INTRODUCTION

The rocks of Zion National Park provide a record of changing environmental conditions through 275 million years of geologic time. The cliffs and mesas of the park and surrounding area are carved from nearly 7,000 feet (2,130 m) of colorful sedimentary strata ranging in age from the Early Permian Toroweap Formation to newly recognized, probable late Early Cretaceous strata (figures 1, 2, and 3). Fossils and other clues in the rocks tell us that they were deposited in a variety of shallow-marine, coastal-sabkha, tidal-flat, coastal-plain, sand-desert, river, and lake environments. Perhaps the most famous of all are the immense, ancient sand dunes of the Navajo Sandstone, seen in the great, sweeping cross-beds of the canyon walls. Zion National Park owes much of its character to the Navajo Sandstone, which attains its maximum thickness of about 2,200 feet (671 m) in this area.

Zion National Park is part of a large structural block at the western margin of the Colorado Plateau, bounded on the west by the Hurricane fault zone and on the east by the Sevier fault zone. Although the structure of the main part of the park is relatively simple — the rocks are tilted gently to the northeast and little complicated by faults — joints are exceptionally well developed and they are largely responsible for the orientation of the existing canyon network. In the Kolob Canyons portion of the park, these rocks are folded into the Kanarra anticline, where beds on the east limb of the anticline are duplicated by back-thrust faults of the Taylor Creek fault zone.
Figure 1. Lithologic column showing rock units present in Zion National Park.
Figure 2. Simplified geologic map of Zion National Park. Compiled and simplified from Cook (1960), Doelling and Davis (1989), and the authors' mapping. Cross sections A-A' and B-B' shown on figure 3.
Figure 3. Simplified geologic cross sections of Zion National Park. No vertical exaggeration, but scales differ from map. See figure 2 for cross section locations.
Zion National Park is a window through which we can view and comprehend these stories entombed in ancient layers of rock, but above all, it is a monument to erosion. The canyons of Zion National Park represent an early stage in the erosion of the Kolob Terrace, which rises high above the Hurricane Cliffs. Erosion of this structural block by the Virgin River and its tributaries began with headward erosion of the first fault scarps on the Hurricane fault zone, which probably first moved in the Pliocene, at least several million years ago. Several times over about the past 1.5 million years, basaltic lava flowed down and blocked some of these drainages, and many of the flows now form classic examples of inverted topography. The flows also provide unique control on the erosive history of Zion National Park and vicinity, and demonstrate that most of Zion Canyon was carved within the past 2 million years.

Because of the impounding effects of landslides and lava flows, the canyons of Zion National Park have periodically held small lakes and ephemeral ponds. Lacustrine deposits associated with at least 14 lakes are known in the park, and they too provide a record of more recent environmental changes. For example, tracks of an Ice Age camel, crane, and various insects are known from deposits of Coalpits Lake, and pollen recovered from these beds is dominated by ponderosa, pinyon, spruce, and fir trees, quite unlike the hot and dry Sonoran climate there today. The enchanting, flat valley floor of Zion Canyon upstream from the Court of the Patriarchs is a reflection of Sentinel Lake, which once occupied this portion of the canyon several thousand years ago. The North Fork of the Virgin River has yet to erode through these lake sediments to re-establish its steeper, pre-landslide gradient.

The geologic guides below — four road guides and a dozen trail guides — describe the geology of the Permian to Cretaceous bedrock units exposed in and near the park (figure 4). They also offer new details on the fascinating erosional history of this area and the formation of Zion Canyon as recorded by a variety of alluvial, mass-wasting, and lacustrine deposits and basalt flows. These geologic guides are designed to provide basic information about specific features along the routes. The accompanying report on the geology of Zion National Park (Biek and others, 2000) should be consulted for background information on the general geology and descriptions of individual formations and structures.
Figure 4. Locations of geologic road and trail guides for Zion National Park and vicinity. Road guides: Utah Highway 9 — Zion National Park Visitor Center to LaVerkin (1a), Zion National Park Visitor Center to Mt. Carmel Junction (1b), Kolob Road — Virgin to Lava Point (2), Zion Canyon Scenic Drive (3), Kolob Canyons Scenic Drive (4). Trail guides: Watchman Trail (5), Sand Bench Trail (6), Emerald Pools Trail (7), Weeping Rock Trail (8), Riverside Walk Trail (9), Canyon Overlook Trail (10), East Rim Trail (11), West Rim Trail and Angels Landing (12), Middle Fork Taylor Creek Trail (13), Timber Creek Overlook Trail (14), Timber Creek Trail and Kolob Arch (15), Hop Valley Trail (16).
UTAH HIGHWAY 9 — ZION NATIONAL PARK VISITOR CENTER TO LAVERKIN

INTRODUCTION

South from the Zion National Park Visitor Center, Utah Highway 9 traverses the lower portion of Zion Canyon (figures 1a and 1b). Because the sedimentary strata are tilted gently to the east, the highway gradually cuts down section between the park and the Hurricane Cliffs. Strata from the Triassic Petrified Forest Member of the Chinle Formation down through the underlying Permian Kaibab Formation can be seen along the highway. Near the junction of the North and East Forks of the Virgin River, the highway gradually cuts through the resistant Shinarump Conglomerate Member of the Chinle Formation, which forms a cliff above the town of Rockville. Farther west, a lava flow atop the high mesa northeast of Virgin, and the nearby Crater Hill basalt flow, provide constraints on erosional rates in Zion Canyon. At the Hurricane Cliffs, a side road to the LaVerkin Overlook leads to unparalleled views westward across the St. George basin and eastward to Zion National Park and surrounding mesas. The Hurricane Cliffs offer excellent exposures of several strands of the Hurricane fault zone, and of the Kaibab and Moenkopi Formations and the Permian-Triassic unconformity that separates these units.

<table>
<thead>
<tr>
<th>MILEAGE INTERVAL/CUMULATIVE</th>
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<tr>
<td>0.0 0.0 BEGIN road guide at the junction of Utah Highway 9 and the entrance to new Visitor Center and Watchman Campground. PROCEED SOUTH ON Utah Highway 9 toward Springdale.</td>
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<tr>
<td>0.1 0.1 ZION NATIONAL PARK GATE AND TOLLBOOTH.</td>
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<tr>
<td>0.1 0.2 Leaving Zion National Park. Petrified Forest strata are exposed to the west at the toe of the landslide.</td>
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<tr>
<td>0.2 0.4 Brightly colored swelling mudstone of the Petrified Forest Member is exposed in road cuts to the west and east. The beds here do not appear to be significantly deformed.</td>
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On July 21, 1998, intense rainfall from a slow moving thunderstorm cell triggered a debris flow that started at the fresh scars near the top of the Kayenta Formation in the small canyon (Sammy's canyon) to the east. About 1.2 inches (3 cm) of rainfall was recorded in 30 to 40 minutes at the park service housing area just to the north (Dave Sharrow, National Park Service, written communication, October 30, 2000). Huge boulders transported by the flow are visible near the mouth of the canyon above the parking lot (figure 2). Further down gradient, the debris flow covered part of the Watchman Campground with about 6 inches (15 cm) of sand, smashing and burying a substantial amount of camping equipment; fortunately no one was seriously injured. The debris flow also blocked the Virgin River and flooded the lower part of the South Campground (figure 3).
Figure 1a. Topographic map showing the eastern part of the route and stops of the Zion National Park Visitor Center to LaVerkin geologic road log. Base map from U.S. Geological Survey St. George and Kanab 30×60 quadrangles.
Figure 1b. Topographic map showing the western part of the route and stops of the Zion National Park Visitor Center to attracted Logan road. Base map from U.S. Geological Survey St. George and Kanab 30x60 quadrangles.
Springdale landslide partially blocks the right-of-way along highway. A movable barricade holds back rock-fall debris.
PARK ALONG HIGHWAY 9 at Balanced Rock Road. STOP 1.

SPRINGDALE LANDSLIDE. The Springdale landslide (figure 4), on the west side of Utah Highway 9, was reactivated by the September 2, 1992, Mr (local magnitude) 5.8 St. George earthquake. The landslide is underlain by weak claystone of the Petrified Forest Member of the Chinle Formation, and the slope displayed evidence of long-term marginal stability prior to the 1992 landslide. The 1992 landslide involved 18 million cubic yards (14 million m³) of material and underwent about 33 feet (10 m) of primarily translational movement (Black and others, 1995; Jibson and Harp, 1995, 1996). An impressive main scarp formed at the headwall of this slide. It ranges from 25 to 50 feet (8-15 m) high, dips 57 to 77 degrees, and is distinguished by well-developed slickensides (Jibson and Harp, 1995, 1996). Longitudinal extension within the landslide mass resulted in numerous fractures and internal scarps. Landslide movement destroyed three homes and two water tanks within the slide area, disrupted utility lines, and temporarily closed Utah Highway 9 (figure 5).

Figure 4. Oblique aerial view of the Springdale landslide. Note prominent main scarp at the head of the landslide. Photo by Barry Solomon, Utah Geological Survey.

Figure 5. Springdale landslide where it encroached onto Highway 9. Photo by Barry Solomon, Utah Geological Survey.
According to residents of the homes on the landslide, noticeable landslide movement began 15 to 30 minutes after the earthquake, and slow movement continued for about 10 hours. Jibson and Harp (1995, 1996) determined that the displacement during the earthquake was small (1 to 8 centimeters [0.4-3.2 in.]), just sufficient to destabilize the slide mass. The brief, high-frequency stresses induced by the seismic shaking were then relieved by creep along a pre-existing slip surface until the slide mass became unstable and underwent large-scale displacement that actually destroyed the houses (Jibson and Harp, 1995, 1996).

The landslide is 27 miles (44 km) from the earthquake's epicenter, which is an unusually large distance for a landslide of this type and size to have been triggered by an earthquake of that magnitude (Jibson and Harp, 1995, 1996; see also Keefer, 1984). However, most magnitude-distance relations are derived from data near plate boundaries (for example, southern California landslides near the San Andreas fault). The extraordinary distance for the Springdale landslide may reflect a relatively lower attenuation of earthquake ground motions within the Colorado Plateau (Jibson and Harp, 1995, 1996).

0.4 1.0 Hill east with older alluvial-fan deposits on top.

0.2 1.2 To the east across the Virgin River, more landslide deposits, some of them active in historical time, are present.

0.5 1.7 Brightly colored swelling mudstone of the Petrified Forest Member is visible to the west.

0.8 2.5 The small drainage to the west was the site of an intense flash flood and debris flow that damaged roads and buildings in the summer of 1998 (figure 6). Debris flows are among the most frequent and damaging geologic hazards in southwestern Utah.

Figure 6. View southeast to debris flow south of Springdale.
0.6 3.1  SPRINGDALE CITY LIMITS. The Shinarump Conglomerate is exposed along the west side of the highway. Also note old river gravels capping Shinarump strata in many places.

0.4 3.5  Tree Ranch. The confluence of North Fork and East Fork of the Virgin River is just east of the highway. This side road leads to Parunuweap Canyon and the East Fork of the Virgin River. The road crosses private land and special permission from the National Park Service must be arranged to access this part of the park. Large gravel terrace deposits, and a large landslide complex, are preserved in this area.

The Eagle Crags, composed of Navajo Sandstone, lie to the south. Their unusual, jagged, pinnacle-like shape is due to the fact that the Navajo Sandstone in this area is highly jointed and involved in a massive landslide. The main slip surface is in the underlying Chinle Formation, but Moenave and Kayenta strata are also involved. The strata dip northward about 3 degrees. Landslide movement is northward, but retrogressive slope failure at the head is causing the landslide to expand to the south as well. The result is increasing deformation to the north.

0.1 3.6  The Shinarump Conglomerate gets unusually thick here, a result of a broad stream channel cut into the underlying upper red member of the Moenkopi Formation.

0.2 3.8  Turnoff to the Chinle Trail parking area on the right. Parking area is near entrance to the Anasazi Plateau subdivision. Well-exposed, imbricated terrace gravels overlie the upper red member of the Moenkopi Formation.

The Chinle Trail leads northwest on the Petrified Forest Member of the Chinle Formation. It eventually joins with the Coalpits Wash Trail, and ends at a trailhead accessible by the Dalton Wash road. The trail is fairly gentle with a few steep pitches where the trail dips through washes, and it affords a different, seldom seen view of Zion National Park. Geologically interesting features include: some of the best exposures of the Petrified Forest Member in the park; features of the Crater Hill basalt dam and resulting Coalpits Lake; thick basaltic ash deposited downwind of the Crater Hill basalt flow; basalt that was undercut by erosion and collapsed into a pile of rubble; and the Coalpits landslide.

0.3 4.1  The big sand bar at river level is at the historic terrace level of the Virgin River. This surface formed between about 1850 and 1920 (Hereford and others, 1996).

0.4 4.5  LEAVING ROCKVILLE.

0.3 4.8  Bridge Road turnoff on south. Across the river, the road branches. The left branch climbs up through upper red and Shinarump strata, and then leads to the hill with the radio towers visible to the southeast. This hill provides an excellent view into lower Zion Canyon, and an overview of the Crater Hill basalt flow and
its relationship to the Virgin River (figures 7 and 8). The trailhead for the Bureau of Land Management trail leading to the Eagle Crags is also near the radio tower hill. The road is unmarked, is impassable when wet, and there are many side roads.

0.7 5.5 Note the huge blocks of Shinarump Conglomerate that fell from the cliffs above on the north side of the road. The blocks offer an attractive landscape around which to build. However, note the numerous blocks still perched above the houses, posing a rock-fall hazard.

0.7 6.2 ENTERING ROCKVILLE.

0.2 6.4 Huber Wash.

0.3 6.7 Deposits of late Pleistocene Lake Grafton, which formed upriver from the Crater Hill basalt dam, are preserved in a terrace-capped slope on the south side of the road. The lake deposits are at least 20 feet (6 m) thick and consist of planar, thinly bedded to laminated claystone and siltstone (figure 9). These lake beds locally overlie a thin basaltic ash about 0.5 to 1 inch (1-2.5 cm) thick. The ash rests on about 5 feet (1.5 m) of colluvium and eolian sand that overlies the Shnaibkaib Member of the Moenkopi Formation.

Note the huge boulders of Shinarump Conglomerate along the east side of the gravel terrace. The large size and angular nature of the boulders suggests that they rolled down a steep escarpment onto the river terrace at a time when the Shinarump-capped mesa to the northeast was closer to the terrace than it is today, probably about in the position of the highway. The Shinarump-capped mesa has since retreated over 2,000 feet (610 m) to its present position. Note similar large boulders now lying on the slope below the modern Shinarump-capped mesa.

0.3 7.0 Several levels of gravel-capped terraces are present on both sides of the highway.

0.7 7.7 COALPITS WASH BRIDGE. TURN RIGHT just east of the bridge and PARK at the Coalpits Wash trailhead. STOP 2. COALPITS WASH. The Coalpits Wash Trail is an unmaintained trail that connects with the Chinle Trail about 2 miles (3.2 km) to the north. It is rugged and disappears in places, but it leads to some of the more interesting geology in the park. It follows the bottom of Coalpits Wash with the Crater Hill basalt flow capping the rim on the left (west) and the Shnaibkaib Member of the Moenkopi Formation on the right (east). The upper red member of the Moenkopi Formation and the Shinarump Conglomerate Member of the Chinle Formation are exposed farther up the canyon. Basaltic ash from the Crater Hill cinder cone and lake sediments deposited in Coalpits Lake, created when the Crater Hill flow dammed upper Coalpits Wash, make an interesting geologic story near the upper end of the trail.
Figure 7. View north into Zion Canyon from the radio towers southeast of Rockville. The Shinarump Conglomerate (TRcs) forms the prominent mesa in the lower left, above which is Petrified Forest strata (TRcp) mostly covered by landslides (Qms) and pediment gravels (Qap). The Petrified Forest Member is overlain by ledges of the Dinosaur Canyon (Jmd) and slopes of the Whitmore Point (Jmw) Members, above which is the prominent cliff of Springdale Sandstone (Jms). The Kayenta Formation (Jk) forms a steep slope mostly covered by talus below the massive cliffs of the Navajo Sandstone (Jn). Note the high pediment surface (Qap) at the eastern base of Mt. Kinesava.
Figure 8. View northwest from the radio towers to snow-capped Crater Hill on the right side of the photograph. Note where the Crater Hill basalt flow plugged the ancestral Virgin River valley in the left central part of the photograph. The Shinarump Conglomerate forms Rockville Bench above the town of Rockville at the bottom of the photograph. Hurricane Mesa, also capped by the Shinarump Conglomerate, and Smith Mesa, capped by the Springdale Sandstone, are visible in the middle distance. The snow-covered Pine Valley Mountains form the skyline.
**Crater Hill basalt flow.** The vent of the Crater Hill basalt flow is marked by a large cinder cone about 2.5 miles (4 km) north-northwest of the parking area (figure 10). The flow is not reliably dated, but we estimate it is about 100,000 years old based on the amount of downcutting that has occurred along the Virgin River since it was erupted. The vent is on a broad slope that was cut by the ancestral Coalpits and Scoggins Washes, which now underlie the middle of the flow. The flow filled and dammed the washes, and spread out across the broad slope. When it reached the Virgin River valley, which has a much lower gradient, it slowed and ponded. The lava flowed at least 5 miles (8 km) down the river valley and ponded to a depth of at least 400 feet (122 m). Nielson (1977) and Downing (2000) interpreted at least four separate major eruptions over a long period; long enough to allow time for incision of channels between events. Our new mapping suggests a single eruptive cycle, perhaps with a few pulses spaced over a period of a few years to decades.
Coalpits Lake. The basalt dam across the ancestral Coalpits and Scoggins Washes created Coalpits Lake, which covered about one square mile (2.5 km²) (Threet, 1958; Hamilton, 1979, undated, 1995). Basaltic ash is preserved at the base of the lake deposits in several locations (figure 11). Hamilton (1979, undated, 1995) reported tracks of a Pleistocene camel, crane, and various insects from the lake deposits, and pollen recovered from these beds is dominated by ponderosa, pinyon, spruce and fir trees (Hevly, 1979). The climate then must have been cooler and wetter than at present.

Lake Grafton. Though much remains speculative, we can assemble at least some of the history of the interaction of the Crater Hill basalt flow and the ancestral Virgin River. The resistant 400-foot-thick (122 m) basalt plug dammed the Virgin River, forming a lake that must have filled with water fairly quickly, after which the river overtopped the basalt dam near its south side. The river did not flow across most parts of the basalt flow we see today, and undoubtedly quickly established a channel in the softer Moenkopi Formation south of the flow. Though the Moenkopi is relatively soft, it does have a few resistant sandstone beds that may have slowed the downcutting, and there must have been a spectacular waterfall or cascades at the west end of the flow. Eventually, the river cut part way through the dam, and the lake partially filled with sediment, such that the lake gradually disappeared and the river established a channel across the lake sediment. Sediments deposited in Lake Grafton are known only from one outcrop just outside the park near Grafton (Hamilton, undated, 1995) (see mile 6.7). (Grafton, a ghost town located on the south side of the Virgin River opposite Coalpits Wash, was founded by Mormon pioneers in 1859. The
Grafton Heritage Partnership is working to restore the historic Grafton townsite. Since the dam raised the river level and lowered the river gradient, the river deposited fairly extensive gravel lenses upstream of the dam, some of which remain today. Some of these gravel lenses are at higher levels than the base of the flow, showing considerable backfilling behind the basalt dam. Eventually, the river cut down through the Moenkopi Formation, re-establishing its original gradient. The steep south flank of the basalt-capped Moenkopi slope was then unstable and prone to sliding (and it remains unstable today), which may have occasionally dammed the river.

**WALK UP THE COALPITS WASH TRAIL** a few hundred feet to where the base of the Crater Hill flow is exposed across the wash to the west. This is the point at which the flow entered the Virgin River channel. Gravel and fine-grained flood-plain deposits of the ancestral Virgin River are exposed beneath the flow. The gravel is about 10 feet (3 m) thick and contains a mix of clasts that must have been transported down the Virgin River in addition to clasts that are more angular and reflect local sources in Coalpits Wash. Deformation is evident in fine-grained sediment beneath the flow where the flow smeared out the soft muds in the channel. Striations and duplicated lenses of gravel and mud can also be seen.

**Old Gravel Deposits.** River gravel is exposed in several terraces in this area, revealing part of a long history of incision, aggradation, and shifting washes and rivers. A gravel terrace more than 60 feet (18 m) thick is exposed in the steep bluff just east of the parking area. The clasts are angular and locally derived, including many from the Crater Hill flow, and clearly contrast with better sorted and rounded, exotic Virgin River gravels. The base of the gravel is only about 25 feet (7.5 m) above the modern Virgin River, so the deposit is probably Holocene or latest Pleistocene in age. These gravels represent stacked debris-flow (flash flood) deposits carried down Coalpits Wash. Since several debris-flow deposits are stacked up here, it shows that the Virgin River was temporarily aggrading, or filling its channel, and that Coalpits Wash adjusted accordingly. The reasons for this are unclear; however, stacked channel deposits are a common feature of rivers and washes in the desert southwest. All through geologic history, thick alluvial gravel stacks clearly show that channels cycle through episodes of incision (arroyo cutting) and aggradation. Such cycles have significant relevance to the modern debate over the impact of cattle and sheep grazing on arroyo cutting in the southwest desert areas.

A few hundred feet up Coalpits Wash from the parking area, thick gravel terrace deposits sit at a higher level than the bluff east of the parking area, and at a higher level than the gravel at the base of the basalt flow. Clasts in this gravel are different from those in the east bluff. These are mostly well rounded and well sorted, and were transported by the Virgin River. Again, there are a few distinctive, angular to subangular clasts probably derived from local tributary drainages just upriver and incorporated into the Virgin River channel. Some of these deposits may predate the basalt flow, while others appear to post-date the
flow. Large boulders of Crater Hill basalt are present in a few locations, showing that the flow edge was close enough that basalt boulders could roll down onto the gravel deposits. This was the position of the Virgin River after it re-established a channel across the lake bed. The river soon stepped down to the south, leaving these gravel terraces behind.

**CONTINUE WEST ON HIGHWAY 9.**

0.2  7.9 Large road cut in gravel terrace with fine-grained overbank and local colluvial deposits. This terrace corresponds to the prehistoric terrace level of Hereford and others (1996).

0.4  8.3 The bluff to the south, Grafton Mesa, is capped by the resistant Shinarump Conglomerate Member of the Chinle Formation. A small but prominent normal fault displaces the Shinarump Conglomerate down to the west about 10 feet (3 m) in this area. Displacement on this fault increases to the south. The fault also cuts outcrops north of the road, though it is poorly exposed due to large blocks of basalt and talus over the Moenkopi Formation.

0.9  9.2 **PARK** at turnout on south side of highway. **STOP 3. VIRGIN RIVER TERRACES.** This turnout leads to a broad bench that stands about 10 feet (3 m) above the modern Virgin River. This bench is one of many terraces along the river described and named by Hereford and others (1996). They divided low-level (late Holocene) terraces into five main groups: (1) prehistoric terraces, which contain rare Anasazi artifacts indicating that these surfaces are older than 500 years, and that here lie 20 to 33 feet (6-10 m) above the active channel; (2) settlement terraces — the surface that the pioneer settlers generally farmed and occupied — which are less than 500 years old and lack Anasazi artifacts, and that here lie 7 to 13 feet (2-4 m) above the active channel; (3) historic terraces, which formed between about 1850 and 1920, lie about 10 feet (3 m) above the river, are generally covered with cottonwood trees that are 80 to 100 years old, and are flooded by unusually high runoff every decade or so; (4) modern terraces, which are typically about 3 to 7 feet (1-2 m) above the river, covered by tamarisk bushes, and flooded one or more times a year; and (5) the active channel and flood plain to normal highwater stage. These various terrace levels are conspicuous throughout the park, but are best developed in this area. The highway generally is constructed on the prehistoric terrace; the broad bench at this stop represents the historic terrace.

1.8  11.0 Historical marker on north side of highway. Note columnar jointing in the Crater Hill flow, and numerous slumps and slides that have displaced large blocks of basalt downward.

1.4  12.4 Columnar joints are common near the base of the Crater Hill flow, high on the ridge to the north. Columnar joints tend to form in areas of basalt flows that undergo slow, uniform cooling.
After its original channel was plugged by basalt, the Virgin River eroded relatively rapidly along the south flank of the flow, leaving a steep, unstable slope of Moenkopi strata held up by the resistant cap of basalt. This slope is prone to mass movement, and large rotational slumps are common along the slope just north of the highway. In some places, slumped blocks make it appear that the base of the Crater Hill flow is lower than it actually is. The large cuts made for the highway exacerbate landslide activity.

A thick pod of gypsum is exposed on the north side of Utah Highway 9 in a channel cut into the Virgin Limestone near the base of the slope. Basalt clasts in the channel-shaped pod show that the pod is a remnant of thick gypsiferous sandy soil, which is common today on parts of the Moenkopi Formation.

A spring emerges and supports lush vegetation near the base of the Crater Hill basalt flow. This is the lowest part of the flow in this area. The ground water emerges from fractured basalt and underlying coarse channel deposits beneath the flow.

The Virgin River flowed across the top of part of the flow in this area as evidenced by river gravel on top of the flow. In this area, the Virgin River re-established itself on top of the flow briefly before eroding a new channel to the south at the expense of the softer Moenkopi Formation.

Crater Hill basalt flow. The highway parallels the south flank of the Crater Hill basalt flow for the next 5 miles (8 km). This flow was derived from a vent about 3 miles (5.5 km) northeast of here at the Crater Hill cinder cone. It flowed down the ancestral Coalpits and Scoggins Washes, entered the Virgin River, and flowed down the river valley about 5 miles (8 km) (it probably flowed farther down the valley, but no evidence remains). This flow is unusually thick compared to other basalt flows in the area. Because the river valley has a low gradient in this area, the basalt lava tended to stack up or pond in the river valley. A drill hole near the center of the flow penetrated over 400 feet (122 m) of continuous basalt before encountering river gravels at the bottom of the hole (many comparable flows average less than 50 feet [15 m] thick). A "lake" of molten basalt probably filled the valley at one time. Concentric pressure ridges and huge rafted blocks, evidence of this ponding, are present on the upper surface of the flow.

The base of the flow is curved or dish-shaped, conforming to the shape of the ancestral Virgin River valley. Because the highway follows the thinner and curved-up south flank, the base of the flow appears much higher than it actually is. The lowest part of the flow, where it flowed in the ancestral Virgin River channel, is about 125 feet (38 m) above the modern Virgin River. This flow has not been reliably dated, but if the average down-cutting rate determined from the Lava Point flow is valid, then this flow is about 100,000 years old.
0.1  13.1  DALTON WASH ROAD.  This side road passes below the west end of the Crater Hill basalt flow and extensive river-gravel deposits, and is well worth a short (0.3 mile) side trip.  The road also leads to an informal trailhead at the west end of the Chinle Trail.  **THOSE VISITING THIS AREA WILL NEED TO SUBTRACT 0.6 MILES FROM THEIR ODOMETER BEFORE REJOINING HIGHWAY 9.**

*Gravel deposits in Dalton Wash.*  Thick gravel lenses of at least two distinct ages are preserved near the south end of the Crater Hill flow.  A thick gravel lens directly underlies the flow and represents fill in the channel of the ancestral Virgin River prior to flow emplacement.  It consists of a mix of clasts transported by the river and locally derived clasts.  The river clasts are generally under 8 inches (20 cm) in diameter and are well rounded.  The local clasts are larger and more angular, showing less reworking by water.  They include a large component of basalt clasts derived from the Lava Point flow, which loomed over the channel at that time even more than it does now, and also large boulders of sandstone derived from the Shinarump Conglomerate, which capped nearby mesas to the north.

We know that the gravels just south of the flow post-date the Crater Hill flow since they are incised into the Moenkopi at a lower level than the flow, and contain clasts from the flow.  They also are composed of a mix of local and exotic (river-transported) clasts and were deposited after the river had re-established itself on the south side of the flow.

0.3  13.4  Road cut in the Virgin Limestone.

0.4  13.8  BRIDGE OVER NORTH CREEK.  Good view back to the northeast of the Lava Point basalt flow atop the high mesa northeast of the town of Virgin (figure 12).  The Lava Point flow is 1.0 to 1.1 million years old (Best and others, 1980; unpublished UGS data), and erupted from vents at Home Valley Knoll, high up on the Upper Kolob Plateau about 13 miles (21 km) to the northeast.  Because it is preserved so close to the Virgin River, it gives us an excellent control point to evaluate the amount of downcutting that has taken place on the river in the past 1 million years.  The flow overlies the thin Shinarump Conglomerate and it is likely that ancestral North Creek, and the base of the flow, were approximately graded to the river.  The flow is about 1,300 feet (396 m) above the Virgin River, thus about 1 million years ago the river was cutting at a level 1,300 feet (396 m) above its present position, giving an average downcutting rate of 1.3 feet (0.4 m) per thousand years.  By projecting this figure upstream, we see that in the vicinity of Zion Lodge, Zion Canyon was only about one-half its current depth 1 million years ago.  Similarly, near the Visitor Center, the Virgin River was at about the level of the base of the Navajo Sandstone, so that the canyon there must have been narrow, as it is today upstream near the Temple of Sinawaya.
0.3  14.1 Gravel terrace in road cut. Gravel terraces are common in the Virgin River valley. They formed when the river temporarily stabilized at various levels and serve as relative indicators of age. When correlated to nearby basalt flows of known age, they provide good control on the river's downcutting history.

0.2  14.3 Virgin town limit.

0.1  14.4 **TURNOFF TO KOLOB ROAD.** See road guide for description of Kolob Road from Virgin to Lava Point.

0.9  15.3 Virgin town limit.

1.5  16.8 View north to landslide deposit at the south end of Hurricane Mesa (figure 13). This landslide involves the Shnabkaib and underlying middle red members of the Moenkopi Formation. Hurricane Mesa, capped by the resistant Shinarump Conglomerate Member of the Chinle Formation, has a World War II-era test track once used by the Air Force for testing ejection seats, and which is now used for testing automobile air bags. The drive to Virgin is mostly over the lower red member with Timpoweap strata exposed in several washes below road level.

1.2  18.0 Oil seep in yellowish-brown limestone of the Timpoweap Member. The seep is located in the bottom of a small wash just 20 feet (6 m) south of Utah Highway 9.

0.2  18.2 **LAVERKIN OVERLOOK TURNOFF.** Dirt road leads 1.5 miles (2.4 km) out to the edge of the Hurricane Cliffs. **THE VIEW DESCRIBED BELOW IS WELL WORTH THE SHORT DRIVE, BUT THOSE VISITING THE OVERLOOK WILL NEED TO SUBTRACT 3.0 MILES FROM THEIR ODOMETER WHEN REJOINING UTAH HIGHWAY 9.**
Figure 14 shows the view westward from the LaVerkin Overlook. The overlook stands high above the Hurricane fault, at the base of the cliffs. The Hurricane fault is discussed under stop 4.

0.7  18.9  Yellowish-brown siltstone and limestone of the Timpoweap Member gives way to the overlying reddish-brown siltstone and mudstone of the lower red member of the Moenkopi Formation.

0.5  19.4  Polished fault surface with slickenlines in the Rock Canyon Member. The fault dips 85 degrees west and the slickenlines show a rake of 85 degrees to the north, indicating a slight component of right-lateral slip along this portion of the fault. For the next 0.8 mile (1.3 km), Utah Highway 9 crosses several slivers of Moenkopi and Kaibab strata separated by fault strands of the Hurricane fault zone.

0.1  19.5  PARK at turnout on east side of road. WALK to the northeast along the east side of the road to a small box canyon. STOP 4. PERMIAN-TRIASSIC BOUNDARY and the HURRICANE FAULT ZONE. The Permian-Triassic boundary is exposed in the cliffs of a small box canyon on the east side of the road. In southwestern Utah, this boundary is a major unconformity that represents 10 to 20 million years of erosion (Nielson, 1981, 1991; Sorauf and Billingsley, 1991). This is the TR-1 unconformity of Pipiringos and O'Sullivan (1978), the first regional unconformity of the Triassic Period in the western U.S. It also represents a period of dramatic, world-wide sea level drop and the largest global extinction event in the history of the world. Erosion during this time produced an irregular surface, locally with several hundred feet of relief, upon which conglomerates and breccias of the Rock Canyon Conglomerate Member of the Moenkopi Formation were deposited in paleocanyons, karst depressions, and as regolith (Nielson, 1991). Limestone of the overlying Timpoweap Member of the Moenkopi Formation was deposited in broader paleovalleys. The cliffs of this small box canyon are capped by Timpoweap strata that overlie channel-form conglomerates of the Rock Canyon Conglomerate (figure 15). Cherty limestone of the Harrisburg Member of the Kaibab Formation (late Early Permian) is exposed at the base of the wash.
Figure 14. Panoramic view west from the LaVerkin Overlook. Beginning at the right, a complete section of the Moenkopi Formation is exposed below the Shinarump Conglomerate, which caps Hurricane Mesa; the overlook itself is on the Timpoweap Member of the Moenkopi Formation. Black Ridge is carved from the east limb of the Kanarra anticline and is locally capped by an 880,000-year-old basalt flow. This flow had its source west of the Hurricane fault and has since been displaced over 1,000 feet (305 m). The Pine Valley Mountains, an early Miocene laccolith intruded into the Claron Formation, form the skyline to the northwest. To the west and southwest, the Virgin River cuts across the north end of the Hurricane volcanic field. The basalt flow exposed in the footwall of the Hurricane fault zone, just south of the Virgin River, yielded an $^{40}$Ar/$^{39}$Ar age of 353 ± 45 ka (Sanchez, 1995); it has been displaced about 240 feet (73 m) by the Hurricane fault. Pillow basalt at the base of this flow, exposed in both the upthrown and downthrown blocks, shows that the flow temporarily blocked the Virgin River. Mollies Nipple, on the skyline at left, is capped by a basaltic flow believed to have originated at Ivans Knoll, just south of Volcano Knoll. The Ivans Knoll flow is about 1,000,000 years old and has been displaced about 1,300 feet (395 m) by the Hurricane fault.
Figure 15. View north-northeast of the Rock Canyon Conglomerate Member (TRmr) overlain by the Timpoweap Member (TRmt) in a small box canyon immediately east of Utah Highway 9.
In this area, the Hurricane fault zone is marked by a west-dipping section of Moenkopi strata that formed as a relay ramp between two en-echelon faults (figures 16 and 17) (Biek, 1998). Although cut by numerous down-to-the-east and down-to-the-west normal faults, the ramp exposes a complete section of Moenkopi strata. This relay ramp also forms an easy way up the Hurricane Cliffs, a fact exploited by Highway 9. Fault blocks of the lower red and Virgin Limestone Members of the Moenkopi Formation are exposed west of the road. About 1,300 feet (396 m) north of this box canyon, on the west side of the road, the lower red member is faulted down-to-the-west against the Rock Canyon Conglomerate (figure 18). The fault plane dips 85 degrees west and slickenlines developed on Rock Canyon strata show a rake of 85 degrees to the north, indicating a slight right-lateral component of slip on this part of the fault. Similar slickenlines are found at mile 19.4, described above, but are located at a dangerous curve of Highway 9.

Figure 16. Oblique aerial photograph of the relay ramp between two parts of the Hurricane fault zone. Utah Highway 9 loops in and out of the photo on the right. Hurricane Mesa, with its flat-lying Moenkopi strata capped by the Shinarump Conglomerate Member of the Chinle Formation, is in the distance.

Figure 17. Block diagram showing the main features of a relay ramp. Modified from Peacock and Sanderson (1994).
The Hurricane fault zone is a major, active, steeply west-dipping normal fault that stretches at least 155 miles (250 km) from south of the Grand Canyon northward to Cedar City. Stewart and Taylor (1996) defined a fault segment boundary just north of Toquerville, thus dividing the Hurricane fault zone into the Ash Creek segment to the north and the Anderson Junction segment to the south. In the Hurricane area, the Iron Springs Formation is down on the west against the Permian Toroweap Formation, resulting in an apparent, or stratigraphic, separation across the fault zone in this area of nearly 9,000 feet (2,744 m) (Biek, 1998). However, by subtracting the effects of previous Sevier-age folding, reverse-drag flexure in the footwall, and rise-to-the-fault flexure in the hanging wall, the true tectonic displacement across the fault at the latitude of Hurricane is about 3,600 feet (1,098 m) (Anderson and Christenson, 1989). At Hurricane, a basalt flow shows about 240 feet (73 m) of stratigraphic offset across the fault zone. This flow yielded an $^{40}$Ar/$^{39}$Ar isochron age of 353 ± 45 ka (Sanchez, 1995), resulting in an average slip rate of about 8 inches/1,000 years (0.2 m/1,000 yr) for this part of the Anderson Junction segment of the Hurricane fault zone since about 350,000 ka (Biek, 1998). Near Ash Creek Reservoir about 12 miles (19 km) to the north, on the Ash Creek segment of the Hurricane fault zone, Lund and Everitt (1998) similarly documented an average

Figure 18. View north-northwest along Hurricane fault zone just north of Utah Highway 9. The lower red member of the Moenkopi Formation is down on the west against the Rock Canyon Conglomerate Member. Black Ridge is on the skyline with the snow-capped Pine Valley Mountains to the west.
slip rate of about 16 inches/1,000 yr (0.39 m/1,000 yr) since about 900,000 years ago. Lund and Everitt (1998) investigated the paleoseismology of the Hurricane fault in Utah and noted that the most recent surface faulting event on the fault occurred in the latest Pleistocene or early Holocene, at the north end of the fault near Cedar City. They further noted that multiple surface faulting earthquakes have occurred in the late Quaternary along most, if not all, of the Utah portion of the fault; additional paleoseismic investigations are underway.

0.4 19.9 Road cuts in the Rock Canyon Conglomerate and Timpoweap Members of the Moenkopi Formation.

0.3 20.2 Base of the Hurricane Cliffs and western part of the Hurricane fault zone. Small road cut in brightly colored swelling mudstone of the Petrified Forest Member of the Chinle Formation. Along most of its length in southwestern Utah, the Hurricane fault zone, at the base of the Hurricane Cliffs, is characterized by numerous fault-bounded blocks of steeply west-dipping Triassic and Jurassic red beds that contrast sharply with mostly gray Permian carbonate strata exposed in the cliffs themselves (Stewart and Taylor, 1996; Biek, 1998; Higgins, in preparation; Hurlow and Biek, in preparation).

0.5 20.7 **END** road guide at the junction of Utah Highway 9 and Utah 17 in LaVerkin.
UTAH HIGHWAY 9 — ZION NATIONAL PARK VISITOR CENTER TO MT. CARMEL JUNCTION

INTRODUCTION

This route follows Utah Highway 9 from Zion Canyon east to Mt. Carmel Junction (figures 1a and 1b). The route crosses strata ranging from the Lower Jurassic Moenave Formation to the Upper Cretaceous Dakota Formation, with much of the route beyond the Zion-Mt. Carmel Highway tunnel in the spectacularly well-exposed Navajo Sandstone. This is one of the few places where you can drive through the entire Navajo section and observe vertical variations in the formation. You will see the three informal subunits of the Navajo Sandstone, cross-bedding and other sedimentary features, and some of the most prominent joints in the park. This route also traverses the Temple Cap, Carmel, newly recognized late Early Cretaceous, and Dakota strata. Near Mt. Carmel Junction, the route drops down into Long Valley and crosses antithetic and synthetic faults associated with the Sevier fault zone.

Figure 1a. Topographic map showing the western part of the route and stops for the Zion National Park Visitor Center to Mt. Carmel Junction geologic road log. Base map from U.S. Geological Survey Kanab 30x60 quadrangle.
On July 21, 1998, intense rainfall from a slow moving thunderstorm cell triggered a debris flow that started at the fresh scars near the top of the Kayenta Formation in the small canyon (Sammy's canyon) to the east. About 1.2 inches (3 cm) of rainfall was recorded in 30 to 40 minutes at the park service housing area just to the north (Dave Sharrow, National Park Service, written communication, October 30, 2000). Huge boulders transported by the flow are visible near the mouth of the canyon above the parking lot (figure 2). Further down gradient, the debris flow covered part of the Watchman Campground with about 6 inches (15 cm) of sand, smashing and burying a substantial amount of camping equipment; fortunately no one was seriously injured. The debris flow also blocked the Virgin River and flooded the lower part of the South Campground (figure 3).
Entrance to South Campground. The reddish-brown outcrop just above the road to the west is the Dinosaur Canyon Member of the Moenave Formation. The prominent sandstone ledge near the top of the slope is the Springdale Sandstone Member of the Moenave Formation, below which is a mostly covered slope of the Whitmore Point Member. The deep-red slope former that is poorly exposed above the Springdale Sandstone is the Kayenta Formation. The resistant ledge near the middle of the Kayenta Formation is the Lamb Point Tongue of the Navajo Sandstone. The many large blocks that litter the lower part of this slope are from the Springdale Sandstone.

From this point northward Zion Canyon begins to narrow significantly. This is because we have now climbed above the non-resistant Petrified Forest strata. Once the river erodes down to the level of the Petrified Forest Member, it is able to rapidly erode the mudstone strata, causing overlying rocks to slump and thereby promoting widening of the canyon downstream.
0.3 0.5 Oak Creek bridge.

0.2 0.7 Entrance to old Visitor Center.

0.6 1.3 VIRGIN RIVER BRIDGE.

0.1 1.4 JUNCTION WITH ZION CANYON SCENIC DRIVE AND UTAH HIGHWAY 9. A road guide for the Zion Canyon Scenic Drive is described separately.

0.1 1.5 Unusually large rock-fall boulder on right side of road.

0.1 1.6 On the right is a landslide that blocked Pine Creek at some time in the past, forming a pond or small lake behind the slide. Note the fresh rock falls off the face of the landslide where it is being undercut by Pine Creek.

0.1 1.7 The floor of Pine Creek canyon widens here due to backfilling in the basin upstream of the landslide. This is also one of the few places in the park where the Whitmore Point Member of the Moenave Formation is exposed near a road. The greenish-gray beds about 10 feet (3 m) thick were deposited in a lake setting, as attested to in part by locally common fossil fish scales. The thicker ledge and thin-bedded overlying rock are the basal part of the Springdale Sandstone Member of the Moenave Formation.

0.2 1.9 Pine Creek bridge and turnout on left side of highway. Good exposure of thin-bedded siltstone and sandstone in the lower part of the Springdale Sandstone on the left. Beginning here the highway climbs up a steep, mostly talus-covered slope over the Moenave and lower Kayenta Formations and then onto a large landslide involving Kayenta strata. The landslide has had the effect of broadening the Kayenta slope, providing road builders room to carve several switchbacks to lessen the road grade.

0.5 2.4 This and several other road cuts over about the next 1.5 miles (2.4 km) provide good exposures of the Kayenta Formation. The Kayenta Formation was deposited in a lake and river system that flowed across a broad, slowly subsiding coastal plain. Most of the dinosaur tracks known in the park and surrounding area are found in the Kayenta Formation.

0.9 3.3 The Lamb Point Tongue of the Navajo Sandstone, the resistant ledge near the middle of the Kayenta Formation, is well exposed across Pine Creek canyon at eye level. On the south side of the canyon, the Lamb Point Tongue is buried beneath landslide deposits.

0.7 4.0 Turnout on right with interpretive signs.
Switchback and turnout on right. PARK AT TURNOUT. If it is full of vehicles, any of the turnouts with a view of Zion Canyon will suffice. STOP 1. OVERVIEW OF ZION CANYON.

*The Navajo Sandstone.* The Navajo Sandstone is locally divided into three informal subunits in southern Utah: the lower brown, middle pink, and upper white subunits. It is important to note that these subunits are not true members because they are not defined by stratigraphic boundaries. Rather, they are defined by color changes that are due to vertical variations in the amount and type of cement bonding the sand grains. The boundaries between these subunits are irregular, rise and fall across cross-bed sets, and are difficult to discern except from a distance. The brown subunit has the strongest cementation and contains more iron oxide, mostly hematite, than the other parts; hanging valleys tend to form at the top of this subunit. The pink subunit appears to be more uniformly stained by iron oxides (hematite) and may reflect the unaltered color of the Navajo. The pink subunit is somewhat porous and friable, but in places, iron mineralization or cementation is very pronounced, and sheets, concretions, and nodules of ironstone litter the outcrops. Ironstone may contain less than 1 percent to about 20 percent iron oxide. The white subunit forms the highest cliffs of the Navajo Sandstone in Zion National Park and is exemplified by the Great White Throne. The white color is due to a change in the oxidation state of the iron minerals that help to cement the sandstone, from the original iron oxide (hematitic) cement of the pink subunit to hydrated and reduced iron oxide (limonite) of the white subunit. Locally, the limonite concentrates in bands to form almost black, resistant veins and nodules. Look for resistant black bands and knobs along the road as you travel through the Navajo Sandstone.

What caused these variations in the cementation of the Navajo Sandstone? Movement of ground water and probably hydrocarbons (natural gas and oil) through the rock. When? It is difficult to determine the timing of this secondary alteration of the rock. We are probably seeing the cumulative effects of fluid movement through the rocks ever since they were deposited.

*Sand Bench.* The large bench across the canyon is called Sand Bench. Does that broad, relatively flat-topped, rubble-covered bench seem out of place for a narrow canyon like Zion Canyon? Sand Bench is actually the collapsed remnant of a large narrow wall or fin of Navajo Sandstone that formed between two joints. Note the extremely coarse, rubbly nature of the material along the slope and rim of Sand Bench. As canyons cut down along joints on each side of the wall into the weak, thin-bedded Kayenta Formation, the wall became increasingly unstable. Finally, about 7,000 years ago, it collapsed catastrophically, damming Zion Canyon and forming Sentinel Lake. Sentinel Lake was at least 200 feet (61 m) deep and stretched from the Court of the Patriarchs upstream nearly to the Temple of Sinawava. Unlike other Quaternary lakes in Zion National Park, Sentinel Lake was probably full of water year round.
Sand talus. Notice several cones of sand talus at the base of the Navajo cliff. Talus is generally thought of as rough angular blocks of rubble that fall and roll down steep slopes. In this case, the source material is weathered sand on the upper part of the Navajo that falls, is blown, or is washed into small gullies and depressions on the upper Navajo Sandstone. It then trickles down these natural "chutes," cascading over the cliffs, and is deposited in piles at the base of the slopes. Coarser, blocky talus is also common in the canyons where it accumulates on the slope-forming Kayenta Formation.

WEST PORTAL ZION-MT. CARMEI HIGHWAY TUNNEL. The Zion-Mt. Carmel Highway tunnel is 1.1 miles (1.8 km) long and passes within a few feet of the face of the south wall of Pine Creek canyon. The tunnel, which was completed in 1930, was drilled and blasted through the lower 260 feet (80 m) of the Navajo Sandstone. It cost a little over $1,000,000 and was the first million-dollar mile of highway construction in U.S. history. The tunnel includes several galleries and windows that offer views of the adjacent canyon. As you travel through the tunnel, the landscape changes from the steep slopes and sheer walls of Zion Canyon to prominently jointed and fantastically sculpted slickrock. For about the next 8 miles (13 km), the highway traverses this intricately carved wonderland in the Navajo Sandstone.

East portal of Zion-Mt. Carmel Highway tunnel and parking area for the Canyon Overlook Trail. Note the sharp boundary between the brown and pink Navajo Sandstone. This boundary happens to roughly follow a planar surface in the Navajo Sandstone. This surface represents an interdunal area (oasis) between the sand dunes and is exceptionally well exposed along the Canyon Overlook Trail, described in a separate trail guide.

Short tunnel through the Navajo Sandstone.

PARK at turnout on right. STOP 2. JOINTS IN THE NAVAJO SANDSTONE. Through this area, you can see that the canyons are long, narrow, straight, and that most trend north-northwest (figure 4). This is because they are aligned along joints. The most prominent joints in the park trend north-northwest. Erosion is accelerated along these joints because more surface is exposed to weathering and because the joints collect sand, which holds moisture that aids weathering of the cement of the sandstone. As the joints enlarge, more water can accumulate. Once water begins to flow, its weathering and erosive ability is greatly increased by the grinding action of sand grains along the joint bottom. Freeze-thaw action also plays a major roll in the enlargement of joints. Some joints have crushed or sheared zones — evidence of microfaulting. Such joints are called deformation band shear zones (Davis, 1999) and are indicative of small-scale displacement. The end result is that erosion occurs most rapidly along the joints. If you look closely though, you will see that this is not always the case. Some joints that have sheared zones are recemented with siliceous cement, actually making the joint more resistant to erosion than the surrounding rock. These joints stand up as resistant ribs or ridges.
Blind arch or alcove is forming to the north. The arch is a natural architectural shape of strength, which is why it is used in so many buildings and bridges. As the Navajo cliffs erode, rock spalls tend to create arches. The self-supporting structure is strong, and in addition, it dries rapidly after a storm, giving water little time to act on the cement. Thus, it will commonly stand for a long time, and may eventually form windows or open arches.

**PARK** at turnout on right. **STOP 3. DIFFERENTIAL WEATHERING OF JOINTS.** In several places you will notice large joints along which the sandstone is "stepped-down" several feet on one side. These are good examples of differential weathering. Many people incorrectly believe these are faults since it appears that the sandstone is dropped down on one side. However, the sandstone is not offset. Instead, weathering acts independently on each side of the joint. The sandstone weathers by a combination of dissolution of cement, flowing water, and frost wedging action along joints, along cross-bed boundaries where the rock is slightly more porous, and between individual sand grains. Slight differences in several factors ranging from the dip of the cross-beds to the amount of shade cause differences in erosion rates on opposite sides of the joints. The joint surface may also be coated with iron-manganese oxides which serve to protect it from erosion.

Turnout on left. Sign discusses large arch and cementation in the Navajo Sandstone.
PARK at turnout on left. **STOP 4. IRON-MANGANESE-OXIDE CONCRETIONS.** In this area, you will see many examples of iron-manganese-oxide accumulations in the sandstone (figure 5). These hardened knobs and bands form in areas where ground water has mobilized and redeposited iron and manganese. Though it may look like iron, if you look closely, you will see that even the dense "ironstone" is composed primarily of sandstone. Several of our analyses show that even the heaviest ironstone typically contains less than 20 percent iron oxide. These features are evidence of extensive ground-water migration through the rock, probably over many millions of years.

*Figure 5. Planar ledge of ironstone in the Navajo Sandstone. Photograph below shows closeup of swirling patterns common in many ironstone blocks.*
0.7  11.1  **PARK** at Checkerboard Mesa parking lot. **STOP 5. CHECKERBOARD MESA.** Checkerboard Mesa derives its name from the checkerboard pattern created by weathering along the roughly perpendicular sets of grooves that are so well developed in the Navajo Sandstone here (figure 6). The nearly horizontal grooves are along layers of coarse sand that coincide with eolian bedding sets. The vertical grooves appear to be shallow fractures that result from local expansion and contraction of the rock surface due to changes in temperature and moisture.

Note the various types of jointing in the sandstone in and near Checkerboard Mesa. Although there is some controversy about the cause of the different types of joints, we can make some generalizations: (1) The largest joints in the area are prominent, north-northwest-trending joints that can be traced for miles. These joints commonly include a narrow zone of brecciated and silicified rock called a "deformation band shear zone," indicating that they have experienced minor movement (Davis, 1999). (Where the movement is measurable and significant, the joint is mapped as a fault.) The formation of these joints is not well understood. They may be related to compressional deformation during the Sevier orogeny, possibly overprinted by extensional deformation related to Basin and Range extension during the past few million years. (2) A variety of secondary cross joints connect the largest joints and are typically oriented 60 to 90 degrees to the major joints. These joints formed simultaneously with, and link, the master joints. (3) Small, non-penetrative joints are common throughout the park, and most are only a few tens of feet to a few hundred feet long on the surface. Some only penetrate the rock a short distance and are related to surface processes, including expansion as the weight of overlying rock is removed by erosion, and even to daily and seasonal warming and cooling of the rock. (4) Locally, joints are clearly related to nearby folds and faults. Such joints are more closely spaced and show more intense deformation than other joints in the park. Many joints in the park can be grouped into one of these four categories, while others are less certain. Some joints have a multiple-event history.

0.2  11.3  Turnoff to East Rim Trail parking area on left. See the trail guide for a description of the East Rim Trail from this trailhead to Weeping Rock in Zion Canyon. Figure 7 shows the view east to a well-exposed section of the Temple Cap Formation.
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Figure 7. View west from near the east entrance to Zion National Park. Note the J-1 unconformity at the top of the Navajo Sandstone (Jn), above which lies the thin, vegetated slope of the Sinawava (Jtw) and thick sandstone cliffs of the White Throne (Jts) Members of the Temple Cap Formation. The lower Co-op Creek Limestone Member (Jccl) of the Carmel Formation forms the skyline on top of the mesa.

0.1  11.4  ZION NATIONAL PARK GATE AND TOLLBOOTH.

0.6  12   East boundary of Zion National Park.

0.9  12.9  Highway 9 passes through the top of the Navajo Sandstone. The Temple Cap Formation is exposed on both sides of the road. The lower, reddish-brown mudstone and siltstone of the Sinawava Member is less resistant and forms the covered slope. The upper White Throne Member forms a well-exposed sandstone cliff or ledge.

0.6  13.5  Highway 9 passes through the top of the White Throne Member, which is mostly concealed by colluvial and alluvial deposits of Co-op Creek valley.

0.2  13.7  Road cut through lower part of Co-op Creek Limestone Member of the Carmel Formation.

0.1  13.8  Turnoff on left to the North Fork of the Virgin River and trailhead for The Narrows hike.

The valley floor here is broad and not dissected by incised streams. This is probably because the mixed eolian-alluvial surficial deposits have good drainage and water soaks in rather than running off.

0.5  14.3  Mixed eolian and alluvial silt and sand blankets the broad bench traversed by Highway 9. There is a good view to the north of Clear Creek Mountain, which is capped by the Late Cretaceous Straight Cliffs Formation.

0.9  15.2  The Crystal Creek Member of the Carmel Formation is exposed in a small road cut on the left.
PARK at turnout on right. **STOP 6. MEADOW CREEK OVERVIEW AND COAL HILL LANDSLIDE COMPLEX.** This location gives a good view of the Carmel Formation exposed in the walls of Meadow Creek canyon to the east and south (figure 8). The upper Navajo Sandstone and Temple Cap Formation are exposed at the canyon bottom in the distance. They are overlain by the Co-op Creek Limestone (pale yellowish-gray barren slopes), Crystal Creek (reddish slope), Paria River (thick white gypsum bed and thin overlying strata), and Winsor (reddish-brown grading upwards to yellowish siltstone and sandstone) Members of the Carmel Formation. The unconformable contact of the Winsor Member with overlying Cretaceous strata is exposed near the southwest end of Coal Hill (the hill to the east across Meadow Creek), in a landslide scarp at the color change from yellow to gray.

![Figure 8. Carmel Formation exposed in Meadow Creek (view looking southeast from the highway). Lower vegetated slopes are the lower unit of the Co-op Creek Limestone Member, and the light-colored barren slopes and ledges are the upper unit of the Co-op Creek. Reddish-brown, slope-forming Crystal Creek Member is overlain by white gypsum bed of the Paria River Member. Reddish-brown to pale yellow sandstone of the Winsor Member caps the sequence.](image)

The view to the northeast gives a good overview of the Coal Hill landslide complex (figure 9), over which Highway 9 passes (you may want to walk down the highway shoulder a few hundred feet to get a better view). The landslide complex covers an area of about 2.5 square miles (6.5 km²) and consists of numerous, relatively small to medium-sized rotational slumps on the steep north side of Coal Hill, as well as a huge composite slide/earthflow that occupies the gently south-sloping basin below the hills that rise steeply to the east (lateral flank) and north (main scarp). The landslides involve Cretaceous strata, including the Dakota Formation, which contains highly plastic bentonitic clays in its lower part.
The Coal Hill landslide complex is notable because it is crossed by Highway 9. However, dozens of similar landslides are located all along the outcrop belt of the Dakota Formation and overlying Tropic Shale on the east side of Zion National Park. Most of the smaller landslides have experienced movement during late Holocene time, and many have been historically active. Most of the large composite slides, which typically cover 1 to 2 square miles (2.6-5.2 km²) or more, were probably active during the Pleistocene. These large landslides have only been locally active during historical time in areas where slopes have been oversteepened by stream incision or road construction, or where ground water is shallow.

To the north, the main scarp of the large composite landslide in the Coal Hill landslide complex is 300 to 400 feet (90-120 m) high, and exposes the upper part of the Dakota Formation (up to the prominent sandstone bed located at mid-slope) and overlying Tropic Shale. Transverse ridges in the head of the slide mass appear to be transported, relatively intact blocks of the upper Dakota Formation. An extensive subsurface investigation by the Utah Department of Transportation (UDOT) in 1962-63, summarized in Doelling and Davis (1989, p. 153), showed that the landslide deposits near the highway west of Meadow Creek are about 40 feet (12 m) thick.

Note the wavy deformation of the highway due to landslide movement for about the next 0.5 mile (0.8 km) (figure 10). This section of road crosses the active portion of the large composite landslide in the Coal Hill landslide complex, and requires almost constant maintenance (repairing pavement cracks and paint-stripe offsets) by UDOT. The original highway, constructed in 1928, was realigned across the landslide complex in 1964. The old highway is about 210 feet (64 m) south of the present highway at this location, and shows about 16 to 20 feet (5-6 m) of pavement offset at the margins of the active landslide.
0.4  17.3  Bump in road at the eastern edge of active part of the Coal Hill landslide complex.

0.5  17.8  Note the relatively thick coal seams, and landslides, in the Dakota Formation on both sides of the road.

0.2  18.0  Road cut in the Dakota Formation. Note the down-to-the-west normal fault that truncates the coal seam at the base of the main body of the Dakota Formation on both sides of the road. To the northwest, the prominent cliff that forms the main scarp of the Coal Hill landslide complex exposes the upper member of the Dakota Formation, the Tropic Shale, and a thick, tan sandstone tongue of the Straight Cliffs Formation. Straight Cliffs Formation sandstone forms the uppermost cliffs on the skyline.

1.0  19.0  **TURN RIGHT** on a small, unmarked side road (the old highway). Take this little-used road back to the northwest 0.3 miles (0.5 km) to see a rare gravel-pit exposure of newly recognized late Early Cretaceous strata. This road crosses private property so please be respectful of the property owner's rights. **IF YOU OMIT THIS STOP, SUBTRACT 0.6 MILES FROM THE CUMULATIVE MILEAGE BELOW. STOP 7. LATE EARLY CRETACEOUS STRATA.** This gravel pit exposes a pebble conglomerate composed of tan, gray, and other light-colored chert pebbles up to 3 inches (8 cm) in diameter. The most distinctive clasts are rare pebbles of petrified wood derived from Mesozoic strata somewhere to the west.

Previous workers mapped this conglomerate and overlying sandstone and mudstone as the Dakota Formation (for example, Doelling and Davis, 1989), which is considered to be Cenomanian (Late Cretaceous) in age. However, the results of recent palynological studies in the Zion area by the authors indicate that the basal sequence of these rocks (strata below the coal seam exposed in the...
highway cut at mile 16.6) is late Early Cretaceous in age. Pollen samples obtained from a mudstone and shale sequence that overlies the basal conglomerate and sandstone sequence in the vicinity of Table Bench, northwest of here between Orderville Gulch and the North Fork of the Virgin River, included an assemblage that indicates an age no younger than late Albian. Also, Doelling and Davis (1989) obtained a sample from near the Zion coal mine, about 0.75 mile (1.2 km) north of Utah Highway 9 along Little Meadow Creek, that yielded Early Cretaceous forms, and concluded that a total absence of angiosperm (flowering plant) pollen in the sample indicates the sample is older than Albian. The palynological data, therefore, suggest that either the basal Dakota in the Zion National Park area is older than it is elsewhere in southern Utah, or it represents previously unrecognized Cedar Mountain Formation, a lithologically similar unit considered to be of Albian age (Tschudy and others, 1984; Kirkland and others, 1997, 1999).

The Cretaceous rocks in and near Zion National Park represent sediment derived from Paleozoic strata that were being uplifted in the Sevier orogenic belt to the west (Kauffman, 1977). The clastic material was shed eastward and was subsequently deposited in fluvial systems in the foreland basin (Tschudy and others, 1984; am Ende, 1991). The Cretaceous rocks rest on a regional angular unconformity that developed on the underlying Jurassic strata, which dip about 2 to 3 degrees to the northeast. The basal conglomerate is typically cliff or ledge-forming and contains well-rounded clasts of quartzite, chert, and limestone, as well as petrified wood that includes silicified logs. Uranium mineralization occurs locally in association with clay lenses and carbonized wood fragments at the base of the conglomerate, and several claims have been worked in the vicinity of Orderville Gulch (Beroni and others, 1953).

2.3 21.3 The Co-op Creek Limestone Member of the Carmel Formation is exposed in small road cut.

0.2 21.5 Bridge. Co-op Creek strata are well exposed in canyon.

0.5 22.0 The Crystal Creek Member is exposed in road cuts for about the next mile.

1.3 23.3 Turnout on both sides of Utah Highway 9 for information on the Zion-Mt. Carmel Highway tunnel. The Co-op Creek Limestone Member is exposed in the bottom of all the washes along this stretch, with Crystal Creek strata near road level.

0.8 24.1 Turnout on the right. To the north, the Crystal Creek Member is well exposed, capped by the thick gypsum bed at the base of the Paria River Member.

0.3 24.4 The road drops down a hill and crosses several small faults that offset members of the Carmel Formation. These small faults are synthetic and antithetic to the main Sevier fault, which lies a couple of miles east of Mt. Carmel Junction.
Highway 9 crosses one of the better exposed of these small secondary faults. The Crystal Creek Member is faulted down to the west against the Co-op Creek Limestone Member (figure 11). Note the "shingled" bedding in Co-op Creek strata in this area. "Shingled" bedding appears as imbricated cross-beds and is indicative of a wave-dominated shoreline deposit.

JUNCTION Utah Highway 9 and U.S. 89 at Mt. Carmel Junction. Mt. Carmel Junction is in the southern part of Long Valley, which was formed by the southwest-flowing East Fork of the Virgin River. Long Valley is in the hanging wall of the Sevier fault and closely parallels the fault. The Sevier fault is a west-dipping, high-angle normal fault zone that can be traced from the Grand Canyon northward to the Marysville volcanic field north of Panguitch. Vertical displacement along the fault is about 2,000 to 2,500 feet (600-750 m) (Davis, 1999). Note the escarpment of uplifted Navajo Sandstone to the east, at the base of the Glendale Bench.

**END** of road guide.

*Figure 11. View north of small normal fault in the Carmel Formation just west of Mt. Carmel Junction. The fault places Crystal Creek strata down on the west against the Co-op Creek Limestone Member.*
KOLOB ROAD — VIRGIN TO LAVA POINT

INTRODUCTION

In the 22 miles (35 km) between the town of Virgin and Lava Point, the Kolob Road climbs over 4,300 feet (1,311 m) from the dry Sonoran climate of the Virgin River lowlands to the cool Ponderosa forests of the Upper Kolob Plateau (figure 1). The road traverses most of the rock formations exposed in Zion National Park, including the Moenkopi, Chinle, Moenave, Kayenta, Navajo, Temple Cap, and Carmel Formations. The middle portion of the route follows 250,000-year-old basalt flows of the ancestral Grapevine Wash and North Creek drainages, which now stand high above adjacent drainages as spectacular inverted valleys. The road also crosses the West and East Cougar Mountain faults. Lava Point offers panoramic views of the Grand Staircase (the "stairstep" topography of cliffs and broad valleys or plateaus), which extends from Paleozoic strata exposed in the Kaibab Plateau near the Grand Canyon in Arizona to the orangish-pink cliffs of the Tertiary Claron Formation made famous at Bryce Canyon National Park and Cedar Breaks National Monument.

MILEAGE

INTERVAL/CUMULATIVE

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<td>BEGIN road guide at the junction of Utah Highway 9 and the Kolob Road in the town of Virgin. <strong>PROCEED NORTH ON KOLOB ROAD.</strong></td>
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<td>The small road cut is in the lower red member of the Moenkopi Formation on the east side of the road; the hill above is capped by the lower part of the Virgin Limestone Member. The Virgin Limestone is not well exposed at the town of Virgin, its namesake, where it is stepped back to the north and covered in part by surficial deposits. Hurricane Mesa, capped and protected from erosion by the resistant Shinarump Conglomerate Member of the Chinle Formation, and the southern end of Smith Mesa, capped by the Springdale Sandstone Member of the Moenave Formation, are visible to the northwest (figure 2).</td>
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<td>The road here traverses the gypsiferous lower portion of the middle red member of the Moenkopi Formation, which is covered by thin surficial deposits. To the east, the high mesa is capped by the 1.0 million-year-old Lava Point basalt flow (Best and others, 1980; unpublished UGS data), which now lies about 1,300 feet (396 m) above the valley floor (figure 3). The basalt overlies a narrow cliff of Shinarump Conglomerate, and the underlying Moenkopi Formation is mostly covered by talus. The Lava Point flow flowed down the ancestral North Creek, which was likely graded to the Virgin River at the time. Thus, we know that in the vicinity of Virgin, the Virgin River has cut down about 1,300 feet (396 m) in the past 1 million years, yielding an average rate of erosion of 1.3 feet per 1,000 years (0.4 m/1,000 yr).</td>
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Figure 1. Topographic map showing route and stops for the geologic road log from Virgin to Lava Point. Base map from U.S. Geological Survey St. George 30x60 quadrangle.
Virgin oil field. The Virgin oil field, the oldest oil field in Utah, was first developed in 1907 following the discovery of oil and asphalt seeps in this area. The primary productive interval at the Virgin oil field was the uppermost part of the Timpoweap Member of the Moenkopi Formation, at a depth of about 600 to 780 feet (183-238 m). Significant shows of oil were also reported from the underlying Kaibab and Pakoon Formations, and the Callville Limestone. Nine wells in the Virgin field, which covered about 2.5 square miles (6.5 km²), produced 201,127 barrels of oil. The field was shut-in in 1967 (Stowe, 1972).
1.0 2.8 South end of the Grapevine Wash basalt flow on the east side of the road. The flow here overlies alluvial gravel deposits of the ancestral Grapevine Wash and North Creek and now forms a classic example of inverted topography. Inverted topography forms when resistant material such as basalt or gravel covers a valley floor. Continued downcutting and erosion then incises along the side of the resistant material, eventually leaving the former valley standing as a ridge, an "inverted" valley. The road crosses the gradational contact of the Shnabkaib and middle red members of the Moenkopi Formation near here. The Grapevine Wash basalt flows are about 250,000 years old and erupted from several vents, including Firepit and Spendlove Knolls, about 8 miles (13 km) to the north.

0.4 3.2 Small bridge over North Creek. Note gravel deposits under Grapevine Wash flow.

1.0 4.2 Old alluvial gravels deposited over the Shnabkaib Member of the Moenkopi Formation are exposed on the east side of the road.

0.3 4.5 Small bridge over North Creek.

0.6 5.1 PARK along side of the road on top of the Grapevine Wash basalt flow. STOP 1. GRAPEVINE WASH BASALT FLOW. Except for a short stretch (about 0.2 mile [0.35 km] long) at the turnoff to Smith Mesa, the road travels over Grapevine Wash basalt flows or overlying Quaternary deposits for about the next 9 miles (14.5 km). For about the next 5 miles (8 km), the road is on the flow-capped inverted valley of ancestral North Creek and Grapevine Wash.

The Grapevine Wash flow erupted on the Lower Kolob Plateau in the west-central part of the park. This flow is actually a group of closely related flows derived from a cluster of cinder cones in the area. We acquired several $^{40}\text{Ar}/^{39}\text{Ar}$ ages on these flows that range from $0.22 \pm 0.03$ to $0.31 \pm 0.02$ Ma. The flows temporarily blocked both the Left Fork and Right Fork of North Creek, probably forming lakes in these canyons upstream of the basalt dams (Hamilton, 1979, 1995).

0.2 5.3 Sunset Canyon Ranch entrance. The road here is at the elevation of the upper red member of the Moenkopi Formation, which is exposed to the northwest and southeast.

0.9 6.2 Steep rise in road results from the Grapevine Wash basalt flow being draped over the resistant Shinarump Conglomerate. The flow widens above this point because the ancestral stream was flowing in the Petrified Forest Member, which erodes easily, producing a wider valley. Landslide complexes cover much of the Petrified Forest Member on both sides of the valley.

0.3 6.5 ZION NATIONAL PARK ENTRANCE.

0.4 6.9 PARK at turnout on east side of road. STOP 2. CANYON OF THE RIGHT
FORK OF NORTH CREEK. From the parking area, the Right Fork Trail leads a short distance southeast to the edge of the basalt flow, then descends steeply to North Creek. The edge of the basalt flow provides a good vantage point for a view of the west part of the Right Fork canyon and the south side of North Creek canyon.

The north-facing slope of the North Creek valley directly across the canyon to the south is blanketed with a complex of both active and inactive landslides. These slides involve the Petrified Forest Member and colluvium, talus, and ancient pediment-mantle deposits that cover the Petrified Forest Member. Parts of the slide complex are active and continue to move; note the dead and tilted vegetation, and fresh scarps, hummocks, and crevasses.

The Right Fork canyon of North Creek begins as a slot canyon in the Navajo Sandstone just north of Ivins Mountain, then opens into a relatively broad basin that extends westward to the Grapevine Wash basalt flow. The basin is floored by Quaternary deposits and the Petrified Forest Member of the Chinle Formation, and the slopes below the rim of Navajo Sandstone cliffs are underlain by the Kayenta and Moenave Formations. The Springdale Sandstone Member of the Moenave Formation forms a ledgy cliff roughly 100 feet (30 m) high that typically occupies a mid-slope position around the basin. However, the stream passes through two short narrows where outcrops of the Springdale Sandstone are at the same level as the stream channel. One of these narrows is towards the eastern end of the basin, where the gently east-dipping Springdale Sandstone intersects the stream channel. The other narrows is near the western end of the basin, where the Springdale Sandstone has been down-dropped in a graben between the north-northwest-trending East and West Cougar Mountain faults.

The East Cougar Mountain fault is the most significant structural feature in the Right Fork canyon. The fault is a steeply west-dipping normal fault that has about 500 feet (150 m) of down-to-the-west displacement (figure 4). It displaces the Navajo Sandstone and older strata, and shows no evidence of Quaternary activity. Just west of the confluence of Right Fork and Left Fork, the West Cougar Mountain fault is mostly concealed beneath Quaternary deposits.

Figure 4. Approximate trace of the East Cougar Mountain fault across the Right Fork canyon of North Creek (view looking north). The high-angle normal fault has about 500 feet (150 m) of down-to-the-west displacement, and juxtaposes the Navajo Sandstone (Jn) against the Springdale Sandstone Member of the Moenave Formation (Jms). Relative movement: D, down; U, up.
However, the fault can be seen to the south, just west of Cougar Mountain, where it offsets and drags down the Springdale Sandstone and shows about 60 feet (18 m) of offset. We postulate that these faults are related to late Cenozoic basin and range extension that also produced the larger Hurricane and Sevier faults west and east of the park.

Quaternary deposits in the Right Fork canyon include stream-channel alluvium; widespread talus, colluvium, and landslide deposits; and local lacustrine deposits and basalt. Perhaps the most significant aspect of the evolution of the Right Fork drainage was periodic blockage of the canyon by basalt flows and landslides in Pleistocene time, which led to the formation of Trail Canyon Lake (Hamilton, 1979, 1995), named for the side canyon that joins the Right Fork canyon near the East Cougar Mountain fault. The Grapevine Wash basalt flow forms the northwest wall of the North Creek drainage just west of the confluence of Right Fork and Left Fork. Erosional remnants of this flow are also present in the lower Right Fork canyon, one on the north side of Right Fork near the confluence, and one on the south side of Right Fork about 1/4 mile (400 m) upstream from the confluence. Right Fork was undoubtedly dammed by the basalt, creating an early stage of Trail Canyon Lake that would have occupied part of the Right Fork canyon about 250,000 years ago, until the dam was breached and stream flow was re-established (Hamilton, 1979, 1995).

Right Fork was later dammed one or more times by a large landslide involving the Kayenta Formation on the north side of the basin, in the vicinity of the western Springdale Sandstone narrows and the East Cougar Mountain fault. The landslide deposits are locally overlain by sediments deposited in a later stage of Trail Canyon Lake that formed upstream of the landslide (figure 5). Hamilton (1979, 1995) reported that these sediments consist of sand, silt, clay, marl, and minor limestone, and contain a variety of fossils: snails, fish vertebrae, and a bison thoracic vertebra have been recovered.

Figure 5. Landslide deposits (Qms) in the Right Fork Canyon of North Creek, below cliffs of Navajo Sandstone (Jn) (view looking west; Pine Valley Mountains in distance). Light-colored lacustrine sand (Qls) overlies part of the landslide deposits. Discontinuous exposures of the Springdale Sandstone Member of the Moenave Formation (Jms) are present beneath the landslide deposits west of the East Cougar Mountain fault.
PARK at Grapevine Springs Trail parking area. STOP 3. GRAPEVINE SPRINGS TRAILHEAD. This trail starts on the narrow Grapevine Wash basalt flow, and goes due east to the edge of the flow. From there it drops down very steep switchbacks to the Left Fork of North Creek. It only continues a short distance before disappearing in the canyon bottom. Grapevine Springs are a series of springs that emerge in rubble at the base of the flow, but they are hard to see due to thick vegetation and talus. It is possible to connect upstream with the Left Fork Trail, but the going is very rough. It is also possible to connect with the Right Fork Trail. Neither route is well marked, but the latter is less rugged than the Left Fork connection.

The highlight of the Grapevine Trail is the view from the rim of the basalt flow. This location provides an excellent view of the lower part of Right and Left Fork, the stacked Grapevine Wash basalt flow, the East and West Cougar Mountain fault zones, and the large landslide complex developed on the Petrified Forest Member near Right Fork. The overlook also affords good views of well-exposed bedrock ranging from the Chinle through the Navajo Formations.

In this area, the Grapevine Wash flow cascaded into the canyon, stacking up about 450 feet (137 m) (figure 6). The stack contains at least 17 distinct flows or cooling units. We initially assumed this thick stack would have a long history associated with multiple eruptions. However, two samples from the base of the stack yielded $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 0.26 $\pm$ 0.1 and 0.26 $\pm$ 0.03 Ma, and one from the top of the stack yielded an $^{40}\text{Ar}/^{39}\text{Ar}$ age of 0.31 $\pm$ 0.04 Ma, suggesting that the stack probably accumulated from one eruptive episode (UGS unpublished data). At this point, several flow lobes that cascaded down Grapevine Wash and Lee's Valley entered Left Fork of North Creek. Left Fork had a significantly lower gradient than the side canyons, thus the flows tended to pond or stack up; only a few lobes continued farther down the canyon. This basalt stack is one of the thickest accumulations of basalt in southwestern Utah.

Figure 6. View south to the basalt stack just north of the confluence of Grapevine Wash and the Left Fork of North Creek.
0.4 7.7 TURNOFF TO SMITH MESA on west side of road. The turnoff is at the contact of the ledge-forming Springdale Sandstone and the overlying, slope-forming, lower Kayenta Formation. Note that the Springdale Sandstone is about 100 feet (30 m) lower here than it is across the deep wash to the west due to offset along the West Cougar Mountain fault.

0.6 8.3 PARK at the Left Fork Trail parking area. STOP 4. LEFT FORK TRAILHEAD AND LEFT FORK CANYON. This is the ending point for the popular Left Fork Canyon and Subway hike. The trail starts on the Grapevine Wash basalt flow and goes northeast to the edge of the flow. From there it descends a series of switchbacks to the canyon floor, and then continues up the canyon. A poorly marked route also extends downstream to join the Grapevine Springs trail. This route passes the base of the stack basalt flow and a narrow gorge cut into the Springdale Sandstone. Plunge pools and small waterfalls can be seen in the gorge. The upstream route passes outcrops of several formations, the fault zone of the East Cougar Mountain fault (not well exposed), a large boulder with well-preserved dinosaur tracks, and ends at a cliff a short distance downstream of the Subway (see discussion at Wildcat Canyon trailhead, mile 15.9).

A short hike to the edge of the flow provides a spectacular view of the North Creek basin, the North and South Guardian Angels, and the stacked basalt flow. Near the edge of the flow, the basalt is locally covered by sand and gravel deposits of ancestral Left Fork North Creek, which, soon after the channel was plugged with basalt, temporarily flowed on top of the basalt before establishing a new channel alongside of the flow.

0.3 8.6 The road heads up into the Grapevine Wash drainage. Grapevine Wash is a much smaller drainage than North Creek and is only slightly incised along the side of the flow; thus, it has not yet formed an inverted valley in this area. To the west, note the lower brown subunit of the Navajo Sandstone, which is characterized by fine- to medium-grained sandstone in thick, mostly planar beds, as opposed to high-angle, cross-stratified beds typical of the rest of the formation. The lower Navajo Sandstone was deposited in a sabkha environment (Tuesink, 1989; Sansom, 1992). A sabkha is a broad, flat evaporating pan with shallow, salty groundwater that most commonly occurs near shallow seas in desert environments. It represents a transition from the distal-fluvial environment of the Kayenta Formation to the vast sand desert of the middle and upper Navajo Sandstone.

1.0 9.6 Approaching Cave Valley, a broad valley underlain by the Grapevine Wash basalt flows. Much of the valley is covered by eolian sand derived from weathering of the Navajo Sandstone, although basalt is exposed in many of the tree- and sagebrush-covered knolls. The northeastern margin of the valley is bounded by cliffs of massively cross-bedded Navajo Sandstone. The valley itself lies between the West and East Cougar Mountain faults. In this area, erosion and downcutting are proceeding at a much slower rate because of the
lack of a drainage area large enough to produce a high-energy stream, and because much precipitation seeps into the porous sand cover rather than collecting into flowing water that can erode.

0.6 10.2 A small cinder cone on the west side of the road has been mostly removed by quarrying. The view northeast up the road lines up with Red Butte, a conical hill of Navajo Sandstone.

0.4 10.6 LEAVING ZION NATIONAL PARK. The Navajo Sandstone of Lambs Knoll is on the south, with a small cinder cone on its northwest side. Spendlove Knoll (figure 7) is on the north side of Cave Valley, and together with Firepit Knoll, is one of several sources of the Grapevine Wash basalt flows.

1.0 11.6 Sharp rise in the road is upheld by basalt flows from Spendlove Knoll.

0.5 12.1 Spendlove Knoll, a cinder cone and one source of the Grapevine Wash basalt flows, is up ahead on the east side of the road. At the bend in the road about 0.5 mile (0.8 km) ahead, you can look west to the Pine Valley Mountains, which consist of an enormous early Miocene laccolith (a mushroom shaped igneous intrusion) that intruded into the Claron Formation. Erosion and mass-wasting have removed most of the sedimentary rock into which the magma intruded. Kolob Canyons are visible to the north. Firepit Knoll is the cinder cone on the north side of the road beyond the bend.

0.6 12.7 ENTERING ZION NATIONAL PARK. Firepit Knoll on the north, and Spendlove Knoll on the south, are young basaltic cinder cones. We obtained 40Ar/39Ar ages of 0.29 + 0.02 and 0.22 + 0.03 Ma on these cinder cones, respectively (UGS unpublished data). Their symmetrical shapes make them some of the most popular volcanic features in the park. Both are near the East Cougar Mountain fault, and their plumbing systems most likely developed in the fractured, weaker rock along the fault zone.
The flat bench north of Firepit Knoll is formed by a basalt flow that ponded in, and flowed up a canyon in that location. Sandstone, since eroded away, must have formed a narrow ridge along the west side of the flow. In a couple of places, the flow topped over a gap in the ridge and cascaded down the slope to the broad flat below. Remnants of the cascades can be seen in a couple of places. This lower, broad flat was a drainage divide and most of the flows on it moved southward, however at least one flow flowed northward into the head of Hop Valley.

0.2  12.9  Hop Valley Trail parking area. Refer to separate trail guide for a description of the Hop Valley Trail.

0.1  13.0  Cross East Cougar Mountain fault.

1.0  14.0  Plaque on north side of the road describes the Firepit Knoll fire that burned almost 300 acres (120 hectares) between August 31 and September 15, 1986.

0.7  14.7  **PARK** at turnout on north side of road. **STOP 5. BASALT FLOWS OF THE UPPER KOLOB PLATEAU.** The view to the north shows a lobe of the Lava Point basalt flow overlying the Navajo Sandstone in Pole Canyon (figure 8). The Lava Point flow is 1.0 to 1.1 million years old (Best and others, 1980; unpublished UGS data) and erupted from Home Valley Knoll, just west of Lava Point. The flow followed the ancestral North Creek for 13 miles (21 km) down to the Virgin River. A remnant of this flow caps the high mesa northeast of Virgin, and has provided a valuable reference point from which to determine long-term erosion rates of Zion Canyon. The 1.4 million-year-old Kolob flow caps the high hill on the skyline. Since we know that these flows originally flowed down canyons or valleys, the high remnants provide and indication of the tremendous amount of erosion that has occurred in this area in the last 1.4 million years.

*Figure 8. View north to the 1 million-year-old Lava Point flow (Qbl) where it cascades through a notch in the Navajo Sandstone. The Kolob flow (Qbk), about 1.4 million years old, caps the ridge on the skyline to the left.*
0.3 15.0 Switchback in road, with good views to the west of the Firepit Knoll and Spendlove Knoll cinder cones.

0.6 15.6 Road climbs up onto the Lava Point basalt flow.

0.3 15.9 Turnout on the right side of the road to the lower trailhead of the Wildcat Canyon trail.

From this parking area, a short trail spur leads to the Wildcat Canyon Trail. The Wildcat Canyon Trail is an old logging road that goes from the Hop Valley Trail on the west to Lava Point on the east. About 0.5 mile (0.8 km) from this parking area, the Northgate Peaks Trail branches off to the south to an overlook of the North Guardian Angel. Near that junction, hikers generally leave the established trail and begin the hike to Russell Gulch and the Subway.

The short spur from the parking lot traverses eolian sand and alluvial gravel, sand and silt that cover the Lava Point basalt flow. In this area, several anastamosing basalt flows join. Lost Creek, which enters the area from the north, was displaced from its channel by the flows, and is now on top of the flow. As a result of the decreased gradient, it has deposited alluvial gravel (small boulders to pebbles) that blankets the top of the basalt flow, forming an alluvial fan. Thus, even though the flow is 1.0 to 1.1 million years old, Lost Creek is small enough that it has not yet eroded through the flow.

The portion of the Wildcat Canyon Trail that leads to the Hop Valley Trail drops off of the Lava Point flow, and then stays on thin alluvium, Navajo Sandstone, and basalt erupted from the Firepit and Spendlove Knolls between which the trail passes. The Northgate Peaks Trail is on basalt for the first part, then is on Navajo Sandstone for the last part. Some impressive erosion, cross-bedding structures, a broad expanse of bare-rock erosional features, and excellent views of North and South Guardian Angels are visible from the overlook at the end of the trail.

Eastward, the Wildcat Canyon Trail follows the old logging road to Lava Point. It stays on the basalt flow for the first portion, eventually shifting onto the Navajo Sandstone, which is poorly exposed. It climbs up through the Temple Cap Formation with a few moderate exposures, then stays in the Temple Cap and Carmel Formations for the rest of the route. Good bedrock exposures are limited due to thick colluvium along the route, but the trail provides excellent views down Great West Canyon, one of the largest canyons in Zion National Park. Great West Canyon is a very straight canyon eroded along the Wildcat Canyon fault and nearby joints, and it trends northwest, parallel to other major structures in the park. The Temple Cap and Carmel Formations rim the canyon wall and are locally very well exposed.
The Subway. The Subway hike is a popular 6 mile (10 km) summer hike through the narrows of the Left Fork of North Creek. The beginning of the trail is marked by rock cairns where it crosses bare Navajo Sandstone. After crossing the bare sandstone, the trail drops down a cleft into Russell Gulch, which merges with Left Fork just downstream of the trail. The first half of the canyon is in bare Navajo Sandstone. The Subway is a rounded alcove carved by the stream that resembles a subway tunnel (figure 9). It is eroded along a thin parting of siltstone in the lower transitional zone of the Navajo Sandstone. Some excellent examples of differential weathering along joints are visible in the bottom of the channel. Below the Subway, the trail drops into the Kayenta Formation, where the canyon widens. Impressive blocks of fallen sandstone clog this part of the canyon. Farther down, one of the branches of the Lava Point flow entered ancestral Left Fork. Left Fork has since cut down below the flow, leaving remnants perched high on the north canyon wall. One of the highlights of the hike is a large boulder of Kayenta Formation just north of the trail (west of the Subway) that is covered with three-toed dinosaur tracks (figure 10). A narrow slot canyon is cut through the Springdale Sandstone along the trail, below which the Whitmore Point Member is locally well exposed. The trail crosses the East Cougar Mountain fault, which can be recognized on both sides of the canyon walls, but is covered near the trail. At its stratigraphically lowest point, the trail is in the Moenave Formation. The lower part of the trail affords an excellent view of the thick stack of basalt flows that filled ancestral North Creek (see figure 6). At least 17 cooling units can be recognized that form a stack of basalt about 450 feet (137 m) thick. The trail climbs up a steep set of switchbacks along the edge of the flows. Near the top, watch for basaltic sand and gravel that was deposited on top of the flow by North Creek, which flowed on top of the flow before establishing a new channel on the east side of the flow. The trail then stays on top of the stacked flows to the parking lot. See stops 3 and 4 for a discussion of these basalt flows and overlying gravel and sand deposits.
0.1  16.0  PINE VALLEY PICNIC AREA.

0.6  16.6  Turnout on east side of road. The unnamed hill to the north is capped by the Kolob basalt flow. We obtained an $^{40}$Ar/$^{39}$Ar age of 1.44 ± 0.04 Ma for this flow, making it the oldest dated flow in the park. Our preliminary mapping suggests that the source of this flow is a vent, now eroded away, a few miles to the north near Little Creek Peak.

0.9  17.5  Small road cut on the west side of the road is in the Lava Point flow.

1.0  18.5  Little Creek Sinks on the west. (They are located on private land; obtain permission before hiking to them). These sinkholes formed by dissolution and collapse of the lower unit of the Co-op Creek Limestone Member of the Carmel Formation. A small stream flows into the sinks; it probably reemerges in Little Creek in the area north of Pocket Mesa.

The tree-covered slope immediately north and west of the sinks is underlain by debris-flow deposits characterized by very large quartz monzonite boulders derived from the Pine Valley Mountains. These boulders are intriguing since the only outcrops of these rocks today are located near Interstate 15 over 11 miles (18 km) to the west. There were apparently shed off of what were once much higher Pine Valley Mountains in debris flows before late-stage movement on the Hurricane fault dropped the igneous rocks to their current position. (Like the sinks, these boulders are on private land; however, larger and more impressive boulders are easily seen beside the road on the east side of Kolob Reservoir about 6 miles (10 km) north of here.)

0.1  18.6  LEAVING ZION NATIONAL PARK.

0.2  18.8  Road cut in the Co-op Creek Limestone and Crystal Creek Members of the Carmel Formation. The Crystal Creek Member here is out of place and may represent collapse into another sinkhole.

0.2  19.0  Road climbs onto the upper unit of the Co-op Creek Limestone Member, which is largely covered by surficial deposits of Oak Spring Valley. Rounded, tree-covered Home Valley Knoll, which bounds the northeast side of Oak Spring Valley, consists of two overlapping cinder cones, the source of the Lava Point basalt flows.

1.5  20.5  TURN RIGHT AND HEAD EAST to Lava Point. (The road to the north continues to Kolob Reservoir, and eventually to Cedar Canyon near Cedar City.)

0.2  20.7  Blue Springs Reservoir is on the north side of the road.

0.6  21.3  Cross Blue Creek and enter Zion National Park.

0.1  21.4  BEAR RIGHT past turnaround to West Rim trailhead.
0.6  22.0  **BEAR RIGHT** past turnoff to Lava Point Campground.

0.2  22.2  **PARK** at Lava Point. **STOP 6. LAVA POINT OVERLOOK.** Lava Point lies on one of the "treads" of the Grand Staircase, which consists of over 6,000 feet (1,830 m) of alternating cliffs, slopes, and terraces in southern Utah and northern Arizona. In Utah, each "riser" is a cliff or slope as much as 2,000 feet (610 m) high and each "tread" is a plateau or terrace as much as 15 miles (24 km) wide. In this area, the "tread" is known as the Upper Kolob Plateau, and it is eroded into the ledge- and slope-forming Carmel Formation. The white cliffs of the Navajo Sandstone form the "riser" below the Kolob Plateau. The pink cliffs of the Claron Formation, the uppermost "riser" in the Grand Staircase made famous at Bryce Canyon National Park and Cedar Breaks National Monument, are visible in the distance to the northeast. Plaques at Lava Point describe the vista (figure 11).

The Lava Point basalt flow forms a resistant cap over the southern part of the Upper Kolob Plateau between Blue Springs Reservoir and Lava Point. It was derived from Home Valley Knoll, a cinder cone about 1.5 miles (2.5 km) to the west. This flow has yielded several K-Ar and $^{40}$Ar/$^{39}$Ar ages of 1.0 to 1.1 million years old (Best and others, 1980; unpublished UGS data). The Lava Point flow eventually entered ancestral North Creek, which it followed 13 miles (21 km) down to the Virgin River. A remnant of this flow is preserved atop the high mesa northeast of Virgin, and has provided a valuable reference point from which to determine long-term erosion rates of Zion Canyon.

**END** of road guide.
# ZION CANYON SCENIC DRIVE

## INTRODUCTION

Zion Canyon is the centerpiece of Zion National Park. The canyon was carved by the North Fork of the Virgin River and its tributaries, and is a stunning example of the influence of various bedrock formations on canyon development. At the Temple of Sinawava, sheer walls of Navajo Sandstone rise 1,200 to 2,000 feet (366-610 m) above the narrow canyon floor. Downstream the canyon widens perceptibly as the Virgin River erodes down to underlying, less resistant bedrock units. The canyon walls are adorned with cross-beds, alcoves, hanging valleys, seeps and hanging gardens, desert varnish, and weathering stains. Most visitors naturally spend most of their time looking up at the canyon walls, but it is the floor of Zion Canyon that reveals its most recent history. Sentinel Lake, or possibly two or more lakes, occupied much of the canyon from about 7,000 to 3,500 years ago when the North Fork of the Virgin River was dammed by the massive Sand Bench landslide. The lake was at least 200 feet (61 m) deep and about 4 miles (6.4 km) long, reaching upstream nearly to the Temple of Sinawava. The Virgin River has yet to re-establish its steeper, pre-landslide profile, so that the valley floor north of the landslide is wide, level, and wonderfully wooded. The Zion Canyon Scenic Drive follows the floor of the canyon for 6.0 miles (9.7 km), from Utah Highway 9 to the Temple of Sinawava (figures 1a and 1b).

More than anything else, Zion Canyon owes its existence to the Hurricane fault, a major, active, steeply west-dipping normal fault just west of the park that stretches at least 155 miles (250 km) from south of the Grand Canyon northward to Cedar City. Anderson and Mehnert (1979) and Anderson and Christenson (1989) consider the fault to be a late Pliocene to Quaternary feature that formed within about the past 3 million years. The down-to-the-west tectonic displacement along the fault at the latitude of the southern boundary of the park is about 3,600 feet (1,098 m) (Anderson and Christenson, 1989). This relative uplift of the eastern block, which includes Zion National Park, has contributed greatly to the erosive power of streams draining the Kolob Terrace. Thus, Zion Canyon is being carved as the Virgin River and its tributaries try to readjust to base level as the lower Virgin River, west of the Hurricane fault, drops incrementally down to the west.

Zion Canyon is closed to private vehicles from May to October and during peak periods. A fleet of free shuttles pickup and drop off visitors at many sites in Zion Canyon and Springdale. You may need to walk a short distance to the stops described in this road guide. The lack of vehicles makes the scenic drive an enjoyable bicycling or walking route.

## MILEAGE

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<td>BEGIN road guide at junction of Utah Highway 9 and Zion Canyon Scenic Drive. <strong>PROCEED NORTH ON ZION CANYON SCENIC DRIVE.</strong></td>
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<tr>
<td>0.1</td>
<td>PARK at turnout on the west side of the road. <strong>STOP 1. PINE CREEK LANDSLIDE AND VIRGIN RIVER TERRACES.</strong> The landslide exposed in the road cut to the right is part of the Pine Creek landslide, a large slide in the Kayenta Formation that continues northward for about 2,000 feet (610 m) along the east side of the road. Note the precarious boulders and deformed bedding in the Kayenta Formation.</td>
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Figure 1a. Topographic map showing the southern part of the route and stops for the Zion Canyon Scenic Drive geologic road log. Base map from U.S. Geological Survey Springdale East and Temple of Sinawava 7.5' quadrangles.
Figure 1b. Topographic map showing the northern part of the route and stops for the Zion Canyon Scenic Drive geologic road log. Base map from U.S. Geological Survey Springdale East and Temple of Sinawava 7.5' quadrangles.
A small diversion dam blocks the Virgin River west of the road. This dam is part of an irrigation network that predates development of the park. The water is used for irrigation purposes in and around Springdale.

The floor of Zion Canyon contains several river terraces that were described and named by Hereford and others (1996). They divided low-level (late Holocene) terraces into five main levels: (1) pre-settlement terraces, which commonly contain artifacts indicating that these surfaces are older than 500 years; (2) settlement terraces, the surface that pioneer settlers generally farmed and occupied, which are less than 500 years old as indicated by the complete lack of Anasazi artifacts; (3) historic terraces, which formed between about 1850 and 1920, lie about 10 feet (3 m) above the Virgin River, are generally covered with cottonwood trees that are 80 to 100 years old, and are flooded by unusually high runoff every decade or so; (4) modern terraces, which are typically about 3 to 7 feet (1-2 m) above the river, covered by tamarisk bushes, and flood one or more times a year; and (5) the active channel to normal high-water stage. Pre-settlement terraces are rare in Zion Canyon; historic terraces, which occur in two or three slightly different levels, are most common.

0.3 0.4 Cone-shaped deposit of sandy talus at the base of the Sand Bench landslide on left.

0.1 0.5 South end of historical portion of Sand Bench landslide.

0.2 0.7 PARK at turnout on east side of road. STOP 2. SAND BENCH LANDSLIDE. The Sand Bench (Zion Canyon) landslide is not a landslide in the traditional sense; rather, it consists of two parts: (1) a huge collapsed wall or fin of Navajo Sandstone that plugged Zion Canyon about 7,000 years ago (figure 2), and (2) smaller parts of the collapsed mass that have been reactivated as recent landslides and that remain active today. The Sand Bench collapse formed from a sandstone wall or fin between two closely spaced vertical joints in the Navajo

Figure 2. View north of the Sand Bench landslide. The slope at left is part of the 1995 landslide that was regraded during reconstruction of Zion Canyon Scenic Drive.
Sandstone on the east side of The Sentinel. As the Virgin River and a tributary stream cut down into the Kayenta Formation, undermining and destabilizing the narrow wall of Navajo Sandstone, it eventually collapsed. The collapsed rock formed a dam just east of The Sentinel that was about 800 feet (244 m) high at its downstream end. The dam impounded the North Fork of the Virgin River, creating Sentinel Lake (Grater, 1945; Hamilton, 1995). Sentinel Lake was at least 200 feet (61 m) deep and about 4 miles (6.4 km) long, stretching from the Court of the Patriarchs on the south upstream nearly to the Temple of Sinawava. After the lake filled with water, the river must have topped over the natural dam. However, unlike many landslide dams, this dam was composed of large blocks of rock. Thus, the river could not rapidly erode through the dam. Rather, evidence suggests that the river incised through the plug very slowly and the lake lasted for about 3,500 years. Even today, the river has not cut down to its original channel. Part of the reason is that as the river cuts down toward its former level, it oversteepens the walls of the collapsed mass. During wet periods, these steeper slopes have periodically reactivated, forming slides. In the last few years, they have blocked the river and caused road crews much grief.

The steep, east face of the collapsed mass shows intact bedding and that, although shattered and deformed, the formations are in proper stratigraphic order. The contact of the Kayenta Formation and Navajo Sandstone has collapsed down about 450 feet (137 m). Also, note the ledge of Springdale Sandstone in the middle of the slide. This ledge has not moved; rather the landslide flowed over it. The ledge now serves as a support or buttress for the upper part of the slide. Another similar Springdale buttress is exposed farther downstream. Near the south end of the slide, note the tilted, deformed bedding in blocks of the Kayenta Formation. The upper part of the mass is colluvium and talus riding on the Kayenta slump material. Note the big scarps that show where younger movement has taken place. Cottonwood trees and small seeps on the slide show evidence of perched water, which is common near the base of landslides.

Also, turn around and look to the east. The Springdale Sandstone is not exposed because it is covered by slide material. This landslide material may represent an eastern remnant of the Sand Bench landslide. The Lamb Point Tongue of the Navajo Sandstone is exposed higher up the slope.

South end of Zion Canyon Scenic Drive retaining wall. This stretch of the Sand Bench landslide has been a recurrent problem in recent decades. Two relatively major episodes of landslide movement were documented in the early 1900s, one in 1923 and the other in 1941 (Grater, 1945). In 1992, the landslide may have been triggered by the M_L (local magnitude) 5.8 St. George earthquake (Solomon, 1995). Most recently, on April 12 at about 9:00 p.m., the landslide surged forward, damming the North Fork of the Virgin River and forming a pond about 20 feet (6 m) deep (Solomon, 1995). The ponded water eventually overtopped the landslide dam. No flooding occurred downstream, but the displaced river eroded the east bank and washed out a 600-foot (180 m) section of road. More
than 300 people were stranded upstream at Zion Lodge until the morning of April 14, when a temporary access road was opened on the east side of the river. The 1995 landslide mass was roughly 500 feet (150 m) long and 150 feet (45 m) wide, and involved approximately 110,000 cubic yards (84,000 m³) of material (Solomon, 1995). The likely cause of that episode was elevated pore pressures and reduced cohesion within the landslide mass due to excessive precipitation during the preceding months.

During the winter of 1996, a retaining wall 450 feet long by 25 feet high (137 m x 8 m) was built of pre-cast concrete T-blocks. These large, interlocking, key-like concrete blocks were veneered with dressed sandstone and backfilled with gravel to provide stability and free drainage. However, on September 11, 1998, a series of nighttime storms on already wet ground produced a short duration flood of 4,500 cubic feet per second (135 m³) (Dave Sharrow, National Park Service, written communication, October 30, 2000). This flood scoured the channel and undercut the retaining wall, removing much of the gravel backfill and creating a large sinkhole in the roadbed. Subsequent investigations found that the retaining wall had inadequate provisions for protecting it from channel scour. The original retaining wall thus had to be disassembled. A 20-foot (8 m) deep secant pile wall (a curtain of overlapping 30 inch (0.75 m) diameter holes drilled into the underlying slide debris and grouted with concrete) was built to provide protection against channel scour, followed by reassembly of the retaining wall. This project was completed in the winter of 1999. In the spring of 2000, the channel was widened and the landslide buttressed to reduce flow velocities along this portion of the river.

0.1 0.9 Turnout on west side of road to view Sand Bench landslide. Over about the next 5 miles (8 km), road cuts expose parts of the Kayenta Formation, and colluvial and small landslide deposits derived principally from Kayenta strata.

0.6 1.5 PARK at the Court of the Patriarchs parking area. STOP 3. DEPOSITS OF SENTINEL LAKE AND THE COURT OF THE PATRIARCHS. The road cut immediately to the south of this parking area exposes Sand Bench landslide deposits in the lower part, overlain by deposits of Sentinel Lake, which in turn are covered by river gravel and colluvium. Note the cable in the fill materials on the east side of the road about 10 feet (3 m) above the road. The fill is part of an old road that crossed at a higher level. This site is near the downstream end of Sentinel Lake.

Sentinel Lake stretched from the Court of the Patriarchs upstream nearly to the Temple of Sinawava (Grater, 1945; Hamilton, 1995). The lake was at least 200 feet (61 m) deep in its early stages, and unlike other Quaternary lakes in Zion National Park, was probably full of water year round. Assuming a lake level of 4,400 feet (1,341 m), the elevation of the highest preserved deep-water lake deposits, the lake surface would have been at least 125 feet (38 m) above Zion Lodge. Sentinel Lake lacustrine deposits consist of thin, horizontal, alternating layers of gray clay and yellow sand, and are well exposed in several side
canyons, including the canyon southwest of Zion Lodge along the Emerald Pools Trail near the river footbridge, and along the first part of the Sand Bench Trail. These alternating layers may be varves, reflecting annual accumulations of sediment, or they may reflect individual, large storm events. They are overlain by several tens of feet of yellowish sand that may represent lake-margin deposits.

Radiocarbon ages on plant material from near the base of the deposits at the Court of the Patriarchs show that the lake was present by about 7,000 years ago (UGS unpublished data), and Hamilton (1979, 1995) reported a radiocarbon age of $3,600 \pm 400$ yr B.P. for the upper part of the lake deposits along a dry fork of Birch Creek at the Court of the Patriarchs. It is unknown whether these ages reflect one or more lacustrine episodes.

A short walk from the parking area leads to an overlook from which to view the Court of the Patriarchs. The view west from the overlook reveals the three subunits of the Navajo Sandstone. The brown subunit roughly coincides with a zone of planar bedding, in contrast to the large, sweeping cross-beds of the pink subunit. The boundary between these two units is sharp but irregular at the southern two patriarchs (the peaks known as Abraham and Isaac). This boundary is not a true stratigraphic contact, as is evident because the colors interfinger and clearly cut across bedding and cross-bed surfaces. The boundary between the pink and white subunits is a broad zone of color change. These color subunits do not reflect changes in the composition of the rock itself. Rather, the differences in color are due to slight changes in the cementation of the Navajo Sandstone, particularly in the concentration and oxidation state of minute traces of iron in the cement. These changes were induced by ground water, and possibly hydrocarbon (oil and gas), migration through the rock.

Also note the stones used in the low wall at the overlook. Some have abundant fucoidal markings (horizontal feeding traces). Early investigators regarded similar markings first discovered in Ohio in 1838 as impressions of seaweed; the term "fucoid" was adopted from the generic name of a seaweed. The term "fucoid" is now used for indefinite trail-like or tunnel-like trace fossils. This stone likely came from outside the park.

0.3 1.8 PARK at turnout on west side of road. WALK ACROSS THE TERRACE TO THE EDGE OF THE VIRGIN RIVER. This terrace level probably corresponds to the historic terrace level of Hereford and others (1996) (see Stop 1). STOP 4. VIRGIN RIVER TERRACES AND SENTINEL LAKE DEPOSITS. Because cottonwood trees need bare sandy soil such as a river sandbar for propagation, and because established cottonwood forests do not reseed themselves, the large cottonwood trees here give the maximum age of these terrace deposits. Note several subtle terrace levels with distinctly different ages of cottonwoods as you look both upstream and downstream. The youngest terrace level has mostly willows and a few small trees.
The river cutbank reveals lake clays deposited in Sentinel Lake. The clays are yellow, gray, and brown because they were derived principally from Carmel and Cretaceous strata exposed upstream on the Kolob Terrace. In 1998, the Utah Geological Survey drilled a hole about 100 feet (30 m) northeast of the footbridge to learn more about the Sand Bench landslide and Sentinel Lake. The drill hole penetrated 11 feet (3.4 m) of river alluvium overlying 30 feet (10 m) of lake deposits, which in turn overlie at least 28 feet (8.5 m) of Navajo and Kayenta landslide deposits. We finally had to stop the hole at 69 feet (21 m) without reaching bedrock under the canyon floor. Radiocarbon ages on plant material from lake deposits near the base of the drill hole show that the lake was present by at least 6,200 to 8,000 years ago (UGS unpublished data), and Hamilton (1995) reported a radiocarbon age of 3,600 ± 400 yr B.P. for the upper part of the deposits. Thus, within about the past 3,600 years, we know that the Virgin River has eroded through 200 feet (61 m) of lake sediments, but that it still has to cut through about at least 70 feet (21 m) of lake and landslide deposits before it re-establishes its pre-landslide gradient.

0.7 2.5 Parking area for the Emerald Pools Trail. See separate trail guide for information on this trail.

0.1 2.6 ENTRANCE TO ZION LODGE PARKING AREA.

0.1 2.7 Just after the turnout on left, the road gradually steps up to slightly higher terraces on which grow older cottonwood trees.

0.5 3.2 PARK at the Grotto picnic and parking area on either side of the road. WALK WEST TO THE FOOTBRIDGE. This is also a parking area for the Emerald Pools Trail, which is described in a separate trail guide. STOP 5. FLOOR OF ZION CANYON AND THE LAMB POINT TONGUE OF THE NAVAJO SANDSTONE. The flat canyon floor here is an indirect result of the Sand Bench collapse, which plugged Zion Canyon about 2 miles (3.2 km) downstream at The Sentinel about 7,000 years ago (see stop 2). The dam created Sentinel Lake, which at the Grotto would have reached at least 125 feet (38 m) high above your head. Because the river is out of grade, it has a tendency to deposit sediment carried down The Narrows, and to meander or migrate laterally through the soft lake deposits, leveling off the broad canyon floor. Along the center of the canyon, the lake sediments are mostly concealed beneath these channel and flood-plain deposits of the North Fork of the Virgin River. Note the use of riprap to control the natural tendency of the river to meander.

The Lamb Point Tongue of the Navajo Sandstone forms a prominent, 55-foot-high (17 m) ledge along the west side of the river. The upper two-thirds of the ledge consists of pale-orange, very thick-bedded, cross-bedded sandstone of the Lamb Point Tongue. The lower one-third of the ledge is the upper part of the main body of the Kayenta Formation, which consists of reddish-brown sandstone with thin interbeds of light-green to light-gray sandstone and siltstone. The Lamb Point Tongue is a thin wedge of windblown sand that thickens eastward
where it merges with the Navajo Sandstone (Doelling and Davis, 1989).

0.2       3.4 Outcrop of the Lamb Point Tongue on the east side of the road.

0.9       4.3 Bridge. **TURN RIGHT** just north of the bridge into the Weeping Rock parking area. **STOP 6. WEEPING ROCK.** Weeping Rock is so named for the series of springs that issue from the base of the Navajo Sandstone. Ground water typically moves freely through the Navajo Sandstone, for it is a relatively porous and permeable unit. The lowermost Navajo, however, contains thin, much less permeable beds, as does the underlying Kayenta Formation, with its mostly thin-bedded siltstone and mudstone. Thus, the lowest Navajo Sandstone and the Kayenta Formation impede the downward movement of ground water, forcing it to move laterally. Where the ground water encounters the face of a cliff, it emerges as seeps and springs near the base of the Navajo Sandstone. The springs at Weeping Rock are located below the mouths of two hanging canyons: Echo Canyon, and a smaller unnamed canyon that lies just east of Observation Point. Weeping Rock is the discharge point for ground water that these two canyons help to funnel into the Navajo aquifer. During heavy runoff events, typically during brief summer cloudburst storms, short-lived waterfalls adorn these and other hanging canyons (figure 3).

The springs at Weeping Rock, as elsewhere in the park, are alkaline, meaning that they contain appreciable amounts of dissolved calcium and other minerals. As alkaline ground water seeps to the surface, the solubility of calcium is decreased as carbon dioxide degasses and is removed by plants such as algae. As a result, this hard water forms a sponge-like limestone rock deposit called tufa, full of small holes or pore spaces.

0.5       4.8 **PARK** at the turnout on the south side of the road. **STOP 7. EROSION OF THE NAVAJO SANDSTONE.** The view west shows an unusual weathering pattern in the sheer wall of Navajo Sandstone below Scout Lookout (figure 4). There, the Navajo Sandstone is deeply weathered and pitted with narrow steps and ledges. This surface is the western face of a prominent, north-trending joint that trends parallel to the cliff face immediately west of Scout Lookout. The joint is open in its upper part and probably filled with sand and weathered blocks of Navajo Sandstone. The weathering may be due to the effects of moist sand in the joint, which would facilitate disintegration of the Navajo Sandstone.
The road cut opposite of the parking area is in the Tenney Canyon Tongue of the Kayenta Formation. A thin dolomite bed is exposed on the low mound at the southwest end of the parking area. Typically, Kayenta strata are covered by talus and form poorly exposed, steep slopes at the base of the great Navajo cliffs.

0.4  5.2  Good view to the west of coarse channel gravels overlain by fine-grained overbank deposits, exposed in the west bank of the Virgin River.

0.3  5.5  Good exposures of the Kayenta Formation in road cut.

0.2  5.7  Good exposure of low-level terrace. Note the recent flood deposits of sand and gravel between the trees.

0.3  6.0  **PARK** at The Narrows parking lot. **STOP 8.** EROSION OF ZION CANYON. Zion Canyon is quite narrow just upstream from the Temple of Sinawava, and abruptly widens downstream from this point. This is a direct result of an erosional process known as canyon widening. At Zion National Park, canyon widening is an important process below the Navajo Sandstone. The relatively soft and thin-bedded siltstone, sandstone, and mudstone of the Kayenta Formation is more easily eroded than the overlying Navajo Sandstone. As the Kayenta is eroded away or slips away in landslides, the great cliffs of Navajo Sandstone are undermined, and despite its inherent strength, it eventually breaks away. Rock falls and landslides are thus an important part of the canyon widening process. Seeps near the contact of permeable Navajo and impermeable Kayenta strata, and joints in the Navajo itself, facilitate undermining and collapse of the Navajo Sandstone.

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*Figure 4. View west during snowstorm at joint surface below Scout Point. Snow highlights the many narrow steps in the cliff of Navajo Sandstone. Photo at right shows view of joint from the Angels Landing Trail.*
The other dominant erosional process that has formed the canyons of Zion National Park is downcutting. Nowhere is downcutting more apparent than here at The Narrows, at the head of Zion Canyon. For about 10 miles (16 km) beyond the end of the Zion Canyon Scenic Drive, the North Fork of the Virgin River flows through a spectacular gorge cut into the Navajo Sandstone (figure 5). The relatively homogeneous Navajo Sandstone is soft enough to be readily eroded but strong enough to stand in tall, vertical cliffs. In places, The Narrows are just 16 feet (5 m) wide at the bottom of a 1,000-foot-deep (305 m) slot. The Virgin River truly acts like a moving ribbon of sandpaper where it cuts through The Narrows.

One of the questions that has long intrigued both geologists and visitors to the park is "How long did it take to form Zion Canyon?" Fortunately, there is some evidence in the rock record to answer that question. At the high mesa northeast of Virgin, a remnant of the 1.0 million-year-old Lava Point basalt flow caps the mesa about 1,300 feet (396 m) above the Virgin River. The Lava Point flow, which erupted from Home Valley Knoll high on the Upper Kolob Plateau to the north, flowed down the ancestral North Creek, which was probably graded to the Virgin River at the time. Thus, we know that in the vicinity of Virgin, the Virgin River has cut down about 1,300 feet (396 m) in the last 1 million years, yielding an average rate of erosion of 1.3 feet per 1,000 years (40 cm/1,000 yr). By projecting the ancestral Virgin River upstream, we find that 1 million years ago Zion Canyon was only about one-half as deep as it is today in the vicinity of Zion Lodge, exposing only the upper half of what was to become The Great White Throne. The Narrows, as we know them today, had not yet begun to form, although similar narrows probably existed downstream in the Navajo Sandstone where the river had not yet cut down into Kayenta strata. Data are admittedly sparse, but given one well-dated control point and assuming constant average erosion rates, approximately 2 million years are required for the formation of Zion Canyon below the level of the Carmel Formation.

END of road guide.
KOLOB CANYONS SCENIC DRIVE

INTRODUCTION

Few short roads in southwestern Utah offer such a diverse stratigraphic and structural cross section as the Kolob Canyons Scenic Drive. The scenic drive is a 5-mile-long (8 km) road that leads to an overlook below the Upper Kolob Plateau, which here is known for the stunning cliffs of Navajo Sandstone that project westward from the plateau margin (figures 1 and 2). The road crosses the Hurricane fault zone, scales the Hurricane Cliffs, and traverses the east-dipping limb of the Kanarra anticline on the way to the overlook. Bedrock that ranges in age from the Early Permian Kaibab Formation to middle Cretaceous strata is exposed along or is visible from the road, as are two Quaternary basalt flows and a variety of surficial deposits. The road also follows the Taylor Creek fault zone — a zone of Sevier-age back-thrust faults that repeat the Moenave Formation on the east limb of the anticline — for several miles.

BEGIN AT THE KOLOB CANYONS VISITOR CENTER.

Figure 1. Topographic map showing route and stops for the Kolob Canyons Scenic Drive geologic road log. Base map from U.S. Geological Survey Kolob Arch 7.5' quadrangle.
The Rock Canyon Conglomerate Member of the Triassic Moenkopi Formation is exposed in a road cut on the east side of the road. Immediately up the road, the Rock Canyon Conglomerate gives way to the overlying Timpoweap Member. These beds dip steeply west here due to fault drag along the Hurricane fault zone.

PARK at turnout on north at bend in road. STOP 1. GENERAL GEOLOGY OF THE LOWER TAYLOR CREEK DRAINAGE. The lower reaches of Taylor Creek cut through the east limb of the Kanarra anticline, exposing a series of east-dipping cuestas developed on the Triassic Moenkopi and Chinle Formations, and, farther up the drainage, the Early Jurassic Moenave Formation. The westernmost cuesta seen just to the northeast of this stop is held up by resistant limestones of the Virgin Limestone; we will see cuestas developed on the resistant Shinarump Conglomerate and Springdale Sandstone farther up the canyon. Stop 1 is near the crest of the anticline, but exact placement of the anticline's axis is complicated by fault drag along the Hurricane fault zone. The west limb of the fold has been dropped down to the west by the Hurricane fault, and is now buried under the New Harmony basin.

Yellowish-brown limestone of the Timpoweap Member of the Moenkopi Formation is exposed in the road cut on the south side of the road, where it is overlain by old river-channel deposits of the ancestral Taylor Creek. A short walk to the north over these gravel deposits yields a view down to Taylor Creek.
(WALK WEST to guardrail and head a short distance down an old, unpaved road to overlook above Taylor Creek). The lower part of the canyon here is carved from Rock Canyon strata, whereas the upper part reveals the thinner bedded cherty limestone of the Timpoweap Member (figure 3). Just to the west, at the entrance to the canyon, these beds, and the underlying Harrisburg Member of the Kaibab Formation, dip steeply west as a result of fault drag along the Hurricane fault zone.

The contact of the Harrisburg Member of the Kaibab Formation and the Rock Canyon Conglomerate Member of the Moenkopi Formation marks the Permian-Triassic boundary, which in southwestern Utah is a major unconformity that represents about 10 to 20 million years of erosion (Nieelson, 1981; Sorauf and Billingsley, 1991). Erosion produced an irregular surface, locally with several hundred feet of relief, upon which conglomerates and breccias of the Triassic Rock Canyon Conglomerate were deposited in paleocanyons, karst depressions, and as regolith (Nieelson, 1991). The overlying Timpoweap Member, which records the first Triassic marine transgression into this part of what is now southwestern Utah, was deposited in broader paleovalleys (Nieelson and Johnson, 1979).

The Hurricane fault zone is a major, active, high-angle, west-dipping normal fault that stretches at least 155 miles (250 km) from south of the Grand Canyon northward to Cedar City. The total stratigraphic separation generally increases northward along the fault, from less than 200 feet (61 m) south of the Grand Canyon (Hamblin, 1970) to 8,265 feet (2,520 m) near Toquerville (Stewart and Taylor, 1996). Near the latitude of Ash Creek Reservoir, about 3.5 miles (5 km) south of Taylor Creek, Lund and Everitt (1998) documented about 1,100 feet (336 m) of net vertical tectonic displacement on basalt flows in the hanging wall and footwall that yielded $^{40}$Ar/$^{39}$Ar isochron ages of $840 \pm 30$ ka and $880 \pm 20$ ka, respectively; the average slip rate for this portion of the Ash Creek segment of the Hurricane fault zone is thus about 16 inches/1,000 yr (0.39 m/1,000 yr). The total separation on the Hurricane fault zone in the Kolob Canyons area is unknown because hanging-wall rocks are buried under alluvium of the Kanarraville and New Harmony basins. However, we believe it to be comparable to the value obtained near Toquerville.
Lund and Everitt (1998) investigated the paleoseismology of the Hurricane fault in Utah and noted that the most recent surface faulting event on the fault occurred in the latest Pleistocene or early Holocene, at the north end of the fault near Cedar City. They further noted that multiple surface faulting earthquakes have occurred in the late Quaternary along most, if not all, of the Utah portion of the fault; additional paleoseismic investigations are underway.

0.1 0.8 Old river-channel deposits of the ancestral Taylor Creek are exposed along the north side of the road. Several small, generally north-trending normal faults, visible in road cuts, displace Moenkopi strata in the lower reaches of the Taylor Creek drainage.

0.3 1.1 Turnout on north side of road. The lower red member of the Moenkopi Formation is exposed in the road cut to the south. To the north, note the Virgin Limestone Member bending down to the east on the east flank of the Kanarra anticline.

0.2 1.3 Virgin Limestone strata are exposed in road cut on south side of road. These beds dip about 23 degrees to the east on the east flank of the Kanarra anticline.

0.5 1.8 Water gap eroded through the east-dipping cuesta of the Shinarump Conglomerate Member of the Chinle Formation. The upper red member of the Moenkopi Formation is exposed in the road cut on the south side of the road, just below the cliff-forming Shinarump Conglomerate strata. The overlying Petrified Forest Member of the Chinle Formation forms a prominent strike valley to the north of the road, and to the south where it is mostly covered by landslide deposits.

0.1 1.9 PARKING AREA FOR THE MIDDLE FORK OF TAYLOR CREEK TRAIL. See the separate geologic guide for this trail.

0.2 2.1 White, very thick-bedded sandstone and pebbly sandstone of the Petrified Forest Member is exposed in the road cut on the south side of the road. This "medial" sandstone is a prominent marker in the Petrified Forest Member throughout most of southwestern Utah. Here, it is surrounded by landslide deposits developed in enclosing bentonitic Petrified Forest mudstones.

0.1 2.2 PARK at turnout on east side of road. STOP 2. TAYLOR CREEK THRUST FAULT. The view to the north provides a good look at the Taylor Creek thrust-fault zone. This fault zone consists of one principal and several lesser, east-dipping thrust faults that repeat Moenave strata on the east flank of the Kanarra anticline. The faults are best illustrated by repetition of the resistant, cliff-forming Springdale Sandstone, the upper member of the Moenave Formation (figure 4); similar faults of smaller displacement are also in Kaibab, Moenkopi, Chinle, and Kayenta strata. The faults formed as back thrusts during initial folding of the Kanarra anticline and were later rotated to steeper east dips with final folding of the anticline. Fault drag and small folds along the length of the
Figure 4. View north to the Taylor Creek thrust-fault zone on the east-dipping flank of the Kanarra anticline. Note how the faults repeat the Springdale Sandstone Member (Jms) of the Moenave Formation to create three east-dipping ledges.
thrust zone in the Kolob Canyons area clearly demonstrate westward-directed compression of these small back thrusts. The Springdale Sandstone is also duplicated in exposures to the east and south. Moenave strata are locally tightly folded as a result of this faulting (figure 5).

Figure 5. View south to tightly folded Moenave (Dinosaur Canyon Member) strata exposed along the Middle Fork of Taylor Creek Trail. These beds lie just above the western splay of the Taylor Creek thrust fault. Although difficult to see from the creek bed, the cliff of Springdale Sandstone immediately to the north is gently warped into a series of north-trending anticlines and synclines.

In the Zion National Park area, the Kanarra anticline involves rocks of likely early Late Cretaceous age and we believe the fold formed during the Late Cretaceous Sevier orogeny. The formation of the Kanarra anticline is doubtless related to the Pintura anticline, a colinear fold about 8 to 10 miles (13-16 km) to the southwest. The Pintura anticline is unconformably overlain by the Canaan Peak Formation, the oldest beds of which are late Campanian (Late Cretaceous) in age.

0.4  2.6 Turnout on east side of road, just south of small road cut. This road cut exposes the lower Moenave Formation (upper Dinosaur Canyon Member and possibly lower Whitmore Point Member) that has been deformed by a small thrust fault (figure 6).

Figure 6. Road cut in lower Moenave strata deformed by small thrust fault.
To the northeast, the sheer cliffs of Navajo Sandstone, and overlying, tree-covered slopes of the Temple Cap Formation and the clifffy limestone of the lower Carmel Formation, can be seen at Horse Ranch Mountain (figure 7). Horse Ranch Mountain is capped by basalt not yet dated; it is probably about 1.5 million years old based on comparison with other flows in the area.

Figure 7. View northeast to Horse Ranch Mountain. Gray limestone of the Co-op Creek Limestone Member of the Carmel Formation is well exposed above the Navajo cliffs; the Sinawava Member of the Temple Cap Formation forms a thin vegetated slope between these two formations. Middle Cretaceous strata are preserved beneath remnants of a basalt flow at the top of Horse Ranch Mountain.

0.1 2.7 Northwest end of large road cut in the Moenave Formation, showing the Dinosaur Canyon, Whitmore Point, and Springdale Sandstone Members.

0.2 2.9 **PARK** at turnout on south side of road. **STOP 3. THE MOENAVE AND KAYENTA FORMATIONS.** The lower two members of the Moenave Formation are well exposed in the road cut immediately west of the water gap formed in the Springdale Sandstone, and the Springdale Sandstone itself is well exposed in the road cut to the north. The member contacts, however, are gradational and difficult to define. Beginning near the base of this sequence at the northwest end of the road cut, the Dinosaur Canyon Member consists predominantly of moderate-reddish-brown, ledge- and slope-forming, thin- to thick-bedded, very fine- to fine-grained silty sandstone with common ripple cross-stratification. At the opposite end of the road cut, the cliff-forming Springdale Sandstone Member is characterized by pale-red to pale-pink, very thick-bedded, fine- to medium-grained sandstone with planar and low-angle cross stratification, and local, channel-form, intraformational pebbly conglomerates with poorly preserved, petrified and carbonized fossil plant remains. The intervening Whitmore Point Member forms lighter colored, ledgy slopes between these two members. In the Kolob Canyons area, we define the base of the Whitmore Point Member to be at the base of the interbedded, grayish-white, fine-grained sandstone, whereas the top of the member includes several ledge-forming, Springdale-like sandstone beds below the massive Springdale cliff itself. The lower Whitmore Point Member thus includes several thin, white-colored sandstone beds.

The lower Kayenta Formation is well exposed in the road cut north of this turnout. The contact with the underlying Springdale Sandstone is gradational and corresponds to the base of the lowest reddish-brown mudstone interval. From here, the road makes a switchback through the Kayenta Formation.
0.1 3.0 Turnout on south side of road. Kayenta strata are exposed in road cut on the north side of the road, with a small down-to-the-east normal fault.

0.2 3.2 PARK at turnout on east side of road. **STOP 4. LAKE DEPOSITS OF THE SOUTH FORK OF TAYLOR CREEK.** A well-traveled but unmarked trail leads from the north side of the switchback up through the canyon of the South Fork of Taylor Creek. The trail leads to lacustrine deposits of two small lakes, and, farther up the canyon, excellent examples of cross-beds and erosional features in the Navajo Sandstone.

The South Fork of Taylor Creek lies between the massive Navajo Sandstone cliffs of Paria Point on the north and Beatty Point on the south. The thin-bedded, light-gray, silty and sandy beds at the bottom of the valley are lacustrine deposits of Paria Lake. Five radiocarbon ages from tree stumps preserved at the base of the deposits and organic debris near the top of the deposits show that the lake existed from about 3,900 ± 60 yr B.P. to 2,880 ± 200 yr B.P. (Eardley, 1966; Hamilton, 1995). Pollen and snail shells collected from these beds suggest that the environment was more like a seasonal pond than a year-round lake (Hevly, 1979; Hamilton, 1995). The lake formed when a small landslide, located to the west and probably just below the water gap formed in the Springdale Sandstone, blocked the South Fork of Taylor Creek. The creek has since cut through about 30 feet (9 m) of lake sediments. Three stumps in growth position near the base of the deposits are progressively older downstream, also suggestive of a long period of aggradation of a shallow pond (Hamilton, undated).

About one-half mile (0.8 km) up the canyon there is a more recent dam between Paria Point and Beatty Point. Eardley (1966) was the first to attribute a landslide origin to this dam, but Hamilton (1979) noted that it looked almost like a terminal moraine. Agenbroad and others (1993) also suggested that the dam was of glacial origin. The similarity to an end moraine is limited, however, and such a deposit seems unlikely at this latitude and elevation. We believe that the dam resulted from a massive rock fall of the Navajo Sandstone on the north side of Beatty Point. This rockfall blocked the South Fork and formed a small, seasonal lake named Beatty Lake (figure 8). For most of the year, this "lake" is a small grassy meadow, but tree limbs and logs accumulated along the shoreline attest to at least seasonal flooding. The meadow lies in a closed basin about 10 feet (3 m) below the crest of the landslide dam. This seasonal pond has no drainage outlet, but springs are located near the toe of the landslide. Upstream from the pond, the South Fork canyon is plugged with sediment deposited behind the dam, forming a flat, tree-covered valley floor that slopes gently up the drainage. Sediments continue to be deposited as the braided ephemeral wash of the South Fork of Taylor Creek migrates across the valley floor. The deposits exposed at the surface are alluvial sand, and, farther upstream, sand and gravel that locally partly bury the trunks of mature trees (figure 9).
Farther up the drainage, the canyon narrows, and the walls of Navajo Sandstone reveal large, sweeping cross-bed sets with tangential lower contacts and truncated slip faces or foresets. Differential weathering along cross-beds is locally well developed, and numerous blind arches or alcoves are also present (figures 10, 11, and 12).

Figure 8. View east up the South Fork of Taylor Creek. The seasonal Beatty Lake periodically occupies the grassy meadow in the foreground.

Figure 9. Braided, ephemeral wash of the South Fork of Taylor Creek upstream from Beatty Lake. Note how trees are slowly being buried by sand as the South Fork migrates across the valley floor.

Figure 10. Differential weathering of the Navajo Sandstone, South Fork of Taylor Creek.
Road cut on south side of the road is in very thick-bedded, fine-grained sandstone of the Kayenta Formation. This, and enclosing thick sandstone beds, lie at about the same stratigraphic horizon as the Lamb Point Tongue of the Navajo Sandstone, which is exposed in Zion Canyon to the southeast. The Lamb Point is an eolian tongue of the Navajo, characterized by large, sweeping cross-beds. At Kolob Canyons, however, thick sandstone beds in this interval lack such cross-beds and are believed to be fluvial or flood plain in origin. The Lamb Point Tongue pinches out in the drainage of the Right Fork of North Creek before reaching the Kolob Canyons.

LEE PASS, the drainage divide between Taylor Creek on the north and Timber Creek on the south. A narrow turnout on the north side of the road offers a good view northward to the east-dipping Kayenta Formation and the sheer Navajo Sandstone cliffs of Paria Point (figure 13). The road cut just ahead to the west is in the lowermost Kayenta Formation. The Springdale Sandstone is exposed in the drainage immediately to the south.

Lee Pass parking area. This is the starting point of the Timber Creek Trail to Kolob Arch, which is described in a separate trail guide.

Road cut in the Springdale Sandstone on the west side of the road. The Springdale Sandstone, or landslide and talus deposits derived from the Springdale, is exposed along the road for about the next 0.9 mile (1.4 km).
STOP 5. THE GRADATIONAL CONTACT BETWEEN THE KAYENTA FORMATION AND THE NAVAJO SANDSTONE. The view east shows the gradational contact between the Kayenta Formation and the overlying Navajo Sandstone (figure 14). Recent geologic mapping by Utah Geological Survey staff in the St. George and Zion National Park areas has led us to place the contact at the top of the stratigraphically highest mudstone interval. In the Zion Canyon area, such a contact is clear. Westward, however, the contact becomes gradational or even interfingering, so that several thick eolian sandstone beds are included in the upper Kayenta Formation. In the Kolob Canyons area, the contact is at the base of a white-weathering sandstone marker bed and so is readily visible from a distance. In southwestern Utah, the contact between the Kayenta Formation and Navajo Sandstone is conformable and gradational and records the transition from distal fluvial, to sabkha, to eolian sand-desert depositional environments (Tuesink, 1989; Sansom, 1992).
Several alluvial hanging canyons adorn the drainages between the “fingers” of Navajo Sandstone that project westward from the Upper Kolob Plateau (figure 15). Such canyons form where tributary drainages cannot keep pace with downcutting of the master stream.

Landslide and talus deposits are exposed in the road cut to the west, where they overlie a dip slope developed on the Springdale Sandstone. Rock falls along this portion of the road require frequent cleanup by park personnel.

0.6  4.7  Turnout on east side of road. Strata of the lower Moenave Formation are overturned in this road cut where they dip steeply west. The road cut probably straddles the gradational contact between the Whitmore Point Member and the underlying Dinosaur Canyon Member, but we map them as undifferentiated here due to poor exposure and structural complexity in the adjacent slopes. The thin-bedded, reddish-brown, fine-grained sandstone at the south end of the road cut contains well-developed ripple marks.

0.1  4.8  Turnout on west side of road. Exposures to the east below the road are in steeply east-dipping lower Moenave strata that are cut by two minor thrust faults (figure 16). There is no trail to this exposure, and the steep slopes and dense Gambel oakbrush make access difficult.

0.3  5.1  PARK at the end of the Kolob Canyons Scenic Drive. STOP 6. FINGER CANYONS OF THE KOLOB. The Finger Canyons of the Kolob are aptly named for a series of west-trending canyons eroded into the edge of the Upper Kolob Plateau. Depending on how they are counted, however, there are seven or more sheer promontories of Navajo Sandstone — the “fingers” — that project westward from the plateau, showing that the analogy with a normal human hand, while expressive, is somewhat exaggerated. Like many canyons in Zion National Park, the Finger Canyons have developed along joints in the massive Navajo Sandstone.
Figure 16. View north of steeply east-dipping Dinosaur Canyon and Whitmore Point strata offset by two small thrust faults.
A plaque describes the main features seen from the overlook (figure 17). At the
top of the cliffs, note again the thin, tree-covered section of the Sinawava
Member of the Temple Cap Formation, the overlying Co-op Creek Limestone
Member of the Carmel Formation, and remnant basalt flow that caps Horse
Ranch Mountain, the highest point in the park at 8,726 feet (2,659 m). About
100 feet (30 m) of Cretaceous strata underlies the basalt at the top of Horse
Ranch Mountain (Hamilton, 1987). Temple Cap and Carmel strata are also
visible atop several of the other "fingers" that extend westward from the plateau.
These formations overlie the planar, truncated top of the Navajo Sandstone,
termed the J-1 unconformity by Pipiringos and O’Sullivan (1978). The J-1
unconformity marks a time when the great Navajo sand desert was eroded prior
to being inundated by rising seas that lead to deposition of the mudstone and
siltstone of the Sinawava Member of the Temple Cap Formation in coastal
sabkha and tidal-flat environments (Blakey, 1994; Peterson, 1994). Desert
conditions returned during deposition of the White Throne Member of the
Temple Cap Formation, which is present at Zion Canyon, but which pinches out
westward before reaching the Kolob Canyons. A fresh, unweathered scar visible
on the north side of Shuntavi Butte resulted from a rock fall that occurred in July
1983 (figure 18).

The overlook area lies within the Taylor Creek thrust-fault zone, although it is
difficult to recognize from this vantage point due to extensive forest and
colluvial cover. This part of the thrust-fault zone is best observed from the
Timber Creek Overlook Trail, described in a separate trail guide, where one can
readily see a duplicated section of Springdale Sandstone on the skyline
northwest of the parking area.

**END** of road guide.
Figure 17. View east-northeast from the overlook at the end of the Kolob Canyons Scenic Drive. A basaltic flow (Qb) and Cretaceous strata (Ku) at Horse Ranch Mountain, the J-1 unconformity (above which is the vegetated slope of the Sinawaava Member (Jts) of the Temple Cap Formation), the Co-op Creek Limestone Member (Jc) of the Carmel Formation, the Navajo Sandstone (Jn), and the Kayenta Formation (Jk) are also shown.

Figure 18. View southeast to Shuntavi Butte. Note fresh Navajo Sandstone on north side of butte, the site of the 1983 rock fall. Also note the gradational contact between the Kayenta Formation (Jk) and Navajo Sandstone (Jn).
ACKNOWLEDGMENTS

Untold numbers of geologists have studied the rocks, sediments, and landforms of Zion National Park, and the geology outlined here draws heavily on their collective efforts. Some of these reports are cited in the road and trail guides and are referenced below, while a more complete list of references is available in *Geology of Zion National Park, Utah*, the companion report to these guides (Biek and others, 2000). A still more comprehensive list of references will be available in our reports (in progress) that accompany geologic maps of the Clear Creek Mountain, Cogswell Point, Kolob Arch, Kolob Reservoir, Springdale East, Springdale West, Temple of Sinawava, and The Guardian Angels 7.5’ quadrangles in which the park lies.

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REFERENCES

(This list of references includes these cited in both the trail and road guides.)


— undated, Quaternary ponds and lakes in Zion National Park, Utah: unpublished 42-page report on file at the Zion National Park library.


