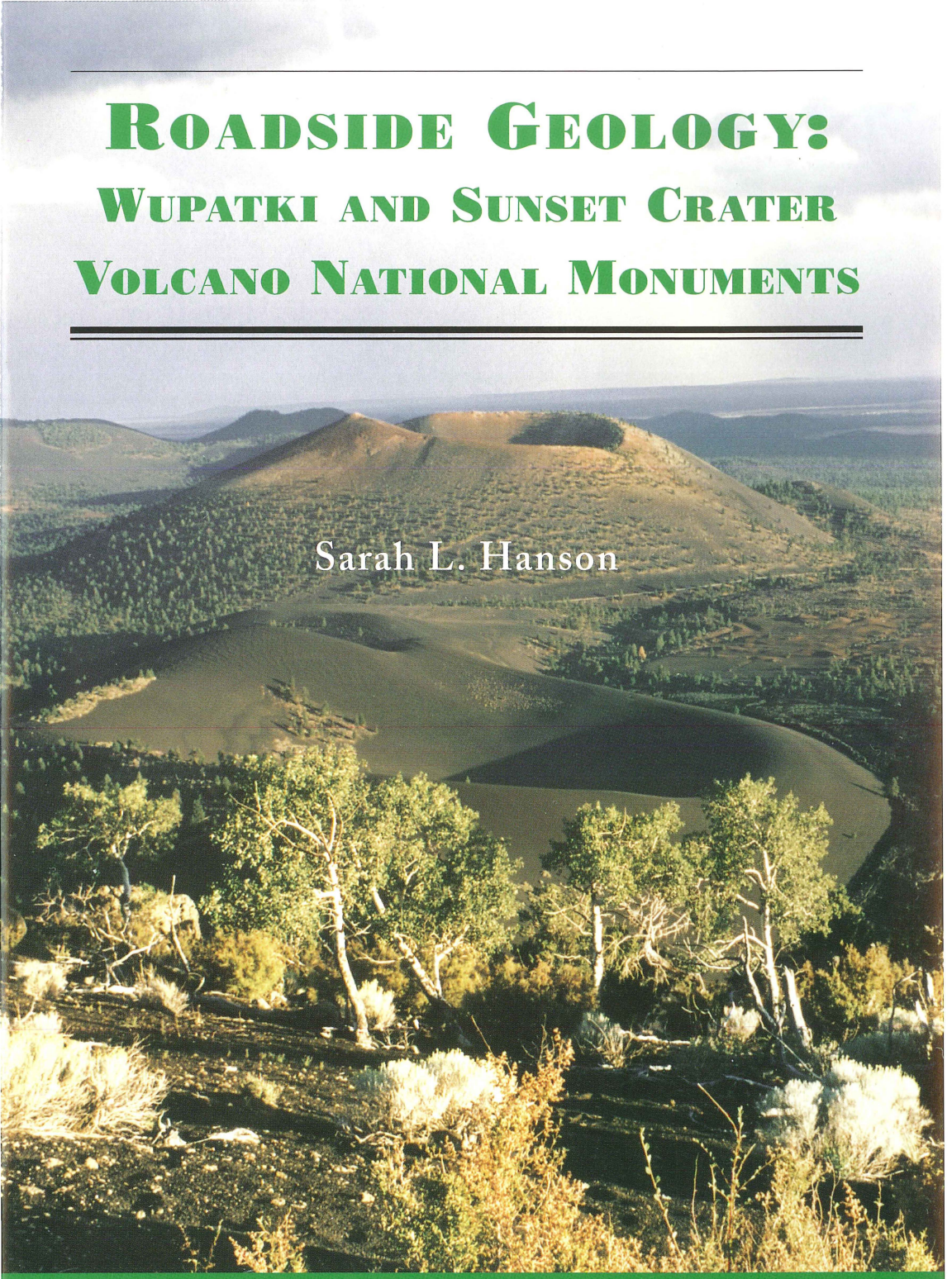
Roadside Geology:
Wupatki and Sunset Crater Volcano National Monuments



Sarah L. Hanson

Arizona Geological Survey
Down-to-Earth 15

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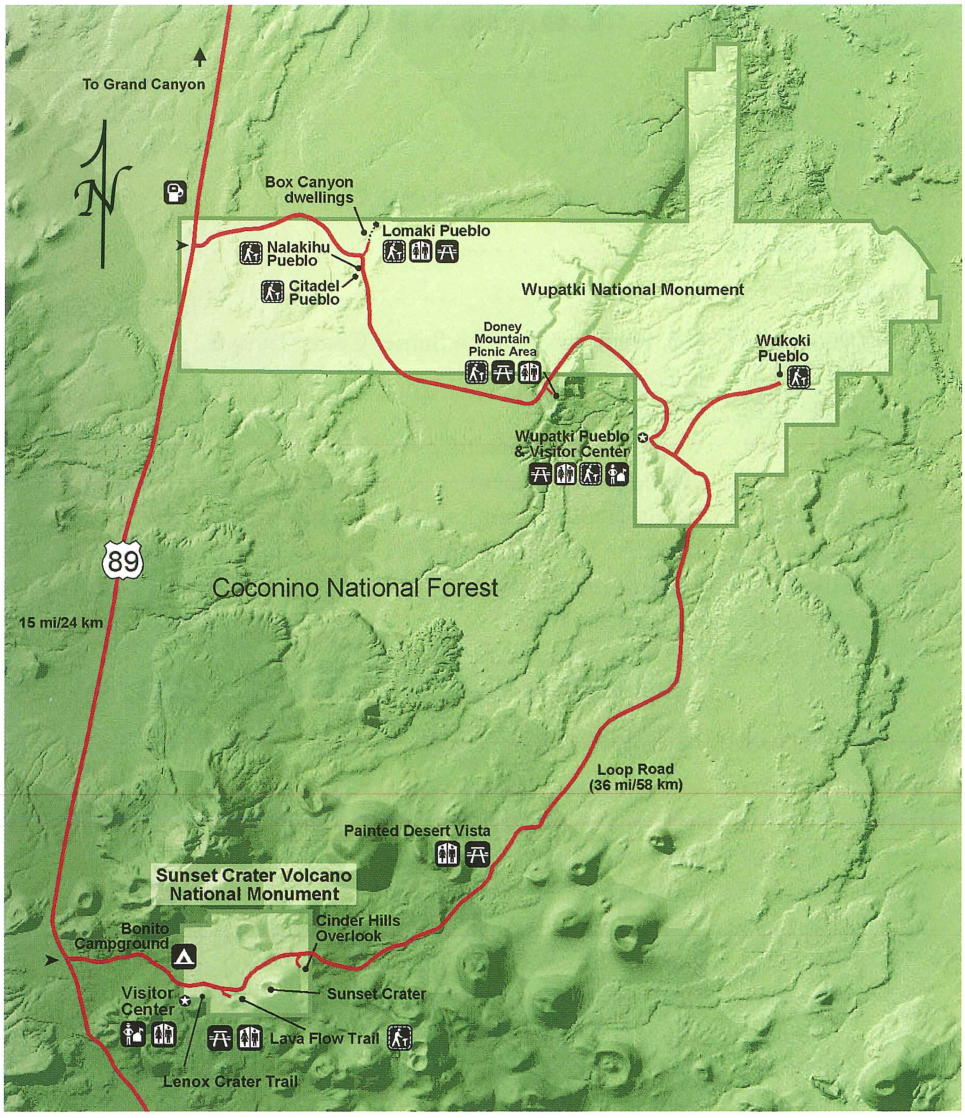


Fig 1. Location map showing Wupatki National Monument, Sunset Crater Volcano National Monument, and the Loop Road that connects them. Map courtesy of the National Park Service.

Introduction

The geologic setting in Wupatki National Monument is distinctly different from that in Sunset Crater Volcano National Monument, even though the monuments are side by side (Figure 1). At Wupatki, sedimentary rocks that were deposited by ancient seas and river systems more than two hundred million years ago during the Permian and Triassic Periods dominate the landscape. The landscape at Sunset Crater is dramatically different. Although underlain by the same rocks exposed at Wupatki, the Sunset Crater area is covered with cinders and cooled lava flows from intermittent volcanic eruptions during the last few million years. The most recent eruption was that of Sunset Crater Volcano, only about 900 years ago.

This guide provides only a glimpse of what can be found in these areas. By hiking the trails and perusing the displays at the Visitor Centers, you will get a much more in-depth view of the monuments.

Most visitors to these monuments travel north from Flagstaff, enter Sunset Crater Volcano National Monument, and drive north on the Loop Road to Wupatki. This road log, therefore, is organized to follow the Loop Road in that direction. Use your odometer readings to guide you to stops along the way. Set the trip odometer to zero immediately after you enter Sunset Crater Volcano National Monument. Additionally, side trips to parking areas will add to the total mileage on your trip odometer. This is not accounted for in the odometer mileages given.

Brown mile markers are located on the right side of the Loop Road as you travel from Wupatki National Monument southward toward Sunset Crater. These markers start at zero at the Wupatki turnoff from U.S. Highway 89 and show the cumulative mileage southward toward Sunset Crater. Those markers can be used conveniently if you start this self-guided tour at Wupatki and drive southward to Sunset Crater. If you do that, however, it will be necessary to start at the end of the road log, at Mile 0.0, and work backward.

The odometer readings from the south entrance are given first in the text and are followed by the cumulative mileage from the north entrance, in parentheses, for those who travel from Wupatki to Sunset Crater.



Please, drive with caution and do not stop in the road. Be alert for wildlife and always, please buckle up and drive posted speed limits.

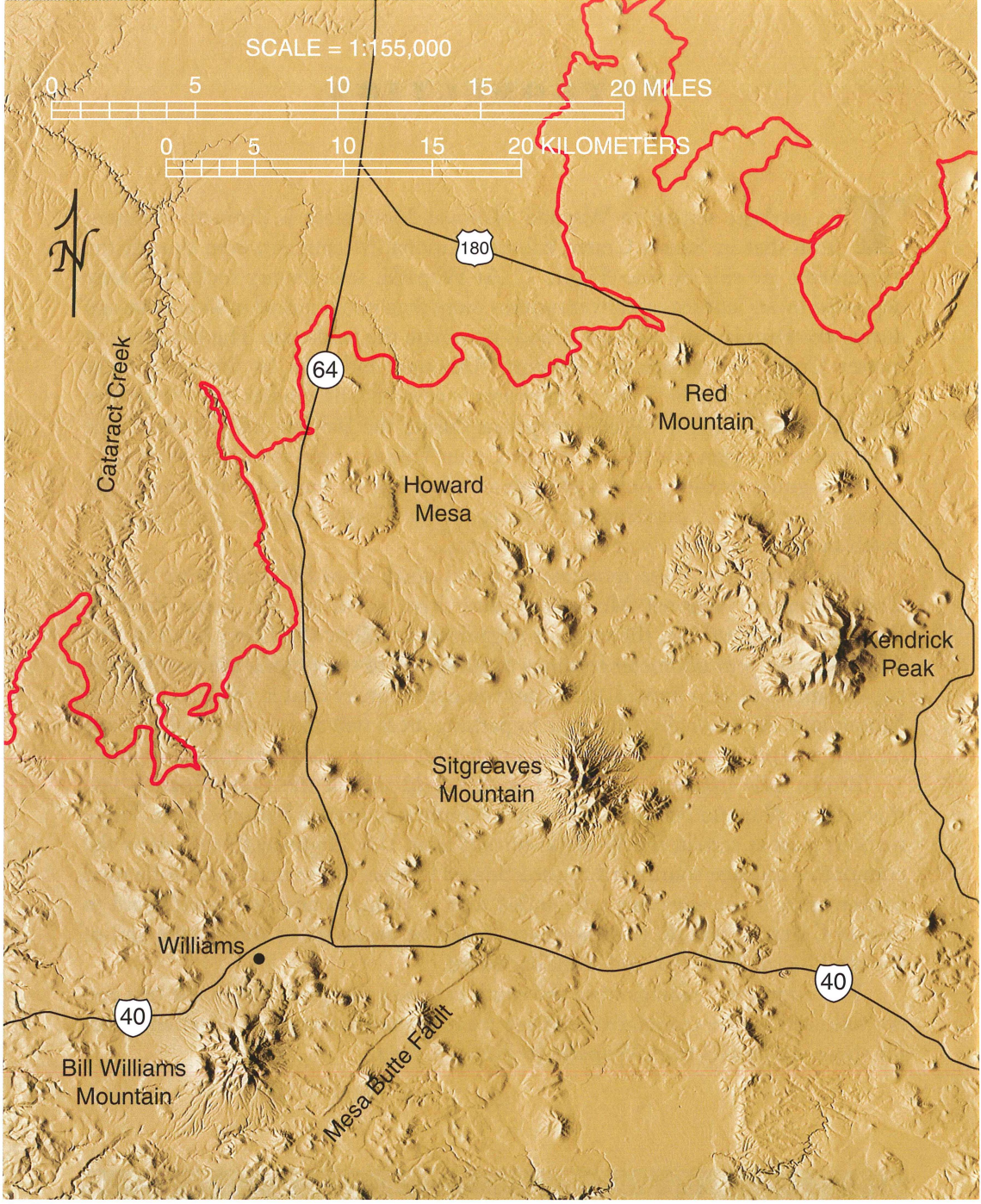
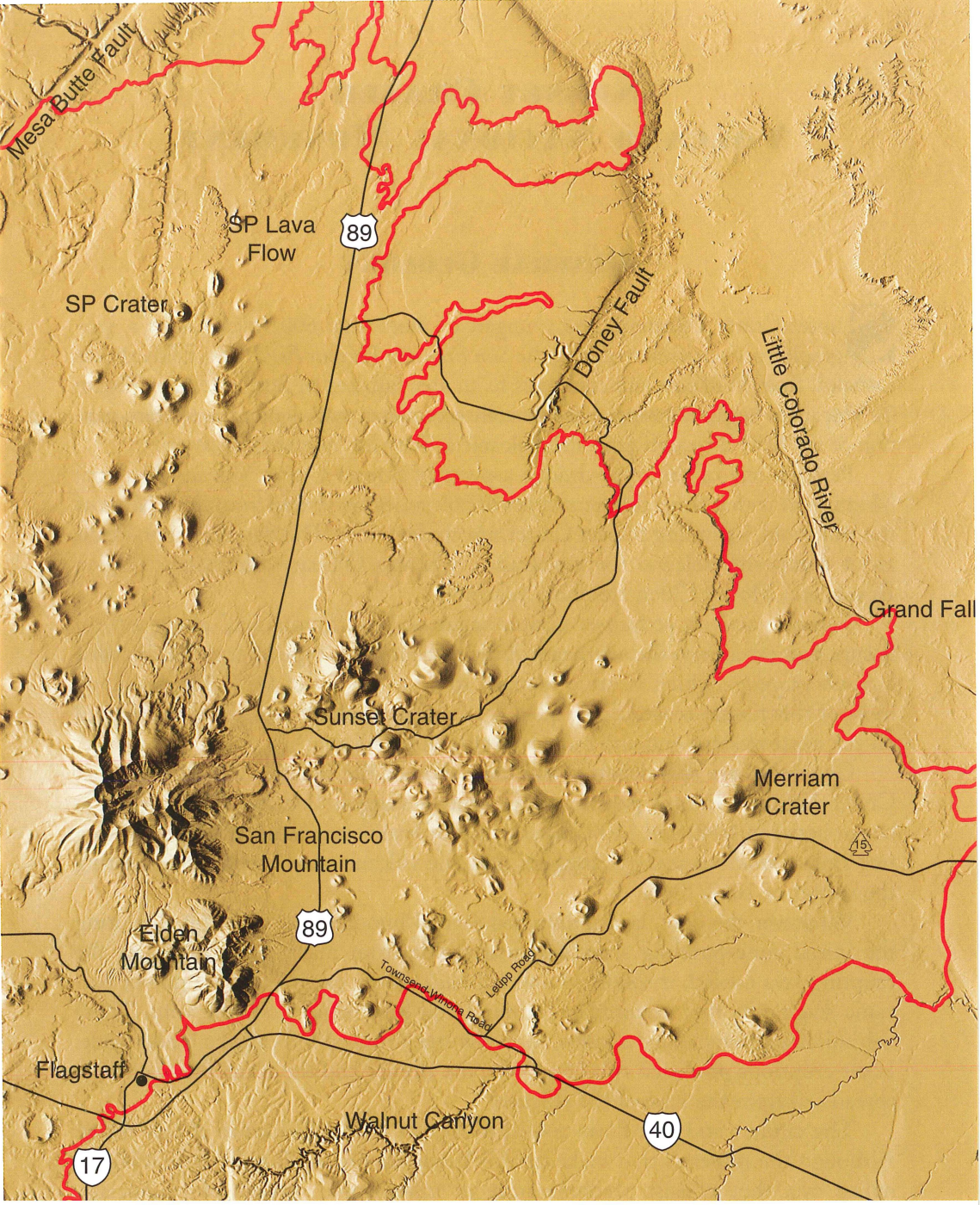


Fig 2. San Francisco Volcanic Field (outlined in red). DEM courtesy of the U.S. Geological Survey, Flagstaff Field Center.


Mesa Butte Fault
SP Lava Flow
89
SP Crater
Doney Fault
Little Colorado River
Grand Fall
Sunset Crater
Merriam Crater
15
San Francisco Mountain
89
Elden Mountain
Townsend-Winona Road
Leupp Road
Flagstaff
Walnut Canyon
40
17

Sunset Crater Volcano National Monument

General Geology

Sunset Crater Volcano is the youngest of more than 600 volcanoes in a geographic province referred to as the *San Francisco Volcanic Field.* This field extends eastward from Williams and continues to an area just east of Sunset Crater (Figure 2). Volcanoes began erupting approximately six million years ago in the western portion of the field. Through time, this volcanic activity has migrated eastward.

Perhaps one of the most unique aspects of Sunset Crater Volcano National Monument is that three different types of volcanoes are visible from here. Most of the volcanoes, including Sunset Crater, are cinder cones. The San Francisco Peaks are a composite volcano (stratovolcano), whereas O'Leary Mountain, Darton Dome, and Mount Elden are dome volcanoes.

Volcanic activity at Sunset Crater began as lava "fountained" along a 6-mi fissure that extends to the southeast of the volcano. This type of eruption is called a *fissure eruption*, which is often referred to as a "curtain of fire." Activity along most of this fissure ceased fairly quickly as volcanic activity became concentrated on the northwestern end and built Sunset Crater Volcano.

Geologists are still debating the exact date of the initial eruption of Sunset Crater Volcano. Recent paleomagnetic studies suggest that the initial eruption began between 1040 and 1100. Dating of roof beams excavated at Wupatki using tree rings (*dendrochronology*) suggests that the volcano may have erupted during the winter of 1064/1065.

Whatever the date, lava fountained several hundred feet into the air during the initial cone-building stage and was visible from many miles away. As the erupting lava cooled, it solidified and fell back to the earth leaving a pile of volcanic fragments that accumulated around and downwind from the vent. These volcanic fragments, called cinders, form the steep conical hill called a cinder cone. Later eruptions produced two lava flows, the Bonito and the Kana'a flows, which spread out from the base of the volcano.

The cinders and lava flows cooled to form a rock called *alkali olivine basalt.* Although the minerals that make up this basalt are too small to be seen with the naked eye, they consist predominantly of microscopic crystals of plagioclase, olivine, and augite.

How long did the eruption of Sunset Crater Volcano last? Geologists are still researching this question. Until recently, they thought the eruption may have lasted nearly 150 years. Recent studies, however, suggest that the duration of the eruption was much shorter, perhaps less than 10 years.

Will Sunset Crater erupt again? This is impossible to predict. Historically cinder cones erupt only once and then are considered extinct. If this is the case, Sunset Crater will not erupt again. The San Francisco Volcanic Field, however, is still considered to be potentially active. It is possible, therefore, that at some time in the future a new eruption may begin forming a new cinder cone near here. There is, however, no evidence to suggest that will happen any time soon.

Road Log

Odometer 0.0 (Mile 34.9, southbound)
U.S. Highway 89 at the Sunset Crater Turnoff

If you travel north on U.S. Highway 89 from Flagstaff, turn right into Sunset Crater Volcano National Monument. (This intersection is approximately 12 mi north of the Townsend-Winona Road turnoff on the northeastern edge of Flagstaff.) Set the trip odometer to zero immediately after you turn right and follow this self-guided geology tour.

This is the end of the road log if you started the tour in Wupatki National Monument. To return to Flagstaff, turn left. If you are going on to the Grand Canyon, turn right.



Odometer 1.1 (Mile 33.8, southbound)
Pullout at Bonito Park

From this pullout you have excellent views of several volcanoes in the area. To the east is a wonderful view of Sunset Crater Volcano (Figure 3). The red color of the volcano summit, especially prominent in the evening, prompted John Wesley Powell to name the volcano Sunset Mountain in 1879. The name was later changed to Sunset Crater. This red color came about during the waning stages of volcanic activity when hot gasses that were escaping from the summit oxidized (rusted) the basalt cinders to a red scoria and deposited minerals such as gypsum, sulfur compounds, opal, and hematite near the rim of the volcano.

To the west are the majestic San Francisco Peaks (Figure 4), a composite volcano that erupted between 2.8 million and 200,000 years ago. The high peak on the north of the mountain is Mount Humphreys, the tallest peak in Arizona, standing 12,633 feet tall. This mountain may have once been much higher than it is today, perhaps as high as 16,000 feet, prior to the explosive eruption and the subsequent collapse of the summit.



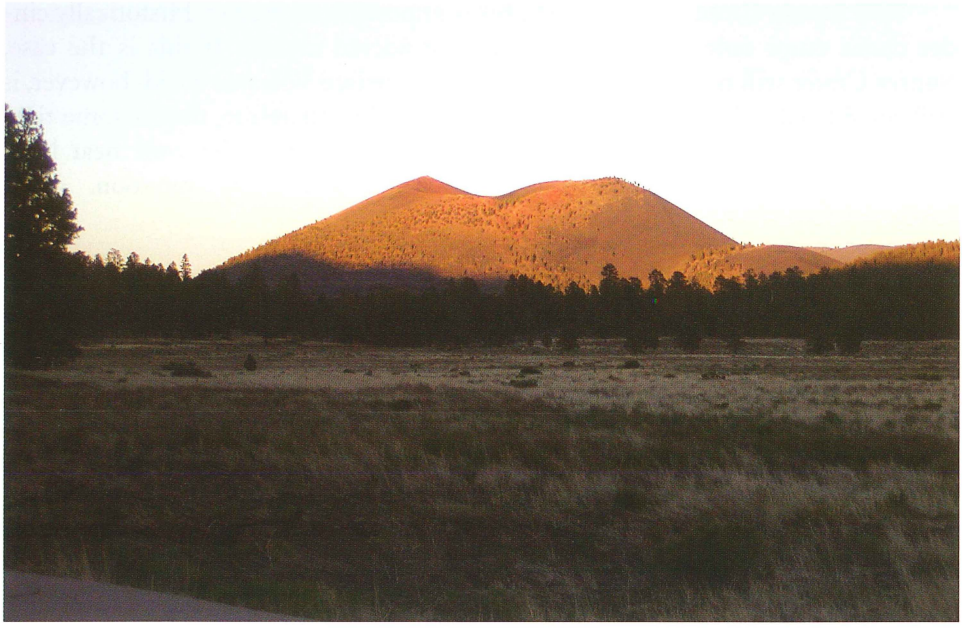


Fig 3. Sunset Crater at sunset from the Bonito Park pullout. Photo by Peter Summers.



Fig 4. San Francisco Peaks from the Bonito Park pullout.

Odometer 1.7 (Mile 33.2, southbound)
O'Leary Road

This road provides access to the O'Leary Peak Fire tower. The road is gated, but you can walk the 4.5 miles to the top. From the top you have one of the most spectacular views of Sunset Crater as well as excellent views of many of the more than 600 volcanoes in the area (Figure 5).

Although basalt covers much of the surrounding area, the rocks that make up O'Leary are called *dacite*, which is different in composition and much lighter in color than the basalt. If you look closely at them, you can see crystals of the minerals *plagioclase* (colorless) and *hornblende* (dark green).



Odometer 1.9 (Mile 33.0, southbound)
Visitor Center-Sunset Crater Volcano National Monument

Odometer 3.2 (Mile 31.7, southbound)
Lenox Trailhead and Lava Flow Vista

At this viewpoint you have an excellent view of the Bonito Lava Flow. This type of flow, called an *aa flow*, was formed by slowly flowing, sticky lava, which carried along a solid rubbly surface, called *clinker*, on the top. Clinker fragments from the top tumbled down the front of the flow and were buried by the advance of the flow. This resulted in a layer of clinker at the top of the flow, massive



Fig 5. View of Sunset Crater Volcano and Bonito lava flow from O'Leary Peak.

Fig 6. View looking north from the Lava Flow Vista.



basalt in the center and a thinner layer of clinker at the bottom of the flow. Here you can see the central portion of the flow (the vesicular basalt that appears smooth) and the top of the flow (the clinker). This flow ranges in thickness from about 5 ft at the margins to perhaps more than 100 ft in the center.

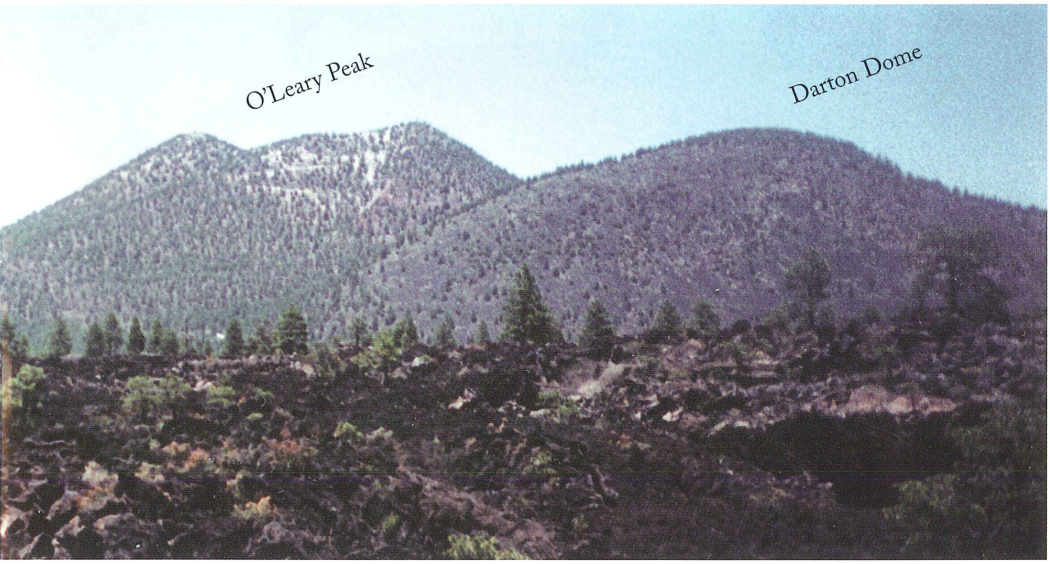
Several other volcanoes are visible behind this flow (Figure 6). Robinson Mountain is a cinder cone that erupted tens of thousands of years ago. The most prominent peaks, O'Leary Peak and Darton Dome, are *lava domes*. Lava domes form when extremely viscous (resistant to flow) lava is extruded from a vent. This lava, too viscous to flow far from the vent, leaves behind a rounded, steep-sided mound called a *lava dome* or *volcanic dome*. These volcanoes were active between 250 and 170 thousand years ago.

Across the road is a short, steep 0.5-mi trail to the top of Lenox Crater. This *cinder cone*, 250 ft tall, is much older than Sunset Crater. It erupted several hundred thousand years ago. Over time, wind and water have eroded away what was once a deeper crater and the vegetation has grown back. More recently, the eruption of Sunset Crater blanketed Lenox crater with a fresh layer of cinders.



Odometer 3.4 (Mile 31.5, southbound)
Lava Flow Trail Parking Area

The parking area for the trail is on your right. From there you can choose between a 0.25-mi hike or a 1-mi self-guided interpretative hike. Both trails wind through the Bonito lava flow, the youngest of the lava flows of Sunset Crater Volcano. A



little more than 900 years ago a river of molten lava flowed where these rocks are today. This lava was hot – nearly 2,200°F. It was extruded from the base of the volcano and flowed toward the west, filling in a basin surrounded by older volcanoes. When the flow stopped, it covered an area nearly 2 square mi with newly formed basalt.

Because the climate here is dry, very little weathering and soil formation have occurred and the vegetation is slow to return. For this reason, the lava flow today looks very much like it did when it cooled and solidified a short time after the eruption.



Fig 7. Xenolith (white). Photo by Bill Hudson.

As you walk along the trail you will see that the basalt contains numerous holes that formed as gases escaped from the cooling lava. Bubbles that were trapped in the lava when it solidified form holes called *vesicles*. Thus, they can be thought of as bubbles frozen in time.

Many fascinating geologic features can be observed along the Lava Flow Trail, including *xenoliths* (Figure 7), a *squeeze-up* (Figure 8), and a *hornito* (Figure 9). Xenoliths are pieces of older rock that were carried to the surface in the lava and encased in the rock when the lava cooled. The xenoliths you see on



Fig 8. Squeeze up. Photo by Bill Hudson.



Fig 9. Hornito. Photo by Bill Hudson.

the Lava Flow Trail are from the Kaibab Formation, a rock layer that is hundreds of feet below the surface here. Squeeze-ups and hornitos form when cracks develop on the solid surface of a cooling lava flow. This allows the semi-solid lava from below to escape to the surface. In the case of squeeze-ups, the pasty lava squeezes up through the crack and solidifies quickly. Hornitos, often thought of as miniature volcanoes, form as lava spatters out of these cracks and builds a steep-sided heap of welded spatter.



Odometer 5.4 (Mile 29.5, southbound)
Cinder Hills Overlook

On your right is the turn-off to the Cinder Hills Overlook. From there you have a wonderful view of several of the volcanoes in the San Francisco Volcanic Field (Figure 10). These volcanoes are much older than Sunset Crater Volcano, the tall peak to the south (your right). They were active several hundred thousand years ago and were subsequently blanketed with a fresh layer of cinders during the eruption of Sunset Crater volcano. The fissure associated with the Sunset Crater eruption can be seen as an outcropping of red cinders extending southeastward from Sunset Crater Volcano.



Odometer 8.0 (Mile 26.9, southbound)
Kana'a Lava Flow

Stop at the paved pull-off on the east side of the road. The basalt east of the road is part of the Kana'a lava flow (Figure 11). This flow, the older of the two lava flows from Sunset Crater, was extruded from a vent at the base of the eastern side of the volcano. The lava, which flowed along an old stream bed, solidified to form a ribbon of basalt several miles long yet only about 1,000 ft wide.



Odometer 9.4 (Mile 25.5, southbound)
U.S. Forest Service Picnic Area (Painted Desert Vista)

Turn left at the sign to the National Forest Recreation Area and proceed to the parking area. You are now on the northern edge of the San Francisco Volcanic Field. The hills around you are all volcanoes that erupted from tens of thousands to hundreds of thousands of years ago. Perhaps the most well known of these is Strawberry Crater, the lone volcano to the west, which erupted approximately 50,000 years ago.

Fig 10. View from Cinder Hills Overlook.

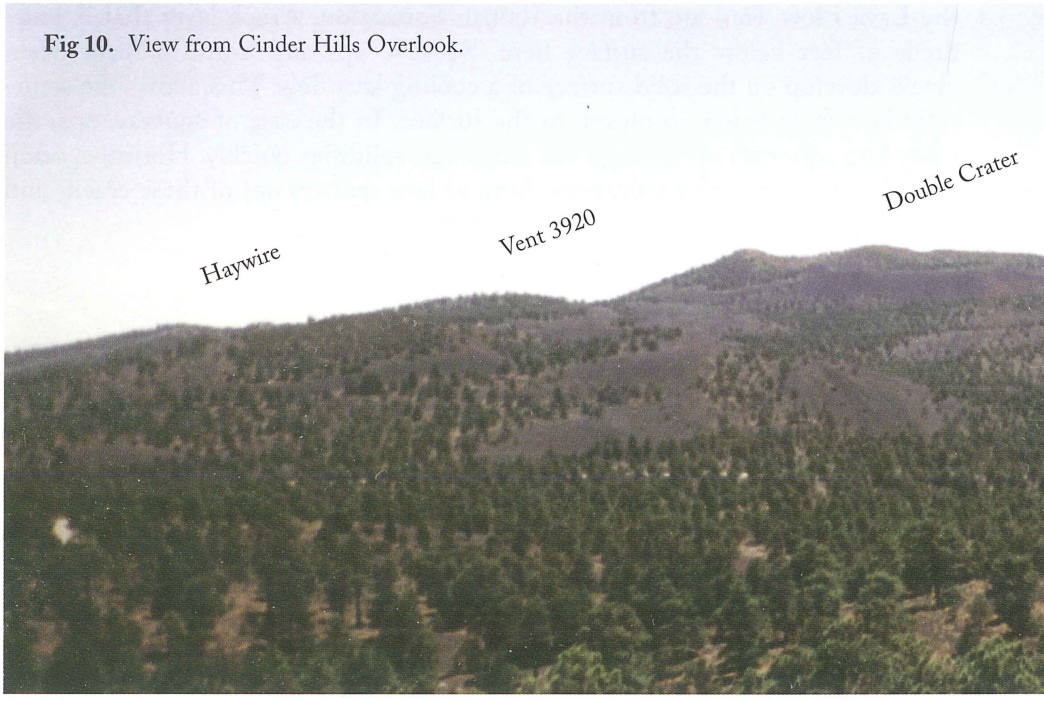
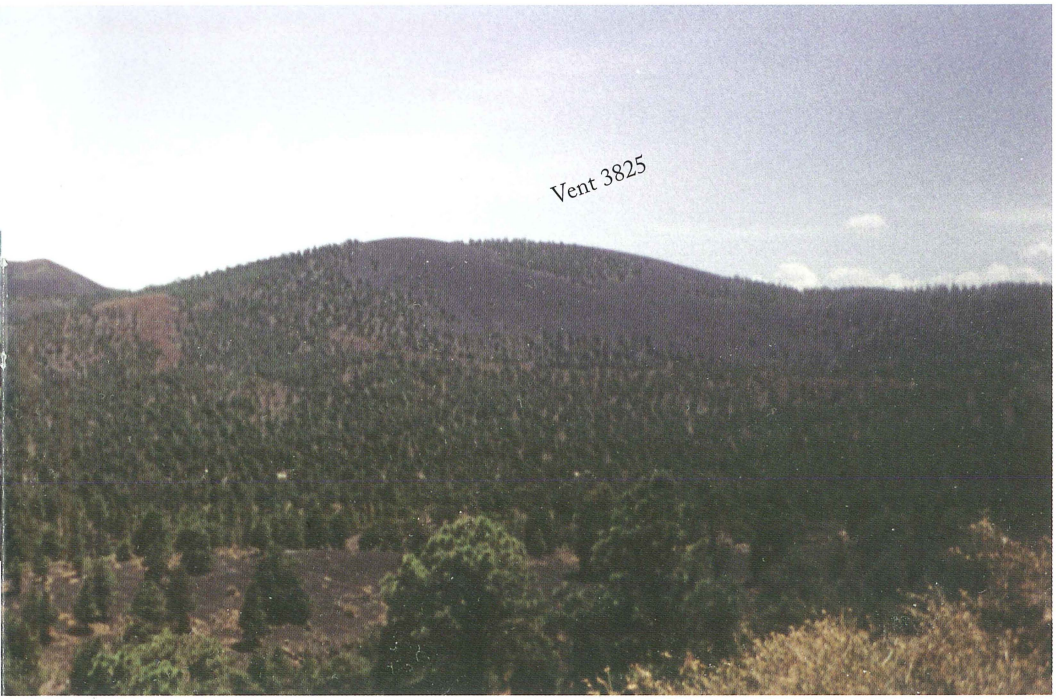




Fig 11. Kana'a lava flow partially covered with cinders.



In the distance to the east you can see the Painted Desert (Figure 12). The most accessible exposures of the Painted Desert are at Petrified Forest National Park, approximately a hundred miles east. The geographic area referred to as the "Painted Desert" curves southward from just north of Tuba City to Winslow, and then east across the Petrified Forest National Park (Figure 13).

As you gaze out into the Painted Desert you see the brightly colored rocks of the Chinle Formation (Figure 14). These rocks formed during late Triassic time when the inland sea began to retreat. The retreating sea left behind an immense alluvial plain on which rivers deposited vast aprons of silt, mud, and sand. The colors reflect the mineral content of the sediment and the rate at which it was deposited. When the sediment was deposited slowly, iron, manganese, and aluminum were oxidized and produced the red and purple hues. When sediment deposition was rapid, a lack of oxygen trapped in the sediments created the blues, greens, and grays. These colors are most brilliant in early morning and late afternoon hours



Fig 12. Painted Desert. Photo by Dallas Larsen.

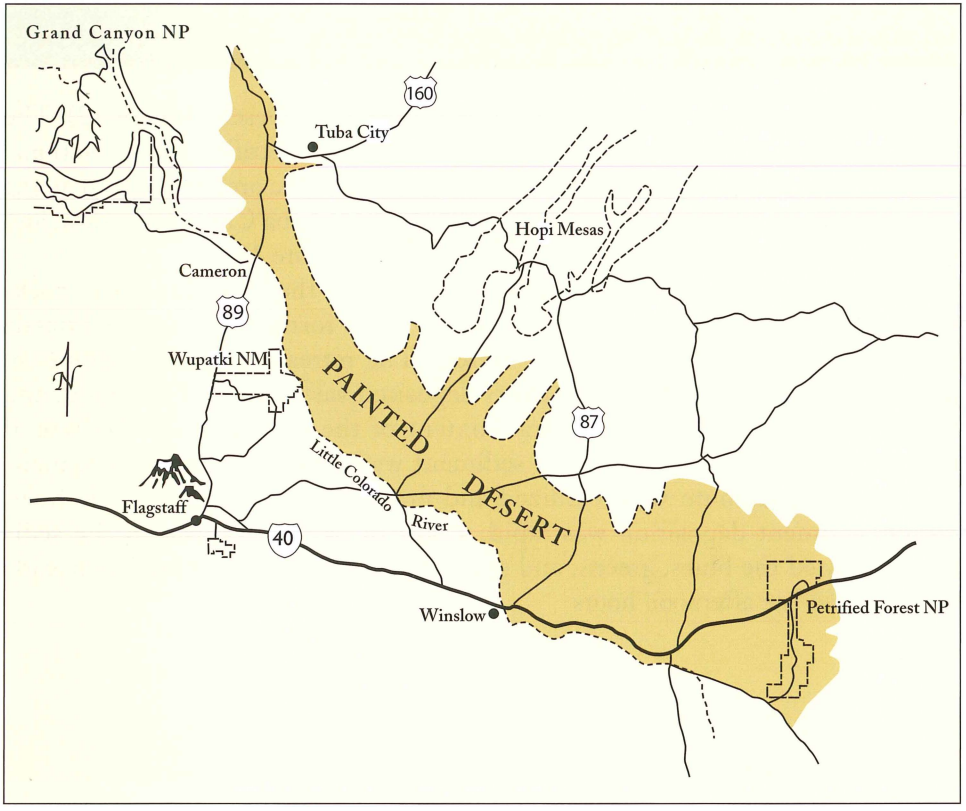


Fig 13. Map showing extent of the Painted Desert. Map courtesy of the National Park Service.

Wupatki National Monument

General Geology

Although images of spectacular pueblo ruins are often conjured up when one thinks of Wupatki National Monument, Wupatki has much more to offer. Geologically, it is a fascinating place to explore as well. The rocks at Wupatki National Monument record geologic time referred to as the Permian and Triassic periods (Figure 14). During this time North America, located much farther south than it is today, experienced a much more tropical climate.

Time Units	Periods	Formation	Geologic Events	Age in millions of years
Cenozoic	Quaternary	Volcanic Rocks	Volcanic Activity of the San Francisco Volcanic Field	~1.0 - recent
Mesozoic	Late Triassic	Chinle	Marine and nonmarine deposition	200
	Early Triassic	Moenkopi	Beach, shallow marine, sabkha, tidal flat. lagoon and flood plain deposition	~240 ~245
Paleozoic	Middle Permian	Kaibab	Shallow marine deposition	~256
		Toroweap	Shallow marine	
	Early Permian	Coconino Sandstone	Flood plain deposits covered by migrating sand dunes	~270

Fig 14. Ages and environments of deposition of rock formations exposed in Wupatki National Monument and the Painted Desert. Wavy lines represent unconformities - times during which rocks were not deposited or existing rocks were eroded.

Numerous times throughout the early Permian, ancient seas advanced into and retreated from what is now northern Arizona. By the middle Permian, a large sea teeming with billions of microscopic organisms covered the area. When these organisms died, their skeletal remains gently sank to the ocean floor. These tiny skeletons accumulated over millions of years, mixed with sand and clay, and formed a layer of briny ooze hundreds of feet thick. This layer of ooze ultimately became the Kaibab Formation. Toward the end of the Permian period the seas began to withdraw as the area was uplifted. Erosion rather than deposition became the dominant geologic process for several tens of millions of years. This resulted in an *unconformity*, a period of time that is not represented by rocks.

During the Triassic period, when dinosaurs ruled the world, this part of what is now northern Arizona was a low coastal plain near a shallow sea that extended northward and westward into Utah and Nevada. Streams flowing into the sea deposited the mud and sand that would become the Moenkopi and Chinle Formations. Just imagine, if you were here then, you would not be in a high desert but would be standing on beachfront property. You would see lagoons, marshes, and large flowing rivers rather than a desert landscape.

Since the deposition of these Triassic rocks, this area has been uplifted at least a vertical mile. The landscape we see today began to take shape about 20 million years ago when the Colorado Plateau began to uplift. As uplift continued, weathering and erosion began to shape the surrounding landscape into the mesas and buttes that are present today. Outpourings of lava from newly formed volcanoes flowed over the area only recently in geologic time, in the last few million years.

The most prominent geologic feature at Wupatki is the 230-ft-high fault scarp exposed at Doney Cliffs. In the western portion of the park, on the upthrown side of the Doney Fault, the erosionally resistant Kaibab Formation is exposed on Antelope Prairie. East of the fault, on the downthrown side, is Wupatki basin where the red beds of the Moenkopi Formation are the predominant rocks exposed.

The buff-colored Kaibab Formation (Permian age) can be divided into two units, called members. The lower unit, the Fossil Mountain member, is generally a massive, cliff-forming, silty dolomite. It is interbedded with less abundant layers of calcareous siltstone or fine-grained sandstone layers. These layers are softer than the dolomite and form recesses rather than cliffs. In the Wupatki area, red or white chert nodules and irregular layers are abundant. This unit contains a wide variety of marine invertebrate fossils.

The upper unit, the Harrisburg member, is an unfossiliferous unit comprised of cherty limestone that grades upward into sandstone and is capped by a blocky limestone. Only the lower portion of the Fossil Mountain member is present at Wupatki because the upper portion has been eroded. The depositional environment of the Kaibab Formation ranged from a shallow, unrestricted marine to a near-shore desert. During deposition of the Kaibab sediment, the seas advanced and retreated several times.

The Moenkopi Formation (Triassic age) is predominantly a red mudstone, siltstone, and sandstone. The sandstone is typically a massive, cliff-forming unit. At the surface, it has broken into flat rocks that made ideal building materials for the prehistoric peoples. The mudstones generally form slopes with occasional weak ledges of siltstone or sandstone. Ripple marks, mudcracks, raindrop impressions, cross bedding, and fossil tracks have all been documented in the Moenkopi. The Moenkopi was deposited near sea level in a variety of depositional environments including shallow marine, beach, tidal flat, lagoon, and floodplain. A long period of time elapsed between the deposition of the Kaibab and the Moenkopi Formations. Geologists refer to this gap in the geologic record as an unconformity.

Road Log

Odometer 18.9 (Mile 16.0, southbound)
Wupatki National Monument Entrance Sign

This point is more than 2,000 ft lower in elevation than the San Francisco Volcanic Field at Sunset Crater, just 15 mi behind you. The elevation change is due, in part, to the more than one thousand feet of volcanic rock that buried the Moenkopi and Kaibab formations, which crop out at the surface in Wupatki National Monument. As you descended you passed through several ecosystems: a Ponderosa Pine forest at the highest elevations, Pinon-Juniper woodlands, and, finally, the High Desert here.



Odometer 20.9 (Mile 14.0, southbound)
Wukoki Pueblo Road Junction

Turn right onto the Wukoki Pueblo road and drive 2.5 mi to the parking area. The trail winds through the red Moenkopi Formation to the Wukoki Pueblo (Figure 15), which was constructed predominantly from sandstone from this formation. If you look closely, however, you will see an occasional basalt or limestone boulder in the wall. As you walk up the trail and into the pueblo, look for ripple marks along the trail and on the floor of the plaza. These ripple marks formed from wave action more than 240 million years ago when this area was covered by water.





Fig 15. Wukoki Pueblo. Photo by Dallas Larsen.

Odometer 21.2 (Mile 13.7, southbound)
Visitor Center-Wupatki National Monument

The Wupatki Pueblo is the largest of the dwellings in Wupatki National Monument. You can walk around this pueblo on the short trail behind the Visitor Center.

The nicely layered red rocks exposed here are sandstones, siltstones, and mudstones that make up the Moenkopi Formation. Each layer represents minor advances and retreats of the Triassic sea. In other words, each layer represents a slightly different depositional environment. Sandstone from this unit was used extensively in the construction of the pueblos.

From the overlook behind the Visitor Center, Doney Crater, a cinder cone that is several tens of thousands of years old, is directly in front of you. Woodhouse Mesa (Figure 16), to your left, is comprised of Moenkopi sandstone that was capped by a lava flow just over a million years ago. The lava solidified to form the black rock called basalt. The loose cinders covering this mesa and other areas nearby are from the eruption of Sunset Crater less than 1,000 years ago.

Near the end of the trail you will find the *blowhole*, a natural phenomenon that acts as a fan or vacuum. This opening connects to the extensive underground fracture system in the Kaibab limestone that is exposed at Lomaki and Box Canyon Pueblos. Whether the blowhole acts as a "fan" or "vacuum" is determined



Fig 16. Woodhouse Mesa from trail.

by surface weather, mainly air temperature and atmospheric pressure. If the temperature outside is cool, the air is more dense (higher pressure) than air in the fracture system in the rocks. This causes air to rush into the blowhole in an attempt to equalize the pressure in the fracture system with that outside. On warmer days, outside air is less dense than air in the fracture system, so air rushes out of the blowhole. Just as temperature affects this natural phenomenon, so does atmospheric pressure. If a low-pressure system moves in, the air in the fracture system is higher in pressure and rushes out of the blowhole. Alternatively, if a high-pressure system moves in, air rushes in to the underground cavern system.

Odometer 23.8 (Mile 11.1, southbound)
Doney Cliffs Pullout

Stop safely at a gravel pull-off on the north side of the road. You are on the western edge of the Wupatki basin, a large basin that is bounded here by the Doney Cliffs to the northwest (Figure 17). These cliffs were formed by uplift and folding of the Black Point Monocline as well as movement along the Doney fault. West of the fault, on the upthrown block, the Kaibab formation is exposed at the sur-



Fig 17. Doney Cliffs. Moenkopi Formation (red) is on the down-dropped side of the Doney Fault. Kaibab Limestone (tan) is on the up-thrown side.

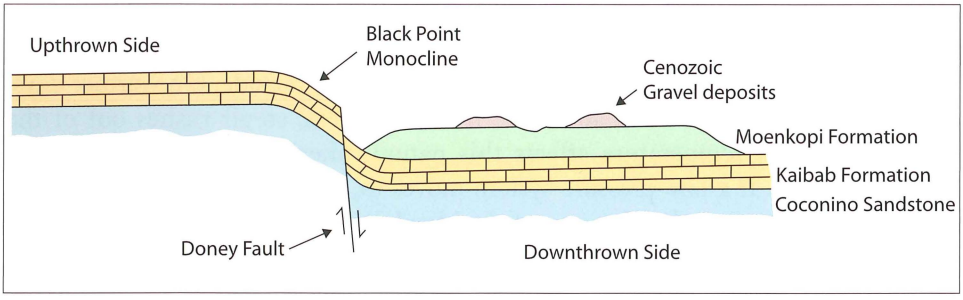


Fig 18. Cross section of the Doney Fault and Black Point Monocline.

face. East of the fault, on the downthrown block, the Moenkopi formation is the dominant rock unit at the surface (Figure 18).

The Doney fault is a near-vertical fault along which the eastern block dropped down relative to the western block as much as 233 ft and formed a prominent fault scarp. The total displacement between the western and eastern sides of the park is more than 400 ft. You can see this displacement here simply by looking out at the rocks to the east. You will notice the younger, red Moenkopi Formation on the downthrown side lies below the buff-colored Kaibab Formation on the upthrown side. Remember that the Kaibab Formation is older and, therefore, normally lies below the Moenkopi Formation.

All of this folding and faulting occurred between roughly 80 and 40 million years ago while two of the Earth's plates, the Pacific plate and the North American plate, were colliding. The resulting compression uplifted the Rocky Mountains. It was during this time that the great single folds, called monoclines, of the western United States were formed. It is likely that the Black Point Monocline formed at this time as well. Exactly when the Doney Fault ruptured remains unclear. Faulting may have occurred at the same time or after the monocline formed.



Odometer 25.5 (Mile 9.4, southbound)
U.S. Forest Service Viewpoint and Lunch Area
(Doney Mountain Picnic Area and Viewpoint)

Turn left and follow the road to the parking area. Four cinder cones in the Doney Mountain area are present along the southern margin of the Doney Fault. When these volcanoes erupted tens of thousands of years ago, frothy lava was ejected high into the air. While in the air, the lava cooled, solidified, and rained back down to the earth, leaving the piles of cinders that make up these cones. Larger fragments of lava (greater than 1.5 inches in diameter) formed *lava bombs*. Like cinders, these particles erupted in a fluid state and solidified as they fell. As they traveled through the air, they became rounded or spindle shaped (Figure 19). During subsequent eruptions lava extruded from the base of these cinder cones and formed the lava flows you see at the trailhead.



Fig 19. Lava bomb along Doney Trail. Photo by Dallas Larsen.

When you pull into the parking area you have an excellent view of Wupatki basin directly in front of you. This basin is almost completely surrounded by mesas, terraces, and plateaus. If you look closely to the right you can see the roof of the Wupatki Visitor Center in the distance. Big Doney, the largest of the cinder cones, is to your left. The red color of the cinders was caused by oxidation of iron oxides (rusting) in the basalt during the late stages of the eruption.

The trail will take you to the top of two of the smaller cinder cones. Near the saddle, the trail splits into a longer trail to the right and a shorter one to the left. If you take the trail to the right, look for lava bombs along the sides of the trail. From the top of either cinder cone you have a breathtaking view of the San Francisco Peaks as well as many of the other nearby cinder cones in the San Francisco Volcanic Field.



Odometer 30.8 (Mile 4.1, southbound)
Citadel and Nalakihu Pueblos Parking Area

The rocks exposed on this knoll are basalt that formed several million years ago when lava flowed over this region and covered much of the Moenkopi and Kaibab formations. Subsequent weathering and erosion removed much of the basalt but left this small knoll behind. Citadel Pueblo (Figure 20), constructed from blocks of both basalt and Moenkopi sandstone, sits at the summit of this small knoll.

A short trail will take you around behind and to the top of this small knoll. As you start up the trail, the first pueblo you encounter is Nalakihu. This 10-room structure was also constructed from Moenkopi sandstone and basalt. As you continue up the trail around the back of the knoll you will see a large depression to the south, called Citadel Sink (Figure 21). This sinkhole formed when weakly acidic ground water dissolved the underlying Kaibab limestone and formed a cavern. As dissolution continued, the cave became so large that it could no longer support the overlying roof material. The roof collapsed and formed the sinkhole you see today. From the summit of this knoll you can walk into Citadel Pueblo and enjoy a wonderful view to the west of many volcanoes in the San Francisco Volcanic Field.



Odometer 31.1 (Mile 3.8, southbound)
Lomaki Pueblo Road Junction

Turn right onto Lomaki Pueblo Road and drive about 0.25 mi to the parking lot. As you travel toward Lomaki and Box Canyon Pueblos, Middle Mesa is on your



Fig 20. Citadel Pueblo.



Fig 21. Citadel Sink.

left and East Mesa is on your right. These limestone mesas of the Kaibab Formation are capped by basalt (solidified lava from ancient flows).

A short trail leads to Lomaki and Box Canyon Pueblos. Both were built adjacent to large earth cracks (Figures 22 and 23). These earth cracks are part of an extensive system of northeast- to northwest-trending, vertical to near-vertical faults as well as vertical fractures, called joints, which formed during uplift of the Rocky Mountains. More than 700 joints and faults have been mapped in the Wupatki area alone. The fault traces and joints were widened as ground water percolated through them, dissolving and carrying away the Kaibab limestone and forming the earth cracks that you see today.

Lomaki and the Box Canyon Pueblos were constructed predominantly with blocks of Moenkopi sandstone, although if you look closely you will see some blocks of the Kaibab Formation.



Odometer 34.9 (Mile 0.0, southbound)
U.S. Highway 89 at the Wupatki Turnoff

This is the end of the road log if you started at Sunset Crater Volcano National Monument. To return to Flagstaff, turn left. (The northeastern edge of Flagstaff is approximately 27 mi south on U.S. Highway 89.) If you are going on to the Grand Canyon, turn right.

If you are just starting this self-guided geology trip, set the trip odometer to zero immediately after you enter Wupatki National Monument, use the brown mile markers to guide you, and follow the road log in reverse order.





Fig 22. Lomaki Pueblo. Photo by Dallas Larsen.

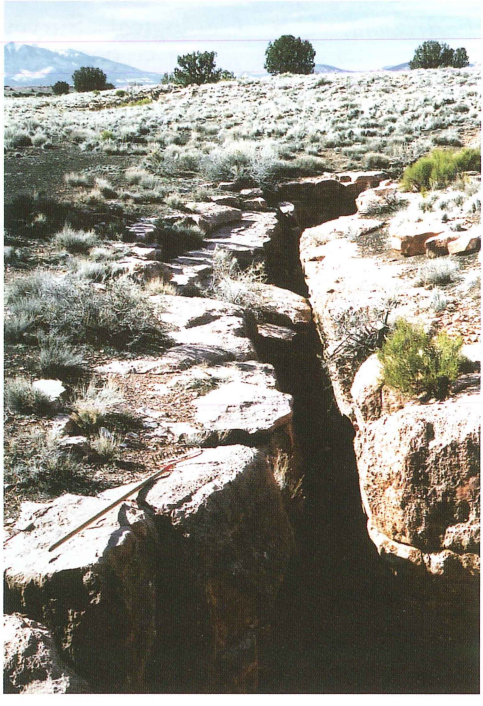


Fig 23. Earth crack near Lomaki Pueblo. Rake for scale. Photo by Dallas Larsen.

Suggested Readings

Bezy, J.V., 2003, *A guide to the geology of the Flagstaff area*: Arizona Geological Survey Down-to-Earth 14, 56 p.

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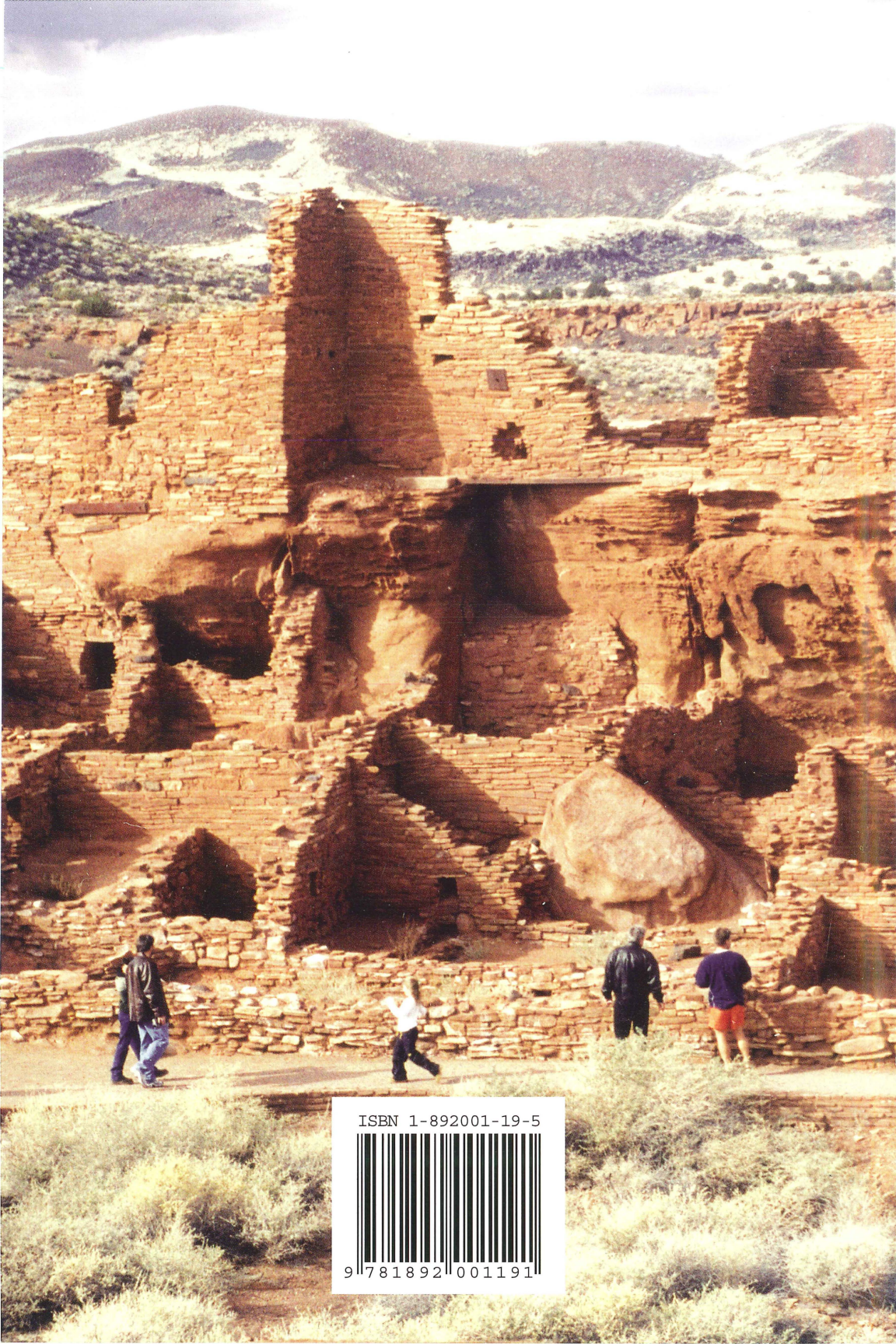
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Back Cover: Wupatki Pueblo



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