Project: The Sage Vista Lane landslide, Cedar Hills, Utah			
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USGS Quadrangles: Timpanogas Cave (1129)	Section/Township/Range: Section 32, T. 4 S., R. 2 E., Salt Lake Base Line and Meridian		
Requested by: David Bunker, Cedar Hills Engineer			Job number: 05-14

INTRODUCTION

On the afternoon of April 28, 2005, a landslide that had moved previously in 1983 (Machette, 1992) reactivated above Sage Vista Lane in a Cedar Hills subdivision (figure 1) and moved against the lower portion of the back wall of a four-unit townhouse (figure 2). Residents of the affected townhouse evacuated and the belongings of a neighboring family in a separate duplex across the street were moved out of their home temporarily. By April 29, the landslide toe had crushed vinyl fencing, air conditioners, and deck supports at the back of three of the units in the townhouse. After the damaging movement on April 29, the rate of landslide movement rapidly decreased to a very slow rate. Following a multiday storm event, during which about 3 inches of precipitation fell, the rate of landslide movement increased again, and by May 13 structural damage to the upslope foundation walls of two units in the four-unit townhouse had occurred. Landslide debris subsequently entered the lower parts of the two units as landslide movement again slowed to a very slow rate as defined by Cruden and Varnes (1996).

As part of the emergency response effort by multiple state, county, and city agencies, the Utah Geological Survey (UGS) performed a reconnaissance of the landslide on the morning of April 29, 2005, and deployed survey stakes to monitor movement of the landslide. We repeated measurements later in the day on April 29 to determine the rate of movement of the slide. We also deployed stakes for high-resolution Global Positioning System (GPS) surveying by the Utah County Public Works Department. UGS geologists visited the site on numerous occasions in May and June to monitor landslide movement, and document ground deformation and changes in the size of the area of landsliding.

The purposes of our investigations were to determine the geologic characteristics of the landslide and evaluate its hazard potential to aid Cedar Hills in assessing the risk to townhouses and city infrastructure. During our field investigations we met on-site with Cedar Hills Mayor Michael McGee, City Councilman Jim Perry, City Manager Konrad Hildebrandt, City Engineer David Bunker, Utah Governor Jon Huntsman Jr., Chief of Staff Jason Chaffetz, Utah County

Emergency Manager Dave Bennett, Bill Gordon (AMEC Earth & Environmental), Utah County Public Works Department surveyors, and numerous residents.

CONCLUSIONS AND RECOMMENDATIONS

The landslide will remain a threat to the area west and downslope across the street until engineering measures are taken to stabilize it. Downslope-directed loading of soils below the toe of the landslide may be occurring. Reactivation or an increase in the rate of movement is possible if significant precipitation falls on the slide and surrounding area or during subsequent snowmelt periods in the future. Downslope enlargement of the landslide may accompany future movement. To date, the landslide has moved relatively slowly and has not posed a life-safety threat, and likely will continue to behave in this way. However, should a rapid loading occur at the head due to collapse of the high, nearly vertical south-facing scarp, particularly during an intense rainfall event, the potential for rapid failure cannot be precluded. Future enlargement of the landslide in an upslope direction that causes the shallow, upper landslide area to merge with the main slide will also increase the overall hazard and potential for renewed movement.

The foundation of the damaged townhouse may be acting as a temporary buttress, possibly protecting against further downslope movement of the slide. We do not recommend removing any of the landslide debris abutting the upslope side of the townhouse while the slide is active and relatively moist. This could increase the movement rate and/or enlarge the landslide.

We recommend the following:

- The developer's geotechnical consultants should assess stabilization options, recommend appropriate pre-design subsurface investigations, and provide final stabilization designs.
- Periodic monitoring of the landslide should be resumed if renewed movement is suspected and/or onset of movement upslope or downslope of the slide occurs.
- The appropriate officials should be perform periodic inspections of buildings, roads, paved areas, and buried utilities for signs of distress or damage. We are particularly concerned that downslope-directed loads from the landslide could affect the city's buried water line near Sage Vista Lane.

Based on our inferred site conditions, we recommend that future studies and stabilization design consider (1) the potential expansion of the landslide upslope with addition of more material from the high, south-facing scarp and upslope areas, and (2) the potential for enlargement of the landslide downslope of the present toe into the area of the duplex and fill slope across Sage Vista Lane. We also recommend reassessment of the slope-stability and landslide-stability conclusions and recommendations in the original subdivision geotechnical report prior to any new development, particularly on lots east of Sage Vista Lane.

GEOLOGIC SETTING AND LANDSLIDE DESCRIPTION

The Sage Vista Lane landslide is a nearly complete reactivation of a southwest-facing historical (1983) slide in the southwestern part of a large prehistoric landslide complex (figure 3; Machette, 1992). The prehistoric landslide complex likely consists of debris derived from the Mississippian-age Manning Canyon Shale, a highly landslide-prone geologic unit found along the mountain front in much of northeastern Utah Valley. These older landslides are prone to reactivation, as indicated by younger active landslides mapped within the older complexes elsewhere in the area (Machette, 1992). The Sage Vista Lane landslide is along the Provo segment of the Wasatch fault, which crosses the slide, and may direct or concentrate ground water in the slide.

The landslide consists of two lobate foot sections and an arcuate head that narrows upslope (figure 4). The main foot of the landslide abuts the townhouse and consists of mostly disrupted debris. A second, smaller foot on the south side of the slide resulted from local southward movement below a pressure ridge or fold that formed near the crest of a cut slope. On April 29, the active landslide was approximately 350 feet (110 m) long and 110 feet (35 m) wide at its toe. The narrower upper part of the landslide was about 70 feet (21 m) wide. The average slope of the landslide was about 37 percent.

Landslide debris consists of cobbles and boulders in an olive-green to brownish clay matrix likely derived from the Manning Canyon Shale. Locally, decomposed black fragments of Manning Canyon Shale were observed in the debris. The lower part of the landslide was disrupted and appeared to be moving as a slow, moist debris flow (figure 5). Test pits excavated by AMEC Earth & Environmental on August 18, 2005, revealed shallow slickensided clay in the upper part of the landslide that varied in color from maroon to black. The clay may be weathered Manning Canyon Shale or clay smears derived from the shale within landslide debris.

The middle part of the landslide was relatively intact and consisted of fractured soil, whereas the upper part of the landslide was somewhat more deformed and disrupted. A cobble-lined drainage ditch in this area remained mostly linear suggesting that it was mostly translated in intact and undeformed blocks (figure 6). Dark gray, highly polished slickensides were locally exposed on top of exposed black clay in the upper part of the landslide, suggesting the upper part of the slide is locally shallow (possibly less than 10 feet deep; figure 7).

The main scarp zone is in the upper narrowest part of the landslide, and on April 29 consisted of several scarps less than 2 feet high in an area of relatively shallow translational landsliding. The main scarp zone joins with the nearly vertical south-facing scarp that bounds the north flank of the 2005 landslide, and that may have been the main scarp of the 1983 slide. On April 29, the combined height of the 2005 and 1983 scarps along the north flank of the landslide was about 40 to 50 feet; the upper 30 to 35 feet representing the scarp of the 1983 event (figure 8). Movement of the landslide caused scarps to form in a colluvial wedge at the base of the 1983 scarp as the colluvium moved downslope on the active part of the slide. The near-vertical scarp suggests that the subsurface geometry of the head of the landslide in a northwest-southeast direction may be asymmetrical with the deepest part being in the northwest part of the head nearest the south-facing scarp.

On April 29, no seepage was observed at the toe of the landslide. Seepage was observed in the upper part of the landslide, particularly near the easternmost part of the main scarp zone. By May 7, the shallow soils in the uppermost head of the landslide were saturated and extremely soft. Ground-water depth in a test pit excavated by AMEC Earth & Environmental on August 18, 2005, was about 8 feet.

Hillslope modifications to the 1983 landslide included excavation of the building pad for the four-unit townhouse across or near the toe of the slide and a cut slope in the lower part of the slide, and construction of a cobble-lined drainage ditch at the crest of the cut slope and a temporary irrigation system on the cut slope. Residents indicated that the toe initially emerged partway up the cut slope behind the townhouse and landslide debris subsequently flowed down against the back wall of the building. Landslide movement destroyed most of the cut slope, damaged the irrigation system, and displaced the drainage ditch relatively intact.

On May 5 we observed cracks in the crest of the south-facing scarp that extended several feet back from the top of the scarp. These cracks intersected the scarp at an acute angle. Significant raveling of the south-facing scarp occurred during the extended period of rain that ended on May 13. A triangular-shaped colluvial wedge of the eroded debris from the scarp formed near its center, and was approximately two-thirds the height of the scarp by May 31. The additional weight from this colluvium likely further destabilized the slide. On May 31, additional fresh cracks were superimposed atop a healed crown crack likely associated with movement of the slide in 1983, about 10 feet upslope of the top of the scarp.

MOVEMENT HISTORY

Between April 28 and June 30, 2005, the landslide experienced two episodes of rapidly accelerating movement followed by a similarly rapid decrease in the rate of movement and either intermittent or continued movement at a slow rate. Only anecdotal accounts exist of the initial landslide movement that began on April 28, but a rapid acceleration in the rate of movement likely occurred during and immediately after a rainstorm on that date. By noon on April 29, however, the rate of movement had already begun to decline. Slow movement of the landslide continued until May 10, when the rate began to accelerate during a multiday storm, during which about 3 inches of precipitation fell, until reaching a maximum measured rate of movement on May 12 of about 13.5 feet per day (4 m/day). After May 13, movement continued, locally intermittently, at a slow rate. By June 30, movement had slowed and GPS monitoring was ended because of the reduced risk.

Between April 29 and May 10, the most movement occurred in the uppermost head of the landslide (UGS stake SV5; figure 9), but minor movement was detected in the lower and upper parts of the slide. During the dry days following the initial movement episode (April 29-May 1), the head of the landslide moved an additional 20 inches (51 cm), and the rate of movement slowed. However, following a period of heavy rainfall beginning on May 5, the rate of movement increased. By May 10, about 10.4 feet (3 m) of movement had occurred in the head of the slide. The remainder of the landslide (figures 10 and 11) also continued to move slowly between April 29 and May 1, but by May 1, movement of the slide either suspended or occurred at a rate too slow to detect. During the extended period of rainfall that began on May 5, movement of the entire landslide resumed or increased in rate (see lower inset on figure 10). Between May 6 and 9 about 2 inches (5 cm) and 4 inches (10 cm) of movement was measured in the lower and upper parts of the landslide, respectively. Continued rainfall through May 13 resulted in a rapid increase in the rate of movement (figure 12). By May 13, the landslide had moved between 7 and 22 feet (2.2-6.7 m) since April 29, causing significant damage to the upslope side of the townhouse building. The return of dry weather was accompanied by a rapid reduction in the rate of movement. Between May 13 and May 31 the landslide moved less than 7 inches (18 cm) (see upper inset in figure 10). Only nominal movement of the landslide occurred in June during which less than 3 inches (7 cm) of movement of the upper part of the slide was measured. GPS survey measurements of stakes above the high, south-facing scarp showed no evidence of movement during the entire measurement period.

PROBABLE CAUSES OF MOVEMENT

The landslide is an almost complete reactivation of a 1983 landslide within a mapped prehistoric landslide complex. The movement in 1983 indicated that this part of the natural hillslope in the prehistoric landslide complex was unstable, and has likely remained marginally stable since it last moved. The 2005 movement indicates that the 1983 landslide was relatively sensitive to changes in soil moisture, ground-water levels, and slope modifications.

One likely cause of reactivation of the landslide was above-normal precipitation over an extended period prior to the landslide. Precipitation for the 2004 calendar year at the National Weather Service Pleasant Grove station was only slightly above normal (102 percent), but was exceptionally wetter than normal for the period between September 2004 and April 27, 2005 (162 percent). Landslide activation occurred during a 24-hour period during which 0.64 inch of rain fell between the mornings of April 28 and 29 at the nearby Pleasant Grove station (National Weather Service, 2005). Seepage was observed in the main scarp where it crosses a drainage, indicating that ground-water flow into the slide mass was occurring prior to movement. Soil moisture and ground-water levels have likely increased greatly as a result of infiltration of excess precipitation (approximately 7.9 inches above normal between September 1, 2004 and April 28, 2005) in the eight months prior to the slide.

We found no evidence for significant failure of the 1983 main scarp prior to the 2005 movement, although a wedge of colluvium at the base of the scarp may have contributed to loading of the head of the historical landslide.

Hillside modifications related to residential development of the area may also have contributed to destabilizing the historical landslide. Removal of part of the toe of the landslide accompanied placement of the townhouse. In addition, a cut slope existed in the slide east of the townhouse. Both of these modifications may have reduced resisting forces in the lowermost part of the slide. Two other hillslope modifications may have contributed to increased soil moisture or ground-water levels in the lower part of the landslide. A cobble-lined, but permeable, drainage ditch at the crest of the cut slope may have promoted infiltration of snowmelt and runoff. Excess irrigation water may also have infiltrated into the lower part of the landslide from a temporary above-ground irrigation system used to water grass seed in the cut slope. A resident reported that the irrigation system was left running prior to movement of the landslide. However, no corroborating evidence in the form of saturated soil or surface water in the area on April 29, or runoff rills or channels that should accompany excess irrigation was found.

ADDITIONAL LANDSLIDES UPSLOPE

On April 29, two additional, small, fresh scarps existed upslope of the main landslide in the prehistoric landslide complex that defined the upslope extent of two separate active shallow slides (figure 3). The scarps occurred within or near areas that had been disturbed by exploratory excavations (test pits or trenches) and subsequently backfilled several years prior to the 2005 landslide. The scarps were several inches high and connected to flanking structures such as ground cracks. The lower of the two slides had an internal longitudinal crack in its upper part and a main scarp that was several inches high with a fissure at least 2.5 feet deep (figure 13). The lower extent of the two upper landslides was unclear due to the absence of well-defined toe or flanking structures. By May 5, the two scarps had joined together to form a continuous scarp zone, suggesting the two small landslides had joined into a single slide (figure 3).

UGS measurements detected no movement during the afternoon of April 29, but the time interval between measurements may have been insufficient to detect very slow movement. However, measurements on May 5 and 7 indicated continued movement of the western part of the upper landslide area at a relatively steady, but very slow rate (figure 14). Subsequent measurements detected movement of the entire upper landslide area by May 12. The rate of movement accelerated between May 9 and 13 (figures 14 and 15), coincident with the increase in the rate of movement of the Sage Vista Lane landslide downslope. During this period, the maximum rate of movement of the upper shallow landslide reached about 2.8 inches per day (7 cm/day).

A reconnaissance of the remainder of the prehistoric landslide complex on April 29 indicated no other areas of active landsliding, but revealed a small historical slide in the complex (figure 3). By May 18, the small historical landslide had reactivated, most likely sometime around May 12. We also inferred, based on field observations and review of aerial photographs, that the prehistoric landslide complex may extend farther upslope than mapped by Machette (1992), likely to the base of the moderately steep, west-facing mountain slope at about elevation 5,780 feet (figure 3).

The upper shallow landslide area's presence indicates the marginal stability of material in the prehistoric landslide complex, particularly where soils are disturbed. Landsliding may have been triggered in the upper slide area due to a local rise in ground-water levels resulting from increased infiltration capacity of the test-pit backfill. In addition, disturbance of the native materials during excavation and backfilling likely resulted in the fill having lower strength than the surrounding landslide debris. The discontinuity between the base of the fill and the underlying debris may have also acted as a slide surface. Landsliding in the upper slide area clearly extended beyond the boundaries of disturbed ground, however, suggesting the marginal stability of shallow soils in the prehistoric landslide complex.

Continued movement and downslope enlargement of the upper landslide may eventually result in the joining of the main and upper landslides into a single slide. A joining of the two slides increases the likelihood of renewed movement of the main slide (in combination with the upper slide area) and enlargement of the slide area downslope of the toe of the original main slide.

POSSIBLE IMPACTS DOWNSLOPE

Horizontal loading caused by movement of the Sage Vista Lane landslide may reduce the stability of the slopes to the southwest of Sage Vista Lane, particularly if landslide deposits underlie surficial alluvial-fan deposits in this area. A steep and relatively high fill slope is directly downslope of the duplex unit across Sage Vista Lane (on the southwest side of the street) from the landslide. We conducted a reconnaissance on April 29 and on subsequent visits of the duplex and noted no obvious distress to the building or grounds. The steep fill slope downslope of the duplex is a concern; the bottom of the fill slope appeared oversteepened, but the cause of this condition was uncertain. A survey point and stake was placed at the base of the fill for movement monitoring, but measurements detected no movement through May 31.

SUMMARY AND FUTURE HAZARD POTENTIAL

On April 28, 2005, a 1983 landslide reactivated above a subdivision along Sage Vista Lane in Cedar Hills and moved against the back of a four-unit townhouse. Although the landslide slowed temporarily during a dry period following initial movement, it accelerated during an extended period of rainfall beginning on May 5 causing structural damage to the townhouse by May 13. The landslide will pose a continuing threat to the immediate area until engineering measures are taken to stabilize it. A threat of expansion of the landslide exists from failure of the main scarp and/or connection with a separate shallow landslide upslope, which may cause renewed (or an increased rate of) movement at the toe. Similarly, the possibility exists that movement of the landslide has reduced the stability of slopes below the landslide. These possibilities should be considered in the design of slope stabilization measures.

FIELD METHODS

The perimeter of the landslide, and estimated slide dimensions and average slope are based on field mapping using a hand-held GPS device. The accuracy of this method varies considerably depending on site conditions and satellite positions. Error typically increases next to high, vertical or near-vertical features such as the walls of the townhouse or south-facing scarp. The accuracy of elevation measurements is also highly variable.

We deployed pairs of wooden survey stakes on April 29, 2005 and on later dates to monitor landslide movement and ground deformation. Typically one stake was placed on the landslide and the other off the slide. For example, stakes SV3-4 consist of stake SV3 below the toe of the landslide, and stake SV4 on the toe (figure 4). Measurements of shortening or stretching between stakes were made using a fiberglass tape and used to estimate landslide movement. Our inferred accuracy is about 0.12 inch (0.3 cm). We also deployed other stakes (labeled 1, 2, etc., on figure 4) that were surveyed by Utah County Department of Public Works surveyors using accurate GPS equipment under the supervision of Assistant County Surveyor Gary Ratcliffe. Duplicate measurements were taking for each survey point and mean positions calculated reducing measurement error.

ACKNOWLEDGMENTS

Utah County Department of Public Works surveyors monitored landslide movement between April 29 and June 30, 2005, sometimes under extremely difficult conditions. Michael Kirschbaum and Richard Giraud, Utah Geological Survey, assisted with some of the field work. Lucas Shaw, Utah Geological Survey, helped prepare some of the figures in this report.

LIMITATIONS

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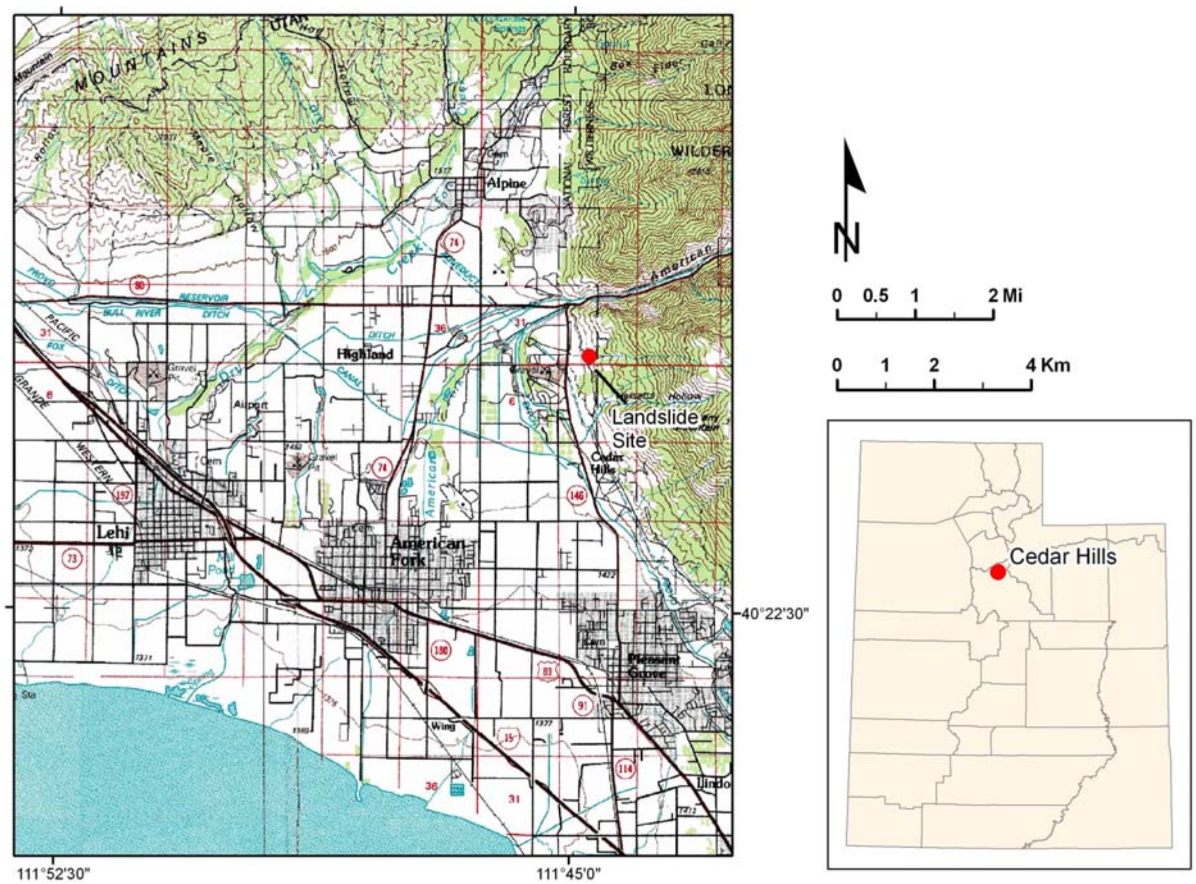

Figure 1. *Location map of Sage Vista Lane landslide in Cedar Hills, Utah. Base from U.S. Geological Survey 1:100,000-scale topographic map for the Provo 30'x 60' quadrangle.*

Figure 2. *View to the northeast of the landslide on April 29, 2005, from Sage Vista Lane.*

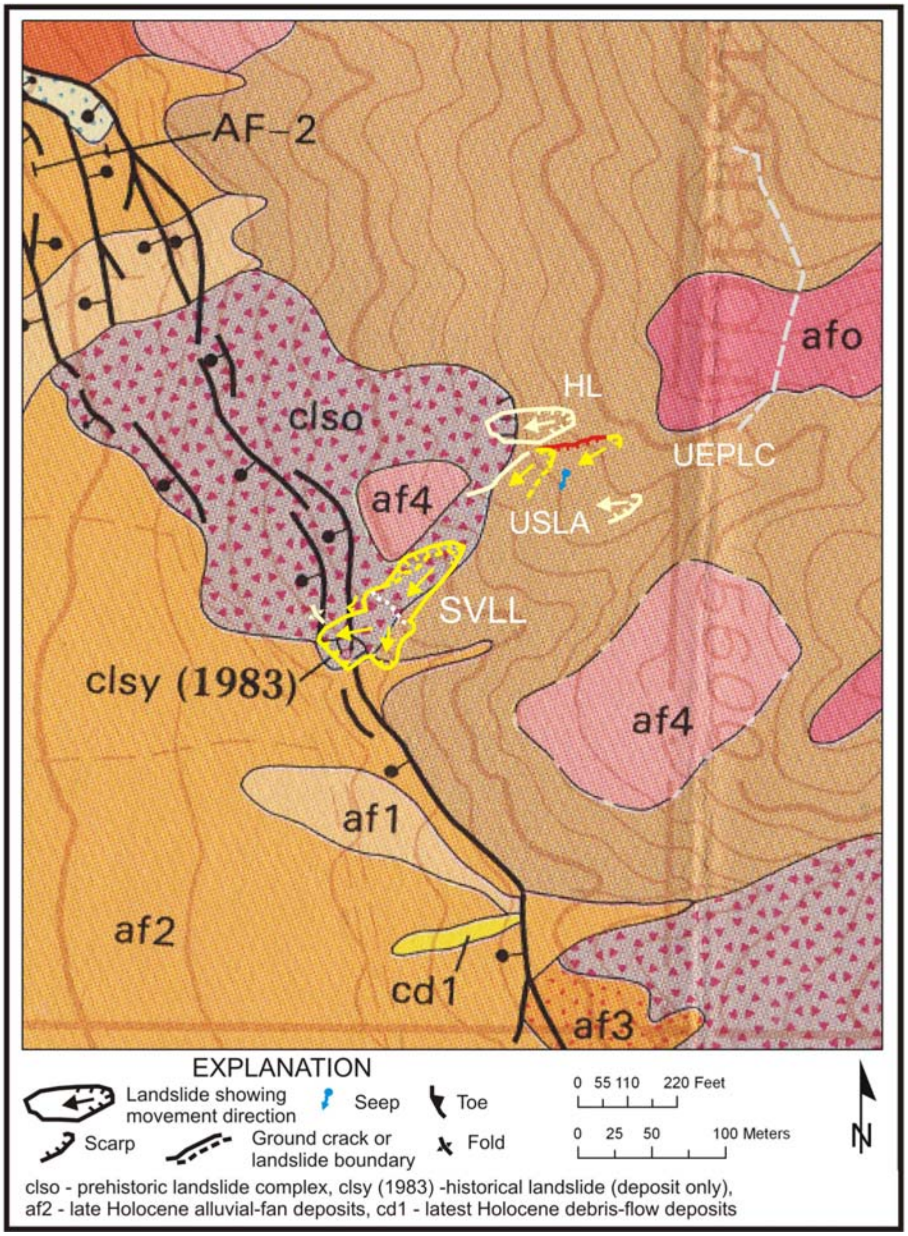

Figure 3. *Surficial geologic map of the site vicinity (after Machette, 1992). Approximate perimeters of Sage Vista Lane landslide (SVLL) and other reactivated historical landslide (HL), and active deformation features associated with upper shallow landslide area (USLA) also shown. UEPLC (light gray dashed line) indicates our estimate of upslope extent of prehistoric landslide complex. Yellow, red, and light yellow colors indicate features present on April 29, May 5, and May 13, respectively. Yellow dashed line in SVLL indicates active scarp position on April 29. By May 13 active scarp extended to or upslope of 1983 scarp. White dotted line in SVLL shows position of cobble lined ditch on May 5. Main geologic unit descriptions shown. Machette (1992) mapped unlabeled brown unit as Paleozoic rock, but lower part likely consists of landslide deposits and colluvium. Solid, thick black lines are traces of Wasatch fault zone. Bar and ball on downthrown side of fault. See Machette (1992) for other unit descriptions.*

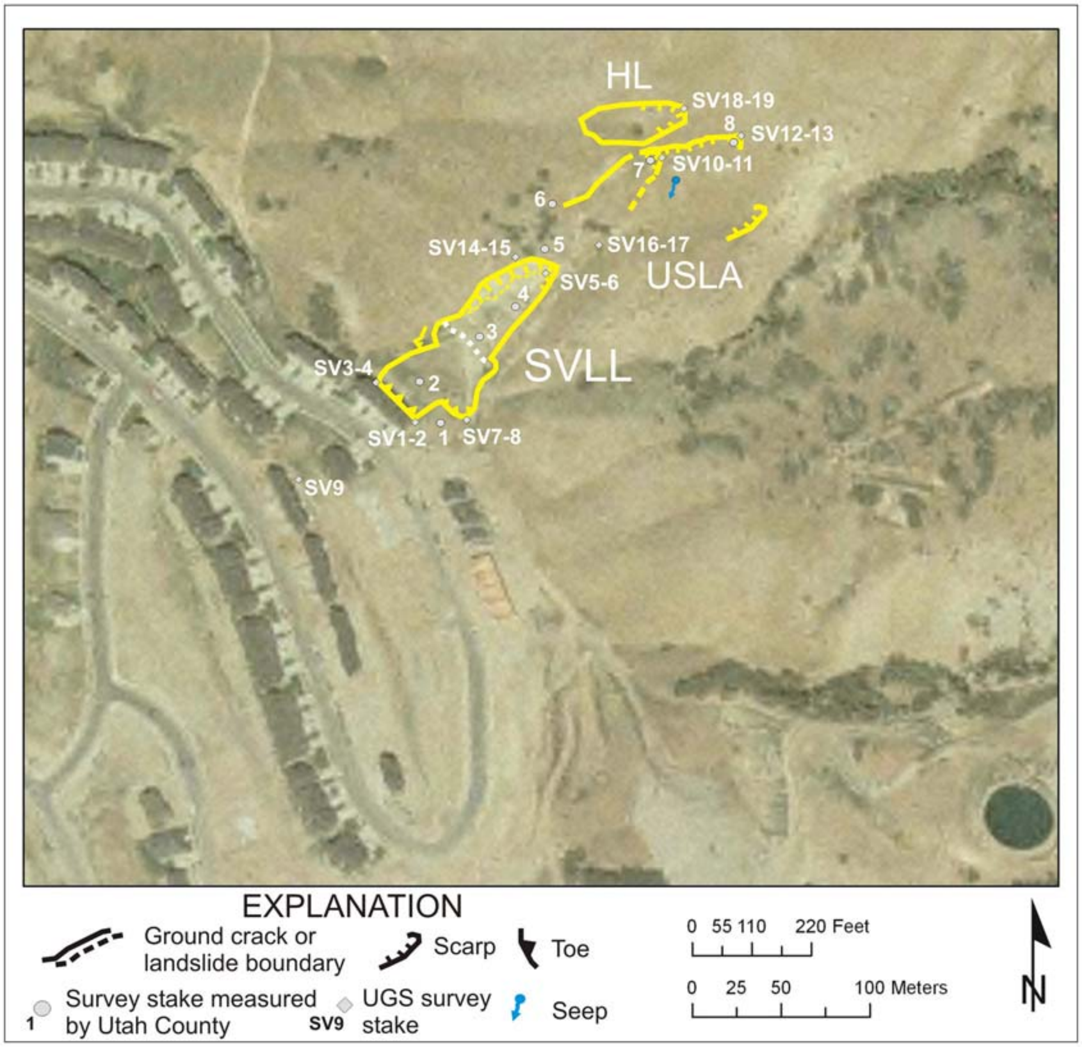

Figure 4. *Orthophotograph showing approximate locations of Sage Vista Lane landslide (SVLL), historical landslide (HL), and traces of landslide deformation features of upper shallow landslide area (USLA). Survey points measured by UGS (diamonds) and Utah County (circles) also shown. Orthophotograph from 2004 USDA National Agriculture Imagery Program.*

Figure 5*. View of the disrupted soil at toe of the landslide and damage to back of townhouse on April 29, 2005.*

Figure 6*. View of relatively intact, translated blocks near the middle of the landslide. Cobble-lined drainage ditch that was originally atop cut slope is translated downslope but relatively undeformed.*

***Figure 7**. View of slickensides in the upper, shallow part of the landslide.*

Figure 8*. View of south-facing scarp along north edge of landslide on April 29, 2005. The upper part of the scarp is from movement of the slide in 1983. The lower nearly vertical part is from movement of the Sage Vista Lane landslide in 2005.*

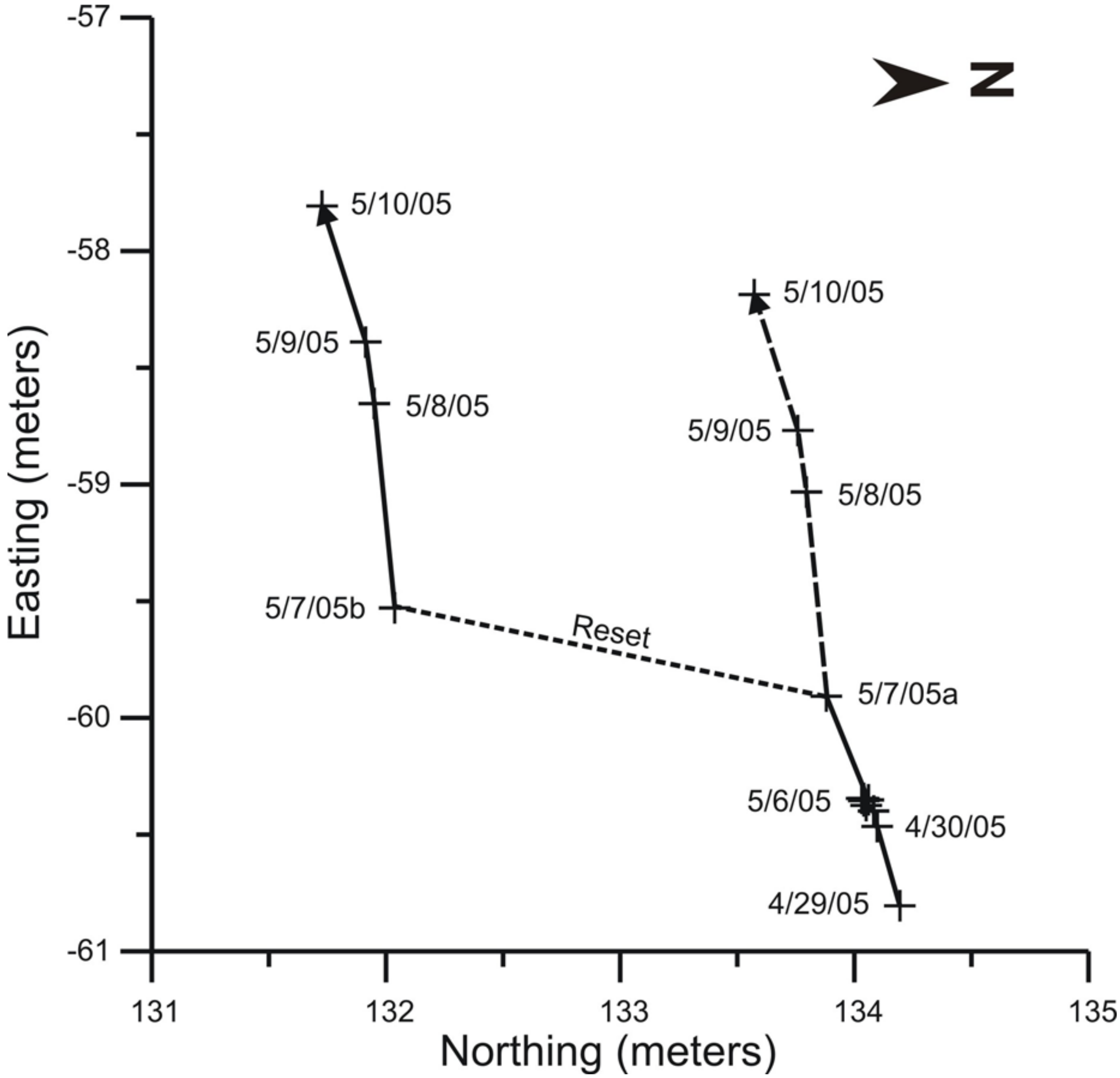

Figure 9. *Plot showing movement of the shallow head of landslide between April 29 and May 10, 2005. Head of landslide moved about 10.4 feet (3.2 m) during measurement period. Position of Utah Geological Survey stake SV5 in head of landslide surveyed by Utah County using accurate GPS equipment. Stake was relocated (reset) to avoid disturbance in saturated soils on May 7 (dashed line). Long dashed line shows probable displacement path for original stake position. Stake lost in saturated surface soils on May 11. Measurement location shown on figure 4. Stake coordinates reported in SI units by Utah County.*

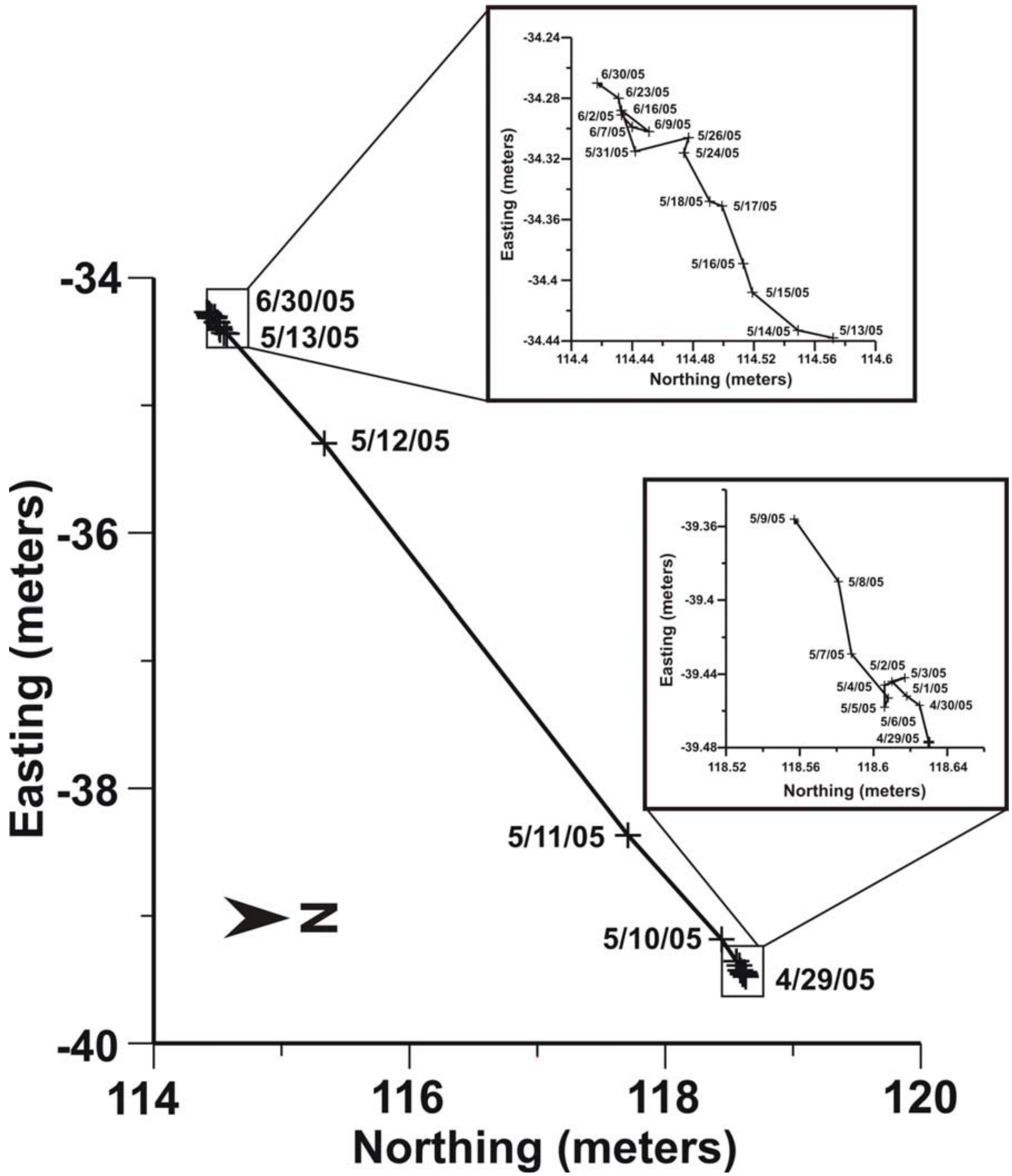

Figure 10. *Plot showing movement of the upper part of Sage Vista Lane landslide between April 29 and June 30, 2005. Total movement during the measurement period was about 23 feet (6.9 m). Most of the movement occurred between May 10 and 13, 2005, during which the townhouse was severely damaged. Insets show minor movement through May 9 (about 6 inches) and following May 13 (about 10 inches). Position of stake 4 (see figure 4 for location) in upper landslide surveyed by Utah County using accurate GPS equipment. Stake coordinates reported in SI units by Utah County.*

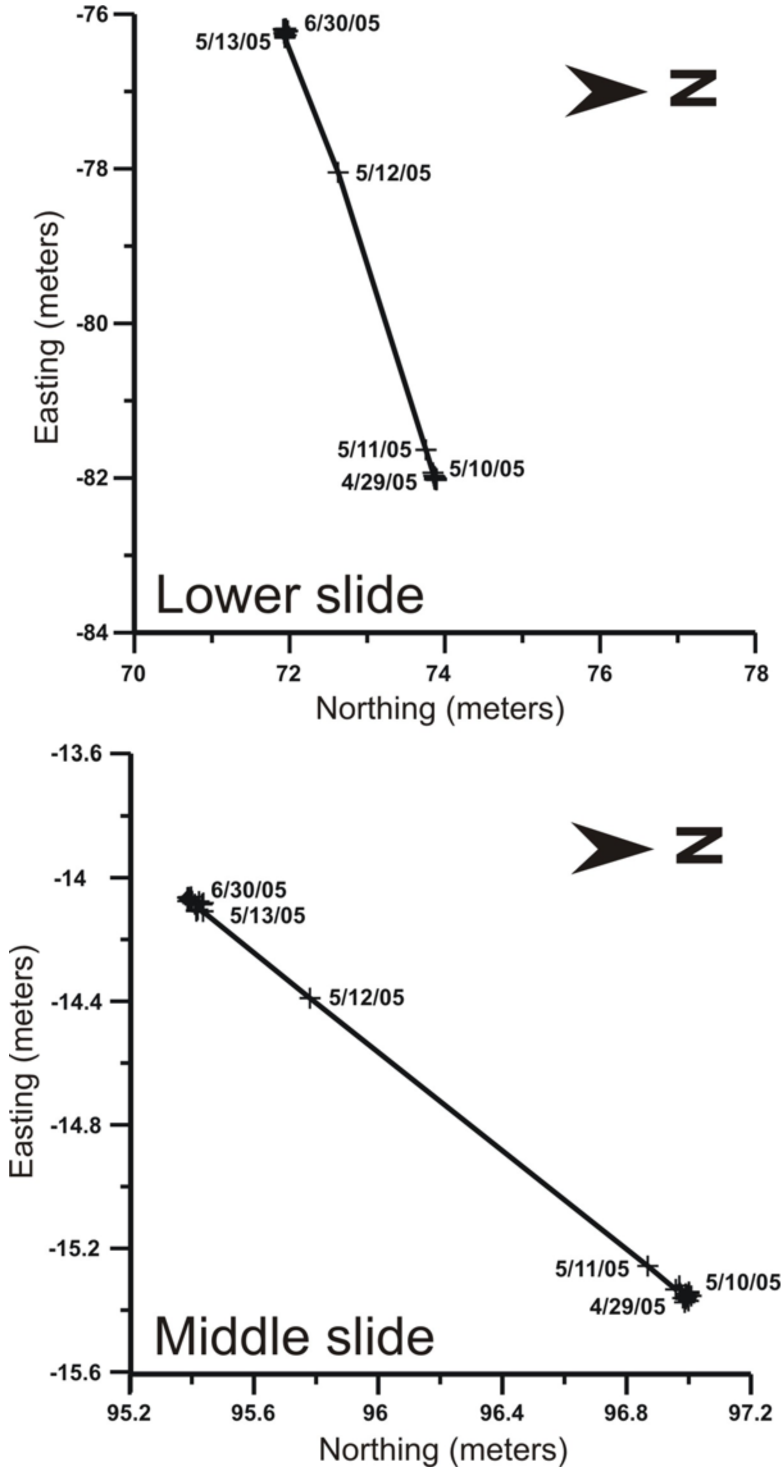

Figure 11. *Plot showing movement of the lower and middle parts of Sage Vista Lane landslide between April 29 and June 30, 2005. Total movement during the measurement period was about 21 feet (6.4 m) and 7.5 feet (2.m), respectively. Positions of stakes 2 and 3 (see figure 4 for locations) surveyed by Utah County using accurate GPS equipment. Stake coordinates reported in SI units by Utah County.*

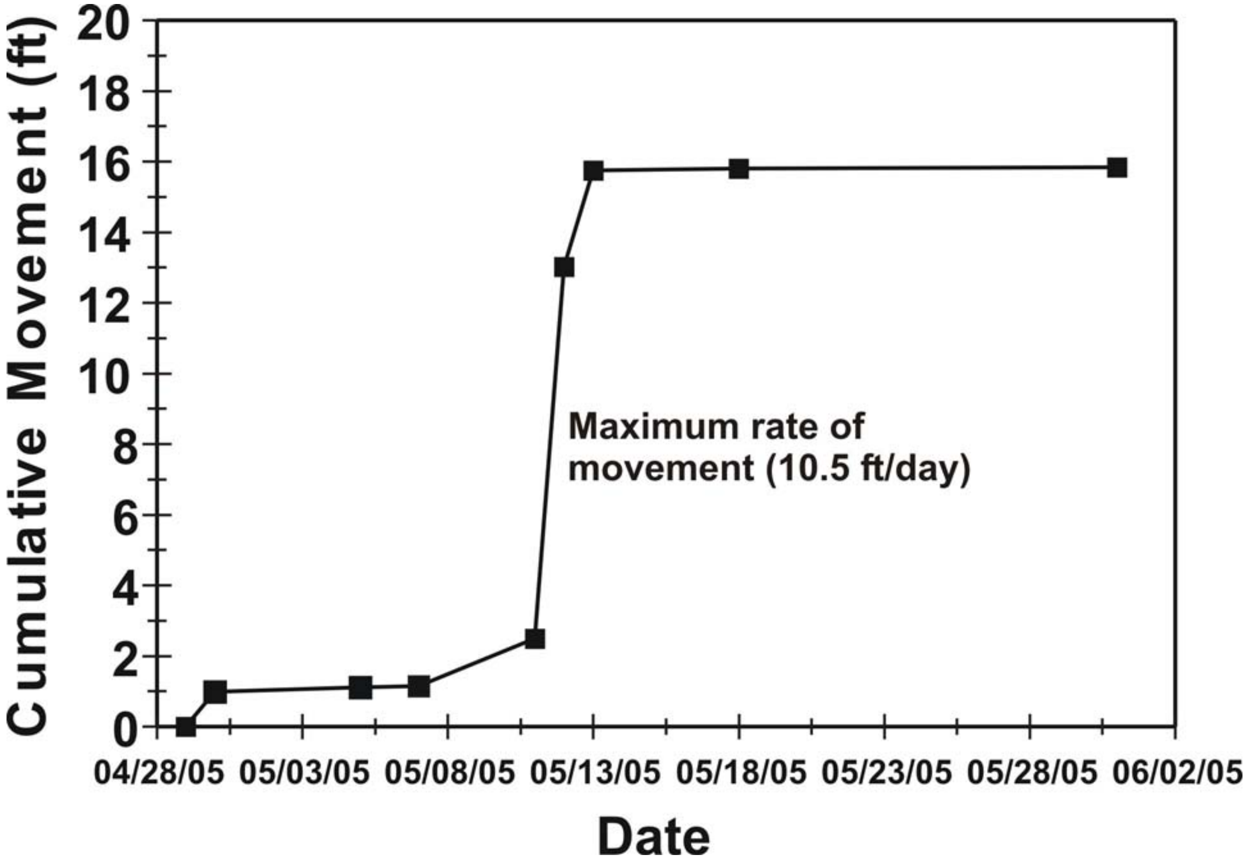

Figure 12. *Plot showing movement of north edge of toe of Sage Vista Lane landslide between April 29 and May 31, 2005. Total movement during the measurement period was about 15.9 feet (5 m). Distance between stakes SV3 and SV4 measured by UGS using fiberglass tape. Stake SV4 located on toe of landslide. Measurement location of station SV3-4 shown on figure 4.*

***Figure 13**. View of main scarp of small landslide upslope of main slide on May 12, 2005. By May 5, 2005 another scarp connected this small slide to one farther upslope joining the two slides into a single shallow landslide.*

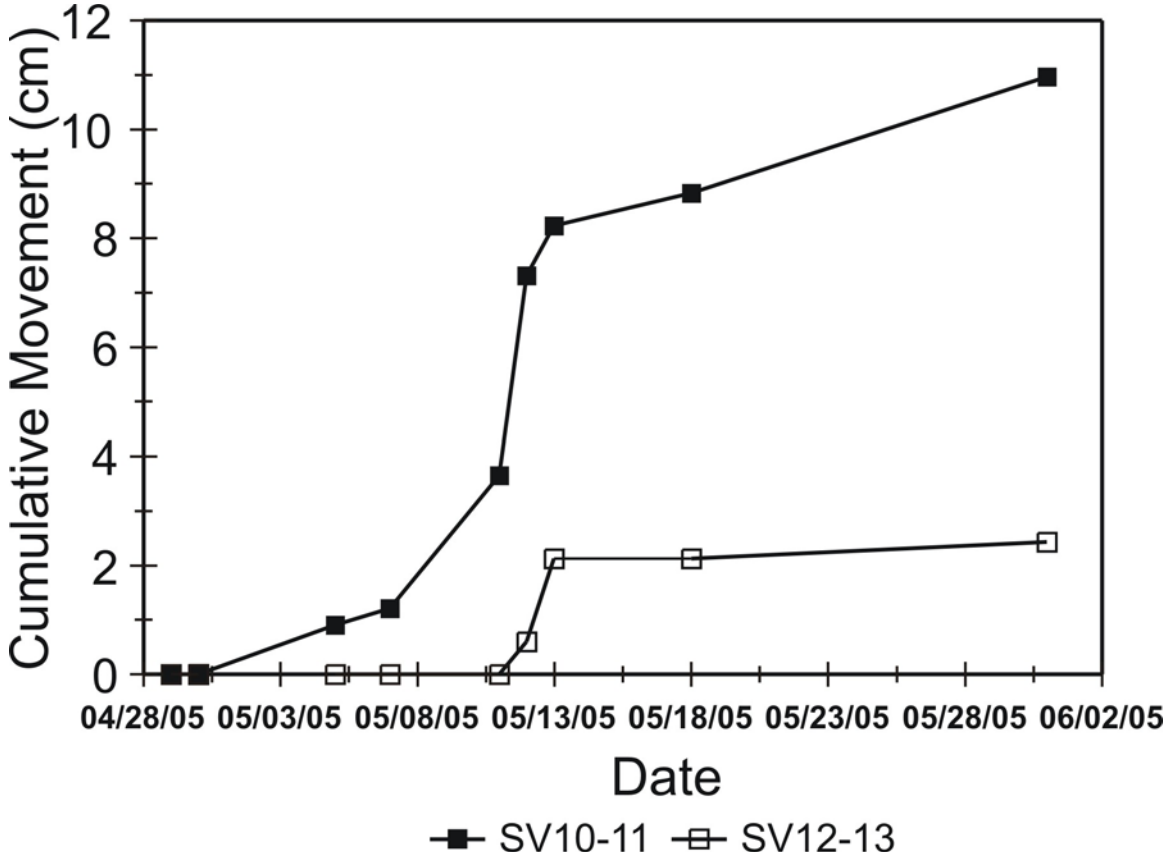

Figure 14. *Plot showing movement of the upper shallow landslide area northeast of Sage Vista Lane landslide between April 29 and May 31, 2005. Total movement during the measurement period was between about 1 and 4.3 inches (2.5-11 cm). Distance between stakes measured by UGS using fiberglass tape. Stake stations spanned scarps observed on April 29 (see figure 3). Measurement locations shown on figure 4.*

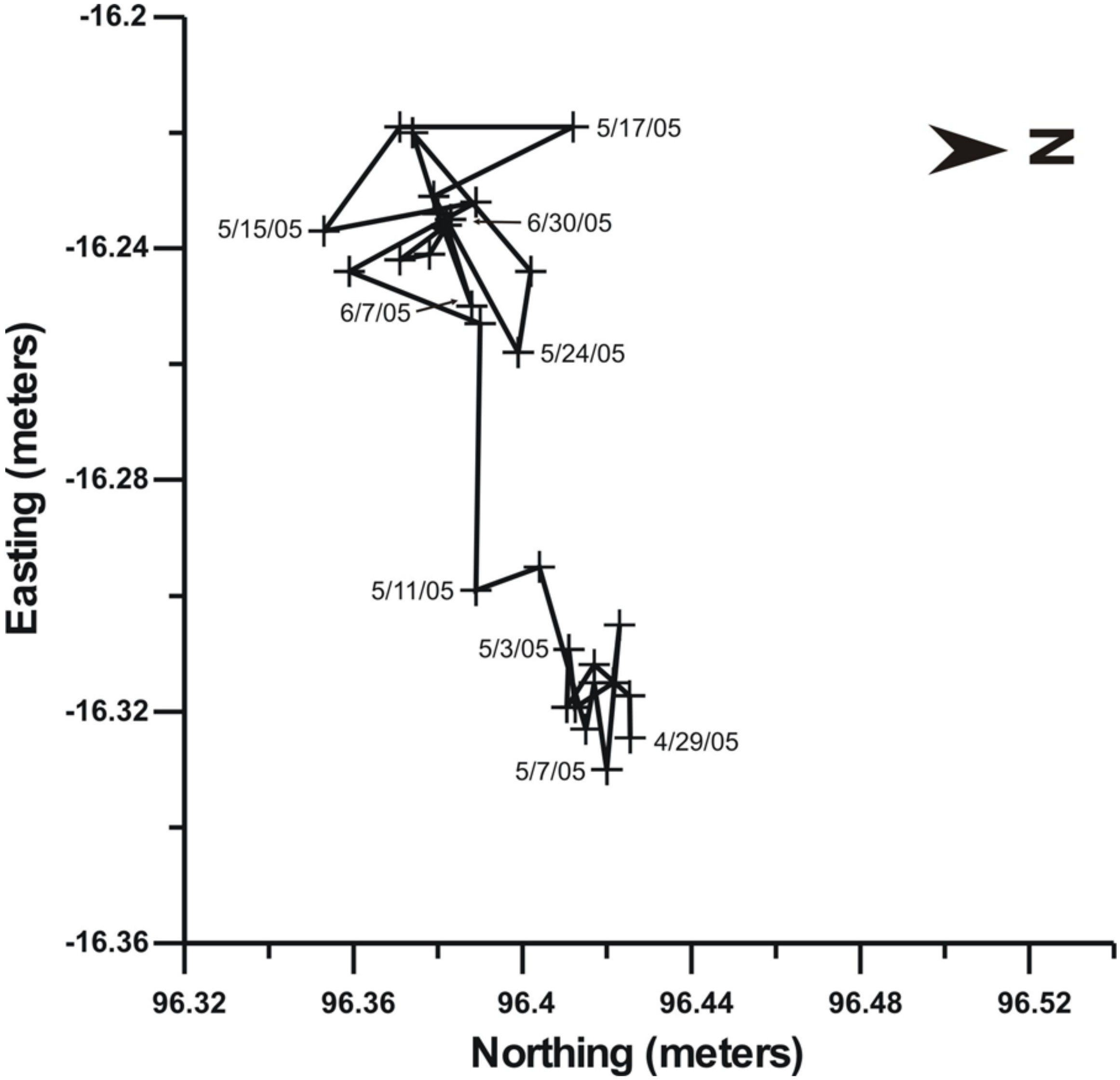

Figure 15. *Plot showing movement of lower part of upper shallow landslide area above Sage Vista Lane landslide between April 29 and June 30, 2005. Total movement during the measurement period was about 5 inches (13 cm). Positions of stake 7 (see figure 4 for location) surveyed by Utah County using accurate GPS equipment. Stake coordinates reported in SI units by Utah County.*