U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science Directorate
Geologic Resources Division

Zion National Park

GRI Geohazards Ancillary Map Information Document

Produced to accompany the Geology Resources Inventory (GRI) Digital Geohazards Data for Zion National Park

zion_geohazards.pdf

Version: 3/8/2013

Geologic Resources Inventory Map Document for Zion National Park

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Geologic Resources Inventory Map Document

Zion National Park, Utah

Document to Accompany Digital Geologic-GIS Data

zion_geohazards.pdf

Version: 3/8/2013

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Zion National Park, Utah (ZION).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

National Park Service (NPS) Geologic Resources Inventory (GRI) Program staff have assembled the digital geologic-GIS data that accompanies this document.

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About the NPS Geologic Resources Inventory Program

Background

Recognizing the interrelationships between the physical (geology, air, and water) and biological (plants and animals) components of the Earth is vital to understanding, managing, and protecting natural resources. The Geologic Resources Inventory (GRI) helps make this connection by providing information on the role of geology and geologic resource management in parks.

Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel with information that can help them make informed management decisions.

The GRI team, working closely with the Colorado State University (CSU) Department of Geosciences and a variety of other partners, provides more than 270 parks with a geologic scoping meeting, digital geologic-GIS map data, and a park-specific geologic report.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm

Geologic Reports: Park-specific geologic reports identify geologic resource management issues as well as features and processes that are important to park ecosystems. In addition, these reports present a brief geologic history of the park and address specific properties of geologic units present in the park.

For a complete listing of Geologic Resource Inventory products and direct links to the download site visit the GRI publications webpage http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

GRI geologic-GIS data is also available online at the NPS Data Store Search Application: http://irma.nps.gov/App/Reference/Search. To find GRI data for a specific park or parks select the appropriate park

(s), enter “GRI” as a Search Text term, and then select the Search Button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: http://www.nature.nps.gov/geology/inventory, or contact:

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The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division.

GRI Digital Map and Source Map Citation

The GRI digital geologic-GIS map for Zion National Park, Utah (ZION):

Digital Geologic Hazards Map of the Zion National Park Geologic-Hazard Study Area, Utah (*GRI MapCode ZION_GEOHAZARDS*)

Utah Geological Survey (UGS) source map and data.

Lund, William R., Knudsen, Tyler R., and Sharrow, David L., 2010, Geologic Hazards of the Zion National Park Geologic-Hazard Study Area, Washington and Kane Counties, Utah, Utah Geological Survey, Special Study Map SS 133, 1:24000, 9 plates. *(GRI Source Map ID 75640)*.

Additional information pertaining to the source map is also presented in the GRI Source Map Information (ZIONMAP) table included with the GRI geology-GIS data.

GRI Source Map Information

Special Study Map SS 133

Lund, William R., Knudsen, Tyler R., and Sharrow, David L., 2010, Geologic Hazards of the Zion National Park Geologic-Hazard Study Area, Washington and Kane Counties, Utah, Utah Geological Survey, Special Study Map SS 133, 1:24000, 9 plates. *(GRI Source Map ID 75640)*.

Special Study Map SS 133 consists of 9 map plates and a report document. Ancillary information and figures from each map plate are presented in this document, as is the report (as an embedded document).

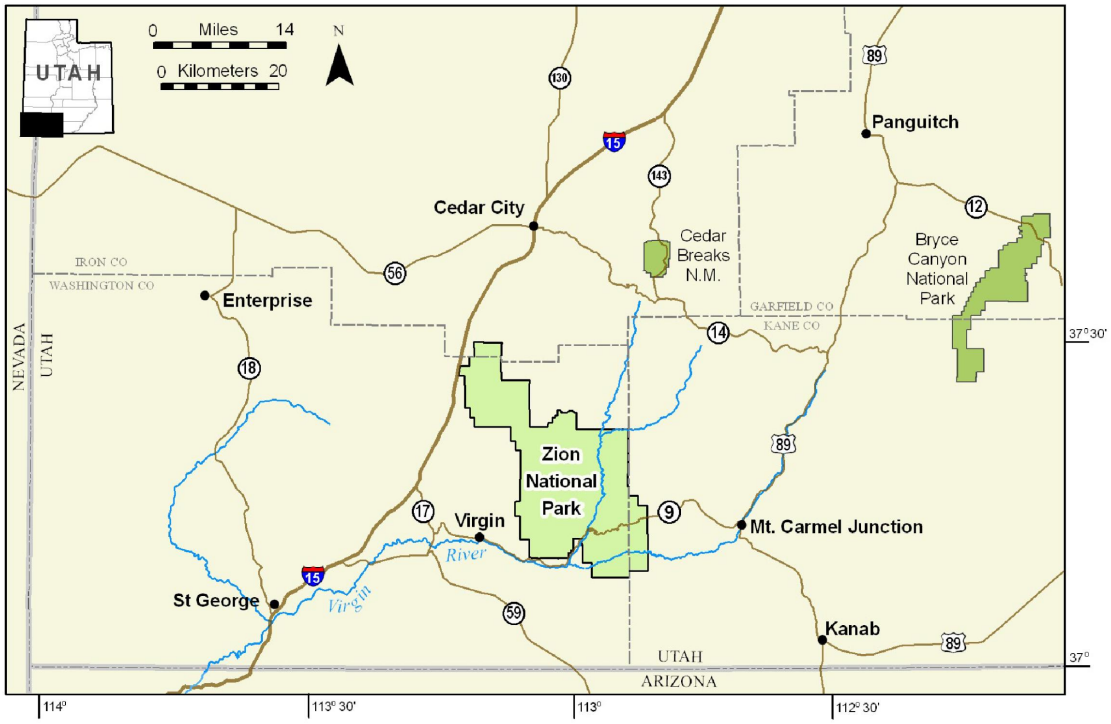
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Report

The source publication and map plates are available in printed format from the Utah Department of Natural Resources Map & Bookstore at: http://www.mapstore.utah.gov/ss133.html. The source map plates and report in PDF format are also available from the Utah Geological Survey (UGS) at: http://geology.utah.gov/maps/geohazmap/washington.htm or http://geology.utah.gov/maps/geohazmap/kane.htm.

Index Map

Map Location



Extracted from: (SS-133).

Report

The report for Utah Geological Survey (UGS) Special Study Map SS 133 is included within this document.

Report Chapters

Chapter 1 - Introduction

Chapter 2 – Flood and Debris-Flow Hazards

Chapter 3 – Rock-Fall Hazard

Chapter 4 – Landslide Hazard

Chapter 5 – Earthquake Hazards

Chapter 6 – Problem Soil and Rock Hazards

To access this document double-click Special Study Map SS 133 Report.

Plate 1 - Flood and Debris-Flow Hazards

Flood and Debris-Flow Hazard - Explanation

Hazard Category	Geologic Units[1]	Description	Hazard Type	Comments
Very High	Qal_1, Qaf, Qaf_1, Qafy, Qaly, Qath, Qat_2, Qac, Qa, Qa_1, Qa_2, Qafc	Active floodplains and low terraces along perennial streams (large drainage basins) subject to periodic riverine and flash flooding and accompanying erosion, active alluvial fans subject to flash floods and debris flows, and slot canyons containing perennial streams that are periodically inundated by flash floods and debris flows, which may occur in response to distant cloudburst storms.	Riverine flood, flash flood, debris flow	North Fork of the Virgin River, North Creek, lower Pine Creek, Deep Creek, Kolob Creek, La Verkin Creek, lower Timber Creek, Orderville Canyon Creek, Imlay Canyon Creek, Goose Creek, and active alluvial fans.
High	Qafc, Qa_1, Qac, Qay, Qaes, Qas	Stream channels, floodplains, and low terraces along normally dry ephemeral streams (smaller drainage basins) and slot canyons that are periodically inundated by flash floods and debris flows during cloudburst storms in their smaller drainage basins.	Flash flood, debris flow	Normally dry streams with comparatively small drainage basins subject to flooding during cloudburst storms.
Moderate	Qaf_2, Qla, Qc, Qca, Qat_2	Active pediments and sloping depositional surfaces flanking ridges and other upland areas that are chiefly inundated by sheetfloods, but possibly by flash floods and debris flows during cloudburst storms.	Chiefly sheetflood, possible flash flood and debris flow	Active depositional surfaces on the flanks and at the base of upland areas subject to flooding during cloudburst storms.
Low	Qaco, Qae, Qaeo, Qafo, Qea, Qafco	Valley bottoms and minor ephemeral drainages subject to possible sheetfloods and minor flash floods from adjacent upland areas during cloudburst storms.	Sheetflood, minor flash flood	Valley bottoms subject to infrequent flooding from adjacent upland areas during cloudburst storms.

Very High: Narrow, bedrock-floored canyons with perennial streams subject to very high flood hazard, but that lack mappable alluvial deposits.

High: Narrow, bedrock-floored canyons with ephemeral streams subject to high flood hazard, but that lack mappable alluvial deposits.

Geologic/map units and their descriptions can be found with the GRI digital (bedrock and surficial) geologic-GIS maps for Zion National Park, as well as with the published Utah Geological Survey 7.5' quadrangle maps.

Extracted from: (SS-133 Plate 1).

Flood and Debris-Flow Hazard - Discussion

Flooding is the overflow of water onto lands that are normally dry, and is the most universally experienced natural hazard (Keller and Blodgett, 2006). Damaging effects from flooding include inundation of land and property, erosion, deposition of sediment and debris, and the force of the water itself, which can damage property and take lives (CH2M HILL, 1997; JE Fuller Hydrology and

Geomorphology, Inc., 2005, 2007; Barjenbruch and others, 2008). Historically, flooding is the most prevalent, destructive, and deadly geologic hazard affecting Zion National Park. Several existing structures in the park, many historic, are located in flood-hazard areas because the rugged park topography leaves few alternatives. Visitors to Zion National Park frequently travel in and through flood-hazard areas.

The high flood hazard results from the complex interaction of the area's rugged topography and southwestern Utah's seasonal weather patterns. Three types of floods typically occur in the study area: (1) riverine (stream) floods, (2) flash floods/debris flows, and (3) sheetfloods. All three types of floods are associated with natural climatic fluctuations and may, under certain circumstances, occur simultaneously. Two additional types of floods may also occur within the study area - unintentional water release from water-retention structures, and flooding due to the breach of rock-fall or landslide dams - neither of which are necessarily associated with precipitation events. The risk from flooding can be significantly increased by wildfires (Neary and others, 2005), and by human activities such as placing structures and constrictions in floodplains and erosion-hazard zones, developing areas without adequate flood and erosion control, and poor watershed management practices.

For additional information about the flood hazard in the Zion National Park Geologic-Hazard Study Area, refer to the Flood and Debris-Flow Hazards chapter in the source map report.

Extracted from: (SS-133 Plate 1).

Flood and Debris-Flow Hazard - Using This Map

This map shows flood-susceptible areas based upon topography and the presence of young, water-deposited geologic units as described in the table above. The extent of drainages in the study area covered by FIRMs, and NPS-defined 100-year and 500-year floodplains in lower Zion Canyon are also shown on the map. However, those data are depicted for information purposes only; readers requiring additional information regarding flood zone boundaries should consult the original FEMA (1986) and NPS (1993) documents.

This map provides a basis for conducting site-specific flood and debris-flow hazard investigations. Site-specific investigations can resolve uncertainties inherent in generalized hazard mapping and help ensure safety by identifying the need for flood-resistant design. However, because intense cloudburst storms create a potential for flash floods, debris flows, and sheetfloods anywhere in the Zion National Park Geologic-Hazard Study Area, even locations outside identified flood-prone areas could be subject to periodic flooding. This map also shows where existing developments lie in flood-prone areas, and; therefore, where flood-resistant-design measures may be required. An evaluation of existing flood-mitigation measures and their likely effectiveness is beyond the scope of this study.

Extracted from: (SS-133 Plate 1).

Flood and Debris-Flow Hazard - Map Limitations

This map is based on limited geological, geotechnical, topographic, and hydrological data; site-specific investigations are required to produce more detailed flood-hazard information. The map also depends on the quality of those data, which varies throughout the study area. The mapped boundaries of the flood-hazard categories are approximate and subject to change as new information becomes available. The flood hazard at any particular site may be different than shown because of geological and hydrological variations within a map unit, gradational and approximate map-unit boundaries, the generalized map

scale, and topographic changes along drainages that postdate mapping. Small, localized areas of higher or lower flood hazard may exist within any given hazard area, but their identification is precluded because of limitations of map scale. The map is not intended for use at scales other than the published scale, and is designed for use in general planning to indicate general hazard areas and the need for site-specific investigations.

Extracted from: (SS-133 Plate 1).

Flood and Debris-Flow Hazard - Hazard Reduction

Early recognition and avoidance of areas subject to flooding are the most effective means of flood-hazard reduction. However, avoidance may not always be a viable or cost-effective option, especially for areas of existing development. Other techniques available to reduce potential flood damage may include, but are not limited to, source-area stabilization, engineered protective structures, flood and debris-flow warning systems, and floodproofing. Some of these techniques can be expensive and their cost-versus-benefit ratio should be carefully evaluated along with effectiveness and reliability. With regard to sheetflooding, a properly sized and integrated drainage system is usually adequate to mitigate the hazard.

We recommend a flood-hazard investigation for new construction in all hazard categories shown. The first consideration in reducing the hazard from stream flooding and debris flows is the proper identification of hazard areas through detailed mapping, and qualitative assessment of the hazard (Giraud, 2005). The stream-flooding hazard assessment should determine the active flooding area, the frequency of past events, and the potential inundation and flow depths. The debris-flow hazard assessment should determine active depositional areas, the frequency and volume of past events, and sediment burial depths (Giraud, 2005). The level of detail for a hazard assessment depends on several factors, including (1) the type, nature, and location of the proposed development, (2) the geology and physical characteristics of the drainage basin, channel, and alluvial fan, (3) the history of previous flooding and debris-flow events, and (4) proposed risk-reduction measures.

Where development is proposed in areas identified on this map as having a potential flood hazard, a site-specific investigation should be performed early in the project design phase. The investigation should clearly establish whether a flood and/or debris-flow hazard is present at a site and provide appropriate design recommendations. Additionally, Zion National Park visitors often enter areas that are prone to flooding. The risk to visitors is short-term, but constitutes a significant threat due to the number of visitors and the fact that most come to the park lacking a full appreciation of the nature of rainfall and flooding in this area. To mitigate this threat, the park has a coordinated program to inform visitors of flood hazards, with particular attention to those who engage in backcountry hiking and canyoneering. This program should continue with periodic review of its effectiveness.

The failure of a water-retention structure or breach of a natural dam represents a low-probability but high-hazard event in the Zion National Park Geologic-Hazard Study Area. Monitoring and periodic inspection of constructed dams and reservoirs help ensure their safety, and Emergency Action Plans that include a notification plan for downstream communities are required for each dam. Similarly, existing and future natural dams within or upstream of the study area should be evaluated for safety and receive periodic inspections. Natural dams from landslides or rock falls are considered to be particularly hazardous, and should be regularly monitored to determine their vulnerability to overtopping or catastrophic breaching.

Extracted from: (SS-133 Plate 1).

Flood and Debris-Flow Hazard - References

Barjenbruch, K., Mernerney, B., Watanabe, J., and Siebeneck, L., 2008, Floods, *in* Utah natural hazards handbook – understanding the hazard: Utah Division of Homeland Security, Online, <http:// publicsafety.utah.govihomelandsecurityidocuments/HazardsHandbookDraft8.pdf>, accessed November 2, 2009, p.58-67.

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Keller, E.A., and Blodgett, R.H., 2006; Natural hazards – Earth's processes as hazards, disasters, and catastrophes: Upper Saddle River, New Jersey, Pearson Prentice Hall, 395 p.

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Extracted from: (SS-133 Plate 1).

Plate 2 - Rock-Fall Hazards

Rock-Fall Hazard - Explanation

High rock-fall hazard: Areas where steep slopes below resistant cliff-forming bedrock units provide acceleration and runout zones littered with abundant rock-fall boulders ≥1.5 feet in diameter. Such large boulders can damage property and threaten lives. Rock units in high-hazard areas include the Shinarump Member of the Chinle Formation, Springdale Sandstone Member of the Kayenta Formation, Navajo Sandstone, Lamb Point Tongue Member of the Navajo Sandstone, and Quaternary basalt flows. Where jointed or fractured, these rock units can produce large (>30 feet in long dimension) angular boulders.

Moderate rock-fall hazard: Areas where (1) slopes provide sufficient relief to create an acceleration zone, but where only sparse rock-fall debris is present on slopes or in the runout zone at the base of the slope; typically bedrock units in these areas crop out in the slope instead of forming a capping unit; (2) talus/cliff-retreat deposits form steep slopes due to erosion and previous rock-fall boulders on those slopes may remobilize; or (3) resistant, cliff-forming bedrock units extend to the canyon floor with no underlying acceleration zone; rock falls in these areas tend to fall straight down and stop immediately at the base of the cliff.

Low rock-fall hazard: Areas where fine-grained, comparatively soft bedrock units such as mudstone and shale crop out on steep slopes, or where rock units typical of moderate- or high-hazard categories crop out in areas of low to moderate relief. Low rock-fall hazard areas typically contain sparse rock sources of limited extent.

Low probability, high hazard: Canyon bottoms subject to very large low-probability, high-hazard rock falls. These areas are typically bordered by towering, jointed Navajo Sandstone cliffs. The largest of these events (fin collapse/rock avalanche) may involve thousands of cubic yards of material, are typically sourced high on canyon walls, and have recurrence intervals likely measured in thousands of years. Runout zones can extend much farther than for the smaller, more frequent rock-fall events.

Extracted from: (SS-133 Plate 2).

Rock-Fall Hazard - Discussion

Rock fall is a natural mass-wasting process that involves the dislodging and downslope movement of individual rocks and small rock masses (Varnes, 1978; Cruden and Varnes, 1996). Rock falls pose a safety threat because a falling or rolling boulder can cause significant damage to property. roadways, and vehicles as well as injury or even loss of life (see, for example, Hylland, 1995; Keller and Blodgett, 2006; Elliot and Giraud, 2009; Lund and others, 2009). Rock-fall hazards exist where a source of rock is present above slopes steep enough to allow rapid downslope movement of dislodged rocks by falling, rolling, and bouncing.

Rock-fall hazard is based on a number of factors including geology, topography, and climate. Rock-fall sources include bedrock outcrops or boulders on steep mountainsides or near the edges of escarpments such as cliffs, bluffs, and terraces. Talus cones and scree-covered slopes are indicators of a high rock-fall hazard, but other less obvious areas may also be vulnerable.

Rock falls are initiated by freeze/thaw action, rainfall, weathering and erosion of the rock and/or surrounding material, and root growth. Rock fall is also the most common type of mass movement caused by earthquakes. Keefer (1984) indicates that earthquakes as small as magnitude (M) 4.0 can trigger rock falls. All nine of Utah's historical earthquakes of M 5 or greater have caused rock falls. Sources of earthquake ground shaking that might produce rock falls in the Zion National Park Geologic-Hazard Study Area include a large earthquake on the Hurricane fault west of the study area. or a moderate earthquake (≤ M 6.5) within the study area itself (Ivan Wong, URS Corporation, written communication, 2008).

Slope modification, such as cuts for roads and building pads or clearing of slope vegetation for development, can increase or create a local rock-fall hazard. However, in many cases a specific triggering event is not apparent. Although not well documented, rock falls in Utah appear to occur more frequently during spring and summer months. This is likely due to spring snowmelt, summer cloudburst storms, and large daily temperature variations (Castleton, 2009).

Rock fall is the most common mass-movement type in the Zion National Park Geologic-Hazard Study Area. The combination of steep slopes capped by well-jointed, resistant bedrock formations provides ample opportunity to generate rock falls. Bedrock units particularly susceptible to rock fall in the study area include the Shinarump Member of the Chinle Formation; Springdale Member of the Kayenta Formation; Lamb Point Tongue Member of the Navajo Sandstone; other ledge- and cliff-forming strata in the Moenkopi, Moenave, and Kayenta Formations; and the massive, pervasively jointed, cliff-forming Navajo Sandstone. Rock falls are particularly prevalent and hazardous where softer, more easily eroded bedrock units crop out on slopes below stronger, more resistant bedrock formations. Erosion of the underlying soft units and subsequent undercutting of the more resistant bedrock formations triggers many rock falls.

Talus deposits blanket steep to moderate slopes throughout the study area. These deposits are derived from upslope ledges and cliffs and consist chiefly of accumulations of poorly sorted, coarse, angular blocks of various sizes. The boulders in talus deposits may exceed 30 feet in long dimension (Biek and others, 2003). The widespread distribution of talus and the direct relation of talus deposits to the rock-fall process attest to the widespread extent of the rock-fall hazard in the study area.

For additional information about the rock-fall hazard in the Zion National Park Geologic-Hazard Study Area, refer to the Rock-Fall Hazard chapter in the source map report.

Extracted from: (SS-133 Plate 2).

Rock-Fall Hazard - Using This Map

This map shows areas of relative rock-fall hazard in the Zion National Park Geologic-Hazard Study Area. Site-specific, rock-fall-hazard investigations should be performed for future development in the study area as recommended in the table below. Existing park facilities, campgrounds, and high-use trails should be evaluated as time and funding allow, also as recommended in the table below. A geotechnical consultant should provide design or site-preparation recommendations as necessary to reduce the rock-fall hazard. These investigations can resolve uncertainties inherent in generalized hazard mapping and help ensure safety by identifying the need for rock-fall-resistant design or mitigation.

For some areas, site-specific assessment may only require a field geologic evaluation to determine if a rock-fall source is present. However, if a source is identified, additional work to adequately assess the hazard is needed. Rock-fall sources should be evaluated for the following parameters: rock type, joints and other fractures, bedding planes, and potential clast size. Slopes below rock sources should be evaluated for slope angle, aspect, substrate, surface roughness, and vegetation. Previous rock-fall deposits should be evaluated for distribution, clast-size range, amount of embedding, and weathering of rock-fall boulders. In addition, evaluation of the runout zone below a source can be estimated using a simple two-dimensional model, such as the Colorado Rock Fall Simulation Program (Jones and others, 2000).

The hazard presented by large rock falls in areas designated "low probability, high hazard" is high, but the likelihood of such an event at any particular location is low. These areas are considered subject only to very infrequent events. Site-specific investigations are not recommended for future development in these areas.

Recommended Requirements for Site-Specific Investigations Related to Rock-Fall Hazards to Protect Life and Safety

Hazard Potential	Occupancy Category[1]				
	I	II		III	IV
	Buildings and Other Structures That Represent a Low Hazard to Human Life in the Event of Failure	Family Dwellings and Campgrounds	All Other Buildings and Structures Except Those Listed in Groups I, III, and IV	Buildings and Other Structures That Represent a Substantial Hazard to Human Life in the Event of Failure	Buildings and Other Structures Designated as Essential Facilities
High, Moderate	No[2]	Yes	Yes	Yes	Yes
Low	No[2]	Yes	Yes	Yes	Yes
None	No	No	No	No	No

[1]Modified from International Code Council (2009). [2]Property damage possible, but little threat to life safety.

Extracted from: (SS-133 Plate 2).

Rock-Fall Hazard - Map Limitations

The map boundaries between rock-fall-hazard categories are approximate and subject to change as new information becomes available. The rock-fall hazard at any particular site may be different than shown because of geological variations within a map unit, gradational and approximate map-unit boundaries, and map scale. Small, localized areas of higher or lower rock-fall hazard may exist within any given map area, but their identification is precluded because of limitations of the map scale. This map is not intended for use at scales larger than the published scale, and is designed for use in general planning and design to indicate the need for site-specific investigations.

Extracted from: (SS-133 Plate 2).

Rock-Fall Hazard - Hazard Reduction

Early recognition and avoiding areas subject to rock fall are the most effective means of reducing rock-fall hazard. However, avoidance may not always be a viable or cost-effective option, especially for existing facilities, and other techniques are available to reduce potential rock-fall damage. These may include, but are not limited to, rock stabilization, engineered structures, and modification of at-risk structures or facilities. Rock-stabilization methods are physical means of reducing the hazard at its source using rock bolts and anchors, steel mesh, or shotcrete on susceptible outcrops. Engineered catchment or deflection structures such as berms or benches can be placed below source areas, or at-risk structures themselves could be designed to stop, deflect, retard, or retain falling rocks. Conversely, after careful consideration of the hazard, it may be possible to conclude that the level of risk is acceptable and that no hazard-reduction measures are required.

Extracted from: (SS-133 Plate 2).

Rock-Fall Hazard - References

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Extracted from: (SS-133 Plate 2).

Plate 3 - Landslide Hazard

Landslide Hazard - 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°).

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.; Shnabkaib 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.

Geologic/map units and their descriptions can be found with the GRI digital (bedrock and surficial) geologic-GIS maps for Zion National Park, as well as with the published Utah Geological Survey 7.5' quadrangle maps.

Extracted from: (SS-133 Plate 3).

Landslide Hazard - 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 the source map report.

Extracted from: (SS-133 Plate 3).

Landslide Hazard - 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.

Extracted from: (SS-133 Plate 3).

Landslide Hazard - 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.

Extracted from: (SS-133 Plate 3).

Landslide Hazard - 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.

Extracted from: (SS-133 Plate 3).

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Extracted from: (SS-133 Plate 3).

Plate 4 - Surface-Fault-Rupture Hazards

Surface-Fault-Rupture Hazard - Explanation

Well-defined Holocene-active (movement within the past 10,000 years [11,500 cal yr B.P.]) or suspected Holocene-active fault: surface-fault-rupture-hazard investigation recommended for all IBC Occupancy Category II, III, and IV buildings and other structures (International Code Council, 2009a).

Buried or approximately located Holocene-active or suspected Holocene-active fault: surface-fault-rupture-hazard investigation recommended for all IBC Occupancy Category II, III, and IV buildings and other structures (International Code Council, 2009a).

Well-defined fault with unknown activity level: paleoseismic data are lacking, recommend treating as a Holocene-active fault until proven otherwise.

Buried or approximately located fault with unknown activity level: paleoseismic data are lacking, recommend treating as a Holocene-active fault until proven otherwise.

Well-defined suspected late-Quaternary- or Quaternary-active fault: normal fault related to the current regional extensional tectonic regime overlain by an unfaulted mid- or late-Quaternary basalt flow ≥ 100,000 years old; the most recent surface-faulting earthquake is older than the age of the overlying basalt, but how much older is unknown. Surface-fault-rupture-hazard investigation recommended for IBC Occupancy Category III and IV buildings and other structures (International Code Council, 2009a). Studies for other structures designed for human occupancy remain prudent for faults demonstrated to be late-Quaternary active (movement within the past 130,000 years), but should be based on an assessment of whether risk-reduction measures are justified by weighing the probability of occurrence against the risk to lives and potential economic loss. Studies for other structures intended for human occupancy for faults demonstrated to be Quaternary active (movement within the past 1,800,000 years) are optional because of the low likelihood of surface faulting, although surface rupture along the fault is still possible.

Buried or approximately located suspected late-Quaternary- or Quaternary-active fault: normal fault related to the current regional extensional tectonic regime overlain by an unfaulted mid- or late-Quaternary basalt flow ≥ 100,000 years old; the most recent surface-faulting earthquake is older than the age of the overlying basalt, but how much older is unknown. Surface-fault-rupture-hazard investigation recommended for IBC Occupancy Category III and IV buildings and other structures (International Code Council, 2009a). Studies for other structures designed for human occupancy remain prudent for faults demonstrated to be late-Quaternary active (movement within the past 130,000 years), but should be based on an assessment of whether risk-reduction measures are justified by weighing the probability of occurrence against the risk to lives and potential economic loss. Studies for other structures intended for human occupancy for faults demonstrated to be Quaternary active (movement within the past 1,800,000 years) are optional because of the low likelihood of surface faulting, although surface rupture along the fault is still possible.

Surface-fault-rupture-hazard special-study area. The special-study areas established for well-defined faults extend for 500 feet on the downthrown side and 250 feet on the upthrown side of each fault. We classified normal faults as well defined if UGS 1:24,000-scale mapping shows them as solid lines, indicating that they are recognizable as faults at the ground surface. Because their location is uncertain, the surface-fault-rupture-hazard special-study areas around buried or approximately located faults are broader, extending 1000 feet on each side of the suspected trace of the faults.

Extracted from: (SS-133 Plate 4).

Surface-Fault-Rupture Hazard - Discussion

Earthquakes occur without warning and can cause injury and death, major economic loss, and social disruption (Utah Seismic Safety Commission, 1995). An earthquake is the abrupt, rapid shaking of the ground caused by sudden slippage of rocks deep beneath the Earth's surface. The rocks break and slip when the accumulated stress exceeds the rock's strength. The surface along which the rocks slip is called a fault. Large earthquakes (>M 6.5) are commonly accompanied by surface faulting. The rupture

may affect a zone tens to hundreds of feet wide and tens of miles long. Surface faulting on normal faults produces ground cracking and typically one or more "fault scarps." When originally formed, fault scarps have near-vertical slopes and, depending on the size of the earthquake, can range from a few inches to many feet high. Local ground tilting and graben formation by secondary (antithetic) faulting may accompany surface faulting, resulting in a zone of deformation along the fault trace tens to hundreds of feet wide. Surface faulting, while of limited aerial extent when compared to other earthquake-related hazards such as ground shaking and liquefaction, can have serious consequences for structures or other facilities that lie along or cross the fault rupture path (Bonilla, 1970). Buildings, bridges, dams, tunnels, canals, and pipelines have all been severely damaged by surface faulting (see, for example, Lawson, 1908; Ambraseys, 1960, 1963; Duke, 1960; California Department of Water Resources, 1967; Christenson and Bryant, 1998; USGS, 2000).

The hazard due to surface faulting is directly related to the activity of the fault—that is, how often the fault ruptures the ground surface and how likely it is to rupture in the future (Christenson and Bryant, 1998). Because designing a structure to withstand surface faulting is generally considered impractical from an economic, engineering, and architectural standpoint for most structures (Christenson and others, 2003; Bryant and Hart, 2007), avoiding active fault traces is the recommended approach for mitigating surface-faulting hazards. Effectively avoiding surface faulting requires conducting a site-specific investigation to (1) identify all potentially active faults at a site, (2) assess the level of activity of the faults, and (3) establish appropriate setback distances from the fault(s).

Extracted from: (SS-133 Plate 4).

Surface-Fault-Rupture Hazard - Activity Classes

In California, the Alquist-Priolo Earthquake Fault Zoning Act (Bryant and Hart, 2007), which regulates development along known active faults, defines an "active" fault as one that has had "surface displacement within Holocene time (about the past 11,000 years)." Because California has a well-recognized earthquake hazard and was the first state to implement regulations designed to mitigate those hazards, the California "Holocene" standard has found its way into many regulations in other parts of the country, even in areas where the Holocene is not the best time frame against which to measure surface-faulting recurrence. dePolo and Slemmons (1998) argued that in the Basin and Range Province, a time period longer than the Holocene is more appropriate for defining active faults, because most faults there have surface-faulting recurrence intervals (average repeat times) that approach or exceed 10,000 years. They advocate a late Pleistocene age criterion, specifically 130,000 years, to define active faults in the Basin and Range Province. They base their recommendation on the observation that six to eight (>50%) of the 11 historical surface-faulting earthquakes in that region were on faults that lacked evidence of Holocene activity but had evidence of late Pleistocene activity.

Because of the difficulties in using a single "active" fault definition, the Western States Seismic Policy Council (WSSPC) has defined the following fault activity classes (WSSPC Policy Recommendation 08-2, 2008; first adopted in 1997 as WSSPC Policy Recommendation 97-1, and revised and readopted in 2002, 2005, and 2008 [WSSPC, 2008]):

Holocene fault – a fault that has moved within the past 10,000 years (11,500 cal yr B.P.) and has been large enough to break the ground surface.

Late Quaternary fault – a fault that has moved within the past 130,000 years and has been large enough to break the ground surface.

Quaternary fault – a fault that has moved within the past 1,800,000 years and has been large enough to break the ground surface.

Christenson and Bryant (1998) and Christenson and others (2003) recommended adopting the WSSPC fault activity-class definitions in Utah, and we follow that recommendation in this study.

For additional information about surface faulting and other earthquake-related hazards in the Zion National Park Geologic-Hazard Study Area, refer to the Earthquake Hazards chapter in this report.

Extracted from: (SS-133 Plate 4).

Surface-Fault-Rupture Hazard - Using This Map

This map shows potentially active faults along which surface faulting may occur. A special-study area is shown around each fault, within which we recommend that a site-specific, surface-fault-rupture-hazard investigation be performed prior to construction. These investigations can resolve uncertainties inherent in generalized hazard mapping and help ensure safety by identifying the need for setbacks from the fault.

The UGS Gui*delines for Evaluating Surface-Fault-Rupture Hazards in Utah* (Christenson and others, 2003) include a detailed rationale for performing surface-fault-rupture-hazard investigations, minimum technical requirements for conducting and reporting those studies, recommendations regarding when surface-fault-rupture-hazard investigations should be conducted based on fault activity class and the type of facility proposed, and procedures for establishing safe setback distances from active faults. Zion National Park staff and others should refer to the UGS guidelines regarding the details of conducting and reviewing surface-fault-rupture-hazard investigations.

For well-defined faults color-coded red and black (Holocene and Suspected Quaternary, respectively), we recommend that surface-fault-rupture-hazard investigations be performed in accordance with the UGS guidelines. Because paleoseismic data are lacking for the orange-coded faults (fault activity class unknown), we recommend that those faults be considered Holocene active until paleoseismic studies demonstrate otherwise.

Because approximately located and buried faults lack a clearly identifiable surface trace, they are not amenable to trenching, which is the standard surface-fault-rupture-hazard investigation technique used to study well-defined faults (McCalpin, 2009). Where development is proposed in a special-study area for a buried or approximately located fault, we recommend that, at a minimum, the following tasks be performed to better define the surface-fault-rupture hazard in those areas:

1. Review of published and unpublished maps, literature, and records concerning geologic units, faults, surface and ground water, previous subsurface investigations, previous geotechnical and geophysical investigations, and other relevant factors.

2. Stereoscopic interpretation of aerial photographs to detect any subtle fault-related features expressed in the site topography, vegetation or soil contrasts, and any lineaments of possible fault origin.

3. Field evaluation of the proposed site and surrounding area to observe pertinent surface evidence for faulting, including mapping of geologic units as necessary to define critical geologic relations; evaluation of geomorphic features such as springs or seeps (aligned or not), sand blows or lateral spreads, or other evidence of earthquake-induced features; and excavation of test pits to evaluate the age of the deposits onsite to constrain the time of most recent surface faulting.

If the results of these investigations reveal evidence of possible surface-faulting-related features, those

features should be trenched in accordance with the UGS guidelines for evaluating surface-fault-rupture hazards in Utah (Christenson and others, 2003). Following the above-recommended studies, if no evidence of surface faulting is found, development at the site can proceed as planned. However, we recommend that construction excavations and cut slopes be carefully examined for evidence of faulting as development proceeds.

Extracted from: (SS-133 Plate 4).

Surface-Fault-Rupture Hazard - Map Limitations

This map is based on 1:24,000-scale geologic mapping, and the inventory of potentially active faults obtained from that mapping and shown on this map reflects that level of detail. Some smaller faults may not have been detected during the mapping or faults may be concealed beneath young geologic deposits. Additionally, approximately located and buried faults by definition lack a clearly identifiable surface trace, and therefore their location is less well known. Site-specific fault-trenching investigations should be preceded by a careful field evaluation of the site to identify the surface trace of the fault, other faults not evident at 1:24,000-scale, or other fault-related features at a site-specific scale.

Extracted from: (SS-133 Plate 4).

Surface-Fault-Rupture Hazard - Hazard Reduction

Because surface faulting is typically confined to relatively narrow zones along the surface trace of a fault, early recognition and avoidance are the most effective strategies for mitigating this hazard. Once the activity class of the fault is determined (see Activity Classes section above), we recommend that setbacks from the fault trace and any associated zone of deformation be established in accordance with UGS guidelines for evaluating surface-fault-rupture hazards in Utah (Christenson and others, 2003). Carefully locating all potentially active fault traces at a site, assessing their level of activity and amount of displacement, establishing an appropriate setback distance from the fault, and proper facility and site design remain the most reliable procedures for mitigating damage and injury due to surface faulting. Considering the proximity of the Kolob Entrance Station and associated buildings to the surface trace of the Hurricane fault, we recommend that a reconnaissance surface-fault-rupture-hazard investigation be conducted for those facilities. If the reconnaissance shows that a surface-rupture hazard may exist, we recommend a follow-up trenching investigation to fully assess the hazard.

In Utah, earthquake-resistant design requirements for construction are specified in the seismic provisions of the IBC (International Code Council, 2009a) and IRC (International Code Council, 2009b), which are adopted statewide. IBC Section 1803.5.11 requires that an investigation be conducted for all structures in Seismic Design Categories C, D, E, or F (see the Earthquake Ground-Shaking Hazard section in chapter 5) to evaluate the potential for surface rupture due to faulting.

Extracted from: (SS-133 Plate 4).

Surface-Fault-Rupture Hazard - References

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Extracted from: (SS-133 Plate 4).

Plate 5 - Liquefaction Susceptibility

Liquefaction Susceptibility - Explanation

Liquefaction-Susceptibility Zone – Areas where potentially liquefiable unconsolidated geologic units may also be saturated. Determining if a liquefaction hazard exists at a particular location requires acquiring site-specific information about soil texture and density, ground-water conditions, and the frequency and intensity of anticipated ground shaking.

Unconsolidated Geologic Deposits[1] that may be Susceptible to Liquefaction if Saturated

Stream and Terrace Alluvium	Alluvial Deposits	Eolian Deposits	Colluvial Deposits	Lacustrine Deposits
Qaly, Qath, Qat_2	Qaso, Qae, Qa, Qa_1, Qa_2, Qac, Qay, Qaec, Qaf, Qaf_1, Qaf_2, Qafy, Qafc, Qage, Qao, Qaeo	Qes, Qea, Qre, Qer, Qed	Qc, Qce, Qces	Qla, Qlbc, Qls

Geologic/map units and their descriptions can be found with the GRI digital (bedrock and surficial) geologic-GIS maps for Zion National Park, as well as with the published Utah Geological Survey 7.5' quadrangle maps.

Extracted from: (SS-133 Plate 5).

Liquefaction Susceptibility - Discussion

Liquefaction and liquefaction-induced ground failure are major causes of earthquake damage (Keller and Blodgett, 2006). During liquefaction, a soil loses its strength and ability to support the weight of overlying structures or sediment. Soil liquefaction is caused by strong earthquake ground shaking where saturated, cohesionless, granular soil is transformed from a solid to a nearly liquid state. Soil liquefaction generally occurs in sand, silty sand, and sandy silt soils (Youd and Idriss, 1997). All of the following conditions are required for liquefaction to occur:

- The soils must be submerged below the water table.
- The soils must be loose/soft to moderately dense/stiff.
- The ground shaking must be intense.
- The duration of ground shaking must be sufficient for the soils to lose their shearing resistance.

Plastic or clay-rich soils having either a clay content greater than 15 percent, a liquid limit greater than 35 percent, or a moisture content less than 90 percent of the liquid limit are generally immune to liquefaction (Seed and Idriss, 1982; Youd and Gilstrap, 1999).

Four types of ground failure commonly result from liquefaction: (1) loss of bearing capacity, (2) ground oscillation and subsidence, (3) lateral spreading, and (4) flow failure (Youd, 1978, 1984; Tinsley and others, 1985). The expected mode of ground failure at a given site largely depends upon the ground-surface slope. Where slope inclination is less than 0.5 percent, liquefaction may cause damage in one of two ways. The first is the loss of bearing capacity and resulting deformation of soil beneath a structure, which causes the structure to settle or tilt. Differential settlement is commonly accompanied by cracking of foundations and damage to structures. Buoyant buried structures, such as underground storage or septic tanks, may also float upward under these conditions. The second results from

liquefaction at depth below soil layers that do not liquefy. Under these conditions, blocks of the surficial, non-liquefied soil detach and oscillate back and forth on the liquefied layer. Damage to structures is caused by subsidence of the blocks, opening and closing of fissures between and within the blocks, and formation of sand blows as liquefied sand is ejected through the fissures from the underlying pressurized liquefied layer.

Lateral spreading may occur where the ground surface slopes from 0.5 to 5 percent, particularly near a "free face" such as a stream bank or cut slope. Lateral spreads are characterized by surficial soil blocks that are displaced laterally downslope as a result of liquefaction in a subsurface layer. Lateral spreading can cause significant damage to structures and may be particularly destructive to pipelines, utilities, bridges, roadways, and structures with shallow foundations.

Flow failures may occur where the ground surface slopes more than about 5 percent. Flow failures are composed chiefly of liquefied soil or blocks of intact material riding on a liquefied layer. Flow failures can cause soil masses to be displaced several miles and are the most catastrophic mode of liquefaction-induced ground failure.

For additional information about the liquefaction hazard in the Zion National Park Geologic-Hazard Study Area, refer to the Earthquake Hazards chapter in the source map report.

Extracted from: (SS-133 Plate 5).

Liquefaction Susceptibility - Using This Map

This map shows areas where liquefaction may be possible in the Zion National Park Geologic-Hazard Study Area. The map is based on limited information about the textural characteristics of unconsolidated geologic units and the distribution and depth of ground water in the study area. The map does not integrate earthquake ground motions with material characteristics and depth to ground water, which is required to determine relative liquefaction potential in susceptible deposits. Consequently, the map does not differentiate ground-failure types or amounts, which are needed to fully assess the hazard and evaluate possible mitigation techniques.

This map is intended for general planning and design purposes to indicate where liquefaction hazards may exist and to assist in liquefaction-hazard investigations. In Utah, soil-test requirements are specified in chapter 18 (Soils and Foundations) of the IBC (International Code Council, 2009a) and chapter 4 (Foundations) of the IRC (International Code Council, 2009b), which are adopted statewide. IBC Section 1803.2 requires a geotechnical investigation be performed in accordance with IBC sections 1803.3 through 1803.5. Section 1803.3 requires an investigation to evaluate liquefaction, and Section 1803.5.11 requires a liquefaction evaluation for structures in Seismic Design Categories C through F (see Earthquake-Ground-Shaking Hazard section in chapter 5 of accompanying text). In general, seismic design categories in the Zion National Park Geologic-Hazard Study Area for structures built on unconsolidated materials fall into Seismic Design Categories C and D (see chapter 5, table 5.4), thus triggering the IBC requirement for a liquefaction investigation. Although the IRC does not specifically mention liquefaction, IRC Section R401.4 states that the local building official determines whether to require soil tests in areas likely to have expansive, compressive, shifting, or other unknown soil characteristics, such as liquefiable soils.

International Building Code seismic design categories are determined on a site-specific basis, and vary throughout the study area depending on IBC site class, maximum considered earthquake ground motions, and the IBC occupancy category of the proposed structure (see Earthquake Ground-Shaking Hazard section in chapter 5 of accompanying text). Because the risk to human life and the requirement that certain essential structures remain functional during natural or other disasters varies by occupancy

category, we recommend the following levels of liquefaction-hazard investigation for the different IBC occupancy categories (see table below) in areas identified on this map as potentially liquefiable. Detailed (quantitative) subsurface investigations should be performed for Occupancy Category II, III, and IV structures, and reconnaissance (screening) investigations for Occupancy Category I structures. Additionally, a reconnaissance investigation should be performed for Occupancy Category II, III, and IV structures in areas mapped as not susceptible to liquefaction followed by a detailed investigation if a liquefaction hazard is determined to be present. Investigations are not recommended for Occupancy Category I structures in nonsusceptible areas. Martin and Lew (1999) provide guidelines for conducting both reconnaissance and detailed liquefaction investigations.

Recommended Requirements for Liquefaction-Hazard Investigations

Liquefaction Hazard	IBC Occupancy Category			
	I	II	III	IV
	Buildings and Other Structures that Represent a Low Hazard to Human Life in the Event of Failure (IBC)	All Other Buildings and Structures Except Those Listed in Categories I, III, and IV (Includes One- and Two-Family Dwellings and Townhouses) (IRC) (IBC)	Buildings and Other Structures that Represent a Substantial Hazard to Human Life in the Event of Failure (IBC)	Buildings and Other Structures Designated as Essential Facilities (IBC)
Susceptible	Reconnaissance	Detailed[1]	Detailed[1]	Detailed[1]
Not Susceptible	None	Reconnaissance[2]	Reconnaissance[2]	Reconnaissance[2]

[1]Detailed evaluation necessary; a detailed liquefaction investigation should be interdisciplinary in nature and performed by qualified experienced geotechnical engineers and engineering geologists working as a team. [2]A reconnaissance investigation should be followed by a detailed investigation if a liquefaction hazard is determined to be present.

Extracted from: (SS-133 Plate 5).

Liquefaction Susceptibility - Map Limitations

This map is based on limited geological, geotechnical, and hydrological data; a site-specific investigation is required to produce more detailed information. The map also depends on the quality of those data, which varies throughout the study area. The mapped boundaries of the Liquefaction-Susceptibility Zone are approximate and subject to change as new information becomes available. Liquefaction susceptibility at any particular site may be different than shown because of geologic and hydrologic variations within a map unit, gradational and approximate map-unit boundaries, and the map scale. Small, localized areas of liquefaction susceptibility may exist anywhere within the study area, but their identification is precluded because of limitations of either data or map scale. Seasonal and long-term fluctuations in ground-water levels can affect liquefaction hazard at a site. The map is not intended for use at scales other than the published scale, and is designed for use in general planning and design to indicate the need for site-specific studies.

Extracted from: (SS-133 Plate 5).

Liquefaction Susceptibility - Hazard Reduction

Although potentially costly when not recognized and properly accommodated in project design, problems associated with liquefaction rarely are life threatening. As with most geologic hazards, early recognition and avoidance are the most effective ways to mitigate this hazard. However, avoidance may not always be a viable or cost-effective option and other techniques are available to reduce liquefaction hazards (National Research Council, 1985).

Liquefaction damage may be reduced either by using ground improvement methods to lower the

liquefaction hazard (for example, compacting or replacing soil; installing drains or pumps to dissipate or lower the water table) or by designing structures to withstand liquefaction effects (using deep foundations or structural reinforcement). Existing structures threatened by liquefaction may be retrofitted to reduce the potential for damage. Because the cost of reducing liquefaction hazards for existing structures may be high relative to their value, and because liquefaction is generally not a life-threatening hazard, we consider it prudent, although not essential, to reduce liquefaction hazards for existing structures, unless significant ground deformation (lateral spreading) is anticipated and the structures fall into IBC Occupancy Categories III or IV, in which case retrofitting is recommended.

Extracted from: (SS-133 Plate 5).

Liquefaction Susceptibility - References

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Extracted from: (SS-133 Plate 5).

Plate 6 - Collapsible-Soil Susceptibility

Collapsible Soil Susceptibility - Explanation

CS_A Unconsolidated geologic units with reported collapse values of ≥3 percent.

CS_B Geologically young (Holocene) unconsolidated geologic units with no available geotechnical data, but whose genesis or texture is permissive of collapse (chiefly geologically young alluvial, colluvial, and eolian deposits).

CS_C Older unconsolidated geologic units (Pleistocene) with no available geotechnical data, but like category CS_B have a genesis or texture permissive of collapse. Because of their age, these deposits have had greater exposure to natural wetting and collapse may have occurred, and/or the deposits may be cemented by secondary calcium carbonate or other soluble minerals.

Geologic Deposits Known or Likely to Have a Significant Potential for Soil Collapse

Type of Deposit	Map Units[1]	Collapsible Soil Category
Stream and Terrace Alluvium	Qa_1, Qal_1, Qat_2, Qat_3, Qath	CS_A
	Qa, Qaly, Qay, Qa_2, Qat_4, Qat_5, Qat_6, Qas, Qaso	CS_B
	Qato, Qav	CS_C
Fan Alluvium	Qafc, Qafco, Qmsc (alluvial parts)	CS_A
	Qae, Qac, Qaes, Qaeo, Qaf, Qaf_1, Qaf_2, Qafy, Qao, Qafo, Qage, $Qmcp_1$, $Qmcp_2$	CS_B
	Qaco, Qaec, Qap_2, $Qmcp_3$	CS_C
Eolian Deposits	Qea, Qer, Qes, Qed, Qre	CS_B
Colluvial Deposits	Qc, Qmt, Qmts, Qce, Qces	CS_B
	Qco	CS_C
Lacustrine Deposits	Qla, Qls	CS_B
	Qlbc	CS_C

Geologic/map units and their descriptions can be found with the GRI digital (bedrock and surficial) geologic-GIS maps for Zion National Park, as well as with the published Utah Geological Survey 7.5' quadrangle maps.

Extracted from: (SS-133 Plate 6).

Collapsible Soil Susceptibility - Discussion

Collapsible (hydrocompactible) soils have considerable dry strength and stiffness in their dry natural state, but can settle up to 10 percent of the susceptible deposit thickness when they become wet for the first time following deposition (Costa and Baker, 1981; Rollins and Rogers, 1994) causing damage to property and structures. Collapsible soils are common throughout the arid southwestern United States and are typically geologically young materials, chiefly debris-flow deposits in Holocene-age alluvial fans, and some wind-blown, lacustrine, and colluvial deposits (Owens and Rollins, 1990; Mulvey, 1992; Santi, 2005).

Collapsible soils typically have a high void ratio and corresponding low unit weight (<80 to 90 lb/ft ; Costa and Baker, 1981; Walter Jones, consulting engineer, written communication, 2007) and a relatively low moisture content (<15%; Owens and Rollins, 1990), all characteristics that result from the initial rapid deposition and drying of the sediments. Intergranular bonds form between the larger grains (sand and gravel) of a collapsible soil; these bonds develop through capillary tension or a binding agent such as silt, clay, or salt. Later wetting of the soil results in a loss of capillary tension or the softening, weakening, or dissolving of the bonding agent, allowing the larger particles to slip past one another into a denser structure (Williams and Rollins, 1991).

In general, collapsible alluvial-fan and colluvial soils are associated with drainage basins that are dominated by soft, clay-rich sedimentary rocks such as shale, mudstone, claystone, and siltstone (Bull, 1964; Owens and Rollins, 1990). Bull (1964) found that the maximum collapse of alluvial-fan soils in Fresno County, California, coincided with a clay content of approximately 12 percent. Alluvial-fan deposits exhibiting dramatic collapse behavior in Nephi, Utah, typically contained 10 to 15 percent clay-size material (Rollins and Rogers, 1994). At clay contents greater than about 12 to 15 percent, the expansive nature of the clay begins to dominate and the soil is subject to swell rather than collapse. Characteristically, collapsible soils consist chiefly of silty sands, sandy silts, and clayey sands (Williams and Rollins, 1991), although Rollins and others (1994) identified collapse-prone gravels containing as little as 5 to 20 percent fines at several locations in the southwestern United States.

Soil composition is the primary indicator of collapse potential in alluvial-fan and colluvial soils. However, along the southern Wasatch Front, Owens and Rollins (1990) found that the degree of collapse generally increased with an increase in the ratio of fan area to drainage-basin area. In other words, alluvial fans (especially large alluvial fans) associated with small drainage basins had a greater likelihood of producing collapse-prone soils. Bull (1964) found a similar relation between fan and drainage-basin size in Fresno County.

Loess—deposits of wind-blown clay, silt, and fine sand—typically has an extremely loose, open structure that is maintained by water-soluble mineral cements or high-plasticity clay that act as a binder between larger grains (Gibbs and Holland, 1960; Costa and Baker, 1981). Like collapse-prone alluvial-fan soils, undisturbed loess typically has a high void ratio, a correspondingly low in-place density, and is relatively dry. When wetted, loess will collapse; the extent of the collapse largely depends on the texture (grain-size distribution) of the deposit. Gibbs and Holland (1960) found that clay-rich loess deposits tend to collapse less than those containing a higher percentage of silt and fine sand.

Naturally occurring deep percolation of water into collapsible deposits is uncommon after deposition due to the arid conditions in which the deposits typically form, and the steep gradient of many alluvial-fan and colluvial surfaces. Therefore, soil collapse is usually triggered by human activity such as irrigation, urbanization, and/or wastewater disposal. Kaliser (1978) reported serious damage (estimated $3 million) to public and private structures in Cedar City, Utah, from collapsible soils. Rollins and others (1994) documented more than $20 million in required remedial measures to a cement plant near Leamington, Utah, and Smith and Deal (1988) reported damage to a large flood-control structure near Monroe, Utah. In 2001, collapsible soils damaged the Zion National Park greenhouse soon after it was constructed, as soils below and around the building were wetted by excess irrigation water. Park employees later reported that a wastewater treatment plant that had once been located nearby had also had a history of damage from ground subsidence. Damage due to collapse of wind-blown deposits is not as well documented in Utah as damage associated with collapsible alluvial and colluvial deposits; this may be due in part to the relatively lesser abundance of loess deposits in the state.

For additional information about collapsible soil in the Zion National Park Geologic-Hazard Study Area, refer to the Problem Soil and Rock Hazards chapter in the source map report.

Extracted from: (SS-133 Plate 6).

Collapsible Soil Susceptibility - Using This Map

This map shows the location of known and suspected collapsible-soil conditions in the Zion National Park Geologic-Hazard Study Area. The map is intended for general planning and design purposes to indicate where collapsible-soil conditions may exist and special investigations should be required. Site-specific investigations can resolve uncertainties inherent in generalized mapping and help identify the need for special design, site grading and soil placement, and/or mitigation techniques. The presence and severity of collapsible soil along with other geologic hazards should be addressed in these investigations. If collapsible soil is present at a site, appropriate design and construction recommendations should be provided.

Extracted from: (SS-133 Plate 6).

Collapsible Soil Susceptibility - Map Limitations

This map is based on limited geologic and geotechnical data; site-specific investigations are required to produce more detailed geotechnical information. The map also depends on the quality of those data, which may vary throughout the study area. The mapped boundaries between susceptibility categories are approximate and subject to change as new information becomes available. The susceptibility may be different than shown at any particular site because of variations in the physical properties of geologic deposits within a map unit, gradational and approximate map-unit boundaries, and the small map scale. The map is not intended for use at scales other than the published scale, and is designed for use in general planning and design to indicate the need for site-specific investigations.

Extracted from: (SS-133 Plate 6).

Collapsible Soil Susceptibility - Hazard Reduction

Although potentially costly when not recognized and properly accommodated in project design and construction, problems associated with collapsible soil rarely are life threatening. As with most geologic hazards, early recognition and avoidance are the most effective ways to mitigate potential problems. However, collapsible soil is widespread in the study area, and avoidance may not always be a viable or cost-effective option.

In Utah, soil-test requirements are specified in chapter 18 (Soils and Foundations) of the 2009 International Building Code (IBC) (International Code Council, 2009a) and chapter 4 (Foundations) of the 2009 International Residential Code for One- and Two-Family Dwellings (IRC) (International Code Council, 2009b), which are adopted statewide. IBC Section 1803.3 contains requirements for soil investigations in areas where questionable soil (soil classification, strength, or compressibility) is present. IRC Section R401.4 states that the building official shall determine whether to require a soil test to determine the soil's characteristics in areas likely to have expansive, compressible, shifting, or other unknown soil characteristics. IBC table 1613.5.2 identifies collapse-prone soils as Site Class F. Site Class F soils require a site-specific investigation to determine the proper seismic design category and parameters for a proposed facility (see chapter 5 – Earthquake Hazards in accompanying text).

Where the presence of collapsible soil is confirmed, possible mitigation techniques include soil removal and replacement with noncohesive, compacted backfill; use of special foundation designs such as drilled

pier deep foundations, grade beam foundations, or stiffened slab-on-grade construction; moisture barriers; and careful site landscape and drainage design to keep moisture away from buildings and collapse-prone soils (Nelson and Miller, 1992; Pawlak, 1998; Keller and Blodgett, 2006).

Extracted from: (SS-133 Plate 6).

Collapsible Soil Susceptibility - References

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Extracted from: (SS-133 Plate 6).

Plate 7 - Expansive-Soil-and-Rock Hazards

Expansive Soil and Rock Hazards - Explanation

EXPANSIVE SOIL

High Hazard – Soils classified by the NRCS as having high hazard for volumetric change. These soils are typically clay rich and have a LL ≥35, PI ≥15, and/or SCT value of ≥3 percent swell (Mortensen and others, 1977; Chen, 1988; Nelson and Miller, 1992). Soils having these characteristics are of limited aerial extent in the study area, and are typically associated with the Petrified Forest Member of the Chinle Formation, other clay-rich bedrock units, and some weathered basalt flows.

Moderate Hazard – Soils classified by the NRCS as having moderate hazard for volumetric change (LL 25–55, PI 5–35). The LL and PI values in this category overlap at their upper ends with soils in the high hazard category. Chen (1988) recognized that while PI is an indicator of expansive potential, other factors also exert an influence, and therefore reported a range of PI values when categorizing a soil's capacity to shrink or swell.

Low Hazard – Soils classified by the NRCS as having low hazard for volumetric change (LL 0-40, PI from nonplastic to 15). The LL and PI values in this category overlap at their upper ends with soils in the moderate hazard category. However, the low hazard category includes soils with highly variable potential for volumetric change that do not fit easily into the moderate or high categories.

No Data – Unconsolidated alluvial deposits in areas of upper Zion Canyon, Hop Valley, and LaVerkin Creek that may contain some clay-rich horizons subject to volumetric change, but a lack of information about the physical characteristics of the deposits precludes hazard categorization. These deposits are not included in the geotechnical database, and are mapped by the NRCS as chiefly Rock Outcrop (NRCS soils-map unit RT) or Fluvaquents and Torrifluvents (NRCS soils-map unit FA) for which soil property estimations and engineering tests were not performed. Due to the variable nature of these deposits and a general lack of geotechnical data for them, we recommend site-specific testing for expansive soil for all proposed construction within map areas having no data.

EXPANSIVE ROCK

High Hazard – Bedrock units with high shrink/swell hazard, which include claystone horizons in the Virgin Limestone Member of the Moenkopi Formation, the Petrified Forest Member of the Chinle Formation, and the lower red beds of the Dinosaur Canyon Member and the Whitmore Point Member of the Moenave Formation. We include landslides mapped within these rock units in the high-hazard category because the landslides contain debris from high-hazard bedrock units. These bedrock units contain an abundance of expansive clay minerals and are commonly associated with expansive rock problems throughout southwestern Utah.

Moderate Hazard – Bedrock units with moderate shrink/swell hazard, which include the Shnabkaib and lower, middle, and upper red members of the Moenkopi Formation; the Sinawava Member of the Temple Cap Formation; and the lower unit of the Co-op Creek Member and the Crystal Creek Member of the Carmel Formation. These rock units are chiefly fine grained and contain alternating strata of shale, claystone, mudstone, siltstone, sandstone, and limestone. Not all or even the majority of these strata contain expansive clay minerals; however, past experience in southwestern Utah has shown that a sufficiently high percentage of strata do contain expansive clay that shrink/swell problems are often associated with these bedrock units. We include landslides mapped within moderate-hazard rock units in this category.

Low Hazard – Bedrock units with low shrink/swell hazard, which include the Timpoweap Member of the Moenkopi Formation, the Kayenta Formation, and the Winsor Member of the Carmel Formation. We consider these units to have a lower hazard than the bedrock units identified above; however, low-hazard units contain some fine-grained, clay-rich strata that may cause shrink/swell problems locally.

CONCEALED HIGHLY EXPANSIVE SOIL OR ROCK

Concealed – Area suspected of having highly expansive soil or rock (≥3 percent swell) in the shallow subsurface (≤20 feet), with little or no evidence of such material at the ground surface. The likely presence of highly expansive materials in the shallow subsurface is based on the outcrop pattern of the Petrified Forest Member of the Chinle Formation, which indicates that the Petrified Forest Member likely underlies thin unconsolidated deposits in those areas. The Petrified Forest Member typically contains highly expansive shale and claystone, and past experience in southwestern Utah has shown that when wetted, highly expansive soil or rock can cause damaging differential displacements at the ground surface even when overlain by as much as 20 feet of nonexpansive material (Lund and others, 2008). Therefore, we consider areas where the Petrified Forest Member may be present in the shallow subsurface to have a potential for highly expansive soil and rock problems despite the lack of surface evidence of such materials.

Extracted from: (SS-133 Plate 7).

Expansive Soil and Rock Hazards - Discussion

Expansive soil and rock increase in volume (swell) as they get wet, and decrease in volume (shrink) as they dry out. Expansive soil and rock contain a significant percentage of clay minerals that can absorb

water directly into their crystal structure when wetted. Some sodium-montmorillonite clay can swell as much as 2000 percent upon wetting (Costa and Baker, 1981). The resulting expansion forces can be greater than 20,000 pounds per square foot (Shelton and Prouty, 1979), and can easily exceed the loads imposed by most structures, resulting in cracked foundations and pavement, structural damage, and other building distress.

Several bedrock formations in the Zion National Park Geologic-Hazard Study Area consist in whole or part of shale, claystone, or mudstone containing expansive clay minerals. These rock units and the expansive soils derived from them are capable of significant expansion and contraction when wetted and dried, causing structural damage to buildings; cracked roads and driveways; damage to curbs, gutters, and sidewalks; and heaving of roads and canals. Expansive soils are chiefly derived from the weathering of clay-bearing rock formations and may be residual (formed in place) or transported (usually a short distance) and deposited in a new location. The principal transporting mechanisms are water or wind, but soil creep and mass-wasting processes may play important roles locally.

For additional information about expansive soil and rock in the Zion National Park Geologic-Hazard Study Area, refer to the Problem Soil and Rock Hazards chapter in the source map report.

Extracted from: (SS-133 Plate 7).

Expansive Soil and Rock Hazards - Using This Map

This map shows the location of known or suspected expansive soil and rock in the Zion National Park Geologic-Hazard Study Area. The map is intended for general planning and design purposes to indicate where expansive soil and rock may exist and special investigations should be required. Site-specific investigations can resolve uncertainties inherent in generalized mapping and help identify the need for special foundation designs, site grading and soil placement, or mitigation techniques. The presence and severity of expansive soil and rock, along with other geologic hazards should be addressed in these investigations. If expansive soil or rock is present at a site, appropriate design and construction recommendations should be provided.

Extracted from: (SS-133 Plate 7).

Expansive Soil and Rock Hazards - Map Limitations

This map is based on limited geologic and geotechnical data; site-specific investigations are required to produce more detailed geotechnical information. The map also depends on the quality of those data, which may vary throughout the study area. The mapped boundaries between hazard categories are approximate and subject to change as new information becomes available. The hazard from expansive soil and rock may be different than shown at any particular site because of variations in the physical properties of geologic deposits within a map unit, gradational and approximate map-unit boundaries, and the small map scale. The map is not intended for use at scales other than the published scale, and is designed for use in general planning and design to indicate the need for site-specific investigations.

Extracted from: (SS-133 Plate 7).

Expansive Soil and Rock Hazards - Hazard Reduction

Although potentially costly when not recognized and properly accommodated in project design and construction, problems associated with expansive soil and rock rarely are life threatening. As with most geologic hazards, early recognition and avoidance are the most effective ways to mitigate potential problems. However, expansive soil and rock are present in some of the most heavily developed parts of the study area, and avoidance may not always be a viable or cost-effective option.

In Utah, soil-test requirements are specified in chapter 18 (Soils and Foundations) of the 2009 IBC (International Code Council, 2009a) and chapter 4 (Foundations) of the 2009 IRC (International Code Council, 2009b), which are adopted statewide. IBC Section 1803.3 and IRC Section R401.4 contain requirements for soil investigations in areas where expansive soil may be present. Where the presence of expansive soil or rock is confirmed, possible mitigation techniques include soil removal and replacement with noncohesive, compacted backfill; use of special foundation designs such as drilled pier deep foundations, grade beam foundations, or stiffened slab-on-grade construction; moisture barriers; chemical stabilization of expansive clays; and careful site landscape and drainage design to keep moisture away from buildings and expansive soils (Nelson and Miller, 1992; Keller and Blodgett, 2006).

Extracted from: (SS-133 Plate 7).

Expansive Soil and Rock Hazards - References

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Extracted from: (SS-133 Plate 7).

Plate 8 - Gypsum Susceptibility

Gypsum Susceptibility - Explanation

GR_A Bedrock units that contain abundant gypsum, often in laterally continuous horizons as much as several feet thick. These units and the soils derived from them are commonly associated with dissolution and collapse features. This category includes the Shnabkaib Member of the Moenkopi Formation and the Paria River Member of the Carmel Formation.

GR_B Bedrock units that lack massive gypsum horizons, but contain thin to medium beds and veins of gypsum interspersed with other rock types. These units and the soils derived from them may contain sufficient gypsum locally to cause foundation or other problems. This category includes the lower red, middle red, and upper red members of the Moenkopi Formation; the Moenkopi Formation undivided; and the Crystal Creek Member of the Carmel Formation.

Geologic Units Known or Likely to Contain Abundant Gypsum

Bedrock Units[1]	Geologic Map Symbols	Gypsiferous Rock Category
Shnabkaib Member, Moenkopi Formation; Paria River Member, Carmel Formation	TRms, Jcp	GR_A
lower red, middle red, and upper red members, Moenkopi Formation; Moenkopi Formation undivided; Crystal Creek Member, Carmel Formation	TRml, TRmm, TRmu, TRm, Jcx	GR_B

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

Geologic/map units and their descriptions can be found with the GRI digital (bedrock and surficial) geologic-GIS maps for Zion National Park, as well as with the published Utah Geological Survey 7.5' quadrangle maps.

Extracted from: (SS-133 Plate 8).

Gypsum Susceptibility - Discussion

Gypsum-bearing soil and rock are subject to dissolution of the gypsum ($CaSO_4 \cdot 2H_2O$), which causes a loss of internal structure and volume. Where the amount of gypsum is $\geq$10 percent, dissolution can result in localized land subsidence and sinkhole formation (Mulvey, 1992; Muckel, 2004; Santi, 2005). Dissolution of gypsum may lead to foundation problems and may affect roads, dikes, underground utilities, and other infrastructure. Gypsum dissolution can be greatly accelerated by application of water, such as that provided by reservoirs; septic-tank drain fields; street, roof, or parking lot runoff; and irrigation (Martinez and others, 1998). Gypsum is also a weak material with low bearing strength and is not well suited as a foundation material. Additionally, when gypsum weathers it forms dilute sulfuric acid and sulfate, which can corrode and weaken unprotected concrete and metals. Type V or other sulfate-resistant cement is typically required in such areas, as is corrosion protection for metals.

SOIL

Information on gypsiferous soil in the study area is limited. Mortensen and others (1977) mapped and described the soils in Zion National Park, and did not report the presence of pedogenic gypsum in their soil profiles. The absence of gypsum in the soil is likely due to the higher average annual precipitation in the study area (10-20 inches; see chapter 6 – Introduction – in accompanying text) than in the more arid

St. George area where average annual precipitation is 8.25 inches and pedogenic gypsum is common (Lund and others, 2008). Because of limited information, no areas of gypsiferous soil are shown on this map. Although unmapped in the study area, we anticipate that locally high concentrations of pedogenic gypsum are present in residual soils formed on gypsum-rich bedrock and in colluvial soils derived from gypsum-bearing rock units.

ROCK

In the Zion National Park Geologic-Hazard Study Area, gypsum is an important component of the Shnabkaib Member of the Moenkopi Formation and the Paria River Member of the Carmel Formation. Gypsum is present in lesser amounts in the lower red, middle red, and upper red members of the Moenkopi Formation, and the Crystal Creek Member of the Carmel Formation. Additionally, residual and colluvial soils derived from these bedrock units may contain locally significant pedogenic gypsum. However, because gypsum is typically concentrated in subsurface horizons by soil-forming processes, problem soils may be difficult to recognize in the absence of subsurface exploration.

We grouped gypsum-bearing bedrock units into two susceptibility categories (GR_A and GR_B) on this map based on the relative amount of gypsum present in the bedrock units that constitute each category. While there is a general decrease in the amount of gypsum present from GR_A to GR_B, both hazard categories may contain abundant gypsum locally, and have a significant potential for dissolution and collapse. Therefore, the classification system presented here employs a relative susceptibility ranking as opposed to a hazard-severity ranking.

For additional information about gypsiferous soil and rock in the Zion National Park Geologic-Hazard Study Area, refer to the Problem Soil and Rock Hazards chapter in the source map report.

Extracted from: (SS-133 Plate 8).

Gypsum Susceptibility - Using This Map

This map shows the location of known and suspected gypsiferous rock in the Zion National Park Geologic-Hazard Study Area. The map is intended for general planning and design purposes to indicate where gypsiferous rock conditions may exist and special investigations, including sodium sulfate testing to determine the presence of corrosive soil or rock, should be required. Site-specific investigations can resolve uncertainties inherent in generalized mapping and help identify the need for special design or mitigation techniques. The presence and severity of gypsiferous rock units and gypsum-rich soils derived from them, along with other geologic hazards, should be addressed in these investigations. If gypsiferous soil or rock is present at a site, appropriate design and construction recommendations should be provided.

Extracted from: (SS-133 Plate 8).

Gypsum Susceptibility - Map Limitations

This map is based on limited geologic and geotechnical data; site-specific investigations are required to produce more detailed geotechnical information. The map also depends on the quality of those data, which may vary throughout the study area. The mapped boundaries between susceptibility categories are approximate and subject to change as new information becomes available. The susceptibility may be different than shown at any particular site because of variations in the physical properties of geologic deposits within a map unit, gradational and approximate map-unit boundaries, and the small map scale.

Additionally, gypsum-bearing bedrock units are locally covered by a thin veneer of unconsolidated deposits. Such areas may be susceptible to sinkhole development or collapse; however, because subsurface information is generally unavailable, those areas are not identified on this map. The map is not intended for use at scales other than the published scale, and is designed for use in general planning and design to indicate the need for site-specific investigations.

Extracted from: (SS-133 Plate 8).

Gypsum Susceptibility - Hazard Reduction

Although potentially costly when not recognized and properly accommodated in project design and construction, problems associated with gypsiferous soil and rock rarely are life threatening. As with most geologic hazards, early recognition and avoidance are the most effective ways to mitigate potential problems. However, avoidance may not always be a viable or cost-effective option.

In Utah, soil-test requirements are specified in chapter 18 (Soils and Foundations) of the 2009 IBC (International Code Council, 2009a) and chapter 4 (Foundations) of the 2009 IRC (International Code Council, 2009b), which are adopted statewide. IBC Section 1803.3 contains requirements for soil investigations in areas where questionable soil (soil classification, strength, or compressibility is in doubt) is present. IRC Section R401.4 states that the building official shall determine whether to require a soil test to determine the soil's characteristics in areas likely to have expansive, compressible, shifting, or other unknown soil characteristics. Where the presence of gypsiferous soil or rock is confirmed, possible hazard-reduction techniques include use of Type V or other sulfate-resistant cement for concrete; corrosion protection for metals; soil removal and replacement with noncohesive, compacted backfill; careful site landscape and drainage design to keep moisture away from concrete and gypsum-bearing deposits; and the use of a vapor barrier beneath concrete slabs to prevent sulfate migration (Keller and Blodgett, 2006). Where gypsum problems are particularly acute, design recommendations should be provided by a qualified corrosion engineer.

Extracted from: (SS-133 Plate 8).

Gypsum Susceptibility - References

International Code Council, 2009a, International building code: Country Club Hills, Illinois, 678 p.

International Code Council, 2009b, International residential code for one- and two-family dwellings: Country Club Hills, Illinois, 870 p.

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Extracted from: (SS-133 Plate 8).

Plate 9 - Piping-and-Erosion Susceptibility

Piping and Erosion Susceptibility - Explanation

Soil susceptible to piping and erosion – Typically fine-grained, noncohesive, loose to poorly consolidated sand, silt, and landslide deposits consisting of similar material. For piping to develop, a free face and percolating ground water are additional necessary requirements.

Rock susceptible to piping and erosion – Typically fine-grained, poorly consolidated siltstone, mudstone, claystone, and landslide deposits consisting of such rock types. For piping to develop, a free face and percolating ground water are additional necessary requirements.

Geologic Deposits Susceptible to Piping and Erosion

Type of Deposit	Geologic Map Units[1]	Piping and Erosion Category
Stream Alluvium	Qa_1, Qa_2, Qal_1, Qa, Qaly	Soil
Alluvial/Terrace Deposits	Qas, Qaso, Qay, Qae, Qac, Qat_2, Qatm, Qath, Qaec, Qaes	Soil
Eolian/Colluvial Sand Deposits	Qes, Qed, Qces, Qer, Qre, Qea, Qce, Qmts	Soil
Lacustrine Deposits	Qlbc, Qls, Qla	Soil
Poorly Consolidated Bedrock	Petrified Forest Mbr., Chinle Fm.; Shnabkaib Mbr. and red mbrs., Moenkopi Fm.; Moenkopi Fm. Undivided; Whitmore Point and Dinosaur Canyon Mbrs., Moenave Fm.; Crystal Creek Mbr., Carmel Fm.	Rock
Landslide Deposits	Qmsy, Qmsh, Qmsc, Qmso	Fine-grained Soil or Rock

Geologic/map units and their descriptions can be found with the GRI digital (bedrock and surficial) geologic-GIS maps for Zion National Park, as well as with the published Utah Geological Survey 7.5' quadrangle maps.

Extracted from: (SS-133 Plate 9).

Piping and Erosion Susceptibility - Discussion

Piping refers to the subsurface erosion of permeable, fine-grained, unconsolidated or poorly consolidated deposits by percolating ground water (Cooke and Warren, 1973; Costa and Baker, 1981). Piping creates narrow, subterranean conduits that enlarge both in diameter and length as increasingly more subsurface material is removed and as the cavities trap greater amounts of ground-water flow. Piping eventually leads to caving and collapse of the overlying surficial materials, and is an important process in the headward extension of gullies in the arid southwestern United States (Costa and Baker, 1981).

For piping to take place, the following conditions are required: (1) fine-grained, noncohesive or poorly consolidated, porous materials, such as some silt and clay; fine sand; poorly consolidated, typically sandy siltstone, mudstone, or claystone; and volcanic ash or tuff, (2) a sufficient thickness of susceptible material in which pipes may form, (3) a sufficiently steep hydraulic gradient to cause ground water to percolate through the subsurface materials, and (4) a free face that intersects the permeable, water-bearing horizon and from which the water can exit the eroding deposit. The walls of an incised stream channel commonly provide the necessary free face, but human-made excavations such as canal banks or road cuts may also induce piping. Parker and Jenne (1967, in Costa and Baker, 1981) describe extensive damage to U.S. Highway 140 where it traverses dissected and extensively piped valley fill along Aztec Wash in southwestern Colorado. Christenson and Deen (1983) reported piping at several locations in the St. George area.

The characteristics that make soil or rock susceptible to piping (fine-grained texture, little or no internal cohesion, and loose or poor consolidation) are also typical of highly erodible materials. Consequently, piping often develops in and is an indicator of otherwise highly erodible deposits. In southern Utah, most erosion occurs during cloudburst storms and is caused by sheetwash and eventual channelization of runoff. If disturbed, highly erodible soil or rock become even more susceptible to erosion, particularly when stabilizing vegetation is removed.

Utah Geological Survey geologic maps (see Sources of Information section in accompanying text) show that fine-grained, noncohesive, loose sand and silt deposits are present in many areas of the Zion National Park Geologic-Hazard Study Area. They include eolian, alluvial, and lacustrine deposits, and mixed-unit geologic deposits that contain a high percentage of wind-blown sand derived from the weathering and erosion of sandstone bedrock that crops out in the study area. Poorly consolidated, often highly weathered, fine-grained bedrock units also crop out over portions of the study area.

For additional information about piping and highly erosive soils in the Zion National Park Geologic-Hazard Study Area, refer to the Problem Soil and Rock Hazards chapter in the source map report.

Extracted from: (SS-133 Plate 9).

Piping and Erosion Susceptibility - Using This Map

This map shows the location of geologic units in the Zion National Park Geologic-Hazard Study Area that are potentially susceptible to piping and erosion. The map is intended for general planning and design purposes to indicate where susceptible soil and rock exist and where special investigations should be required. Site-specific investigations can resolve uncertainties inherent in generalized mapping and help identify the need for special design or mitigation techniques. The presence of soil or

rock susceptible to piping and erosion along with other geologic hazards should be addressed in these investigations. If a potential for piping and erosion is present at a site, appropriate design and construction recommendations should be provided.

Extracted from: (SS-133 Plate 9).

Piping and Erosion Susceptibility - Map Limitations

This map is based on limited geologic and geotechnical data; site-specific investigations are required to produce more detailed geotechnical information. The map also depends on the quality of those data, which may vary throughout the study area. The boundaries of the areas shown as susceptible to piping and erosion are approximate and subject to change as new information becomes available. The susceptibility may be different than shown at any particular site because of variations in the physical properties of geologic deposits within a map unit, gradational and approximate map-unit boundaries, and the small map scale. Localized areas of piping and erosion susceptibility may exist throughout the study area, but their identification is precluded because of limitations of map scale. The map is not intended for use at scales other than the published scale, and is designed for use in general planning and design to indicate the need for site-specific investigations.

Extracted from: (SS-133 Plate 9).

Piping and Erosion Susceptibility - Hazard Reduction

Although potentially costly when not recognized and properly accommodated in project design and construction, problems associated with piping and erosion rarely are life threatening. As with most geologic hazards, early recognition and avoidance are the most effective ways to mitigate potential problems. However, geologic units susceptible to piping and erosion are widespread in the study area, and avoidance may not always be a viable or cost-effective option.

In Utah, soil-test requirements are specified in chapter 18 (Soils and Foundations) of the 2009 IBC (International Code Council, 2009a) and chapter 4 (Foundations) of the 2009 IRC (International Code Council, 2009b), which are adopted statewide. IBC Section 1803.3 contains requirements for soil investigations in areas where questionable soil (soil classification, strength, or compressibility in doubt) is present. IRC Section R401.4 states that the building official shall determine whether to require a soil test to determine the soil's characteristics in areas likely to have expansive, compressible, shifting, or other unknown soil characteristics. Where the presence of soil or rock susceptible to piping or rapid erosion is confirmed, possible mitigation techniques include minimizing disturbance of vegetated areas, controlling the flow of shallow ground water, and managing surface drainage onsite in a controlled manner.

Extracted from: (SS-133 Plate 9).

Piping and Erosion Susceptibility - References

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Extracted from: (SS-133 Plate 9).

GRI Digital Data Credits

This document was developed and completed by Derek Witt (Colorado State University) for the NPS Geologic Resources Division (GRD) Geologic Resources Inventory(GRI) Program. Quality control and format edits of this document by Stephanie O'Meara (Colorado State University).

The information in this document was compiled from the GRI source map, and intended to accompany the digital geohazards-GIS map(s) and related digital data for Zion National Park, Utah (ZION) developed by Derek Witt and Stephanie O'Meara using Utah Geological Survey source digital data, map plates and report (see the GRI Digital Map and Source Map Citation section of this document for all sources used by the GRI in the completion of this document and related GRI digital geohazard-GIS data).

GRI finalization by Stephanie O'Meara (Colorado State University).

GRI program coordination and scoping provided by Bruce Heise and Tim Connors (NPS GRD, Lakewood, Colorado).