Note: Numbers on the sketch map of the trail (figure 1) are linked to the descriptions that follow. In the text describing each stop, figures (as indicated in italics) are used to clarify explanations. Photos (as indicated in bold) show the features described at each of the stops.

Figure 1. Sketch map of the Sipapu Trail in Natural Bridges National Monument (map is not to scale).
INTRODUCTION

OVERVIEW OF TRAIL: The Sipapu Bridge trail takes you from the rim to the bottom of White Canyon. It is an excellent place to hike through a thick section of the Permian Cedar Mesa Sandstone, the formation in which all of the bridges in Natural Bridges National Monument formed. Along the trail you will see most of the characteristic features of the Cedar Mesa, including sedimentary structures and trace fossils that indicate deposition in non-marine eolian and fluvial floodplain environments.

TO USE THIS GUIDE: Begin your hike at the interpretive sign at the top of the Sipapu Bridge hiking trail. As you hike down the trail keep your eyes open for rock faces and surfaces that look like those shown in the pictures. The numbered stops are keyed to the numbers on the sketch map of the trail, which is not to scale. Some of the stops are very close together, while some are farther apart.

STOP 1 The trail begins on slickrock, a common name for the smooth, soil-free rock surfaces that are found in the canyon country. This rock is sandstone and it was deposited approximately 270-260 million years ago (during the early part of the Permian Period of geologic time). During the Permian Period, the west coast of North America ran approximately north-south through central to western Utah. Sand grains that make up the sandstone were blown into the Natural Bridges area from the coast by onshore winds. At that time, wind-blown sand dunes were present in this area, and the region probably looked something like the modern Sahara Desert. The canyon that you see in front of you and the natural bridges that span the canyon probably formed within the last 10 million years, long after the sand grains were cemented together into solid rock.

STOP 2 Sand dunes continually move while they are forming. Although the grains of sand in the rock on which you are walking are now cemented together, at one time they were part of dunes that actively migrated downwind. Cross-bedding is a sedimentary structure that results from the migration of dunes. Cross-bedding forms when layers of rock are deposited at angles, rather than horizontally. In desert dune fields, cross-bedding is produced when sand grains blow up the back (or windward face) of a dune and are then deposited on the relatively protected front (or lee face) of a dune. You can see (Stop 2, Photo 1) cross-bedding in rocks across the canyon; the nearly parallel lines in the rock that dip from left to right at about $20^\circ$ from the horizontal (parallel to the arrow) are...
cross-beds. The cross-bedding is actually a series of fossilized slipfaces that formed on the lee side of a dune. High-angle cross-bedding, like that seen here, is typical in dunes that are deposited by wind-blown (rather than water-laid) sand. The direction in which the cross-beds dip downward is the same as the direction in which the dunes migrated when they were active. An active wind-blown sand dune is shown in the figure below (Stop 2, Figure 1).

Although cross-bedding is a major product of dune movement, other features are also present here that indicate the sand was moved by wind. One example, grainflow stratification, forms when part of the downwind side (slipface) of a dune avalanches. If you’ve ever walked across the face of a modern sand dune you have probably produced little avalanches wherever you stepped. Avalanches happen even when no one steps across a dune; the face of the dune simply becomes too steep and it collapses (Stop 2, Figure 2). Avalanche deposits are called grainflow stratification when they are found in rocks.

Stop 2, Figure 1: Example of an active dune showing cross-bedding, the active slipface, and the direction of migration.

Stop 2, Figure 2: Example of a dune with an oversteepened slipface before an avalanche and a grainflow stratum produced by an avalanche.
The photograph (Stop 2, Photo 2) shows grainflow stratification exposed on slightly inclined surfaces of rock along the trail. The arrows in the photo point to the top and bottom of a single grainflow stratum. Note that grainflow stratification thickens and thins in three dimensions.

**Stop 2, Photo 2: Grainflow stratification.** In the photo, the scale shows centimeters (each white and black box on the left side of the scale is one centimeter high) and inches (each white and black box on the right side of the scale is one inch high).

**STOP 3** If you walk down the steps cut into the rock and look back at the rock face you can see “pinstripe laminat**ion” that gives the rock a flaky appearance. Pinstripe laminat**ion is produced when wind-blown rip**ples migrate downwind. Each lam**ina, or layer, is formed by a single ripple. This type of layering (or stratification) is technically known as translatent strata (Stop 3, Photo 1). Grains of sand are slightly coarser at the top of each lamina (or pinstripe) relative to the size of grains at the base of each lamina. Each lamina may be only a few grains thick, so you may need to use a magnifier to see the change in grain size. The arrows in the photo point to the bases of three layers of translatent strata.

**Stop 3, Photo 1: Translatent strata.**
STOP 4  At the base of the next set of stone steps, just before the trail makes a sharp turn to the right, traces of wind-blown ripples can be seen. These ripples have very low amplitudes (they are short) and long wavelengths (they are spaced far apart) compared to ripples that form under water (Stop 4, Figure 1). The crests of the ripples show up right on the trail; look at the straight, slightly raised lines in the rock. The arrows in the photo point to two ripple crests (Stop 4, Photo 1).

STOP 5  After you round the corner on the trail, look back to the top of the trail (Stop 5, Photo 1). You can see cross-bedding, and can possibly imagine how all the layers reflect the movement of dunes. The arrow in the photo points to a surface that represents the contact between two dunes. The contact formed when one dune migrated across the top of the other dune. Whenever one dune migrates up onto the back of another dune, the buried dune is no longer exposed to the wind. Once a dune is out of contact with the wind it can be-
gin to be lithified (made into rock). After dunes are buried, rainwater and groundwater move through the dunes precipitating minerals such as calcite, quartz, and gypsum. Where these minerals grow they cement sand grains together, and the sand becomes rock.

STOP 6 At this site you are walking along the top of a single cross-bed (Stop 6, Photo 1).

While you’ve already seen evidence of dune avalanches and ripple migration, a third type of stratification (grainfall stratification) is present here. Grainfall stratification forms when sand grains blow up the back of a dune and then, when they reach the lee (downwind) side of the dune and are somewhat protected from the wind, they fall back onto the surface of the dune (Stop 6, Figure 1). The arrows on the second photo for Stop 6 point to the tops of two layers of grainfall stratification (Stop 6, Photo 2).

Grainfall stratification looks similar to grain-flow stratification (the stratification produced by avalanches) except that it does not thicken and thin in three dimensions. Instead, each lamina has approximately the same thickness everywhere you see it, although the thickness of an individual lamina can differ greatly from that of its neighbors. Grainfall strata are generally thicker than pinstripe laminae.

Stop 6, Photo 1: View of the trail ahead from stop 6.

Stop 6, Figure 1: Wind blowing sand grains up the windward side of a dune and depositing the sand on the lee side of the dune to produce grainfall stratification.

Stop 6, Photo 2: Close-up view of grainfall stratification.
STOP 7  Here are more wind-blown sand ripples lying along the trail (Stop 7, Photo 1). Arrows in the photo point to the crests of two ripples. The edges of the yellow notebook and black and white photo scale are parallel to the crests of the ripples. At this location you are walking on a single cross-bed surface.

STOP 8  Just before the trail makes a sharp turn to the left, look back towards the parking lot. You can see a single large set of cross-bedding (Stop 8, Photo 1). That is, all the cross-beds trend in the same direction at about the same angle and were formed by migration of a single large dune.

STOP 9  After you make the sharp left turn and walk about 50 feet, look at the cliff face on the left side of the trail. In contrast to the last stop, several sets of cross-beds are present at this location. Each set represents one dune, so several dunes are represented by the rocks at this location (Stop 9, Photo 1).
STOP 10 This stop is located where the trail intersects a red layer that is composed of silt and smaller sized grains of sand than those that made up the dune deposits above. This layer may have been deposited when water flooded the dune field. During times of relatively wet climates, streams flowed from the Ancestral Rocky Mountains (located to the east, approximately coincident with the present-day border between Utah and Colorado) out into the dune field. Although not well preserved at this site, the upper surface of this red layer contains traces of tree roots that indicate that vegetation grew on top of the flood deposit once it was laid down. The tree roots are the bleached, blotchy areas in the rock (Stop 10, Photo 1).

STOP 11 At the base of the metal stairs look out across the canyon toward Sipapu Bridge. The stream in White Canyon once occupied the bottom of the canyon between you and the southeast buttress of the bridge. At that time a sandstone wall existed beneath the present-day span of Sipapu Bridge. Water probably seeped through the wall along the top of a red silty sandstone layer (like the one you just saw). The seepage, along with the action of frost, plants, exfoliation, and gravity continually thinned the cliff until the White Canyon stream broke through the wall. Once the barrier was penetrated, the stream changed its course and straightened its channel by flowing through the wall. The old channel in front of you is now a cutoff meander, that is, a bend in the stream that is no longer used by the stream.

It is important to realize that the White Canyon stream never completely filled this canyon. Instead, the stream continually cut down into the rock, lowered its bed, and deepened the canyon. You can estimate the amount of incision (deepening) of the stream’s channel since the wall beneath Sipapu Bridge was penetrated by comparing the elevation of the base of the abandoned channel to the elevation of the base of the present-day channel. How long ago did the White Canyon stream cut through the wall beneath Sipapu Bridge? We don’t know for sure, but it must have occurred over 1,000 years ago. Organic materials collected along a stream terrace upstream from Sipapu Bridge in White Canyon are about 1,000 years old, and the stream terrace must be younger than the abandoned channel in front of you because the terrace would have been completely submerged when the stream occupied this abandoned meander. An upper limit to the bridge’s age is also poorly defined, but the bridge must be younger than 10 million years. The rock layers exposed in the mesas surrounding Natural Bridges National Monument once extended across the top of the Monument, and they did not begin to be removed until about 10 million years ago. The bridge is most likely between 1.64 million and 10,000 years old. This estimate is based on the observation that Utah’s climate was relatively wet during the Pleistocene Epoch of geologic time (between...
1.64 million and 10,000 years before present). The wetter climate would have resulted in higher than present-day amounts of precipitation. In the White Canyon area, large amounts of precipitation would have resulted in high runoff, and the White Canyon stream would have had additional power to cut through the rock wall that once existed beneath Sipapu Bridge (Stop 11, Figure 1).

About 30 feet down the trail, a yellow-green sandstone layer contains trace fossils. Trace fossils are not true fossils (like shells or bone) but rather are the fossilized traces of an organism’s activity. At this location both horizontal traces, probably formed as small animals crawled along or just beneath the surface, and vertical traces, probably the result of burrowing, are present. The finger in the photo points to a spot just below a horizontal surface that contains many horizontal trace fossils. The arrows point to two of the horizontal trace fossils (Stop 11, Photo 1).

STOP 12 About 30 feet further down the trail similar trace fossils are found in red silty sandstone.

STOP 13 At the top of the first wooden ladder more trace fossils are found (Stop 13, Photo 1). The number of trace fossils in the red silty sandstone layers supports the interpretation that this area was somewhat wet when the red layers were deposited. The arrows point to two horizontal trace fossils.

STOP 14 The first wooden ladder takes you down a steep part of the trail. Note that the wind-blown sandstone is much more resistant to weathering than the red silty sandstone, and that while the red silty
sandstone tends to erode easily, the wind-blown sandstone is more likely to form cliffs (Stop 14, Photo 1).

Looking out across the canyon, you can see dark stains formed by water seeping out of the rock. Note that the water tends to seep out preferentially where there are red silty sandstone layers. This probably occurs because the finer grained red layers are less permeable than the coarser grained wind-blown sand layers. Precipitation that falls on the rock migrates downward through the wind-blown sand layers until it reaches the silty sandstone layers. It is easier for the water to then migrate horizontally out to the side of a cliff than it is for the water to move down through the silty layers. Seeps form where the water flows out of the rock. The water exiting the rock at the seeps carries minerals with it that previously cemented the rock together. Removal of cement at the seeps makes the wind-blown sandstone above the seeps less resistant to weathering and it erodes more easily above the seeps than it does elsewhere.

STOP 15 At the base of the first ladder look around at the blocks of rock that line the trail. Some have mudcracks on them. The arrow in the photo points to a mudcrack that protrudes from the underside of a rock (Stop 15, Photo 1). The cracks once penetrated into underlying sediment, but they were filled with sandstone and now point up and out of the rock because this piece of rock is upside down. This rock, along with several others that lie along this part of the trail did not come from the Cedar Mesa Sandstone. Instead they were once part of the Triassic Moenkopi Formation that forms the upper half of the cliffs that surround Natural Bridges National Monument.
STOP 16 When the trail begins to level off, look down the trail. Note that the sheer cliff protects plants from the intense sun, and the seeps along the top of another red silty sandstone layer provide the plants with water. Even though the cliff looks very solid it is being eroded away. Sheets of sandstone fall off of the vertical face due to the effects of water percolation, stress-release exfoliation, frost wedging, plant growth, and gravity. When water percolates through the wind-blown sandstone above the red silty sandstone layer it dissolves cement from the rock along its path. This causes the cliff to erode more easily directly above seeps as described at Stop 14. Stress-release exfoliation occurs because the cliff, until fairly recently (in geologic terms), was confined by rock that existed next to it in the space that is now occupied by air in White Canyon. When the rock in White Canyon was removed it reduced the pressure on the side of the cliff and the cliff is now responding to the drop in pressure by flaking away into the emptiness. Frost wedging occurs when water in cracks in the rock freezes and expands, widening the cracks. Tree roots and plants also grow in cracks in the rock and pry the rock apart in a similar way. Gravity continually exerts a downward force on the rocks (Stop 16, Photo 1).

In another fallen block at about this point on the trail you can see ripple marks. This block, like the one with mudcracks that you may have seen earlier, came from the Moenkopi Formation. These ripples formed beneath flowing water. Note that they are more closely spaced (shorter wavelength) and taller (higher amplitude) than the wind-blown ripples you saw earlier (Stop 16, Photo 2).
STOP 17 Walk off the main trail to the bridge overlook. The ledge you are standing on formed where soft red silty sandstone eroded away above a hard cross-bedded sandstone. Look across White Canyon toward the north-northwest. Ancestral Puebloan ruins are present along a cliff about 50 feet above you (Stop 17 Photo 1). Like us, the Ancestral Puebloans used the natural benches formed where red silty sandstone eroded back from the cliff to build their granaries, dwellings, and kivas.

As previously mentioned, the red silty sandstone layers were probably deposited when water flooded the dune field. Further support for this interpretation is found in the sandstone above the red layer at this location. Note that the cross-bedding in the white sandstone directly above the red silty sandstone is irregular, wavy, and contorted (Stop 17 Photo 2). This suggests that the dunes collapsed and slumped when they migrated out onto a wet, flooded surface. The arrow in the photo points to a the contorted cross-bedding.

Stop 17 Photo 1: Cliff face containing at least two Ancestral Puebloan ruins.

Stop 17 Photo 2: Contorted cross-beds above a red silty sandstone layer.
STOP 18   About halfway between the bridge overlook ledge and the main trail, stop and look at the southeast buttress of Sipapu Bridge. From here you can see cross-bedding and joints in the buttress (Stop 18 Photo 1). Joints are fractures in the rock along which no movement of the rock has occurred. These joints are, however, sites of concentrated erosion. Water can easily trickle down into the joints, dissolving cement in the rock and providing relatively hospitable places for plants to grow. In winter, frost widens the cracks as water freezes and expands.

STOP 19   Head down the trail toward the bridge. When you see a large boulder on the right side of the trail stop and look around. At this point you are at approximately the same elevation as the abandoned channel, the cutoff meander (Stop 19, Photo 1). This photo of the southeast buttress (with its cross-beds and joints) is taken from approximately the elevation of the abandoned channel.

STOP 20   When you start walking on solid sandstone again you are beginning to cross the mouth of the abandoned channel (Stop 20, Photo 1).

STOP 21   From the top of the highest handrail you can look upward toward the mouth of the old channel. This gives you some idea of the difference in elevation between the modern channel and the abandoned channel. Cross-bedding in the southeast buttress of the bridge is prominent when viewed from this location.
STOP 22  At the base of the highest handrail you can see translatent strata, the pinstripe lamination that forms from wind-ripple migration (Stop 22, Photo 1).

STOP 23  From the ledge at the top of the final ladder, look upward and across the canyon toward the northeast side of Sipapu Bridge. An abandoned stream terrace is located on the side of the cliff (Stop 23, Photo 1). If you can’t quite see it from here, continue hiking down into the modern channel and look back up this trail toward the mouth of the abandoned meander. The old terrace is on the opposite side of White Canyon, but at the same elevation as the mouth of the abandoned meander. At the time that the stream occupied the abandoned meander, it flowed from the mouth of the abandoned meander directly across the trend of the modern channel and then along the abandoned terrace. The abandoned terrace, like the abandoned meander, marks the path of the White Canyon stream at sometime in the past. At that time the deep parts of the modern channel, at elevations below the mouth of the abandoned meander, were still filled with solid rock because the stream had not yet cut all the way down to its present floor. The arrow in the photo points to the floor of the abandoned terrace. Many other abandoned terraces and abandoned meanders are present within White Canyon.
STOP 24  Continue into White Canyon and stand beneath Sipapu Bridge (Stop 24, Photo 1). If you have time, energy, and water, sign your name in the book and continue to hike down the canyon to see Kachina and Owachomo Bridges.

Stop 24, Photo 1: Sipapu Bridge viewed from White Canyon.
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