Utah Geological Survey

Project: Investigation of the April 11, 2009, 1550 East Provo rock fall, Provo, Utah			
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USGS Quadrangles: Orem (1088), Bridal Veil Falls (1087)	Section/Township/Range: Sections 32 and 33, R. 3 E., T. 6 S., SLBM		
Requested by: Lewis Billings, Mayor, Provo City			Job number: 09-02

INTRODUCTION

On April 11, 2009, around 11:30 a.m., rock detached from a cliff band producing a rock fall on the upper part of Y Mountain (figures 1 and 2) above Provo, Utah. Rock debris traveled down the west side of Y Mountain into a subdivision. One rock impacted and severely damaged a vacant house at 1496 North 1550 East (figure 3). Another rock damaged a fence and playhouse at 1522 North 1550 East (figure 4). The damaged house at 1496 North 1550 East is one lot north of 1468 North 1550 East, where a guest house was destroyed by a rock fall on May 12, 2005 (Christenson and Giraud, 2005). The 2005 and 2009 rock-fall paths are shown in figure 2.

Provo City Mayor Lewis Billings requested that the Utah Geological Survey (UGS) investigate the rock fall. On April 15, 2009, we provided Mayor Billings a letter with our initial conclusions and recommendations. This report provides supplemental information on the rock-fall hazard and restates our conclusions and recommendations. The purpose of our investigation was to determine the geologic characteristics of the rock fall and evaluate future-hazard potential to aid Provo City in assessing the risk to houses and city infrastructure in the area. We focused on the relative susceptibility of rock outcrops to initiate rock fall, the rock-fall travel paths to houses, and rock-fall runout distance.

Ashley Elliott and Jessica Castleton, UGS, visited the site on April 13, 2009. On April 20, 2009, Ashley Elliott, Greg McDonald, and Steve Bowman, UGS, visually inspected and photographed the rock fall cliff area on Y Mountain during a helicopter flight. For this investigation, we studied relevant geologic literature and maps. We also reviewed early 1970s 1:15,000-scale stereo aerial photographs (Bowman and others, 2009); U.S. Geological Survey 1997 orthophotography at various scales (Utah Automated Geographic Reference Center, 2009a); and 2004 and 2006 National Agriculture Imagery Program (NAIP) orthophotography at various scales (Utah Automated Geographic Reference Center, 2009b).

APRIL 11, 2009 ROCK FALL

On April 11, 2009, rock-fall debris bounced and rolled downslope and damaged a vacant house and playhouse (figures 3 and 4). The rock that damaged the vacant house at 1496 North 1550 East traveled through the house and into the garage. Figure 3 shows house damage and figure captions describe the rock's travel path through the house. We estimate the rock's dimensions to be 4 x 5 x 4 feet (figure 3D) and weight to be about 6 tons. The dimensions of this rock are similar to other equidimensional to rectangular rock-fall boulders deposited on the alluvial fan to the south. The rock that damaged the playhouse at 1522 North 1550 East (figure 4) bounced into a chain link fence, pushing the fence into the playhouse. We estimate the rock's dimensions to be 2 x 4 x 3 feet and weight to be about 1.8 tons.

PHYSIOGRAPHIC AND GEOLOGIC SETTING OF Y MOUNTAIN

Y Mountain is a steep west-facing mountain front along the Wasatch Range above Provo. The cliff bands on the upper part of Y Mountain are divided into three Mississippian formations (Baker, 1972; Hintze, 1978), the Gardison Limestone, Deseret Limestone, and Humbug Formation (listed from oldest to youngest). The Gardison consists mostly of thin-bedded to massive limestone with abundant chert. The Deseret is primarily interbedded limestone and dolomite in thick beds with light- and dark-gray banding. The Humbug is composed of a thin- to thick-bedded limestone with interbeds of sandstone. These bedrock formations form a series of continuous and discontinuous cliff bands near the top of Y Mountain (figure 5).

Steep mountain slopes below the cliff bands extend downslope into a small drainage basin. The upper mountain slopes below the cliff are composed of talus that grades downslope into colluvium. The colluvium is a firm slope substrate. The mountain slopes are covered with oak brush and grass. A small alluvial fan mapped by Machette (1992) lies at the mouth of the small drainage basin. Houses damaged by the 2005 and 2009 rock falls are on the north side of this alluvial fan.

ROCK-FALL SOURCES, PATHS, AND DEPOSITION

The rock fall initiated in Deseret Limestone (figures 5 and 6) at approximately 7,700 feet elevation. The limestone cliffs are massive beds broken by discontinuities or cracks that consist of joints, fractures, and bedding planes (figure 6). Weathering along these discontinuities weakens the rock mass and creates opportunities for triggering mechanisms such as frost and root wedging, rainfall, snowmelt, or earthquakes to initiate rock fall. The orientation and spacing of discontinuities determine the overall stability and generally the initial size and shape of rock fall produced. The limestone bedding planes are flat to gently dipping and joints are near vertical, widely spaced, and perpendicular to bedding planes. The orientation, spacing, and intersection of bedding planes and joints produce large, roughly equidimensional to rectangular rock-fall blocks. The rock-fall-detachment surface is above an undercut cliff face that likely results from preferential weathering of thin bedded rock below massive thick-bedded rock (figure 6).

The cliff bands on Y Mountain are extensive and an obvious rock-fall source. The number of cliff bands and their area (length and height) represent a large area of bedrock (figure 5) exposed to rock-fall triggering mechanisms that will continue to generate rock falls. These cliff bands are the source of prehistoric and historical rock falls.

Following April 11, 2009, multiple fresh rock-fall paths were present on Y Mountain (figure 7, 8C, 8D). After detaching from the cliff face, rocks dropped vertically and then impacted the steep talus slope below, churning up talus, soil, and vegetation (figure 6). The rock debris then traveled down a small talus-lined gully. Freshly deposited rock was observed on the talus slope and in the gully. Rock debris continued rolling and bouncing down the mountain flank creating multiple linear rock-fall paths, shown by fresh bounce marks, or impact craters, and damaged vegetation (figures 7 and 8). The vertical drop along the cliff face and the steep 37º talus slope and gully likely provided a high initial velocity to rock debris. The firm mountain slopes that range from 27º to 35º maintained rock debris momentum, promoting the long runout distance into the subdivision. The rock debris traveled approximately 2,500 vertical feet and 5,000 feet slope distance to reach the affected structures. The mountain slopes are part of a small drainage basin that funnels rock-fall debris onto the alluvial fan below (figure 7).

A rock larger than those shown in figures 3D and 4 stopped about 650 feet slope distance above the damaged house and playhouse. Rock-fall paths suggest the rock that damaged the playhouse broke from a corner of the rock that damaged the house about 400 feet slope distance above the affected structures. If the larger rock had stayed intact, the house may have sustained more damage and the rock may have had enough momentum to exit the garage and continue farther into the subdivision.

Many large boulders are present on the alluvial fan to the south and the slope above houses damaged in 2005 and 2009 (figure 9). Some of the boulders on the alluvial fan may have a debris-flow origin, but we believe most of these boulders have a rock-fall origin because they lie directly on the fan surface in a random pattern, rather than in a debris-flow-deposition pattern, where boulders are partially buried or concentrated along levees or lobe fronts. Many of the large boulders are equidimensional to rectangular and reflect the orientation and spacing of bedding planes and joints in the cliff bands above.

The average slope from the apex of the talus slope to the rock's resting place, known as the "shadow angle" (Evans and Hungr, 1993), is about 29° for the 2009 event, similar to the 28.5° shadow angle for the 2005 event (Christenson and Giraud, 2005). Minimum shadow angles are used to estimate maximum rock-fall runout distances, and typical minimum shadow angles for rock falls measured elsewhere are about 22° (Wieczorek and others, 1998). This indicates that rocks may potentially travel farther downslope than houses damaged in 2005 and 2009, and that the rock-fall hazard area includes parts of the subdivision to the west, as shown by Robison (1990). The runout distances and size of these large rocks on the alluvial fan and the slope above houses damaged in 2005 and 2009 events show the proximity of houses to the rock-fall hazard.

PROBABLE CAUSES

Rock-fall initiation can sometimes be attributed to a specific cause or mechanism, but not always. Rock falls are generally the result of the cumulative effects of weathering and other geologic processes, but may be initiated by discrete events like earthquakes or meteorological events. In this particular case, the rock fall occurred approximately 47 hours after a storm on April 8-9, 2009, delivered 1.3 inches of precipitation as snow at the Cascade Mountain Snotel site (MesoWest, 2009), about 3 miles southeast of Y Mountain. The storm was followed by above-freezing temperatures at the Snotel site and air temperatures were above freezing at the time of the rock fall. Valley precipitation at the Provo Brigham Young University National Weather Service reporting station totaled 0.63 inches of precipitation as rain for the April 8-9 storm (National Weather Service Forecast Office, Salt Lake City, 2009). A specific triggering mechanism is not apparent, but the April 11, 2009 rock fall may be related to snowmelt following the April 8-9 storm and water infiltrating into fractures may have increased pore pressures and the potential for rock fall. Undercutting of the cliff face (figure 6) is an on-going process that contributes to rock-fall potential.

SUMMARY AND FUTURE HAZARD POTENTIAL

On April 11, 2009, rock detached from a cliff band on Y Mountain producing a rock fall that severely damaged a vacant house and slightly damaged a playhouse. The damaged vacant house is one lot north of a guest house destroyed by 2005 rock fall. Snowmelt from a storm on April 8-9, 2009 and an undercut part of the cliff band likely increased the rock-fall potential but a specific triggering mechanism is not apparent.

The continuous and discontinuous cliff bands on Y Mountain are extensive and have produced prehistoric and historical rock falls. Numerous potential rock detachment sites exist throughout the cliff bands and rock-fall initiation mechanisms will trigger future rock falls. The combination of rock size, cliff and mountain slope steepness, firm slope substrate, and lack of inhibiting dense vegetation promote a high momentum to rock fall resulting in long runout distances. The presence of large rock-fall boulders on the slopes above the subdivision and the alluvial fan clearly show that houses damaged by the 2005 and 2009 rock-fall events and adjacent houses are in a rock-fall-hazard area.

The timing of rock falls cannot be predicted, but they are most common during and following storms and earthquakes, and during periods of freeze-thaw such as spring and fall. However, rock falls are possible at any time and typically occur with no warning. Residents should be informed they are in a rock-fall-hazard area, and that they may wish to hire a geological consultant to investigate the risk from rock falls to the neighborhood or to individual homes and the feasibility of rock-fall risk-reduction measures.

LIMITATIONS

Although this product represents the work of professional scientists, the Utah Department of Natural Resources, UGS, makes no warranty, express or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, UGS, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

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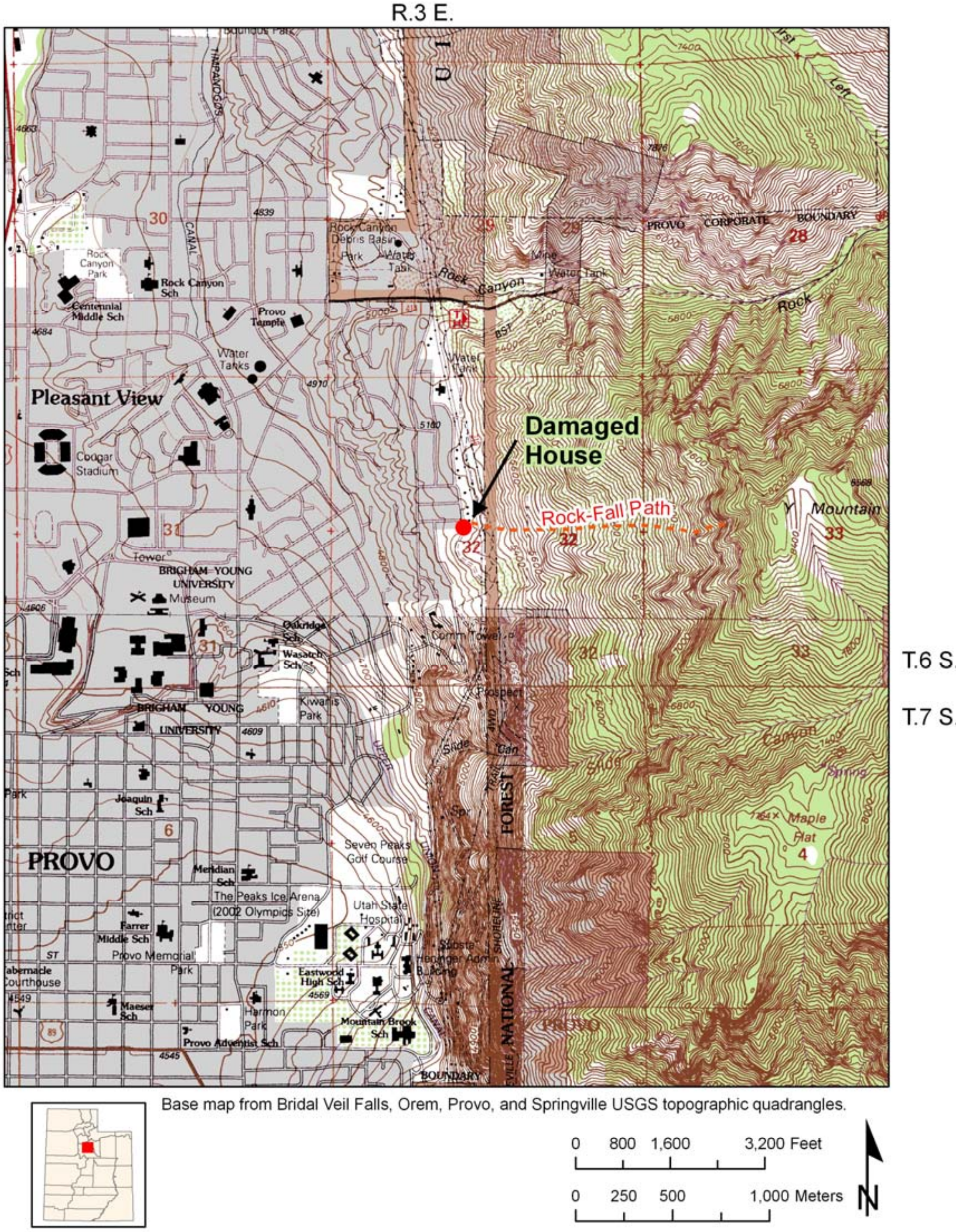

Figure 1. *Location of the April 11, 2009, 1550 East Provo rock fall showing generalized rock-fall path.*

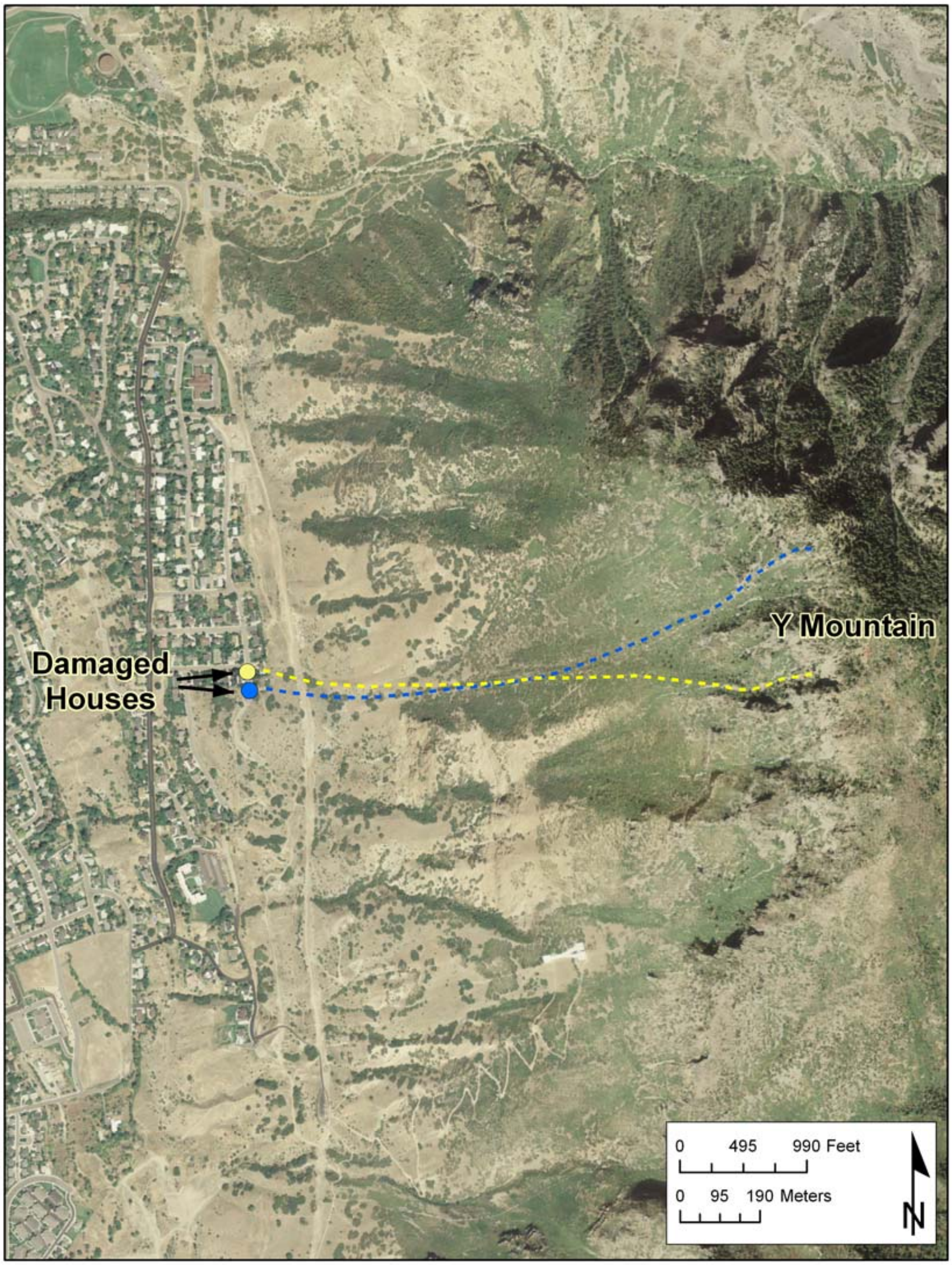

Figure 2. *2006 NAIP orthophoto showing Y Mountain, the 2005 (blue) and 2009 (yellow) rock-fall paths, and damaged houses.*

(A)

(B)

(C)

(D)

Figure 3. *Rock-fall damage to a vacant house at 1496 North 1550 East (Provo Fire Department photos).* ***A.*** *The rock bounced downslope, impacted and bent the red steel post, traveled over the chain link fence, impacted the lawn leaving a bounce mark, and entered through the back wall with an upward bounce trajectory.* ***B.*** *Looking through the back wall into the house. Once inside with an upward trajectory, the rock impacted the ceiling and traveled downward through an interior wall and then down through the floor into the garage below.* ***C.*** *Hole in the floor where the rock traveled into the garage below. As the rock traveled through the floor it pulled carpet into the garage below.* ***D.*** *The rock stopped inside the garage. The rock size is estimated to be 4 x 5 x 4 feet and broke through part of a garage door.*

Figure 4. *Rock-fall damage to chain link fence and playhouse at 1522 North 1550 East (Provo Fire Department photo). The rock size is estimated to be 2 x 4 x 3 feet.*

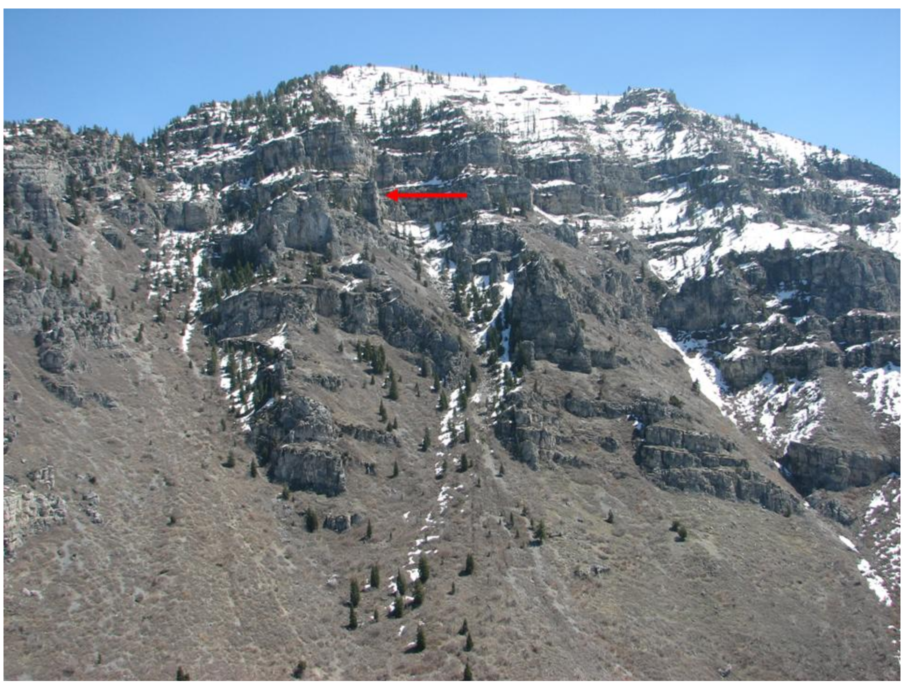

Figure 5. *West side of Y Mountain and extensive rock-fall source cliff bands. Steep, smooth mountain slopes below the cliff bands promote high rock-fall velocity and long runout distance. Red arrow points to the 2009 rock-fall detachment location.*

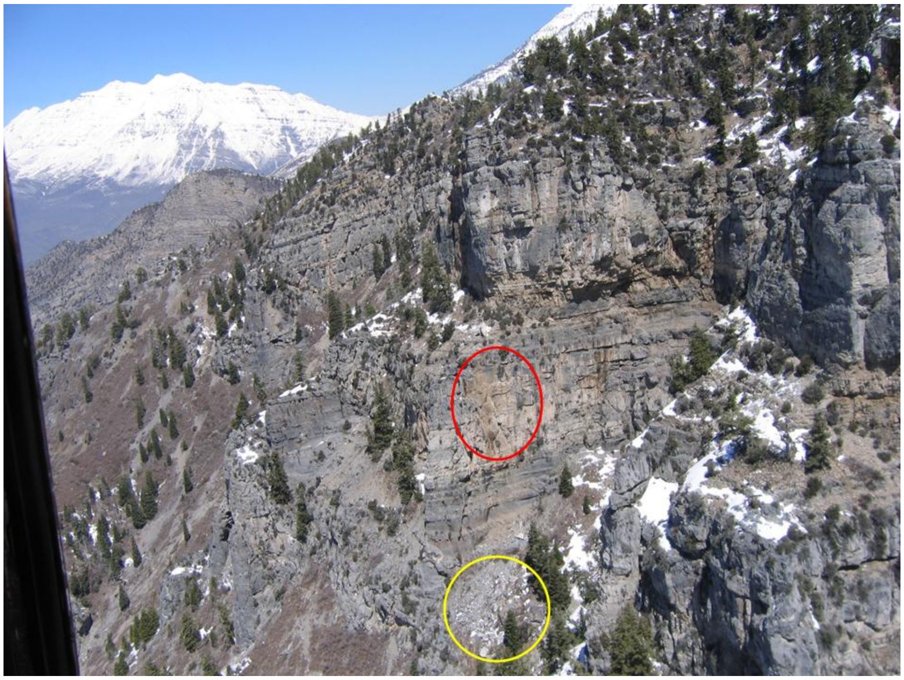

Figure 6. *Rock-fall detachment surface (red circle), photo taken 9 days after April 11, 2009. Rock debris impacted the talus slope below the cliff band (yellow circle). Cliff face undercutting is apparent below the detachment surface.*

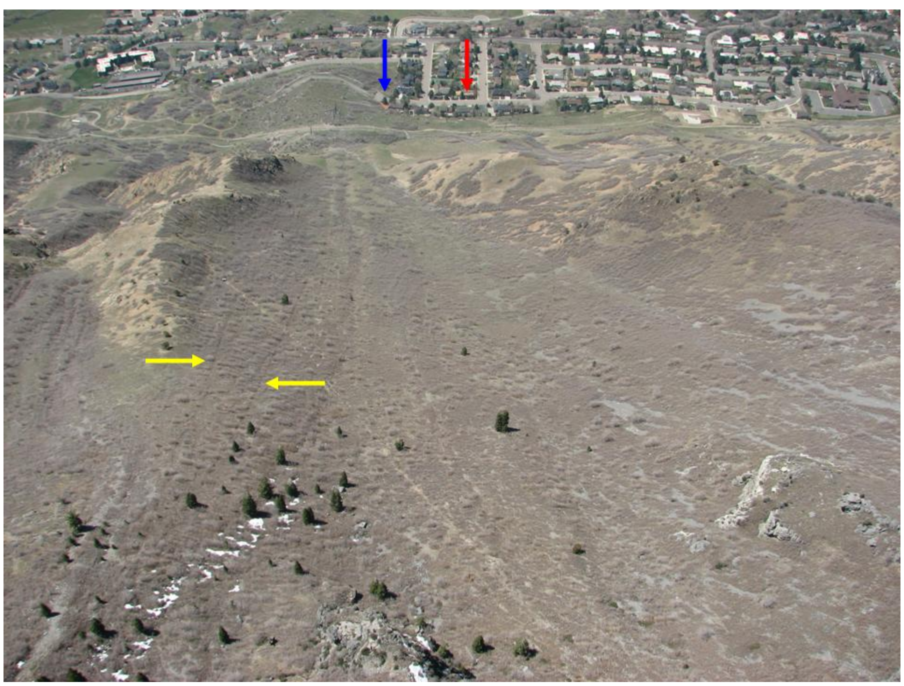

Figure 7. *View downslope showing rock-fall paths on Y Mountain above the subdivision. Yellow arrows point to two of multiple April 11, 2009, rock-fall paths. Older rock-fall paths are also evident. Blue and red arrows point to houses impacted in 2005 and 2009 respectively (also see figure 9).*

(A)

(B)

(C)

(D)

Figure 8. *Rock-fall travel paths.* ***A.*** *A smaller rock that broke off a larger piece as it traveled downslope.* ***B.*** *Rock fall damaged oak brush.* ***C.*** *Multiple travel paths (yellow arrows).* ***D.*** *Multiple travel paths (yellow arrows) evident directly above the damaged house and playhouse.*

Figure 9. *Previous guest house location destroyed by the 2005 rock fall (blue arrow) and the house damaged by the 2009 rock fall (red arrow). Rock-fall boulders on the alluvial fan left of the blue arrow and the slope above the impacted houses show the distribution and size of historical and prehistorical rock fall and the proximity of houses to the hazard.*