near the northern edge of the Olympus Mons aureole at 31.6N,134W. Image is 1.12 km x 1.57 km. Sample resolution 1.3 m/pixel; actual line resolution 5.1 m/pixel. A series of dark streaks deflect around some topographic obstacles and override others, in some cases reaching the field of transverse dunes at the foot of the slope (bottom of picture). Dark streak on left appears to have moved around obstacle at foot of slope, but this was not the case for the dark streak on the right.

References. [1]Morris E. (1982) *JGR* 87, 1164-1178. [2]Ferguson and Lucchitta (1984) *NASA TM86246*, 188-190. [3]Williams (1991) *LPSC XXII*, 1509-1510. [4] Moncrief S. and Williams S. (1989) LPI Summer Intern Abstract (cited in [3]). [5] Graham J. (1984) in Brunsden D. and Prior D. *Slope Instability* 175-177. [6]Ward et al. 1985, *J. Glaciology*, 31, 18-27. [7]Fisher 1866, *Geolog. Mag.*, 3, 354-356. [8]Bakker and Le Heux 1952, *Konnink. Nederland. Akad. Wetenschappen*, B55, 399-410 and 554-571. [9]Selby, 1993, *Hillslope materials and processes*, Oxford, p. 367.