ZION-MOUNT CARMEL HIGHWAY
SWITCHBACK LANDSLIDE FIELD TRIP GUIDE
ZION NATIONAL PARK, UTAH

34TH NORTHWEST GEOTECHNICAL WORKSHOP
SPRINGDALE, UTAH

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Figure 1: Regional Location Map

1 GEOLOGIC SETTING

The exposed rock formations within Zion National Park are part of a thick sequence of sedimentary rock units known as the Grand Staircase. These rocks represent approximately 150 million years of mostly Mesozoic-aged sedimentation in the Colorado Plateau physiographic region. The formations exposed in Zion Canyon were deposited as sediment in several different environments, including shallow seas, streams, and long periods of desert sand dunes. This resulted in alternating layers of limestone, siltstone, claystone, and sandstone.

After these deposits were formed, approximately 25 million years ago, the entire Colorado Plateau began to experience rapid regional uplift, causing an increase in river gradients and erosion rates throughout the area. This increased erosion created several well-known canyon systems in the region, including Bryce Canyon, Zion Canyon, and the Grand Canyon. Rivers became incised, or trapped into one channel, following rock structure and other zones of weakness, creating narrow valleys and canyons. Uplift rates were irregular; interruptions caused rivers to slow the downcutting process, and temporarily cut sideways, especially where softer rock layers were present. This resulted in the widening of Zion Canyon below the Temple of Sinawa within the Park, and allowed for tributary streams to enter the Virgin River at grade. Approximately 13 million years ago, uplift resumed, causing the Virgin River to cut down once again. The tributaries couldn't keep up with the rate of downcutting, due to their lesser water volume, and some of their valleys have been left hanging above the main canyon floor. These "hanging valleys" stand at 1,100 to 1,300 feet above the Virgin River at the present time. Examples of this include the hanging valley located between the peaks of the "Twin Brothers" feature, and a smaller less developed valley located directly above the subject area.

Geologic mapping (Hamilton, 1978) indicates that specific rock formations within Zion Canyon include the following, from oldest to youngest (bottom to top):

- Moenave Formation: siltstone and sandstone composed of river and lake deposits (includes the Springdale Sandstone member)
- Kayenta Formation: sandstone and shale composed of river deposits
- Navajo Sandstone: represents 10 million years of desert dune deposition, 1,600 to 2,200 feet thick, with large cross-bedding; 80% quartz grains, lower portions stained by iron oxidation. Forms most of the tall cliffs within the Park
- Temple Cap Formation: siltstone, claystone, and sandstone composed of flood deposits overlain by more desert dune deposition
- Carmel Formation: limestone and sandstone composed of shallow sea, coastal desert, and evaporite deposits

The project site lies on the north-facing slope of the valley formed by Pine Creek, a tributary to the Virgin River. The geomorphologic history of the project site is complex. There is evidence that after Zion Canyon formed, a large debris flow originating from the hanging valley above the project area deposited boulders, sand, and silt at the location of the present-day switchback section of the roadway. These debris flows most likely occurred repeatedly over time. These materials were then re-worked by surface water and eolian processes, creating some small dune features within a more gently-sloping section of the area (Figure 2). These dune features are currently sparsely vegetated and appear to be no longer active. At some point, most likely due to prolonged high groundwater levels, a large landslide occurred within the loosely deposited overburden materials. Evidence of this slide includes the lack of cohesive bedrock outcrops within the area, disturbed ground, vegetation changes, head-scarp features, and hummocky landforms. This larger slide appears to be no longer active; however, the overburden materials now have been weakened, with lower, residual soil strength characteristics remaining. It is likely that disturbance from the construction of the Mt. Zion-Carmel Highway in the late 1920s, combined with surface drainage changes and subsequent failures, has caused reactivation of this slide mass to a lesser extent.

Groundwater seepage was observed below the project area, forming seeps just above the bedrock contact, in an area with relatively heavy vegetation (Figure 3). Groundwater most likely moves along the bedrock-overburden interface, flowing from the steep canyon wall beneath the project area to the Pine Creek drainage.

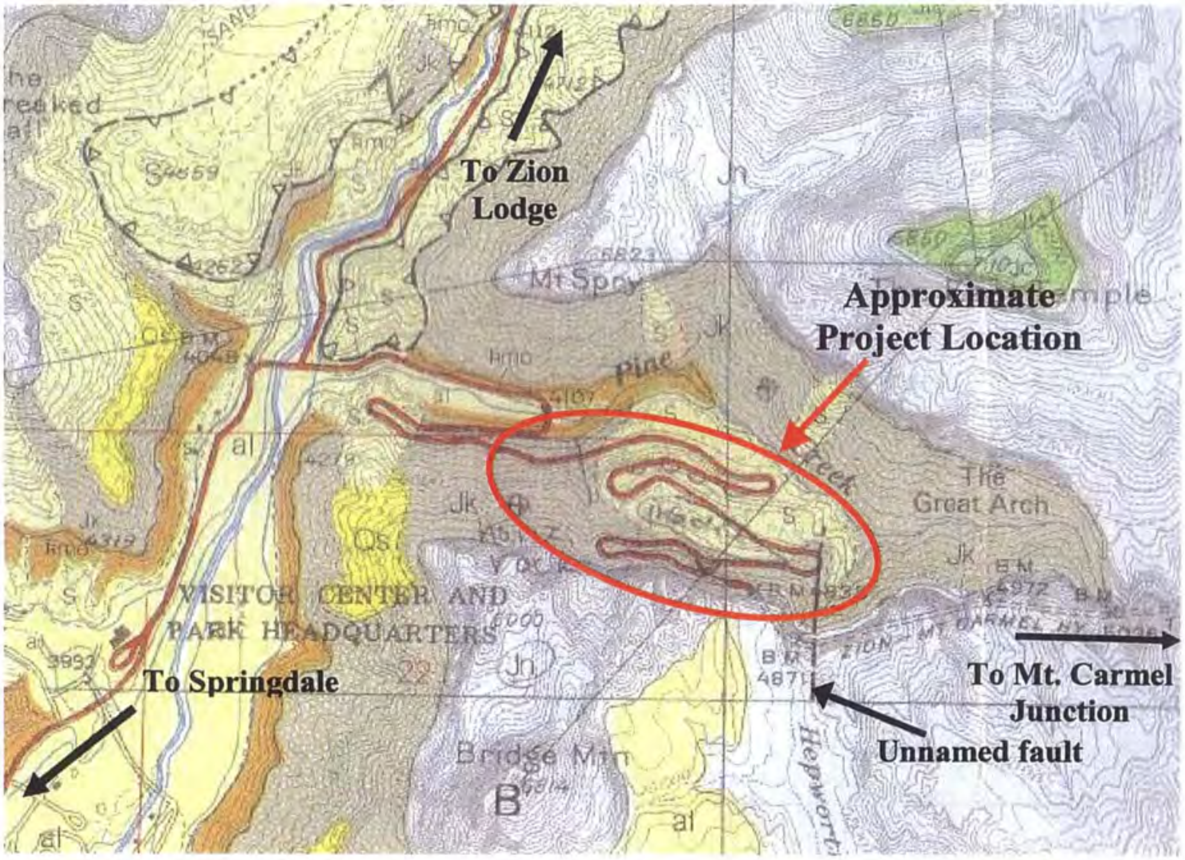
The geologic history of Zion Canyon, and the specific project site, has resulted in overburden materials consisting of very loose, fine-grained, poorly graded silty sand with some gravel and boulders. This material is easily infiltrated and eroded by surface water, and can also become hydro-compacted. Bedrock beneath this material is presumably Kayenta sandstone, based on published geologic mapping (Hamilton, 1978). An unnamed normal fault is mapped near the east end of the project area (Figure 4 and Appendix A); movement here may have resulted in weaker materials and an even greater susceptibility to failure. A geologic map of the project site, with bedrock and surficial material descriptions, is shown in Figure 4.

Figure 2: Recent eolian features are apparent within the project limits.

Figure 3: Groundwater seepage was observed forming seeps just above the bedrock contact, below the project area.

1.1 Seismicity

The Peak Ground Acceleration (PGA) for the Zion-Mt. Carmel Highway was obtained using the 2002 U.S. Geological Survey National Seismic Hazard Maps. Peak Ground Acceleration, assuming a latitude of 37.21° N and a longitude of 112.96° W, with a 10% probability of exceedance in 50 years, is 0.1g.



al

Alluvium

Silt, sand, and gravel in floodplain, stream channel, and alluvial fan deposits.

S

Slide deposits

Fragmented rockfall debris, including talus from Mesozoic sedimentary rocks and Quaternary basalts.

Jtc

Temple Cap Formation

Sandstone, gray and tan, crossbedded, overlying sandstone, red-brown, flatbedded, with thin basal red shale. Thickness 0 - 260 feet (0 - 80m) in the Park.

Normal fault

Dashed where inferred, dotted where concealed. Ball and bar on downthrown side.

Jn

Navajo Sandstone

Sandstone, white, gray, yellow, tan, pink, medium to fine-grained, crossbedded increasingly toward top. Maximum thickness attained at West Temple, an estimated 2000 feet (610m).

Jk

Kayenta Formation

Mudstone, reddish brown, siltstone, and sandstone representing stream deposition. Dinosaur trackways are relatively common. A tongue of crossbedded Navajo Sandstone occurs about midway in the formation in the southeastern part of the Park. Thickness approximately 600 feet (180m).

Jmo

Moenave Formation

Sandstone, mauve, overlying reddish-brown siltstone and mudstone stream channel and floodplain deposits. Thin gray lake clays are present beneath the upper sandstone. Total thickness approximately 490 feet (150m).

Figure 4 –Localized Geologic map (from Hamilton, 1978)

2 SITE CONDITIONS

The site is located on the north-facing slopes of Bridge Mountain. In general, soils consist of loosely consolidated poorly-graded fine sands with some gravel and large boulders, up to 15 feet in diameter. A normal fault cuts through Nevada Switchback, oriented North-South following Hepworth Wash, near the southeast end of the project. Topography ranges from shallow inclines in the road to sheer rock faces, but is mostly steep to very steep. The roadway grade is approximately 5%, with a total elevation gain of approximately 550 feet within the project limits. Numerous seasonal tributaries and gullies drain the slopes, joining Pine Creek at the bottom of the valley. Slopes are moderately vegetated with primarily large shrubs and grasses, trees are also found along watercourses and north facing slopes.

2.1 Site Investigation

Seven borings were drilled in the travel lanes of the Zion-Mt Carmel Highway and encountered 0.7 to 1.0 feet of asphalt pavement over silty clay man-placed fill to a depth of about 2.0 feet. Below the fill, subsurface conditions varied slightly throughout the project. The overburden generally consisted of fine-grained, poorly graded sand with some gravel and boulders up to 15 feet in diameter, overlying sandstone and mudstone bedrock. Construction of the road appears to have utilized existing soil for man-made fill, making it very difficult to identify the fill/natural soil boundary. A review of photographs of the original construction, obtained from available publications, allowed an estimate of the extent of fill placement.

2.2 Groundwater

Groundwater was encountered only in borings 08S-SI04 and 08S-SI03, presumably due to the lower elevations of these borings, making them closer to the bedrock contact and therefore to the groundwater table. At the time of exploration, groundwater was found overlying bedrock and in bedrock fracture zones or planes of weakness, which allow for higher permeability rates. Groundwater conditions in the study area will likely vary considerably throughout the year. The subsurface investigation for this project was conducted in December 2007 and January and February 2008, when groundwater levels are typically at a seasonal low. A groundwater monitoring system was included in the scope of work; therefore, measurements of long-term and year-round conditions can be made. Active springs and seeps were observed above the switchbacks, in particular Spring Bend, but also originating out of the bedrock face at some locations. Groundwater levels are expected to vary with seasonal runoff and precipitation. Due to the high permeability of the colluvium along the entire site, locations of seeps and springs are expected to change with the seasons.

2.3 Bedrock and Surficial Mapping

To evaluate the slope stability of the project area, exposed bedrock outcrops and surficial features near the subject site were identified and mapped. No in-place bedrock outcrops could be located within the landslide limits. The lack of outcrops is interpreted as evidence of the presence of a landslide. Bedrock outcrops at the margins of the landslide consist of red and reddish-brown sandstone, with rounded exposures and a moderate amount of joints. Bedding orientation in the area surrounding the project site is nearly horizontal. Identified landslide scarps and boundaries are shown in Appendix A-1.

3 ADDITIONAL OBSERVATIONS

3.1 Rockfall

During both site exploration operations, rockfall was observed in numerous locations alongside the Zion-Mt Carmel Highway. Multiple rockfall events occurred between the Virgin River bridge and the Pine Creek bridge in late December 2007 and early February 2008. In late December, rockfall also occurred to the west of a small drainage on the western side of the slide area. In all cases rockfall was limited to small quantities, consisting mainly of gravel and cobbles with a few boulders up to 4 feet diameter. Only cobbles and gravel-size fragments were observed to reach roadway surface.

The published history of the site describes a rockfall that occurred in 1928 on the Nevada Switchback (to the east of Site 3). The failure caused the death of a construction worker. The rockfall may be related to the unnamed normal fault mapped at this location. This fault cuts through the sandstone at the eastern edge of the switchback roadway, creating the potential for a brecciated fault zone to experience slope failure. Therefore it is possible that the weakened sandstone increases the potential for future slope failure or rockfall at the Nevada Switchback.

3.2 Drainage

Several locations with inadequate surface drainage were observed within the project area. The areas inside the switchbacks and along the ditches shows signs that water is ponding and not flowing through the cross culverts. The ponding water is allowed to infiltrate the soils causing hydrocompactive settlement. Some culverts were observed to be obstructed by debris. Culvert outlets below the roadway appeared to have little outlet erosion protection. At these locations, the fine soils had been eroded away, leaving only cobbles and boulders. Retaining walls that were constructed at the time of original road construction included drainage holes or "scuppers" that would allow runoff to flow through. These holes are blocked by pavement material and debris at some locations.

In general, poor drainage is promoting water infiltration into the embankment and slide materials. Saturation can cause the silty sand soils to rapidly consolidate, resulting in settlement of the roadway and pavement distress. Surface water infiltrating into the slide zone will reduce the stability of the slide mass. Although improvements and mitigation have been attempted by Zion National Park to prevent further damage, overall, surface drainage conditions along the project site were observed to be poor, and are a contributing factor in pavement and embankment failures.

4 PRELIMINARY SLOPE STABILITY ANALYSIS

Preliminary global stability analysis was performed for both the large, ancient landslide mass and for typical, smaller, more localized slide feature. No detailed topographic survey of the area has been completed yet, so topographic profiles for this analysis were derived from a 1:31680-scale topographic map, dated 1964, with a contour interval of 50 feet. More accurate topographic information would increase the reliability of any slope stability analysis. Stability analysis was performed using the PCStabl6 algorithm (Purdue, 1999) with the STEDwin editor (Van Aller, 2000).

Global stability analysis indicates that the large ancient slide mass is marginally stable, and its continued stability depends strongly on the levels of groundwater within the overburden material. For a groundwater level similar to that encountered during drilling, the Factor of Safety (FS) for the large ancient slide mass was found to be 1.56. Since drilling took place in December through February, this level of groundwater is presumably low compared to the rest of the year. For a much higher groundwater level near the ground surface, the FS was 0.96, indicating that elevated groundwater levels for this type of large slope failure could reactivate the ancient landslide.

Stability analysis was also performed for the typical, smaller, and more localized failure. This was a hypothetical slope failure since detailed cross-sections have not yet been developed for this project. The actual small slumps observed within the project limits could not be analyzed with any greater level of detail with the currently available topographic information. Based on the site observations and the stability analysis, the fluctuation in groundwater levels also has an effect on the smaller slope failures. For low groundwater levels, the FS was 1.05; for high groundwater levels near the ground surface, the FS was 0.79. It is important to note that although the analysis would suggest a larger, more defined failure has taken place, conservative values were chosen for soil strength properties, and the slope geometry is known to be imprecise.

5 REFERENCES

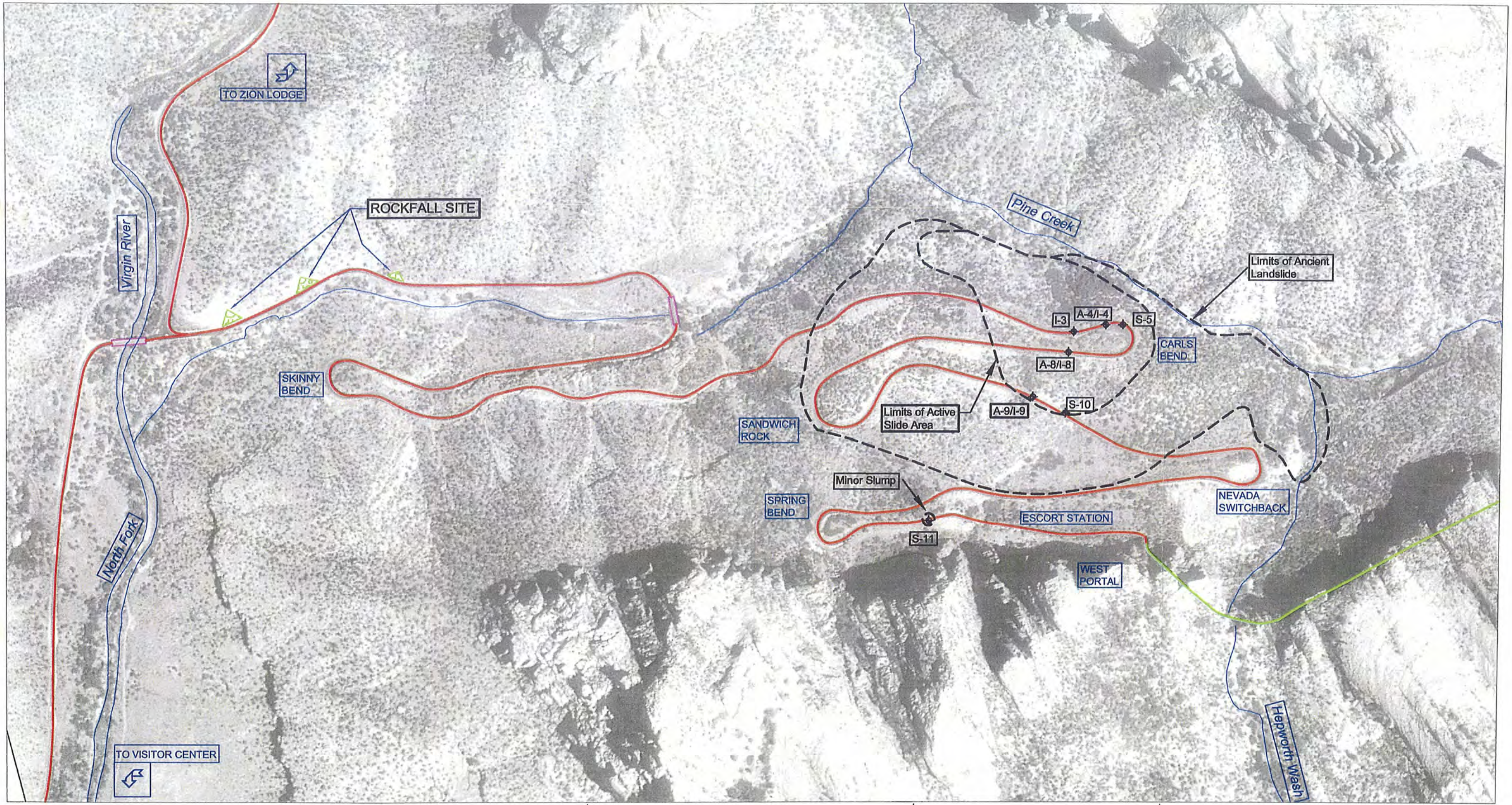
Garate, Donald T. "The Zion Tunnel – From Slickrock to Switchback," Zion Natural History Association Inc., Zion National Park. Springdale, Utah. 1989.

Hamilton, W.L., 1977, *Geological Map of Zion National Park, Utah:* Zion Natural History Association (in conjunction with National Park Service), scale 1:31,680.

USGS, 2002. National Seismic Hazard Maps. Found online at: http://earthquake.usgs.gov/research/hazmaps/products_data/2002/wus2002.php

USGS, 1997. Topographic Map of the Springdale East Quadrangle, Utah. U.S. Geological Survey 7.5-Minute Series Topographic map, Scale 1:24,000.

USGS, 1964. Topographic Map of Zion National Park Utah (Zion Canyon Section). U.S. Geological Survey. Scale 1:31,680.



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Site Plan/Boring Locations

Project: Zion-Mt.Carmel

Figure: A-1