UTAH GEOLOGICAL AND MINERAL SURVEY

REPORT OF INVESTIGATION

NO. 214

STUDY OF LANDSLIDES WEST OF THE K & J SUBDIVISION IN SNAKE CREEK CANYON, WASATCH COUNTY, UTAH

by
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and
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STUDY OF LANDSLIDES WEST OF THE K & J SUBDIVISION
IN SNAKE CREEK CANYON, WASATCH COUNTY, UTAH

By Robert H. Klauk and William Mulvey

ABSTRACT

The K & J Subdivision in Snake Creek Canyon, Wasatch County, Utah is within a large landslide complex that formed after late-Pleistocene deglaciation. Although the large landslides have ceased, smaller, shallow slides on steep hillsides within the complex continue to fail. Three active landslides are presently on a steep hillside west of the subdivision. Wasatch County placed a moratorium on new development in the subdivision until it could be determined if the unstable hillside was a danger to the development.

The three landslides occurred between 1982 and 1985 as a result of an extended period of above-normal precipitation which destabilized the unconsolidated sediments that cover near-surface bedrock. Although these slides have not stabilized, shallow failure planes and considerable distances from the property line prevent the landslides from adversely affecting the subdivision. Future slides in this unstable area also will not affect the subdivision. Slopes immediately adjacent to the subdivision are less steep, exhibit no historical landslide activity, and therefore are more stable. Development of the hillside that includes the recent slides, however, will further disturb an unstable setting, accelerating failure. Dwellings constructed in this area would be threatened. Therefore, prior to development in any part of the large landslide complex, a detailed geologic/soils engineering study should be conducted to address slope stability.

INTRODUCTION

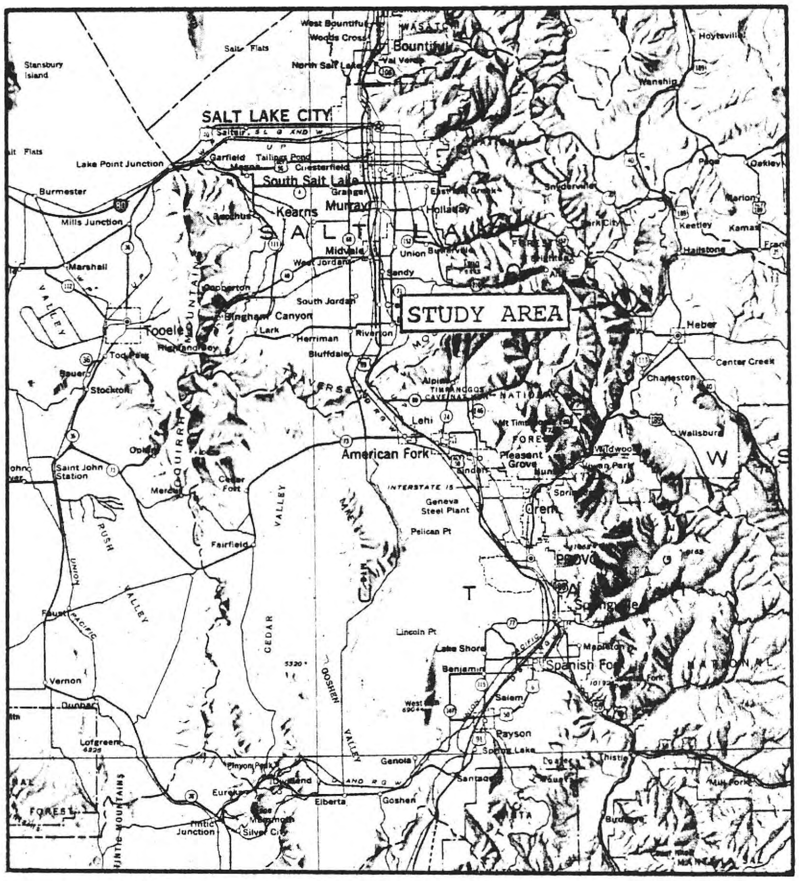
Background and Purpose

In response to a request from Robert A. Mathis, Wasatch County Planner, the Utah Geological and Mineral Survey (UGMS) made an investigation of slope failure and mudflow hazards to the K & J Subdivision in Snake Creek Canyon, Wasatch County, Utah (figure 1). The area investigated is located in the SE 1/4 sec. 18 and SW 1/4 sec. 17, T. 3 S. R. 4 E., Salt Lake Baseline and Meridian and includes the subdivision and the hillside to the southwest (figure 2). Mr. Mathis placed a moratorium on further development in the subdivision until the hazard could be evaluated. The purpose of the investigation was to determine: 1) the cause of three slope failures and an associated debris flow/mud flow that occurred on an east-facing slope above the subdivision in the spring of 1985; 2) if continued movement of these failures could endanger the subdivision; and 3) if other, presently inactive, areas on the hillside could fail and endanger the subdivision or future development in other areas of the canyon.

Scope of Work

The scope of work for this investigation included:

1. Review of published and available unpublished literature and other information including reports, maps, and well logs pertinent to the geology, hydrology, and soils of the site.
2. Examination of stereoscopic aerial photographs of the site.
3. Aerial reconnaissance of the site.
4. Seismic refraction profiling.

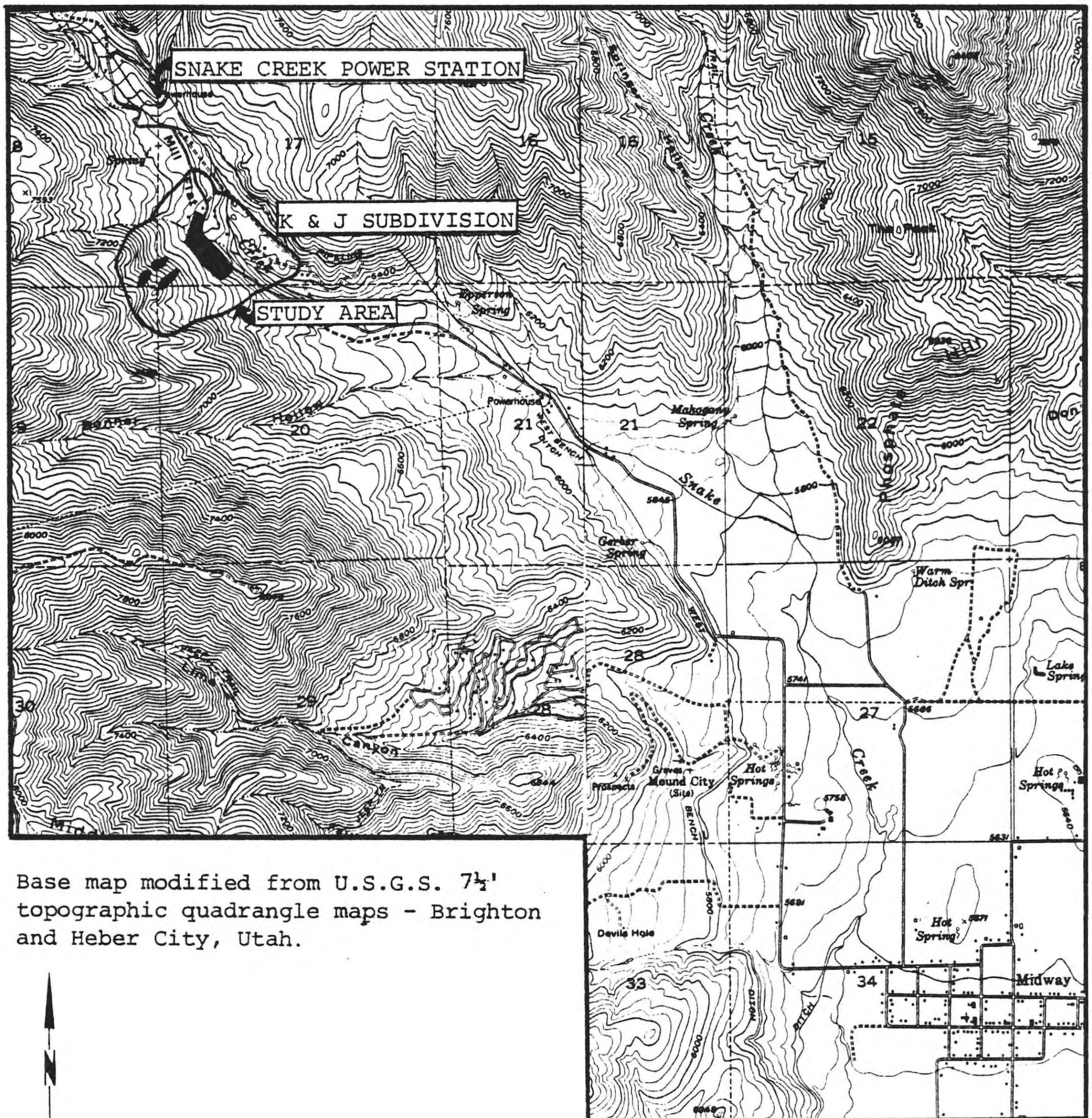


Base map from UGMS Relief Map of Utah, 1974.

Scale

0 10 20 30 Miles

Figure 1. Regional location map of the study area in Wasatch County, Utah.



Base map modified from U.S.G.S. 7½'
topographic quadrangle maps - Brighton
and Heber City, Utah.

N

Scale

0 6000 Feet

Contour interval 40 feet

Figure 2. Location map of the study area in Wasatch County, Utah.

5. Field reconnaissance, geologic mapping and profiling.

6. Report writing.

The scope of work did not include test borings or the excavation of test pits.

Setting

The K & J Subdivision is less than 2 miles above the mouth of Snake Creek Canyon in the Wasatch Range (figure 2). The subdivision occupies the base of the hillside on the southwest side of the canyon that has upper slopes greater than 55 percent. The 3 landslides hereafter referred to as slides I, II and III are located on this slope (figure 3). Thick brush, scrub oak, aspen and scattered evergreen trees cover the slope. Two springs present on the hillside have been developed for culinary use for the subdivision. A 2-inch diameter PVC pipe carries water from concrete collection boxes at each spring (designated as 1 and 2) to a water tank downslope (figure 3). Associated with development of these springs is a road complex that was in place prior to 1969 as evidenced from air photographs. Part of the road complex was used as a snowmobile trail for Wasatch Mountain State Park (located in the canyon) from 1982 to 1984 (figure 3). An unnamed ephemeral drainage originating high on the hillside enters Snake Creek within the subdivision. Elevations in the study area range from 7,320 feet at springs 1 and 2 to less than 6,500 feet in the channel of Snake Creek. Mean annual precipitation for this area is between 20 and 30 inches, falling mainly in the form of snow (Jeppson and others, 1968).

Figure 3. Oblique air photograph of the study area in
Snake Creek Canyon, Wasatch County Utah.

GEOLOGY BY PREVIOUS INVESTIGATORS

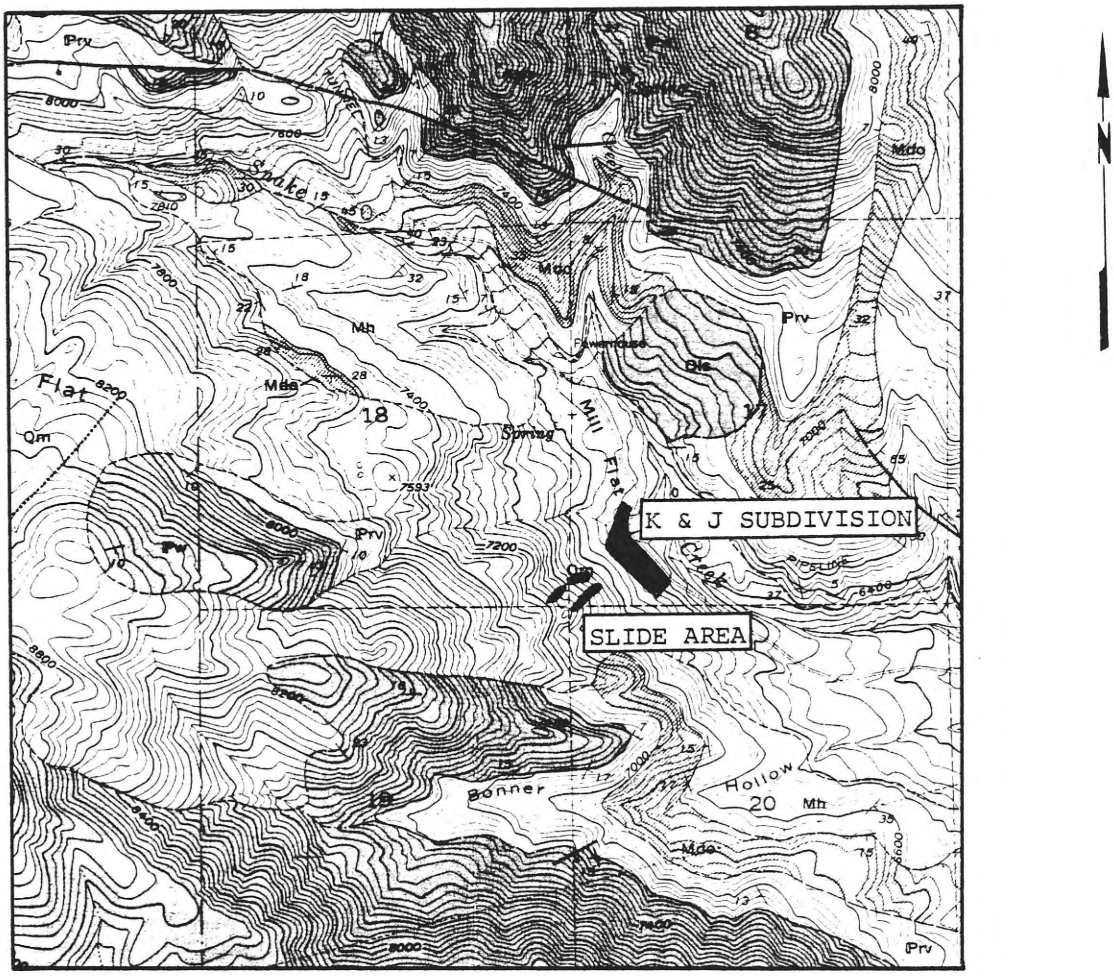
The K & J Subdivision is located in the Wasatch Range of the Middle Rocky Mountain physiographic province (Stokes, 1977). Baker and others (1966) have mapped glacial moraine deposits on the southwest side of the canyon in the vicinity of and including the subdivision (figure 4). They also mapped a large landslide on the northeast side of Snake Creek Canyon (figure 4).

Bedrock does not crop out on the hillside adjacent to or in the subdivision. However, bedrock is exposed within a one-half mile radius of the subdivision and includes the Mississippian Humbug and Doughnut Formations, and the Pennsylvanian Round Valley Limestone and Weber Quartzite (Baker and others, 1966; figure 4). The Humbug Formation is composed of gray limestone with interbedded, tan sandstone. Gray, fossiliferous, silty limestone, black shale, and rusty sandstone make up the Doughnut Formation. The Round Valley Limestone is gray limestone with chert nodules and silicified fossils, whereas the Weber Quartzite is gray quartzite and limey sandstone with some gray to white, interbedded limestone and dolomite.

Several normal faults striking in various directions have been mapped within 2 miles of the subdivision; however none are closer than 3500 feet and all are considered inactive.

GROUND WATER

According to Baker (1970), consolidated rocks are the principal source of ground water in the study area. Bedrock in Snake Creek Canyon has been subjected to considerable deformation and is highly fractured, faulted, and folded. Because bedrock consists primarily of carbonate rocks, solution cavities are abundant. Thus, water moves easily along numerous fractures,



Scale

0 4000 Feet

Contour interval 40 feet

Figure 4. Geology including the study area in Wasatch County, Utah (modified from Baker and others, 1966).

EXPLANATION

Qal Qt Qls

Alluvial deposits

Qal, stream gravel and valley fill
Qt, talus and high-angle alluvial cones
Qls, landslides

Qm

Glacial deposits

Pw

Weber Quartzite

Prv

Round Valley Limestone

Mdo

Doughnut Formation

Mh

Humbug Formation

Contact

Long dashed where approximately located; short dashed where inferred or projected from underground, dotted where concealed

Fault, showing dip

Dashed where approximately located; short dashed where inferred or projected from underground; dotted where concealed. Bar and ball on downthrown side

Thrust fault

Dashed where approximately located, saw-teeth on upper plate

Strike and dip of beds

Strike and dip of overturned beds

Strike and dip of vertical beds

solution cavities, and fault planes. Baker (1970) also reports that the Weber Quartzite and carbonate rocks of Mississippian and Pennsylvanian age yield water to many springs in this part of the Wasatch Mountains. These rock units crop out in the study area and may provide conduits for ground water that recharges springs 1 and 2, developed as culinary sources for the subdivision (figure 3).

RESULTS OF INVESTIGATION

Air Photo Analysis and Field Reconnaissance

Air photo analysis revealed that the K & J Subdivision and part of the hillside to the southwest, mapped by Baker and others (1966) as mantled by glacial moraine deposits, is part of what appears to be a large, landslide complex that failed since late-Pleistocene deglaciation 14,000 years ago. The extent of the slide complex is presented in figure 5. The complex is primarily made up of large individual earth flows; the zones of accumulation from a number of these flows appear to have blocked Snake Creek which subsequently cut through to its present base level, accounting for its incised morphology through the study area.

The field investigation of the hillside above the K & J Subdivision identified three separate, active debris slides in an area between two large earth flows (figure 3). Material displaced and/or exposed by these failures consists of heterogeneous clay, silt, sand, gravel, cobbles, and boulders. The investigation also discovered morphological evidence that areas adjacent to these presently active slides have also failed at various times in the past, substantiating what was observed on the air photographs. Figure 3 identifies such an area adjacent to slide II. The previous slide is sufficiently old that the area has revegetated and masked the failure. A second area, between slides

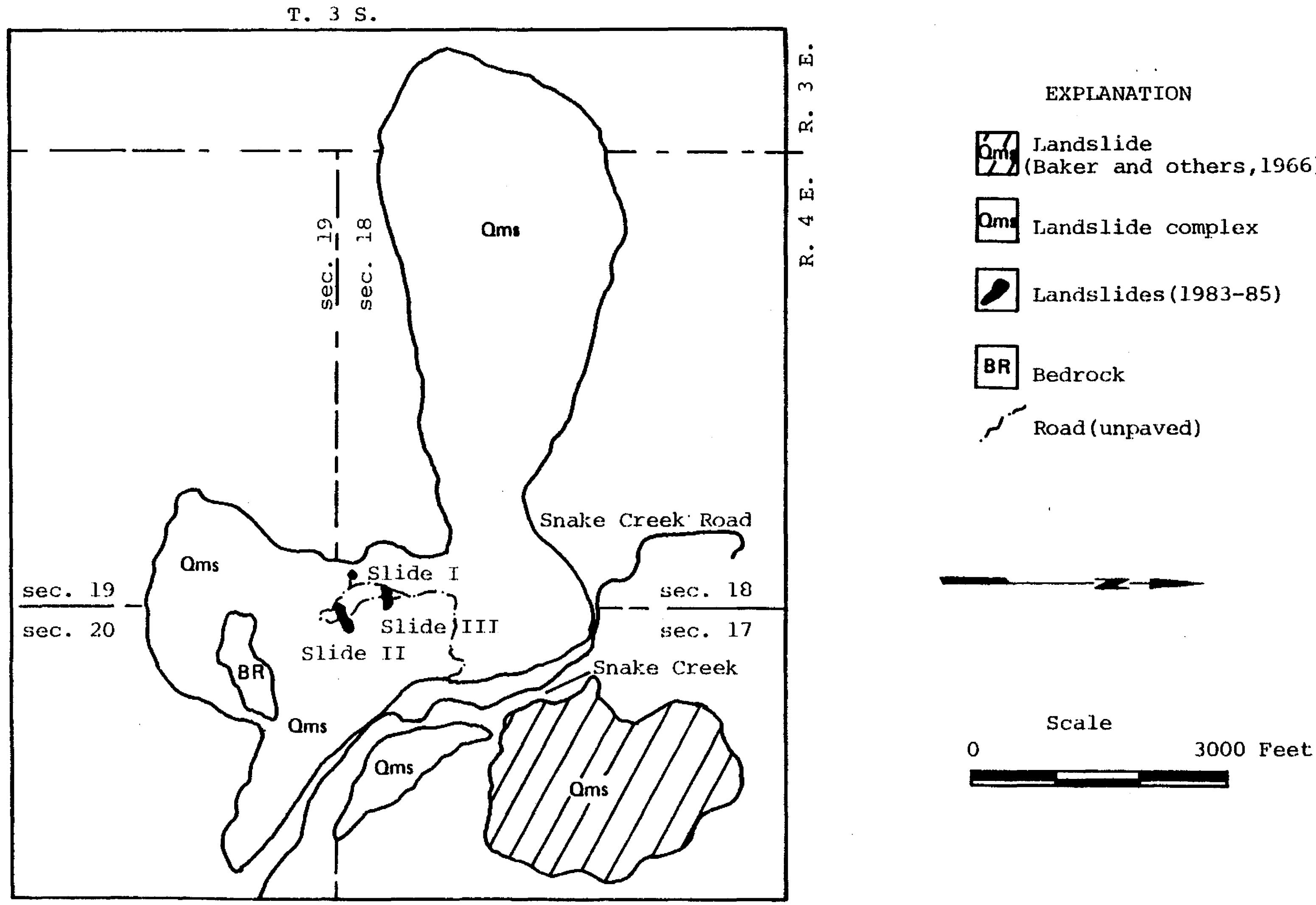


Figure 5. Map of landslide complex.

II and III, is devoid of trees and may represent another, young failure (figures 3 and 6). Trees may not have had time to reoccupy this slope since the event.

Although no outcrops are present, shallow road cuts on the hillside locally expose bedrock, indicating the colluvial mantle is thin. It could not be determined if this bedrock had been previously displaced by the large slide. To further investigate the thickness of colluvium on the hillside where bedrock is not exposed in road cuts, a seismic refraction line was run. Figure 3 shows the location of the geophone array. Interpretation of velocity data from refraction lines 1 and 1-reverse determined an average depth to bedrock of 19 feet, indicating a relatively shallow mantle on most of the hillside. This implies the failure planes for the recent slides are shallow and may be structurally controlled by the contact between bedrock and the overlying colluvium. Arrival times versus distance plots for survey lines 1 and 1-reverse are presented in figure 7. The derived thicknesses and velocities are listed in table 1.

Table 1. Layer velocities and thickness determined from seismic refraction survey in the study area.

Line	Velocity No. 1	Velocity No. 2	Depth to Bedrock
1	968 ft./sec.	7692 ft./sec.	18.5 ft.
1-reverse	1000 ft./sec.	8333 ft./sec.	19.5 ft.

Figure 6. Area devoid of trees that may identify a previous landslide.

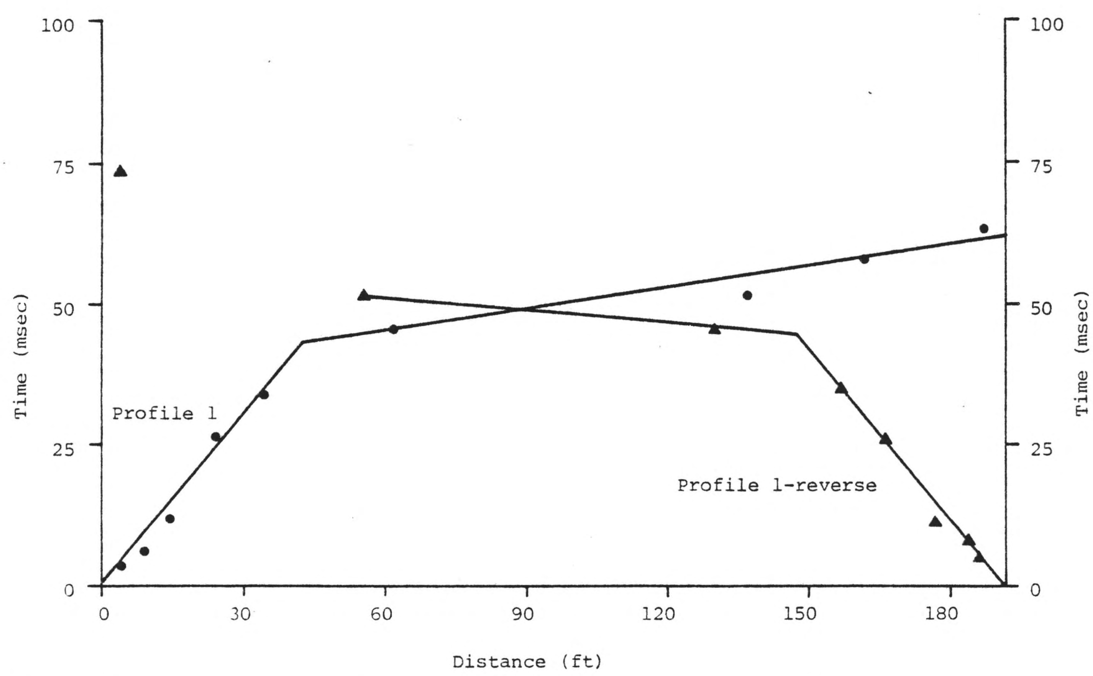


Figure 7. Results of seismic refraction survey. Profile 1-reverse was conducted to verify results of profile 1.

Profiling and Mapping Active Debris Slides

Profiles were measured near the center of each landslide using a tape and Brunton compass. Profiles begin and end on undisturbed slopes above and below the failures. Detailed observations of slide features were made during profiling. Furthermore, reference points were established to aid in mapping the remaining dimensions and features of the slides with a Brunton compass and a tape. Each slide has characteristics that distinguish it from the others and all are described separately.

Slide I

Slide I is a small translational debris slide approximately 50 feet long and 80 feet wide located at the end of an access road (figure 3; plate 1). The road has not been maintained for several years. Undisturbed slopes above (60 percent) and below (53 percent) the slide are heavily vegetated. The main scarp coincides with the road and exhibits a maximum offset of 4.0 feet. Profile I-I' shows a shallow projected failure plane (plate 1).

Slide II

Slide II, located approximately 350 feet southeast of slide I, is a complex debris slide composed of multiple failures (figure 3; plate 2). The maximum width of the disturbed zone is greater than 200 feet; total length is more than 350 feet. The failure plane(s) is shallow and may be structurally controlled by the contact between bedrock and the overlying unconsolidated material. Slopes above and below the failures are 40 percent whereas slopes adjacent to the complex are 60 percent. The entire area is heavily vegetated.

The uppermost main scarp occurs in the same unmaintained road as slide I (figures 3 and 8). This scarp is complex and has a maximum offset of 6.7 feet (plate 2). The main scarp extends for more than 190 feet along the road; however, significant movement below the scarp occurs in a failure zone less than 60 feet wide identified by areas C and E on plate 2 . The zone of accumulation (toe) associated with this failure is above the lower road previously used as a snowmobile trail. Blocks of detached material with back-rotated aspen and scrub oak are present in the upper parts of this zone. Below the back-rotated blocks, but still above the lower road, is an area partially devoid of vegetation and colluvium. The material formerly occupying this part of the slide is thought to have slumped onto the lower road and been removed during maintenance of the snowmobile trail in 1983 and 1984. This area is designated as E on plate 2.

The main scarp for a second debris slide in this complex is in the lower road immediately below area E discussed above (plate 2; figure 9). The scarp has a maximum displacement of 4.5 feet and is associated with back-rotated block A' on plate 2. Two areas of bulging (C') separated by an area where material has been removed (E') are also associated with this second debris slide. Profiles II-II' and II''-II''' present shallow failure planes for the upper and lower slides (plate 2).

Parallel with and approximately 60 feet to the southeast of the upper slide (borders area F on plate 2) is a continuous fracture that extends from the upper to the lower road (plate 2). Maximum offset along this fracture is 5.0 feet. A well-developed fracture/offset system with a maximum displacement of 2.0 feet is parallel to, and approximately 100 feet northeast of, the upper slide (borders area F' on plate 2). Thick vegetation obscurs this fracture system. A tape and Brunton survey was conducted to approximately locate some

Figure 8. Uppermost main scarp in slide II complex.

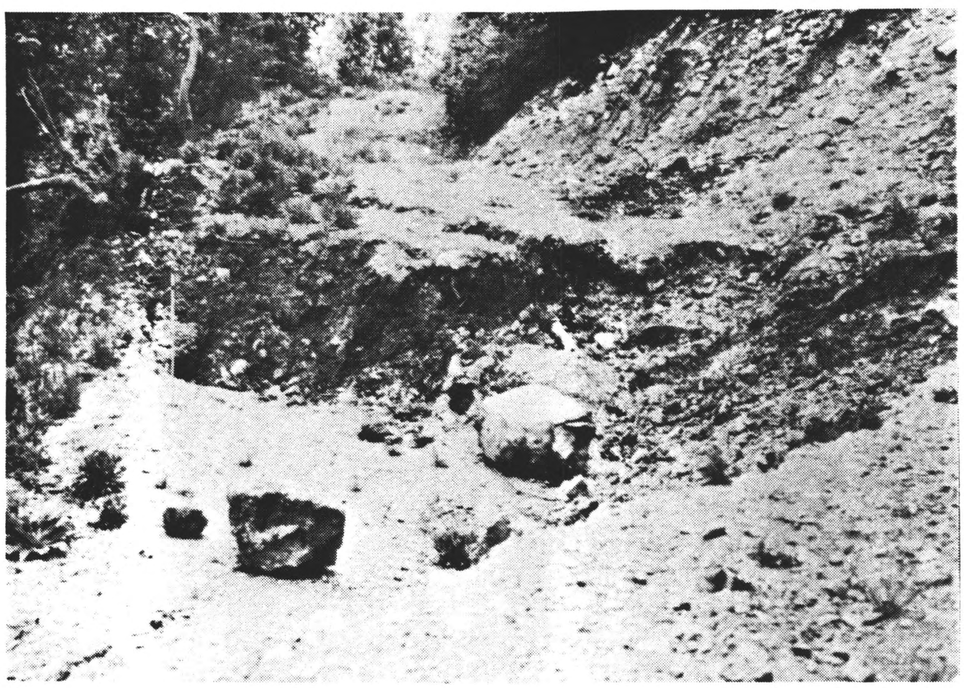


Figure 9. Main scarp in lower road (snowmobile trail in slide II complex).

of the fractures composing this system. Orientations were measured with a Brunton compass.

Two minor slump blocks identified as A'' and A''' on plate 2 are in the lower road on either side of the head scarp of the lower slide. Offsets on these blocks are 3.0 feet or less. A small seep in block A'' remained wet through the summer and into the fall (figure 10). The northwestern edge of this slump extends downslope in a northeasterly direction for approximately 50 feet. Further downslope a series of short transverse offsets/cracks have formed. The offset bordering the other side of this slump block continues downslope, eventually becoming a crack with no displacement before being obscured by thick vegetation. Offsets bordering slump block A''' could only be traced a few feet downslope.

Figure 10. Seep on lower road within slide II, area A'', plate 3.

Slide III

Slide III, located 300 feet north of Slide II, is a translational debris slide with an associated debris flow that changed to a mud flow further downslope (figure 3; plate 3). Maximum width is 120 feet. Length of the principal disturbed area is approximately 220 feet. However, the area of mud-flow runout forms a thin veneer of sediment that extends approximately 500 feet further downslope, where it entered the K & J Subdivision for a short distance. Slopes above, below, and adjacent to the slide are approximately 60 percent. The entire area is heavily vegetated.

The main scarp for slide III is above an abandoned road that connects the lower and upper roads and is designated as area A on plate 3. The road contained the buried PVC water pipe connecting springs 1 and 2 with the water tank. Maximum offset on this scarp is 4.0 feet. Profile III-III' projects a shallow failure plane similar to slides I and II. Two successive back-rotated blocks (B and B' on plate 3) extend from this scarp downslope 80 feet. The hillside from the lower block to the road is undisturbed and has a slope of 60 percent.

Adjacent to both sides of the back-rotated blocks are two scoured areas C and C' on plate 3. Immediately south of area C is a minor slump block designated as B''. Area C is larger than area C' and has a maximum width and length of 25 and 120 feet, respectively. Maximum depth is 6.0 feet. Two large debris blocks, D and D', have moved downslope in this zone; D' partially blocks the lower road. Other debris from this area blankets part of the road and lower slope (area E). Area C' on plate 3 has a maximum width of 15 feet, a maximum length of 90 feet and ends 60 feet above the lower road (figure 11). Maximum depth is 7.0 feet. Two small seeps and a severed 2-inch diameter PVC water line were observed in this zone. Debris from this area coalesces with debris from area C and together extend approximately 50 feet below the road.

Figure 11. Scoured zone with severed PVC water pipe in slide III.

Cause of Failures

Many landslides occurred in Utah in 1983 as a result of above-normal precipitation that began in September, 1982. Christenson (1986) states that these landslides are most common in moist, higher elevations in areas of steep slopes and slide-prone geologic materials. The hillside above the K & J Subdivision meets all of these criteria. Sowers and Royster (1978) report that water is a major factor in most landslides. The Snake Creek power station (figure 2), less than one mile from the subdivision, recorded much higher than normal precipitation for several months between September, 1982 and May, 1985 (figure 12). Slides I, II and III occurred within this period, above an elevation of 6,800 feet, on steep slopes, in landslide susceptible material. The precipitation saturated the unconsolidated material resulting in high pore water pressure that reduced intergranular pressure and friction resulting in failure.

Main scarps for slides I and III, and the two main scarps in slide II all formed in or adjacent to roads cut into the hillside prior to 1969. These roads likely allowed water (snowmelt and rain) to pond and infiltrate. Lack of dense vegetation (bushes and trees) may have also resulted in more infiltration as less water was given up to evapotranspiration. The debris flow associated with slide III appears to be anomalous because flows are not associated with slides I and II, and no debris-flow morphology was observed on mountain slopes elsewhere in or adjacent to the study area. Failure of slide III eventually severed the water line found in area C' on plate 3 that formerly extended from springs 1 and 2 to the water tank (figure 3). This additional water may have saturated the soil, and resulted in the debris flow/mud flow that reached the K & J Subdivision. Water was flowing from the pipe shortly after the debris flow occurred (H. E. Gill, oral commun., 1986). The 2 seeps found within the slide may be remnants of springs that also contributed water to the failure.

Maintenance of the snowmobile trail (lower road) did not cause landsliding. The original road cuts made prior to 1969 may have decreased stability and contributed to the magnitude of the failures during the recent period of greater-than-normal precipitation. However, initial maintenance in 1982 of the road to prepare it as a snowmobile trail only involved removal of upslope slough according to Roper (1985) and would not have any affect on slope stability. If the material removed was not slough but landslide debris,

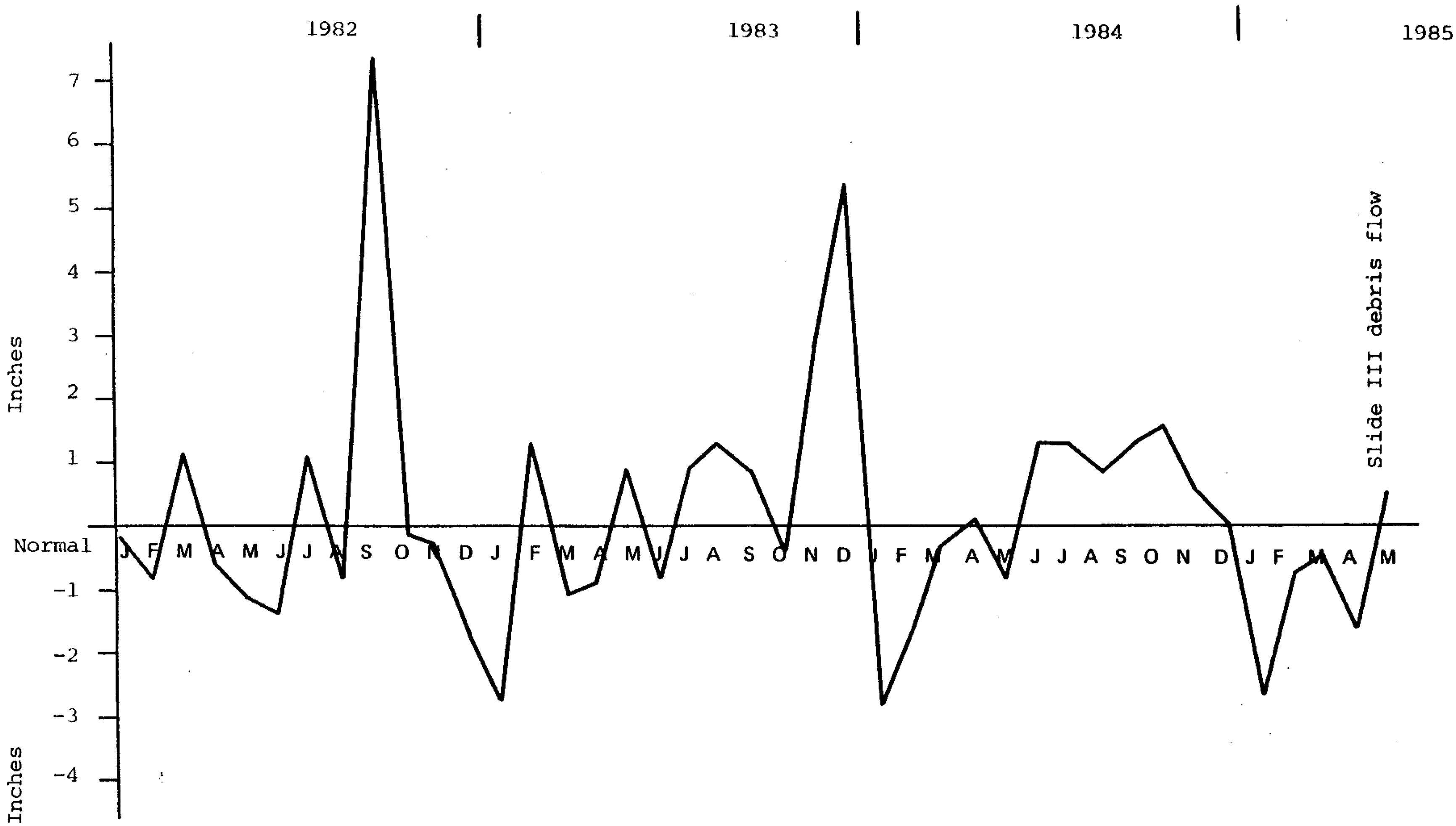


Figure 12. Comparision of monthly accumulation of precipitation to monthly average precipitation for 1982, 1983, 1984, and January through May, 1985. Average precipitation is based on a 30 year mean (from National Oceanographic and Atmospheric Adminstration, 1982-1985).

failure would have begun prior to maintenance. Furthermore, if initial maintenance was the cause, it seems reasonable to assume that both slides II and III would have occurred in 1983; however, it appears that slide II did not occur until 1984. Removal of material in 1983 and 1984 in the zone of accumulation for slide III is likely to have accelerated the movement that eventually severed the water line. Removal of material in the zone of accumulation in the upper failure in slide II accelerated movement but reduced the load on the head of the lower failure and probably did not contribute to movement on that slide. It is not known when slide I occurred, but its location is far removed from any recently maintained roads.

CONCLUSIONS AND RECOMMENDATIONS

The K & J Subdivision is in a large landslide complex that formed after late-Pleistocene deglaciation. The massive failures have ceased; however, in historical time smaller, shallow slides within the complex have occurred. Three slides are presently active on the steep hillside above the subdivision. These failures have occurred since 1982 as a result of above-normal precipitation. The precipitation saturated unconsolidated sediments covering shallow bedrock, resulting in translational debris slides whose failure plane is thought to be partly coincident with the bedrock surface. These active slides will continue to move until equilibrium is attained.

Shallow failure planes and considerable distances from cabins and sites for future cabins prevent the debris slides from adversely affecting the K & J Subdivision. Slopes immediately adjacent to the subdivision are less steep, exhibit no historical landslide activity, and are not expected to fail if left in an undisturbed condition. The shallow failure planes of the active slides indicates that future failures in adjacent areas on the hillside will also be shallow and will not endanger the subdivision. Development of the upper hillside will, however, disturb an already unstable setting, accelerating failure. Cuts made for roads and lots would destabilize slopes, and dwellings constructed in this area would be threatened. Therefore, prior to future development in the large landslide complex outside of the K & J Subdivision, a detailed geologic/soils engineering study should be conducted to identify landslide hazards and recommend mitigating measures.

During the air photograph analysis for this study, other areas both in and outside of Snake Creek Canyon appeared to have landslide morphology. Some of these areas have been developed. It is recommended that all proposed future developments in Snake Creek Canyon and adjoining areas include studies to determine the presence, extent and severity of any landslide hazard.

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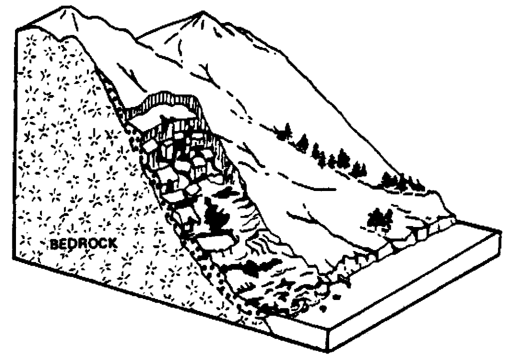
APPENDIX I

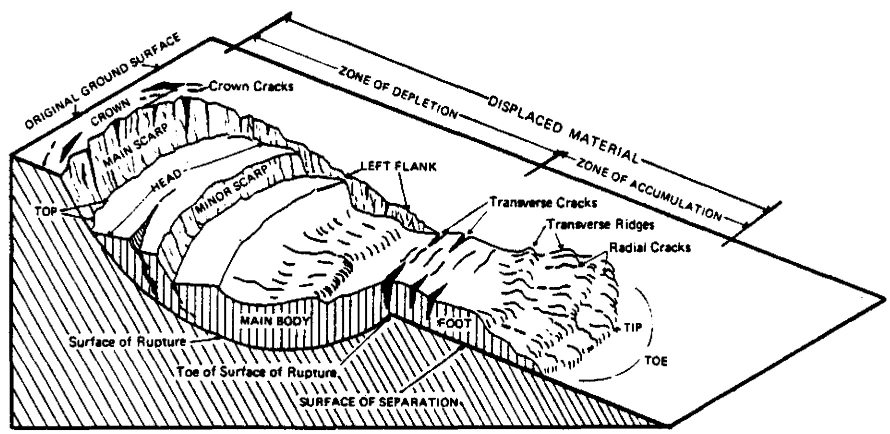
GLOSSARY OF TERMS

Colluvium:	Poorly sorted mixture of angular rock fragments and fine-grained materials moved by gravity.
Debris flow:	Movement of soil in a viscous state that contains more than 50 percent by weight of gravel, cobbles, and boulders.
Deglaciation:	Process of uncovering of an area by waning glacier ice.
Glacial moraine:	A general term applied to certain landforms composed of till.
Mud flow:	Movement of soil in a viscous state that contains more than 50 percent by weight of sand, silt and clay.
Normal fault:	The hanging wall (upper block) has moved downward relative to the foot wall (lower block).
Seismic refraction:	Subsurface exploration method that utilizes variations in primary or compressional wave velocities from energy sources.

TRANSLATIONAL DEBRIS SLIDE

Movement predominantly along more or less planar or gently undulatory surfaces.
Movement frequently is structurally controlled by surfaces of weakness, such as faults, joints, bedding planes, and variations in shear strength between layers of bedded deposits, or by the contact between firm bedrock and overlying detritus.





LANDSLIDE NOMENCLATURE

MAIN SCARP—A steep surface on the undisturbed ground around the periphery of the slide, caused by the movement of slide material away from undisturbed ground. The projection of the scarp surface under the displaced material becomes the surface of rupture.
MINOR SCARP—A steep surface on the displaced material produced by differential movements within the sliding mass.
HEAD—The upper parts of the slide material along the contact between the displaced material and the main scarp.
TOP—The highest point of contact between the displaced material and the main scarp.
TOE OF SURFACE OF RUPTURE—The intersection (sometimes buried) between the lower part of the surface of rupture and the original ground surface.
TOE—The margin of displaced material most distant from the main scarp.
TIP—The point on the toe most distant from the top of the slide.
FOOT—That portion of the displaced material that lies downslope from the toe of the surface of rupture.
MAIN BODY—That part of the displaced material that overlies the surface of rupture between the main scarp and toe of the surface of rupture.

FLANK—The side of the landslide.
CROWN—The material that is still in place, practically undisplaced and adjacent to the highest parts of the main scarp.
ORIGINAL GROUND SURFACE—The slope that existed before the movement which is being considered took place. If this is the surface of an older landslide, that fact should be stated.
LEFT AND RIGHT—Compass directions are preferable to describing a slide, but if right and left are used they refer to the slide as viewed from the crown.
SURFACE OF SEPARATION—The surface separating displaced material from stable material but not known to have been a surface on which failure occurred.
DISPLACED MATERIAL—The material that has moved away from its original position on the slope. It may be in a deformed or undeformed state.
ZONE OF DEPLETION—The area within which the displaced material lies below the original ground surface.
ZONE OF ACCUMULATION—The area within which the displaced material lies above the original ground surface.

Modified from: David J. Varnes, Slope Movement and Types and Processes, *in* Landslides: Analysis and Control, Transportation Research Board, National Academy of Sciences. Washington D.C., Special Report 176, Chapter 2, 1978.

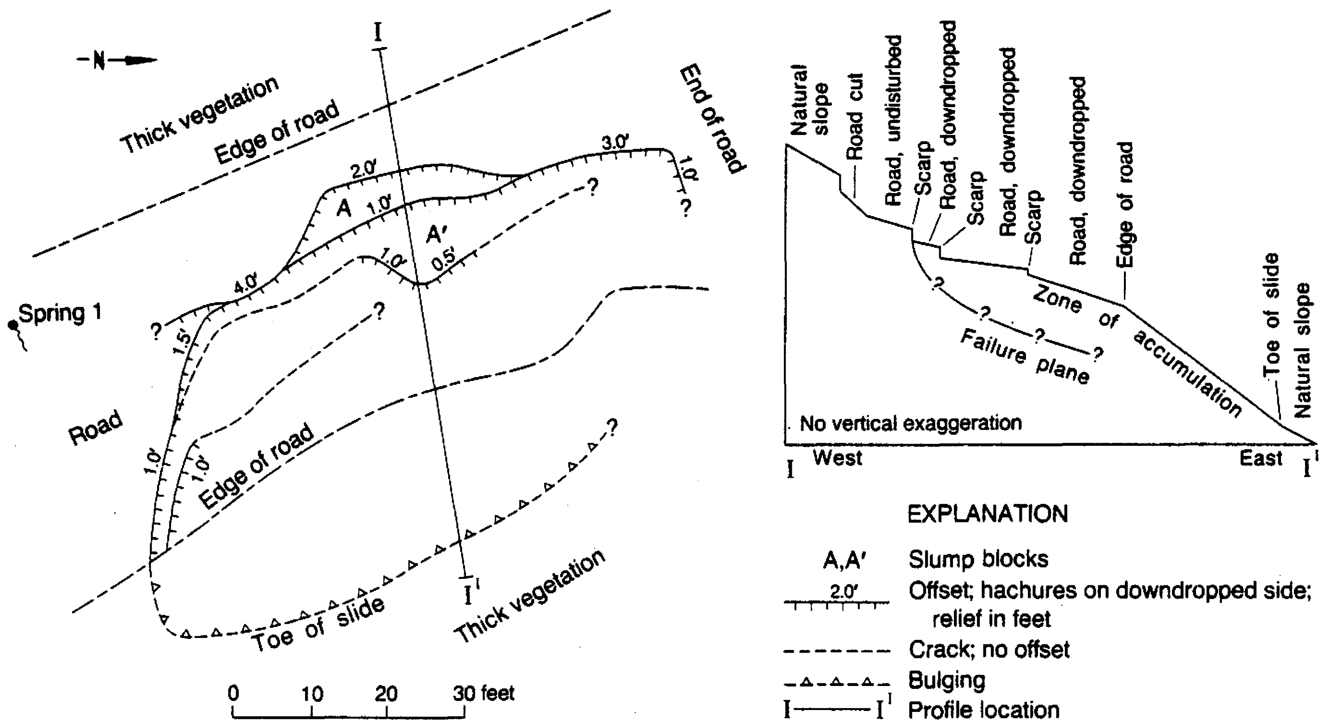


Plate 1
Map and Profile of Slide I West of the K & J Subdivision
in Wasatch County, Utah
Mapped by Robert H. Klauk and William Mulvey

Plate 2
Map and Profile of Slide II
West of the K & J Subdivision
in Wasatch County, Utah

Mapped by Robert H. Klauk
and William Mulvey

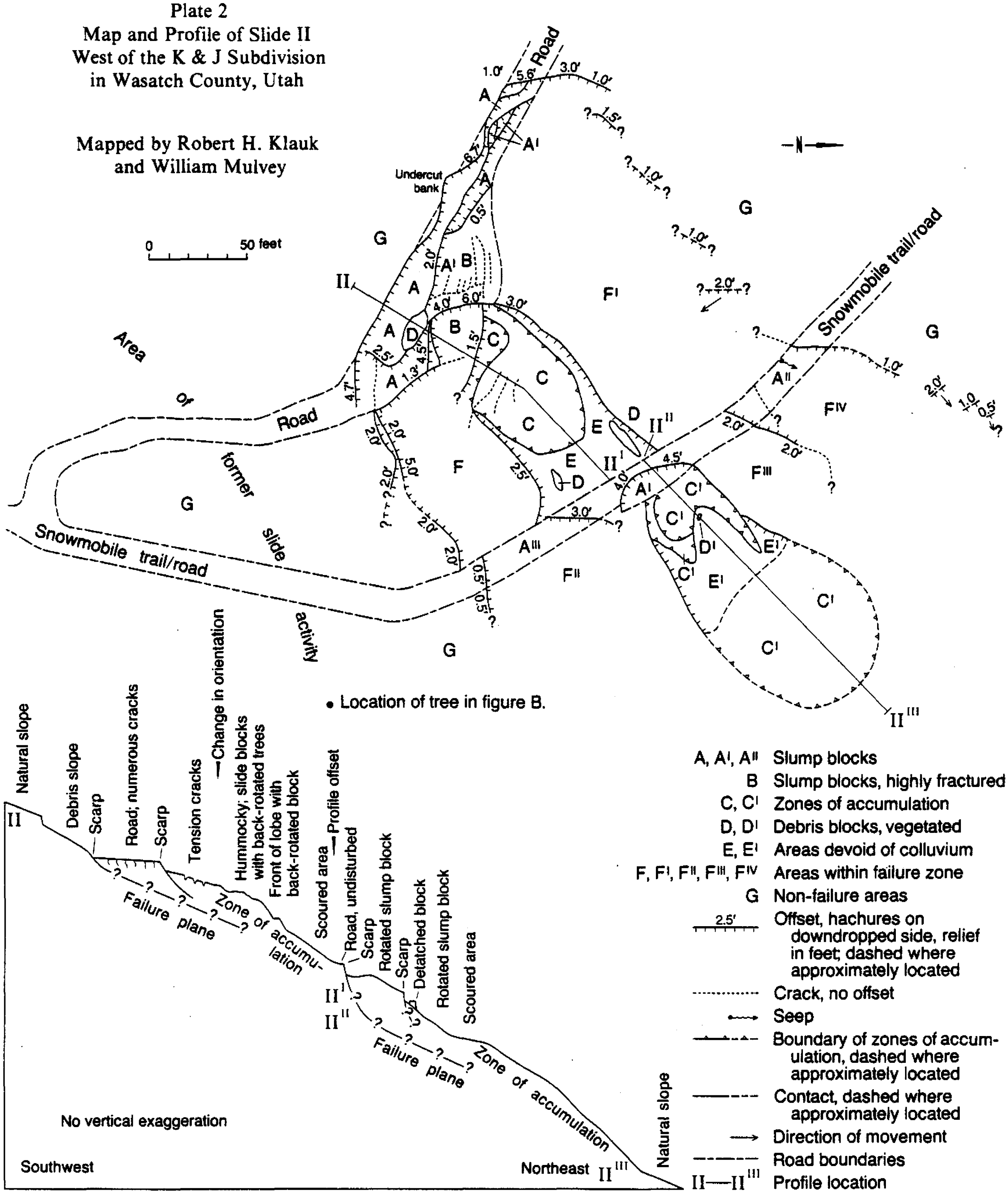
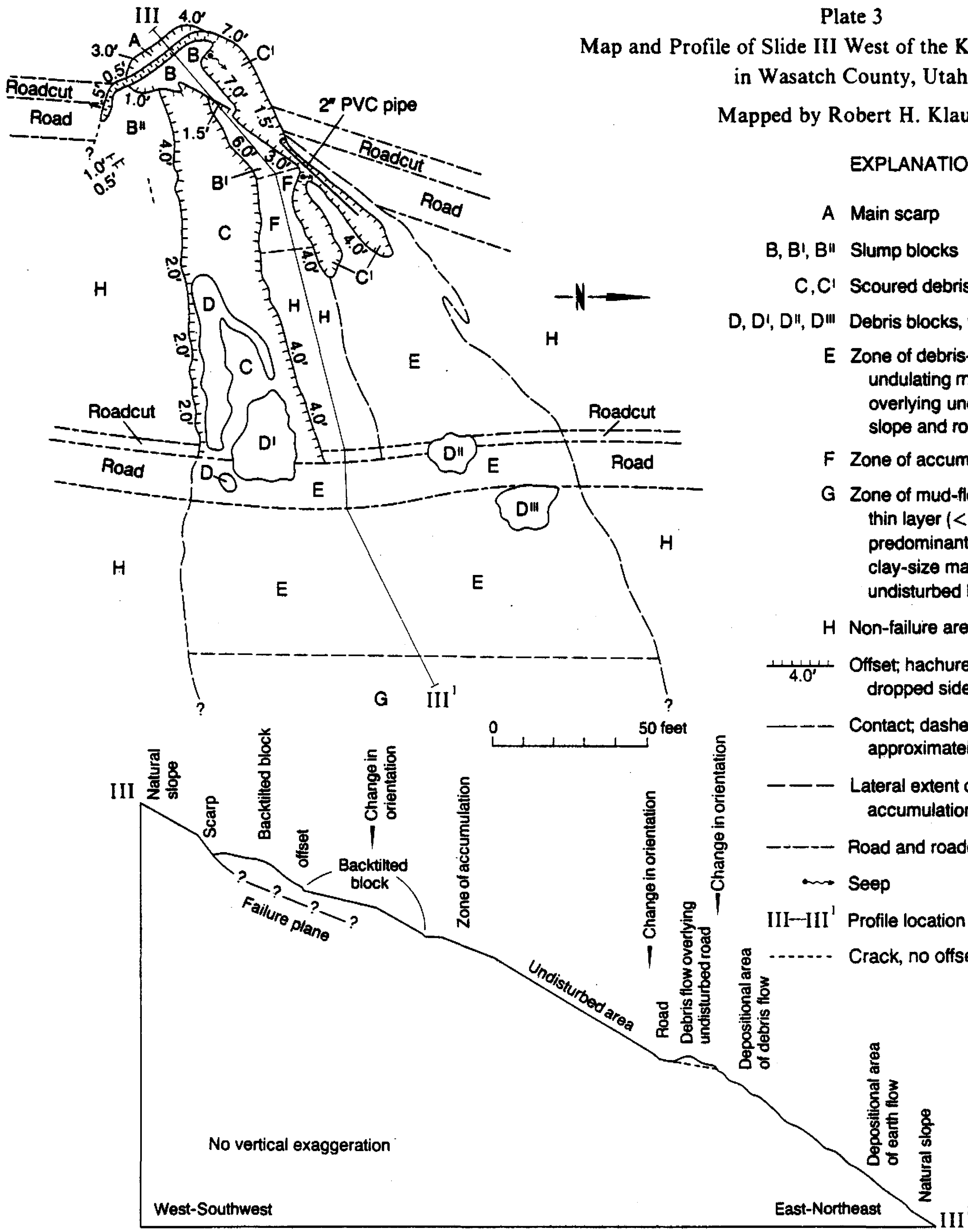


Plate 3
Map and Profile of Slide III West of the K & J Subdivision in Wasatch County, Utah
Mapped by Robert H. Klauk



EXPLANATION

A Main scarp
B, B', B'' Slump blocks
C, C' Scoured debris flow areas
D, D', D'', D''' Debris blocks, vegetated
E Zone of debris-flow accumulation, undulating mantle of debris overlying undisturbed slope and road
F Zone of accumulation
G Zone of mud-flow accumulation, thin layer (< 0.5 feet) of predominantly sand-, silt-, and clay-size material covering undisturbed hillside
H Non-failure areas
4.0' Offset; hachures on down-dropped side; relief in feet
Contact; dashed where approximately located
Lateral extent of flow accumulation
Road and roadcut boundaries
Seep
III—III[1] Profile location
Crack, no offset