UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources
in cooperation with
National Park Service

Plate 3
Utah Geological Survey Special Study 133
Zion National Park Geologic-Hazard Study Area, Washington and Kane Counties, Utah

LANDSLIDE HAZARD
ZION NATIONAL PARK GEOLOGIC-HAZARD STUDY AREA

By

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Base map consists of U.S. Department of Agriculture 2006 National Agricultural Imagery Program natural color aerial photography and shaded relief generated from digital elevation data acquired from the Utah Automated Geographic Reference Center.

Universal Transverse Mercator Projection, zone 12
North American Datum of 1983

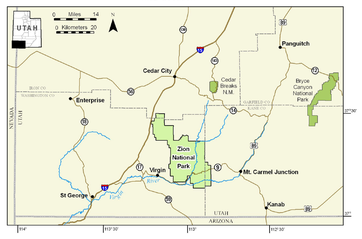
SYMBOLS

- Zion National Park Geologic-Hazard Study Area boundary
- Zion National Park boundary
- County boundary
- State highway
- Minor road
- Foot trail
- Existing park structure
- Area not studied

EXPLANATION

- Very High: Existing landslides (susceptibility category A).
- High: Areas where the Petrified Forest Member of the Chinle Formation and the overlying Moenave Formation (susceptibility category B) crop out on slopes greater than 15 percent (8°).
- Moderate C: Areas where susceptibility-category C geologic units crop out on slopes greater than 20 percent (12°).
- Moderate B: Areas where the Petrified Forest Member of the Chinle Formation crop out on slopes less than 15 percent (8°).
- Low: Areas where susceptibility-category D geologic units crop out on slopes greater than 30 percent (17°).

Map Location



SCALE 1:24,000

1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER

12°N TRUE NORTH MAGNETIC NORTH

Approximate mean declination, 2009

Landslide Susceptibility of Geologic Units

Susceptibility Category	Geologic Units[1]	Comments
A	Existing landslides	Existing landslides are considered the most likely units in which new landslides may initiate (Ashland, 2003).
B	Petrified Forest Mbr., Chinle Fm.; Moenave Fm. where above slopes of Petrified Forest Mbr.	The Petrified Forest Member consists chiefly of bentonitic clay, which is expansive and has low shear strength. This unit includes the greatest number of landslides in the study area. Numerous landslides have also formed in the overlying Moenave Formation where the Petrified Forest crops out on lower slopes.
C	Harrisburg Mbr., Kaibab Fm.; Shinarump Mbr. and red members, Moenkopi Fm.; Moenave Fm. not above slopes of Petrified Forest Mbr.; Kayenta Fm. above Springdale Sandstone Mbr.; Temple Cap Fm.; Carmel Fm.; Cedar Mountain Fm.	These bedrock units contain varying amounts of gypsum, shale, claystone, mudstone, siltstone, or a combination of these rock types that impart weak shear strength to the units, at least locally, and make them susceptible to landsliding. These units contain the second greatest number of landslides in the study area, which often occur as landslide complexes.
D	Remaining bedrock and unconsolidated geologic units exclusive of the Navajo Sandstone. Slope failures in the Navajo are limited to rock falls and fin-collapse mass wasting which are discussed in the Rock-Fall Hazard section of this study.	These geologic units either contain a higher percentage of stronger rock types, crop out on slopes too gentle to generate landslides, or generate failures that are too small to map at 1:24,000-scale. As a result, they exhibit few or no mapped landslides. Landslides identified within these units typically result from mass movement or erosion in underlying, weaker geologic units.

[1]See chapter 1, figure 1.4, in accompanying text for complete geologic unit names.

DISCUSSION

Landslide is a general term covering a wide variety of mass-movement landforms and processes involving the downslope transport, under gravitational influence, of soil and rock material en masse (Cruden and Varnes, 1996; Neuendorf and others, 2005). The term includes both deep-seated and shallow mass movements (Cruden and Varnes, 1996). The moisture content of the affected materials at the time of landsliding may range from dry to saturated.

Landslides can be both damaging and deadly. The U.S. Geological Survey (USGS) estimated that in the United States, landslides on average cause $1-2 billion in damage and more than 25 deaths annually (USGS, 2008). Giraud and Shaw (2007) compiled mapping of approximately 14,000 landslides statewide in Utah. Anderson and others (1984) estimated that the total direct costs of landslides in Utah in the abnormally wet spring of 1983 exceeded $250 million. The 1983 Thistle landslide, Utah's single most destructive landslide, is recognized, both in terms of direct and indirect costs, as the most expensive individual landslide in North American history (University of Utah, 1984; Schuster, 1996; USGS, 2008).

Rock and soil units susceptible to landsliding underlie parts of the Zion National Park Geologic-Hazard Study Area. Historical landslides have disrupted transportation routes, houses, commercial sites, and public utilities within and adjacent to the study area (Black and others, 1995; Lund and Sharrow, 2005; Lund and others, 2007).

For additional information about the landslide hazard in the Zion National Park Geologic-Hazard Study Area, refer to the Landslide Hazard chapter in this report.

USING THIS MAP

This map shows areas of relative landslide hazard, and provides a basis for requiring site-specific hazard investigations. Site-specific investigations can resolve uncertainties inherent in generalized geologic-hazard mapping and help ensure safety by identifying the need for hazard mitigation.

This map identifies areas, based on previous landslide history, material characteristics, and slope, where site-specific slope-stability conditions (such as material strength, orientation of bedding or fractures, ground-water conditions, erosion or undercutting) should be evaluated prior to development. The level of investigation needed at a given site depends on the relative hazard and the nature of the proposed development (structure type, size, use, and placement; required cuts and fills; and changes in ground-water conditions). A valid landslide-hazard investigation must address all pertinent conditions that could affect, or be affected by, the proposed development, including earthquake ground shaking. This can only be accomplished through the proper identification and interpretation of site-specific geologic conditions and processes (Blake and others, 2002). Nearby conditions that may affect the site must also be considered.

The analysis of natural and modified slopes for static and/or seismic stability is a challenging geotechnical problem. Blake and others (2002, p. 3) consider the following steps required for a proper static and seismic slope-stability analysis.

> "Accurate characterization of:
> 1. Surface topography,
> 2. Subsurface stratigraphy,
> 3. Subsurface water levels and possible subsurface flow patterns,
> 4. Shear strength of materials through which the failure surface may pass,
> 5. Unit weight of the materials overlying potential failure planes.
>
> The stability calculations are then carried out using an appropriate analysis method for the potential failure surface being analyzed. A seismic slope-stability analysis requires consideration of each of the above factors for static stability, as well as characterization of:
>
> 1. Design-basis earthquake ground motions at the site, and
> 2. Earthquake shaking effects on the strength and stress-deformation behavior of the soil, including pore pressure generation and rate effects."

Blake and others (2002) consider all of the above factors vital for a proper slope stability analysis, but note that some factors are more easily characterized than others. They identify two factors—subsurface stratigraphy/geologic structure and soil shear strength—as particularly challenging to accurately characterize.

Accordingly, landslide-hazard investigations must be interdisciplinary in nature and performed by qualified, experienced geotechnical engineers and engineering geologists working as a team. Utah Geological Survey Circular 92 *Guidelines for Evaluating Landslide Hazards in Utah* (Hylland, 1996) presents minimum standards for performing landslide-hazard evaluations. Turner and Schuster (1996), and Blake and others (2002) provide additional guidance for evaluating landslide hazards. Local jurisdictions may adopt more stringent requirements for slope-stability investigations, as they deem necessary, to meet local needs and conditions. The UGS recommends that the following site-specific investigations be conducted for each of the landslide-hazard categories.

Landslide-Hazard Category	Recommended Site-Specific Study
Very High	Detailed engineering geologic and geotechnical-engineering investigation necessary. Predevelopment stabilization recommended for historical and geologically young (late Pleistocene or Holocene) landslides.
High	Detailed engineering geologic and geotechnical-engineering investigation necessary.
Moderate	Geologic evaluation and reconnaissance-level geotechnical-engineering investigation necessary; detailed engineering geologic and geotechnical-engineering investigation may be necessary.
Low	Geologic evaluation and reconnaissance-level geotechnical-engineering investigation necessary, detailed geotechnical-engineering investigation generally not necessary.

MAP LIMITATIONS

This map is based on 1:24,000-scale UGS geologic mapping, and the inventory of landslides obtained from that mapping and shown on this map reflects that level of mapping detail. Some smaller landslides may not have been detected during the mapping or are too small to show at that scale. Therefore, site-specific geotechnical and geologic-hazard investigations should be preceded by a careful field evaluation of the site to identify any landslides present. The mapped boundaries of the landslide-hazard categories are approximate and subject to change as new information becomes available. The landslide hazard at any particular site may be different than shown because of variations in the physical properties of geologic units, ground-water conditions within a map unit, gradational and approximate map-unit boundaries, and the generalized map scale. Small, localized areas of higher or lower landslide hazard may exist within any given map area, but their identification is precluded by limitations of map scale. This map is not intended for use at scales other than the published scale, and is intended for use in general planning and design to indicate the need for site-specific investigations.

HAZARD REDUCTION

As with most geologic hazards, early recognition and avoidance are the most effective ways to mitigate landslide hazards. However, avoidance may not always be a viable or cost-effective option, especially for existing developments, and engineering techniques are available to reduce potential landslide hazards. Techniques for mitigating landslide hazards include, but are not limited to, care in site grading; proper engineering, construction, and compaction of cut-and-fill slopes; careful attention to site drainage and dewatering of shallow or perched ground water; construction of retaining structures within the toe of slopes; and use of mechanical stabilization including tiebacks or other means that penetrate the landslide mass to anchor it to underlying stable material. Other techniques used to reduce landslide hazards include benching, bridging, weighting, or buttressing slopes with compacted earth fills, and installation of landslide warning systems (Keller and Blodgett, 2006). However, some geologic units, for example the Petrified Forest Member of the Chinle Formation, may be too weak to buttress, and may continue to move upslope of the buttress (Francis Ashland, UGS, written communication, 2007).

Where development is proposed in areas identified on this map as having a potential for landsliding, we recommend that a phased site-specific investigation be performed early in the project design phase. A site-specific investigation can establish whether the necessary conditions for landsliding are present at a site; if they are, appropriate design and construction recommendations should be provided.

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