THE JUNE 3, 2005, BLACK MOUNTAIN DEBRIS FLOW, IRON COUNTY, UTAH

by

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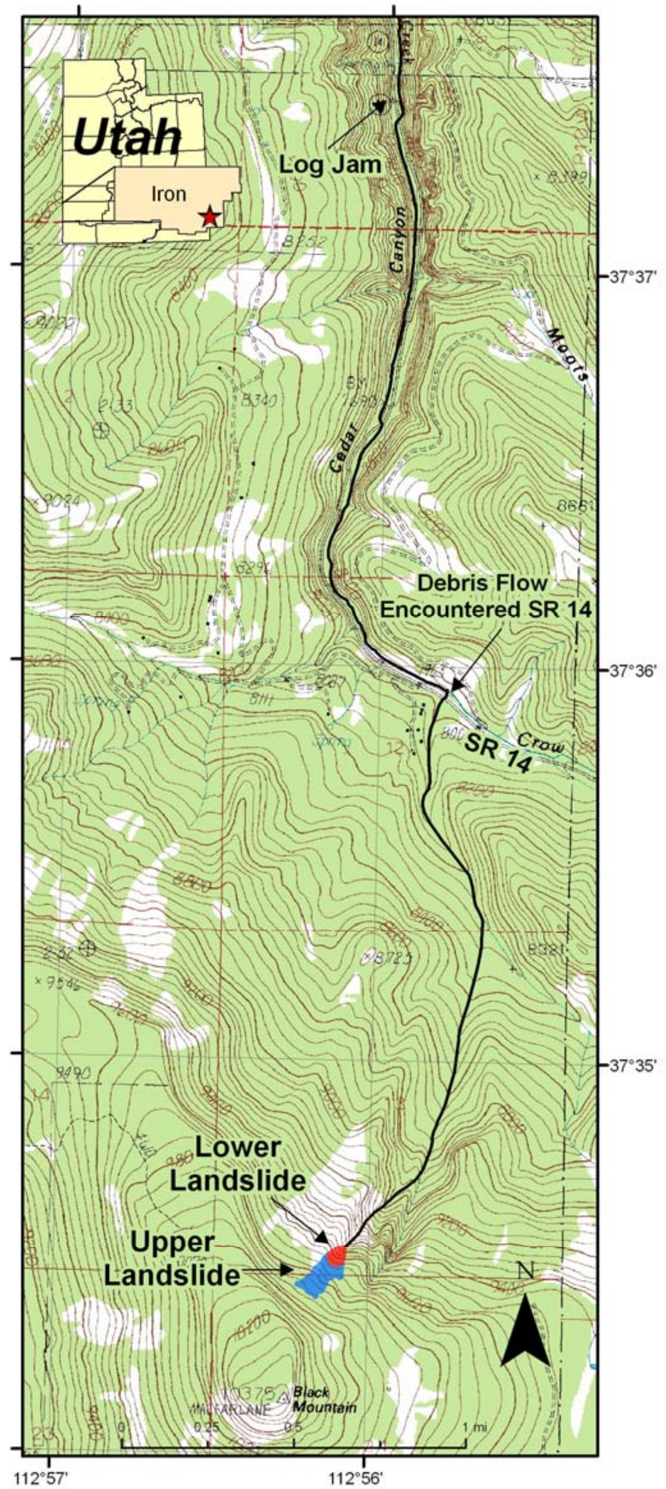
ABSTRACT

Reactivation of a landslide on the north side of Black Mountain in southwestern Utah generated a large debris flow on June 3, 2005. The landslide and debris flow were initiated by a combination of rapid snowmelt, weak geologic materials, pre-existing landslide deposits, and steep terrain. The debris flow was triggered when the lower part of the landslide released into a steep, narrow mountain channel where rapid mixing of the landslide mass transformed it into a debris flow. Flow down the steep channel accelerated the debris flow, resulting in a long runout distance. The debris flow traveled down an unnamed valley 1.6 miles before blocking State Route 14 (SR-14) and flowing into Crow Creek. The debris flow demolished a forest of mature trees along the upper valley floor. The debris-flow deposits in the upper part of the unnamed valley are wider, thicker, and rougher than in the lower part. Downstream in Cedar Canyon, water from Crow Creek and its tributaries diluted the debris flow into a sediment-laden flood that caused flood and erosion damage to SR-14 and closed the highway for a week.

A large volume of material remains in the landslide on Black Mountain, and this material could catastrophically release into the narrow mountain channel to form another large debris flow. The main hazards associated with a future large debris flow are direct impact and sediment burial in the unnamed valley and on SR-14. Hazards along Crow Creek and Cedar Canyon (Coal Creek) include flooding, erosion, and creek and culvert blockage. Only partial melting of the 2005 snowpack was needed to trigger landslide movement and the subsequent debris flow. The 2005 snowmelt pattern can be used to anticipate future landslide movement and possible debris flows.

INTRODUCTION

On the morning of June 3, 2005, a pre-existing landslide on the north side of Black Mountain in southeastern Iron County reactivated and generated a large debris flow, which flowed approximately 1.6 miles down an unnamed stream drainage before encountering Utah State Route 14 (SR-14) and Crow Creek (figure 1). Lund and others (2005) made a reconnaissance on June 4, 2005, to document the event, determine the debris flow source, and evaluate the resulting damage. The debris flow buried a 100-foot-long section of SR-14 with mud, boulders, and large trees, and then continued down Crow Creek (Cedar Canyon) causing erosion and flood damage to SR-14 at several locations and blocking culverts with large tree trunks and gravel- to boulder-size debris (figure 1) (Lund and others, 2005). Water from Crow



Base map from Webster Flat USGS
7.5-minute topographic quadrangle

Figure 1. *Map showing upper and lower landslide and flow path (heavy black line) of the Black Mountain debris flow and related flooding in Cedar Canyon.*

Creek and its tributaries eventually diluted the debris flow and transformed it into a sediment-laden stream flood. SR-14 was closed for a week for cleanup and repair (Giraud and Lund, 2006). In this report, we designate the source landslide as the Black Mountain landslide, and the landslide-generated debris flow as the Black Mountain debris flow. The purpose of this investigation was to examine the source landslide, determine its triggering mechanism, quantify the volume and geologic characteristics of the resulting debris-flow deposits, and evaluate the potential for future large debris flows.

GEOLOGIC SETTING

Gregory (1950) mapped the bedrock geology on the north side of Black Mountain. Quaternary basalt caps the mountain, and Gregory (1950) showed the basalt overlies, from youngest to oldest, the Cretaceous Kaiparowits, Wahweap, and Straight Cliffs Formations. The area where the Black Mountain landslide occurred is underlain by the Kaiparowits Formation (Gregory, 1950). Moore and Straub (2002) redefined the Upper Cretaceous bedrock units in Cedar Canyon, but they did not remap the north side of Black Mountain. Moore and others (2004) mapped the Navajo Lake quadrangle east of Black Mountain, and their stratigraphic column shows the informal "formation of Cedar Canyon" (Paleocene to Upper Cretaceous) above the Straight Cliffs Formation, rather than the Wahweap and Kaiparowits Formations. Gregory (1950) and Moore and others (2004) described the Kaiparowits Formation and formation of Cedar Canyon, respectively, as mostly sandstone with interbeds of conglomerate, mudstone, and shale. Moore and others (2004) mapped numerous landslides within the formation of Cedar Canyon east of Black Mountain. Gregory (1950) showed the steep, narrow mountain channel (figure 2) directly below the Black Mountain landslide as underlain by the Straight Cliffs and Wahweap Formations.

Surficial geologic deposits on the north side of Black Mountain consist of landslide deposits, debris-flow deposits, basalt talus, colluvium, and stream alluvium. Based on mapping by Moore and others (2004) in the Navajo Lake quadrangle, these surficial deposits generally range in age from late Pleistocene to Holocene. Colton and others (1986) mapped a landslide on the north side of Black Mountain; however, that landslide is much larger than the 2005 Black Mountain landslide because their mapping includes the large basalt talus deposit that lies west of the Black Mountain landslide. The pre-2005 landslide is evident on 1998 U.S. Geological Survey (USGS) (TerraServer USA, 2005) and 2004 National Agriculture Imagery Program (NAIP) (Utah Automated Geographic Reference Center, 2005) aerial photos, as are young debris-flow deposits immediately below the steep, narrow mountain channel where it empties into the unnamed stream valley.

BLACK MOUNTAIN LANDSLIDE

The Black Mountain landslide consists of two distinct parts, an upper and a lower landslide (figure 2). Table 1 shows the physical characteristics of the upper and the lower landslide. The upper landslide is shown in figures 2 and 3. On June 3, 2005, the lower landslide catastrophically released into the steep, narrow mountain channel (figures 2 and 4), and quickly

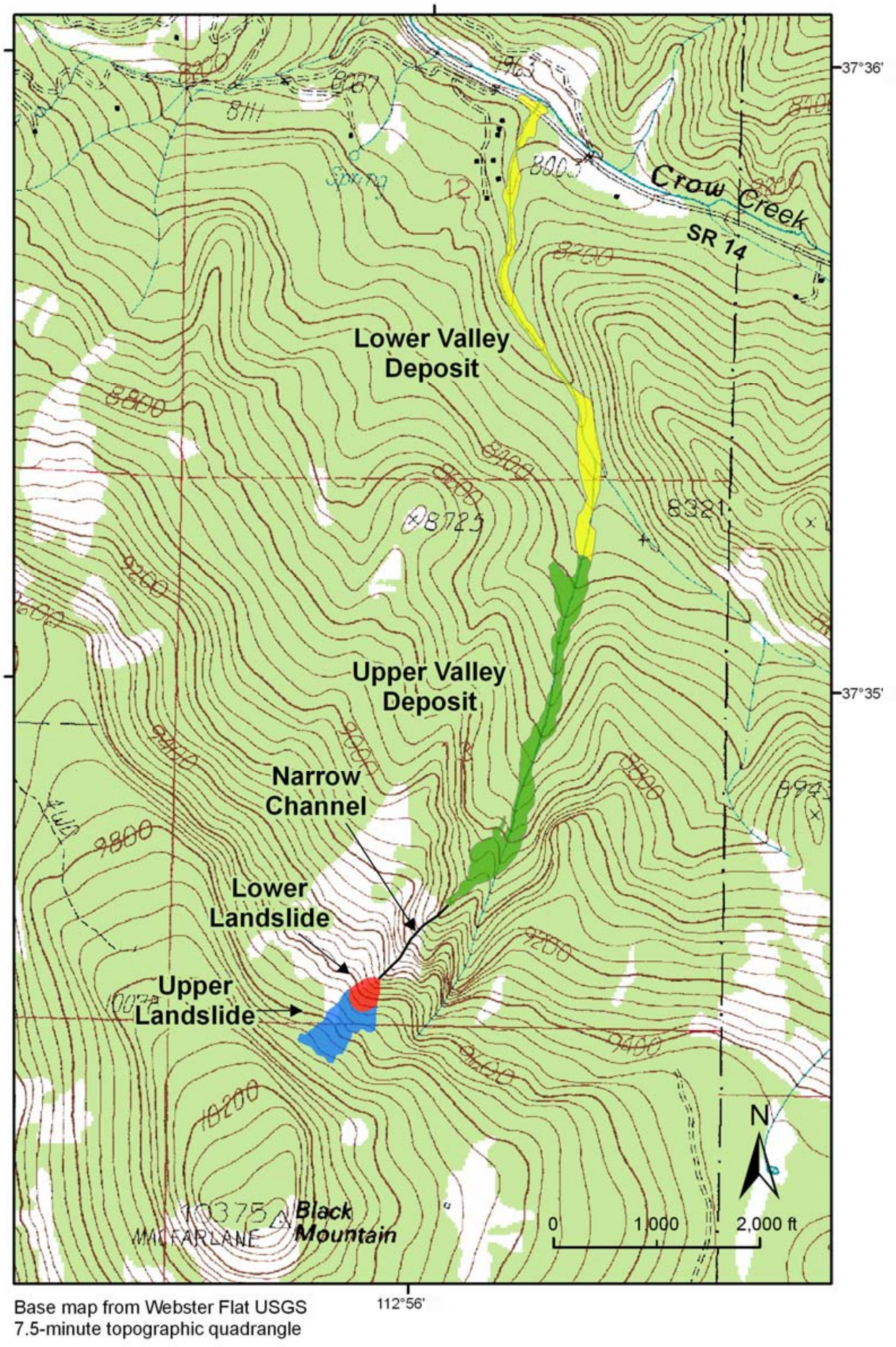


Figure 2. *Map showing upper and lower landslide, narrow channel, and upper and lower valley debris-flow deposits.*

Table 1. *Physical characteristics of the Black Mountain landslide, narrow channel, and upper and lower valley debris-flow deposits.*

Geologic Feature	**Average slope**	**Area acres**	**Volume cubic yards**	**Slope Length feet**
Upper Landslide	43% (23°)	5.6	155,000 to 160,000	550
Lower Landslide	60% (31°)	1.6	50,000 to 60,000	450
Narrow Channel	45% (24°)	-	-	1200
Upper and Lower Valley Debris-Flow Combined Deposit	12.5% (7°)	26.6	73,000	8500 (1.6 miles)
Upper Valley Deposit	16% (9°)	13.7	55,000	3800
Lower Valley Deposit	9% (5°)	12.9	18,000	4700

Figure 3. *The remaining upper landslide on the north side of Black Mountain. The upper landslide is perched above the narrow mountain channel (figure 4) that is out of view and below the photo. Photo taken on June 3, 2005, by Lt. David Excel, Utah Highway Patrol.*

Figure 4. *View down the steep, narrow mountain channel. The lower part of the landslide released into the channel and was transformed into a rapidly moving debris flow. Part of the debris-flow path is evident below the channel.*

transformed into the Black Mountain debris flow. The upper landslide moved downslope but did not release into the channel and remains perched on the mountain slope. A large evacuated area now exists where the lower landslide was formerly located (figure 5). We estimate the volume of lower landslide material released was between 50,000 and 60,000 cubic yards. An estimated 155,000 to 160,000 cubic yards of material remains in the upper landslide, which is perched above the narrow channel (figure 6). The landslide volume estimates are based on methods outlined by Cruden and Varnes (1996, p. 42-43). Based on the position of the pre-existing landslide's main scarp as indicated on 2004 aerial photos, the main scarp of the upper 2005 landslide is 400 feet upslope and slightly to the west. Both the upper and lower landslides have steep slopes (table 1).

The upper landslide has a very rough surface and consists of clay-rich debris with angular cobbles and boulders of basalt and sandstone (figures 3 and 7). Where exposed downslope from the main scarp of the upper landslide, the rupture surface beneath the upper part of the upper landslide is shallow and movement involved only the upper few vertical feet of slope (figure 7). The rupture surface dips from 58 to 67% (30 to 34^{o}) and formed in weathered, soft, low-strength shale and mudstone. However, the rupture surface becomes significantly deeper downslope, and we estimate it was 40 to 50 feet deep where the lower landslide catastrophically failed into the mountain channel (figures 5 and 6). Several springs are present in the evacuated area and were discharging in late July 2005 from the exposed rupture surface.

Figure 5. *View west into the evacuated area of the lower landslide. The estimated evacuated volume is 50,000 to 60,000 cubic yards. The landslide left flank (upper part of photo) exposes basalt talus. The reddish colored material is weathered shale and mudstone and is the landslide rupture surface.*

Figure 6. *View from the evacuated area of the lower landslide toward the remaining upper landslide. The upper landslide lies on a steep rupture surface.*

Figure 7. *View from the upper landslide main scarp toward Crow Creek and SR-14. The main scarp is covered with slickensides. The debris-flow path and deposits are evident in the unnamed tributary stream valley to Crow Creek.*

BLACK MOUNTAIN DEBRIS FLOW

Once the lower landslide released into the steep, narrow mountain channel, rapid mixing of the landslide mass quickly transformed it into a debris flow. As it proceeded down the 1200-foot-long channel, the debris flow scoured additional debris from the channel bottom and sides before exiting into the more gently sloping unnamed tributary stream valley to Crow Creek. The debris flow continued down the valley, scouring additional sediment, taking out trees, and depositing large volumes of sediment (figure 2). The debris flow plugged the box culvert under SR-14 with sediment and then overtopped the road, depositing sediment and blocking the highway (figure 8). Lund and others (2005) discussed the damages downstream in Crow Creek and Cedar Canyon.

The steep, narrow mountain channel played an important role in the formation of the debris flow by promoting mixing and acceleration of landslide material released into the channel (figure 4). The channel is a distinct topographic feature at the head of the unnamed stream valley (figure 2). The channel has an average gradient of 45% (24°), but steeper parts have gradients of as much as 103% (46°). The channel also has several short, vertical drops, which accelerated mixing of material moving down the channel. Snowmelt water in the narrow channel and in the unnamed stream valley below was incorporated into the flowing mass. Upon exiting the channel, the rapidly moving debris flow superelevated (climbed) up onto the east wall of the unnamed stream valley (figures 2 and 9). The debris flow then quickly traveled the 1.6 miles to SR-14 and Crow Creek. The long runout distance is due to the water content of the flow, the

Figure 8. *View northwest of SR-14 blocked by sediment from the Black Mountain debris flow. Crow Creek is on the right. Photo taken on June 3, 2005, by Lt. David Excel, Utah Highway Patrol.*

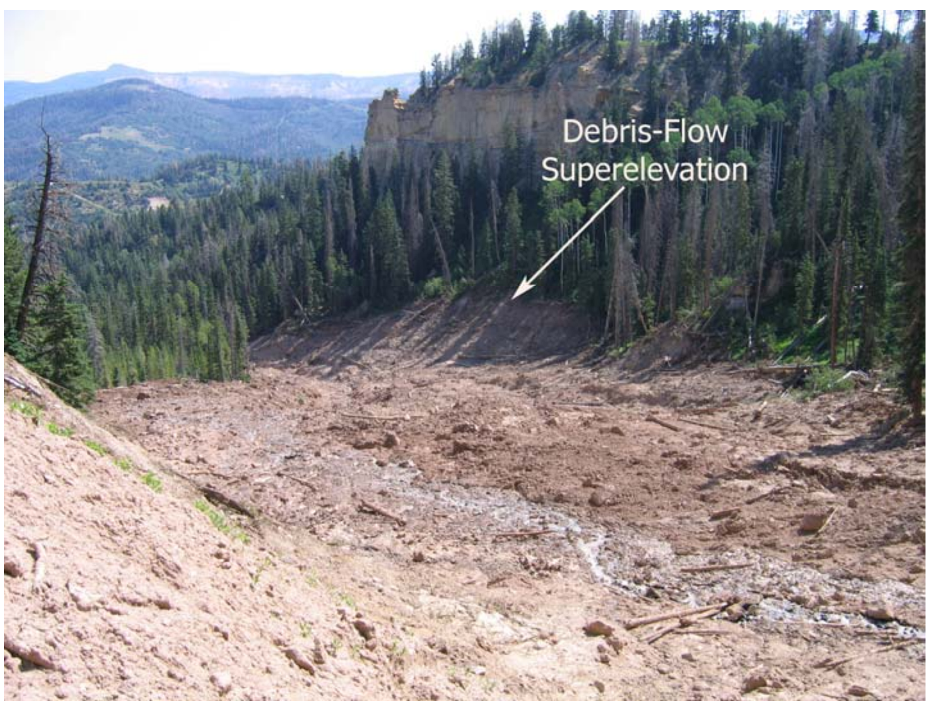


Figure 9. *Northeast view down the upper stream valley at the debris-flow deposit below the narrow mountain channel. The debris flow had sufficient velocity to superelevate up onto the valley side below the sandstone cliff.*

initial high flow velocity of the debris flow as it left the narrow mountain channel, and the V-shape of the unnamed valley which kept the flow confined as it moved down the relatively low-gradient (12.5% [7°]) valley. If the debris flow had become unconfined, it likely would have quickly spread laterally, thinned, and deposited sediment, resulting in a shorter runout distance. The physical characteristics of the narrow channel and debris-flow deposits are shown in table 1.

Based on deposit character, we mapped upper and lower debris-flow deposits in the unnamed stream valley (figure 2). The upper valley deposit covers and obscures the pre-existing flow topography and previous debris-flow deposits. The upper and lower valley debris-flow deposits are composed of gravel, sand, silt, and clay with boulders and cobbles of basalt and sandstone. The debris flow demolished a forest along the upper valley floor, and both upper and lower valley debris-flow deposits contain tree trunks and woody debris. Both matrix-supported and clast-supported textures were observed in the deposits.

The upper valley debris-flow deposit below the mountain channel is as much as 550 feet wide and locally as much as 10 feet thick (figure 9). Below an elevation of 8800 feet the deposit narrows, and from 8440 to 8400 feet elevation a small lobe of material was deposited along the west edge of the valley (figure 2). The deposit thins downvalley and is only 1 to 2 feet thick immediately upstream from the lower valley deposit. The largest observed boulder in the deposit is 22 feet long (figure 10). We measured scour depths as deep as 30 feet in the drainage channel along the upper deposit; however, the original channel depth is unknown. Along the drainage channel, stream flow late in the debris flow event incised into 2005 debris-flow deposit. The upper deposit is wide and has a rough surface (figures 9 and11).

Along the upper valley deposit margins, the debris flow removed mature, similar-aged conifer trees, and left distinct tree trim lines (figures 9, 10, and 11). Based on their size, these trees were a minimum of 100 years old and likely were older (Burrows and Burrows, 1976), which suggests that a minimum of 100 years had passed since the last similarly large debris flow in this drainage. We observed pre-2005 debris-flow deposits at an elevation of 8800 feet along the west margin of the 2005 deposit. Relatively young conifer trees 4 to 5 inches in diameter are growing on this deposit, which suggests that the deposit is relatively young and possibly related to a small-volume historical debris flow. On aerial photos, we observed young debris-flow deposits immediately below the steep, narrow mountain channel. These small-volume deposits likely represent relatively high-frequency, small-volume flows that occur more frequently than large-volume flows.

The break between the upper and lower valley deposits is at an elevation of 8360 feet (figure 2). Compared to the upper valley deposit, the lower valley deposit is narrower, thinner, smoother, and lacks the demolished forest and tree trim lines (figure 12). The drainage channel was locally scoured as deep as 3 feet, but erosion from the lower valley did not add a significant volume of material to the debris flow. The lower valley deposit is generally 1 to 2 feet thick, has an average slope of 9% (5°), an estimated volume of 18,000 cubic yards, and area of 12.9 acres.

A volume discrepancy exists between the landslide volume that released into the mountain channel (50,000 to 60,000 cubic yards plus finer fraction flushed down Crow Creek) and the debris-flow deposit volume (73,000 cubic yards) in the valley below. This discrepancy

Figure 10. *Large boulder transported by the debris flow, now part of the upper valley deposit. The boulder measures 22 feet long, 9.5 feet wide, and 6.5 feet high. The tree trim line is evident in the background.*

Figure 11. *Upper valley debris-flow deposit showing the rough, wide, and thick deposit and distinct tree trim lines along the deposit flanks.*

Figure 12. *Lower valley deposit showing the relatively smooth, narrow, thin deposit compared to the upper valley deposit.*

is due to scouring of additional sediment from the steep, narrow mountain channel and from the stream channel in the upper part of the unnamed stream valley. A significant volume of tree trunks and woody material was also incorporated into the flow as it passed through the upper valley area. An undetermined amount of sediment was transported down Crow Creek, first as a debris flow and then, with the addition of more water, as a sediment-laden stream flood. Finally, the Utah Department of Transportation removed an estimated 20,000 cubic yards of sediment from various locations along the SR-14 right-of-way (Leslie Heppler, Utah Department of Transportation, verbal communication, 2005), part of which came from the debris flow and part from local channel scour.

The Black Mountain debris flow differs from most other large, historical, landslide-generated Utah debris flows in topographic setting, sediment deposition, and origin of sediment. Most other debris flows started in short steep drainage basins, eroded sediment from steep drainage channels, and deposited sediment on alluvial fans. The Black Mountain debris flow started as a large landslide on a steep mountain flank, traveled a sort distance down a steep mountain channel, and then deposited sediment as it traveled a long distance down a low-gradient valley. About 80% of the Black Mountain debris-flow volume was from the landslide mass, which differs from most other historical debris flows where 80 to 90% of the debris-flow volume is scoured from the drainage channel (Croft, 1967; Santi, 1988; Keaton and Lowe, 1998).

PROBABLE LANDSLIDE CAUSES

Snowmelt water infiltrating the subsurface is a major factor contributing to spring-season landslides (Chleborad, 1997). Snowmelt provides a more continuous supply of water over a longer period of time than does infiltration from rainfall (Wieczorek and Glade, 2005). The Black Mountain landslide likely reactivated when snowmelt water infiltrated the subsurface and raised the pore-water pressure in the landslide.

Black Mountain had an above-average snowpack at the onset of the 2005 spring snowmelt. The nearest snowpack, snowmelt, and temperature measurement site is at the Natural Resources Conservation Service (NRCS) Utah Snow Survey Webster Flat SNOTEL site (NRCS, 2005a), 1.75 miles east of the landslide. The SNOTEL data are useful for evaluating the spring snowmelt pattern. Regional spring snowmelt air temperatures are broadly the same for a given elevation. The Webster Flat SNOTEL site is at an elevation of 9200 feet, lower than the Black Mountain landslide which is between 9450 and 9900 feet in elevation. On April 1, 2005, the Webster Flat SNOTEL site had a snow-water equivalent of 33.4 inches, which is 210% of the 1977-2000 average (NRCS, 2005b).

The rate of snowmelt depends primarily on air temperature, which in turn relates to the timing of snowmelt-generated landslides (Chleborad, 1997, 1998). A strong relation exists between snowmelt landslides and rising spring temperatures in the central Rocky Mountains (Chleborad, 1997; Chleborad and others, 1997). Figure 13 is a plot of daily snowmelt and average daily temperature at the Webster Flat SNOTEL site, which melted out on May 27, 2005. Even though the SNOTEL site melted out six days before the landslide and debris flow occurred, the SNOTEL data can be used to infer temperatures and snowmelt patterns on Black Mountain. At the Webster Flat SNOTEL site, snowmelt generated an average of 1.5 inches of water per day from May 14 through May 27, 2005. This period of rapid snowmelt corresponds to a significant increase in average daily temperature (figure 13). The snowmelt rate at the Black Mountain landslide was probably slightly less due to the area's north aspect and higher elevation. The average daily temperature remained high through June 3, 2005 (figure 14), which suggests rapid snowmelt preceding the landslide and debris-flow events.

Aerial photos and field observations indicate a snowpack approximately 3 feet thick remained on Black Mountain on June 3, 2005 (figure 3). The remaining snowpack indicates that only partial snowpack melting was sufficient to trigger landslide movement. A rapid rate of snowmelt over several days may be a more critical parameter in triggering landslides than the total volume of snow melted and water added. Melting of an above-average snowpack in 1983 triggered numerous landslides in Utah, and Wieczorek and others (1989) observed that most of those landslides triggered during the most rapid period of snowmelt.

Chleborad and others (1997) used a six-day moving average of daily maximum air temperature with an optimum threshold of 58°F for anticipating the onset of snowmelt-generated landslides. Their study concluded that most snowmelt-triggered landslides occur within two weeks after the first yearly occurrence of this threshold. Figure 14 shows the six-day moving average of daily maximum temperature at the Webster Flat SNOTEL site. The first occurrence of the 58°F threshold was on May 19, 2005. The Black Mountain debris flow occurred on June

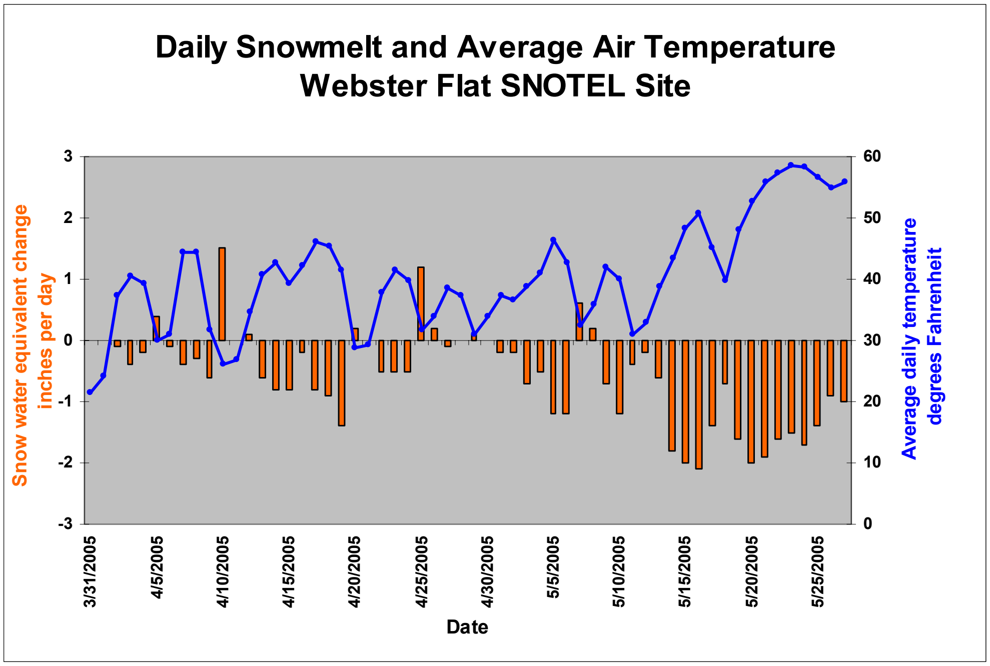


__Figure 13.__ Daily snowmelt and average daily temperature at the Webster Flat SNOTEL site. From May 14 to May 27, 2005, an average of 1.5 inches of water per day melted from the snowpack.

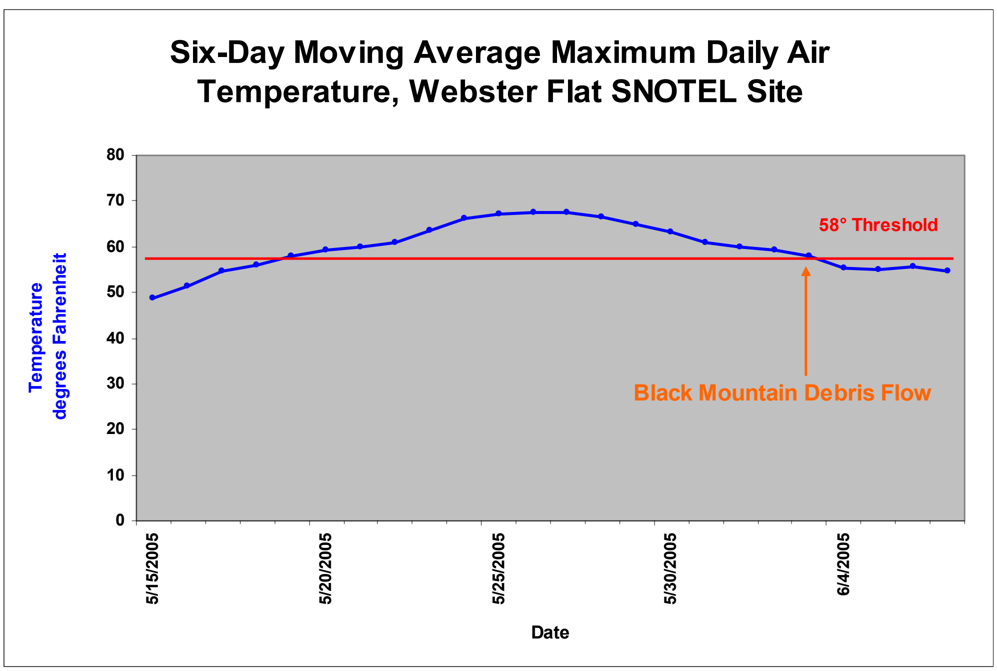


__Figure 14.__ Six-day moving average maximum daily air temperature at the Webster Flat SNOTEL site. The Black Mountain debris flow occurred 16 days after the 58°F threshold was reached at the Webster Flat SNOTEL site.

3, 2005, 16 days after reaching the temperature threshold at Webster Flat. Sixteen days is longer than Chleboard's two-week period for most snowmelt-generated landslides, but Chleborad and others (1997) did observe some landslides triggering within three weeks. Also, the longer-than-two-week period may be due to the higher elevation and north aspect of the landslide and therefore cooler temperatures as compared to the SNOTEL site. The landslide also has a deep surface of rupture, and the time required to increase the pore-water pressure at depth was likely longer.

HAZARD ASSESSMENT

Based on the results of our investigation, we conclude that future movement of the Black Mountain landslide downslope toward the steep, narrow mountain channel is likely, and that the release of additional landslide material into the channel could generate future large debris flows. An ample volume of material (155,000 to 160,000 cubic yards) remains in the upper landslide to supply future debris flows. The landslide also has the potential to enlarge upslope and incorporate additional material as occurred in 2005. The steep average landslide slope and steeply dipping rupture surface promote additional landslide movement.

The age of conifer trees removed by the Black Mountain debris flow along the upper stream valley shows that a minimum of 100 years had passed since the last similarly large debris flow occurred in this drainage. Debris-flow deposits in the valley need to be investigated and dated to understand long-term debris-flow frequency. Debris-flow deposits in the upper valley and below the steep mountain channel indicate that smaller volume debris flows are more frequent than large events. Even though an understanding of long-term frequency could be obtained, the short-term debris-flow hazard is controlled by the remaining landslide mass poised above the mountain channel and its potential to reactivate and release large volumes of material into the channel to generate debris flows.

The major structure at risk from future debris flows originating on the north side of Black Mountain is SR-14, which is subject to culvert blockage, overtopping, erosion, and sediment burial. The unnamed stream valley above SR-14 is presently undeveloped, and we recommend structures not be built in the valley bottom unless the debris-flow hazard is reduced to an acceptable level. Downstream from the unnamed drainage, potential impacts along Crow Creek and Cedar Canyon include further erosion and damage to SR-14, blocked culverts, potential creek blockage, and influx of sediment. A site-specific, detailed investigation is needed to determine possible highway risk-reduction measures and their cost. Giraud (2005) outlines methods for the geologic evaluation of debris-flow hazards.

SUMMARY

The June 3, 2005, Black Mountain landslide and debris flow clearly demonstrate the ability of the terrain on the north side of Black Mountain to produce large, destructive debris flows. The Black Mountain landslide and debris flow were initiated by a combination of rapid snowmelt, weak geologic materials, pre-existing landslide deposits, and steep terrain. The

remaining Black Mountain landslide contains an estimated 155,000 to 160,000 cubic yards of material, which could catastrophically release into the mountain channel on the north side of Black Mountain. The channel provides a mechanism to mix and transform the landslide material into a debris flow, and also to accelerate the flow, which can then runout long distances in the low-gradient stream valley and reach Crow Creek. The main hazard associated with future large debris flows in the unnamed stream valley is damage to SR-14 caused by direct impact and sediment burial. Hazards along Crow Creek and Cedar Canyon (Coal Creek) include flooding, erosion, and creek and culvert blockage.

Rapid melting of an above-average snowpack and infiltration of the meltwater into the landslide increased the pore-water pressures in the landslide and triggered landslide movement. Only partial melting of the above 2005 snowpack was necessary to initiate movement. The 2005 snowmelt pattern can be used to anticipate future reactivation of the remaining Black Mountain landslide and possible future debris flows. The remaining landslide and its potential to reactivate and release large volumes of material into the steep mountain channel controls the short-term debris-flow hazard.

Future large debris flows will likely reach and damage SR-14. We recommend structures not be built in the presently undeveloped stream valley bottom unless the debris-flow hazard is reduced to an acceptable level. We also recommend a detailed investigation to determine the best methods to mitigate future debris-flow damage to SR-14.

ACKNOWLEDGMENTS

Lt. David Excel, Utah Highway Patrol, provided the aerial reconnaissance photographs of the landslide and debris flow. Leslie Heppler, Utah Department of Transportation (UDOT), provided information on the volume of material removed from SR-14. Jim McConnell, UDOT, provided photographs and video clips of plugged culverts and highway cleanup. Mike Hozik, Garrett Vice, and Joe Buckley provided valuable field assistance.

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