UTAH GEOLOGICAL SURVEY
*a division of*
Utah Department of Natural Resources

## EXPLANATION

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

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

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

## INTRODUCTION

Collapsible (hydrocompactible) soils have considerable dry strength and stiffness in their dry natural state, but can settle up to 10 percent of the susceptible deposit thickness when they become wet for the first time following deposition (Costa and Baker, 1981; Rollins and Rogers, 1994) causing damage to property and structures (figure 1). Collapsible soils are common throughout the arid southwestern United States and are commonly geologically young materials, chiefly debris-flow deposits in Holocene-age alluvial fans, and some wind-blown, lacustrine, and colluvial deposits (Owens and Rollins, 1990; Mulvey, 1992; Santi, 2005). David Black (Rosenberg Associates, written communication, 2012) reports that honeycomb structure caused by gypsum dissolution in both rock and soil can extend to as much as 10 feet below the ground surface in gypsum-susceptible areas in southwestern Utah and may lead to collapse-prone foundation conditions (see Gypsiferous Soil and Rock Map [plate 6]).

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

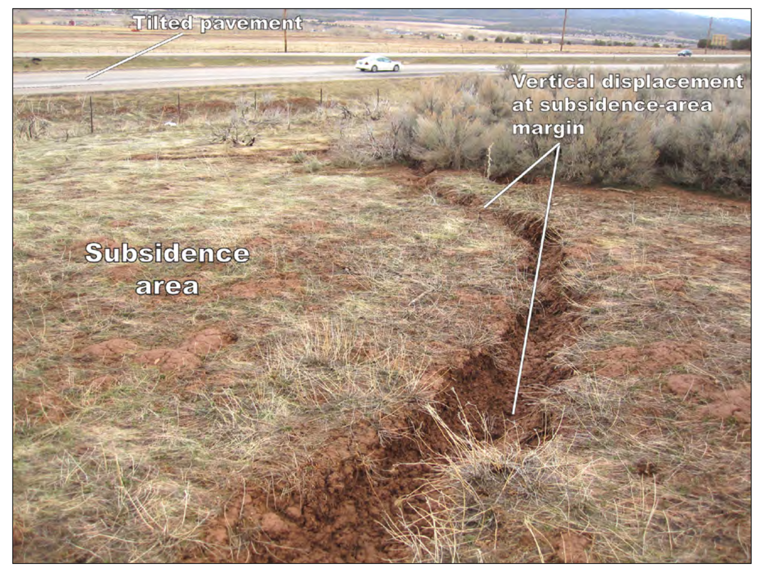


***Figure 1.*** *Ground subsidence caused by poor drainage in collapsible soils adversely affects Interstate 15 in southwestern Utah. Photo date: March 7, 2010.*

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

Naturally occurring deep percolation of water into collapsible deposits is uncommon after deposition due to the arid conditions in which the deposits typically form, and the steep gradient of many alluvial-fan and colluvial surfaces. Therefore, soil collapse is usually triggered by human activity such as irrigation, urbanization, and/or wastewater disposal. Kaliser (1978) reported serious damage (estimated $3 million) to public and private structures in Cedar City, Utah, from collapsible soils. Rollins and others (1994) documented more than $20 million in required remedial measures to a cement plant near Leamington, Utah, and Smith and Deal (1988) reported damage to a large flood-control structure near Monroe, Utah. In 2001, collapsible soils damaged the Zion National Park greenhouse soon after it was constructed (figure 2), as soils below and around the building were wetted by excess irrigation water. Park employees reported that a wastewater treatment plant that had once been located nearby also had a history of damage from ground subsidence.

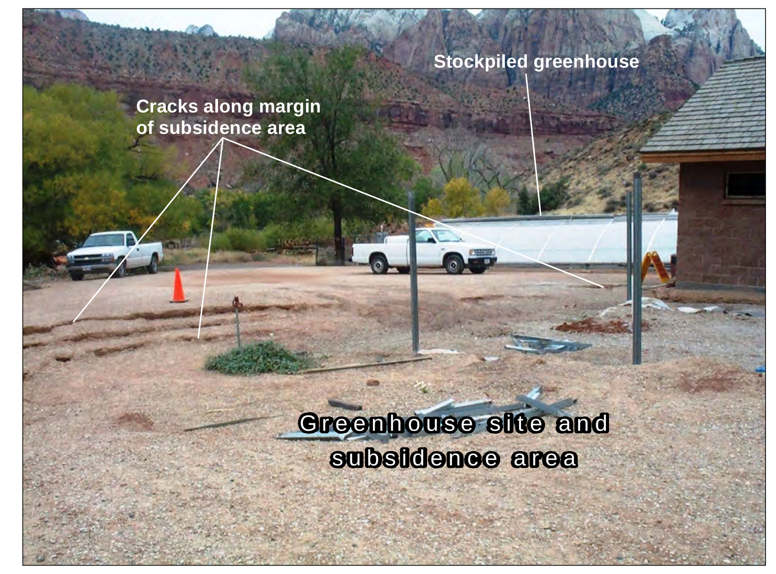


***Figure 2.*** *Site of the Zion National Park greenhouse (stockpiled behind truck near photo center) damaged by collapsible soils. Circa 2001 photo; courtesy of the National Park Service.*

## SOURCES OF INFORMATION

Sources of information used to evaluate collapsible soil in the State Route 9 Corridor Geologic-Hazard Study Area (SR-9 study area) include (1) 40 geotechnical reports on file with the National Park Service (NPS), the Utah Department of Transportation (UDOT), and the towns of Springdale and Virgin, (2) Natural Resources Conservation Service (NRCS) (formerly Soil Conservation Service) *Soil Survey of Washington County Area, Utah* (Mortensen and others, 1977), (3) the four Utah Geological Survey (UGS) 1:24,000-scale geologic quadrangle maps that cover the study area (Virgin [Hayden and Sable, 2008], Springdale West [Willis and others, 2002], Springdale East [Doelling and others, 2002], and Smithsonian Butte [Moore and Sable, 2001]), (4) *Engineering Geology of the St. George Area, Washington County, Utah* (Christenson and Deen, 1983), (5) "Geologic Hazards of the St. George Area, Washington County, Utah" (Christenson, 1992), (6) *Engineering Geologic Map Folio, Springdale, Washington County, Utah* (Solomon, 1996), (7) *Geologic Hazards and Adverse Construction Conditions, St. George–Hurricane Metropolitan Area, Washington County, Utah* (Lund and others, 2008), and (8) *Geologic Hazards of the Zion National Park Geologic-Hazard Study Area, Washington and Kane Counties, Utah* (Lund and others, 2010).

## DESCRIPTION

### Geologic Characteristics

Review of geotechnical reports prepared for projects in and near the SR-9 study area showed that collapsible soils are common in areas underlain by geologically young alluvial-fan and colluvial deposits. However, the geotechnical data are limited to a few newer buildings in Zion National Park just outside the study area boundary, to shuttle bus stops in Zion Canyon, to areas of newer development in the towns of Springdale and Virgin, and to a few bridges and borrow pits along the State Route 9 right-of-way. To estimate the collapse potential of soils where geotechnical data were not available, it was necessary to extrapolate based on the geologic unit characteristics shown on UGS geologic maps (see Sources of Information) and make comparisons with similar units in the St. George area, where geotechnical data are more abundant (Lund and others, 2008). The NRCS *Soil Survey of Washington County Area, Utah* (Mortensen and others, 1977) does not contain information on soil-collapse potential.

Utah Geological Survey geologic mapping classifies the unconsolidated deposits in the study area into 41 geologic units. Swell/collapse test (SCT) data are available for only a few of those units. Eight units have reported collapse values of ≥3 percent, the level at which collapse generally becomes a significant engineering concern given a sufficient thickness of susceptible soil (Jennings and Knight, 1975). As discussed above, soil collapse is closely associated with soil texture. A variation of a few percent in clay content can be the difference between a deposit that will collapse and one that will swell when wetted. The unconsolidated geologic units on UGS geologic maps are defined by geomorphology (landform), genesis, and to a lesser extent texture. Therefore, some unconsolidated geologic units show considerable textural variation. For example, geologic unit Qafc, which denotes mixed alluvial-fan and colluvial deposits, is reported, depending on location, to have SCT values in excess of 3 percent collapse and 3 percent swell. Therefore, while geology can be used as an indicator of collapse potential, it is not an infallible guide, and site-specific soil testing is always required.

### Geotechnical Data Evaluation

The geotechnical database compiled for this study contains 90 SCT soil/rock sample test results. The results for 54 of the samples (60%) indicate collapse potential. Of the 54 collapsible samples, 26 have SCT values ≥3 percent, and therefore are problematic from an engineering standpoint. Table 1 shows the relation between ASTM Unified Soil Classification System (USCS) soil types and collapse values ≥3 percent in the SR-9 study area and vicinity. As expected, most collapsible soils consist of silty or clayey sand and silts. The silts (ML) tested show a higher percentage of collapsible samples than do clayey sands (SC). The silts are likely loess deposits of eolian origin. Clay-rich soils (CL and CH) and poorly graded (well sorted) sands (SP) show the lowest potential for collapse, but nevertheless, more than 8 percent of low-plasticity (CL) clays tested show significant collapse potential.

***Table 1.*** *Relation of high collapse test values (≥3%) to USCS soil types in the geotechnical database.*

| USCS Soil Type | Total Samples in Database | Samples Tested (number) | Samples Tested (percent) | Samples Having Collapse ≥3% (number) | Samples Having Collapse ≥3% (percent) |
|---|---|---|---|---|---|
| **SM** | 223 | 31 | 14 | 16 | 52 |
| **SC** | 35 | 5 | 14 | 3 | 60 |
| **SM/SP** | 30 | 4 | 13 | 2 | 50 |
| **SP** | 19 | 1 | 5 | 0 | 0 |
| **CH** | 13 | 5 | 38 | 0 | 0 |
| **ML** | 27 | 3 | 11 | 2 | 67 |
| **CL** | 189 | 36 | 19 | 3 | 8 |
| **Bedrock** | 21 | 5 | 24 | 0 | 0 |
| **Total** | 557 | 90 | 16 | 26 | 29 |

## HAZARD CLASSIFICATION

We grouped unconsolidated geologic units that may be prone to collapse into three susceptibility categories (table 2). The categories are based on available geotechnical data, and if the deposit genesis or texture is permissive of collapse. Due to the lack of geotechnical data over much of the study area, the classification system presented here employs a relative susceptibility ranking as opposed to a hazard-severity ranking. The soils in all three categories could exhibit ≥3 percent collapse, and therefore be regarded as having significant collapse potential. The collapsible-soil susceptibility categories are described in the Explanation section.

***Table 2.*** *Geologic deposits known or likely to have a significant potential for soil collapse.*

| Type of Deposit | Geologic Map Units[1] | Collapsible Soil Category |
|---|---|---|
| Stream and Terrace Alluvium | $Qa_1$, $Qa_2$, $Qat_1$, $Qat_2$, $Qat_3$, Qath, Qatm, Qats | $CS_A$ |
| | Qay | $CS_B$ |
| | Qag, $Qat_4$, $Qat_5$, $Qat_6$, $Qat_7$ | $CS_C$ |
| Fan Alluvium | Qae, Qafc, Qafco, Qmsc (alluvial parts) | $CS_A$ |
| | Qac, $Qaf_2$, Qao, Qagp, $Qmcp_1$, $Qmcp_2$, $Qmcp_3$ (alluvial parts) | $CS_B$ |
| | Qaco | $CS_C$ |
| Eolian Deposits | Qea, Qer | $CS_A$ |
| | Qes, Qec | $CS_B$ |
| Colluvial Deposits | Qc, Qmt, Qmts, Qmr | $CS_B$ |
| | Qco, Qmto | $CS_C$ |
| Lacustrine Deposits | Qlg | $CS_C$ |

[1]Refer to UGS 1:24,000-scale geologic maps (see Sources of Information section) for a description of map units.

## USING THIS MAP

This map shows the location of known and suspected collapsible-soil conditions in the SR-9 study area. The map is intended for general planning and design purposes to indicate where collapsible-soil conditions may exist and where special investigations are required. Site-specific investigations can resolve uncertainties inherent in generalized mapping and help identify the need for special design, site grading and soil placement, and/or mitigation techniques. The presence and severity of collapsible soil along with other geologic hazards should be addressed in these investigations. If collapsible soil is present at a site, appropriate design and construction recommendations should be provided.

## HAZARD REDUCTION

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

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

Where the presence of collapsible soil is confirmed, possible mitigation techniques include soil removal and replacement with noncohesive, compacted backfill; use of special foundation designs such as drilled pier deep foundations, grade beam foundations, or stiffened slab-on-grade construction; moisture barriers; and careful site landscape and drainage design to keep moisture away from buildings and collapse-prone soils (Nelson and Miller, 1992; Pawlak, 1998; Keller and Blodgett, 2006).

## MAP LIMITATIONS

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

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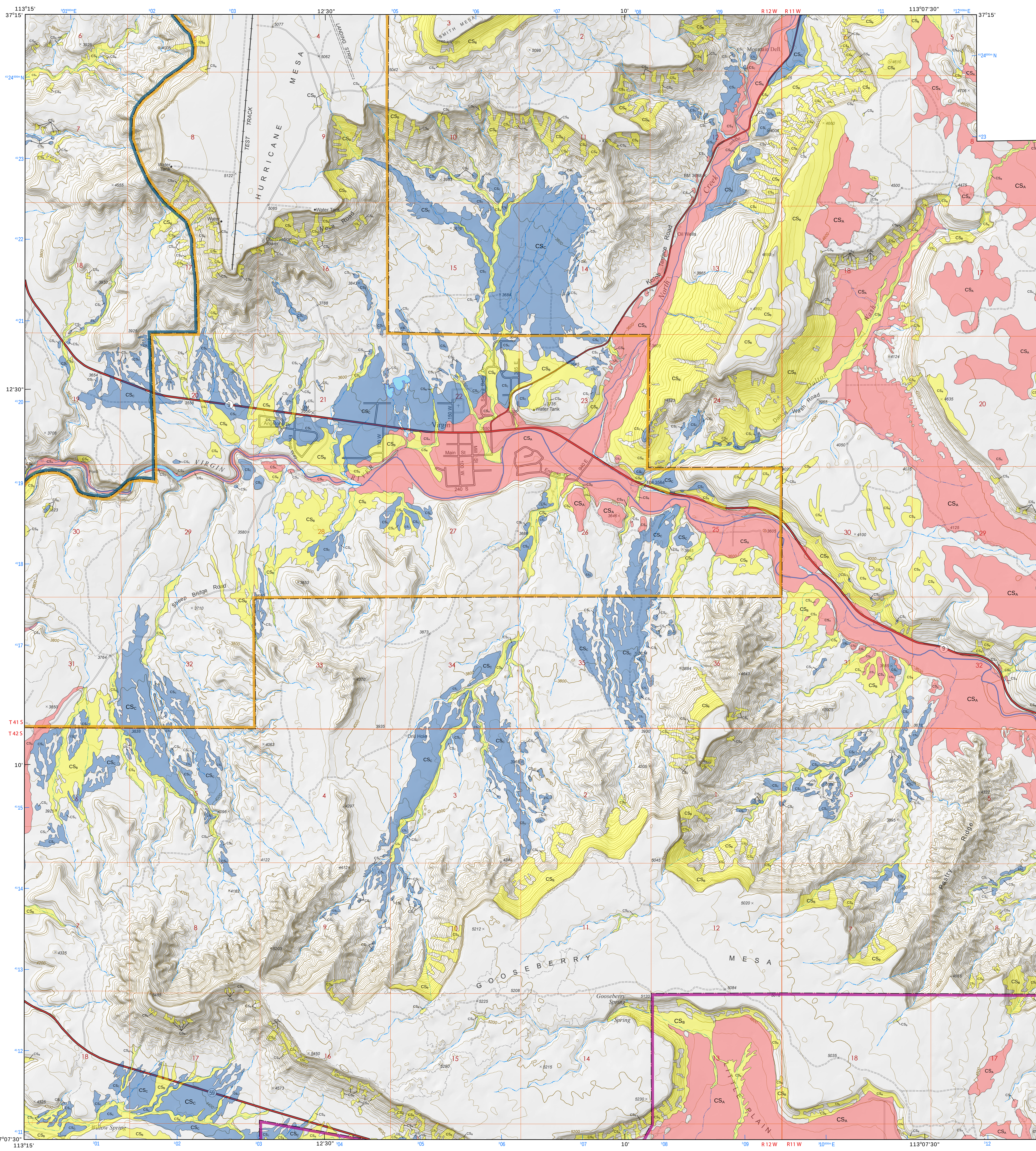


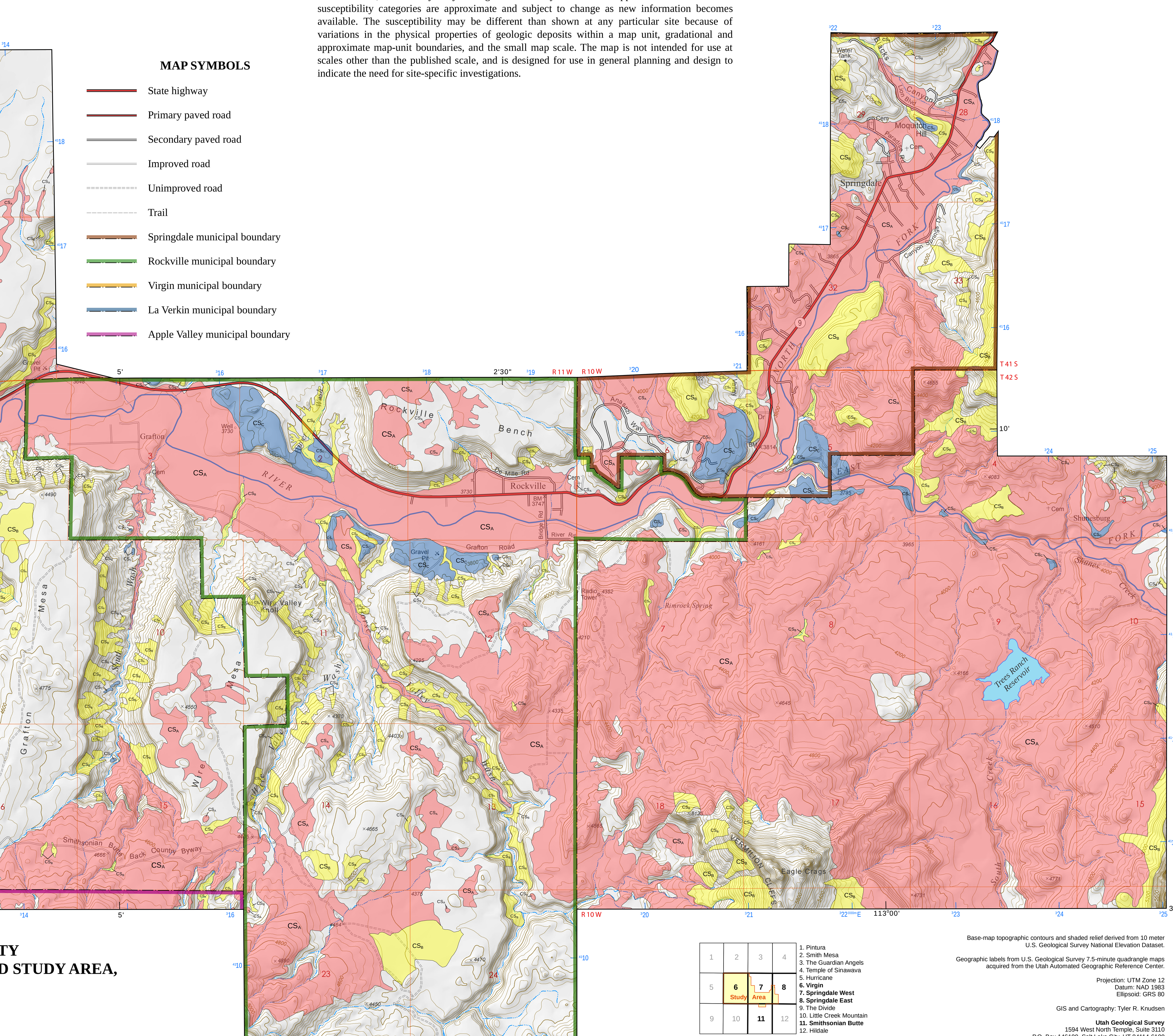


APPROXIMATE MEAN DECLINATION, 2013

SCALE 1:24,000

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

CONTOUR INTERVAL 40 FEET

MAP LOCATION — UTAH

# COLLAPSIBLE-SOIL SUSCEPTIBILITY
# STATE ROUTE 9 CORRIDOR GEOLOGIC-HAZARD STUDY AREA, WASHINGTON COUNTY, UTAH

by

**Tyler R. Knudsen and William R. Lund**

**2013**

This geologic-hazard map was funded by the Utah Geological Survey, the Utah Permanent Community Impact Fund Board, and the municipalities of Springdale, Rockville, Virgin, and La Verkin. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the governmental entities listed above.



7.5' QUADRANGLE INDEX

1. Pintura
2. Smith Mesa
3. The Guardian Angels
4. Temple of Sinawava
5. Hurricane
6. Virgin
7. Springdale West
8. Springdale East
9. The Divide
10. Little Creek Mountain
11. Smithsonian Butte
12. Hildale

Base-map topographic contours and shaded relief derived from 10-meter U.S. Geological Survey National Elevation Dataset.

Geographic labels from U.S. Geological Survey 7.5-minute quadrangle maps acquired from the Utah Automated Geographic Reference Center.

Projection: UTM Zone 12
Datum: NAD 1983
Ellipsoid: GRS 80

GIS and Cartography: Tyler R. Knudsen

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