RECONNAISSANCE OF LANDSLIDES AND PRELIMINARY LANDSLIDE HAZARD ASSESSMENT ALONG A PORTION OF BROWNS PARK ROAD, DAGGETT COUNTY, UTAH

by Gregg Beukelman and Ben Erickson

UTAH DNR GEOLOGICAL SURVEY

REPORT OF INVESTIGATION 271
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
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Cover Photo: *View of Browns Park Road damaged from one of five landslides in lower Jesse Ewing Canyon, Daggett County, Utah*

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RECONNAISSANCE OF LANDSLIDES AND PRELIMINARY LANDSLIDE HAZARD ASSESSMENT ALONG A PORTION OF BROWNS PARK ROAD, DAGGETT COUNTY, UTAH

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ABSTRACT

In June 2011, the Utah Geological Survey performed a reconnaissance investigation of five landslides that had recently occurred in lower Jesse Ewing Canyon, Daggett County, Utah, along a section of Browns Park Road that was realigned in 2009. One landslide (Landslide A) was a partial reactivation of a preexisting rotational rockslide, and four landslides (Landslides B through E) were translational rockslides that involved cut slopes above the realigned roadway. The landslides are all underlain by shale and silty sandstone containing lenses of silicic conglomerate. With the exception of the conglomerate, these materials exhibit intense fracturing and deep and rapid weathering upon exposure at the surface. The landslides impacted the roadway to varying degrees, from Landslide B that blocked the southbound lane and part of the northbound lane, to Landslide D that partially covered only a guardrail and filled a small roadside ditch.

The two landslides that pose the greatest immediate hazard to the public are Landslides A and B, both near a through cut about 18.2 miles along Browns Park Road from its intersection with U.S. Highway 191. Landslide A is a partial reactivation of a preexisting landslide, and has developed an arcuate scarp that, at its apex, extends above the road and intersects it near both ends, resulting in pavement distress where the scarp crosses the roadway. Just downhill of the roadway and the recently developed scarp is a waste pile of material excavated during the roadway realignment that was placed on a nearly level surface formed by rotational movement of the preexisting landslide. Although data from this reconnaissance do not permit a precise explanation for the cause of this partial reactivation, a combination of added weight of the waste pile and an increase in pore water pressure along the rupture surface resulting from extreme recent precipitation likely contributed to slope instability.

Landslide B is a translational rockslide that occurred early in the week of June 5, 2011, and affected the western side of the through cut. Conditions that may have contributed to Landslide B movement include very weak geologic materials, and the relation between the orientation of bedrock bedding planes and surface slope angles. Above-normal precipitation, including a very wet winter and spring and several intense rain events in the latter part of May 2011, may have been a factor in triggering landslide movement.

The three other small translational rockslides (Landslides C through E) involved bedrock failure along bedding planes exposed in road cut slopes. Although geologic materials were similar to those observed at Landslide B, bedding planes do not dip out of the slope at any of these rockslides, which likely limited their downhill extent. The exact timing of these three landslides is unknown, but recent precipitation may have been a factor in triggering these landslides as well.

INTRODUCTION

In the spring of 2011, landsliding occurred along part of Browns Park Road (Daggett County Highway 1364) in lower Jesse Ewing Canyon. This landsliding affected cut slopes and pavement along a section of the road that had been realigned in 2009 (figures 1 and 2). This reconnaissance investigation focused on five landslides along a length of the realignment between 18.2 and 18.8 miles east of the intersection of Browns Park Road and U.S. Highway 191 (figures 1 and 2). Four landslides were new rockslides involving weak bedrock, and one was a partial reactivation of an existing rotational rockslide. One of the new rockslides, reported to have occurred early in the week of June 5 in an east-facing slope of a through cut, blocked the entire southbound lane and part of the northbound lane (figure 3). For this reconnaissance, we designated the landslides as Landslides A through E, based on their relative position from north to south along the road (figure 2).

On the afternoon of June 21, 2011, we met with Daggett County Commissioner Jerry Steglich, Stanley Crawforth of American Geotechnics, James Olsen of the Daggett County Road Department, and representatives of Questar Gas on Browns Park Road to discuss Landslides A and B. Our field reconnaissance began at that time and continued through June 23, 2011. An unpublished Utah Geological Survey (UGS) letter report (Beukelman, 2011) provided to Daggett County on June 30, 2011, included observations and initial conclusions and recommendations from our reconnaissance investigation. In addition to our findings,

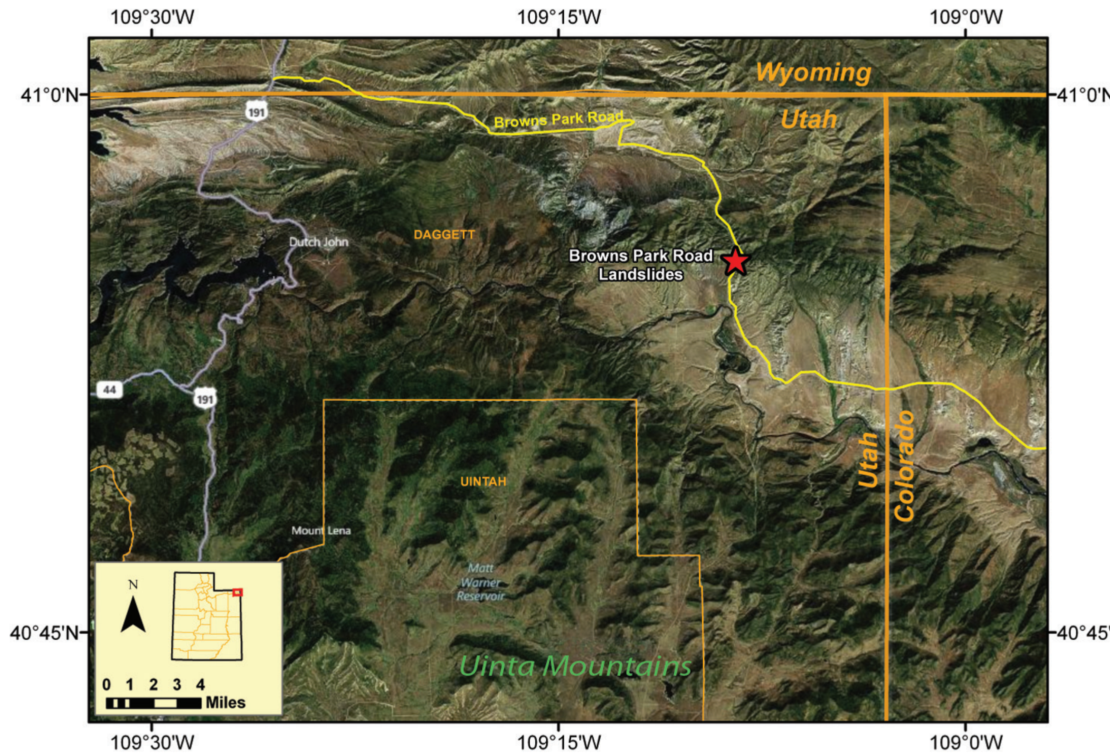

Figure 1. *Location of Browns Park Road landslides in Daggett County, Utah. Base map imagery from Microsoft Bing Maps accessed through ArcGIS software on October 29, 2011.*

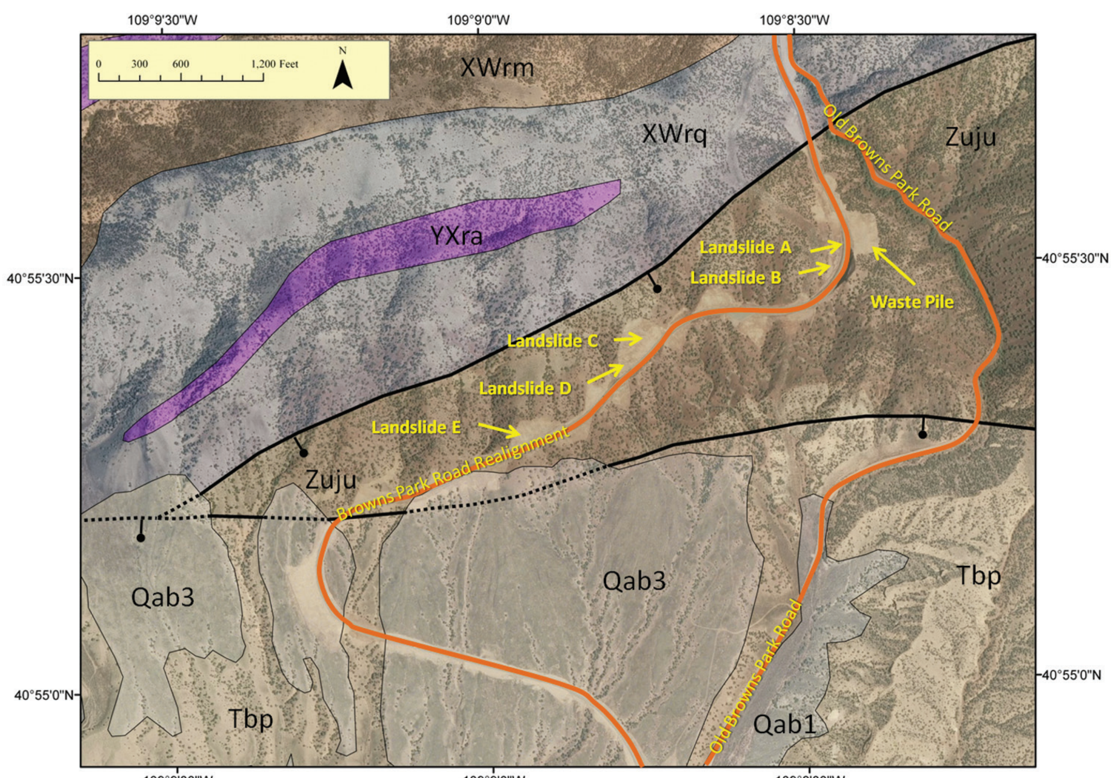

Figure 2. *Landslides along Browns Park Road investigated in this reconnaissance. Regional faults shown in black (bar and ball on down-dropped side, dotted where concealed). Geologic units include Browns Park piedmont alluvium (Qab1 [youngest] and Qab3 [older]); Browns Park Formation sandstone, with siltstone, conglomerate, and rhyolitic air-fall tuff (Tbp); Upper Jesse Ewing Canyon Formation shale interbedded with quartzose and lithic sandstone (Zuju); and Red Creek Quartzite containing three rock types: amphibolite (YXra), metaquartzite (XWrq), and mica schist (XWrm). Geology from Sprinkel (2006), base from 2009 National Agriculture Imagery Program.*

the Utah Department of Transportation (2011) on June 20, 2011, provided Daggett County with a memorandum report presenting preliminary conclusions and recommendations regarding the landslides based on observations during their site visit on June 9, 2011.

Purpose and Scope

The purpose of this reconnaissance investigation is to determine the geologic characteristics and causes of the spring 2011 Browns Park Road landslides, and to make a preliminary assessment of the likelihood and extent of hazard from future landslides. This report is intended to provide supplemental information to the June 30, 2011, UGS letter report, and make the findings of our reconnaissance investigation more broadly available. This report summarizes our observations and conclusions, discusses future landslide hazard, and provides recommendations for consideration by Daggett County officials in managing landslide risk.

The project scope was mostly limited to the interpretation of existing data to characterize landslide hazard in a general manner. Except for our reconnaissance-level field observations, no additional fieldwork, subsurface exploration, or laboratory testing was conducted or other data collected as part of this investigation. As part of our field reconnaissance, we characterized bedrock conditions by observation and measured bedding-plane orientations and cut-slope angles using a Brunton compass. Mapping of landslide boundaries and features was completed using a Global Navigation Satellite System (GNSS) hand-held Trimble GeoXT instrument. In addition to our field reconnaissance, we analyzed local conditions, including slope angles, that existed prior to construction of the Browns Park Road realignment using aerial photographs and geographic information system (GIS) methods.

Sources of Information

We reviewed relevant geologic maps, literature, and aerial photographs including UGS 1:100,000-scale geologic and landslide maps of the Dutch John 30' x 60' quadrangle (Sprinkel, 2006, and Elliott and Harty, 2010, respectively); the U.S. Geological Survey 1:24,000-scale geologic map of the Clay Basin quadrangle (Hansen, 1957); 1938 aerial photographs (Soil Conservation Service, 1938); and 2009 National Agriculture Imagery Program (NAIP) orthophotography at various scales (Utah Automated Geographic Reference Center, 2009). We used a 5-meter-resolution digital elevation model (DEM) (Utah Automated Geographic Reference Center, 2007) to construct a three-dimensional model of a portion of the area surrounding Browns Park Road and to calculate slope angles that existed prior to roadway construction.

We conducted interviews with Daggett County personnel, including county commissioner Jerry Steglich and James

Figure 3. *Browns Park Road looking south. Landslide A, a partial reactivation of a preexisting landslide, is shown in the foreground (yellow line marks landslide scarp and arrows show approximate direction of movement). At right is debris from Landslide B, a translational rockslide that blocked the southbound (downhill) lane of the roadway. Behind the debris is intact shale and silty sandstone bedrock showing bedding planes (one bedding plane highlighted by dashed yellow line) that are dipping out of the slope. The slope angle of the western road cut was measured as 45 degrees (1H:1V) in the upper part of the slope and about 65 degrees (1/2H:1V) near its base. Photo taken on June 21, 2011.*

Olsen of the Daggett County Road Department, and with others knowledgeable about the construction of the road realignment and the 2011 landslides. We also discussed the original geotechnical investigation and design of the realignment with Stanley Crawforth of American Geotechnics, who was involved in both the original geotechnical investigation and subsequent design.

GEOLOGIC SETTING

Bedrock in the immediate vicinity of the landslides is mapped by Hansen (1957) and Sprinkel (2006) as the Upper Jesse Ewing Canyon Formation of the Neoproterozoic Uinta Mountain Group (figure 2). Geologic materials involved in landsliding and exposed in road cuts consist of intensely fractured, dark- to medium-red-brown shale and silty sandstone, and medium- to thick-bedded conglomerate (figure 3). In the area of our reconnaissance, regional-scale, steeply dipping, down-to-the-south, normal faults bound the Upper Jesse Ewing Canyon Formation to the north and south. The northern fault is exposed in a road cut about 800 feet north of Landslide A. The southern fault acts as the northern basin-bounding fault for Browns Park, and is approximately 900 feet south of Landslides C through E. In addition to these regional-scale faults, road cuts near Landslides A and B expose many smaller, steeply dipping, normal faults that intensely fracture all of the exposed rock (figure 4). Sprinkel (2006) reported bedding within this unit dips generally to the south at about 25° to 60°; locally, we measured southeast to northeast dips of 15° to 56°. Bedrock weathering has resulted in locally rounded topography and few bedrock outcrops, with the exception of the silicified conglomerate layers, which are more resistant and show little affect of weathering.

Geologic mapping during our reconnaissance, and analysis of aerial photos, revealed a large, preexisting, rotational rockslide that involved movement on an east-facing slope in the vicinity of Landslides A and B (figure 5). The main scarp of this preexisting landslide is near the crest of the ridge above Browns Park Road, and the landslide mass extends to the bottom of the slope near the stream that drains Jesse Ewing Canyon. The landslide flanks are difficult to identify due to erosion and cut-slope modification during roadway realignment. However, the landslide's left and right flanks are exposed in road cuts where landslide debris is juxtaposed against in-place bedrock. On the landslide's right (southern) flank, this contact is marked by a light-colored zone that may reflect groundwater bleaching, or mineral precipitation that resulted from preferential groundwater movement along the flank (figure 6). Similar light-colored materials were also observed along many of the normal faults exposed in the cut slopes, which also may provide paths for preferential groundwater flow. Based on the cut-slope exposures of the landslide margins, other landslide features identified during our reconnaissance, and aerial photo interpretation, we estimate the

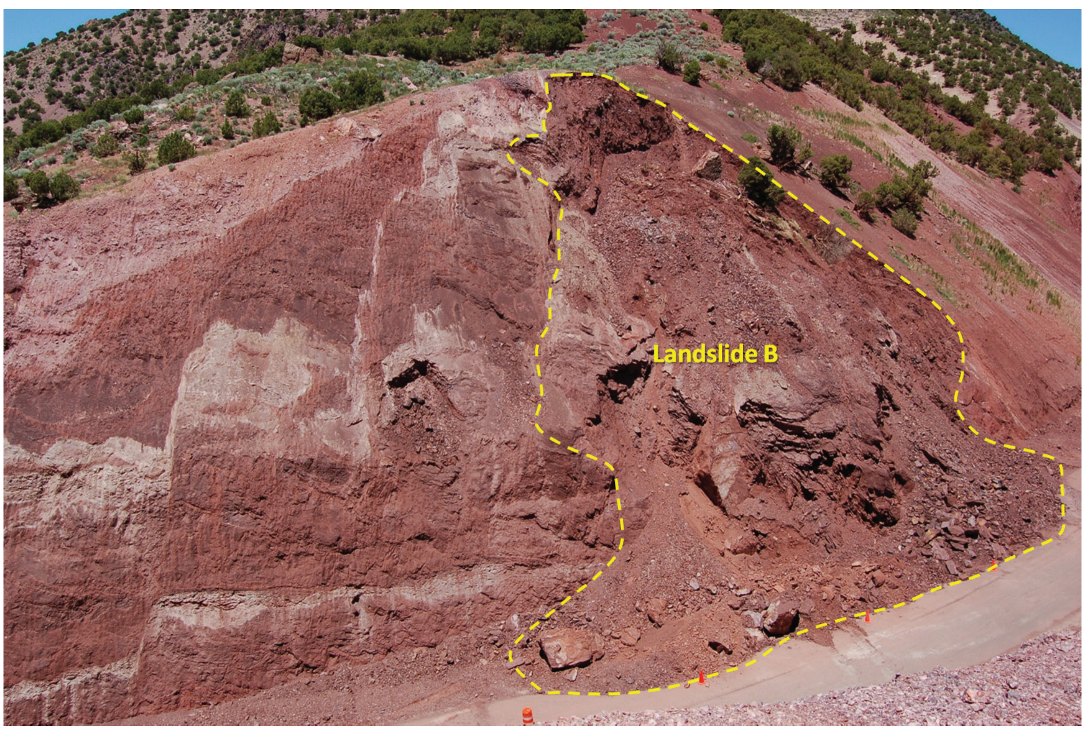

Figure 4. *Western cut slope of roadway through cut showing Landslide B. Browns Park Road with one lane blocked in the foreground. Bedrock is Upper Jesse Ewing Canyon Formation shale and silty sandstone. Numerous steeply dipping normal faults are marked by offset of light-colored beds in left part of photo. Photo taken on June 21, 2011.*

preexisting rockslide to be approximately 550 feet wide at the road and to extend about 700 feet downslope from its main scarp, about 200 feet above the road, to the stream at the bottom of the slope (figure 5). About 250 feet below the road, we observed a prominent back-tilted surface, formed during rotational movement of the rockslide (figure 7).

LANDSLIDE EVENTS OF SPRING 2011

Although other landslides exist in the area, this reconnaissance addresses five landslides that occurred during 2011 in slopes modified during the 2009 realignment of Browns Park Road in lower Jesse Ewing Canyon (figure 2). Landslide activity along the Browns Park Road realignment began in 2010, but became more pronounced in the spring of 2011 (James Olsen, Daggett County Road Department supervisor, verbal communication, 2011).

Landslide A

About 18.2 miles east of the Browns Park Road intersection with U.S. 191, we observed distress of the asphaltic concrete roadway pavement and a cut slope during our reconnaissance (figures 3 and 5). The distress included an approximately 195-foot-long, arcuate-shaped landslide scarp and abundant pavement cracking. Vertical offset across the scarp consisted of warping of the pavement at the scarp's northern end and pavement cracking on its southern end (figure 3). Vertical offset of the pavement was about 9 inches on the north and 6 inches on the south. Maximum deformation near the apex of the scarp, which extended approximately 29 feet west of the roadway into its cut slope, produced less than one foot of vertical offset of older landslide debris.

Adjacent to, and below the roadway, is a waste pile of materials excavated during 2009 road realignment (figures

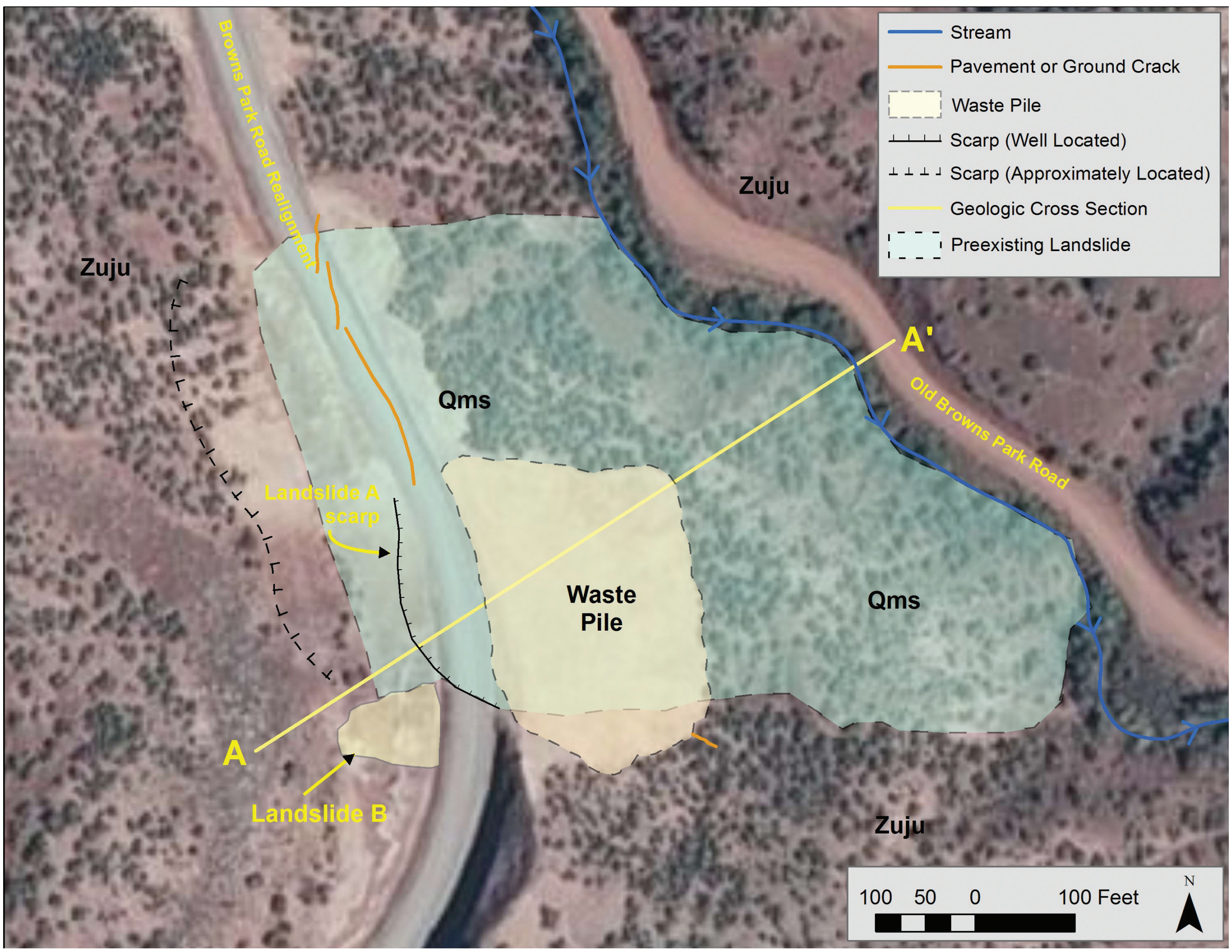

Figure 5. Map of preexisting landslide, Landslide A scarp, and waste pile. Geologic cross section A–A' is shown on figure 8. Geologic units include landslide debris (Qms) and Upper Jesse Ewing Canyon Formation shale interbedded with quartzose and lithic sandstone (Zuju). Bedrock geology from Sprinkel (2006) and landslide and waste pile extents from this reconnaissance. Base from 2009 National Agriculture Imagery Program.

5, 7, and 8) activities. The waste pile has dimensions of about 300 feet north to south, 200 feet east to west, and is up to 30 feet thick. Waste material was placed on top of a rotated surface developed by prior movement of the large preexisting landslide discussed above. In addition to the recent pavement distress related to scarp formation in the vicinity of the waste pile (figure 3), longitudinal pavement cracking with very slight vertical offset extended approximately 260 feet north from the waste pile. With the exception of a small ground crack near a small drainage that bounds the landslide to the south below the waste pile (figure 5) that may be related to this landslide, no landslide flank or toe features were observed. The observed features suggest an incipient partial reactivation of the preexisting landslide that has not developed to the point of full failure.

Examples of reactivation of large, generally old landslide deposits are abundant in Utah and include a 1983 reactivation of the Thistle landslide (Duncan and others, 1986), the 2005 reactivation of a 1983 landslide in Cedar Hills (Ashland and McDonald, 2005), the 1985–86 movement of part of the Pine Ridge landslide in Timber Lakes Estates east of Heber City (Ashland and Hylland, 1997; Biek and others, 2003), the 1997 Shurtz Lake landslide (Ashland, 1997), and the 2005 Horse Ranch landslide in the Sherwood Hills landslide complex in Provo (Ashland, 2006). Human modifications to these landslides contributed to some of the reactivations, but all illustrate the susceptibility of existing landslides to renewed movement.

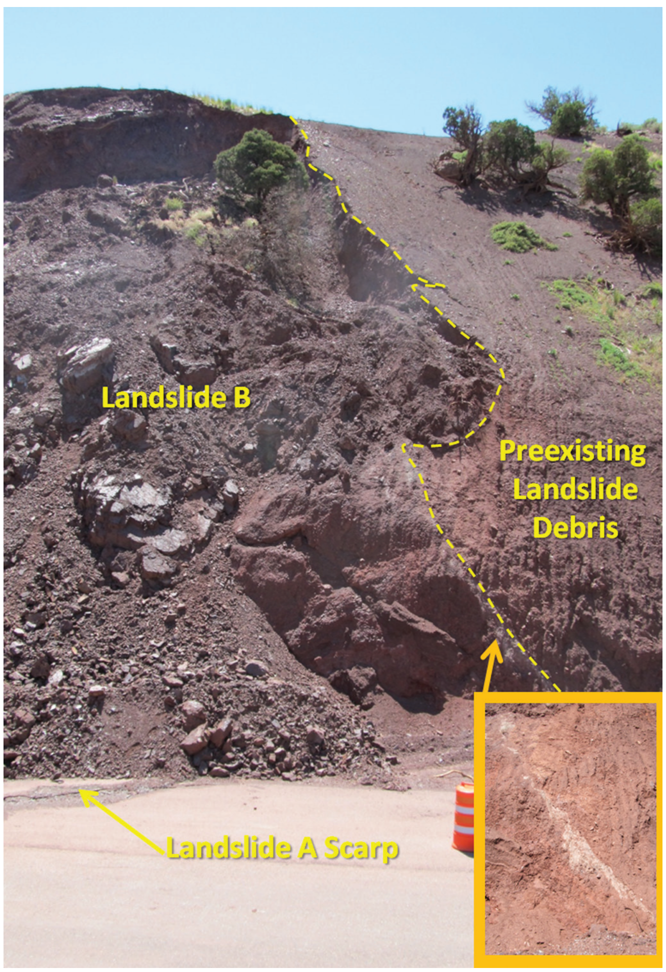

Figure 6. *Contact between Landslide B and preexisting landslide debris. Exposure in western road cut slope along Browns Park Road. Inset shows discoloration of material along right flank shear plane of preexisting landslide low on cut slope. Photo taken on June 21, 2011.*

Landslide B

Landslide B is a translational rockslide that occurred adjacent to, and southwest of, Landslide A. This slide extends from the roadway to the top of the road cut slope; it is about 150 feet wide at the road elevation, and 50 feet wide at the crest of the cut slope (figures 4 and 5). During our reconnaissance, debris from this landslide blocked the southbound lane of Browns Park Road, limiting traffic to one lane. James Olsen, Daggett County Road Department, stated that landslide movement began in 2010, became much more significant in spring of 2011, and finally resulted in failure of nearly the entire height of the slope during the early part of the first week of June 2011 (figures 3, 4, and 6). Rockslide materials consist of dark red-brown silty sandstone and shale with interbedded silicified conglomerate. Based on road-cut exposures south of the rockslide, abundant near-vertical faults cut these materials (figure 4) resulting in intensely fractured bedrock that weathers to gravel-sized fragments. Daggett County Road Department personnel reported that fresh bedrock cobble-sized blocks that fall from the road cut typically weather to a soil-like material within a month. During the rockslide, a resistant sandstone bed approximately halfway up the slope slid downslope 5 to 15 feet while breaking into blocks more than 6 feet long on all sides with fresh, unweathered surfaces (figure 4).

Bedding planes are discontinuities or divisional planes that separate adjacent rock strata, and may have a large influence on the mechanical behavior of the rock mass. We measured bedding plane orientations (strike and dip) in nearby intact bedrock; strike ranges from N15°E to N30°W and dip ranges from 15°SE to 56°NE. The slope angles of the cut-slope surface that failed ranged from about 45° (1 Horizontal [H]:1 Vertical [V]) in the upper two-thirds of the slope to approximately 65° (1/2H:1V) in the lower one-third (figure 3). Relations between the surface-slope and bedding-plane angles result in bedding planes that locally dip out of the slope. Out-of-the-slope bedding dip conditions occur where bedding planes dip in the same general direction but at a shallower angle than the slope of the ground surface, and can promote translational landsliding due to low resisting forces. Observations of surface-of-rupture exposures suggest that landslide movement occurred along bedding planes.

The northern extent (left flank) of Landslide B appears to be limited by the presence of preexisting landslide debris, as Landslide B extends only to the southern margin of the preexisting landslide (figure 6). This configuration may be a result of the type of movement in Landslide B. Landslide B is a translational rockslide that occurred along bedding planes and continuous bedding planes were not observed within the landslide debris of the preexisting landslide.

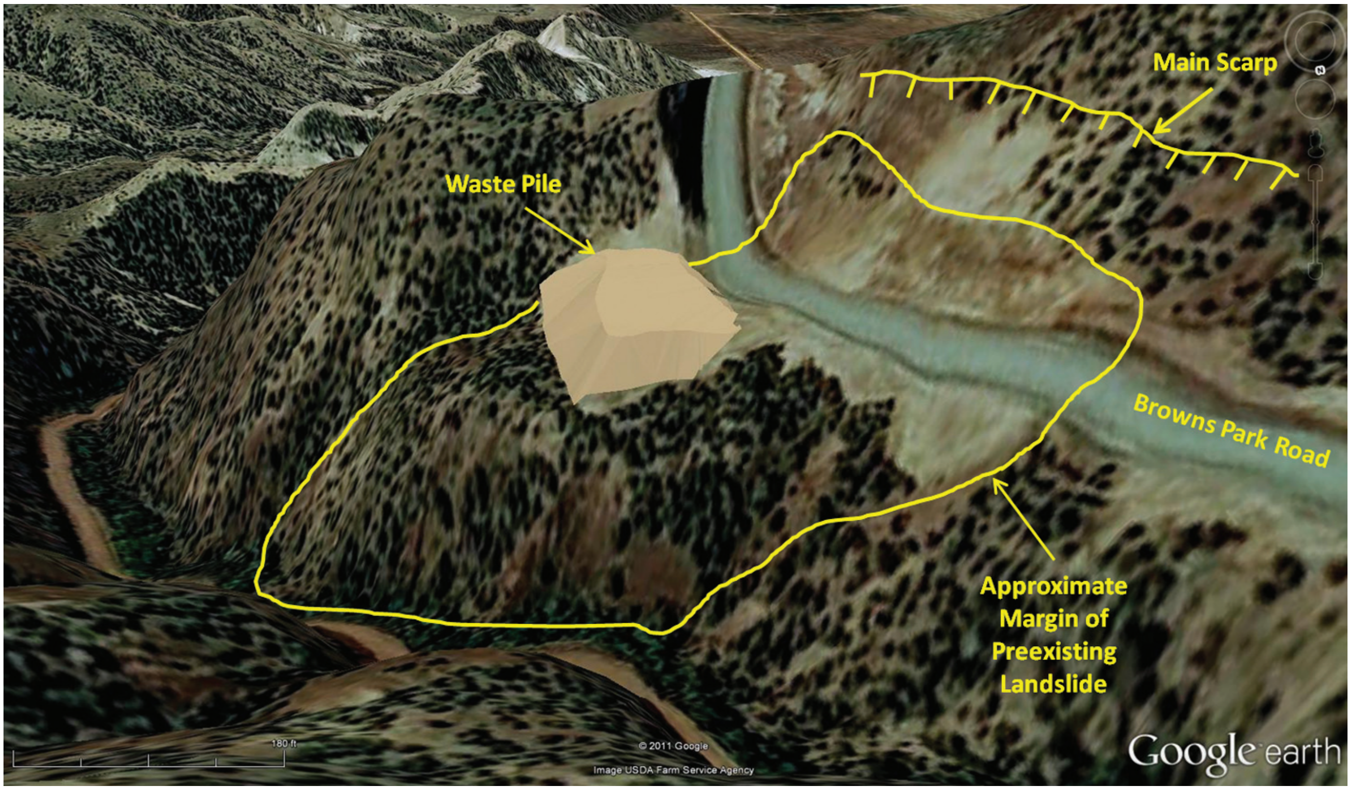

Figure 7. *Oblique view, looking south, of preexisting landslide and waste pile. Waste pile was constructed on top of a back-tilted surface created during previous landslide movement. Google Earth image from 2009 National Agriculture Imagery Program.*

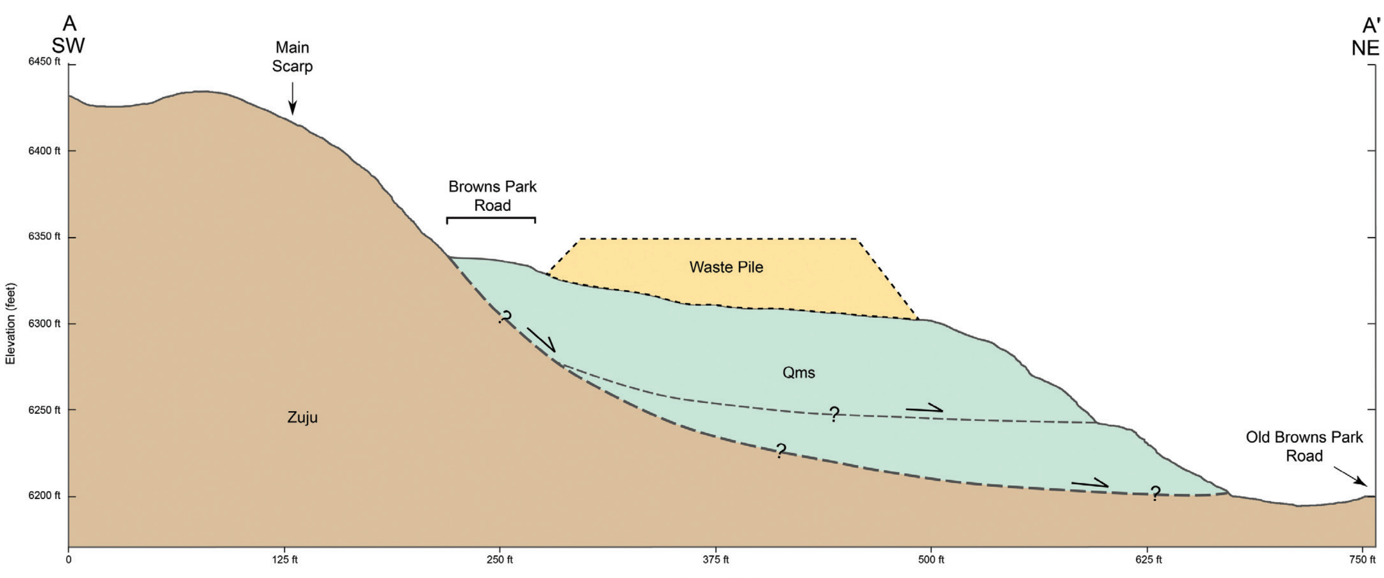

Figure 8. *Geologic cross section of preexisting landslide. Surface profile based on DEM of the pre-road realignment landscape. Bounds of preexisting landslide (Qms) and waste pile are from geologic mapping conducted during this reconnaissance. Landslide (Qms) overlies intensely fractured and weathered shale, sandstone, and siltstone with minor lenses of silicic conglomerate (Zuju). See figure 5 for cross section line location.*

Landslide C

In addition to Landslides A and B, we investigated three south-facing cut-slope failures during our reconnaissance. Landslides C and D are on a cut slope about 18.6 miles from U.S. 191 (figures 2, 9, 10 and 11). The slope extends about 250 feet above the roadway at an angle of about 34° [1.5H:1V]. Landslide C is a translational rockslide near the middle of the slope that extends about 120 feet from its main scarp down slope to a well-developed toe thrust about 40 feet above the roadway (figure 10). The width of this rockslide ranges from about 68 feet at the main scarp to about 90 feet near the toe. The main scarp is about 13 feet high and exposes dark red-brown silty sandstone and silicified conglomerate with bedding-plane strike and dip of about N55°E, 65°SE. At the time of our reconnaissance, Landslide C had not affected the roadway. Although much of this road cut is underlain by intensely fractured and weathered bedrock, in the immediate vicinity of Landslides C and D less intense fracturing was observed, and landslide movement occurred along bedding planes.

Landslide D

Landslide D is also a translational rockslide on the same cut slope as Landslide C, about 110 feet farther to the southwest and 40 vertical feet lower (figure 9). Landslide D extends downslope a maximum of about 70 feet from its main scarp and ranges in width from about 76 feet at its main scarp to about 120 feet near its toe (figure 11). The main scarp is about 3 feet high and exposes the same dark red-brown silty sandstone as we observed in Landslide C. We measured a bedding plane at the main scarp having a strike and dip of N55°W, 42°SW. The toe of the landslide filled the road drainage ditch and impacted the guardrail.

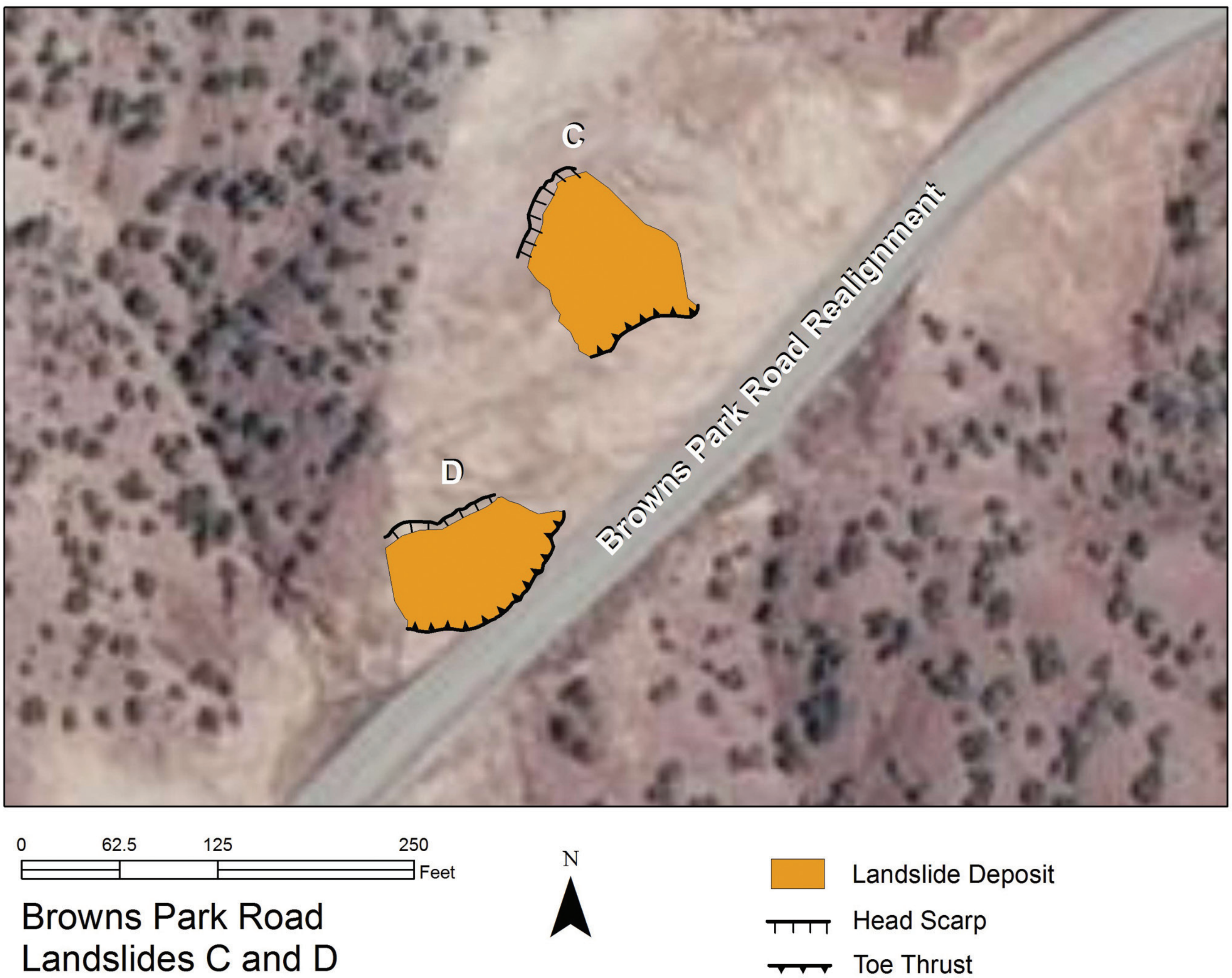

Figure 9. *Locations of Landslides C and D. Both landslides are translational rockslides on a 34° (1.5H:1V) cut slope above Browns Park Road. Landslide D impacted a guardrail and filled the small roadside drainage ditch. Base from 2009 National Agriculture Imagery Program.*

Landslide E

Landslide E is a rockslide, located about 18.8 miles along Browns Park Road from its intersection with U.S. 191, that occurred on a 65-foot-high cut slope with a slope angle of approximately 34° (1.5H:1V) (figures 2, 12 and 13). The rockslide occupies a large portion of the cut slope, and has a well-developed main scarp and associated graben extending about 140 feet across the slope face (figure 12). The rockslide extends downslope approximately 75 feet to a small toe thrust about 45 feet above the roadway (figure 13). The main scarp is a maximum of 5 feet high and exposes intensely fractured and weathered silty sandstone and silicified conglomerate. Movement appears to have occurred along bedding planes. Although no discontinuity data were collected at this landslide, observations suggest that bedding planes dip slightly steeper than the slope itself and strike near perpendicular to the direction of the maximum slope angle. This relation resulted in a limited downslope extent of landslide movement. The dimensions of the rockslide deposits are approximately 140 feet wide, 30 feet long, and an average of about 3 feet deep.

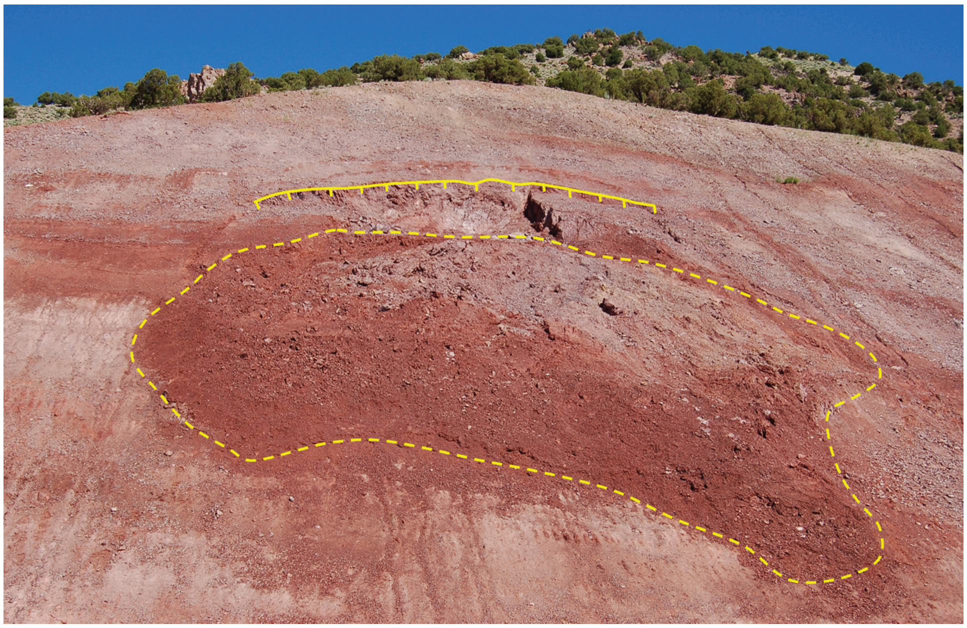

Figure 10. *Landslide C main scarp and deposits on road cut slope. Hachured yellow line marks main scarp and dashed yellow line shows approximate boundary of landslide deposits. Photo taken on June 22, 2011.*

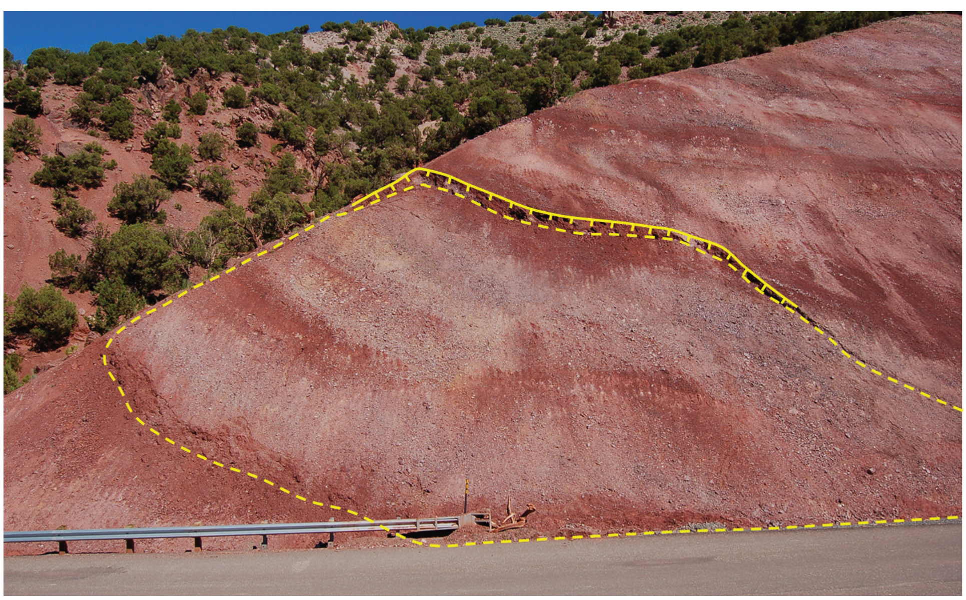

Figure 11. *Landslide D main scarp and a part of its deposits on road cut slope. Landslide deposits filled a small roadside ditch and covered a portion of a guardrail. Hachured yellow line marks main scarp and dashed line shows approximate boundary of landslide deposits. Photo taken on June 22, 2011.*

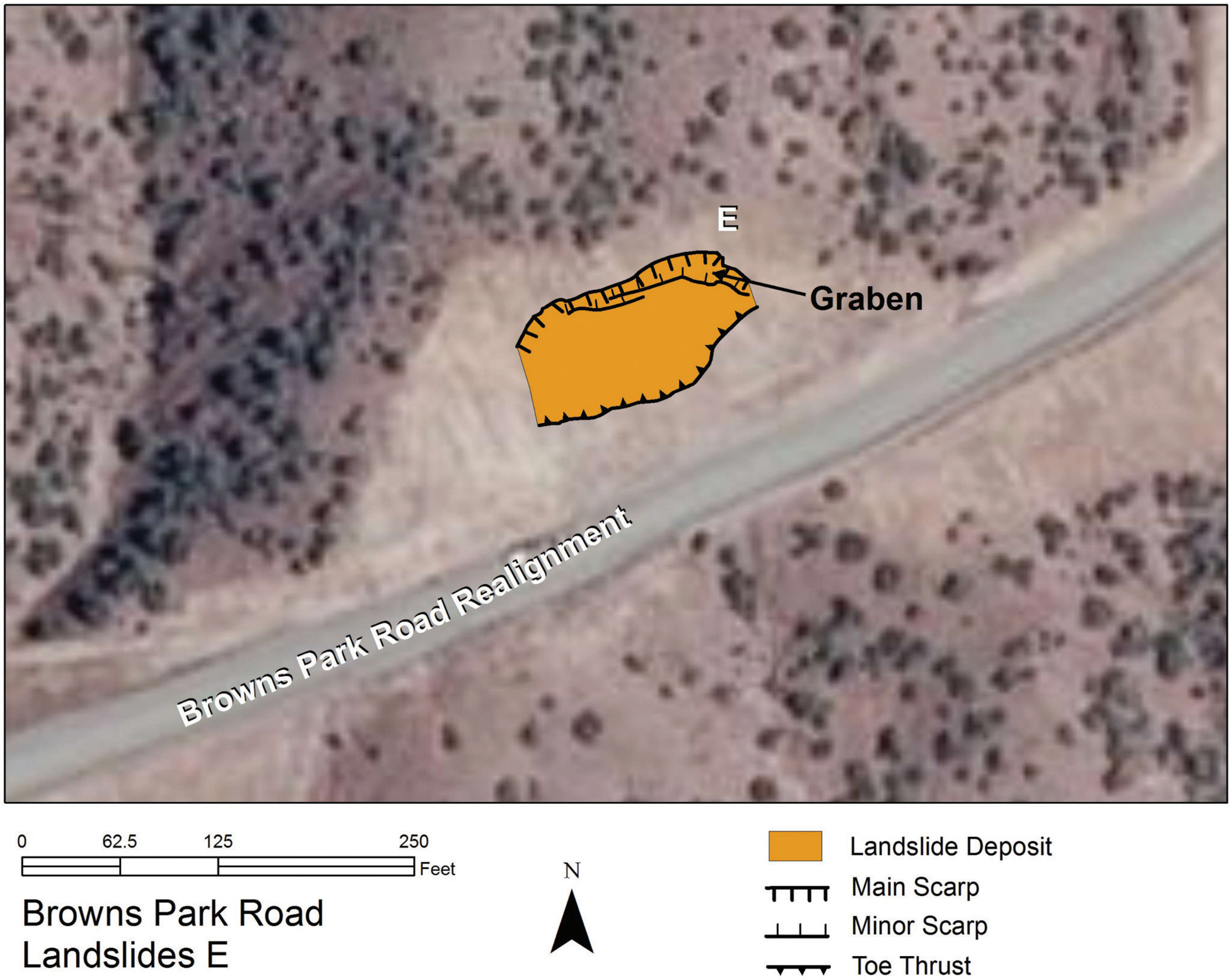

Figure 12. *Location of Landslide E. Landslide E is a translational rockslide that failed along bedding planes and affected a road cut slope above Browns Park Road. Base from 2009 National Agriculture Imagery Program.*

Figure 13. *Landslide E on upper part of road cut slope. Yellow hachured line marks main scarp and dashed line shows approximate boundary of landslide deposits. Photo taken on June 22, 2011.*

PROBABLE LANDSLIDE CAUSES

Landslides may have many causes, including those related to geological, morphological, physical, and human-caused conditions; however, landslides typically also have a discrete trigger such as intense rainfall, earthquake shaking, or rapid stream erosion that causes a near-immediate lowering of slope stability by rapidly increasing the stresses or reducing the strength of slope materials (Varnes, 1978; Cruden and Varnes, 1996; Wieczorek, 1996). However, in some cases, landslides may occur with no discernable trigger because of the cumulative effects of ongoing processes, such as physical and chemical weathering, that bring the slope to failure.

As elsewhere in Utah, the fall, winter, and spring of 2010–11 were unusually wet in the vicinity of the landslides. Between August 2010 and June 2011, the Jarvie Ranch weather station operated by the National Weather Service, approximately 2.5 miles southwest of the landslides, received 6.24 inches of precipitation, which is 148% of normal (Utah Climate Center, 2011) (figure 14). In addition to the wet seasonal conditions, Utah Climate Center (2011) data record two intense rain events that moved through the area in the latter part of May 2011 (figure 15). From May 15 to May 21, 1.91 inches of rain was recorded and from May 29 to May 31, 0.90 inches of rain fell.

Storms that produce moderate to intense rainfall over several days are a common landslide trigger (Wieczorek, 1996). Shallow landslides are often generated on steep slopes during the most intense part of a storm as pore water pressures increase as a result of rapid infiltration of water into near-surface soils and weathered bedrock (Campbell, 1975; Ellen and others, 1988). The increased soil moisture results in an increase in local pore water pressure along discontinuities in bedrock and in unconsolidated surficial materials overlying the bedrock. Precipitation from a wetter than normal winter combined with storms that produced intense rains just before the reported date of the main movement of Landslide B (figures 14 and 15) suggest that precipitation was a significant contributing factor in the recent movement of all the observed landslides.

Landslide A is a partial reactivation of a preexisting, deep-seated, rotational rockslide. Conditions that may have led to reactivation include the assumed reduction of material strength along the surface of rupture during previous movements and increased pore water pressure along that surface. Evidence for groundwater movement along the rupture surface was observed along the southern margin of the preexisting landslide where its flank is marked by a light-colored, 4- to 6-inch-wide zone just above the marginal shear boundary of the slide that may reflect preferential groundwater movement that resulted in bleaching or mineral precipitation.

Anthropogenic activities that may have contributed to the movement of Landslide A include placement of the waste pile on a back-tilted surface developed during earlier movement of the preexisting landslide, and modification of the upper portion of the landslide slope during the road realignment. Based on topographic data collected during

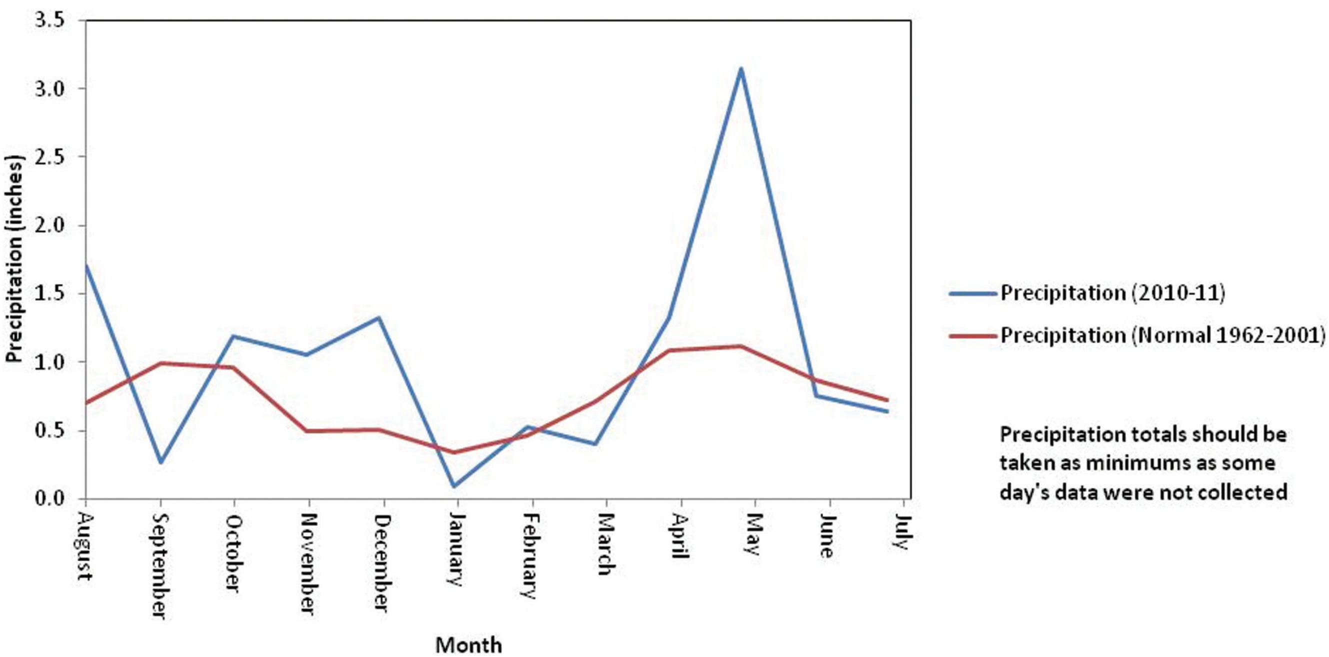

Figure 14. *Monthly precipitation totals recorded at Jarvie Ranch weather station. Recent precipitation data are from August 2010 through June 2011 (Utah Climate Center, 2011). Normal precipitation is the monthly average from 1962 to 2001 (Western Regional Climate Center, 2011).*

our reconnaissance and available digital data (5-meter DEM [Utah Automated Geographic Reference Center, 2007]), we calculated the approximate volume of the preexisting landslide and the additional volume of material added to the landslide by construction of the waste pile. The preexisting landslide has a volume of approximately 560,000 cubic yards, and the volume of the waste pile is about 36,600 cubic yards. It is reasonable to conclude that the addition of the waste pile on top of an already marginally stable landslide could cause partial reactivation of the preexisting landslide. Evidence that the waste pile contributed to instability of the preexisting landslide includes the newly formed scarp that extends only to the margins of the waste pile (figure 5). However, although longitudinal cracks in the pavement extend nearly the full width of the preexisting landslide, those outside the limits of the waste pile do not show significant vertical offset, and while they may be the result of landslide activity, they also may reflect settlement of poorly compacted roadway subgrade or base fill materials unrelated to landsliding.

GIS analysis of the surface topography that existed prior to road construction suggests the base of the main scarp of the preexisting landslide was about at the current base of the cut slope (figure 5). Such a configuration would allow surface water runoff from both the cut slope and roadway to intercept the surface of rupture of the preexisting landslide. Groundwater transported to and along the surface of rupture could locally increase pore water pressure, promote weathering, and thereby produce a subsequent reduction in material strength which may contribute to landslide instability.

Landslide B is a rockslide in the east-facing slope of a through cut excavated as part of the road realignment. The weak nature of geologic materials, including the presence of east-dipping, faulted, intensely fractured, and deeply weathered shale and silty sandstone likely contributed to landsliding. Local bedding-plane orientation and its relation to cut-slope angles produced out-of-the-slope bedding dip conditions (figure 3) in the vicinity of Landslide B. Although the triggering mechanism is unknown, elevated pore water pressure along bedding planes in the shallow subsurface resulting from a wet winter and spring and recent moderately intense rain events are likely contributing factors. Evidence for failure along bedding planes includes exposures along the southern margin of the rockslide where the angle of the surface of rupture coincides with the dip of the bedding planes.

Landslides C through E are translational rockslides that originated in exposures of bedrock within road cut slopes excavated at an angle of about 34 degrees (1.5H:1V). Similar to Landslide B, geologic materials underlying these

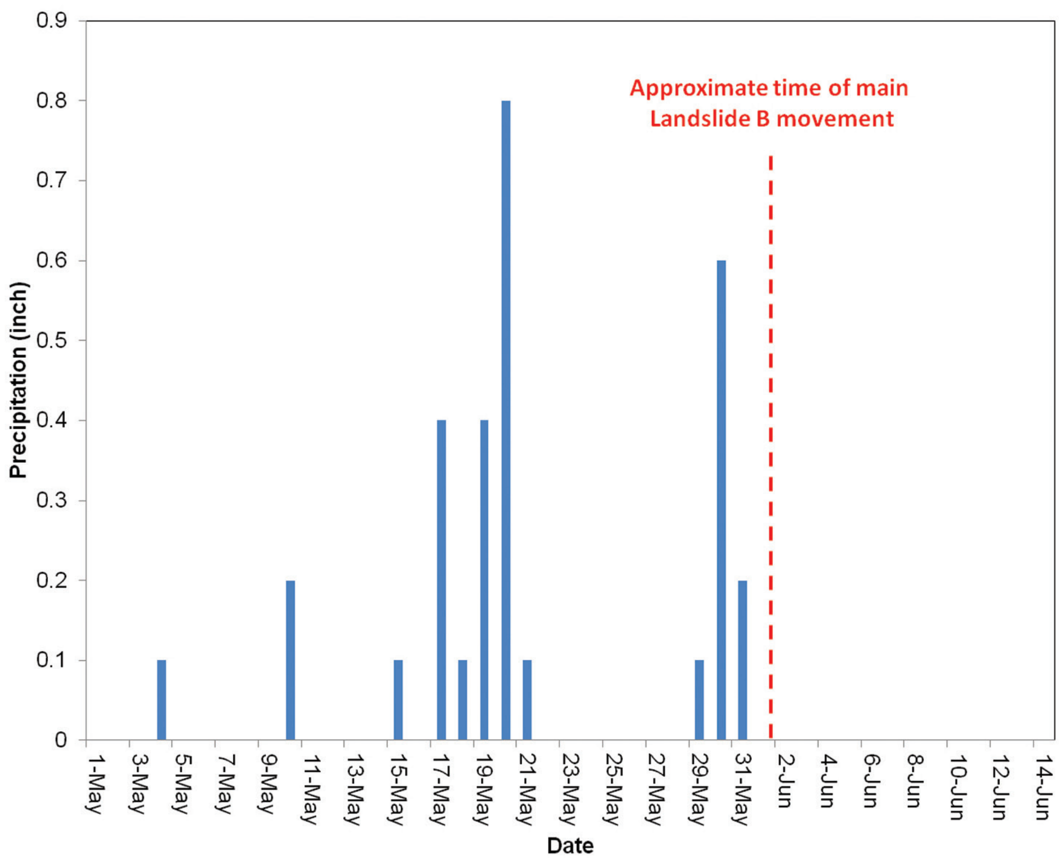

Figure 15. *Daily precipitation data for May and early June 2011. Data from the Jarvie Ranch weather station (Utah Climate Center, 2011).*

slopes are faulted, intensely fractured, and deeply weathered shale and silty sandstone. Each rockslide appears to have failed along bedding planes, and extends a maximum of about 125 feet downslope from its main scarp with very little, if any, run-out of debris overriding the original slope surface. On all of these slopes, bedding plane angles are slightly steeper than slope angles. This relation may act to limit the downslope extent of landslide movement as resisting forces along a single bedding plane increase with increasing distance downhill. The landslides are wider (across the slope) than they are long (down the slope). Weathering of newly exposed bedrock after excavation of the cut slopes, and possible local increases in pore water pressure along bedding planes as a wetting front migrated downward from the surface following a wet winter and spring and recent moderately intense rain events, may have triggered these rockslides.

CONCLUSIONS AND RECOMMENDATIONS

In the spring of 2011, several landslides occurred in lower Jesse Ewing Canyon along a portion of Browns Park Road that had been realigned in 2009. One landslide was a partial reactivation of a preexisting rotational rockslide (Landslide A). Four of the landslides were translational rockslides (Landslides B through E) involving intensely fractured and weathered shale and silty sandstone containing lenses of silicic conglomerate of the Upper Jesse Ewing Canyon Formation of the Neoproterozic Uinta Mountain Group. Although three of the four rockslides did not significantly impact the roadway, Landslide B closed the entire southbound lane and a part of the northbound lane at a through cut about 18.2 miles along Browns Park Road from its intersection with U.S. Highway 191.

The partial reactivation of a preexisting rotational rockslide (Landslide A) may have been related to construction of the road. Realignment activities included modification of the rockslide head, and placement of a waste pile on a relatively level surface formed by back-tilting of the preexisting landslide. Partial reactivation of the rockslide may have been triggered by a very wet winter and spring and several moderately intense spring rainfall events (figures 14 and 15). Without knowing the exact time of movement of Landslide A, it is not possible to conclude whether intense rainfall was the triggering event.

To fully understand the preexisting rockslide and its relation to Landslide A, the UGS recommends a more detailed investigation by a Utah-licensed engineering geologist and/or geotechnical engineer with significant experience in landslide investigation and mitigation. This investigation should address, at a minimum, the surface and subsurface geology; delineate ground-movement areas; define the surface of rupture; determine and monitor groundwater depths and sources; determine expansion and weathering characteristics that may lead to a subsequent reduction in material strengths; and provide recommendations for appropriate mitigation measures. Over time, if the preexisting landslide is not stabilized, future landsliding may cause extensive damage to the roadway resulting in a subsequent hazard to the public and increased maintenance and possible liability costs.

Landslide B movement appears to have occurred on bedding planes that locally dip out of the slope. In addition, bedrock conditions, including intense fracturing and deep weathering, locally produce material that behaves more like soil or very weak rock than intact bedrock and is unstable on steep slopes. Possible methods of stabilizing this rockslide include reducing the road cut slope angle or using mechanical stabilization. Mitigation design should include an analysis of materials comprising the slope and their strength, discontinuity, and weathering parameters.

Landslides C through E involve material similar to that at Landslide B. However, the relations between the orientation of bedrock bedding planes and slope angles differ, and thus do not result in the same out-of-the-slope bedding dip conditions observed at Landslide B. The lack of out-of-the-slope bedding dip conditions may have limited the downhill extent of these relatively small rockslides that have not, or have only marginally, impacted the roadway. Landslides C through E occurred on south-facing slopes as bedding-plane failures of more competent rock. Once mobilized, movement extended into more weathered materials downslope. Depending on conditions of the bedrock involved, their position on the slope, and climatic conditions, these landslides may impact the roadway in the future. Continued raveling of material above the landslides will result in headward expansion, but given the relation between surface cut-slope angles of about 34° (1.5H:1V) and the dip of bedding planes (42° to 65° [1H:1V to 1/2H:1V]), large-scale failure of the entire slope is not anticipated under the current conditions. However, as exposed materials continue to weather and with a reoccurrence of extreme precipitation events, future large-scale landsliding cannot be ruled out. Under current conditions, and at the discretion of Daggett County, mitigation of existing and future failures of these slopes may likely be limited to ongoing slope and road maintenance.

Guidelines have been developed by the UGS to assist in the performance of landslide-hazard studies (Hylland, 1996) and are available online (http://ugspub.nr.utah.gov/publications/circular/C-92.pdf). Additional geologic-hazard resources for consultants and design professionals are available from the UGS to assist those involved with geotechnical, geologic-hazards, and other land-use investigations in Utah (http://geology.utah.gov/ghp/consultants/index.htm).

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