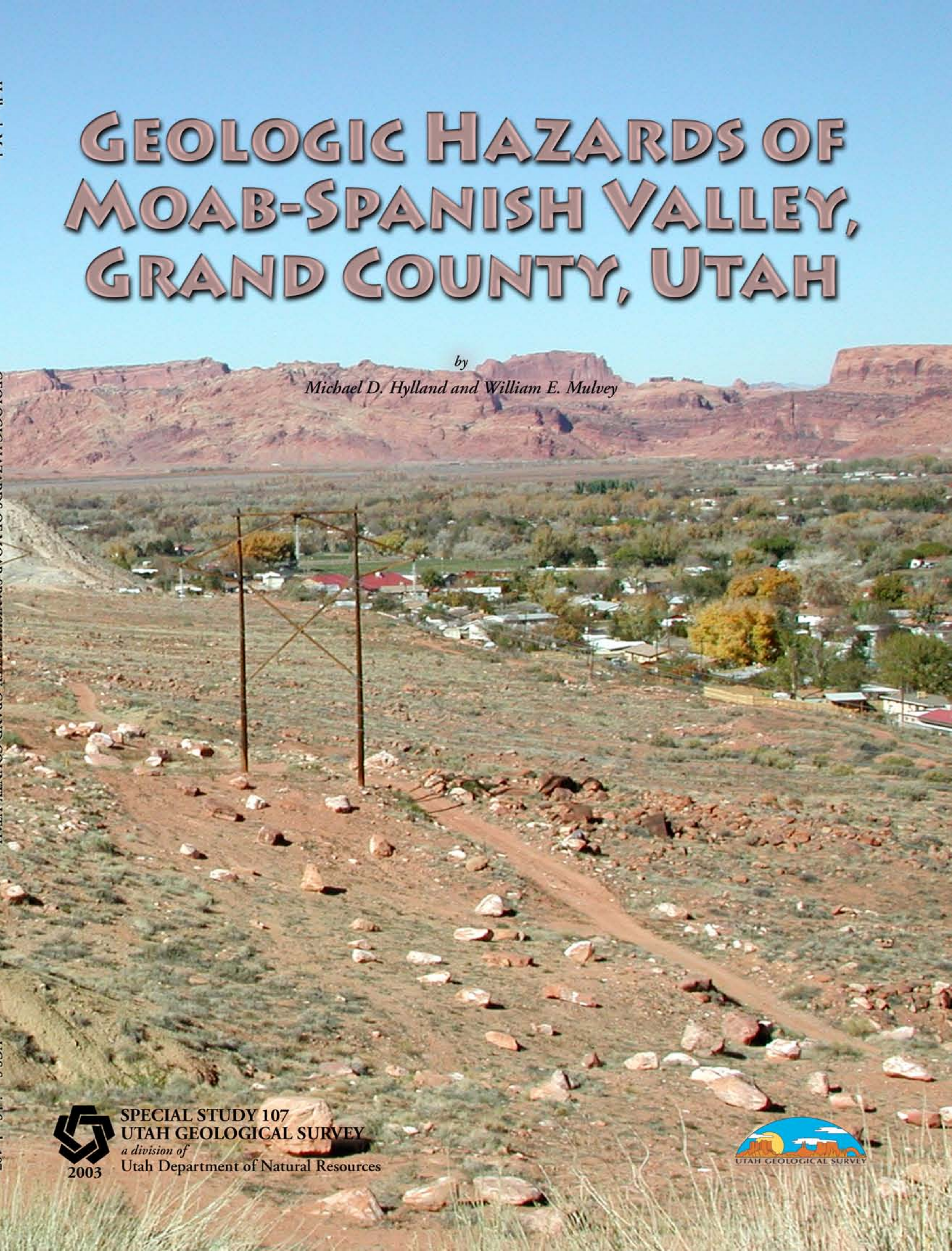

GEOLOGIC HAZARDS OF MOAB-SPANISH VALLEY, GRAND COUNTY, UTAH

by

Michael D. Hylland and William E. Mulvey

SPECIAL STUDY 107
UTAH GEOLOGICAL SURVEY
a division of
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2003

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Cover photo: Northwest view of the northern end of Moab-Spanish Valley. Light-colored Chinle Formation in lower left corner is extensively fractured, highly susceptible to erosion, and may locally contain expansive clays. White hill (left edge of front cover) is exposed Paradox Formation cap rock, which contains expansive clays and soluble gypsum. Gentle, boulder-strewn slope in middle ground comprises alluvial fans where debris flows, alluvial-fan flooding, and collapsible soils may occur. The upper part of the alluvial fans is within a runout zone for rock falls originating from Wingate Sandstone cliffs above (in shadow). Much of the valley floor is an area of shallow ground water, particularly at the northern end of the valley.

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GEOLOGIC HAZARDS OF MOAB-SPANISH VALLEY, GRAND COUNTY, UTAH

by

Michael D. Hylland and William E. Mulvey[1]

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ABSTRACT

Moab Valley and the contiguous Spanish Valley comprise a popular residential and recreational area in east-central Utah. Geologic processes that created the rugged and scenic landscape of Moab-Spanish Valley are still active today and can be hazardous to property and life. To address development in areas with geologic hazards, the Utah Geological Survey (UGS) conducted a geologic-hazards investigation to provide information to Moab City and Grand County to help guide development and reduce losses from geologic hazards.

Development in Moab-Spanish Valley could be impacted by a variety of geologic hazards. Paradox Formation cap rock poses a hazard associated with expansive and gypsiferous soil and rock. The Chinle Formation also locally contains expansive clays, but the hazards related to high clay content (shrink-swell, landsliding) in the Chinle are not as great in Moab-Spanish Valley as they are elsewhere in Utah. Flooding can occur along the Colorado River, Mill and Pack Creeks, and ephemeral stream channels in the area, as well as on alluvial fans. Holocene alluvial fans are also sites of debris-flow and collapsible-soil hazards. Fine-grained, Holocene alluvial and eolian deposits are susceptible to erosion by flowing water, and are locally susceptible to piping. The Chinle Formation and associated soils can also be highly erodible, and sand on the valley floor is easily eroded by the wind and can migrate over roads. The cliffs that border the valley are source areas for rock falls that can travel out onto the edge of the valley floor. Shallow ground water is present beneath much of the valley floor, and zones of highly fractured rock lie along the edges of the valley. Other geologic hazards may exist that are difficult to predict and map, but need to be considered in the design and construction of new development in Moab-Spanish Valley as appropriate; these hazards include earthquakes, subsidence, landslides, and indoor radon.

This report includes maps of Moab Valley and the northern and central parts of Spanish Valley that provide information on geologic hazards to assist homeowners, planners, and developers in making informed decisions. The maps show areas where hazards may exist and where site-specific studies are advisable prior to development. The maps are for planning purposes only, and do not preclude the necessity for site investigations. Site-specific studies by qualified professionals (engineering geologists, geotechnical engineers, hydrologists) should evaluate hazards and, if necessary, recommend hazard-reduction measures. Because of the small scale of the maps, some hazard areas are not shown; hazard studies are therefore recommended for all critical facilities (for example, hospitals, schools, fire stations), including those outside the mapped hazard areas.

INTRODUCTION

Moab Valley and Spanish Valley are in Grand County in east-central Utah (figure 1). The composite Moab-Spanish Valley trends northwest-southeast, is 15 miles (24 km) long, and averages 2 miles (3.2 km) wide. Cliffs along the northeast and southwest margins of the valley rise to broad bedrock uplands. The Colorado River emerges from an incised canyon at the northeastern corner of the valley, flows across the broad flood plain of northwestern Moab Valley, and then enters the mouth of another incised canyon at The Portal on the southwestern margin of the valley. Mill and Pack Creeks traverse the valley from southeast to northwest; their headwaters are approximately 12 miles (19 km) to the east in the La Sal Mountains, which reach elevations of over 12,000 feet (3,700 m). Elevations in the study area range from about 6,000 feet (1,830 m) at the top of the southwestern valley-margin cliffs to about 3,950 feet (1,205 m) along the Colorado River at The Portal. The central business district of the city of Moab is along the northeastern margin of the valley between Mill Creek and the Colorado River.

Many of the geologic processes that shaped Moab-Spanish Valley's scenic and rugged landscape over millions of years are still active today and potentially hazardous to property and life. Principal geologic hazards mapped in the Moab-Spanish Valley area are: (1) expansive soil and rock, (2) gypsiferous soil and rock, (3) stream and alluvial-fan flooding and debris flows, (4) collapsible soils, (5) soils susceptible to piping and erosion, (6) rock fall, (7) shallow

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[1] *Now at 4408 Surry Ridge Circle, Apex, North Carolina 27502*

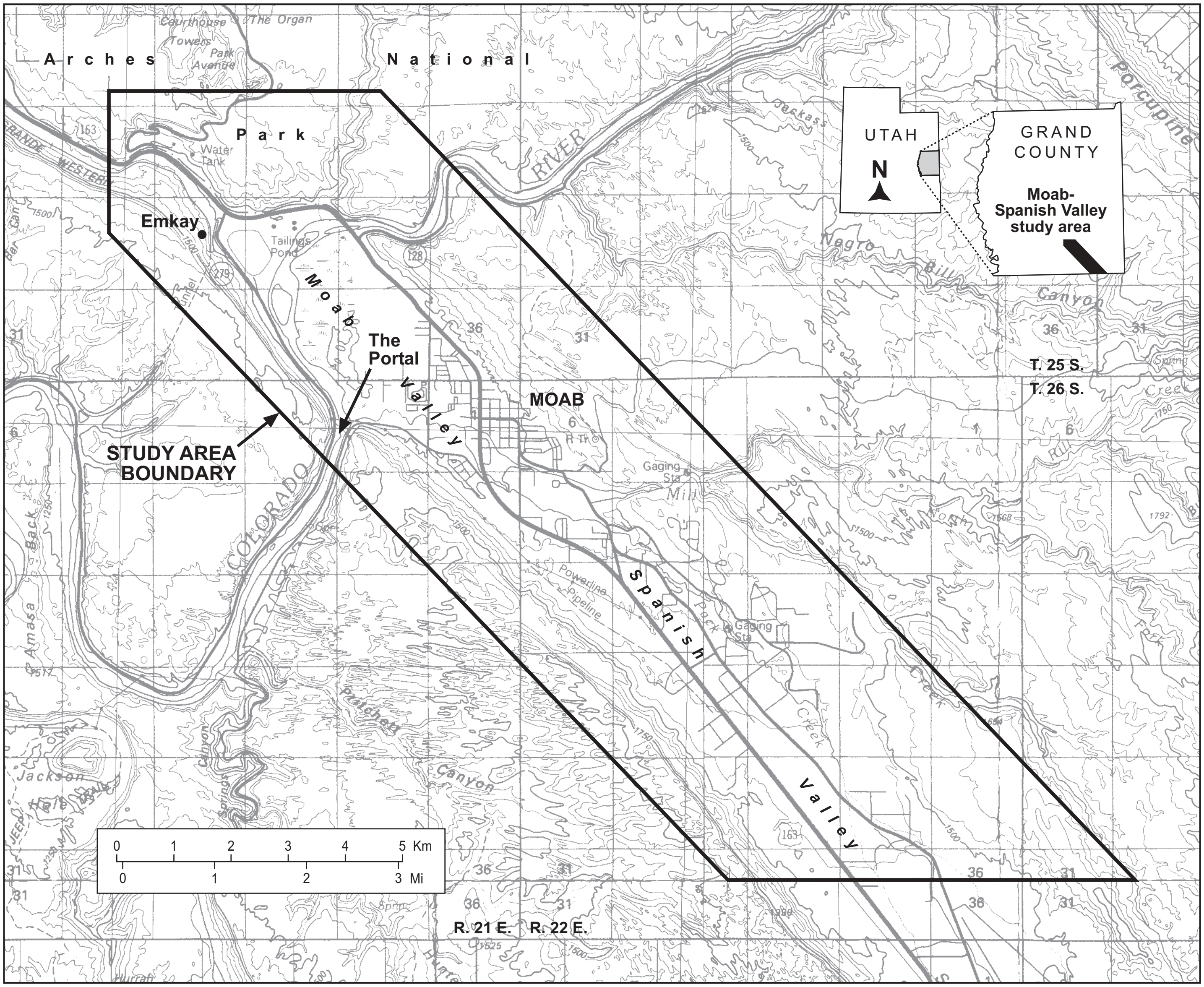

Figure 1. Location of Moab-Spanish Valley study area. Base from USGS Moab (1983) and La Sal (1982) 30 x 60-minute quadrangles.

ground water, and (8) fractured rock. Other possible hazards include earthquakes, subsidence due to salt dissolution, landslides, and indoor radon. In this report, the term "soil" is used in an engineering context and refers to all unconsolidated earth materials; it is not used in an agricultural context.

This report includes discussions of each of the principal geologic hazards listed above. Each discussion describes the characteristics of the hazard and the types of damage that may result, summarizes measures that may be taken to reduce the hazards, and provides guidance for recommended site investigations. The maps that accompany this report show areas associated with each of the principal geologic hazards where site-specific studies are recommended to evaluate the hazard and develop hazard-reduction measures appropriate for the planned development. This report also includes discussions of the geologic hazards for which hazard areas have not been mapped. A glossary at the end of the report gives definitions of technical terms used in the text. Appendix materials include a geologic time scale and list of local, state, and federal government agencies that can provide additional information on geologic hazards and related issues.

PURPOSE AND SCOPE

Where development takes place in geologically hazardous areas, geological input is most important early in the planning and development process; redesigning subdivisions and other development around geologic problems or repairing damage from hazard events is costly and time consuming. This report provides Moab-Spanish Valley homeowners, government officials, and developers and their consultants with maps and other information concerning geologic hazards that may affect development in Moab Valley and the central and northern parts of Spanish Valley.

The hazard maps included with this report are derived largely from published geologic maps of the area (Doelling, 2001; Doelling and others, 2002) and unpublished geologic mapping by the Utah Geological Survey (UGS). The geologic-hazards data were compiled and mapped at a scale of 1:24,000. The areal extent of many geologic hazards is based on the distribution of surficial and bedrock deposits associated with known and potential geologic hazards. The maps are designed to stand alone, and include a summary discussion of each hazard depicted.

The scope of work for this report included meeting with local-government officials and residents, review of pertinent literature and aerial photographs, and field reconnaissance. Most of the work was conducted in 1994; the report was finalized following completion of detailed studies of the Moab fault (Olig and others, 1996; Woodward-Clyde Federal Services, 1996), detailed studies of the uranium mill tailings site along the Colorado River northwest of Moab (see references in U.S Nuclear Regulatory Commission, 1997), and publication of new UGS geologic mapping in the Moab area (Doelling, 2001; Doelling and others, 2002). The report presents a detailed discussion of geologic hazards specific to Moab-Spanish Valley and addresses (1) possible hazard-reduction measures, (2) the scope of recommended site-specific hazards investigations, and (3) application of the maps to land-use planning.

GEOLOGY

Moab-Spanish Valley lies within the Colorado Plateau physiographic province, which overall is characterized by relatively simple "layer-cake" geology. The local geology of Moab-Spanish Valley, however, has been complicated by the interactions of salt-diapir development, salt dissolution, and erosion by running water. Because of this complexity, detailed discussion of the geology of the area is beyond the scope of this report, and only a brief description of geologic units in the area is included herein. Detailed information on the geology of the greater Moab-Spanish Valley area can be found in Doelling (1985, 1988, 2000a, 2000b, 2001), Huffman and others (1996), and Doelling and others (2002).

Exposed bedrock in the Moab-Spanish Valley area consists of a vertical sequence of sedimentary rock layers ranging in age from Pennsylvanian (about 300 million years ago) to Jurassic (about 150 million years ago) (appendix A). Bedrock units are shown diagrammatically on figure 2. Various unconsolidated deposits of Quaternary age (1.6 million years ago to present) overlie the bedrock. The following descriptions of geologic units are modified from Doelling (2001) and Doelling and others (2002).

The oldest rock unit is the Middle Pennsylvanian Paradox Formation. Evaporite minerals, including halite (table salt) and some potash and magnesium salts, may constitute as much as 85 percent of the formation. The buried, low-density salts readily deform and migrate upward in salt diapirs, and subsequently dissolve and leave behind a caprock residue consisting of contorted beds of gypsum, shale, and limestone. Paradox Formation cap rock is exposed in two discontinuous bands along the northeastern and southwestern margins of Moab-Spanish Valley. The Upper Pennsylvanian Honaker Trail Formation crops out in slopes across the valley from the Arches National Park visitor center. It is composed of grayish sandstone, siltstone, and limestone. Overlying the Honaker Trail Formation is the Lower Permian Cutler Formation, also seen across from Arches National Park. It forms cliffs and slopes of red-brown and maroon cross-bedded sandstone and conglomerate with a few thin

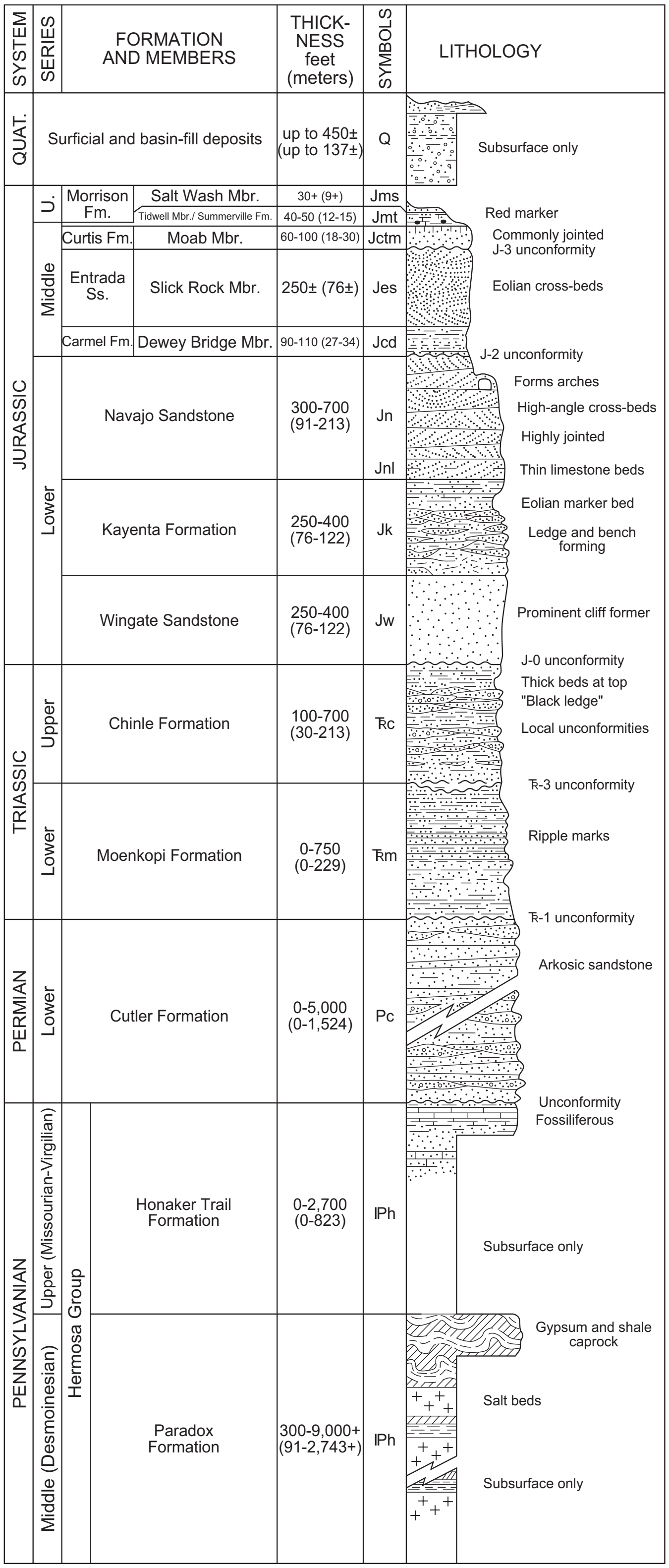

***Figure 2.** Summary of geologic units exposed in the Moab-Spanish Valley area (from Doelling and others, 2002).*

siltstone and limestone beds.

Above the Cutler Formation is the Lower Triassic Moenkopi Formation. The Moenkopi forms steep slopes with ledges around the entrance to the railroad tunnel at Emkay (figure 1). It consists of brown, micaceous sandstone, siltstone, mudstone, and shale. Above the Moenkopi is the Upper Triassic Chinle Formation, also a slope-forming unit. The Chinle is red-brown sandstone, siltstone, conglomeratic sandstone, and mudstone. Near the base of the unit is a poorly cemented gritstone. Capping these formations are cliffs of the Lower Jurassic Wingate Sandstone and Kayenta Formation. The Wingate Sandstone forms the massive cliffs south and west of Moab, and along the Colorado River north of Moab. It is composed of fine-grained, well-sorted sandstone that forms a dark-brown cliff. On top of the Wingate is the Kayenta Formation, a ledgy, step-like, lavender-gray and dark-brown sandstone. The Kayenta Formation caps many of the cliffs in the valley. The Lower Jurassic Navajo Sandstone overlies the Kayenta, forming the irregular surface of pale-orange to light-gray sandstone fins, hills, and swales on the northeastern and southwestern sides of Moab-Spanish Valley.

Overlying the Navajo Sandstone is a Middle to Late Jurassic sequence of mostly sandstone units exposed in and near Arches National Park. These rocks include the Dewey Bridge Member of the Carmel Formation, Slick Rock Member of the Entrada Sandstone, Moab Member of the Curtis Formation, Summerville Formation, and Tidwell and Salt Wash Members of the Morrison Formation. The Dewey Bridge and Moab Members had previously been assigned to the Entrada Sandstone (for example, Wright and others, 1962; Doelling, 1985; Peterson, 1988), but recent work by O'Sullivan (2000) and the UGS (Doelling, 2001; Doelling and others, 2002) resulted in the reassignment of these units. Most of the arches in Arches National Park are formed in sandstone of the Dewey Bridge, Slick Rock, and Moab Members. Strata of the Summerville and Morrison Formations, exposed in only a small part of the study area within Arches National Park, generally consist of red to brown sandstone and siltstone and gray limestone, overlain by pale-yellow-gray sandstone interbedded with green and red mudstone and siltstone.

The floor of Moab-Spanish Valley is composed of Quaternary deposits derived from the La Sal Mountains and local valley slopes. Valley side slopes are covered with colluvium and talus largely derived from rock falls from the cliffs above. Downslope of these deposits are alluvial fans derived from erosion of upstream channel deposits and slope sediments. The alluvial-fan deposits interfinger with stream alluvium of Mill and Pack Creeks and the Colorado River in the interior of the valley.

EXPANSIVE AND GYPSIFEROUS SOIL AND ROCK

Expansive soil and rock contain clay minerals capable of absorbing large quantities of water. As their moisture content changes, the clay minerals expand (water added) and contract (water removed), causing as much as a 10 percent change in soil volume (Sheldon and Prouty, 1979). When water is added, clay minerals expand both vertically and horizontally. Clay soils may swell either by absorption of water between clay particles or by incorporating water directly into the crystal lattice of individual clay minerals (figure 3). In both processes, the added water causes the soil or rock to expand. As the material dries, the loss of water causes shrinkage that can create near-surface cracks in the material (figure 4). This "shrink-swell" process can churn and disturb the surface of expansive deposits, giving some of them a characteristic "popcorn" surface texture. In Moab-Spanish Valley, the Paradox and Chinle Formations, and the soils derived from them, are the most likely sources of expansive minerals (plate 1). However, clayey mudstone and shale comprise a relatively minor component of the Chinle Formation in the Moab area, so the expansive-soil-and-rock hazard associated with the Chinle is significantly less here than it is elsewhere in Utah (for example, the St. George area).

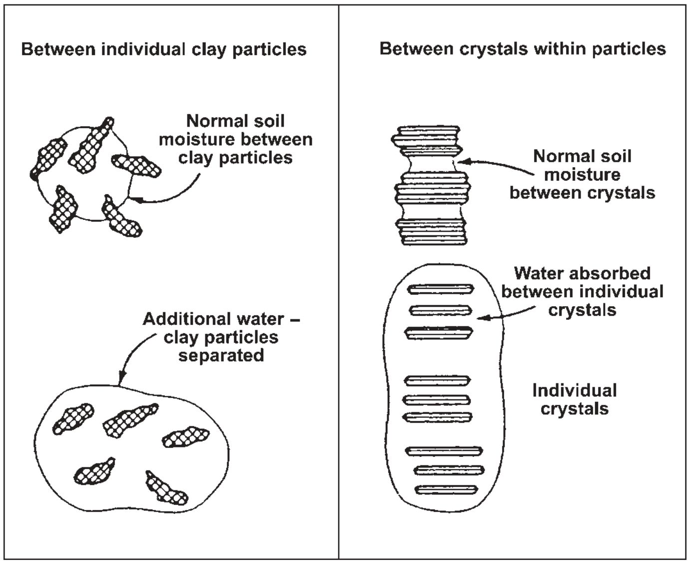

Figure 3. Schematic diagram of water-absorption processes in expansive clay minerals (modified from Mulvey, 1992).

The volumetric changes associated with expansive soil and rock may damage structures, roads, and utilities built on or buried in the expansive materials. Problems commonly associated with expansive soil and rock include cracked foundations and other structural damage to buildings; heaving and cracking of roads, sidewalks, and driveways; damage to pipelines; and plugging of wastewater-disposal drain fields. Single-family homes are particularly susceptible to heave because foundation loads (typically 1,500 to 2,500 pounds per square foot [7,400-12,200 kg/m^2]) may be less than expansive pressures from clays (3,000 to 11,200 pounds per square foot [14,600-54,700 kg/m^2]) (Costa and Baker, 1981). Larger, heavier buildings are less susceptible to expansive-soil problems.

Maps published by the U.S. Department of Agriculture Soil Conservation Service (now Natural Resources Conservation Service) indicate that soils in the Moab-Spanish Valley area generally have a low shrink-swell potential (Hansen, 1989; Lammers, 1991). Also, Lammers (1991) shows a moderate shrink-swell potential in soils of the Jocity series, found in a localized area of alluvial deposits adjacent to Pack Creek in the NW$^1/_4$ sec. 22, T. 26 S., R. 22 E., Salt Lake Base Line and Meridian.

Figure 4. *Fractures formed by shrinkage in expansive clay in a mudstone interbed of the Chinle Formation. Outcrop exposed in cut at base of slope east of downtown Moab.*

Gypsiferous soil and rock are very localized hazards in Moab-Spanish Valley. These deposits contain significant amounts of the evaporite mineral gypsum. Gypsum is a weak material with low bearing strength, which can cause foundation problems for heavy structures. Gypsiferous deposits are also subject to subsidence and collapse due to dissolution of gypsum and other soluble evaporite minerals commonly associated with gypsum, which creates a loss of internal structure and volume within the deposit. Dissolution of gypsum and associated ground settlement may take place where water is introduced into the subsurface as the result of irrigation, wastewater disposal, or ponded water due to natural topography or altered surface drainage. If thick gypsum beds are present, underground solution cavities may develop and collapse, forming sinkholes. Paradox Formation cap rock and associated soils contain significant amounts of gypsum (figure 5; plate 1).

Gypsiferous soil and rock can promote concrete deterioration over time. When gypsum weathers it forms sulfuric acid and sulfate, which may react with certain types of cement and weaken foundations. Soil Conservation Service maps show that soils in the Moab-Spanish Valley area generally have a moderate concrete corrosion potential (Hansen, 1989; Lammers, 1991). However, Lammers (1991) indicates soils of the Moenkopie series, located along the northeastern valley margin and in the southwestern corner of the study area, are mildly to strongly alkaline (pH 8.8) and have a high concrete corrosion potential. (Note that the distribution of the Moenkopie soil series does not correspond to the distribution of Moenkopi Formation outcrops.) Also, Lammers (1991) shows soils having a high concrete corrosion potential along the flood plains and terraces of the Colorado River, Mill Creek, and Pack Creek.

Figure 5. *Outcrop of gypsiferous Paradox Formation cap rock on western side of valley, just south of The Portal, showing small dissolution caverns. Apparent large cavern to right of geologist is actually the base of a rock-fall boulder from Wingate Sandstone cliffs exposed below skyline.*

Hazard-Reduction Measures

Surface drainage conditions affecting soil-moisture content are important in areas of expansive soil and rock. Gutters and downspouts should direct water at least 10 feet (3 m) away from foundation slabs (Costa and Baker, 1981). Vegetation that requires substantial amounts of irrigation should not be placed near foundations. Concrete foundations can be strengthened with additional steel reinforcing bars. Walls and floors can be supported on piles or footings placed to depths below the active shrink-swell zone (Costa and Baker, 1981).

Wide shoulders and good drainage along highways can minimize road damage from expansive soil and rock. In highway foundations, a combination of hydrated lime, cement, and organic compounds can be added to road subgrade materials to stabilize the underlying soil (Costa and Baker, 1981). Wastewater disposal systems are generally not viable in areas of expansive soil and rock. The addition of water from disposal systems expands the soil, reducing percolation rates below acceptable limits and clogging drain lines. Buried pipelines can be protected by backfilling around the pipe with sand and gravel, which increases permeability and permits expansion and contraction of the soil without damage to the pipe.

In gypsiferous soils, laboratory tests are required to determine the amount of gypsum present. Control of drainage around structures as recommended above for expansive soils pertains to construction in gypsiferous soils as well. Also, the outer walls of concrete foundations can be covered with impermeable membranes or bituminous coatings to protect them from deterioration, and special sulfate-resistant concrete can be used.

Scope of Recommended Site Investigations

Site investigations in areas of problem soil and rock (plate 1), as well as other areas of unconsolidated Quaternary deposits along the valley margins and floor, should include a standard soil-foundation investigation to identify expansive and gypsiferous soil and rock. If present, further specialized soil testing to determine clay mineralogy, expansive pressures, and gypsum content may be advisable to better understand the problem. The report should include recommendations on foundation design.

STREAM FLOODING, ALLUVIAL-FAN FLOODING, DEBRIS FLOWS, AND COLLAPSIBLE SOILS

Cloudburst storms and snowmelt can produce stream and alluvial-fan flooding, and debris flows. Sediment deposited in alluvial-fan floods and debris flows may be prone to collapse due to hydrocompaction when rewetted.

Cloudburst storms are the most common cause of flooding in streams and on alluvial fans in Moab-Spanish Valley. The flood potential of cloudburst rainstorms depends on numerous factors including: (1) the intensity or amount of rainfall during a given period of time, (2) the duration or length of time of rainfall, (3) the distribution of rainfall and direction storms move over a drainage basin, (4) soil characteristics, (5) antecedent soil moisture, (6) vegetation, (7) topography, and (8) drainage pattern. Because many of these conditions are unknown until rain is falling on critical areas, the magnitude of flooding from a particular storm is difficult to predict. In contrast, snowmelt floods from rapid melting of snow in the La Sal Mountains are more predictable because flood levels depend primarily on snow amounts in the mountains and temperature. Snowmelt floods are characterized by high-volume runoff, moderately high peak flows, and diurnal fluctuation in flow.

Rapidly deposited sediment in alluvial-fan floods and debris flows may retain an open structure subject to collapse and subsidence when wetted. Thus, areas of collapsible soil typically coincide with areas of alluvial-fan-flooding and debris-flow hazard and are discussed together here.

Stream Flooding

Stream flooding can occur in Mill and Pack Creeks, and Moab has had numerous damaging floods from these creeks (Woolley, 1946; Butler and Marsell, 1972). In addition, floodwaters from the Colorado River inundated the low-lying Moab Slough area in the northwestern part of the valley (site of the Scott M. Matheson Wetlands Preserve) in 1983 and 1984. The primary source of flooding in Moab-Spanish Valley is cloudburst storms, which typically occur between mid-April and September; seasonal snowmelt can also cause stream flooding. Flood-hazard-boundary maps (Federal Emergency Management Agency, 1981) are available for the unincorporated part of Moab-Spanish Valley, and flood-insurance rate maps (U.S. Department of Housing and Urban Development, 1980) are available for the city of Moab; these maps can be viewed online at <hazardmaps.gov>. These maps show flood-hazard areas as delineated in the Federal Insurance Administration's National Flood Insurance Program. Because of the existence of these maps, we did not map stream-flood hazards as part of this study.

Alluvial-Fan Flooding

Alluvial-fan flooding occurs with little advance warning. Flooding generally occurs when cloudburst storms drop large volumes of water over an area in a short period of time. Storms generate high-velocity flows that may simultaneously occupy several different channels on the fan surface at once. Floodwaters erode some channels while depositing large volumes of sediment in others, making it difficult to predict flood paths on alluvial fans. Alluvial-fan floodwaters commonly contain large amounts of coarse sediment, including boulders and cobbles.

The areas of potential alluvial-fan flooding shown on plate 2 correspond to active (Holocene) alluvial fans. Channels on these alluvial fans are generally incised at the apex of the fan and become shallower where sediment deposition is more active on the middle and distal parts of the fan. The flood hazard is therefore greatest where floodwaters first overflow main channels and move across the fan surface as sheet flow or in shallow minor channels. Floodwater depth then decreases down-fan. In places, distal fan surfaces have been isolated by a road or other drainage diversion, and are no longer susceptible to alluvial-fan flooding except in extreme events. Older alluvial fans are more deeply incised than younger fans, and the channels can generally contain floodwaters. We therefore excluded these older alluvial fans from the flood-hazard area.

Debris Flows

Debris flows are a heavily sediment-laden phase of alluvial-fan flooding that remain in the channel until the channel loses confinement or incision, allowing the flow to spread onto the fan surface. Debris flows are mixtures of water, sediment (such as boulders, cobbles, sand, silt, and clay), and organic material and other solid debris that form a muddy slurry much like wet concrete (Wieczorek and others, 1983). By a conventional engineering interpretation, debris flows have sediment concentrations of 80 percent or greater by weight (60 percent or greater by volume), and flows having sediment concentrations of 40 to 80 percent by weight (20-60 percent by volume) are called hyperconcentrated flows (Beverage and Culbertson, 1964; Costa, 1984). In spite of this technical distinction, our use of the term "debris flow" in this report refers to all floodwaters that are heavily sediment-laden, including hyperconcentrated flows. Debris flows generally remain confined to stream channels in mountainous areas, but may reach and deposit debris over large areas on alluvial fans at canyon mouths. Alluvial fans on the southwestern side of Moab-Spanish Valley are particularly susceptible to debris-flow hazards (plate 2) because of the steep slopes below cliffs and the highly erodible bedrock (Chinle and Wingate Formations).

Debris flows form in at least two different ways: (1) hillside and channel erosion by runoff during cloudburst storms, and (2) directly from debris slides. In Moab-Spanish Valley, runoff from cloudburst storms can scour materials from the ground surface and stream channels, increasing the proportion of soil materials to water until the mixture becomes a debris flow. The size and frequency of debris-flow events generated by rainfall runoff depend on several factors, including the amount of loose material available for transport, the magnitude and frequency of the storms, the density and type of vegetative cover, and the moisture content of the soil (Campbell, 1975; Pack, 1985; Wieczorek, 1987). Debris flows can also mobilize from debris slides, which are landslides composed mainly of coarse-grained debris, usually derived from colluvium. A debris flow may form when a debris slide reaches a stream, or when the water content otherwise increases until flow begins. Little geologic evidence exists for debris slides on hillsides above alluvial fans in the Moab-Spanish Valley area, so this does not appear to be a significant mechanism of debris-flow initiation in this area.

Collapsible Soils

Hydrocompaction, which causes subsidence in collapse-prone soil, occurs in loose, dry, low-density deposits. These deposits decrease in volume or collapse when saturated for the first time since deposition (Costa and Baker, 1981). Collapsible soils are subject to volumetric reductions that can damage structures. Collapsible soils are mainly found in alluvial-fan and loess deposits. When wetted for the first time since deposition (by irrigation, wastewater disposal, surface drainage), collapsible soils lose the internal bonds holding the soil grains together, causing the ground surface to subside or collapse. These soils generally consist of fine sand and silt held together by small amounts of clay (less than 12 percent). When the soil becomes saturated, the clay bonds dissolve and the soil collapses.

Collapsible soils are common in Utah, particularly in alluvial fans that have shale in their source areas. The Paradox, Moenkopi, and Chinle Formations contain shale (clays) and contribute sediments to alluvial fans in Moab-Spanish Valley. Because collapsible soils are common in alluvial-fan deposits, maps of alluvial-fan-flood and debris-flow hazard areas where such deposits are found (plate 2) also show where collapsible soils may be found. Eolian deposits in Moab-Spanish Valley are typically sand sheets and dunes rather than loess (Doelling, 2001; Doelling and others, 2002), and therefore are generally not prone to collapse. However, unmapped loess deposits may be present locally.

Hazard-Reduction Measures

Much of the flood damage to roads and culverts in Moab-Spanish Valley is due to alluvial-fan flooding. Methods for reducing stream-flooding, alluvial-fan-flooding, and debris-flow hazards and damage include: (1) avoidance, (2) drainage-basin improvement, (3) flow modification and detention, (4) floodproofing, and (5) flood-warning systems. Different methods or combinations of methods may be appropriate for individual drainages or types of development.

Stream-flood, alluvial-fan-flood, and debris-flow hazards may be reduced by avoiding areas at risk (source areas, stream channels, and alluvial fans) either permanently or at the time of imminent danger. Permanent avoidance is not possible in some areas, because existing development already occupies the flood plains along Mill and Pack Creeks and active alluvial fans. Permanent avoidance may be required for new development through enforcement of Federal Emergency Management Agency regulations under the National Flood Insurance Program and zoning ordinances.

Channel modifications are designed to reduce erosion and improve the ability of the channel to pass debris downstream. Scour of unconsolidated material in stream channels and undercutting of stream banks are two of the most important processes that contribute sediment to floods. Check dams (small debris and water-retention structures in channels that are designed to prevent erosion by reducing velocity and causing deposition) reduce damage from flooding and debris flows. Stream channels may be stabilized by lining the channels. The potential for stream channels to pass floodwaters and debris downstream can be improved by: (1) removal of channel irregularities, (2) enlargement of culverts combined with installation of removable grates over the mouth of the culverts to prevent blockage, and (3) construction of flumes, baffles, deflection walls, and dikes (Jochim, 1986; Baldwin and others, 1987). Whenever these methods are used, attention must be given to possible related adverse effects to other properties downstream.

Structures crossing channels may be protected by: (1) bridging the channel to allow floodwater and debris to pass underneath, and/or (2) strengthening the structures to withstand floodwater and debris-flow impact, burial, overtopping, and re-excavation (Hungr and others, 1987).

Defensive measures in the debris-flow deposition zone are designed to limit both the areal extent of deposition and damage to structures in the zone (Hungr and others, 1987). Defensive measures include deflection devices and debris basins. Deflection devices are used to control flow direction and reduce the velocity of debris flows (Baldwin and others, 1987). Types of deflection devices include: (1) pier-supported deflection walls, (2) debris fences (a series of steel bars, cables, or mesh fences placed horizontally at increasing elevations above the stream channel), (3) berms, (4) splitting-wedge walls (a reinforced concrete wall in the shape of a "V" with the point facing uphill), and (5) gravity structures like gabions (hollow metal wicker-works or iron cylinders filled with cobbles or earth) (Jochim, 1986; Baldwin and others, 1987).

Two types of debris basins, open and closed, are commonly used to reduce debris-flow hazards. Both types are designed to control the area of debris deposition (Hungr and others, 1987). Any suitable location along a debris-flow path can be chosen to erect a dam and create a basin. Open debris basins commonly have a basin-overflow spillway designed to direct water and excess material to a noncritical area or back into the stream channel. Open debris basins should be located where they utilize the original natural depositional area as much as possible (Hungr and others, 1987). Closed debris basins have both straining outlets to pass water discharges, and spillways to handle emergency debris overflows (Hungr and others, 1987). Closed debris basins can be located in the lower part of the main channel or on the alluvial fan (Hungr and others, 1987). Both types of debris basins require periodic removal of debris and maintenance.

Although collapsible soils have not been documented in Moab-Spanish Valley, geologic conditions on alluvial fans are locally favorable for them. Collapsible soils have few diagnostic field characteristics, although a pinhole texture and low density are indicators of collapsible soil. Laboratory soil consolidation tests are generally needed for positive identification. If present, collapsible soils must be compacted, removed, or "collapsed" by presoaking prior to development. In areas of collapsible soils, drainage from the roof and sprinkler systems should be channeled away from structures to reduce potential damage.

Scope of Recommended Site Investigations

Site investigations in stream-flood, alluvial-fan-flood, and debris-flow hazard areas may include: (1) definition of 100-year flood plains in areas subject to stream flooding, (2) delineation of the most active alluvial-fan surfaces, including parts of the fan subject to sheet flow, (3) analysis of debris-flow potential on alluvial fans based on the number and size of past debris slides, volume of colluvium-filled slope concavities, and debris accumulation in channels and on slopes in the drainage, (4) examination of drainages to determine if they will supply debris, impede flow, or contain flows in the area of the proposed development, (5) analysis of existing upstream structures that might divert, deflect, or contain flows, and (6) recommendations concerning channel improvements, flow-modification and catchment structures, direct-protection structures, or floodproofing measures necessary to protect the proposed development.

For development in alluvial-fan-flood and debris-flow hazard areas, the storage capacity and design of existing debris basins or other structures that may divert floodwaters (such as roads or storm drains) upstream from the site should be evaluated to ensure that they are capable of diverting, containing, or passing floodwaters. The mapped hazard areas shown on plate 2 do not consider the possible role of these existing structures in reducing the hazard. Debris basins must be regularly maintained. Predicting flow discharge rates and volumes, extent of alluvial-fan flooding, and volumes of debris is difficult, particularly in Moab-Spanish Valley, where few data on previous events have been recorded. Because of this lack of data, sizing of water-retention structures and debris basins should incorporate a considerable degree of conservatism to increase margins of safety.

Collapsible soils should be addressed in standard soil-foundation investigations prior to development, and laboratory soil-consolidation tests performed when their presence is suspected.

SOIL SUSCEPTIBLE TO PIPING AND EROSION

Soil susceptible to piping and erosion covers much of the floor of southern Moab-Spanish Valley (plate 2). The soil consists of eolian and minor fine-grained alluvial deposits composed of sand, silt, and clay, and is up to 30 feet (10 m) deep based on data from water-well logs.

Piping is subsurface erosion by ground water that moves in permeable, noncohesive layers in unconsolidated materials and exits at a free face that intersects the layer (figure 6). Removal of fine-grained particles (silt and clay) by this process creates voids that act as minute channels that further direct the movement of water. Channels enlarge as water velocity increases and removes more material, forming a "pipe." The pipe becomes a preferred avenue for ground-water flow and enlarges as more water is intercepted. Pipe enlargement removes support of the walls and roof, causing eventual collapse of the pipe. Sinkholes may form at the surface above the pipes, directing even more surface water into them. Eventually, total pipe collapse may form a gully on the surface that continues to enlarge as water flows through it.

Characteristics that make soil susceptible to piping also make it subject to rapid erosion by running water or wind. Soil susceptible to erosion covers much of the floor of Moab-Spanish Valley (plate 2). Also, the Chinle Formation and soils derived from the Chinle can be highly erodible (figure 7; plate 2). Erosion commonly occurs during cloudburst storms. Associated sheetwash may erode fine-grained valley-floor sediments, and channelized runoff can create gullies on slopes and erode the banks of stream channels. High winds associated with cloudburst storms or the approach and passage of frontal systems commonly create dust clouds in southern Moab-Spanish Valley that reduce visibility on U.S. Highway 191 and county roads.

Piping and erosion can damage roads, earth-fill dams, farmland, bridges, culverts, and buildings. In Moab-Spanish Valley, roads are the most susceptible because they parallel and cross incised drainages, altering natural runoff and channeling water.

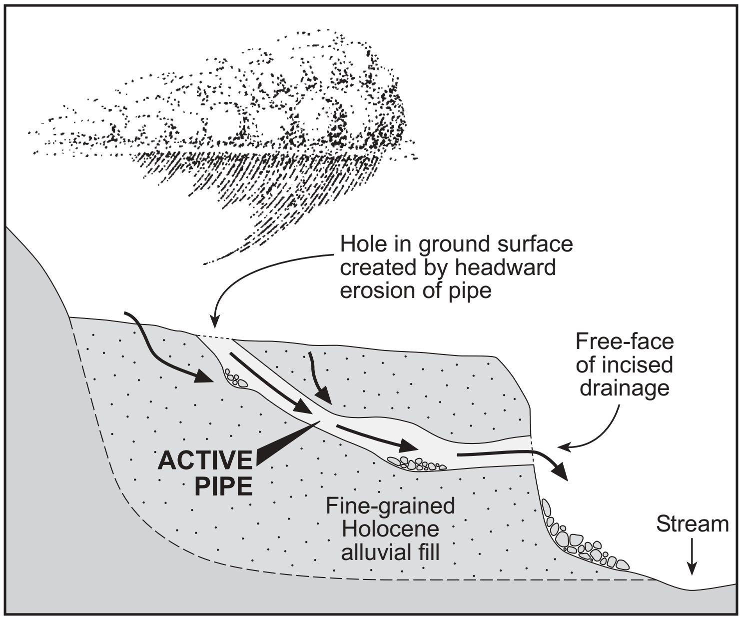

Figure 6. *Schematic cross section of a pipe in Holocene alluvium.*

Hazard-Reduction Measures

The best method of reducing piping and erosion hazards is to control drainage and avoid concentrating runoff. Riprap can be used on slopes around culverts and near bridges to reduce the potential for erosion and development of pipes. Erosion can be reduced by lining canals and drainages with concrete, riprap, or gabions. Diversion of natural drainage or site grading must be done carefully to avoid initiating or accelerating piping or erosion. Irrigation ditches in suscept-ible areas should be lined and maintained. Landscape designs should distribute runoff away from structures and disperse flow. Wind erosion can be limited by reducing disturbance of vegetation during construction, careful management of livestock grazing, and limiting vehicle traffic on erodible soils.

Scope of Recommended Site Investigations

The presence of soil susceptible to piping and erosion should be addressed in standard soil-foundation investigations prior to development.

Figure 7. *Gully erosion in slope underlain by Chinle Formation, along the northeast side of U.S. Highway 191 northwest of downtown Moab.*

ROCK FALL

Rock falls originate when erosion and gravity dislodge rocks from cliffs or slopes. The dislodged rocks may then travel great distances by falling, rolling, bouncing, and sliding. The primary factor in determining if an area is susceptible to rock falls is the presence of a source of rocks (figure 8). If there are no cliffs, bedrock outcrops, or rocks on a steep slope, the rock-fall hazard is negligible. Other major considerations are the distance and direction rocks will travel downslope.

Primary causes of rock falls are chemical and physical weathering, including root growth and freeze-thaw of water in outcrop discontinuities; erosion of the rock and surrounding material; and ground shaking during earthquakes. Keefer (1984) found that rock falls may be triggered by earthquakes as small as magnitude (M) 4. The August 1988 San Rafael Swell earthquake (M 5.3) near Castle Dale in central Utah generated hundreds of rock falls that temporarily obscured the surrounding cliffs in clouds of dust (Case, 1988).

With the exception of the Paradox Formation, all of the bedrock units in the Moab-Spanish Valley area produce rock-fall debris (Doelling and others, 2002); however, the units most susceptible to rock falls are the Wingate Sandstone, Kayenta Formation, and Navajo Sandstone. In these units, outcrops are disrupted by bedding surfaces, joints, or other discontinuities that break rock into loose fragments, blocks, or slabs.

We determined runout distances for rock falls and the lower limit of the rock-fall hazard area (plate 3) by mapping on 1:20,000-scale aerial photographs the outermost rock-fall boulders on slopes below cliffs. We also checked the rock-fall "shadow angle" in the field at several locations. The shadow angle is the angle of a line drawn between the top of the talus slope and the lower limit of the runout zone (Evans and Hungr, 1993). Based on empirical data, Evans and Hungr (1993) suggested a minimum shadow angle of about 28 degrees may be useful for establishing a preliminary estimate of the maximum rock-fall runout distance. Our spot checks supported a 28-degree minimum shadow angle as being reasonably consistent with maximum runout distances of rock falls in Moab-Spanish Valley.

Rock-fall-hazard areas delineated on plate 3 have either a relatively high or moderate hazard. Areas shown as having a high rock-fall hazard are generally cliff areas of high relief, typically with steep slopes below the cliffs (figure 8). Rocks dislodged in these areas may include very large boulders that can become airborne by falling and bouncing, reach high velocities, and travel long distances (in excess of 1,000 feet [300 m]) in the runout zones. Areas shown as having a moderate rock-fall hazard are generally low-relief upland areas underlain by exposed bedrock or colluvium, and areas with locally steep slopes underlain by massive, competent bedrock (figure 9). Rock falls are possible in these areas, but dislodged rocks are unlikely to reach high velocities or travel more than a few tens of feet. Where plate 3 does not indicate either a high or moderate rock-fall hazard, the hazard is low due to gentle slopes and an absence of rock-fall sources.

Rock falls present a hazard to structures and personal safety. In Grand County, rock falls have blocked roadways and railroads and have struck vehicles. In the Moab-Spanish Valley area, buildings on slopes below the cliffs of the southwestern valley margin, and the northeastern valley margin between Moab and the Colorado River, are particularly vulnerable to rock-fall hazards. As development advances higher onto alluvial fans and slopes below cliffs, the risk from falling rocks increases.

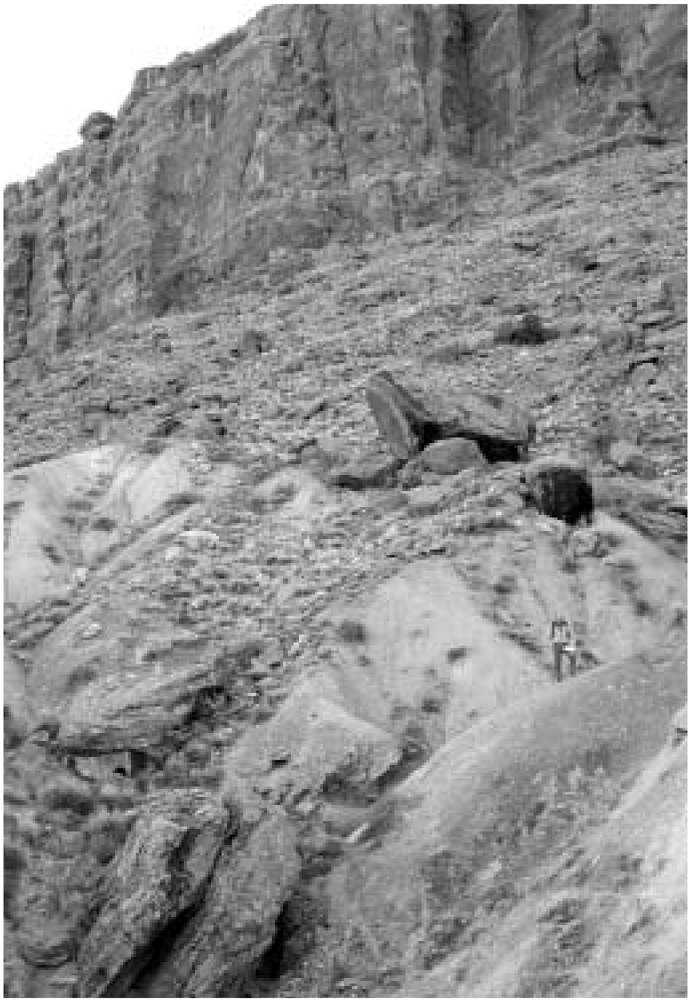

Figure 8. *Rock-fall-hazard area along valley margin west of Moab, characterized by high cliff (source area) and abundant boulders on slope below cliff (runout or "shadow" zone). The rock-fall hazard in areas such as this is relatively high. Note that local topography (for example, hills and ravines) in the runout zone can trap rock-fall boulders and limit their runout distance; boulders generally travel farther downslope where slopes are smooth.*

Rock falls are the principal mass-movement hazard in Moab-Spanish Valley. In general, the potential for other types of mass movement, such as rotational slumps and deep-seated landslides, is low (see Landslides section).

Hazard-Reduction Measures

Buildings are best located outside areas susceptible to rock falls, but methods are available for reducing rock-fall hazards. These methods include rock stabilization; removal or break-up of source rocks; and construction of deflection berms, slope benches, and rock-catch fences that may prevent, stop, or at least slow moving rocks. Structures may also be strengthened to withstand impact. Other techniques for reducing landslide hazards including rock falls are described by Kockelman (1986).

Figure 9. *Example of moderate rock-fall-hazard area, where Sand Flats Road traverses Navajo Sandstone "slick rock" southeast of downtown Moab. Rock falls occasionally occur in these areas, but the relative lack of rock-fall sources and the generally limited travel distance of rock-fall boulders results in a lower hazard than in other rock-fall-hazard areas (see figure 8).*

Scope of Recommended Site Investigations

Site investigations in rock-fall hazard areas should define rock-fall source areas and estimate rock runout paths and distances. Rock-fall sources may be cliffs, outcrops, or individual clasts on a slope. Rock size, shape, depth of burial, and slope geometry should be considered in defining sources as well as hazard areas. A preliminary estimate of runout distance can be made by measuring the "shadow angle" below the base of the rock-fall source (Evans and Hungr, 1993). Computer models are available to help evaluate rock-fall hazards (for example, CRSP [Jones and others, 2000]; ROCKFALL [Hungr and Evans, 1988, 1989]), but physical evidence such as extent of clast accumulations below sources, topography, damaged vegetation, and natural barriers can also be used to define rock-fall hazard areas.

SHALLOW GROUND WATER

In Moab-Spanish Valley, shallow ground water (water at depths below the ground surface of 10 feet [3 m] or less) is present in an unconfined aquifer in the unconsolidated deposits that cover the valley floor from the Colorado River to the Grand County-San Juan County line (plate 3) (Hecker and others, 1988). Shallow zones of perched ground water may also exist locally in the valley-fill deposits. The unconfined aquifer in Moab-Spanish Valley consists of alluvial, alluvial-fan, and eolian deposits of varying thickness. Maximum valley-fill thickness ranges from less than 155 feet (47 m) near the confluence of Pack and Mill Creeks (Harden and others, 1985) to possibly greater than 450 feet (137 m) in the northwestern part of the valley (Doelling and others, 2002). Sumsion (1971) indicates the average thickness of the saturated alluvium is 70 feet (21 m).

Surface and subsurface sources recharge the unconfined aquifer in Moab-Spanish Valley. Primary surface recharge is from snowmelt and rainfall that becomes stream flow in Mill and Pack Creeks, which then infiltrates the ground. Mill Creek is the largest source of surface recharge, providing water to the northwestern part of the valley (Blanchard, 1990). Pack Creek also provides surface recharge to the unconfined aquifer, mostly in southern Spanish Valley in San Juan County (Steiger and Susong, 1997). Irrigation waters may also contribute to recharge. Major subsurface recharge is from fractured-rock aquifers on the northeastern side of the valley.

Plate 3 shows the areal extent of shallow ground water in Moab-Spanish Valley. We delineated the shallow-ground-water area by contouring the depth to the water table as reported on drillers' logs of water wells. The map represents an "average" ground-water level taken from data collected during various seasons and years. Ground-water levels may fluctuate several feet, locally tens of feet, in response to seasonal and long-term climatic conditions. Also, local shallow water tables may be induced by landscape irrigation, water-line breaks, and septic-tank soil-absorption systems.

The most significant hazard associated with shallow ground water is the flooding of subsurface facilities such as basements, utility lines, and septic-tank soil-absorption drain fields. Shallow ground water can increase the potential for corrosion of subsurface concrete walls and slabs, and structures extending below the water table may experience water damage to foundations and building contents. Landfills and waste dumps may become inundated and contaminate aquifers. Underground utilities may also experience water damage. Septic-tank soil-absorption drain fields can become flooded, which may cause ground-water contamination as well as system failure. Wetting of collapsible or expansive soils by ground water may cause settlement or expansion and damage to foundations and structures. Roads and airport runways may heave or settle when collapsible and expansive soils become saturated at shallow depths. Shallow ground water may cause sinkholes by soil piping or the dissolution of gypsum or soluble salts.

Shallow ground water can become contaminated by leaking underground or above-ground storage tanks. Pollutants will flow with the ground water and possibly impact deeper aquifers, and the contaminated water and associated vapors may seep into wells and basements.

Hazard-Reduction Measures

Avoidance is one method of reducing shallow ground-water problems. However, much of Moab-Spanish Valley's population and development are already in areas of shallow ground water. Construction techniques such as drainage systems, sump pumps, and waterproofing and other protective measures may reduce or eliminate the adverse effects of shallow ground water. Slab-on-grade buildings with no basements are an alternative construction design used in areas having a shallow water table. Pile foundations can be used to increase foundation stability. Adding fill can raise building grades, and pumping can lower the water table. Hazard-reduction measures should be based on the shallowest anticipated water level, taking into account both climatic and development-induced conditions.

Septic-tank soil-absorption drain fields may fail when inundated by ground water. To reduce the potential for drain-field failures, State of Utah regulations require that drain lines be at least 2 feet (0.6 m) above the highest seasonal ground-water table (Utah Division of Water Quality, 2000).

Scope of Recommended Site Investigations

Site-specific studies are recommended for all types of construction involving subsurface facilities in areas where the water table is or may rise to within 10 feet (3 m) of the ground surface (plate 3). Site-specific studies should identify the highest water level recorded or evident in sediments, as well as the present and highest expected level. Data on long-term water-level fluctuations in nearby wells over time can be obtained to define a range of seasonal and annual water-table fluctuations. Water-table measurements during known wet periods, such as 1983-85, can be used to approximate highest levels. Studies need to also consider potential development-induced changes to ground-water levels; septic-tank soil-absorption systems may raise water levels to near the level of drain lines, and excess landscape irrigation may also significantly raise ground-water levels.

Shallow-ground-water hazards can be addressed in the soil-foundation report for a site. The report should contain recommendations for stabilizing or lowering the water table, if necessary, and design of waterproofing or other hazard-reduction strategies. Such studies must also address soil conditions including the potential for collapse, piping, dissolution, or swelling, and the potential for ground-water contamination by soil-absorption systems.

Because of seasonal and long-term fluctuations of the water table, the accompanying maps are not intended to replace site-specific data. Ground-water information is available from drillers' logs in the urbanized areas of northern Moab-Spanish Valley, but is sparse in the southeastern end of the valley near the Grand County-San Juan County line.

FRACTURED ROCK

Dissolution of salt in the diapir beneath Moab-Spanish Valley and accompanying collapse caused extensive fracturing and displacement of much of the overlying rock (figure 10). Fractured rock is exposed along the base of the cliffs bordering Moab-Spanish Valley to the northeast and southwest; Doelling and others (2002) refer to these areas as the northeast- and southwest-valley-margin deformation belts. Doelling and others (2002) mapped numerous faults within these deformation belts; while these faults share hazard characteristics with other types of fractures, and may be subject to small subsidence-related displacements, they lack geologic evidence that would indicate they present a significant hazard from surface fault rupture related to earthquakes (see Earthquake Hazards and Subsidence discussions below).

Fractures increase secondary permeability and weaken the rock. Problems associated with development in zones of fractured rock are increased potential for contamination of ground water (such as with effluent from individual wastewater disposal systems) and unstable conditions in road cuts and tunnels. Fractures enable effluent to travel long distances without proper filtering of pathogens, which can result in contamination of shallow unconfined aquifers. Excavations and cuts in fractured rock are susceptible to failure and may generate rock falls.

Hazard-Reduction Measures

In fractured rock, use of individual wastewater disposal systems should be limited to areas having at least 4 feet (1.2 m) of natural soil present between drain lines and underlying fractured rock, as required by the Utah Division of Water Quality (2000). Hazard-reduction measures for potential rock falls in road cuts in fractured rock include installing rock catch fences, covering cuts with wire mesh, and stabilizing rock faces with rock bolts and surficial coatings. Road cuts and tunnels in fractured rock should be designed and constructed under the direction of a geotechnical engineer experienced in rock construction and rock-slope stability.

Scope of Recommended Site Investigations

Site investigations in areas of fractured rock (plate 4) should include geotechnical and hydrologic evaluations to

Figure 10. *Highly fractured Navajo Sandstone exposed at the northwestern end of Moab-Spanish Valley, at the intersection of Utah Hwy. 279 (foreground) and U.S. Hwy. 191 (at base of slope). Fractured rock such as this poses a variety of problems for development.*

identify the extent and nature of fractures, evidence for subsidence, stability of cut-slope materials, and potential for ground-water contamination. For foundations, assessment of stability should be included in the soil-foundation investigation. For roads and road cuts, geotechnical investigations should address subgrade and cut-slope stability. If potential sources of contamination are included in development plans, the potential for contamination must be determined through hydrogeologic studies to determine ground-water flow direction and recharge.

UNMAPPED HAZARDS

In addition to those discussed above, other geologic hazards may exist in Moab-Spanish Valley that could affect development, including: (1) earthquakes, (2) subsidence caused by salt dissolution, (3) landslides, and (4) indoor radon. Where these hazards are likely to occur is difficult to predict except in a very gross sense. Although plate 4 shows the trace of the Moab fault and the generalized area of potential valley-floor subsidence, we otherwise do not delineate hazard areas for these additional geologic hazards on the plates that accompany this report. However, these hazards should be considered in the design and construction of new development in Moab-Spanish Valley as appropriate.

Historically, earthquake activity has been low in the area. Subsidence in late Quaternary time is evident along the Colorado River in northwestern Moab-Spanish Valley and elsewhere in the valley. Naturally occurring landslides are scarce in the Moab-Spanish Valley area, but landslide triggering could be a concern in areas of hillside development. Uranium, which is the source of radon, is found in rocks in the Moab-Spanish Valley area, and readings indicate that elevated levels of indoor radon are present locally.

Earthquake Hazards

The Moab-Spanish Valley area is one of low historical earthquake activity. In general, earthquakes in the area are infrequent and of small to moderate magnitude (Wong and Humphrey, 1989; Wong and others, 1996). If a significant earthquake were to occur in the Moab-Spanish Valley area, potential geologic hazards would include ground shaking and possibly surface fault rupture, liquefaction, landslides, and rock falls. As discussed below, however, the possibility of any of these potential earthquake hazards causing appreciable damage is low.

Ground shaking could result from an earthquake generated by movement on a mapped fault, or from an earthquake not necessarily attributable to a mapped fault (background, or random earthquake). The general area around Moab-Spanish Valley has a number of faults that have possibly been active during Quaternary time (Hecker, 1993; Black and others, 2003); these faults are considered the most likely to undergo future movement. However, Quaternary movement on all but one of these fault zones has been shown to be the result of deformation associated with buried salt deposits (Colman and others, 1986; Oviatt, 1988; Olig and others, 1996), either diapirism (the upward movement of salt due to its low density) or collapse due to salt dissolution. Because these faults extend only to relatively shallow depths in the crust, they are not considered capable of producing significant earthquakes or strong ground shaking. The one Quaternary fault zone in the area that is associated with regional crustal stresses rather than salt movement, the Uncompahgre fault zone, is about 30 miles (50 km) northeast of Moab-Spanish Valley. Based on this distance and an estimate of maximum earthquake magnitude, Wong and others (1996) concluded that earthquakes generated by this fault zone would produce an insignificant ground-shaking hazard to the Moab area.

Most earthquakes on the Colorado Plateau (including Moab-Spanish Valley) cannot be attributed to movement on known faults (Wong and Humphrey, 1989; Wong and others, 1996). Although the maximum magnitude of these background earthquakes could approach M 6.5, historical earthquakes in the Moab-Spanish Valley area have been much smaller. Wong and Humphrey (1989) summarized the seismicity of the area during the eight-year period following installation in July 1979 of a regional seismograph network in the Canyonlands region of southeastern Utah. During this period, the largest recorded earthquake was M_L 3.3, and the most seismically active area near Moab-Spanish Valley was in the vicinity of the Cane Creek potash mine, about 7 miles (11 km) southwest of Moab. However, most of the earthquakes recorded in the mine area were less than M_L 1.0, and may have been related to mining-induced subsidence (Wong and Humphrey, 1989). This general pattern of seismicity has continued to the present (University of Utah Seismograph Stations, unpublished data). Regionally, only a few earthquakes have been recorded that have been of M 5 or larger; four of these were in northern Arizona, and one was in the San Rafael Swell (1988, M_L 5.3) (Wong and others, 1996).

Earthquake ground motions are typically reported in units of acceleration as a fraction of the force (acceleration) of gravity (g). In general, the greater the acceleration or "g" force, the stronger the ground shaking and the more damaging the earthquake. Locally, ground motions can be amplified (more severe shaking) or deamplified (less severe shaking) depending on specific rock and soil conditions.

Probabilistic ground motions have been calculated for the uranium mill tailings site at the northwestern end of Moab-Spanish Valley relative to various earthquake return periods (the elapsed time between earthquakes of a given size). At return periods of 500, 1,000, 5,000, and 10,000 years, the mean peak ground accelerations are 0.05, 0.07, 0.14, and 0.18 g, respectively (Wong and others, 1996; Woodward-Clyde Federal Services, 1996). Probabilistic ground motions for the Moab-Spanish Valley area are also shown on national seismic-hazard maps developed by Frankel and others (1996, 2002), available online at <geohazards.cr.usgs.gov/eq/index.html>. These maps give probabilistic ground motions for rock sites (*International Building Code* [IBC] site class B; International Code Council, 2000a) in terms of peak ground acceleration and 0.2-, 0.3-, and 1.0-second-period spectral accelerations having 10, 5, and 2 percent probabilities of exceedance in 50 years (corresponding to return periods of approximately 500, 1,000, and 2,500 years, respectively). The different values are used by engineers for earthquake-resistant design of structures, based in part on the height and intended use of the structure as well as specific code requirements. Table 1 summarizes probabilistic accelerations derived from the national seismic-hazard maps applicable to rock sites near Moab; these values are given solely for the purpose of illustrating the generally low levels of expected ground motions. For building design, values from similar seismic-hazard maps in the IBC must be used, with a correction based on the particular geologic conditions at the site (site class).

Even the highest probabilistic ground motions for the Moab-Spanish Valley area, which have the lowest probability of occurrence in any given year, would likely only cause slight to moderate damage to well-built structures. To ensure that structures are well built relative to earthquake ground shaking, all new structures should be designed and built in accordance with the seismic provisions in the IBC and *International Residential Code* (IRC; International Code Council, 2000b), as appropriate. For the site classes anticipated in the Moab-Spanish Valley area, most construction will likely fall under IBC Seismic Design Category B, although some construction on sandstone bedrock may fall under Seismic Design Category A, and some critical facilities may fall under Seismic Design Category C.

The closest major fault with possible activity during Quaternary time is the Moab fault, exposed at the northern end of Moab-Spanish Valley (plate 4). Prior to detailed geologic mapping by H.H. Doelling and colleagues at the Utah Geological Survey, the northern trace of the fault was depicted as splitting at the northwestern end of the valley and then extending along both the northeastern and southwestern valley margins (for example, Hecker, 1993). The new mapping shows that the Moab fault trends down the middle of the valley, and is concealed beneath unfaulted Quaternary valley-fill deposits (Doelling and others, 2002). Surface rupture along the fault is possible, but in Moab-Spanish Valley where the fault is buried by Quaternary deposits, the likely location of such a rupture is difficult to predict. No evidence has been

Table 1. *Probabilistic ground-motion values (in g) generally applicable to rock sites near Moab, Utah.*

	10% PE in 50 yr	**5% PE in 50 yr**	**2% PE in 50 yr**
PGA	0.05	0.07	0.11
0.2 sec SA	0.10	0.15	0.24
0.3 sec SA	0.08	0.12	0.18
1.0 sec SA	0.03	0.04	0.06

Abbreviations: PE, probability of exceedance; PGA, peak ground acceleration; SA, spectral acceleration; sec, second; yr, years.

Ground-motion values determined from national seismic-hazard maps (Frankel and others, 1996) using latitude/longitude computations available online at <geohazards.cr.usgs.gov/eq/index.html>, and representing general values for ground shaking on rock (IBC site class B) at latitude 38°35′ N., longitude 109°32′30″ W. Ground motions at any specific site will vary from these values because of site-specific rock and soil conditions. Values for use in design must be derived from IBC seismic-hazard maps and corrected for geologic site conditions (site class) as required in the IBC seismic provisions.

found to indicate that late Quaternary valley-fill deposits have been cut by the fault. Also, geomorphic relations along the fault indicate very low rates of activity, and bedrock-scarp retreat rates indicate the fault has not moved significantly for at least 1.2 million years (Olig and others, 1996). Therefore, the surface-fault-rupture hazard along the Moab fault during an earthquake appears to be low. The hazard associated with ground shaking produced by movement on the Moab fault is also low. Subsurface and map data (Woodward-Clyde Consultants, 1986; Morgan, 1993; Cooksley Geophysics, 1995; Woodward-Clyde Federal Services, 1996; Doelling and others, 2002) indicate the fault soles into salt deposits at a relatively shallow depth, and therefore is not capable of producing significant earthquakes (Olig and others, 1996; Woodward-Clyde Federal Services, 1996).

Other faults in Moab-Spanish Valley active during Quaternary time are faults in the valley-margin deformation belts. These faults formed as a result of structural collapse in response to dissolution of salt in the diapir beneath Moab-Spanish Valley (Doelling and others, 2002). Although collapse of Moab-Spanish Valley occurred mostly in Quaternary time (Doelling and others, 2002), no evidence exists for significant displacements along the valley-margin faults in late Quaternary time. Therefore, the surface-fault-rupture hazard along these faults during an earthquake appears to be low. Also, the valley-margin faults likely sole into salt deposits at a shallow depth and, like the Moab fault, are not considered capable of producing significant earthquakes.

Areas having shallow ground water (plate 3) and sandy soils are most susceptible to liquefaction during strong earthquake ground shaking. However, liquefaction potential is low even in these susceptible areas in Moab-Spanish Valley because of the low probability of occurrence of earthquakes large enough to cause liquefaction (about M 5; Kuribayashi and Tatsuoka, 1975; Youd, 1977). Woodward-Clyde Federal Services (1996) evaluated an extreme scenario to determine liquefaction potential at the uranium mill tailings site at the northwestern end of the valley, involving the simultaneous occurrence of shallow ground water associated with incipient flooding of the Colorado River and a M 5.5 earthquake. Although liquefaction is predicted under this scenario, the combined probability of incipient flooding and the earthquake is one in 1,250,000 (Woodward-Clyde Federal Services, 1996).

Earthquakes can trigger translational or rotational landslides, but these types of landslides generally are triggered by earthquakes of about magnitude 4.5-5.0 or greater (Keefer, 1984). Because earthquakes in the area typically have magnitudes less than this (see discussion above), the likelihood of earthquake-induced landsliding is low. Earthquake-triggered rock falls are more likely, and would be in the areas shown on plate 3 and discussed above under Rock Fall.

Subsidence

Ultimately, the existence of Moab-Spanish Valley is attributed to dissolution of salt in the salt diapir that underlies the valley by ground water moving from the La Sal Mountains toward the Colorado River. As the salt has dissolved, the overlying rock has collapsed or subsided, creating the valley. Much of the faulting and other deformation in the valley-margin deformation belts formed as a result of salt dissolution and associated subsidence (Doelling and others, 2002).

Several lines of geologic and geomorphic evidence point to broad subsidence of Moab-Spanish Valley during late Quaternary time. Harden and others (1985) attribute the downstream convergence of Pleistocene terraces along Mill Creek, and burial of Pleistocene terraces along Pack Creek, to aggrading conditions in a subsiding basin. Doelling and others (2002) arrived at the same conclusion to explain the disappearance of Mill Creek terraces in Moab Valley. Significant thicknesses of Quaternary basin fill suggest late Quaternary subsidence; Harden and others (1985) report Quaternary deposits greater than 200 feet (61 m) thick in parts of the Moab-Spanish Valley, and Doelling and others (2002) estimate that Quaternary basin fill in the northwestern part of the valley may exceed a thickness of 450 feet (137 m). Finally, the existence of the broad, low-lying Moab Slough area adjacent to the channel of the Colorado River, an unusual occurrence on the Colorado Plateau where erosion and channel incision predominate, indicates recent subsidence and sediment deposition in the northern part of the valley (Harden and others, 1985).

Evidence exists for localized collapse in bedrock along the northeastern margin of Moab-Spanish Valley. Weir and others (1994) identified 33 breccia pipes in Navajo Sandstone within the present study area, and Doelling (2000) identified a similar "collapse feature" in the Entrada Sandstone near the main entrance to Arches National Park. These generally oval-shaped pipes of angular rock fragments have diameters ranging from about 100 to 1,500 feet (30-450 m) and have dropped downward from 30 to over 1,400 feet (10-440 m) (Weir and others, 1994). Although the origin of the breccia pipes remains uncertain, Weir and others (1994) hypothesize that they resulted from continuous collapse of rock caused by dissolution of deeply buried salt and limestone by ground water heated by igneous intrusions of the La Sal Mountains.

Woodward-Clyde Federal Services (1996) estimated Quaternary subsidence rates at the northwestern end of Moab-Spanish Valley of 0.08 to 0.2 millimeters per year (3-8 in/1,000 yr) based on thicknesses of basin-fill sediments, and late Pleistocene rates of 0.4 to 1 millimeter per year (16-40 in/1,000 yr) based on stream incision rates, stratigraphic correlation, and soil development. Woodward-Clyde Federal Services (1996) acknowledge that the estimated subsidence rates, in particular the late Pleistocene rates, are conservative (high) due to poor constraints on ages of deposits and incision rates.

Subsidence due to dissolution of salt at depth appears to be an ongoing process in Moab-Spanish Valley that needs further evaluation. Faults mapped within the valley-margin deformation belts lack evidence demonstrating late Quaternary movement, so the hazard from surface faulting in these areas appears to be low. However, continued subsidence could affect development in a number of ways, including tilting or damage to structures due to differential settlement, lateral earth pressures, ground cracks or displacements in fractured rock, or ground collapse (sinkhole formation). In general, subsidence due to salt dissolution beneath Moab-Spanish Valley is likely characterized by small, incremental displacements over a broad area (Woodward-Clyde Federal Services, 1996), and so the overall hazard is probably low. Also, the absence of sinkholes in Moab-Spanish Valley indicates that the hazard associated with local subsidence or collapse related to underground solution cavities is also low.

Landslides

Geologic evidence shows that, under natural conditions, slopes in the Moab-Spanish Valley area are generally not susceptible to landsliding characterized by deep-seated, rotational or translational movement of soil or rock masses. Only one such landslide deposit is mapped in the study area, a mass of Moab Member of the Curtis Formation on the north side of U.S. Highway 191 near Arches National Park (figure 11); Doelling and others (2002) believe this landslide moved during late or latest middle Pleistocene time. Some of the faults in cliffs along the southern margin of the valley may represent scarps of large-scale late Pleistocene landslides, but strong evidence to support this hypothesis is lacking.

We consider landsliding (exclusive of rock falls and debris flows; see discussions above) to be unlikely under present conditions unless water is introduced or slopes are altered. Landslides would be most likely in highly fractured rock, in the Paradox Formation cap rock, and in clay-rich strata of the Chinle and Kayenta Formations where they locally dip toward valleys or canyons, particularly where these units are exposed in the valley-margin deformation belts (Doelling and others, 2002).

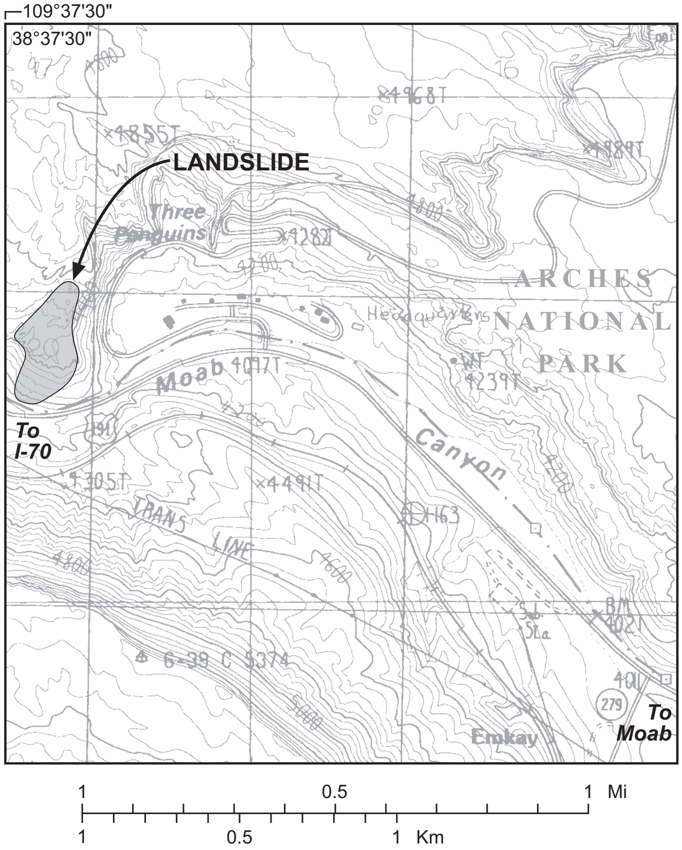

Figure 11. The only landslide deposit mapped in the study area is a mass of Moab Member of the Curtis Formation on the north side of U.S. Hwy. 191 near Arches National Park, in the extreme northwest corner of the study area (modified from Doelling and others, 2002). This landslide moved probably during late or latest middle Pleistocene time.

Design and construction of new development on hillsides should take into account the potential effects of the proposed development on slope stability, such as removing material in cut slopes, adding material by placing fill, and raising local ground-water levels through landscape irrigation or the use of septic-tank soil-absorption systems. Hillside development must adhere to standards set forth in city and county codes and ordinances; where grading or hillside-development permits are required or where construction limitations may apply (generally on slopes greater than 15 percent in the city of Moab, and greater than 30 percent in Grand County), pre-development studies should include geologic and geotechnical evaluations of slope stability and the potential for landsliding following the guidelines presented in Hylland (1996).

Indoor Radon

Radon is an odorless, tasteless, colorless, naturally occurring radioactive gas produced from the radioactive decay of uranium. Uranium, and thus radon, is found in almost all rock and soil in very small concentrations. Because radon is an inert gas, it is very mobile. It can move with air or can be dissolved in water and travel through openings in soil and rock. When present near the ground surface or beneath well-drained, porous, and permeable soil, radon gas can migrate into buildings. Certain types of water usage (such as showering) can release radon gas from well water into the air where it can be inhaled. When inhaled over a long period of time, radon decay products are a significant cause of lung cancer.

Granite, metamorphic rocks, black shales, and some volcanic rocks may be enriched in uranium; these rocks, and the soils derived from them, are the most common sources of radon gas (Sprinkel and Solomon, 1990). Other sources of radon are uranium mines and tailings from uranium mills. In the Moab-Spanish Valley area, uranium occurrences have been documented in mines and prospects in the Honaker Trail, Cutler, and Chinle Formations (Black, 1993; Doelling and others, 2002), and therefore these geologic units are potential radon sources. Also, the Moenkopi Formation has documented uranium occurrences elsewhere in Utah (Black, 1993), and the intrusive igneous rocks of the La Sal Mountains contain uranium (data in Nelson and Davidson, 1998). Streams draining the La Sal Mountains (Mill and Pack Creeks) and areas to the northwest (Courthouse Wash) transport sediment derived from these source rocks into Moab-Spanish Valley, and much of the valley floor is covered by these alluvial deposits.

Near-surface geologic conditions affect the ability of radon to migrate upward from source rocks to the ground surface. For example, most of the alluvium from Mill and Pack Creeks is coarse grained (boulders, cobbles, gravel, and sand), and radon moves readily to the surface in such permeable deposits. However, shallow ground water traps radon and can reduce radon emissions to the ground surface; areas of shallow ground water (<10 feet [3 m]) cover much of Moab-Spanish Valley (plate 3). Faults and zones of highly fractured rock, such as the valley-margin deformation belts, act as pathways for the movement of radon gas. A statewide evaluation of geologic factors that influence indoor-radon levels found the Moab-Spanish Valley area to have a low to moderate radon-hazard potential (Black, 1993).

In addition to geologic conditions, other factors affect indoor-radon concentrations, including the type of structure, methods of construction, and occupant lifestyle. The greatest radon concentrations are commonly in basements and crawl spaces where radon can enter from surrounding soil. Cracks in foundations, leaky seals around pipes that pass through foundations, floor drains, and the water supply are the most common pathways for radon to enter a home.

With the trend toward more energy-efficient construction, newer buildings generally have less air circulation than older buildings and may trap radon gas that enters the structure. However, less radon will be trapped if windows are frequently open. Older buildings may be draftier and allow radon gas to escape more easily than newer buildings, but may also allow more radon to continuously enter through foundation cracks and poorly sealed basements.

Radon concentration is measured in picocuries per liter of air (pCi/L). Most buildings in the United States contain small amounts of radon; however, these concentrations are typically less than 3 pCi/L (Nero and others, 1986). The average indoor-radon concentration is about 1 pCi/L (Sextro, 1988). Long-term exposure to these levels is considered a low health risk to the general population; higher concentrations pose greater risk. The U.S. Environmental Protection Agency (EPA) has established an action level of 4 pCi/L; if short-term (less than 90 days) testing indicates radon levels in excess of 4 pCi/L, follow-up testing should be conducted and remedial measures undertaken as appropriate. A 1988 statewide indoor-radon survey by the Utah Bureau of Radiation Control reported two test results from the Moab area that were 0.7 and 5.6 pCi/L (Sprinkel and Solomon, 1990); the specific locations of these tests are unknown (Barry Solomon, UGS, verbal communication, 2003). More recent unpublished test results on file with the Utah Division of Radiation Control indicate generally low levels of indoor radon in the Moab-Spanish Valley area. Out of 18 long-term (greater than 90 days) tests, only one documented a radon level above 4 pCi/L; a test result of 4.4 pCi/L was obtained from a house in the southwestern part of Moab, in an area underlain by Pack Creek alluvium.

Homeowners should consider testing for indoor-radon concentrations, particularly if the residents are smokers (radioactive isotopes formed from radon decay attach to smoke particles which are then inhaled and increase the risk of lung cancer). Short-term (20-30 days) radon test kits are readily available from most home-improvement stores. For the most accurate assessment of long-term radon exposure, a year-long test should be conducted. One-year test kits are not readily available, but a list of vendors certified to sell them can be obtained from the Utah Division of Radiation Control in Salt Lake City (appendix B). The longer test periods are the most diagnostic of the long-term indoor-radon exposure level because changes in atmospheric pressure, temperature, and moisture can affect radon concentrations.

High indoor-radon levels can be reduced by a variety of methods. Short-term measures with minimum expense include discouraging smoking indoors and spending less time in areas with high radon concentrations such as basements. Increasing ventilation by opening windows or turning on fans may also reduce radon concentrations. Long-term measures include sealing openings in the foundation to prevent radon entry, and ventilating the structure to remove radon-contaminated indoor air and venting it outdoors. Sub-slab suction is a soil ventilation method that can be very effective in removing radon from soil gas before it enters a structure. The sub-slab suction method uses pipes inserted through the floor slab into a layer of crushed rock between the foundation and soil. A fan removes radon-contaminated soil gas from beneath the slab and forces it into the pipes, which release the radon outdoors (U.S. EPA, 1992).

If tests in existing buildings indicate areas of high indoor-radon concentration (greater than 4 piC/L), the reason for the high concentrations should be evaluated. Depending on these results, builders of new homes in those areas should consider incorporating radon-resistant design following the guidelines given in appendix F of the IRC (International Code Council, 2000b). Similar to methods used to retrofit existing buildings, such designs may (1) prevent radon from entering structures by sealing cracks and openings around pipes penetrating the basement floor and walls, and (2) intercept the radon before it enters the house by using sub-slab ventilation (Osborne, 1988). Detailed descriptions of these construction methods are available from the U.S. Environmental Protection Agency.

USES OF THE HAZARD MAPS IN LAND-USE PLANNING

Plates 1 through 4 can be used in a variety of ways by homeowners and other residents, developers, and local governments. The maps can be used as general information to show what hazards may occur and where. In this way, homeowners and residents can assess their exposure to hazards and take whatever action they deem appropriate. The maps may be used in real-estate disclosure so that sellers of homes in hazard areas can disclose to buyers the possible existence of hazards. Also, local governments may use the maps to show where site-specific hazard studies are needed prior to development.

Plates 1 and 2 depict some of the non-life-threatening, soil-related hazards and may be used to alert developers and home builders of potential problems. Hazard studies are most effective when conducted prior to construction to define hazards and guide appropriate design of structures and landscapes. Maps depicting life-threatening hazards (plates 2, 3, and 4) may be used for emergency-response planning, or more comprehensive land-use planning to protect life safety and reduce damages. All of the maps may be adopted in local-government ordinances to show areas where site-specific investigations addressing the particular hazard are required prior to development. These site-specific studies should, in addition to evaluating the hazards, include recommendations for hazard-reduction measures. To be effective, such ordinances must stipulate that the studies be prepared by qualified professionals (engineering geologists, geotechnical engineers, hydrologists) and be reviewed by qualified professionals acting on behalf of government.

Because of the relatively small scale of the maps, some small hazard areas may not be shown. We therefore recommend complete hazard studies even outside the mapped hazard areas for all critical facilities (category II and III structures as defined in the IBC, table 1604.5, p. 297 [International Code Council, 2000a], including hospitals, schools, fire stations, high-occupancy buildings, water-treatment facilities, and facilities containing hazardous materials [IBC class E, H, and I structures]).

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GLOSSARY

Alluvial fan – A generally low, cone-shaped deposit formed by deposition from a stream issuing from mountains as it flows onto a lowland.

Alluvial-fan flooding – Flooding and sediment deposition, including debris flows, on an alluvial-fan surface by overland (sheet) flow or flow in channels branching outward from a canyon mouth. See also *alluvial fan*, *debris flow*.

Alluvium – General term for unconsolidated sediments (clay, sand, gravel) deposited by a stream.

Aquifer – A permeable body of rock or sediment that conducts ground water and can yield significant quantities of water to wells and springs.

Bedding – The arrangement of a sedimentary rock in beds or layers of varying thickness and character.

Breccia pipe – A cylindrical chimney filled with coarse, angular rock fragments held together by a mineral cement or in a fine-grained matrix; may be formed by collapse of rock material.

Cap rock – An impervious concentration of evaporite minerals and other rocks that overlies a buried salt body.

Collapsible soil – Soil that has considerable strength in its dry, natural state but that settles significantly due to hydrocompaction when wetted. Typically associated with geologically young alluvial fans, debris-flow deposits, and loess.

Colluvium – General term applied to any loose, unconsolidated mass of soil material, usually at the foot of a slope or cliff, and brought there chiefly by gravity.

Colorado Plateau physiographic province – Area of generally flat-lying sedimentary rocks in plateaus, mesas, and canyons in southeastern Utah and parts of Arizona, Colorado, and New Mexico.

Debris flow – Slurry of rock, soil, organic matter, and water that flows down channels and onto alluvial fans.

Diapir – Dome or anticlinal (arch-shaped) fold containing a core of salt or shale, where the overlying rocks have been ruptured by the squeezing-out of the plastic core material.

Dip – The angle that a bedding plane makes with the horizontal.

Dissolution – The conversion of rock from solid to liquid state.

Earthquake – Sudden motion or trembling in the Earth's crust as stored elastic energy is released by fracture and movement of rocks along a fault.

Eolian – Pertaining to erosion and deposition accomplished by the wind, and the geologic features formed by wind action.

Erosion – Removal and transport of soil or rock from a land surface, usually through chemical or mechanical means.

Evaporite – A mineral or rock (halite and gypsum, for example) formed by precipitation from a saline solution, typically by evaporation but also by other mechanisms.

Expansive soil/rock – Soil or rock that swells when wetted and contracts when dried. Associated with high clay content, particularly sodium-rich clay.

Fault – A break in the Earth's crust along which movement occurs.

Flood plain – An area adjoining a body of water or natural stream that has been or may be covered by floodwater.

Formation (geologic) – A rock unit consisting of distinctive features/rock types that distinguish it from units above and below.

Gabion – A container of corrosion-resistant wire that holds coarse rock aggregate, and is used to reduce erosion or improve slope stability.

Ground shaking – The shaking or vibration of the ground during an earthquake.

Gypsiferous soil – Soil containing appreciable amounts of gypsum. Gypsiferous soil is subject to subsidence and collapse due to dissolution of the gypsum.

Gypsum – Common evaporite mineral composed of hydrated calcium sulfate.

Hydrocompaction – See Collapsible soil.

Landslide – General term referring to any type of slope failure, but usage here refers chiefly to large-scale rotational slumps and slow-moving earth flows.

Liquefaction – Sudden large decrease in shear strength of a saturated cohesionless soil (generally sand or silt) caused by collapse of soil structure and temporary increase in pore water pressure during earthquake ground shaking. Liquefaction may induce ground failure, including lateral spreads and flow-type landslides.

Loess – A fine-grained blanket deposit of wind-blown (eolian) silt with minor clay and fine sand.

Permeability – Capacity of a porous rock or soil for transmitting a fluid.

Picocurie – Unit of measure of radioactivity. Picocuries per liter (pCi/L) is a common unit used to measure the concentration of radon in air.

Piping – Subsurface erosion by movement of ground water forming a void or "pipe."

Radon – Radioactive gas that occurs naturally through the decay of uranium.

Riprap – A layer of large fragments of broken rock used to prevent erosion by waves or currents.

Rock fall – The relatively free falling or precipitous movement of a rock from a slope by rolling, falling, toppling, or bouncing. The rock-fall runout zone is the area below a rock-fall source which is at risk from falling rocks.

Scarp – A steep slope or face breaking the general continuity of the land by separating surfaces lying at different levels (for example, where there is vertical movement along a fault, or at the head of a landslide).

Subsidence – Permanent lowering of the normal level of the ground surface by any of a number of processes, including dissolution of buried salt.

Surface faulting (surface fault rupture) – Propagation of an earthquake-generating fault rupture to the ground surface, displacing the surface and forming a scarp.

Talus – Rock fragments of any size or shape (usually coarse and angular) derived from and lying at the base of a cliff or very steep, rocky slope.

Weathering – A group of processes involving physical disintegration and chemical decomposition that breaks down rock and produces soil.

APPENDIX A

GEOLOGIC TIME SCALE

(after Palmer and Geissman, 1999)

Subdivisions of Geologic Time			Apparent Ages (millions of years before present)
Era	Period	Epoch	
CENOZOIC	Quaternary	(Recent) Holocene	0.01
		Pleistocene	1.8
	Tertiary	Pliocene	5
		Miocene	24
		Oligocene	34
		Eocene	55
		Paleocene	65
MESOZOIC	Cretaceous		144
	Jurassic		206
	Triassic		248
PALEOZOIC	Cretaceous		290
	Pennsylvanian (Upper Carboniferous)		323
	Mississippian (Lower Carboniferous)		354
	Devonian		417
	Silurian		443
	Ordovician		490
	Cambrian		543
Precambrian			

APPENDIX B

AGENCIES PROVIDING INFORMATION ON GEOLOGIC HAZARDS AND RELATED ISSUES

LOCAL

City of Moab Planning Department
115 West 200 South
Moab, Utah 84532
(435) 259-5129
moabcity.org

Information on planning, zoning, and community development issues.

City of Moab and Grand County Building Department
125 East Center Street
Moab, Utah 84532
(435) 259-1343
grandcountyutah.net

Information on current county development and building regulations.

STATE

Utah Department of Health
Southeastern Utah District Health Department
28 South 100 East
P.O. Box 800
Price, Utah 84501
(435) 637-3671
hlunix.hl.state.ut.us/lhd/html/southeastern_utah_district_hea.html

Information on current Health Department regulations concerning wastewater disposal and systems.

Utah Division of Emergency Services and Homeland Security
Rm. 1110, State Office Bldg.
Salt Lake City, Utah 84114
(801) 538-3400
des.utah.gov

Information concerning emergency response, preparedness, and mitigation. Source of information on FEMA National Flood Insurance Program.

Utah Division of Radiation Control
168 North 1950 West
Building #2, Room 212
P.O. Box 144850
Salt Lake City, Utah 84114-4850
(801) 536-4250
www.deq.state.ut.us/EQRAD/drc_hmpg.htm

Information on indoor-radon testing and mitigation.

Utah Division of Water Rights
1594 W. North Temple Suite 220
P.O. Box 146300
Salt Lake City, Utah 84114-6300
(801) 538-7240
waterrights.utah.gov

Regulations concerning appropriation and distribution of water in the state of Utah. Technical publications concerning local and regional water resources. Publications contain information on water source, amount, and quality in Utah.

Utah Geological Survey
1594 W. North Temple, Suite 3110
P.O. Box 146100
Salt Lake City, Utah 84114-6100
(801) 537-3300
geology.utah.gov

Geologic information concerning geologic hazards, ground water, geologic mapping, fossils, and economic geology. Geologic Hazards Program conducts local and regional geologic-hazards studies. Topographic and geologic maps, and publications on geologic hazards and other geology topics available through the Natural Resources Map and Bookstore; (801) 537-3320, 1-888-UTAH MAP, mapstore.utah.gov.

FEDERAL

U.S. Bureau of Land Management
Moab District Office
82 East Dogwood
Moab, Utah 84532
(435) 259-2100
blm.gov/nhp

Ownership and management of federal lands; knowledge of geology, water resources, and vegetation on lands under their jurisdiction.

U.S. Environmental Protection Agency – Region 8
Mail Code (8P-AR)
999 18th Street, Suite 300
Denver, Colorado 80202-2466
(303) 312-6031; 1-800-227-8917
www.epa.gov/region08/air/iaq/radon/radon.html

General information on indoor radon and testing for indoor-radon levels.

U.S. Geological Survey
Salt Lake Information Office
2329 W. Orton Circle
West Valley City, Utah 84119
(801) 908-5000
usgs.gov
ut.water.usgs.gov

General geologic information, data on surface and ground water, and USGS publications available.

U.S. Natural Resources Conservation Service (formerly Soil Conservation Service)
Price Service Center
350 North 400 East
Price, Utah 84501
(435) 637-0041
nrcs.usda.gov

Regional and local soil surveys. Surveys contain information on soil type, description, engineering properties, and agricultural uses.

PLATE 1
SPECIAL STUDY 107
UTAH GEOLOGICAL SURVEY

UTAH GEOLOGICAL SURVEY
a division of
Department of Natural Resources

EXPANSIVE AND GYPSIFEROUS SOIL AND ROCK
MOAB - SPANISH VALLEY
GRAND COUNTY, UTAH

by

Michael D. Hylland and William E. Mulvey

Digital Compilation by

Justin P. Johnson and Matt Butler

2003

SCALE 1:24,000

1 ½ 0 1 MILE

1 ½ 0 1 KILOMETER

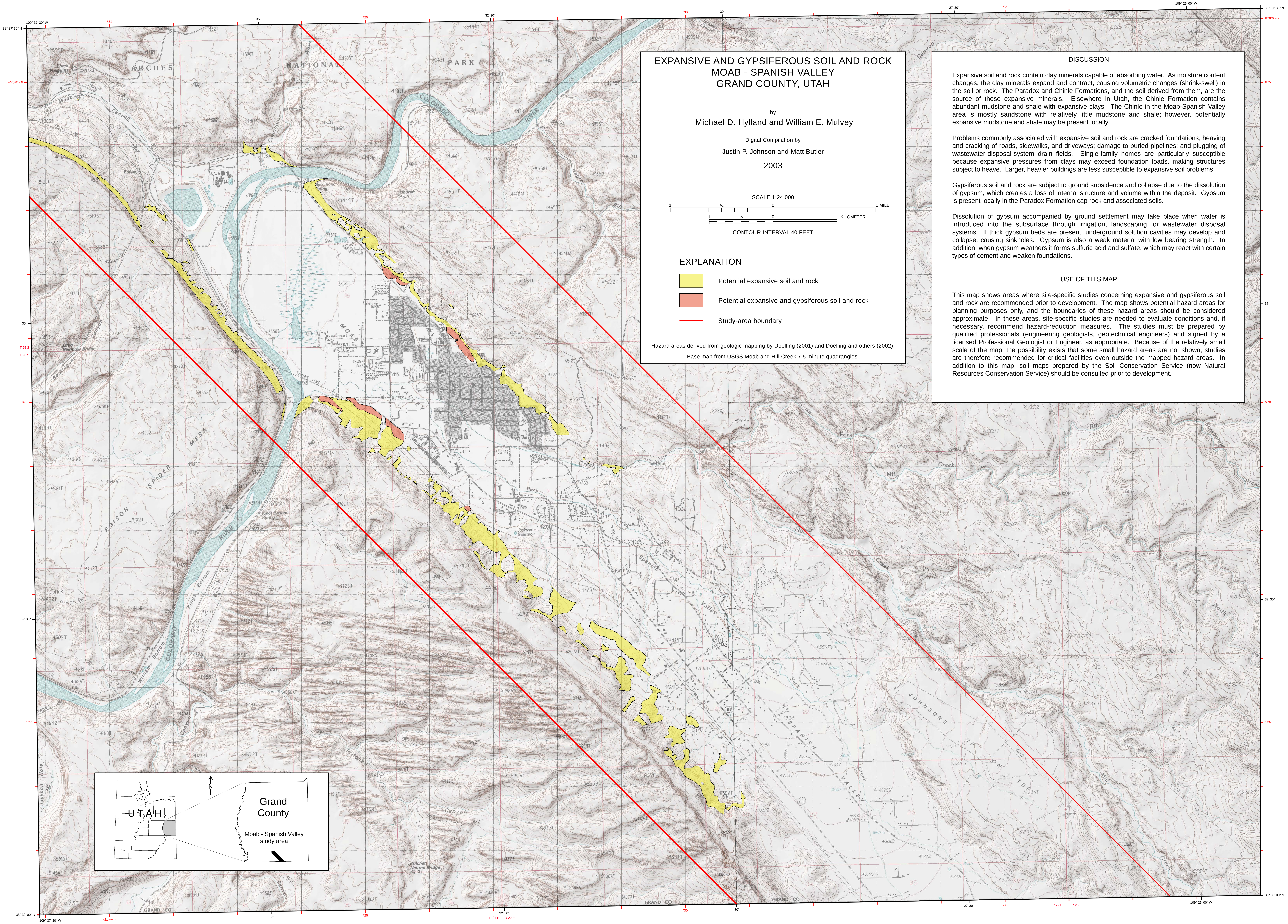
CONTOUR INTERVAL 40 FEET

EXPLANATION

🟨	Potential expansive soil and rock
🟥	Potential expansive and gypsiferous soil and rock
—	Study-area boundary

Hazard areas derived from geologic mapping by Doelling (2001) and Doelling and others (2002).

Base map from USGS Moab and Rill Creek 7.5 minute quadrangles.



DISCUSSION

Expansive soil and rock contain clay minerals capable of absorbing water. As moisture content changes, the clay minerals expand and contract, causing volumetric changes (shrink-swell) in the soil or rock. The Paradox and Chinle Formations, and the soil derived from them, are the source of these expansive minerals. Elsewhere in Utah, the Chinle Formation contains abundant mudstone and shale with expansive clays. The Chinle in the Moab-Spanish Valley area is mostly sandstone with relatively little mudstone and shale; however, potentially expansive mudstone and shale may be present locally.

Problems commonly associated with expansive soil and rock are cracked foundations; heaving and cracking of roads, sidewalks, and driveways; damage to buried pipelines; and plugging of wastewater-disposal-system drain fields. Single-family homes are particularly susceptible because expansive pressures from clays may exceed foundation loads, making structures subject to heave. Larger, heavier buildings are less susceptible to expansive soil problems.

Gypsiferous soil and rock are subject to ground subsidence and collapse due to the dissolution of gypsum, which creates a loss of internal structure and volume within the deposit. Gypsum is present locally in the Paradox Formation cap rock and associated soils.

Dissolution of gypsum accompanied by ground settlement may take place when water is introduced into the subsurface through irrigation, landscaping, or wastewater disposal systems. If thick gypsum beds are present, underground solution cavities may develop and collapse, causing sinkholes. Gypsum is also a weak material with low bearing strength. In addition, when gypsum weathers it forms sulfuric acid and sulfate, which may react with certain types of cement and weaken foundations.

USE OF THIS MAP

This map shows areas where site-specific studies concerning expansive and gypsiferous soil and rock are recommended prior to development. The map shows potential hazard areas for planning purposes only, and the boundaries of these hazard areas should be considered approximate. In these areas, site-specific studies are needed to evaluate conditions and, if necessary, recommend hazard-reduction measures. The studies must be prepared by qualified professionals (engineering geologists, geotechnical engineers) and signed by a licensed Professional Geologist or Engineer, as appropriate. Because of the relatively small scale of the map, the possibility exists that some small hazard areas are not shown; studies are therefore recommended for critical facilities even outside the mapped hazard areas. In addition to this map, soil maps prepared by the Soil Conservation Service (now Natural Resources Conservation Service) should be consulted prior to development.

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ALLUVIAL-FAN FLOODING, DEBRIS FLOWS, COLLAPSIBLE SOIL, AND SOIL SUSCEPTIBLE TO PIPING AND EROSION
MOAB - SPANISH VALLEY
GRAND COUNTY, UTAH

by

Michael D. Hylland and William E. Mulvey

Digital Compilation by

Justin P. Johnson and Matt Butler

2003

SCALE 1:24,000

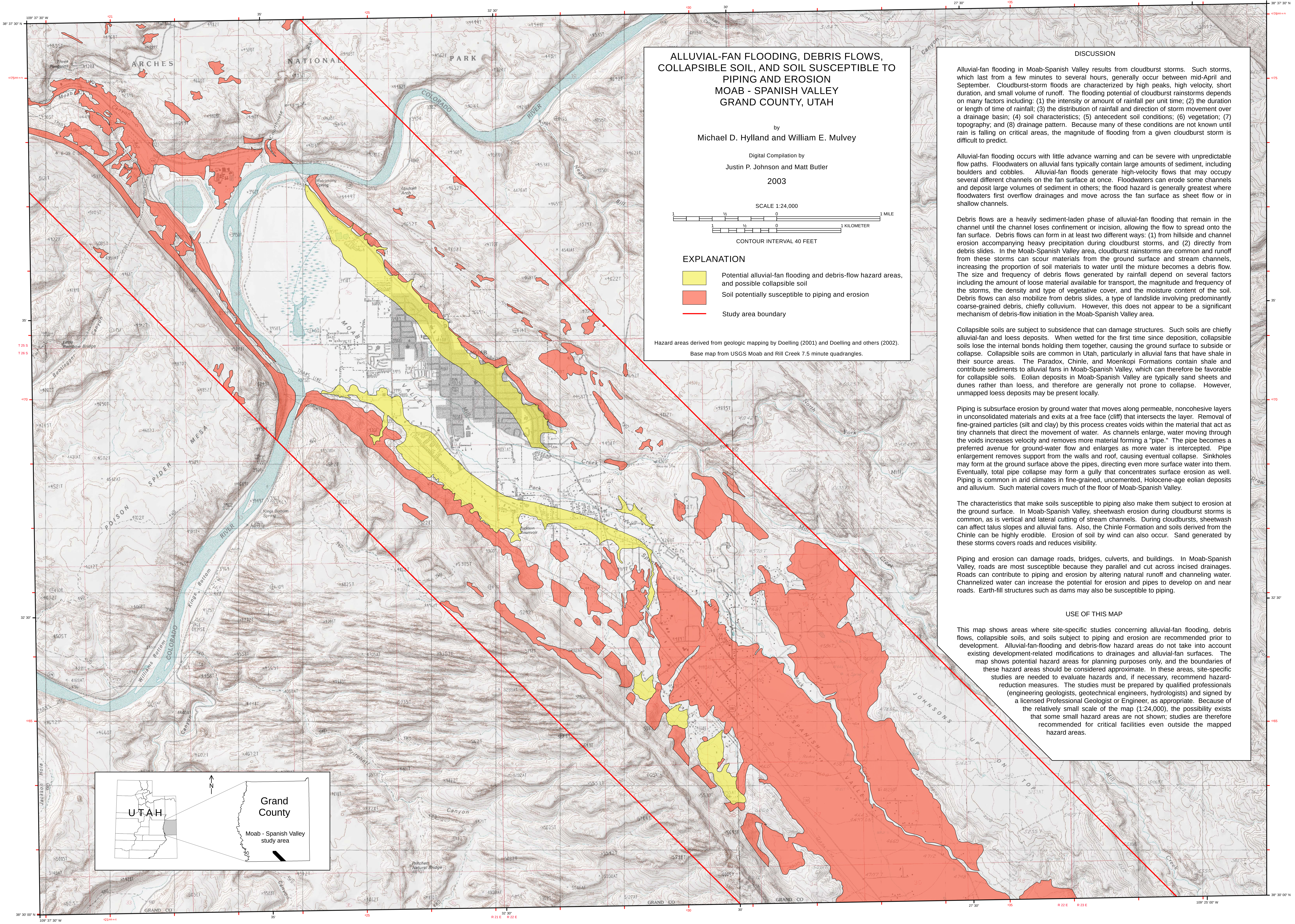
CONTOUR INTERVAL 40 FEET

EXPLANATION

🟨	Potential alluvial-fan flooding and debris-flow hazard areas, and possible collapsible soil
🟥	Soil potentially susceptible to piping and erosion
—	Study area boundary

Hazard areas derived from geologic mapping by Doelling (2001) and Doelling and others (2002).

Base map from USGS Moab and Rill Creek 7.5 minute quadrangles.



DISCUSSION

Alluvial-fan flooding in Moab-Spanish Valley results from cloudburst storms. Such storms, which last from a few minutes to several hours, generally occur between mid-April and September. Cloudburst-storm floods are characterized by high peaks, high velocity, short duration, and small volume of runoff. The flooding potential of cloudburst rainstorms depends on many factors including: (1) the intensity or amount of rainfall per unit time; (2) the duration or length of time of rainfall; (3) the distribution of rainfall and direction of storm movement over a drainage basin; (4) soil characteristics; (5) antecedent soil conditions; (6) vegetation; (7) topography; and (8) drainage pattern. Because many of these conditions are not known until rain is falling on critical areas, the magnitude of flooding from a given cloudburst storm is difficult to predict.

Alluvial-fan flooding occurs with little advance warning and can be severe with unpredictable flow paths. Floodwaters on alluvial fans typically contain large amounts of sediment, including boulders and cobbles. Alluvial-fan floods generate high-velocity flows that may occupy several different channels on the fan surface at once. Floodwaters can erode some channels and deposit large volumes of sediment in others; the flood hazard is generally greatest where floodwaters first overflow drainages and move across the fan surface as sheet flow or in shallow channels.

Debris flows are a heavily sediment-laden phase of alluvial-fan flooding that remain in the channel until the channel loses confinement or incision, allowing the flow to spread onto the fan surface. Debris flows can form in at least two different ways: (1) from hillside and channel erosion accompanying heavy precipitation during cloudburst storms, and (2) directly from debris slides. In the Moab-Spanish Valley area, cloudburst rainstorms are common and runoff from these storms can scour materials from the ground surface and stream channels, increasing the proportion of soil materials to water until the mixture becomes a debris flow. The size and frequency of debris flows generated by rainfall depend on several factors including the amount of loose material available for transport, the magnitude and frequency of the storms, the density and type of vegetative cover, and the moisture content of the soil. Debris flows can also mobilize from debris slides, a type of landslide involving predominantly coarse-grained debris, chiefly colluvium. However, this does not appear to be a significant mechanism of debris-flow initiation in the Moab-Spanish Valley area.

Collapsible soils are subject to subsidence that can damage structures. Such soils are chiefly alluvial-fan and loess deposits. When wetted for the first time since deposition, collapsible soils lose the internal bonds holding them together, causing the ground surface to subside or collapse. Collapsible soils are common in Utah, particularly in alluvial fans that have shale in their source areas. The Paradox, Chinle, and Moenkopi Formations contain shale and contribute sediments to alluvial fans in Moab-Spanish Valley, which can therefore be favorable for collapsible soils. Eolian deposits in Moab-Spanish Valley are typically sand sheets and dunes rather than loess, and therefore are generally not prone to collapse. However, unmapped loess deposits may be present locally.

Piping is subsurface erosion by ground water that moves along permeable, noncohesive layers in unconsolidated materials and exits at a free face (cliff) that intersects the layer. Removal of fine-grained particles (silt and clay) by this process creates voids within the material that act as tiny channels that direct the movement of water. As channels enlarge, water moving through the voids increases velocity and removes more material forming a "pipe." The pipe becomes a preferred avenue for ground-water flow and enlarges as more water is intercepted. Pipe enlargement removes support from the walls and roof, causing eventual collapse. Sinkholes may form at the ground surface above the pipes, directing even more surface water into them. Eventually, total pipe collapse may form a gully that concentrates surface erosion as well. Piping is common in arid climates in fine-grained, uncemented, Holocene-age eolian deposits and alluvium. Such material covers much of the floor of Moab-Spanish Valley.

The characteristics that make soils susceptible to piping also make them subject to erosion at the ground surface. In Moab-Spanish Valley, sheetwash erosion during cloudburst storms is common, as is vertical and lateral cutting of stream channels. During cloudbursts, sheetwash can affect talus slopes and alluvial fans. Also, the Chinle Formation and soils derived from the Chinle can be highly erodible. Erosion of soil by wind can also occur. Sand generated by these storms covers roads and reduces visibility.

Piping and erosion can damage roads, bridges, culverts, and buildings. In Moab-Spanish Valley, roads are most susceptible because they parallel and cut across incised drainages. Roads can contribute to piping and erosion by altering natural runoff and channeling water. Channelized water can increase the potential for erosion and pipes to develop on and near roads. Earth-fill structures such as dams may also be susceptible to piping.

USE OF THIS MAP

This map shows areas where site-specific studies concerning alluvial-fan flooding, debris flows, collapsible soils, and soils subject to piping and erosion are recommended prior to development. Alluvial-fan-flooding and debris-flow hazard areas do not take into account existing development-related modifications to drainages and alluvial-fan surfaces. The map shows potential hazard areas for planning purposes only, and the boundaries of these hazard areas should be considered approximate. In these areas, site-specific studies are needed to evaluate hazards and, if necessary, recommend hazard-reduction measures. The studies must be prepared by qualified professionals (engineering geologists, geotechnical engineers, hydrologists) and signed by a licensed Professional Geologist or Engineer, as appropriate. Because of the relatively small scale of the map (1:24,000), the possibility exists that some small hazard areas are not shown; studies are therefore recommended for critical facilities even outside the mapped hazard areas.

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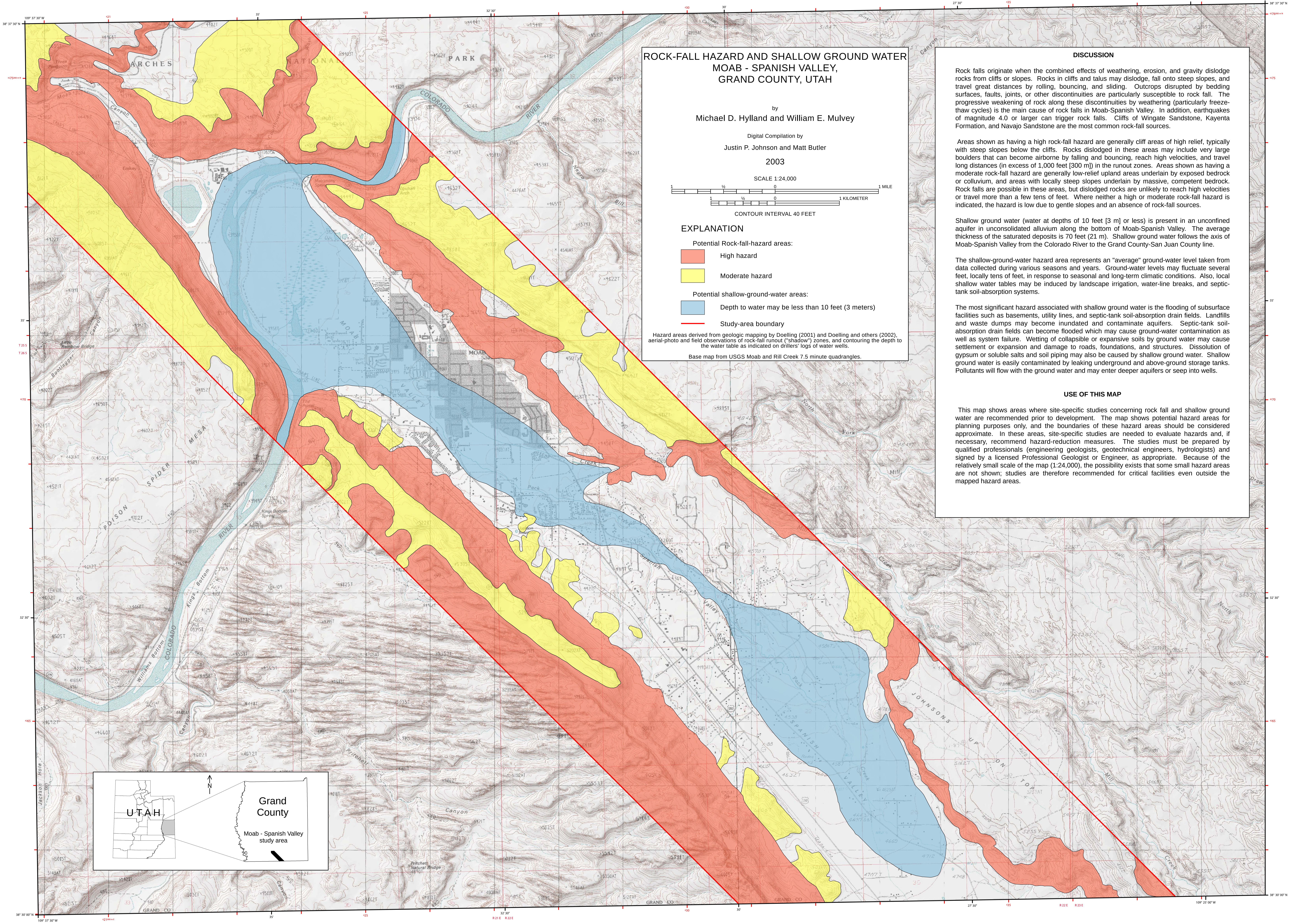

ROCK-FALL HAZARD AND SHALLOW GROUND WATER MOAB - SPANISH VALLEY, GRAND COUNTY, UTAH

by

Michael D. Hylland and William E. Mulvey

Digital Compilation by

Justin P. Johnson and Matt Butler

2003

SCALE 1:24,000

CONTOUR INTERVAL 40 FEET

EXPLANATION

Potential Rock-fall-hazard areas:

🟥 High hazard

🟨 Moderate hazard

Potential shallow-ground-water areas:

🟦 Depth to water may be less than 10 feet (3 meters)

— Study-area boundary

Hazard areas derived from geologic mapping by Doelling (2001) and Doelling and others (2002), aerial-photo and field observations of rock-fall runout ("shadow") zones, and contouring the depth to the water table as indicated on drillers' logs of water wells.

Base map from USGS Moab and Rill Creek 7.5 minute quadrangles.

DISCUSSION

Rock falls originate when the combined effects of weathering, erosion, and gravity dislodge rocks from cliffs or slopes. Rocks in cliffs and talus may dislodge, fall onto steep slopes, and travel great distances by rolling, bouncing, and sliding. Outcrops disrupted by bedding surfaces, faults, joints, or other discontinuities are particularly susceptible to rock fall. The progressive weakening of rock along these discontinuities by weathering (particularly freeze-thaw cycles) is the main cause of rock falls in Moab-Spanish Valley. In addition, earthquakes of magnitude 4.0 or larger can trigger rock falls. Cliffs of Wingate Sandstone, Kayenta Formation, and Navajo Sandstone are the most common rock-fall sources.

Areas shown as having a high rock-fall hazard are generally cliff areas of high relief, typically with steep slopes below the cliffs. Rocks dislodged in these areas may include very large boulders that can become airborne by falling and bouncing, reach high velocities, and travel long distances (in excess of 1,000 feet [300 m]) in the runout zones. Areas shown as having a moderate rock-fall hazard are generally low-relief upland areas underlain by exposed bedrock or colluvium, and areas with locally steep slopes underlain by massive, competent bedrock. Rock falls are possible in these areas, but dislodged rocks are unlikely to reach high velocities or travel more than a few tens of feet. Where neither a high or moderate rock-fall hazard is indicated, the hazard is low due to gentle slopes and an absence of rock-fall sources.

Shallow ground water (water at depths of 10 feet [3 m] or less) is present in an unconfined aquifer in unconsolidated alluvium along the bottom of Moab-Spanish Valley. The average thickness of the saturated deposits is 70 feet (21 m). Shallow ground water follows the axis of Moab-Spanish Valley from the Colorado River to the Grand County-San Juan County line.

The shallow-ground-water hazard area represents an "average" ground-water level taken from data collected during various seasons and years. Ground-water levels may fluctuate several feet, locally tens of feet, in response to seasonal and long-term climatic conditions. Also, local shallow water tables may be induced by landscape irrigation, water-line breaks, and septic-tank soil-absorption systems.

The most significant hazard associated with shallow ground water is the flooding of subsurface facilities such as basements, utility lines, and septic-tank soil-absorption drain fields. Landfills and waste dumps may become inundated and contaminate aquifers. Septic-tank soil-absorption drain fields can become flooded which may cause ground-water contamination as well as system failure. Wetting of collapsible or expansive soils by ground water may cause settlement or expansion and damage to roads, foundations, and structures. Dissolution of gypsum or soluble salts and soil piping may also be caused by shallow ground water. Shallow ground water is easily contaminated by leaking underground and above-ground storage tanks. Pollutants will flow with the ground water and may enter deeper aquifers or seep into wells.

USE OF THIS MAP

This map shows areas where site-specific studies concerning rock fall and shallow ground water are recommended prior to development. The map shows potential hazard areas for planning purposes only, and the boundaries of these hazard areas should be considered approximate. In these areas, site-specific studies are needed to evaluate hazards and, if necessary, recommend hazard-reduction measures. The studies must be prepared by qualified professionals (engineering geologists, geotechnical engineers, hydrologists) and signed by a licensed Professional Geologist or Engineer, as appropriate. Because of the relatively small scale of the map (1:24,000), the possibility exists that some small hazard areas are not shown; studies are therefore recommended for critical facilities even outside the mapped hazard areas.

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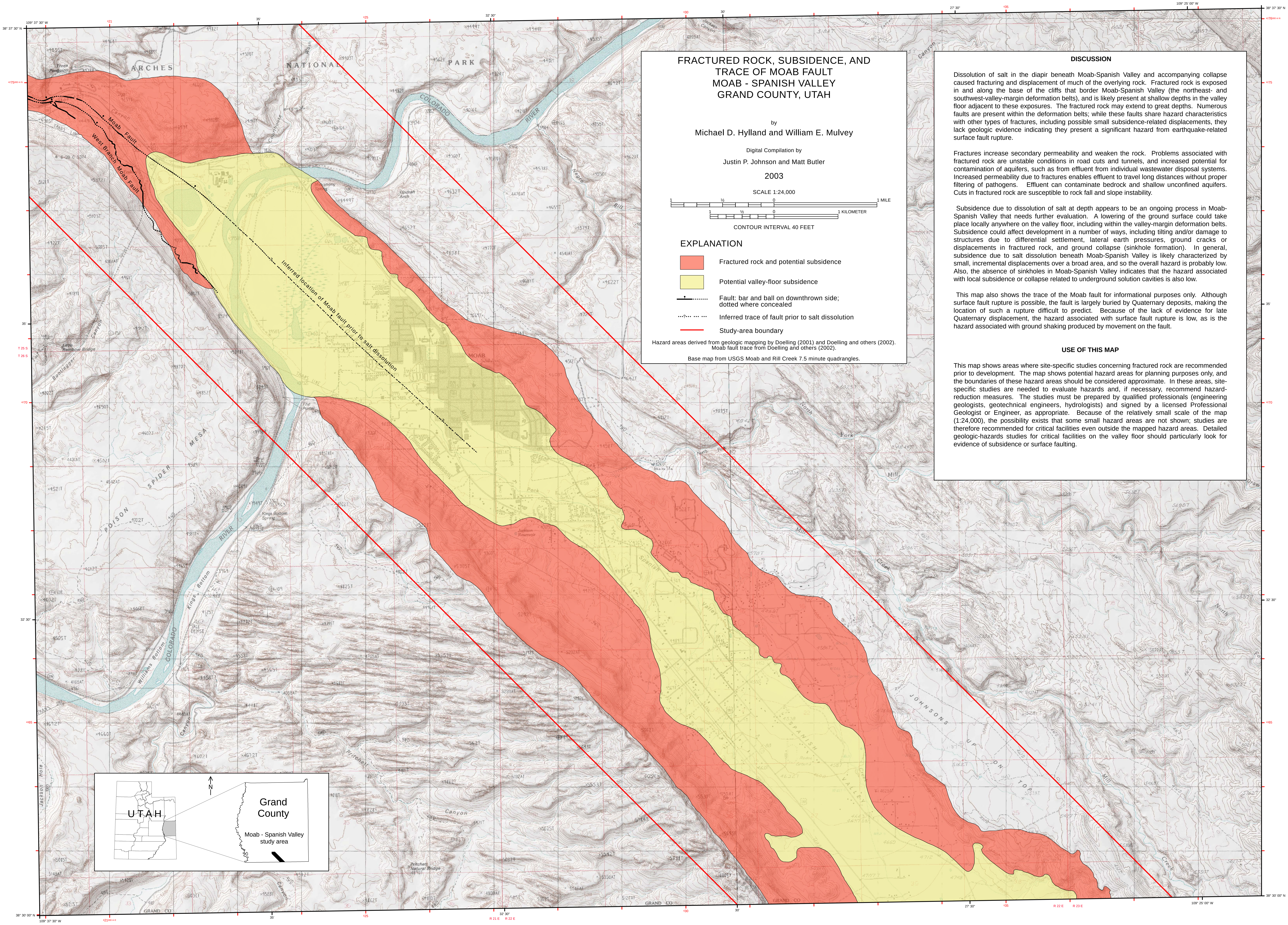
PLATE 4
SPECIAL STUDY 107
UTAH GEOLOGICAL SURVEY



FRACTURED ROCK, SUBSIDENCE, AND TRACE OF MOAB FAULT MOAB - SPANISH VALLEY GRAND COUNTY, UTAH

by

Michael D. Hylland and William E. Mulvey

Digital Compilation by

Justin P. Johnson and Matt Butler

2003

SCALE 1:24,000

1 ½ 0 1 MILE

1 ½ 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET

EXPLANATION

🟥 Fractured rock and potential subsidence

🟨 Potential valley-floor subsidence

—•—······· Fault: bar and ball on downthrown side; dotted where concealed

···?··· ··· ··· Inferred trace of fault prior to salt dissolution

— Study-area boundary

Hazard areas derived from geologic mapping by Doelling (2001) and Doelling and others (2002). Moab fault trace from Doelling and others (2002).

Base map from USGS Moab and Rill Creek 7.5 minute quadrangles.

DISCUSSION

Dissolution of salt in the diapir beneath Moab-Spanish Valley and accompanying collapse caused fracturing and displacement of much of the overlying rock. Fractured rock is exposed in and along the base of the cliffs that border Moab-Spanish Valley (the northeast- and southwest-valley-margin deformation belts), and is likely present at shallow depths in the valley floor adjacent to these exposures. The fractured rock may extend to great depths. Numerous faults are present within the deformation belts; while these faults share hazard characteristics with other types of fractures, including possible small subsidence-related displacements, they lack geologic evidence indicating they present a significant hazard from earthquake-related surface fault rupture.

Fractures increase secondary permeability and weaken the rock. Problems associated with fractured rock are unstable conditions in road cuts and tunnels, and increased potential for contamination of aquifers, such as from effluent from individual wastewater disposal systems. Increased permeability due to fractures enables effluent to travel long distances without proper filtering of pathogens. Effluent can contaminate bedrock and shallow unconfined aquifers. Cuts in fractured rock are susceptible to rock fall and slope instability.

Subsidence due to dissolution of salt at depth appears to be an ongoing process in Moab-Spanish Valley that needs further evaluation. A lowering of the ground surface could take place locally anywhere on the valley floor, including within the valley-margin deformation belts. Subsidence could affect development in a number of ways, including tilting and/or damage to structures due to differential settlement, lateral earth pressures, ground cracks or displacements in fractured rock, and ground collapse (sinkhole formation). In general, subsidence due to salt dissolution beneath Moab-Spanish Valley is likely characterized by small, incremental displacements over a broad area, and so the overall hazard is probably low. Also, the absence of sinkholes in Moab-Spanish Valley indicates that the hazard associated with local subsidence or collapse related to underground solution cavities is also low.

This map also shows the trace of the Moab fault for informational purposes only. Although surface fault rupture is possible, the fault is largely buried by Quaternary deposits, making the location of such a rupture difficult to predict. Because of the lack of evidence for late Quaternary displacement, the hazard associated with surface fault rupture is low, as is the hazard associated with ground shaking produced by movement on the fault.

USE OF THIS MAP

This map shows areas where site-specific studies concerning fractured rock are recommended prior to development. The map shows potential hazard areas for planning purposes only, and the boundaries of these hazard areas should be considered approximate. In these areas, site-specific studies are needed to evaluate hazards and, if necessary, recommend hazard-reduction measures. The studies must be prepared by qualified professionals (engineering geologists, geotechnical engineers, hydrologists) and signed by a licensed Professional Geologist or Engineer, as appropriate. Because of the relatively small scale of the map (1:24,000), the possibility exists that some small hazard areas are not shown; studies are therefore recommended for critical facilities even outside the mapped hazard areas. Detailed geologic-hazards studies for critical facilities on the valley floor should particularly look for evidence of subsidence or surface faulting.