GEOLOGY OF ZION NATIONAL PARK, CORAL PINK SAND DUNES STATE PARK AND SNOW CANYON STATE PARK

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Zion National Park

Introduction

Zion is located on the western margin of the Colorado Plateau Province, in the High Plateaus section. This section of the Colorado Plateau is characterized by a number of north-northeast trending normal faults which divide it into a series of plateaus. Zion occurs on the Markagunt Plateau which is bounded to the west by the Hurricane and east by the Sevier Faults. Uplift and tilting along these faults resulted in a gentle northeast dip of the rocks. The "Grand Staircase" a series of roughly east-west cuestas characterizes this part of the Colorado Plateau. Zion is located on one of these cuestas, the "White Cliffs," formed by the resistant Navajo Sandstone.

Stratigraphy and Geologic History

Sedimentary rocks ranging in age from Permian through Cretaceous dominate the park (Figures 2 & 3). The oldest rocks, the Kaibab Limestone are restricted to small outcrops at the base of the Hurricane Cliffs. The three Triassic units, Moenkopi, Chinle and Moenave Formations can be observed along the Kolob Canyons Road. The Moenkopi Formation is exposed in the Hurricane Cliffs. This unit consist of red to red-brown siltstones and mudstones with gray gypsum rich shale beds and was deposited in a coastal flood plain environment. Above the Moenkopi is the Chinle Formation a mauve, gray and white shale. The Shinarump Conglomerate member forms a distinctive light tan cliff at the base of the Chinle. Alteration of volcanic ash in the Chinle released silica which lead to formation of petrified wood. The overlying Moenave Formation was deposited by streams. It consists of reddish-brown siltstones and shales at the base with a resistant sandstone at the top called the Springdale Member. The Jurassic Kayenta Formation and Navajo Sandstone are responsible for most of the spectacular scenery seen at Zion. The Kayenta Formation consist of reddish-brown, interbedded sandstone, siltstone and shale deposited in a delta or flood plain environment. The Navajo Sandstone up to 670 m (2200 ft.) thick is a cross-bedded sandstone composed of 98% quartz that was deposited in an eolian environment. The upper Navajo is

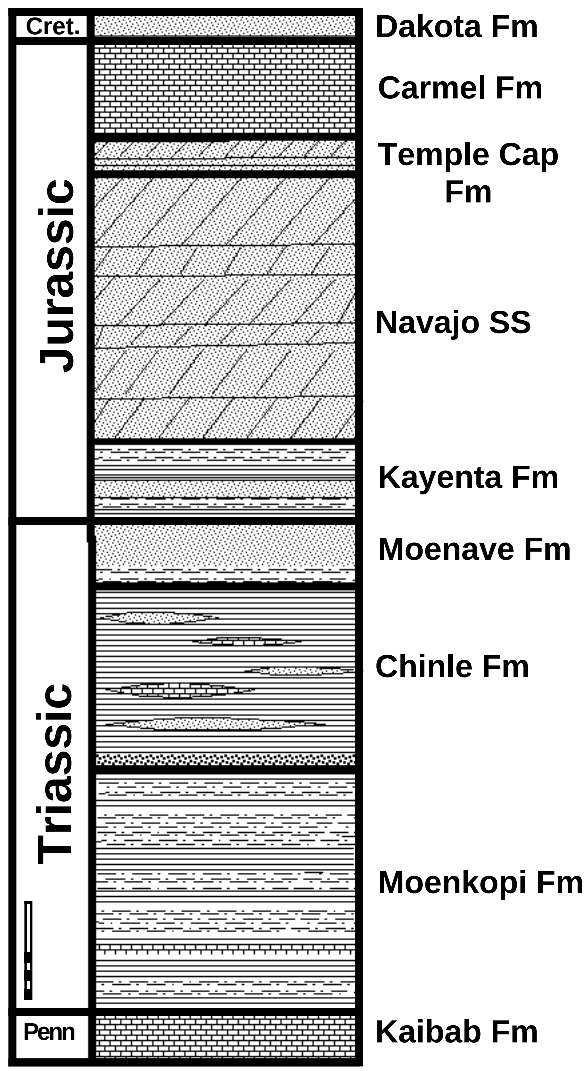

Figure 2. General stratigraphic section for Zion National Park, scale bar = 60 m (200 ft).

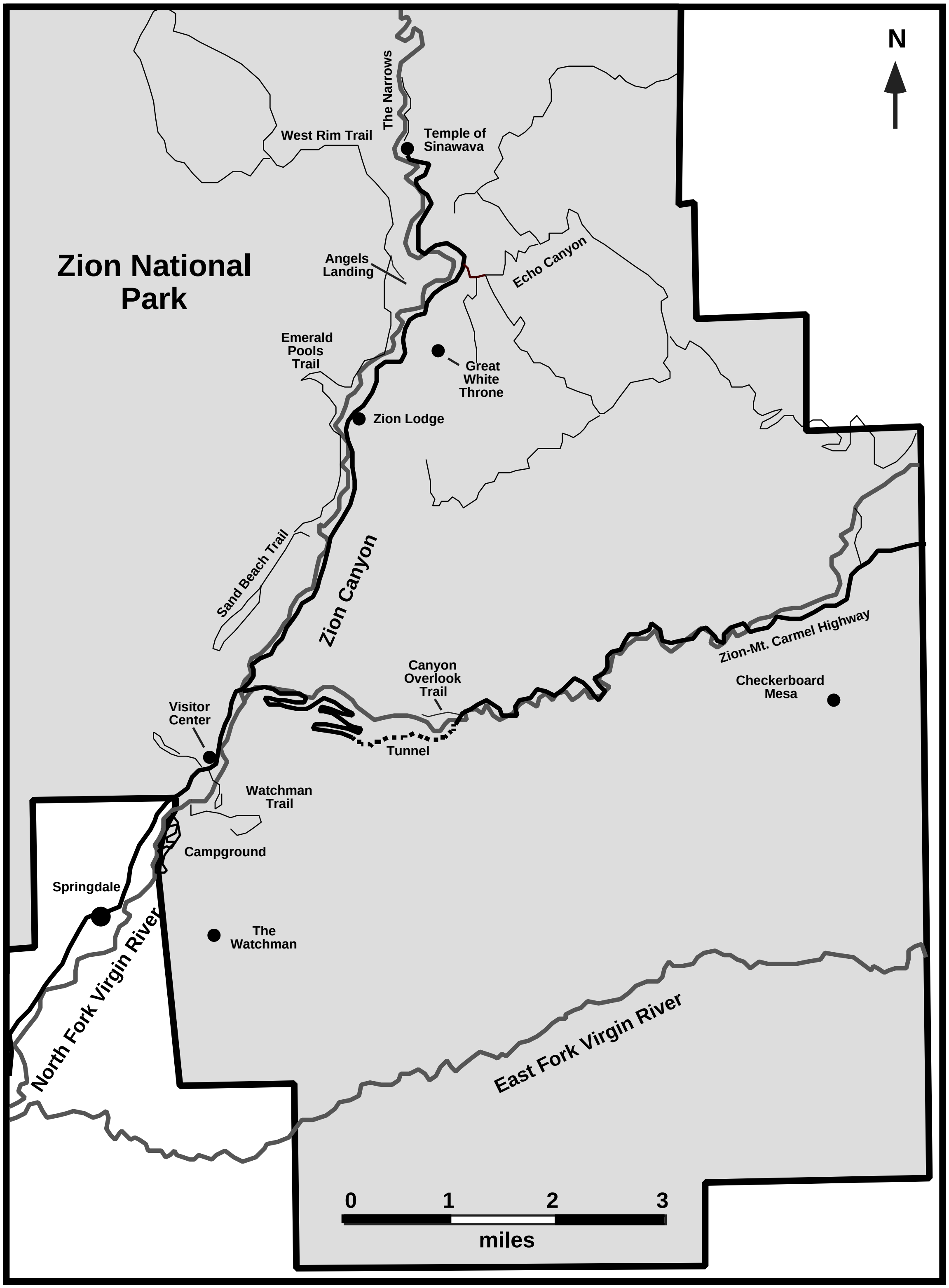

Figure 1. Map of the Zion Canyon section of Zion National Park (after National Park Service map)

Age	Thick. (ft.)	Description	
Quaternary	**variable**	**Q**	**Alluvium**
	variable	**Qv**	**Volcanic Rocks** Basalt flows and cinder cones dated at .26 to 1.4 million years
Cretaceous	**100**	**Kd**	**Dakota Formation** Sandstone, tan, fine grained, overlying conglomerate at top of Horse Ranch Mountain
Jurassic	**850**	**Jc**	**Carmel Formation** Limestone, tan and gray; sandstone and siltstone, banded pink and gray; gypsum; and fine-grained sandstone
Jurassic	**0-260**	**Jtc**	**Temple Cap Formation** Sandstone, gray and tan, cross-bedded, overlying red-brown, flat-bedded sandstone
Jurassic	**2000**	**Jn**	**Navajo Sandstone** Sandstone, white, gray, yellow, tan, pink, medium to fine grained, cross-bedded increasingly toward the top, eolian deposit
Jurassic	**600**	**Jk**	**Kayenta Formation** Mudstone, reddish brown, siltstone, and sandstone representing stream deposition.
Triassic	**490**	**Trmo**	**Moenave Formation** Sandstone, mauve, overlying reddish-brown siltstone and mudstone, stream channel and floodplain deposits.
Triassic	**400**	**Trc**	**Chinle Formation** Shale, mauve, gray,and white, weathered to clay on exposure, with sandstone and limestone lenses; overlying the Shinarump, a light tan conglomeratic sandstone.
Triassic	**1800**	**Trm**	**Moenkopi Formation** Siltstone and mudstone, red and red-brown, with many gray gypsiferous shale beds in the upper part and two limestone members in the lower part.
Permian		**Pk**	**Kaibab Formation** Limestone, yellowish gray, massive, containing chert and marine fossils.

Figure 3. Description of Stratigraphic Units of Zion National Park (modified from Hamilton, 1987).

white and weathers into rounded hills and the lower Navajo is red to pink and forms more vertical cliffs. The Jurassic Temple Cap Formation, a tan to gray sandstone that ranges in thickness from 0 to 80 m (260 ft) is best exposed on higher plateaus of Zion. The youngest units of Zion, the Jurassic Carmel and Cretaceous Dakota Formations, can be observed on top of Horse Ranch Mountain the highest peak in the park at 2618 m (8726 ft). Capping Horse Ranch Mountain is a Pleistocene basalt flow. Pleistocene volcanic rocks are restricted to the western part of the the park. They occur as basalt flows which frequently cap mesas and as cinder cones associated with normal faults.

Compressional stresses, most likely related to the Sevier Orogeny caused folding and thrust faulting that can be observed in the Kolob section of the park. Beginning in the Miocene there was a change to extensional tectonics resulting in normal faulting and uplift of the Markagunt Plateau. Most of the vertical jointing observed throughout the park is believed to be related to this event (Hamilton, 1992).

Navajo Sandstone and Eolian Cross-bedding

The spectacular cliffs in Zion National Park are made of Navajo Sandstone, which reaches thicknesses of 600 m in southwestern Utah. Even at a distance, you can see the large, well-defined cross-beds which are a hallmark of this unit. Cross-beds are a typical structure of sandstones created by the migration of bed forms which vary in scale from less than a centimeter to more than 10 meters high. Large-scale cross-beds are ubiquitous in the Navajo Sandstone, yet small-scale cross-beds are commonly hard to find. Why is this?

In some settings, especially deserts, wind is more important than rivers for transporting sediment. When you mention deserts, people usually think of vast expanses of sand dunes. As in rivers, the sand contained in the dunes is simply in transit from a source area (where erosion predominates) to a sink (where different processes will take over, e.g., a coastline). Thus sand dunes are found in some, but not all, parts of a desert. Areas where dunes are abundant are known as ergs (an Arabic word for sand seas). The Sahara, for example, has a number of separate ergs which only cover 15-30% of the total area. The Navajo Sandstone can be correlated with the Aztec Sandstone to the southwest in California and Nevada and with the Nugget Sandstone to the north in Wyoming (Porter, 1987). Collectively, these sandstones represent an erg that occupied an area over 1,000 km from north to south and 400 km from east to west during the Jurassic (figure 4).

Eolian dunes are analogous to subaqueous bedforms in that they come in certain predictable shapes related to specific conditions. The commonest types of eolian dunes are 1) barchans (crescent-shaped, isolated dunes), 2) transverse (dunes elongated perpendicular to the dominant wind direction), 3) linear or seif dunes (dunes elongated parallel to the dominant wind direction), and 4) pyramid or star dunes (large omnidirectional piles of sand) (figure 5). The large cross-beds seen in the Navajo and other eolian sandstones are simply cross-sections through certain types of dunes, namely those with steep foresets or slipfaces

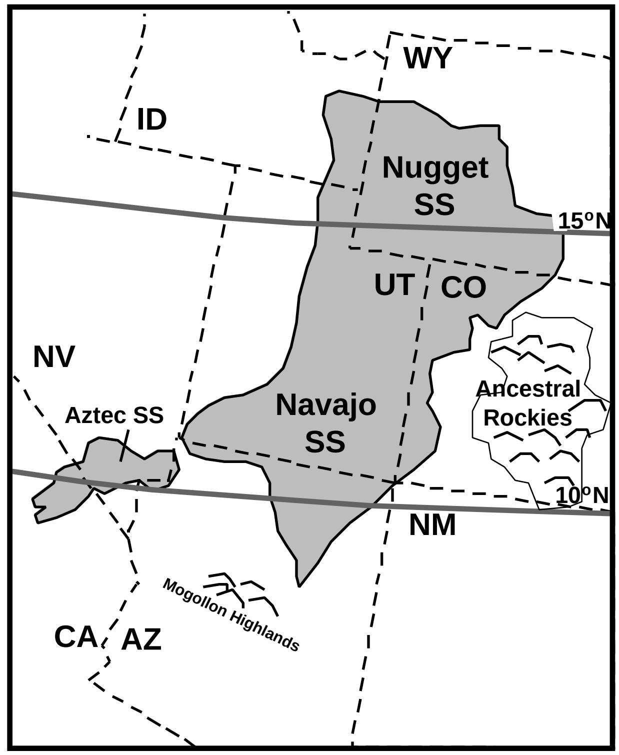

Figure 4. Paleogeography of the western US during Navajo time, showing the distribution of sand seas.

The Navajo, like most eolian sandstones, consists almost entirely of well-sorted, well-rounded quartz sand (average diameter 0.2 mm). Sand accumulates in abundance in eolian environments mainly by default. Gravel, on the one hand, is too large for wind to move very far. However, the wind may sandblast pebbles into characteristic shapes (known as ventifacts or dreikanters) and leave behind a surface-armoring lag deposit known as a desert pavement. Clay, on the other hand, is so fine-grained that it gets lifted high in the air and only comes to rest far downwind, even in the middle of the oceans (for example, fine quartz from Asian deserts has been blown all the way to Hawaii). The only particle size wind can move a little at a time is sand, so it forms the vast majority of the sediment found in ergs, although minor amounts of clays and/or evaporites can accumulate locally in small, ephemeral interdune ponds.

If you look at the surface of a sand dune

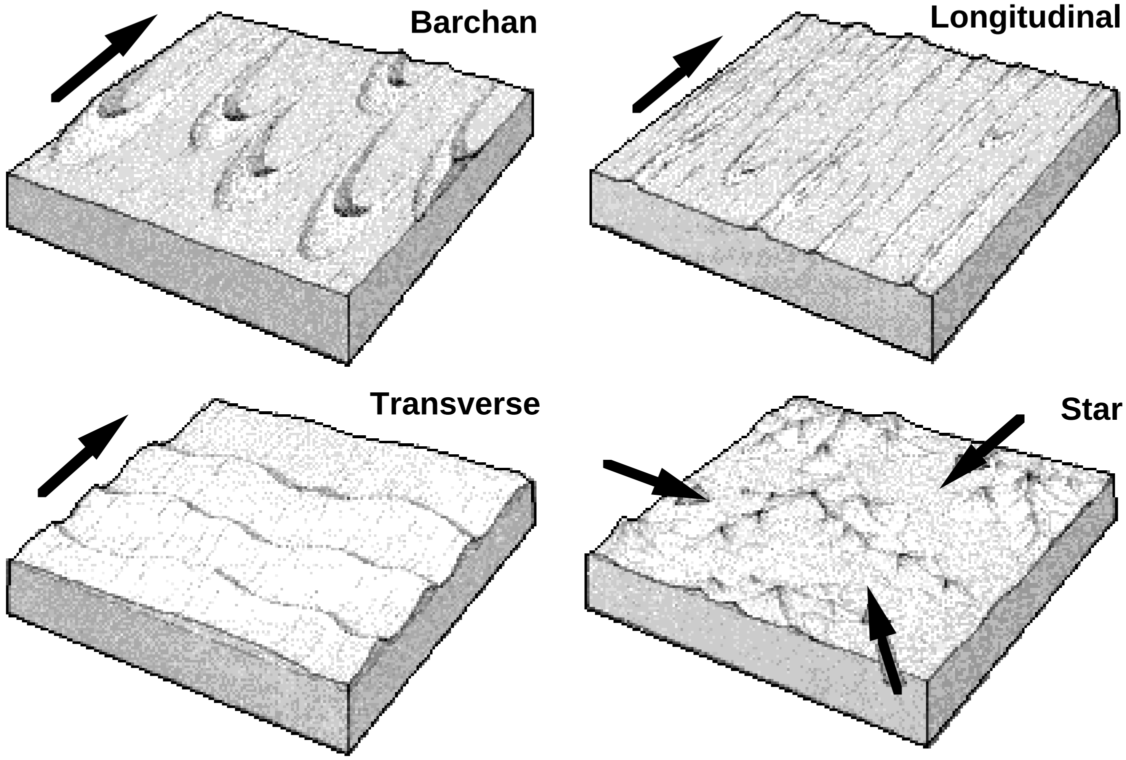

Figure 5. The major types of dunes. Arrows indicates wind direction. (Tarbuck and Lutgens, 1991)

close-up, you often see small-scale bed forms known as wind ripples. Such ripples have a corrugated look that superficially resembles the wave ripples you might see in shallow standing water, but the two are different in subtle ways. Wind ripples tend to have rounder crests and gentler sloping sides than wave ripples, for one thing. Moreover, the sand is generally coarser on the crests and finer in the troughs of wind ripples, while it's just the opposite for wave ripples. Because of these characteristics, cross-beds rarely form when wind ripples migrate downwind. What often forms instead is a pronounced thin layering or lamination, a mm- to cm-scale alternation of finer sand (trough deposits) with coarser sand (crest deposits), via a combination of downwind migration and slow vertical accretion. Paradoxically, the layering that wind ripples usually leave behind make it look like the surface of the dune was flat at the time of deposition rather than bumpy!

Layering formed by climbing wind ripples is only one of 3 different types of layering commonly formed by eolian dunes (figure 6). Unlike the climbing ripple lamination, which can form on either flat or inclined surfaces, the other two types of layers only form on the steep foreset or slipface of a dune. One type of "layer" is actually the localized wedge of sand deposited by an individual avalanche. Despite their impressive size, the slipface of a dune actually migrates by a series of small avalanches, each of which is

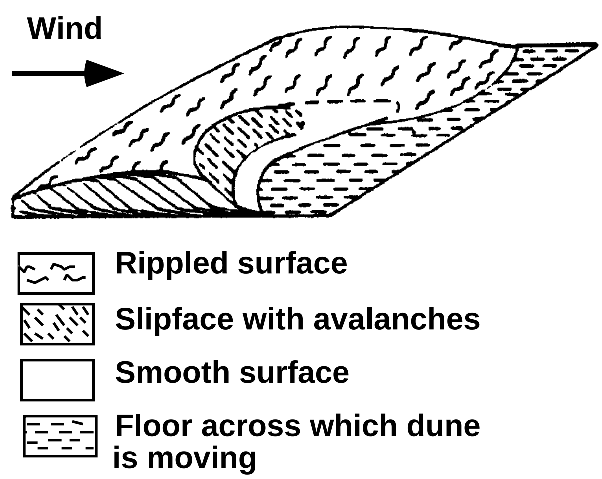

Figure 6. Schematic diagram of an eolian dune. (Hunter, 1977)

no more than a meter in width. When sand blown over the crest of the dune piles up near the top of the slipface, it gets progressively steeper until it exceeds the angle of repose. An avalanche then occurs, known in more technical terms as a grain or sandflow, and sand flows out of a shallow scoop-shaped region high on the slipface and into a long, narrow cone low on the slipface. Because they require a high angle to move, these sandflows "freeze up" as soon as the slope angle diminishes, and they give rise to individual, wedge-shaped layer that are internally massive. In cross-section, sandflows can be recognized by their characteristic saber-like toes.

The third and final type of layering typical of eolian dunes is also associated with the steep slipfaces, but it is made by sand that is moving much faster when it comes over the crest of the dune. As a consequence, this sand flies over most of the foreset and comes to rest at or even beyond the toe of the slipface via a process known as grainfall. The sand deposited by this process tends to have faint laminations that are gently curved, in contrast to the climbing ripple lamination which more planar and pronounced, and the sandflow layers which are internally massive. Grainfall sand also tends to accumulate as a wedge at the base of the slipface, thereby decreasing its average slope. This results in a constant battle with the sand brought in by sandflows, which form at a higher angle and tend to steepen the slope.

You will be able to see all three of these layering types in the Navajo Sandstone, and careful studies of their distributions have been used to reveal some amazing details about what this place was like during the Jurassic. For example, cyclically interbedded grainfall and sandflow deposits along some cross-beds have been interpreted as varves, i.e. the product of a consistent annual fluctuations in wind velocity. If so, it means these Jurassic dunes were advancing at a rate of about 1.5 meter per year, which may not sound like much, but it would require an average wind speed of 23 meters/second (= 52 miles/hour) day in and day out all year round! Even tough the dunes didn't advance very far in a given year, they were probably around 33 meters (108 feet or eleven stories) high on average, so you had to move a lot of sand around.

You will also be able to see the truncation or hiatus surfaces that separate one set of cross-beds from another. These surfaces have been the focus of much attention lately which has shown that they can form by a number of different mechanisms. Some are simply a consequence of the inevitable erosion on the upwind side of a dune as it migrates, but others appear to be more widespread, perhaps regional in character, and may reflect large-term fluctuations in the balance of rates of sand supply vs. removal. Still others probably represent times when all of the sand was blown away unless it had water in its pores to hold it in place via surface tension. Such deflation would lower the land surface until it reached the water table, forming what are known as Stokes surfaces.

Research is continuing on the complex and fascinating topic of cross-bedding in eolian sandstones. This has been spurred on by the presence of large petroleum reserves in eolian sandstones, e.g. in the southwestern USA and the North Sea, and the recent realization that even small-scale heterogeneities like these can exert a big influence on permeability and should be taken into account during production of reservoirs in such rocks.

Erosion

Following uplift and the lowering of it's base level, the North Fork of the Virgin River began rapidly downcutting forming Zion Canyon. Uplift must have been irregular as evidenced by the hanging valleys at 360 m (1,200 ft), and terraces at 150 m (500 ft) and 75 m (250 ft) above the Virgin River (Alberding, 1979). A system of joints and faults plays a dominant role in the drainage pattern of Zion. Tributary canyons are frequently straight and parallel to each other and it is not uncommon to see rectangular bends in a streams course. Slot canyons with vertical walls such as the "Narrows" occur where streams are rapidly downcutting within the Navajo Sandstone. When the stream valleys reach the elevation of the Kayenta-Navajo contact, they begin to widen. A line of springs occurs along this contact where ground water moving through the porous Navajo Sandstone reaches the impermeable shale beds of the Kayenta. Erosion of the shales undermines the overlying sandstone in a process called sapping. The canyon then widens by vertical retreat of the canyon walls.

Kolob Section

In most of Zion the rocks are flat lying and Jurassic in age. In the Kolob section, located in the northwest corner of the park, the rocks range in age from Permian through Cretaceous and in places are tilted up to 50^{o} (figure 7). Two tectonic episodes affected this area (Grant, 1987). The first was folding and low-angle thrust faulting associated with the Sevier Orogeny during the Late Cretaceous or Early Tertiary. The Taylor Creek Thrust Zone formed at this time. The second tectonic episode was the Late Cenozoic movement along the Hurricane Fault. Normal faulting occurred 5-6 million years ago and had a displacement up to 7000 feet with rocks to the east uplifted relative to rocks toward the west.

The Kolob Canyon road crosses the Hurricane Fault Zone and the Taylor Creek Thrust Zone. The following formations outcrop along the road; L. Triassic Moenkopi Formation., U. Triassic Chinle and Moenave Formations, and L. Jurassic Kayenta Formation. The visitors center is located at the base of the Hurricane Cliffs, the topographic expression of the Hurricane Fault. The rocks exposed on the cliffs consist of the Moenkopi Formation. Between 1/2 and 1 mile from the visitors center a number of small normal faults dissect the Moenkopi. The contact between the Moenkopi and the Chinle occurs at about mile 1.5. The first turn off occurs on a Holocene slide deposit of fragmented rockfall debris. After the slide deposits the road crosses the Moenave, followed by the Kayenta Formation. The Taylor Creek Thrust Zone can be observed at the trailhead parking area at mile 2.1. Look for the three fault-repeated ledges of the Springdale Sandstone Member of the Moenave Formation. The picnic area at the end of the road is on the margin of another Holocene slide. Horse Ranch Mountain to the northeast is capped by Quaternary basalt. The Finger Canyons of the Kolob formed along joints and tear faults developed on the overthrust plate of the Taylor Creek Thrust (Hamblin, 1984). Note their hanging valleys which formed in response to a sudden lowering of the base level which may have resulted from the capture of west-flowing streams by the south-flowing Timber Creek.

Snow Canyon State Park

Introduction

Snow Canyon State Park, Utah, is located in the High Plateaus Section on the western margin of the Colorado Plateau. The Beaver Dam Mountains to the west and the Tonoquints Volcanic Field to the north are part of the Basin and Range Province. Here on the margin of the Colorado Plateau, we can observe Quaternary basalts overlying the Jurassic Kayenta Formation and Navaho Sandstone (figure 1).

Geologic Units

Kayenta Formation

The Jurassic Kayenta Formation is well exposed at the south entrance to the park. It consist of red sandstones, siltstones and shales that were deposited by rivers and streams. The lower half of the unit consist of slope forming siltstone, shale and fine sandstone. The upper part of the Kayenta contains more sandstone and is resistant to erosion. Close examination of this unit yields evidence of former stream deposits such as ripple marks and mud cracks.

Navajo Sandstone

The Jurassic Navaho Sandstone is massive cross-bedded sandstones deposited in an eolian environment. It forms the major cliffs at Zion and is responsible for much of the spectacular scenery across the Colorado Plateau. Some interesting features occur within the Navajo at Snow Canyon. Enigmatic dark, blackish-red wavy looking rocks occur along the nature trail across from the campground. They have been interpreted as petrified algae that grew in desert waters or soft sediment deformation features. How do you think they formed? Moki marbles, weathered out iron and manganese concretions, can be found in piles on top of the Navaho Sandstone.

Rocks of the upper Navajo at Snow Canyon are white and the lower Navajo has a reddish-orange color which results from iron

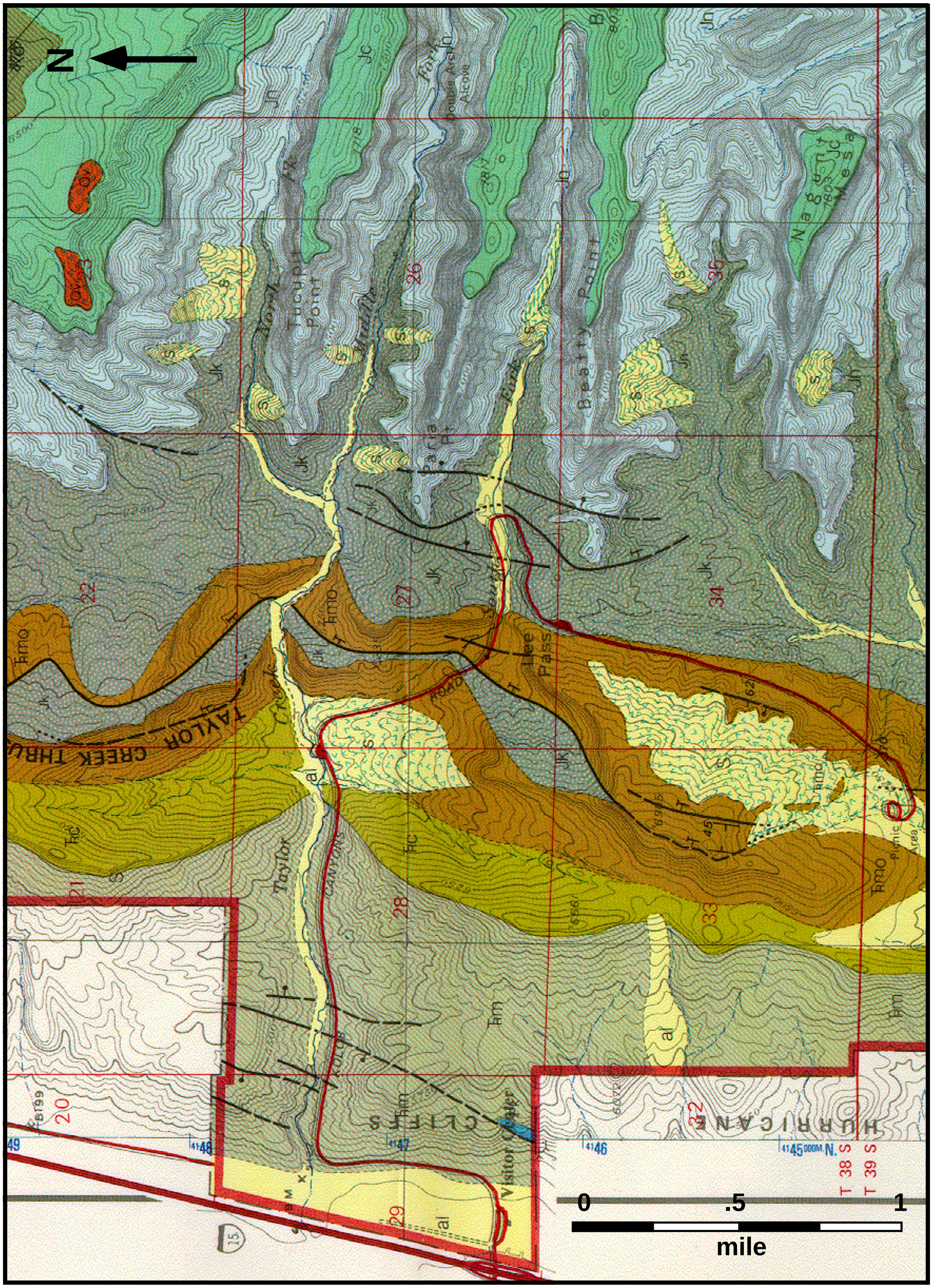

Figure 7. Geologic map of the Kolob Section of Zion National Park (Hamilton, 1987).

oxide staining. A number of models have been proposed to explain why iron oxide is present in the lower part of the formation but absent in the upper part. One model suggest that the iron oxides had the same source as the sands and with time the source area became depleted in iron minerals. A second model proposes that all the rocks were once red and groundwater leached the iron minerals from the upper Navajo. A third model speculates that the iron minerals were brought in by iron-rich waters that circulated through the rocks after they were deposited. This transition from an upper white to a lower red Navajo Sandstone is also observed at Zion where it corresponds to the elevation of the hanging valleys suggesting it represents the groundwater table during a stillstand when the Virgin River ceased to cut downwards.

Tertiary Basalts

Volcanic eruptions spewed lavas of black basalt which flowed into Snow Canyon 3 million to 2,000 years ago. Like waterfalls the youngest lava flows cascaded over and around domes of Navaho Sandstone. The lava flows initially infilled low areas such as river valleys, gullies and depressions. After they cooled they become resistant to erosion. As the softer sedimentary rocks were eroded away the basalt was left behind as ridges forming a feature know as inverted topography. There are three distinct phases of this inverted topography which indicate the relative ages of basalt flows at Snow Canyon. The oldest layer forms the plateau to the east of Rt 18, the next forms the plateau that Rt 18 is built on, and the last forms the floor of Snow Canyon. The two oldest flows are 2 and 1 million years old. The margins of these lava flows have been dissected and the original surface features have been destroyed by erosion. The youngest flow, known as the Santa Clara flow, is estimated to be about 1000 years old. It flowed across open plains and down narrow canyons. Lava cascades occur where its lobes spilled over cliffs of Navajo Sandstone. Original surface features such as pressure ridges, aa crust, and flow structures are preserved on this youngest flow. (Hamblin, 1987)

The texture or surface of the basalt depends on factors such as the rate of cooling, viscosity and gas content of the lava. Scoria, a highly vesicular basalt, is a common texture. The vesicles or voids are formed by gases that get trapped in the lava as it cools. Scoria has a texture that is partly glassy and partly crystalline and may contain phenocrysts of olivine. Pahoehoe basalt has a billowy or ropy surface and aa basalt has a rough jagged or clinkery surface. Massive flows that cooled more slowly often display columnar jointing. Lava tubes and caves form when the outer surface of a lava flow cools and solidifies. This outer crust acts as an insulator that prevents lava within the tube from solidifying. When the fresh hot lava within the tube flows out it leaves behind a void or lava cave.

Cinder Cones

There are 2 cinder cones in the northern part of the park. These represent the youngest basalt deposits of the park. They have not been dated but geologist estimate they are 1,000 years old based on their fresh appearance and well preserved textures (Hamblin, 1987). The cinder cones mark the site of extrusion of the Santa Clara flow. Cinder cones form from magmas that have a high viscosity and high gas content. They are commonly associated with the last stages of volcanic eruption.

Quaternary Deposits

As the rocks of Snow Canyon slowly erode they provide sediment that is deposited on the floor of the canyon along stream channels, evidence that the processes of erosion and deposition continues today. Eolian sand dunes slowly migrate along the west side of the canyon road. Wind transports sand up the windward side of a dune. The sand then cascades down the lee slope. The cross-beds produced by this process have an angle of approximately 34^{o}, the angle of repose for dry sand. What do you think the chances are that these sediments will become buried and preserved so they can be studied by post-Quaternary geologist?

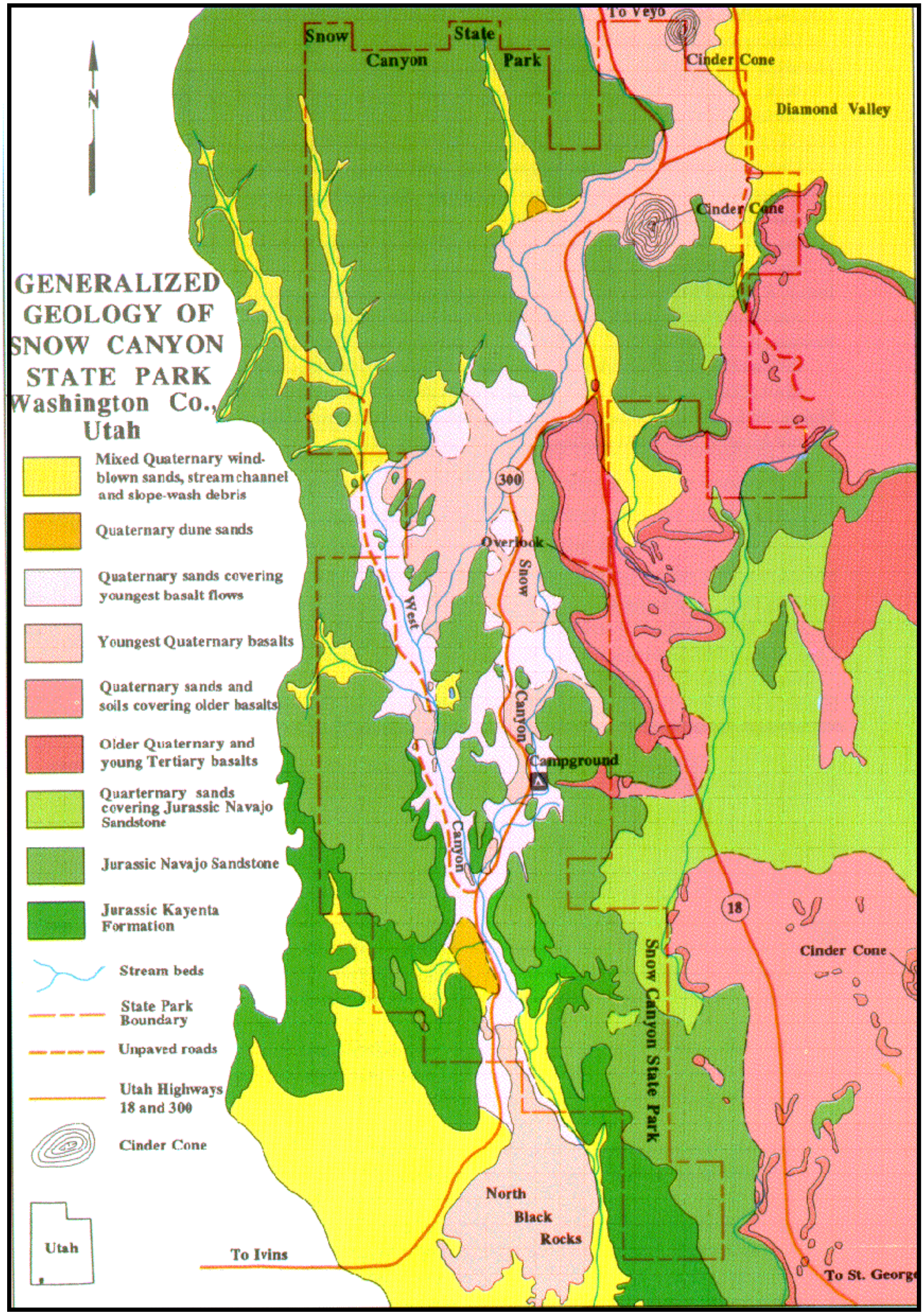

Figure 8.1 Geologic map of Snow Canyon State Park (Bugden, 1992)

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Exercises

Coral Pink Sand Dunes State Park

At Coral Pink Sand Dunes State Park we will observe the characteristics of modern eolian sand dunes which we will later compare to the Navajo Sandstone.

1) Observe the sand. What is its color, grain-size, sorting, roundness, and mineralogy? How does it vary on different parts of the dunes?

2) What type of sand dunes are present (figure 5)? Can you determine the prominent wind direction from the morphology of the dunes?

3) Observe and sketch the minor structures and laminations on various parts of the dune such as slipface. Can you relate any of the minor structures you see to processes that are currently active? Record your observations for later comparisons with the Navajo Sandstone.

Navajo Sandstone

1) Observe a hand sample of the Navajo Sandstone. What is its color, grain-size, sorting, roundness, and mineralogy?

2) Describe the sedimentary structures and different types of laminations you observe in the Navajo Sandstone. Did you observe a modern equivalent for any of these features at Coral Pink Sand Dunes?

Emerald Pools Trail

1) Describe the Kayenta Formation along the trail. Include characteristics such as color, lithology, grain size, bedding, sedimentary structures, trace fossils and fossils.

2) On the topographic map of the Emerald Pools trail, draw in the contact between the Navajo Sandstone and the Kayenta Formation.

3) How were you able to identify this contact?

4) What features occur along this contact?

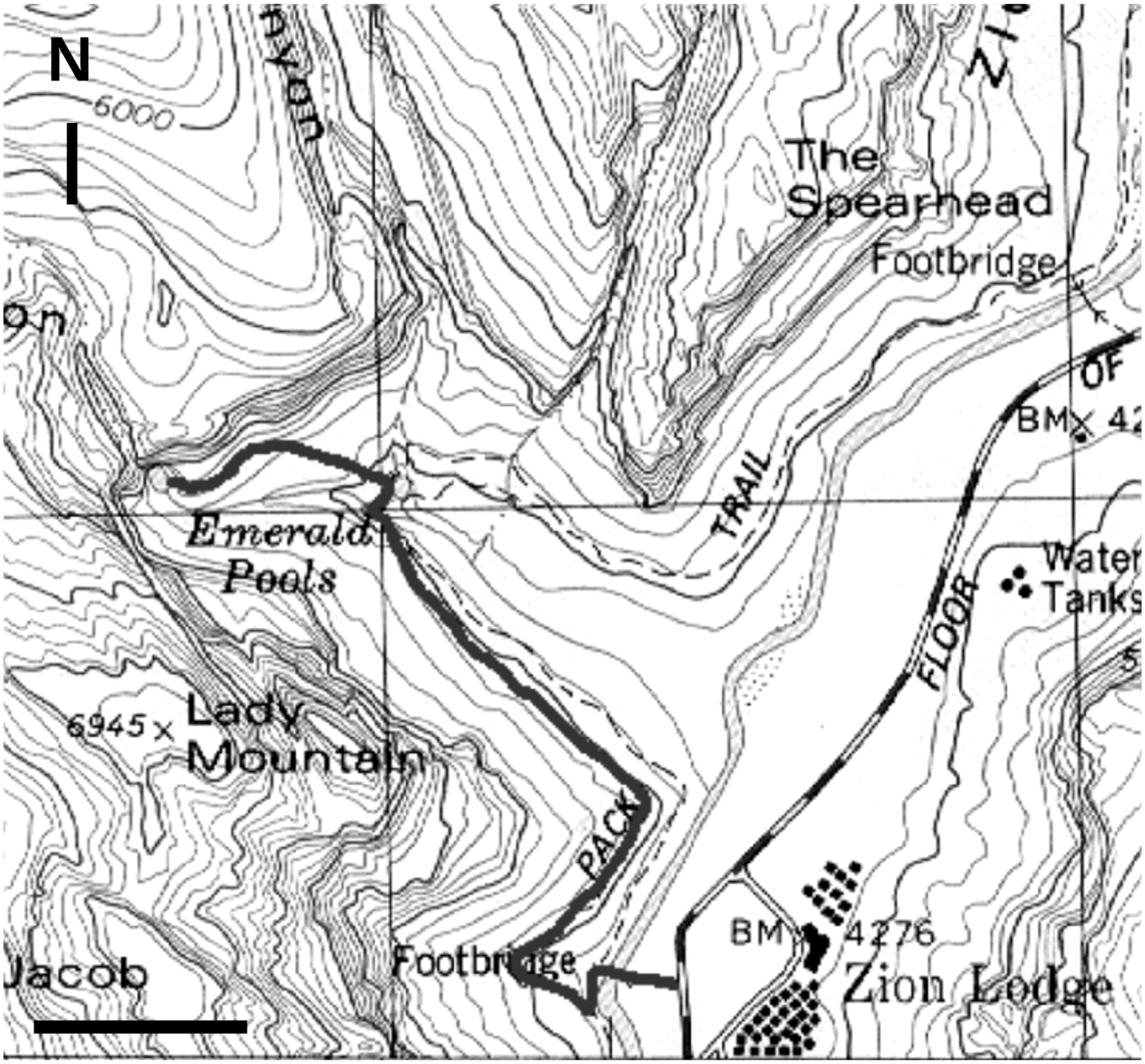

Figure 8. Topographic map of the Emerald Pools Trail (Scale bar = 1000 ft; contour interval = 80 ft).

Canyon Overlook

1) Measure the orientation of a number of joints occurring along the Canyon Overlook Trail.

2) Plot the joint orientations on the topographic map.

3) Measure the orientation of 3 tributary canyons in the Zion-Mt Carmel highway area.

4) How does the orientation of the joints compare with the drainage pattern of the area?

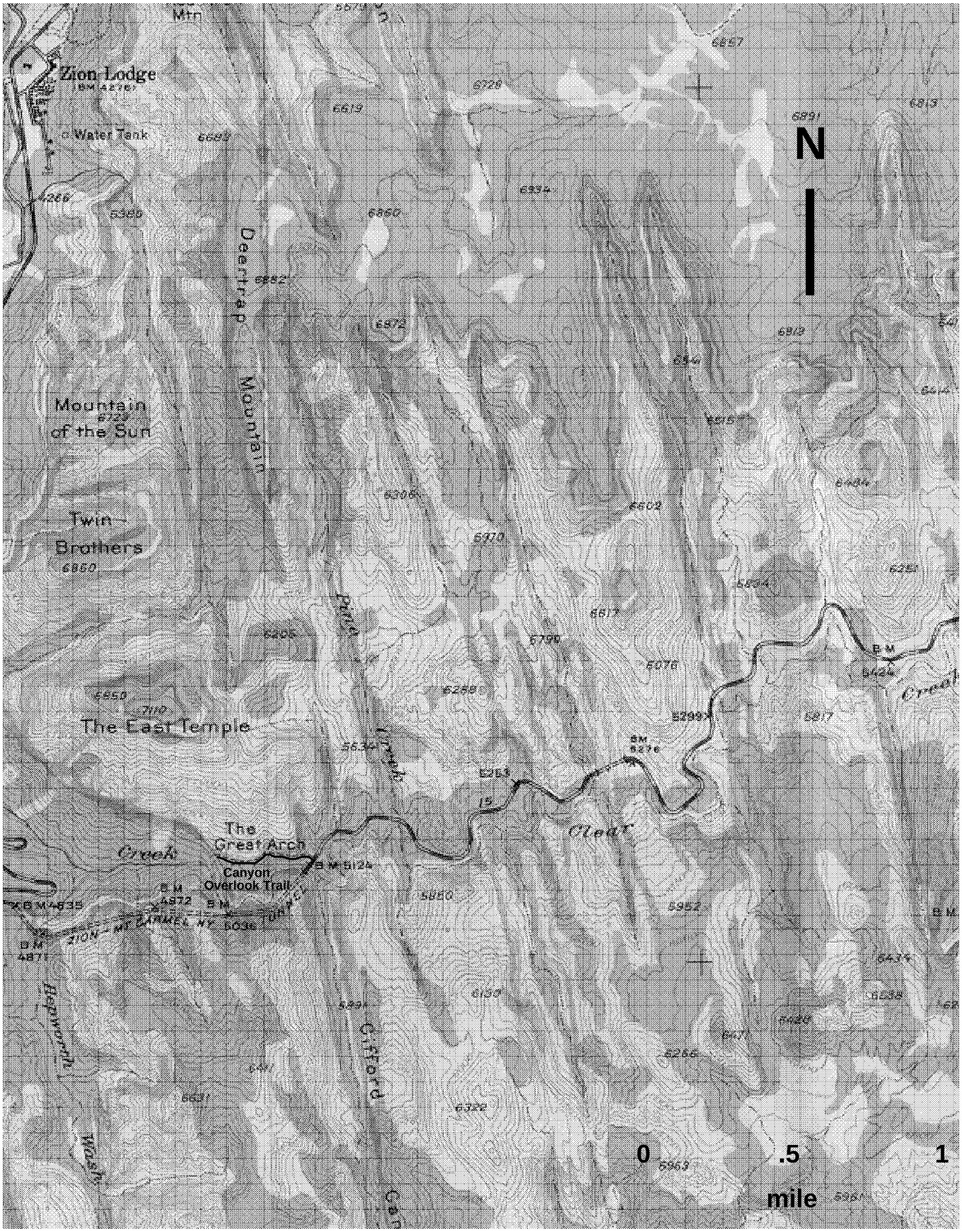

Figure 9. Topographic map of Zion-Mt Carmel Highway area (contour interval = 50 ft)

Snow Canyon State Park

1) West Canyon Overlook Trail and Lava Cave.

A. Describe a sample of the basalt that occurs along the trail.

B. Record the lava features that you observe along the trail.

C. How does the basalt change as you go from the surface down into the lava cave? What do you think causes this change in the texture of the basalt?

2) Relative age dating applies the principles of superposition and cross-cutting relationships. List the relative sequence of events at Snow Canyon State Park and the evidence for your interpretation.

Definitions
Define the following terms and give examples of each feature.
Cinder cone

Columnar jointing

Cross-bedded

Desert pavement

Eolian

Hanging valley

Inverted topography

Lava cave

Pahoehoe

Sapping