The Geology of Zion National Park

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Zion National Park is a wonderland for lovers of wilderness and dramatic geological formations. The towering cliffs, deep canyons, and rock formations are remarkable in themselves, and also demonstrate remarkable episodes in Earth's long history. The scenic wilderness includes desert, high plateau country with woodlands like the Rocky Mountains, and narrow canyons with lush stream-side habitat. The geological history of Zion created the canyons, cliffs, spires, and the all rock features which delight visitors and intrigue and inform geologists.

Zion's complex topography and striking geology are the result of geologic processes and events during the past 270 million years, creating a natural setting like few other places on Earth. The geology of Zion National Park is well understood in broad outlines, but important questions remain matters of debate by geologists, including some of the Earth's big geological mysteries.

A Very Short Summary

The rocks of Zion National Park are mostly flat-lying sedimentary layers. The prominent cliffs are sandstone, made from sand dunes in an ancient, large, Sahara-like desert. Long after they were deposited, all the rock layers were uplifted some two and a half miles (3.8 km), and then incised by erosion of rivers and streams which cut deep canyons and left behind high cliffs. Natural minerals embedded in the rocks, and minerals washed down from higher layers, as well as plant growth and mineral alteration on the rock faces, create the colors of Zion.

The Long Accumulation in Lowlands

The oldest rocks you can see in Zion National park date back to about 270 million years ago. The rocks of Zion were laid down as river, lake, and windblown sediments in broad, flat, lowlands, close to sea level. The settings included shallow marine inundations, tidal flats and channels, coastal lowlands, rivers, lakes, and flood plains. Fossilized ripple marks made by waves in shallow water remain in rocks composed of silt and mud. There are also fossils of shells and tropical plants and reptiles. Iron minerals stain many of these layers shades of rusty red and yellow. The highest and youngest of these rocks is the Kayenta formation, forming reddish ledges and slopes just below the big cliffs. Dinosaur tracks occur in the Kayenta around Zion, and in Arizona fossil remains of eight kinds dinosaurs have been found in the Kayenta formation.

A Sea of Sand

After 80 million years accumulating water-borne sediments, which were buried and consolidated into colorful layers of rock, the climate and geological conditions changed and a Sahara-like desert extended across the region, forming an enormous sea of sand or *erg*, extending from what is now Nevada and Arizona to Colorado and Wyoming, 400 miles (650 km) across. Enormous sand dunes with sloping faces were gradually buried by more dunes and, in time, converted into a thick uniform sandstone unit, called the Navajo sandstone, which preserves the sloping dune faces as sloping lines crossing cliffs and rock exposures. These angular bundles of lines in outcrops, which you see in many places in Zion, are called cross-bedding. The Navajo is the thickest and most prominent formation in Zion.

The total thickness of the Navajo sandstone in Zion is more than 2500 feet (762 m). It is not likely that so much sand accumulated in an ever-growing pile, thousands of feet above sea level. It appears that the underlying crust of the Earth flexed or subsided downward, probably due to the weight of mountains building just west of Zion, creating an enormous shallow basin to hold the deepening sea of sand. The rate of accumulation of such sandstone varies, but the time to build up all the Navajo sandstone in Zion would have been about 10 to 20 million years.

The ancient desert was hot and windy. Sand grains, mostly pure quartz, were blown into the Zion region from eroding mountains far away. Only a few fossil traces of plants and animals remain from this barren desert, but the fossil dunes show that winds were generally from the northwest – what then was due west or upwind – and perhaps occasionally from the Appalachian mountains far to the east, which at that time were as tall as the Himalayas today. The grains of sand, when turned to rock, became the hard and massive Navajo formation which forms the tall cliffs of Zion.

> "…the Navajo sand sea was one of the most extensive desert systems ever to have existed in the history of the Earth, and probably contained the largest sand dunes that ever moved across the surface of the planet." -- Jonathan E. Verlander, *Geology Today*, 1995.

Trace minerals in the sandstone create vivid colors in the rocks, iron minerals making reds, pinks, oranges, and yellows, and the mineral calcite providing the white streaks that wash down cliff faces. Some middle and upper parts of the Navajo, made almost entirely of quartz grains, are the white of pure quartz. Glossy black streaks on the cliffs are "desert varnish," a coating on some rocks in arid regions, composed of clay particles combined with iron and manganese oxides in a chemical combination, facilitated by limited moisture, and possibly with some microbiological organisms such as bacteria.

The Missing Rocks

After the Navajo desert, the Zion area, still at or near sea level, experienced continuing periods of sediment deposition from mountains to the west, and marine inundation from the east, alternating with periods of erosion. Zion was last at or near sea level 90 million years ago when an oceanic seaway stretched from Zion eastwards for more than 1000 miles (1600 km) to the region of St. Louis, across where the Rocky Mountains are now. But no rocks younger than 100 million years old remain in Zion. Any younger rocks, which we know once existed (they survive in higher and younger rocks layers outside Zion), were all removed by later erosion. There is one exception – mesas and buttes on the southwestern edge of the park are capped with dark volcanic lava flows 1.4 million to 100,000 years old, a comparatively recent volcanic eruption that occurred after the Park was much as we see it today.

If geologic activity in Zion had stopped after creation of its flat sedimentary formations, Zion today would lie near sea level and might look like Kansas or the steppes of Russia. But something remarkable occurred – uplift of a remarkable extent.

Grand Uplifts

During its long geologic history the Zion region was at or near sea level for more than 430 million years. Today Zion is far above the level of the sea: the top of the Navajo sandstone on the West Temple is near 7810 feet (2380 m). Even the floor of Zion Canyon is near 4000 feet (1220 m). Zion has been uplifted a great distance since its rocks formed. The Colorado Plateau, including Zion National Park, is the Earth's largest region of flat-lying sedimentary layers at high elevation.

How high was the uplift? Clearly, at least 7800 feet. But it was much more. In Bryce Canyon National Park, only 60 miles from Zion, the U.S. Geological Survey mapped a series of rocks 4800 feet (1460 m) thick above the Navajo sandstone, ending with limestone formed near sea level. The top of the Navajo sandstone probably was below sea level by about that amount when those rocks were laid down. Bryce and Zion have a similar geologic history and moved together. So the uplift at Zion can be estimated at about 12600 feet (3840 m), nearly two and a half miles.

Large changes in height of geological layers are found elsewhere, but most were caused by mountain formation involving large folds and faults in rock layers, generally with much greater horizontal compression and shortening than uplift; for example, in the Alps, Andes, and Himalaya mountains. Zion and the Colorado Plateau of which it is a part were uplifted with comparatively little folding or faulting and only a little horizontal deformation (about 1 %), as if this 500 mile (800 km) wide region were rigid and floated straight upwards as a single undeformed unit. Whereas most geological activity crunches sideways, the Zion area went straight up, 2 miles and more. The broad, largely undeformed, and high uplift of the Colorado Plateau is a remarkable feature of North American geology.

It appears that a large part of the western United States was uplifted from 70 to 45 million years ago, at the same time of mountain building in the Rockies. Substantial uplift of the Colorado Plateau and Zion, as much as 1.6 km (5200 feet) or more, occurred then. Another pulse of uplift may have occurred over the most recent 6 million years; perhaps some 600 m (2000 feet); or perhaps little or none. A third period of uplift may have occurred between those two time intervals. Exactly when the uplifts occurred, how much uplift occurred in each episode, and the causes are uncertain, and these questions continue to provoke research, field work, and debate by geologists.

Regardless of the timing and causes, today the Colorado Plateau has an average elevation of 1.9 km (6200 feet). This is less than the 3.8 km uplift in Zion since a great thickness of rocks have been eroded off the top and carried aways by streams and rivers.

Cutting the Canyons

The final act in Zion’s long and eventful geologic history was the cutting of the canyons. The small rivers in Zion really did cut the huge canyons they lie in. Erosion is powerful, and it is most powerful where there is a big drop to sea level over a short distance, as from the high country around Zion to the mouth of the Colorado River only 500 miles (800 km) downstream.

Geological evidence indicates that the canyons of Zion, the Grand Canyon, and the other canyons of the Colorado Plateau began only 6 million years ago. Before that time rivers on the Colorado Plateau drained into the center of the Plateau, not to the oceans. When the rivers finally cut through to the sea, they became energized by the large drop in elevation from the Plateau to the sea. What we see in Zion today was largely cut over the last 2 million years. Before then similar canyons would have been further downstream and somewhat higher.

Watching the gentle Virgin River in Zion National Park gives no idea that it could cut through solid rock, but it does. How does it do that? Part of the answer is long geological time, but equally important is that erosion is tremendously increased when river flow becomes swift and voluminous, as occurs in flash floods after thunderstorms. Flash floods increase river flow, and speed is increased as well. In 2010 a flash flood increased flow in the Virgin River from about 60 cubic feet per second (2 cubic meters/sec) to 1200 cfs (35 cubic meters/sec) in only an hour. The calm river you see normally was churning, dark with mud, littered with trees, and up to some of the pedestrian bridges. At this flow rate 30 tons of water pass a point on the stream bank each second. Such powerful, turbulent, and chaotic flash floods carry mud, sand, large rocks, and trees, and can even move boulders along stream beds. This 'load' is the tool that digs out the channel. More erosion may occur during one flash flood than otherwise may happen in a year. The canyons of Zion are mostly carved by thunderstorms, not by drip, drip, drip.

Erosion cuts narrow, deep canyons in hard uniform rock with no fractures or planes of weakness, such as the Navajo sandstone. Some canyons are so narrow they are called "slot canyons." The Narrows of the Virgin River in Zion are a perfect example; in places the canyon is less than 15 m (50 feet) wide, and yet hundreds of meters (feet) deep. In softer rocks such as near Springdale the same river leaves wide valleys behind. Two factors cause this: weaker, fractured rocks on slopes above the river can slide or slump down into the river and be washed away, and the river can move move from side to side (in geological time), scouring out a wide valley floor. Weak rocks can't support tall cliffs and narrow canyons.

The dramatic landscape of Zion National Park is a combination of thick, colorful, and durable sandstones, broad and high uplift, and powerful erosion of the rocks by rivers and streams.