Snow Canyon State Park

Geology Group Tour
Friends of Snow Canyon State Park

Note: *Blue, italic text represents optional text for answering advanced questions.*

Stop #1 – Upper Galoot Parking Lot: The Navajo Sandstone

- Geologically, the centerpiece of Snow Canyon State Park is the Navajo Sandstone Formation. It was named in 1917 by the first geologist to study the formation in detail in Navajo Indian Country, Arizona.
- This formation prominently outcrops as towering cliffs, buttes, landscapes and colorful canyons across southern Utah and northern Arizona, and into Colorado. It dominates the landscape of Zion National Park, Capitol Reef National Park, Grand Staircase-Escalante National Monument, Glen Canyon, and Canyonlands National Park.
- It forms all of the massive cliffs enclosing Snow Canyon and all of the white and red outcrops on the valley floor – everywhere you look you see the Navajo Sandstone, except where it is covered by black lava, the only other rock type in Snow Canyon.
- The Navajo Sandstone is a terrestrial sedimentary rock – which is any rock that was originally formed by sediment, such as sand, silt, or clay, that was carried from mountains over great distances by streams, rivers and wind, and deposited in valleys or on vast plains by river channels, floods, and wind.
- The sediment that formed the Navajo Sandstone was wind blown sand that accumulated in sand dunes over a ten million year period, hence the Navajo Formation is entirely sandstone rock. There are other types of sedimentary rock found in the St. George region, but none of those rocks are exposed in this part of the canyon.
- The thickness of the Navajo Sandstone below the canyon floor is about 800 feet. About 1,500 feet of the sandstone has been eroded from where we stand. We know this because the top of the white Navajo cliffs to the north are 1,500 feet higher than we are here. Together with the 800 feet of sandstone beneath us, the total thickness of the formation before erosion sculpted this beautiful canyon was at least 2,300 feet.

Stop #2 – Petrified Dunes: Navajo Sandstone – Crossbedding

- Cross the Park road and walk to Petrified Dunes outcrop
- The most distinctive feature of the Navajo Sandstone reflects its original deposition as sand dunes.
- On the wall of the massive outcrop before us, notice how the thin layers of the rock, called beds by geologists, are organized in roughly parallel sets of beds inclined in different directions: the upper set has mostly horizontal beds, the middle set consists of beds that are inclined downward to the left, and the lower set is more steeply inclined downward to the left.
- Each of the three groups of beds is called a crossbed set.
- **Please refer to the first page of your handout. The upper photo** illustrates the three major crossbed sets that make up much of this outcrop of Petrified Dunes.
- **The lower photo** illustrates the inclined beds of the middle crossbed set. If you look at the crossbed set closely, there are actually hundreds of the thin inclined beds, as we'll see later.
- Crossbed sets are the hallmark of sandstone rock formations formed by sand dunes. They are everywhere in this formation.
- Each crossbed set represents the leading slope of a single sand dune that migrated very slowly in the direction of the downward slope of the inclined beds in the set.
- Wind blown sand dunes migrate on Earth in the same way today at a rate from about 500 feet to 2 miles every 1,000 years.

Stop #2 (cont.) – Navajo Sandstone – Crossbedding (cont.)

Refer to page two of your handout.

- The diagram at the top of the page illustrates how sand dunes form.
- Dune formation starts with strong winds that lifts sand grains from the back of a dune and carries them to the top of the dune in a process called erosion – which means to transport sediment from one place to another place.
- When the wind blows over the top of the dune, the wind velocity diminishes and can't carry the sand anymore, causing the sand to fall onto the crest of the dune.
- Eventually, the volume of sand on the crest becomes unstable and collapses, causing the sand to slide down the front slope of the dune to the bottom until the dune crest becomes stable again. Sort of like an avalanche.
- The process then starts over.
- Each time a dune crest collapses and slides down the dune face, it leaves behind a thin inclined bed of sand that will ultimately become preserved with thousands of other beds as a crossbed set in sandstone rock.

Stop #2 (cont.) – Navajo Sandstone – Crossbedding (cont.)

- Notice on the diagram the two red rectangles connected by a red arrow. The inclined beds within the red rectangle on the left, that is on the dune face, are the only beds that remain in place after the wind has pushed the sand dune along the desert floor.
- Another way of stating that is: erosion at the back of the dune leaves behind only the inclined sand layers that originally formed on the leading toe of the dune.
- Later, when another dune migrates over the same place, it too will leave behind only the inclined sand layers of its forward slope.
- These are the layers reflected in the Navajo Sandstone as crossbed sets.
- Compare the photo of the outcrop to the diagram. Notice that the middle crossbed set in the photo matches exactly the crossbed set at the bottom of the diagram. The paleo wind direction at the time the middle crossbed set was formed is deduced from the direction of the inclined beds, and is to the south in the outcrop.
- Wind direction changes locally over long periods of time. When that happens, successive crossbeds sets will incline in the direction of the wind shift.
- Looking at the outcrop before us, it appears that the beds in the top crossbed set are inclined toward us, which is why they are horizontal, indicating the wind was blowing the sand dune to the east.

Stop #3 – Composition of the Navajo Sandstone

Hike to base of Petrified Dunes

- More than 90% of the Navajo Sandstone consists of very small sand grains of the mineral quartz.
- Quartz is one of the most abundant minerals on Earth because it is a major constituent mineral of the igneous rock granite, one of the most abundant rock types on Earth. This tells us that the sand in the formation was from a much older granite rock formation.
- Very small numbers of other mineral grains in the sandstone include feldspar, mica, zircon and, especially, iron-bearing minerals.
- The sandstone is well-sorted, which means that all of the sand grains are the same size, that is fine-grained sand up to only 2/10th of a millimeter in diameter.
- The surface of this sandstone is rough to the touch; as you would expect, just like sandpaper. Despite that, the very tiny quartz grains are rounded, meaning that they are close to spherical in shape and have no angles or corners.
- Roundness is an indicator of the degree of abrasion of the sand grains and specifically tells us that the sand grains in the Navajo Sandstone have traveled a long time and over great distances by rivers, streams and wind to become rounded.
- For ten million years the sand dunes piled up to more than 2,500 feet across a vast area, all of which in turn was buried by another 5,000 feet of different sediment types over a period of 150 million years; the weight of the overlying sediment compacted the sand until all grains were touching other grains.
- However, like putting baseballs in a box, gaps remained between the well-rounded sand grains. The gaps impart a porosity, that is empty space, to the sandstone which ranges from 10% to 30% of the total rock volume. That's why this sandstone is an important regional water aquifer. St. George City operates several water wells in the northwest part of Snow Canyon.
- As the Navajo sand dunes were being buried and compacted by overlying sediment there was a regional water table at shallow depths that filled the pores between the sand grains with groundwater.
- The interaction between the groundwater and the small amounts of the other minerals formed cements that bound the sand grains to each other under pressure of burial of the overlying sediments to form the solid rock we see here today.

Stop #4 – Weathering Cracks – Elephant Skin Pattern

Hike to flat overlook of west wall

- Another interesting feature of the Navajo Formation are the cracks that form polygons on some of the flat surfaces and slopes of the formation.
- You can see these cracks everywhere. Notice how they are superimposed on the bedding within the crossbed sets. From a distance the polygons sometimes resemble an elephant's skin.
- The fine cracks are up to 1 foot deep and form four, five, and six-sided polygons.
- They are called weathering cracks because they only occur on rock surfaces exposed to weather.
- During hot summers, the surface of the sandstone is subjected to daily temperature increases of up to 77 degrees Fahrenheit, which causes the rock on convex surfaces to expand. Relatively minor rainfall events on summer afternoons then cause sudden, drastic cooling of the sandstone near the surface of up to 60 degrees Fahrenheit, creating thermal stresses that open the small cracks. Very, very slowly over time the cracks grow into each other to form the polygons that are 4-, 5-, and 6-sided on flat surfaces like we are standing on.
- On steeper sandstone slopes, such as the slope to our east, weathering cracks tend to form mostly four-sided polygons.
- Over time rainwater seeps into the cracks causing granular disintegration of the sandstone that widens the cracks at the surface.
- This widening is more pronounced on steep outcrop slopes than on the flat surfaces, because of the erosive effect of rainwater running down steep slopes.

Stop #4 (cont.) – Joints

- But there are other much larger fractures in the Navajo Sandstone.
- Looking southwest across the valley, on the west wall of Snow Canyon you can see prominent vertical fractures in the tall sandstone cliffs.
- Those fractures are called joints by geologists and are caused by extension of the Earth's crust over a large region.
- Some geologists attribute the joints to the San Andreas Fault in California. Since about 250 million years ago, oceanic tectonic plates had been subducting beneath the entire west coast of North America. These plates exerted an eastward "push" on the continent, which kept the interior of the North America plate in a state of compression, and which uplifted the many mountains along the west coast.
- At roughly 17 Myr ago, subduction along the coast of central and southern California ceased and was replaced by lateral northwestward movement of the Pacific tectonic plate along its border with North America to create the San Andreas fault.
- As the Pacific plate slowly slides northwestward away from the interior areas of North America, it imposes an extensional force on the North America interior.
- Because the Navajo Sandstone is a brittle rock, the crustal extension of the previously compressed sandstone caused it to fracture, thus forming the joints.
- The joints occur in northeast trending sets, are roughly parallel, unevenly spaced, and can extend for several miles.
- **The bottom photo on page two of your handout is an aerial view of the jointed rock mass across from us.** The red arrow marks the spot where we now stand and the direction of our view. The parallel joints are pervasive throughout the rock mass of the west wall.
- Finally, notice that rainwater has exploited the joints to form deeper channels that separate canyon walls into a series of columns.

Stop #4 (cont.) – Desert Varnish

- Note the dark stains on the weathered surfaces of the vertical sandstone cliffs.
- The stain is known as desert varnish because it is most common in arid environments; however, it occurs in other environments as well.
- In general, the varnish forms when moisture from rain, fog, dew, and snow reacts with clay particles and dust on the rock surfaces.
- The precise reactions to form the desert varnish are debated.
- Some researchers suggest that varnishes form inorganically when iron and manganese are leached from dust grains and clay particles into water and fog droplets on the rock face to precipitate iron and manganese oxides that stain the rock red and black. The residual dust and clay grains are then removed by rain and wind.
- Another group of researchers claim that desert varnish has a biological origin, that is, the separation of iron and manganese oxides from dust and clay requires the presence of bacteria.
- Most desert varnish is dark brown to black in color.
- The darker color is attributed to a greater abundance of black manganese oxide that masks the red color of iron oxide.
- It can take as long as 200,000 years to form a black stain on rock surfaces in the desert.

Stop #5 – Navajo Sandstone – Bounding Surface

Walk to bounding surface between massive crossbed sets.

- Here is a dramatic boundary between two large crossbed sets separated by what geologists call a bounding surface.
- Bedding in the lower, older crossbed set is inclined steeply down to the south, indicating that the sand dune migrated to the south.
- Bedding in the upper crossbed set is generally horizontal, indicating that the sand dune migrated in a westward direction long after the lower dune migrated away from this area.
- Notice how thin the individual beds are, each representing a single landslide event of sand falling from the crest of the dune to the toe of the dune.
- Notice again the parallel weathering cracks that uniformly form square polygons on the steep erosional slope of the upper crossbed set. Only a few weathering cracks cross the bounding surface. That’s because of the acute angle at which the lower beds contact the horizontal upper beds.

Stop #5 (cont.) – Navajo Sandstone –Moki Marbles & Ironstone Boulders

- By now you all have noticed the rock spheres laying around us as well as the several blocks of dark rock.
- The spheres are called Moki Marbles and the blocks are called ironstone.
- Both are from the Navajo Sandstone and I’ll talk about them, and the color of the sandstone, when we get to the top of this outcrop.
- But first, I’ll explain how the Navajo sandstone rock was formed and where all of the sand came from.

Stop #5 (cont.) – Origin of the Navajo Sandstone – Source of the sand grains

- Where did the Navajo sand come from and how did it get here?
- **Let's refer to the upper map on page three of your handouts**, which is a paleogeographic map of the United States as it may have looked from 220 million to 190 million years ago.
- Utah it outlined in black and Snow Canyon is marked by the red dot.
- Note that California had not yet been fully formed on the western margin of the US. Also, the east coast of the US was joined to North Africa along the Appalachian Mountains as a result of the amalgamation of Earth's continents into the supercontinent of Pangea.
- The blue arrows indicate large westward flowing rivers and their tributaries carrying huge volumes of sediment from as far away as the southern Appalachians, which at the time extended into southern Texas, westward into a sedimentary basin, circled in white, that stretched from Wyoming, southward across Utah, and well into Arizona.
- *The sedimentary basin had formed due to the uplift of the high mountains along the continental margin.*
- As the sediment filled the basin, it slowly sunk downward, to subside as geologists say, *due to the weight of the sediment and downward flexure of the crust due to the weight of the adjacent mountains* which allowed accommodation space for more sediment.
- After thirty million years the sediment-filled basin had become a vast, flat, and featureless plain during a time of semi-arid climate.

Stop #5 (cont.) – Origin of the Navajo Sandstone – Navajo Erg

- **Now let's look at the second paleogeographic map on the handout.**
- By 190 million years ago, the climate in the southwestern US had become extremely arid, one of absolute and relentless drought.
- Strong, persistent winds from the north easily lifted the small quartz sand grains brought into the northwestern US by the large rivers and blew them back onto the vast, hot plains of the sedimentary basin.
- These conditions persisted for 10 million years to create an enormous sea of sand dunes, called an erg, that overwhelmed and completely covered the river system that had been filling the basin. The erg reached thicknesses up to 2,500 feet of buried sand dunes, stretching from Wyoming to southern Arizona and from western Colorado and New Mexico to Nevada.
- **The** Navajo Erg is one of the largest dune fields in the history of Earth.
- The sand sea was subsequently buried by 5,000 feet of younger sediments over the next 120 million years until the sand dunes were compacted and cemented into the petrified dunes we see here today.
- Then, starting about 70 Ma, tremendous tectonic forces along the continental margin began to uplift the buried sedimentary basin and all the sedimentary rock in it. As the uplift continued in fits and starts, weathering and erosion removed the 5,000 feet of sedimentary rocks until the Navajo Sandstone became exposed at the surface as we see it today.
- *Most of that erosion occurred in the past 5.3 million years when 175,000 square miles of rock was removed by the Colorado River and its tributaries to the Gulf of California from the uplifted sedimentary basin.*

Stop #5 (cont.) – Summary of Why the Navajo Dune Field Formed

In summary, just like the dune fields on Earth today, the ancient Navajo dune field required several critical factors to develop:

1. An arid climate. *The early Jurassic was a time of extremely* ***arid climate*** *conditions – it was very hot and there was almost no rainfall, so that virtually no plants were able to survive in this region;*
2. A flat landscape. *Millions of years of erosion prior to onset of the arid climate had removed all mountains and other large landscape features to create vast, flat plains and landscapes on which the dunes could form and migrate;*
3. A steady source of sand *was supplied by large rivers that originated in ancient mountains far to the east.*
4. And strong, persistent winds. *After the rivers deposited the sand, strong persistent winds from the and north northwest blasted it back to the southeast into the dune field.*

Stop #6 – Color of the Navajo Sandstone:

Hike to the "pond" of Moki Marbles on top of Petrified Dunes

- Here is a great place to talk about the color of the Navajo Sandstone, the Moki marbles, and the ironstone blocks.
- Let's start with color.
- When the sand dunes were migrating across the Great Navajo Erg between 190 and 180 million years ago, the quartz sand grains were white, the color of quartz.
- Remember that quartz grains comprise more than 90% of the sand in the formation. However, among the small percentage of other mineral grains, were iron-bearing *silicate* minerals (*pyroxenes, amphiboles, biotite*) that originated from the same igneous rocks of the Appalachian Mountains that provided the quartz.
- As the older sand dunes became buried below the ground by overlying younger sand dunes, the sand grains were exposed to groundwater, which in the presence of oxygen in the atmosphere, reacted with the small amounts of iron-bearing minerals *to remove electrons from the iron atoms, that is to oxidize the iron atoms, and add oxygen,* to form a red-colored iron oxide *mineral hematite (sometimes goethite)* also known as rust, in the same manner that rust forms on a nail left out in the rain. *(The reaction between dissolved oxygen and iron-silicate minerals aggressively removes electrons from, and adds oxygen atoms to, the iron atoms).*
- Eventually, the *iron oxide* rust adhered to and covered all the white quartz grains with a thin, red, paint-like coating. *The amount of hematite needed to coat all of the quartz grains is small because iron is a powerful pigment.*
- After the three to four thousand feet of sand dunes were buried by several thousand feet of younger sediments, the quartz sand grains were compacted and cemented into a red sandstone.

Stop #6 (cont.) – Color of the Navajo Sandstone

- Well, that's great George, but why is the Navajo Sandstone white in the massive outcrops to the north, all red in the canyon to the south, and white and red in the middle? Good question.
- The red-colored Navajo Sandstone remained buried by thousands of feet of younger sedimentary rocks for more than 100 million years before tectonic forces along the margin of the North America exhumed the sandstone to near the surface during several episodes of uplift of the Earth's crust, starting about 70 million years ago.
- Then, about 20 million years ago, a large body of magma rose from the mantle through the sedimentary rock layers, including the still-buried Navajo Sandstone, to form the Pine Valley Mountains, located a few miles northeast of here. *Some geologists theorize a much older date of bleaching.*
- The magma released large volumes of carbon dioxide which mixed with small amounts of methane gas in the sandstone pore spaces which acidized the groundwater around the magma body.
- Over several million years, the acidized groundwater percolated into the porous Navajo Sandstone where it dissolved and removed the rust-colored stain from the quartz sand grains (weakly acidized water is a reducing agent that removes oxygen from the iron atoms while adding an electron) returning them to their original white color. Sort of like bleaching the sandstone.
- However, the groundwater only moved so far into the sandstone before the carbon dioxide in the water diminished and the water lost its ability to remove the red stain from the sand grains.
- The interfingering of the layers of white sandstone into the red sandstone in the middle portion of the west wall represents the farthest extent of the acidizing groundwater that originated near the magma intrusion in the Pine Valley Mountains.
- The separate fingers of bleached sand represent intervals where the porosity of the sand was slightly greater, thus allowing easier groundwater flow through them.

Stop #6 (cont.) – Moki Marbles

- Bleaching the sandstone was also responsible for the formation of the Moki marbles and the ironstone.
- The chemical reaction that dissolved the red paint on the sand grains also released free iron *(ferrous iron, Fe^{2+})* into the groundwater. Being heavy, the free iron settled downward into underlying sandstone layers *where it re-oxidized*, thereby "enriching" the iron *oxide* content in the unbleached layers, creating a darker red to brownish color, *and sometimes re-staining bleached layers from white back to red*. We are standing on an example of iron enriched sandstone beds, which are much darker than the red sandstone beds surrounding this area.
- As the iron enrichment increased, some of the free iron precipitated out of the groundwater in the tiny pore spaces to form spheres *of iron carbonate (siderite) and ferrous calcite,* called concretions by geologists.
- Each concretion began as a small speck, or nucleus, in the sandstone *e.g. as a nucleus of iron carbonate (siderite) onto a clay particle or sand grain* that over time grew into a round concretion whose size was determined by the amount of iron in the surrounding ground water *by forming concentric rings of the iron carbonate (siderite - $FeCO_3$) that fills the pore spaces of the sandstone.*
- Sometimes the concretions grew into each other, forming knobby clumps of spheres.
- *Later, acidic groundwater oxidized the concretions from the outside inward to form goethite, an iron hydroxide mineral, that itself forms a hard rind around the concretion.*
- The concretions are harder than the sandstone, so that when the sandstone rock around the concretions is weathered and eroded away at the surface by wind and water, the hard concretions become exposed as you see here. *It is the hard rinds that resist weathering.*
- When the concretions weather completely out of the rock, they are called Moki Marbles.
- Moki is a Hopi Indian word that means "dear departed ones." According to Hopi tradition, spirits of the dead would play with the marbles at night, leaving them behind in the morning to reassure the living that they are happy in the afterlife.

Stop #6 (cont.) – Ironstone

- Extremely **high iron enrichment** in some layers resulted in multiple generations of **iron** *and manganese* **oxide cement filling** the pore spaces of the sandstone, to **produce the dark brown to black**, very hard **ironstone**, that occurs in slabs up to several feet thick, isolated pods, and small irregular shapes in many of the outcrops here in Snow Canyon.
- Because the ironstone is so **hard**, the softer sandstone rock surrounding it weathers and erodes away, leaving isolated blocks of the ironstone layers.

Stop #7 – Lava Flows

Hike to East Edge of Big Galoot overlooking canyon floor

- This is a great spot from which to turn our attention to the lava exposed in Snow Canyon below us and on top of the bench above the canyon wall opposite us.
- Before I go farther, I'd like to make a few comments about how the lava was formed – please refer to the diagram at the top of page 4 of the handout.
- Lava is an igneous rock made from magma, which is molten rock.
- The magma rises from the molten mantle of the Earth up through fractures in the Earth's crust and forms giant magma chambers beneath the surface of the crust.
- Over time, some of the magma in the chamber exploits weaknesses in the rock above the chamber and makes its way to the surface. Magma that flows onto the surface is called lava.
- Magmatic eruptions at the surface usually forms a volcano composed of layers of lava and volcanic ash.
- Sometimes, the magma finds only a small fracture in the crust, known as a fissure vent, through which the lava flows onto the ground without forming a volcano.
- In this region, most fissure vents emit explosive gases that blow small blobs of lava high into the air, which cool into cinders that fall to the ground to form small volcano-like features called cinder cones.
- All of the lava flows and cinder cones in this region were formed by fissure vents, which typically produce only one eruptive cycle that lasted less than a year to as much as a few tens of years.

Stop #7 (cont.) – Lava Flows

- There are 24 fissure vents with associated cinder cones and 19 lava flows along the Santa Clara River, stretching from just north of Pine Valley, down past Veyo and Gunlock, and all the way to Shivwits. A distance of nearly 30 miles.
- There are another 14 fissure vents with cinder cones on the southwest flank of the Pine Valley Mountains and 10 lava flows that flowed down slope from the mountains, some flowing all the way to St. George - a distance of 20 mi.
- Among the latter group is the Snow Canyon Lava Flow, the black rock below us, and the Cedar Bench Lava Flow, which forms the caprock on the bench above the canyon wall opposite us.
- All of the lava flows I've mentioned are a type of volcanic rock known as basalt and range from 33,000 to 2.5 million years old.

Stop #7 (cont.) – Cedar Bench Flow

- To discuss the two lava flows in Snow Canyon, refer to the lower diagram on page 4 of your handout.
- Let’s start with the lava flow that forms the black caprock on Cedar Bench, indicated by the yellow arrows on the diagram.
- The lava flowed from fissure vents at two overlapping cinder cones located about 5 miles northeast of here about 1.1 million years ago. The lava flowed down a shallow, narrow, stream valley eroded into the Navajo Sandstone, filling the valley as the basalt lava solidified into rock.
- The basalt flowed down the stream all the way to St. George where it also forms the caprock of Airport Mesa.
- That valley was the ancestral Snow Canyon. In other words, 1.1 million years ago the bottom of Snow Canyon, now below us, was below the Cedar Bench caprock across the way.
- Basalt is a very hard rock, much harder than the Navajo Sandstone, and much more resistant to weathering and erosion by wind, rainwater, and streams than the sandstone.
- After the basalt hardened, a new stream developed along the contact between the hard basalt lava flow and the softer sandstone wall that confined it on this side of the flow. Over the past 1.1 million years the erosive power of the stream completely removed the sandstone wall and carved out Snow Canyon as we see it today while the basalt has remained at its original elevation.
- Cedar Bench and Airport Mesa, with their basalt caprock, are classic examples of what geologists call an “inverted valley.” The lava that filled a stream valley 1.1 million years ago is now, ironically, the top of a ridge. Refer to the diagram of page five of the handout: The top figure illustrates a lava flow filling a wash in the Navajo Sandstone where it solidifies; the bottom figure shows the Navajo Sandstone after 1.1 million years of erosion, leaving the lava flow as an inverted valley mesa.

Stop #7 (cont.) – Santa Clara Flow

- The Santa Clara Lava Flow in Snow Canyon is much younger.
- Refer again to the lower figure on page 4.
- About 33,000 years ago lava flowed from a fissure vent located just on the other side of the white sandstone mountain to the north.
- The Santa Clara cinder cone now sits above the solidified fissure vent.
- The lava flowed down into Snow Canyon through a pass in the sandstone at the head of the valley. It then cascaded through several gaps in the sandstone, rejoining to form one main flow in the lower part of the canyon.
- The flow continued out of the canyon to a point 4-1/2 miles farther to the south in the town of Santa Clara, stopping just short of where Harmons is located today.
- I'll point out a few features about the Santa Clara lava flow at a later stop where we can see it up close.

Stop #8 – Large Crossbed Set

Hike to Butterfly Trail and along ravine separating the lava flow from the Navajo Sandstone outcrop and stop at massive crossbed set

- This outcrop is a single, very large, steeply inclined crossbed set created by an immense sand dune.
- The top of the crossbed set is out of view higher up this cliff.
- There are thousands of thin, individual beds of the crossbed set extending from the top of the outcrop to the bottom of the ravine – a distance I measured at about 60 feet.
- Each thin bed represents an avalanche of sand that slid down the face of this dune from its crest.
- Now let’s hike along the ravine to find the bottom of the crossbed set.

Stop #9 – Large Crossbed Set, Iron Enrichment

Hike to where the crossbed set disappears beneath alluvium.

- Here is the bottom of the crossbed set, which I estimate to be a thickness of about 150 feet. Given that crossbed sets represent only the forward toe of the dune, the height of the dune was probably in excess of 500 feet.
- This is the largest dune set that I've seen in Snow Canyon.
- This is a great place to see the effects of iron enrichment I spoke of earlier, as indicated by the concentration of iron concretions at the bottom of some of the crossbed sets above the giant dune. The bounding surface between the two crossbed sets prevented further downward migration of the iron enriched water.
- Notice also that the entire outcrop here is a darker red than everywhere else. This is also an effect of iron enriched groundwater.

Stop #10 – Butterfly Rock

Hike up to Butterfly Rock

- Butterfly Rock is formed by two large slabs of ironstone that fell from the iron enriched layer in the cliff above us.
- *Pointing to massive outcrop we just passed*: This entire outcrop will eventually erode away, leaving the Santa Clara Lava Flow behind us as an inverted valley.
- By that time, the top of the lava flow will have been weathered and eroded into a planar surface, as is the Cedar Bench Lava Flow today.

Stop# 11 – Santa Clara Lava Flow

Hike across the Santa Clara Lava Flow stream

- Here is a good location to look closely at the Santa Clara lava flow.
- Looking north, note that the surface of the flow is almost always uneven, blocky and jagged, a type of solidified lava known as aa, which is a Hawaiian name for blocky lava. Occasionally you will notice pahoehoe, a Hawaiian name for smooth, ropy, and billowy lava, but it is common only where the flow spills into the canyon north of here.
- The color of the lava ranges from a dark brown to the much more common black.
- The lava has an iridescent sheen on surfaces protected from weathering and commonly has small cavities called vesicles, that form in rapidly cooling lava flows when gas separates *exsolves* from the liquid lava to form bubbles.
- Due to the hardness of basalt, the flows have weathered very little in the past 33,000 years.
- Now let's look at the lava in this wash. Here the basalt has been abraded by sand-laden seasonal floods to form a smooth, polished surface with a distinct gray color.
- The vesicles are much more easily seen in this rock and in places are elongated in the direction of the flow of the lava.
- The flows are typically 10 to 30 feet thick, but locally thicker where they fill topographic lows.

Stop# 11 (cont.) – Santa Clara Lava Flow – Lava Tubes

- A well-developed lava tube is in the Santa Clara lava flow.
- Lava tubes form as the surface of the flow cools and hardens, thus insulating the underlying molten lava.
- As the lava drains from the tube, a cave forms.
- Weathering eventually leads to a gravity collapse of the roof, which allows access to the tube-shaped cave.
- The largest tube-cave collapse structures in the park measure about 100 feet by 150 feet, while the cave entrance measures about 15 feet by 25 feet.