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<tr><td colspan="3">Project:
Investigation of the February 10, 2010, Rock Fall at 274 Main Street, Rockville, Utah</td><td rowspan="3"></td></tr>
<tr><td>By:
Tyler R. Knudsen, P.G.</td><td>Date:
March 9, 2010</td><td>County:
Washington</td></tr>
<tr><td>USGS Quadrangles:
Springdale West</td><td colspan="2">Section/Township/Range:
Section 1, R. 11 W., T. 42 S., SLBM</td></tr>
<tr><td>Requested by:
Allen Brown, Mayor, Rockville City</td><td colspan="2">Date report received at UGS:
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INTRODUCTION

At approximately 7:40 a.m. on February 10, 2010, a large rock released from the upper south-facing slope of Rockville Bench above Rockville, Utah (figures 1 and 2). The rock proceeded to slide downslope for several feet until it fell over a ledge and began to roll. The rock collided with a large previous rock-fall boulder at the base of the slope and shattered into numerous smaller fragments that damaged several outbuildings, two cars, and a house at 274 Main Street (figures 3 and 4). Although the house was occupied at the time, no injuries occurred. Another large boulder, similar to the boulder that fell, remains on the upper slope.

On the afternoon of February 10, 2010, Rockville City Mayor Allen Brown requested that the Utah Geological Survey (UGS) investigate the rock fall. Tyler Knudsen and Robert Blackett, UGS, met with the mayor and the occupants of the home that evening and investigated the rock fall until dusk. On February 11, 2010, we provided Mayor Brown with our initial conclusions and recommendations. This report provides supplemental information on the rock-fall hazard and restates our conclusions and recommendations. We focused on the rock-fall susceptibility of rock outcrops and talus above the site, the rock-fall travel path to structures, and rock-fall runout distance.

In addition to a site reconnaissance, we reviewed relevant geologic maps, literature, and aerial photography including the UGS 1:24,000-scale (1 inch = 2000 feet) geologic map of the Springdale West quadrangle (Willis and others, 2002), rock-fall hazard maps for Zion National Park (Lund and others, in review) and the St. George – Hurricane area (Lund and others, 2008), U.S. Geological Survey 1993 orthophotography at various scales (Utah Automated Geographic Reference Center, 2010a), 2004 and 2009 National Agriculture Imagery Program (NAIP) orthophotography at various scales (Utah Automated Geographic Reference Center, 2010b), and 2006 high-resolution orthophotography (HRO; Utah Automated Geographic Reference Center, 2010c).

DESCRIPTION AND GEOLOGIC SETTING

The rock fall consisted of a single remobilized sandstone talus boulder of the Shinarump Conglomerate Member of the Triassic Chinle Formation that had been resting just below the Shinarump cliff capping the Rockville Bench mesa (figure 2). The Shinarump outcrop is about 320 feet above the adjacent valley floor. The boulder had previously detached from the cliff, traveled a slope distance of about 40 feet, and came to rest on a 44° slope underlain by shale, siltstone, and sandstone of the upper red member of the Triassic Moenkopi Formation. A review of historical orthophotography shows the boulder had been at that position, 290 vertical feet above the slope's base, since at least 1993 (figure 5). Downslope-oriented parallel grooves in the boulder's detachment surface indicate that the rock fall initiated as a rockslide (figure 6). After sliding about 15 feet, the boulder fell over a resistant sandstone ledge that forms a small cliff about 12 feet high and began rolling down a shallow talus-lined gully. Near the bottom of the gully, the boulder deflected to the southeast, collided with an existing large boulder at the base of the slope, and shattered into numerous smaller fragments.

Debris from the impact damaged a private residence and several outbuildings near the impact site. Two small sheds immediately adjacent to the impact area were destroyed, and a larger wood-framed workshop was severely damaged and knocked off its foundation (figure 3). Three other outbuildings ranging from a small chicken coop to a more substantial wood and stone hay barn sustained moderate to light damage from falling and rolling debris. An approximately 3.5 x 3 x 1.7-foot boulder weighing an estimated 1.3 tons rolled through a mudroom on the east side of the house, broke through a glass doorway, exited through an exterior wall, and struck and severely damaged a vehicle parked in the driveway (figure 4). A second vehicle parked near the workshop was also heavily damaged. Both vehicles had been removed from the property by the time of our site visit.

We found the largest post-impact fragment about 50 feet from the impact site; it measured about 9 x 6 x 5 feet and weighed an estimated 20 tons (figure 3E). Most post-impact debris accumulated within a 75-foot radius of the impact site, but we found a few small (0.5- to 1-foot-diameter) fragments as much as 180 feet away. Based on our aerial-photo analysis, the size of the boulder's detachment surface, and amount of material observed at the bottom of the slope, we estimate the boulder was roughly rectangular with dimensions of about 21 x 17 x 17 feet and weighed an estimated 450 tons.

Disturbed and freshly deposited debris remaining in the rock-fall path appears to be stable and presents little hazard to structures below. However, a second large boulder, approximately 30 x 15 x 14 feet and weighing an estimated 470 tons, lies about 80 feet east of where the rock fall originated and appears similar to the boulder that rolled down the slope. The remaining boulder is also Shinarump Conglomerate talus and rests on a 44° slope of the upper red member of the Moenkopi Formation (figure 7A). Inspection at the boulder's base revealed a 1- to 2-foot-wide undercut beneath the boulder's eastern edge where surface water has removed underlying shale and siltstone (figure 7B). This boulder is also visible in 1993 orthophotography (figure 5). The impacted house, the Amber Inn, and other structures at the base of the slope may be damaged if this boulder also moves downslope.

ROCK-FALL SOURCES, PATHS, AND DEPOSITION

The well-indurated Shinarump Conglomerate, where it caps slopes of less-resistant Moenkopi Formation, is a well-known source of rock falls in southwestern Utah (Lund and others, 2008). The Shinarump cliff north of Rockville sourced a large rock fall in October 2001 that severely damaged a home at the corner of Terry Lane and De Mille Road (figure 1; Lund, 2002). Numerous fresh-appearing rock-fall scars on the cliff face and widespread distribution of Shinarump rock-fall boulders at the base of Rockville Bench attest to the frequency of rock falls sourced from the Shinarump ledge.

In the Rockville area, the Shinarump Conglomerate ranges from 60 to 135 feet thick, dips 1° to 2° to the east, and contains widely spaced vertical joints (Willis and others, 2002). Weathering along joints combined with undercutting of the cliff face by erosion of the softer underlying Moenkopi Formation weakens the Shinarump rock mass and creates opportunities for triggering mechanisms such as frost and root wedging, rainfall, or earthquakes to initiate rock falls. The orientation, spacing, and intersection of bedding planes and joints within the Shinarump typically produce large, equidimensional rock-fall blocks.

The February 10, 2010, rock fall demonstrated that in addition to rock falls detaching directly from the Shinarump cliff, talus below the cliff but high on the steep slope of Rockville Bench may also remobilize.

We observed a clear rock-fall path delineated by churned soil and vegetation, fresh rock deposition, rock gouge, and impact craters from the February 10, 2010, event (figure 8). After sliding from its resting place, the 12-foot vertical drop and average 38° slope along the gully bottom imparted a high initial velocity to the rock fall. Several large, freshly broken boulders in the rock-fall path likely include pieces broken off the falling/rolling boulder as well as shattered talus impacted by the moving boulder. Near the bottom of the slope, the boulder deflected slightly eastward either off the western gully wall or perhaps off another large talus boulder before striking a stationary rock at the base of the slope. The rock fall traveled a total distance of 500 feet before striking the boulder, and debris ejected by the impact traveled as much as an additional 180 feet. If the rock-fall boulder had stayed intact, the house may have sustained more damage, and the rock may have had enough momentum to impact the nearby Amber Inn on Main Street and/or other nearby structures.

Numerous large Shinarump boulders, as much as 45 feet in long dimension, are present on and at the base of the Rockville Bench slope. Most of the boulders are equidimensional to rectangular, and reflect the orientation and spacing of joints and bedding planes in the Shinarump cliff above. Many smaller rock-fall boulders and some larger ones have likely been removed at the base of the slope to accommodate construction of buildings and roads as well as leveling of farm and pastureland.

The average angle of an imaginary line extending from the bottom of the rock-fall source area to the rocks' resting place is termed the "shadow angle" (Evans and Hungr, 1993; Wieczorek and others, 1998). Shadow angles vary based on rock type, boulder shape, slope steepness, slope composition, and rock source height. Minimum shadow angles are used to estimate maximum rock-fall runout distances for geologic-hazard evaluations.

A shadow angle of 25° was measured for both the 2010 and 2001 damaging Rockville rock falls, but since both rock falls broke apart and impacted other boulders and structures, this should be considered a maximum angle. A large boulder south of SR-9 near Rockville's west entrance has an approximate shadow angle of 22°, similar to typical shadow angles measured for dozens of rock falls in Zion Canyon (Lund and others, in review), the St. George area (Lund and others, 2008), and elsewhere (Wieczorek and others, 1998). Until a rock-fall inventory and study is completed for Rockville Bench, we believe a 22° shadow angle is a reasonable value for estimating maximum runout distance for rock falls originating from the Shinarump cliff face in Rockville.

The gentle regional structural dip combined with the upstream grade of the Virgin River valley causes the height of the Shinarump ledge capping Rockville Bench to gradually decrease from a maximum of 400 feet above the valley floor near Rockville's western border to 40 feet on the east side of town near Anasazi Way. Therefore, runout distances will generally decrease eastward along the base of the slope north of town.

Projection of a 22° shadow angle from the base of the Shinarump ledge would place many homes in the northern part of Rockville within a high rock-fall-hazard area. Several structures south of the Virgin River on 230 South may also be at risk from falling debris originating from the Shinarump-capped mesa to the south.

PROBABLE CAUSES

Rock falls typically result from the cumulative effects of weathering and other geologic processes, but may also be initiated by discrete triggers such as earthquakes or meteorological events. In this instance, no earthquakes were recorded at the time of the event, however, the rock fall occurred shortly after a prolonged period of rain on February 5-9, 2010, that produced 1.38 inches of precipitation at the Zion Canyon RAWS MesoNet station (MesoWest, 2010) about 4.5 miles northeast of Rockville. Station records show that 0.35 inch of rain fell the evening before the rock fall. Although it was not raining at the time of the rock fall, soil and rock slopes near the source area were still saturated when we visited the site approximately 9 hours after the rock fall occurred. Observation of the detachment zone revealed a zone of saturation extending 1 to 2 feet inward from the outer perimeter of the boulder's footprint. Although saturation of the relatively weak siltstone and mudstone beneath the boulder likely affected the timing of the rock fall, the precise mechanism is unclear. Surface water may have eroded material out from beneath the boulder causing instability, or increased pore pressure within the silty and clayey material beneath and/or buttressing the boulder may have resulted in a reduction of cohesion and subsequent failure.

A triggering mechanism for a particular rock fall is not always apparent. The 2001 rock fall was preceded by several weeks of dry weather, and no earthquakes were recorded at the time of or prior to the event (Lund, 2002). Initiation of that rock fall was attributed to the cumulative effects of gravity and erosion.

SUMMARY AND FUTURE HAZARD POTENTIAL

On February 10, 2010, a large talus boulder slid and fell from the upper slope of Rockville Bench, rolled downslope 500 feet, impacted a large stationary boulder, and shattered into dozens of smaller boulders that damaged several outbuildings, two cars, and a home at 274 Main Street in Rockville. The impacted property is less than 2000 feet west of a home damaged in 2001 by a similarly large rock fall. Moisture from a protracted storm on February 5-9, 2010, likely triggered the rock fall. Another similarly sized boulder remains high on the hillside.

The Shinarump cliff capping Rockville Bench has produced numerous prehistoric and historical rock falls. Erosion of the underlying Moenkopi slope will continue to destabilize the Shinarump cliff and rock-fall initiation mechanisms will undoubtedly trigger future rock falls. The combination of rock size and shape, cliff height, slope steepness, and a lack of dense vegetation promotes high momentum of rock falls initiating from the Rockville Bench, resulting in long runout distances. The damaging 2001 and 2010 rock falls, and the presence of numerous large boulders on the slopes above (and in some cases surrounding) homes at the base of the Rockville Bench, clearly indicate many homes there are in an area of high rock-fall hazard.

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. However, rock falls are possible at any time and typically occur with no warning. Rockville residents should be informed they are in an area of high rock-fall hazard, and they may wish to hire a geological consultant to investigate the risk from rock falls and the feasibility of rock-fall risk-reduction measures relative to their properties.

LIMITATIONS

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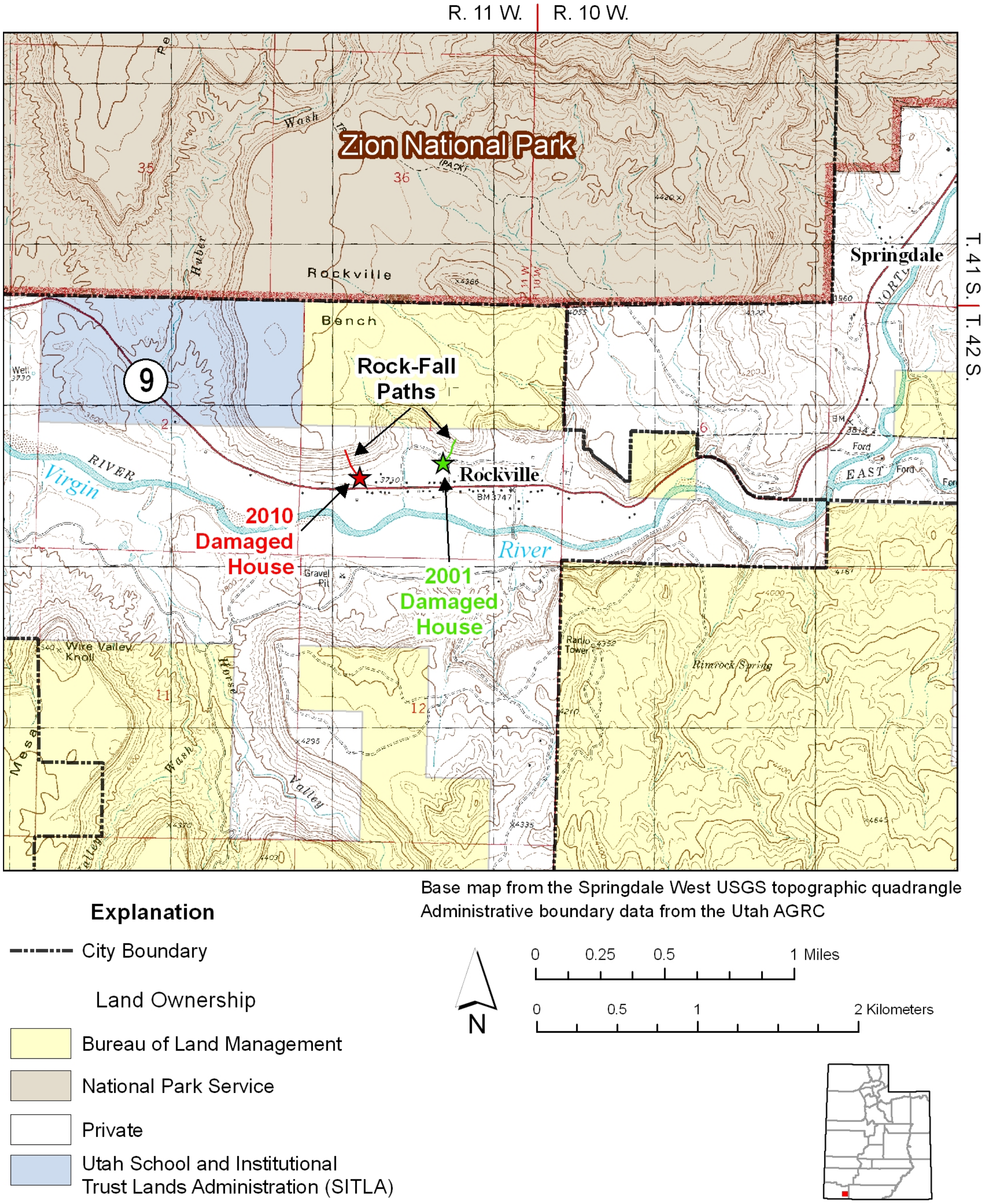

Figure 1. *Location of the February 10, 2010, rock fall in Rockville, Utah. Also shown is the location of a rock fall that damaged a house in October 2001.*

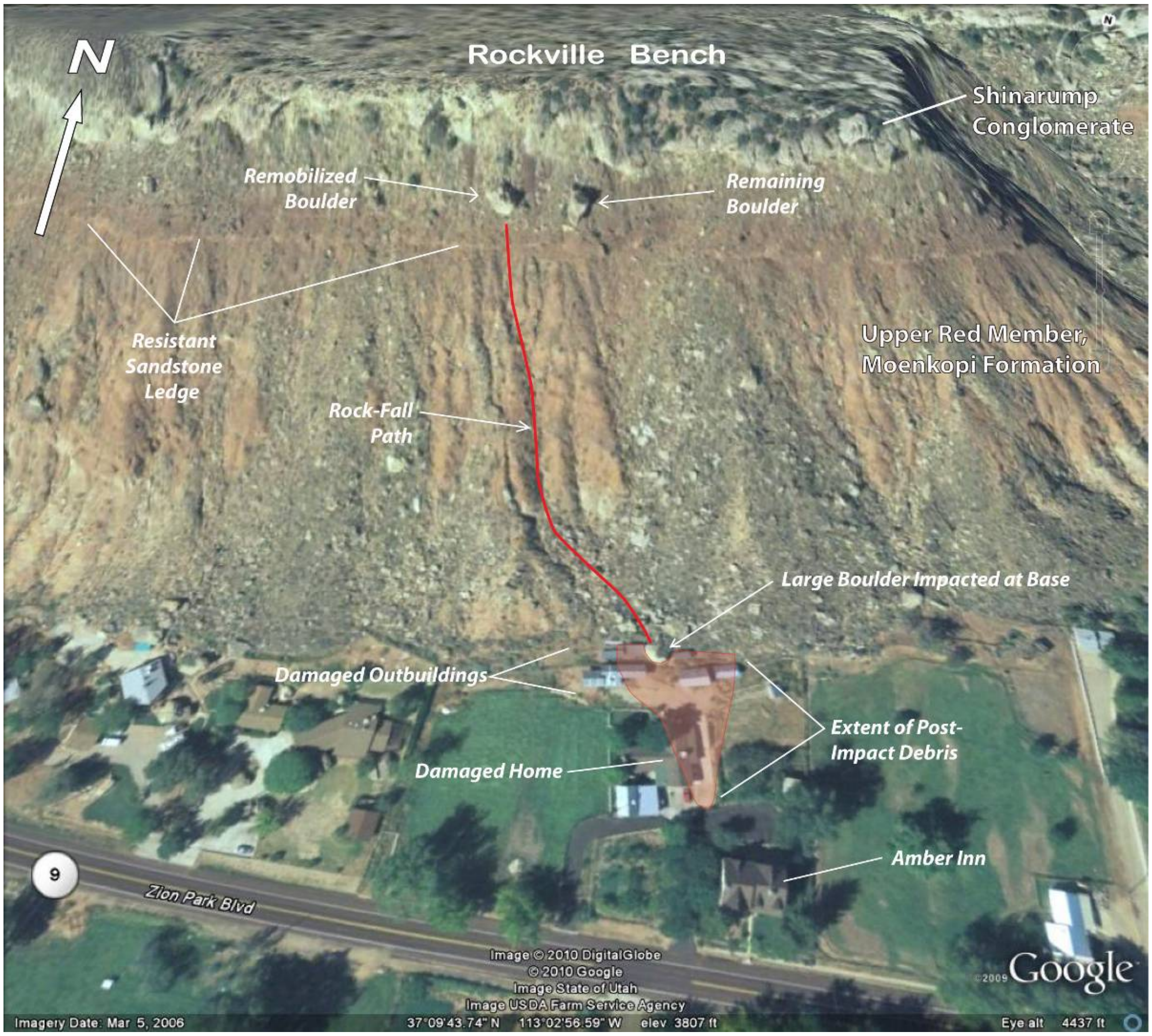

Figure 2. *Google Earth image showing source area, rock-fall path, extent of post-impact debris field, and damaged structures.*

Figure 3. *Impact area and damage to outbuildings.* ***A.*** *Large boulder (red arrow) at base of slope that broke up the rock fall. Yellow arrows show location of destroyed sheds.* ***B, C.*** *Destroyed sheds adjacent to impact area.* ***D.*** *Damaged workshop knocked off its foundation.* ***E.*** *Largest (9 x 6 x 5 feet) post-impact boulder that damaged a workshop (right) and shed (left).*

Figure 4. *Rock-fall damage to the house at 274 Main Street.* ***A.*** *View downslope along path of rock that damaged the house. Narrowly missing a barbeque grill, the rock rolled through the entryway and mudroom on the left (east) side of the house.* ***B.*** *Looking through the mudroom where the boulder broke through a glass door, which is still on its hinges, and exited through an exterior wall and window.* ***C.*** *After exiting the mudroom, the rock collided with a parked car and came to a rest. The rock, estimated to be 3.5 x 3 x 1.7 feet, was later moved up against the house when the damaged car was removed.*

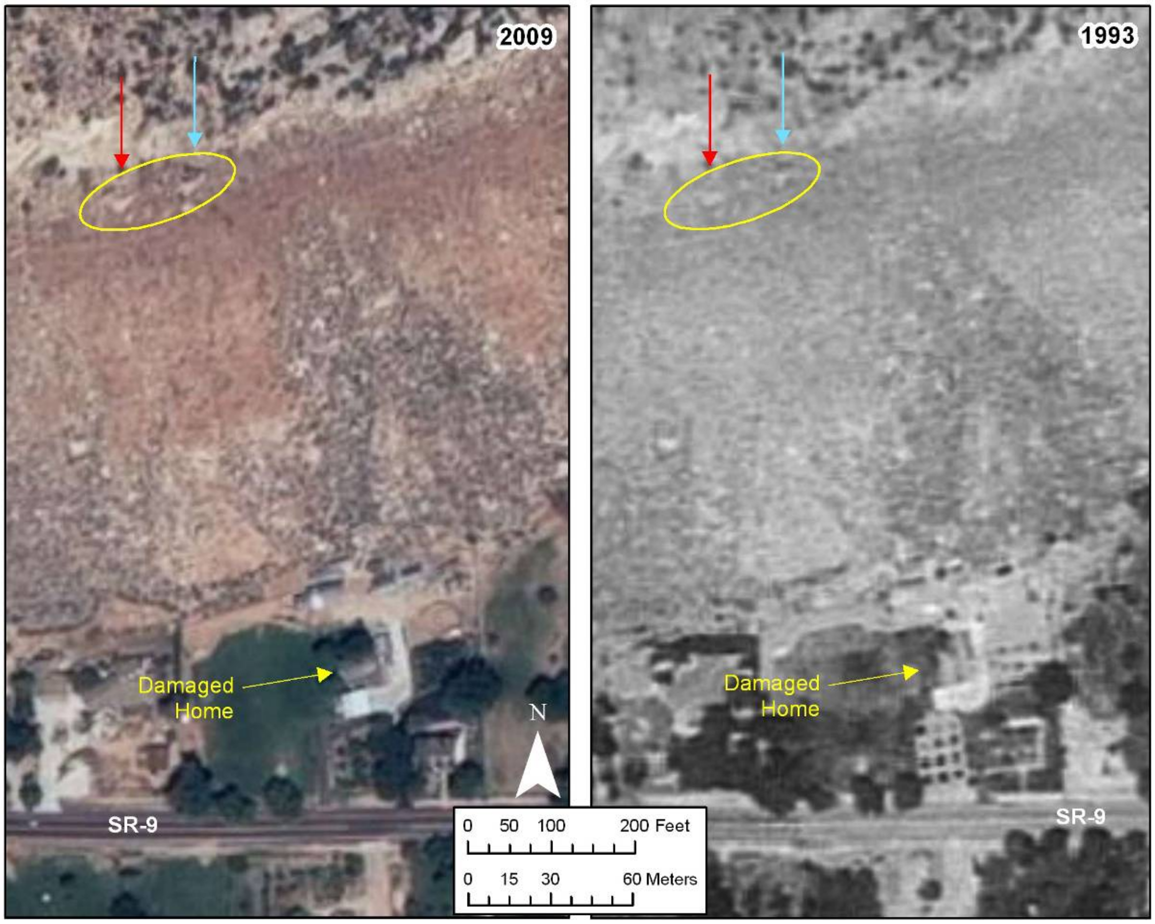

Figure 5. *Comparison of 2009 NAIP and 1993 U.S. Geological Survey orthophotos showing the source area and damaged home. Both the 2010 rock fall (red arrow) and the boulder remaining on the hillside (blue arrow) are visible in the 2009 photo; although not as clear, the boulder pair also appears to be present in the 1993 photo.*

Figure 6. *Slide plane and grooves (~5 feet long) in the detachment area; left is downslope.*

Figure 7. *Remaining boulder above damaged house.* ***A****. Rock resting on steep slope of mudstone and siltstone of the upper red member of the Moenkopi Formation; the rock is about 30 feet wide in this view to the west.* ***B.*** *Void space (~1 foot high) created by surface erosion extending 1 to 2 feet beneath the eastern edge of the boulder.*

Figure 8. *View looking north to the rock-fall source area (yellow arrow) showing fresh rock fragments in the rock-fall path (dashed yellow line). Remaining talus boulder is shown with blue arrow.*