HiRISE observations of slope streaks on Mars

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[1] Images from the High Resolution Imaging Science Experiment have revealed new details on the morphologic and topographic characteristics of slope streaks on Mars. Over 1500 HiRISE images were analyzed with 78 unique image sites having slope streaks. Images with low sun illumination reveal that dark slope streaks have topographic relief where streaked surfaces are lower than their surroundings. Slope streaks often initiate below localized features such as rock outcrops, individual boulders, and impact craters. They are also abundant in great numbers within the blast zones of small young impact craters 10–50 m in diameter. These observations suggest that slope streaks can be triggered by localized disturbances such as rockfalls and impact blasts. Seismic activity from external (e.g., impacts) or internal forces could also trigger slope streaks. The topographic relief and triggering mechanisms of slope streaks seem to best fit models that involve dry dust avalanches. Martian slope streaks and meters-thick avalanche scars are part of a continuum of active mass-wasting features at meter to sub-meter scales. Citation: Chuang, F. C., R. A. Beyer, A. S. McEwen, and B. J. Thomson (2007), HiRISE observations of slope streaks on Mars, Geophys. Res. Lett., 34, L20204, doi:10.1029/2007GL031111.

1. Introduction

[2] Slope streaks are common features in the equatorial regions of Mars and are easily recognizable from their contrast in tone relative to their surrounding surfaces. These features have been identified since the early Mariner and Viking missions to Mars and have received more imaging from recent missions beginning with Mars Global Surveyor (MGS) [Malin and Edgett, 2001; Schorghofer et al., 2002; Aharonson et al., 2003]. Early studies using Viking data suggested that slope streaks formed as a result of debris weathering, stants from wet flows, or erosional landslips [Morris, 1982; Ferguson and Lucchitta, 1983; Williams, 1991]. More recent wet-based models include briny liquid flows, groundwater piping, mixed water-dust flows, and ground wetting and/or wick-

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[3] Although most streaked surfaces have dark streaks, light-toned streaks are also observed and some individual streaks transition from light to dark along their paths. Dark slope streaks are thought to fade over time by mantling of new dust [Sullivan et al., 2001; Motazedian, 2003]. The widths of individual slope streaks vary, but are generally a few tens to hundreds of meters across at their widest location. Their lengths also vary from tens of meters to a few kilometers. A single slope streak can split into two separate streaks, form anastomosing patterns, and develop multiple fingers at its terminus. Deposits at the termini of streaks are generally absent, not resolved. Repeat imaging by the Mars Orbiter Camera (MOC) [Malin et al., 1992] indicates that new slope streaks are forming within the time between two or more images, which can be up to several years [Malin and Edgett, 2001; Aharonson et al., 2003]. Gerstell et al. [2004] identified “meters-thick avalanche scars,” which they indicated were a separate population of mass-wasting features from slope streaks. Although avalanche scars are apparently concentrated in the lower reaches of Olympus Mons aureole deposits, they are likely to be as widespread as slope streaks on the Martian surface.

[4] The High Resolution Imaging Science Experiment (HiRISE) instrument [McEwen et al., 2007a] onboard the Mars Reconnaissance Orbiter (MRO) spacecraft [Zurek and Smrekar, 2007] provides the opportunity to study slope streaks in greater detail than could be done with MOC. Here we present the morphologic and topographic characteristics of slope streaks, and their possible triggering mechanisms from the first 7 months of data (11/2006–5/2007) during the 2-year MRO Primary Science Phase (PSP).

2. HiRISE Coverage

[5] Early in the PSP, most of the slope streak-specific targets were sites previously imaged by MOC, but also included sites not imaged by MOC. This study examined over 1500 HiRISE images from orbits 1300 to 3600 at resolutions up to ~25–32 cm/pixel. Of these images, 106 (~7%) have slope streaks and 22 have stereo coverage to look specifically for newly formed streaks. Of these locations with stereo pairs, 3 had new streaks in the 23–67 days between the two images (mean 41 days). Overall, 78 unique sites with slope streaks were identi-
Distribution and Observations

Slope streaks and avalanche scars in HiRISE images occur within the latitudinal range from approximately 39°N to 28°S, consistent with previous global studies of these features [Schorghofer et al., 2002; Aharonson et al., 2003; Gerstell et al., 2004]. Their locations in thermal inertia data [Putzig et al., 2005] have a range of 30–293 J m⁻² K⁻¹ s⁻⁰.5 and a mean and standard deviation of 88 ± 41 J m⁻² K⁻¹ s⁻⁰.5. Approximately 90% of the values are ≤116 J m⁻² K⁻¹ s⁻⁰.5, consistent with previous estimates of low thermal inertia at slope streak locations [Schorghofer et al., 2002, 2007].

Topographic Relief

Prior to HiRISE, studies of slope streaks had little or no discussion of discernable topographic relief. Analyses of MOC images indicated that they did not disturb the pre-existing surface and left only a dark or light-toned trail as the youngest surface feature [Sullivan et al., 2001; Motazedian, 2003]. Analyses of slope streaks from HiRISE data indicate that these features do have topographic relief as a result of their formation (Figure 1). Images with low sun illumination reveal that the area within the streak has a slightly lower surface than its surroundings. The topographic signature and outer margin of a streak are particularly evident where the tone of the streaked surface is the same as the surrounding surface. In addition to low sun illumination, the ability to detect topographic relief is also dependent on the spatial resolution, dust thickness, and slope face orientation. For example, images of slope streaks at the highest possible resolution, in an area with significant dust coverage, and along shadowed slopes are optimal conditions for detecting streak relief. Slope streaks do not consistently have the same depth and in some cases, a small area (with similar lighting and viewing conditions) with multiple streaks can have some streaks with clear topographic relief, and others with little to no apparent relief.

Figure 1. Portion of HiRISE image PSP_003259_1850 (5.0°N, 32.7°E) near Naktong Vallis with dark slope streaks located along the north facing interior slope of an impact crater. Arrows point to the margin of slope streaks that have topographic relief where the streaked surface is lower than the surrounding un-streaked surface. The ability to detect topographic relief is highly dependent on the spatial resolution, low sun illumination, dust thickness, and slope face orientation in the images. Note how several of the streaks are triggered by impact craters that have dark ejecta. Image resolution is 54 cm/pixel.


Figure 2. Portion of HiRISE image PSP_001472_1745 (5.3°S, 213.7°E) with slope streaks along the east-facing slopes of a highland escarpment near Mangala Valles. Meter-scale ripples (arrows) can be traced across both streaked and un-streaked surfaces suggesting a thin layer of material was removed. Shadow length measurements along margin of two slope streaks indicate depths of ≤1 m. Image resolution is 26.5 cm/pixel and downslope direction is to the east.

Figure 3. Portion of HiRISE image PSP_002586_1880 (8.0°N, 45.6°E) along the interior slopes of an impact crater in Terra Sabaea. Each of the light-toned slope streaks that reach the crater floor (to the north-northeast) can be traced to a point below a small impact crater. Longitudinal ridges parallel to the scar margins are visible within the streaked surface (arrows). Note how the eastern margin of the right streak traveled over an impact crater without disruption. Image resolution is 27 cm/pixel.
3.2. Triggering Mechanisms

Slope streaks on Mars generally initiate at a small area or point. From MOC images, these initiation sites often appear along featureless parts of the slope, but in some cases, they can start below knobs, spurs, crater rims, or other areas of localized steepening [Sullivan et al., 2001; Gerstell et al., 2004]. Detailed examination of HiRISE images indicates that many of these localized sites have positive-relief features such as rock outcrops, individual boulders, and impact craters. Rock outcrops typically form horizontal ledges, creating a small break-in-slope where the slope below the ledge appears to be steeper than the overall wall slope. It is at these steeper parts where many slope streaks initiate. Large individual boulders along wall slopes are often eroded materials from the top of the slope that have rolled or bounced downslope. Figure 4 shows one case...

Figure 4. Portion of HiRISE image PSP_003569_2035 (23.2°N, 207.6°E) along the interior slopes of an impact crater in Amazonis Planitia. A boulder that bounced repeatedly downslope towards the northeast has triggered dark slope streaks at many of its bounce points (dark dashed trail). Image resolution is 29 cm/pixel.

Figure 5. Portion of HiRISE image PSP_002764_1800 (0°N, 226.9°E) in the blast zone north of a cluster of impact craters west of Tharsis Montes. (left) Image in simple cylindrical projection has thousands of dark slope streaks along the slopes of the hummocky terrain. The number of dark streaks along concentric arcs at 1, 3, and 5 km distances from the approximate center of the blast site (white dot) decreases from 305 at 1 km to 65 at 5 km. (right) White boxed area in left image shows dark slope streaks in detail, many with topographic relief, particularly along north-northwest-facing slopes that face away from the blast direction. Image resolution is 27 cm/pixel.
where a rockfall boulder triggered slope streaks at many of its bounce spots. Small impact craters that trigger a slope streak are often less than a few tens of meters in diameter and some have dark radiating ejecta (see Figure 1). Several HiRISE images of very recent (perhaps <10 yr) impact craters 10–50 m in diameter have large blast zones extending many kilometers from the impact site [Malin et al., 2006; McEwen et al., 2007b]. Within these blast zones, the terrain is hummocky with hundreds to tens of thousands of dark slope streaks along the slopes of individual hummocks (Figure 5). Many of the streaks form within small narrow chutes with ridge-like margins.

4. Discussion

[10] Evidence of topographic relief within slope streaks from HiRISE images clearly indicates that their formation involves removal of material. This observation and those made by C. B. Phillips et al. (Mass movement within a slope streak on Mars, submitted to Geophysical Research Letters, 2007, hereinafter referred to as Phillips et al., submitted manuscript, 2007) casts doubt upon previous slope streak models that suggest staining, wetting, or wicking of the surface by liquids. Because many slope streaks occur in areas that have little or no evidence of fluvial activity in recent geologic time, models involving liquid water or other types of fluid flow are not required to explain many, if not all of the observed slope streaks. In light of these new observations from HiRISE, models that involve dry dust avalanches seem to best fit the morphologic and topographic characteristics of Martian slope streaks [Williams, 1991; Sullivan et al., 2001; Miyamoto et al., 2004; Gerstall et al., 2004; Baratoux et al., 2006].

[11] HiRISE observations indicate that slope streaks and avalanche scars can be triggered in several different ways that involve a localized disturbance along a sloped surface. Weathering and erosion of exposed layers or bedrock near the top of the slope produces boulders or blocks that fall and strike the surface below, triggering an avalanche within a layer of dust. If the initial fall is a considerable distance, the momentum may be sufficient to cause multiple bounces, triggering more than one dust avalanche. Figures 1 and 5 show that impacts on the surface or the force of the blast from impact explosions can also trigger dust avalanches, forming single or multiple slope streaks. From Figure 1, the albedo or darkness of the ejecta appears to be as dark as the streak interior, suggesting that both features were formed very recently if streaks only remain visible on the surface for decades, possibly centuries [Schorghofer et al., 2007]. In Figure 5, we have counted the number of dark streaks along concentric arcs at 1, 3, and 5 km distances from the approximate origin of the blast site. The number of streaks decreases from 305 at 1 km to 65 at 5 km, but the hummocky terrain of the blast region extends beyond 5 km. This suggests that the atmospheric forces from the impact only trigger slope streaks within a limited area. Seismic activity from external [Davis, 1993] or internal forces could also directly trigger slope streaks, or indirectly via rockfall events.

[12] Although we have described many slope streaks and avalanche scars with clear triggering mechanisms, there are also many that initiate where no mechanism is observed. In these cases, the disturbance may occur by eolian activity where saltating fine materials, possibly pebble-sized grains (i.e., objects unresolvable to HiRISE), strike the surface and trigger dust avalanches. Also, the triggering of slope streaks below localized features could be due to the preferential accumulation and avalanching of dust on the downstream side of objects in the path of wind flow [Baratoux et al., 2006].

[13] Gerstall et al. [2004] concluded on the basis of a suite of observations and statistical analyses that meters-thick avalanche scars are a distinct class of mass wasting features separate from slope streaks. While the observed avalanche scars may be the result of deeper excavation, many of their lines of evidence, based on MOC observations at the time of their study, are less compelling in HiRISE images. One characteristic of meters-thick avalanche scars that are less common to slope streaks are their relatively straight margins unaffected by topographic obstacles such as small hollows, impact crater rims, and boulders. This characteristic is likely due to the amount of material involved where the deeper excavated avalanche scars forms a potentially more coherent mass movement with greater momentum, and are less affected by obstacles along their path. This behavior is not entirely unique to avalanche scars and has been observed by Phillips et al. (submitted manuscript, 2007) in some slope streaks near their apexes along steeper portions of the slope.

[14] Our analysis of dark slope streaks and meters-thick avalanche scars from HiRISE images suggests that the two features are related and part of a continuum of active mass-wasting features at meter to sub-meter scales formed by dust avalanches. Several lines of evidence support their relationship: (1) occurrence in the same equatorial latitudes, (2) formation in similar geologic settings and local regions, (3) initiation from a point source, and (4) topographic relief where material has been removed by mass-wasting processes. HiRISE observations indicate that dark slope streaks without observable depth in MOC images do have topography and are thinner than meters-thick avalanche scars. While many slope streaks do not appear to have topography in HiRISE images, this does not indicate that topography is absent, but that the excavated dust is not sufficiently thick to be resolved by HiRISE data acquired at the 3 PM local surface time. The presence and continuing formation of slope streaks on Mars further highlights the modification of the current-day surface by mass-wasting and eolian processes.

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