UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

Plate 8
Utah Geological Survey Special Study 148
State Route 9 Corridor Geologic-Hazard Study Area

EXPLANATION

Holocene-active or suspected Holocene-active fault - Surface-fault-rupture-hazard investigation recommended for all International Building Code (IBC) Occupancy Category II, III, and IV buildings and other structures (International Code Council, 2009a). *None currently mapped in the study area.* Ball and bar on downthrown side of fault.

Approximately located fault with unknown activity level - Paleoseismic data are lacking, recommend treating as a Holocene-active fault until proven otherwise. Ball and bar on downthrown side of fault.

Possible late-Quaternary- or Quaternary-active fault - Normal fault related to the current regional extensional tectonic regime overlain by an unfaulted mid- or late-Quaternary basalt flow > 100,000 years old; the most recent surface-faulting earthquake is older than the age of the overlying basalt, but how much older is unknown. Surface-fault-rupture-hazard investigation recommended for IBC Occupancy Category III and IV buildings and other structures (International Code Council, 2009a). Studies for other structures designed for human occupancy remain prudent for faults demonstrated to be late-Quaternary active (see Activity Classes section), but should be based on an assessment of whether risk-reduction measures are justified by weighing the probability of occurrence against the risk to lives and potential economic loss. Studies for other structures intended for human occupancy for faults demonstrated to be Quaternary active (see Activity Classes section) are optional because of the low likelihood of surface faulting, although surface rupture along the fault is still possible. Solid line indicates well-defined fault trace, dotted line indicates buried fault trace. Ball and bar on downthrown side of fault.

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

INTRODUCTION

Earthquakes occur without warning and can cause injury and death, major economic loss, and social disruption (Utah Seismic Safety Commission, 1995). An earthquake is the abrupt, rapid shaking of the ground caused by sudden slipping of rocks deep beneath the Earth's surface. The rocks break and slip when the accumulated stress exceeds the rock's strength. The surface along which the rocks slip is called a fault. Large earthquakes (>M 6.5) are commonly accompanied by surface faulting. The rupture may affect a zone tens to hundreds of feet wide and tens of miles long. Surface faulting on normal faults produces ground cracking and typically one or more "fault scarps" (figure 1). When faults rupture the surface, fault scarps have near-vertical slopes and, depending on the size of the earthquake, can range from a few inches to many feet high. Local ground tilting and graben formation by secondary (antithetic) faulting may accompany surface faulting, resulting in a zone of deformation along the fault trace tens to hundreds of feet wide (figure 1). Surface faulting, while of limited aerial extent when compared to other earthquake-related hazards such as ground shaking (see Earthquake Ground-Shaking Hazard section in accompanying text document) and liquefaction (see Liquefaction Susceptibility map [plate 9]), can have serious consequences for structures or other facilities that lie along or cross the fault rupture path (Bonilla, 1970). Buildings, bridges, dams, tunnels, canals, and pipelines have all been severely damaged by surface faulting (see for example, Lawson, 1908; Ambraseys, 1960, 1963; Duke, 1960; California Department of Water Resources, 1967; Christenson and Bryant, 1998; U.S. Geological Survey, 2000).

The hazard due to surface faulting is directly related to fault activity—that is, how often the fault ruptures the ground surface and how likely it is to rupture in the future (Christenson and Bryant, 1998). Fault-related surface rupture has not occurred in southwestern Utah historically; however, geologic data for faults in the region indicate a moderate rate of Quaternary surface-faulting activity. Mid-Quaternary basalt flows are displaced more than a thousand feet at several locations, and alluvial and colluvial deposits have been displaced feet to tens of feet in late Quaternary time.

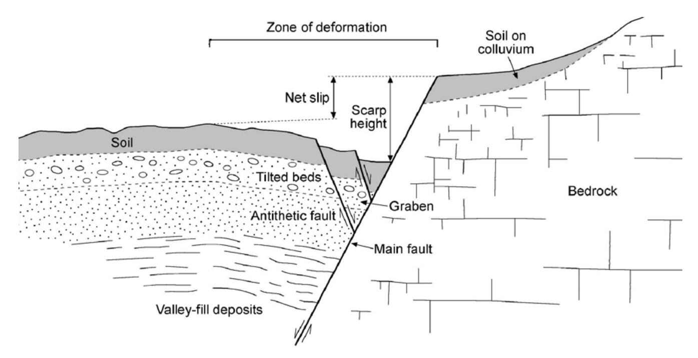

Figure 1. *Cross section of a typical normal fault showing scarp formation, tilted beds, and graben formation in the deformation zone associated with the fault (modified from Robison, 1993).*

SOURCES OF INFORMATION

Sources of information used to evaluate surface-fault-rupture hazard in the State Route 9 Corridor Geologic-Hazard Study Area (SR-9 study area) include (1) 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]), (2) *Geologic Hazards and Adverse Construction Conditions, St. George–Hurricane Metropolitan Area, Washington County, Utah* (Lund and others, 2008), (3) *Geologic Hazards of the Zion National Park Geologic-Hazard Study Area, Washington and Kane Counties, Utah* (Lund and others, 2010), and (4) the *Quaternary Fault and Fold Database of the United States* (U.S. Geological Survey, 2011).

ACTIVE FAULTS IN SOUTHWESTERN UTAH

Because earthquakes result from slippage on faults, from an earthquake-hazard perspective, faults are commonly classified as (1) active, capable of generating damaging earthquakes, or (2) inactive, not capable of generating earthquakes. The term "active fault" is frequently incorporated into regulations pertaining to earthquake hazards, and over time, the term has been defined differently for different regulatory and legal purposes. In nature, faults possess a wide range of activity levels. Some, such as the San Andreas fault in California, produce large earthquakes and associated surface faulting every hundred years or so, while others, like the Wasatch fault and other faults in the Basin and Range Province, produce large earthquakes and surface faulting every few hundred to tens of thousands of years. Therefore, depending on the area of interest or the intended purpose, the definition of "active fault" may vary. The time period over which faulting activity is assessed is critical because it determines which faults are ultimately classified as hazardous, and therefore, subject to regulatory hazard mitigation (Allen, 1986).

Activity Classes

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

Because of the difficulties in using a single "active" fault definition, the Western States Seismic Policy Council (WSSPC) has defined the following fault activity classes (WSSPC Policy Recommendation 11-2, 2011; first adopted in 1997 as WSSPC Policy Recommendation 97-1, and revised and re-adopted in 2002, 2005, 2008, and 2011 [WSSPC, 2011]):

Holocene fault – a fault that has moved within the past 10,000 years (11,700 cal yr B.P.) and has been large enough to break the ground surface.

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

Quaternary fault – a fault that has moved within the past 2,600,000 years and has been large enough to break the ground surface.

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

Evaluating Fault Activity

Because both the instrumental and historical records of seismicity in Utah are short (less than 200 years), geologists must use other means to assess fault activity levels, including evaluating the prehistoric record of surface faulting. Paleoseismology is the study of prehistoric surface-faulting earthquakes (Solonenko, 1973; Wallace, 1981; McCalpin, 2009). Paleoseismic studies can provide information on the timing of the most recent surface-faulting earthquake (MRE) and earlier events, the average recurrence interval between surface-faulting earthquakes, net displacement per event, slip rate (net displacement averaged over time), and other faulting-related parameters (Allen, 1986; McCalpin, 2009). Determining the timing of the MRE establishes the fault's activity class (see above). Paleoseismic data from multiple sites can show if a fault ruptures as a single entity, or if it is subdivided into smaller segments that are each independently capable of generating earthquakes. Importantly, paleoseismic studies can establish the relation between the elapsed time since the MRE and the average recurrence interval between surface-faulting earthquakes. Once that relation is known, the likelihood of surface faulting in a time frame of significance to most engineered structures can be estimated.

FAULTS IN THE SR-9 STUDY AREA

The UGS geologic maps used as the basis for this study (see Sources of Information section) show only two normal faults in the SR-9 study area. Normal-slip faulting occurs when the fault hanging wall moves downward relative to the fault footwall (figure 2). Normal faults form in response to tensional (pulling apart) forces, typically dip between 45 and 90 degrees, and place younger rock on older rock. Tensional forces have characterized the regional stress regime in southwestern Utah for the past several million years. Consequently, normal faults in and near the SR-9 study area are typically geologically young and many, if not most, are considered capable of producing earthquakes.

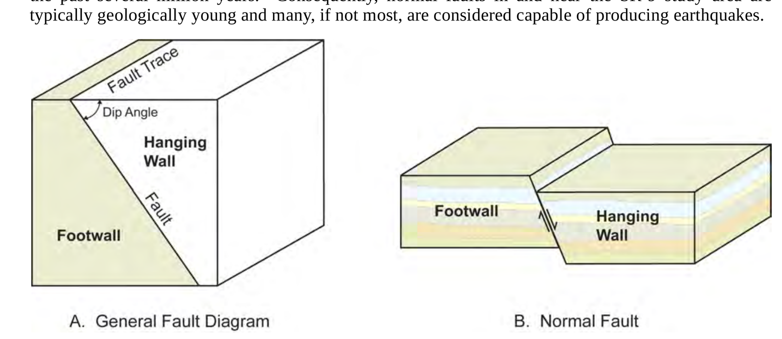

Figure 2. *Characteristics of a typical normal fault in the State Route 9 Geologic-Hazard Study Area.*

Grafton Mesa Fault

The Grafton Mesa fault (mapped by Willis and others, 2002; named by Lund and others, 2010) is an approximately 5-mile-long, northeast-trending, west-dipping normal fault with less than 200 feet of vertical displacement. In many places the displacement is contained entirely within the Shinarump Conglomerate Member of the Chinle Formation (figure 3; Willis and others, 2002), which in the study area is 60 to 135 feet thick (Biek and others, 2010). At its south end, the fault brings the Shinarump into fault contact with the overlying Petrified Forest Member of the Chinle Formation. Those two rock units are normally in stratigraphic contact with each other, so minimal fault displacement is required to create a fault contact between them. No detailed paleoseismic studies have been conducted on the Grafton Mesa fault; however, mapping by Willis and others (2002) shows that unconsolidated Quaternary deposits along the fault are not displaced. North of the study area, the fault is overlain by and does not displace (Willis and others, 2002) the estimated 100,000-year-old Crater Hill basalt flow (Biek and others, 2010), indicating that the most recent surface faulting earthquake on the Grafton Mesa fault occurred more than 100,000 years ago. Despite its apparent very low level of activity, because the Grafton Mesa fault is a normal-slip fault and related to the current regional extensional tectonic regime, it is considered potentially active and capable of producing infrequent future earthquakes.

Figure 3. *Oblique aerial view to the east of the Grafton Mesa fault displacing Shinarump Conglomerate Member of the Chinle Formation. Fault scarp is approximately 80 feet high. Photo is from Microsoft's Bing Bird's Eye viewer.*

Unnamed Fault

An approximately located, north-trending normal fault less than 0.5 mile long enters the extreme southern part of the SR-9 study area (Moore and Sable, 2001). The steeply east-dipping fault displaces the Shinarump Conglomerate and the Petrified Forest Members of the Chinle Formation a few tens of feet. No paleoseismic studies have been conducted on the fault. There are no Quaternary basalt flows or unconsolidated deposits along the fault, and therefore no constraints on MRE timing. However, because it is a normal fault related to the current regional extensional tectonic regime, it is considered potentially capable of producing future earthquakes.

SURFACE-FAULT-RUPTURE-HAZARD CLASSIFICATION

This map shows the normal faults in the SR-9 study area mapped by the UGS. Because of the prevailing regional extensional tectonic regime, we consider all normal faults in the study area as potentially active until proven otherwise.

Special Study Areas

Based upon UGS geologic mapping, we categorized the normal faults in the SR-9 study area as either "Well Defined," "Approximately Located," or "Buried," and established surface-fault-rupture-hazard special-study areas (Christenson and others, 2003; Lund and others, 2008) for each fault category.

Well-Defined Faults

We consider a fault well defined if its trace is clearly detectable by a trained geologist as a physical feature at the ground surface (Bryant and Hart, 2007). We classified normal faults in the SR-9 study area as well defined if UGS 1:24,000-scale mapping shows them as solid lines, indicating that they are recognizable as faults at the ground surface. The surface-fault-rupture-hazard special-study areas established for well-defined faults extend for 500 feet on the downthrown side and 250 feet on the upthrown side of each fault (see Explanation).

Approximately-Located and Buried Faults

The UGS mapped some normal faults in the SR-9 study area as approximately located (dashed lines) or buried (dotted lines) because the traces of those faults are not evident at the ground surface. The reasons for the lack of clear surface evidence for these faults are varied, but are chiefly related to one or more of the following causes: (1) long earthquake recurrence intervals combined with a long elapsed time since the MRE allow evidence for the faults to be obscured by subsequent erosion and deposition, (2) rapid deposition occurs in some areas that quickly obscures faults, even those with comparatively short recurrence intervals, (3) the faults generate earthquakes that produce relatively small scarps (<3 feet) that are quickly obscured, or (4) faulting occurs at or above the bedrock/alluvium contact in relatively steep terrain and is difficult to identify.

Although not evident at the surface, these faults may still represent a surface-fault-rupture hazard and should be evaluated prior to development in areas where they may rupture to the ground surface. Because of fault-location uncertainty, the surface-fault-rupture-hazard special-study areas around these faults are broader, extending 1000 feet on each side of the suspected trace of the faults.

Fault Activity Levels

The faults on this map are color-coded to indicate what is presently known about their activity level (see Explanation). Each color-code category includes recommendations for surface-fault-rupture special investigations based on fault activity class (see Activity Classes section above) and the type of building or structure proposed. These recommendations are modified from the UGS *Guidelines for Evaluating Surface-Fault-Rupture Hazards in Utah* (Christenson and others, 2003).

USING THIS MAP

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

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

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

Because approximately located and buried faults lack a clearly identifiable surface trace, they are not amenable to trenching, which is the standard surface-fault-rupture-hazard investigation technique used to study well-defined faults (Christenson and others, 2003; McCalpin, 2009). Where development is proposed in a special-study area for a buried or approximately located fault, we recommend that, at a minimum, the following tasks be performed to better define the surface-fault-rupture hazard in those areas:

1. Review of published and unpublished maps, literature, and records concerning geologic units, faults, surface water, groundwater, previous subsurface investigations, previous geotechnical and geophysical investigations, and other relevant factors.
2. Stereoscopic interpretation of aerial photographs to detect any subtle fault-related features expressed in the site topography, vegetation or soil contrasts, and any lineaments of possible fault origin.
3. Field evaluation of the proposed site and surrounding area to observe pertinent surface evidence for faulting, including mapping of geologic units as necessary to define critical geologic relations; evaluation of geomorphic features such as springs or seeps (aligned or not), sand blows or lateral spreads, or other evidence of earthquake-induced features; and excavation of test pits to evaluate the age of the deposits onsite to constrain the time of most recent surface faulting.

If the results of these investigations reveal evidence of possible surface-faulting-related features, those features should be trenched in accordance with the UGS *Guidelines for Evaluating Surface-Fault-Rupture Hazards in Utah* (Christenson and others, 2003). Following the above-recommended tasks, if no evidence of surface faulting is found, development at the site can proceed as planned. However, we recommend that construction excavations and cut slopes be carefully examined for evidence of faulting as development proceeds.

HAZARD REDUCTION

Because surface faulting is typically confined to relatively narrow zones along the surface trace of a fault, early recognition and avoidance are the most effective strategies for mitigating this hazard. Once the activity class of the fault is determined (see Activity Classes section above), we recommend that setbacks from the fault trace and any associated zone of deformation be established in accordance with UGS *Guidelines for Evaluating Surface-Fault-Rupture Hazards in Utah* (Christenson and others, 2003). Carefully locating all potentially active fault traces at a site, assessing their level of activity and amount of displacement, establishing an appropriate setback distance from the fault, and proper facility and site design remain the most reliable procedures for mitigating damage and injury due to surface faulting.

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

MAP LIMITATIONS

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

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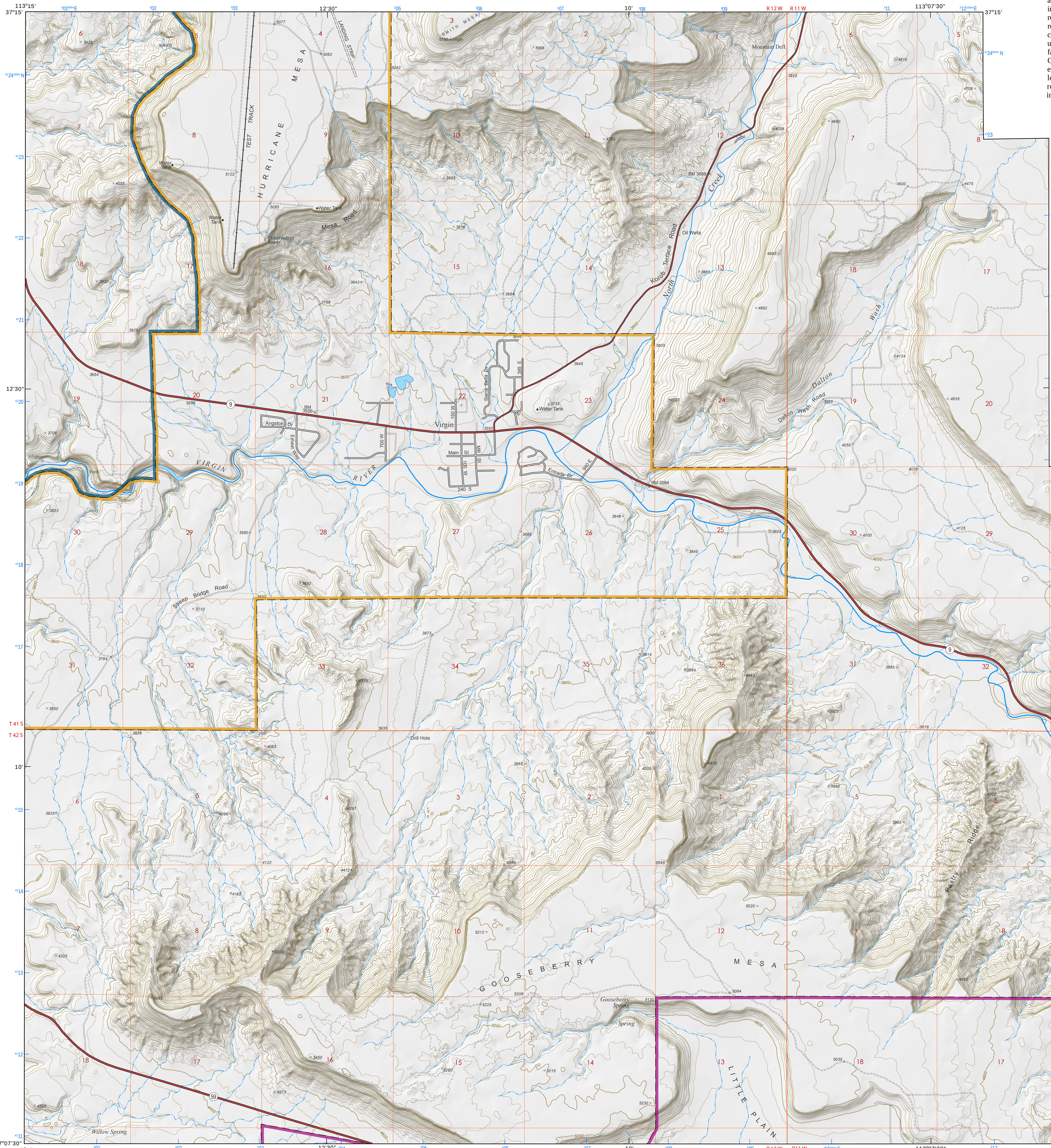
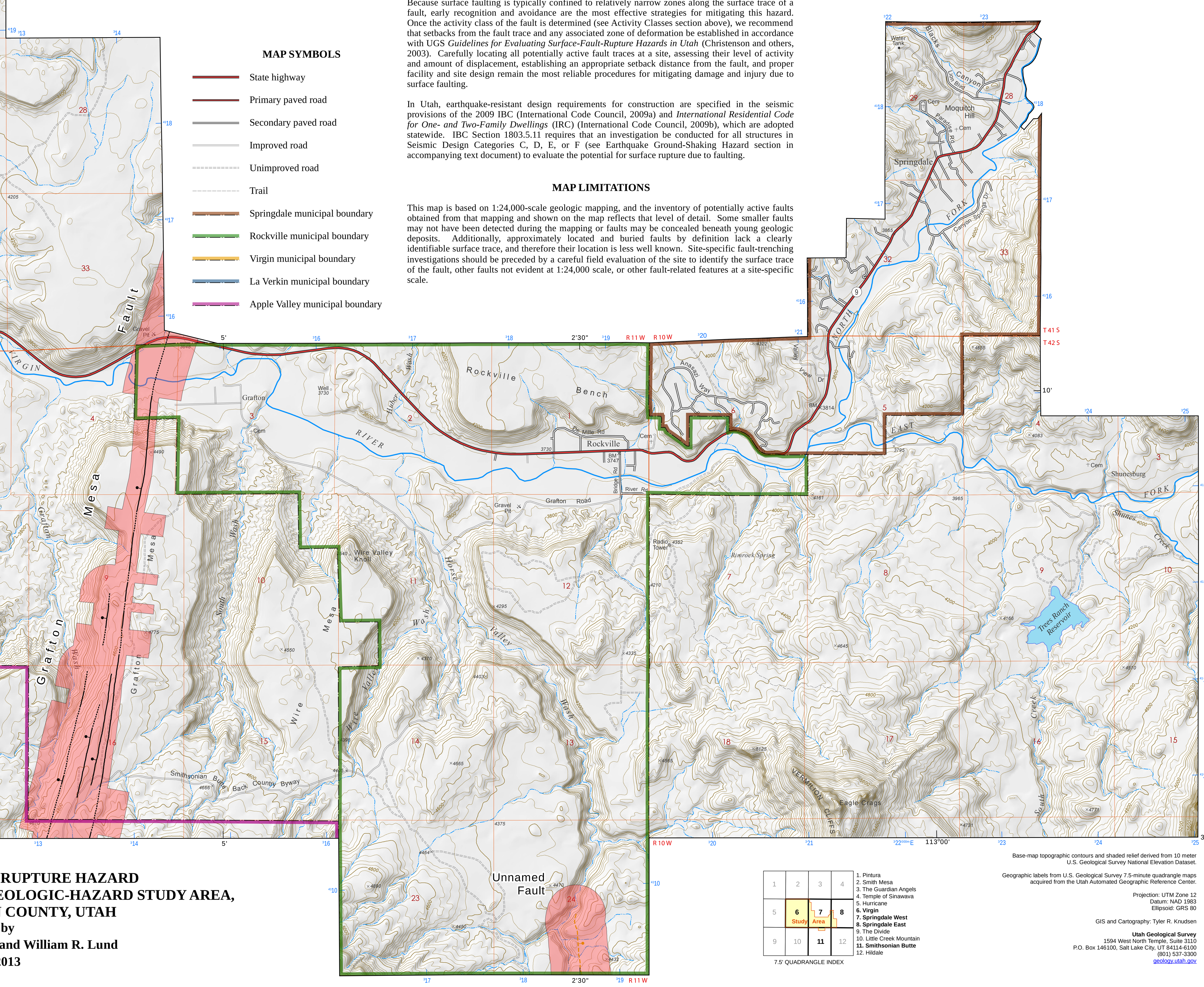



MAP SYMBOLS

- State highway
- Primary paved road
- Secondary paved road
- Improved road
- Unimproved road
- Trail
- Springdale municipal boundary
- Rockville municipal boundary
- Virgin municipal boundary
- La Verkin municipal boundary
- Apple Valley municipal boundary

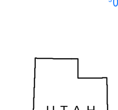
SURFACE-FAULT-RUPTURE HAZARD
STATE ROUTE 9 CORRIDOR GEOLOGIC-HAZARD STUDY AREA, WASHINGTON COUNTY, UTAH

by
Tyler R. Knudsen and William R. Lund
2013

SCALE 1:24,000

CONTOUR INTERVAL 40 FEET

APPROXIMATE MEAN DECLINATION, 2013



MAP LOCATION

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

7.5' QUADRANGLE INDEX

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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