LAVA FLOW TRAIL

TRAIL GUIDE

SUNSET CRATER NATIONAL MONUMENT

50¢

Trail Information

The Lava Flow Trail is a one mile loop that winds through a section of the Bonito Flow. The trail is mostly level and special footwear is not required. Along the trail are signs corresponding to captions and paragraphs in this booklet.

There is no trail going to the top of the volcano. In order to preserve Sunset Crater from further erosion, hiking and climbing on the volcano is not permitted.

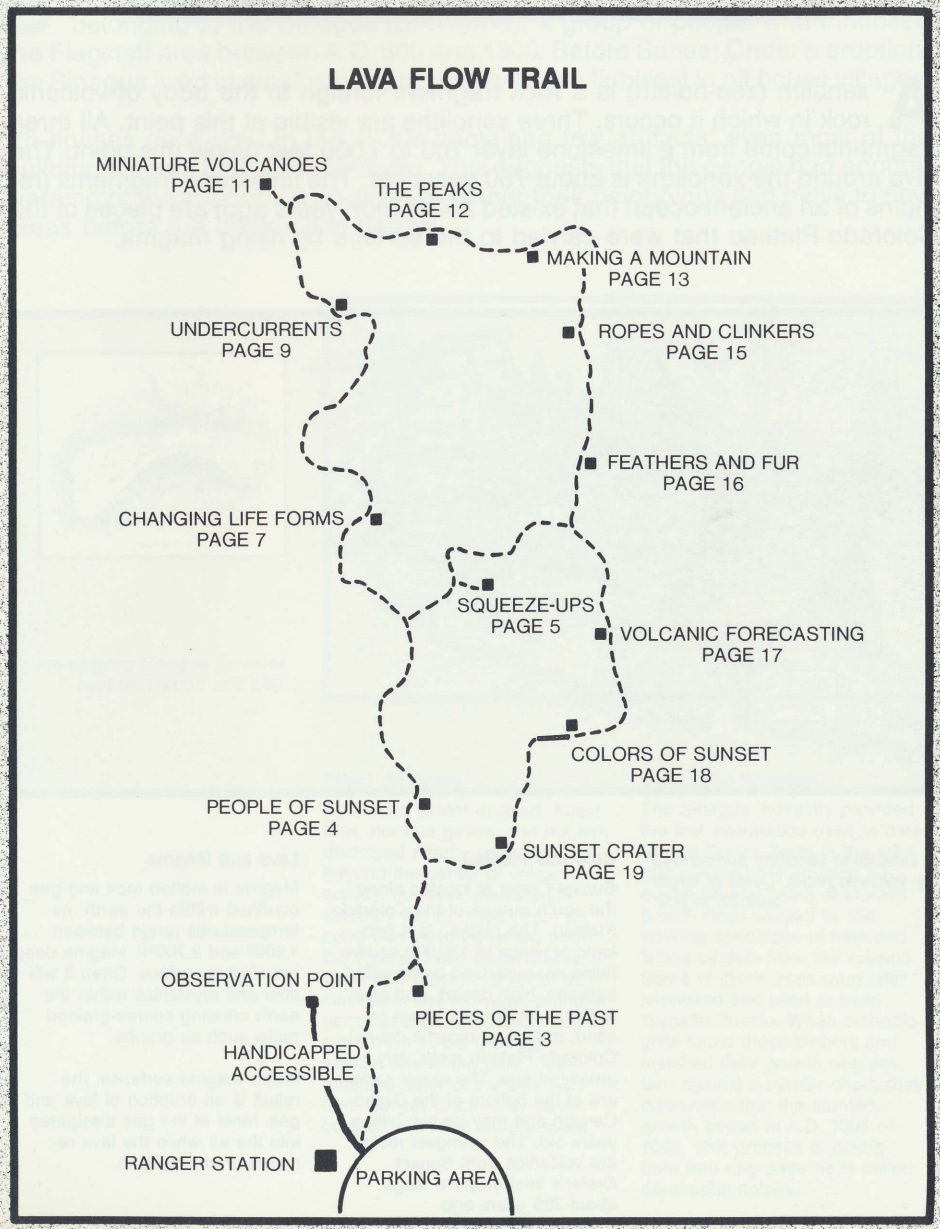
Introduction

Sunset Crater and its lava flows are part of the San Francisco Volcanic Field, an expanse of more than 400 volcanoes. The San Francisco Peaks, the high mountains eight miles west of here, dominate the volcanic field.

Sunset Crater is a colorful volcanic cone composed of lava fragments called cinders. The cinder cone is the result of an eruption that began in late A.D. 1064 or early 1065. The eruption may have continued periodically for more than 200 years.

Two lava flows are associated with Sunset Crater's eruption. Northeast of the cinder cone is the Kana-a Flow, a seven mile flow mostly covered with cinders and ash. The Bonito Flow is on the west side of Sunset Crater. While part of the flow is buried under cinders and ash, most of it is visible.

It is not known where the Bonito Flow originated—a reasonable estimate would be in an area north of the road near the northwest base of the volcano. The Lava Flow Trail passes through part of this flow.

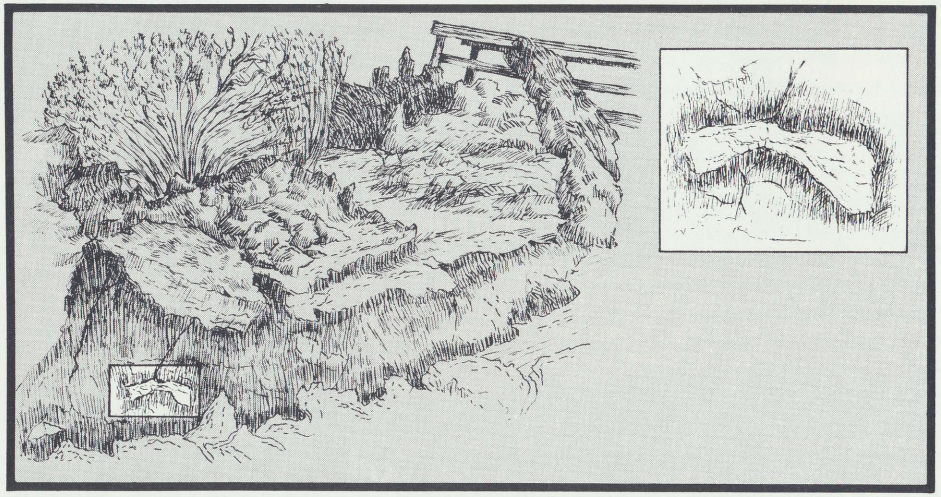


PIECES OF THE PAST

Here about the beach I wander,
Nourishing a youth sublime
With the fairy tales of science,
And the long results of time.

Alfred Tennyson

A xenolith (zee-no-lith) is a rock fragment foreign to the body of volcanic rock in which it occurs. Three xenoliths are visible at this point. All three fragments come from a limestone layer 700 to 1,000 feet below this point. The lava around the xenoliths is about 750 years old. The limestone fragments (remains of an ancient ocean that existed 250 million years ago) are pieces of the Colorado Plateau that were carried to the surface by rising magma.



Limestone xenoliths surrounded by volcanic rocks. Detail of larger xenolith in box.

Colorado Plateau

Sunset Crater is located along the south margin of the Colorado Plateau. The plateau is a geologic province of 130,000 square miles characterized by beautiful canyons, high desert, and sedimentary rocks (rock layers of sand, mud, and organic debris). Colorado Plateau rocks vary greatly in age. The oldest rocks are at the bottom of the Grand Canyon and may be two billion years old. The youngest rocks are volcanics from Sunset Crater's final eruptive stage about 700 years ago.

Lava and Magma

Magma is molten rock and gas confined within the earth. Its temperatures range between 1,500° and 2,700°F. Magma does not always surface. Often it will cool and crystallize within the earth creating coarse-grained rocks such as granite.

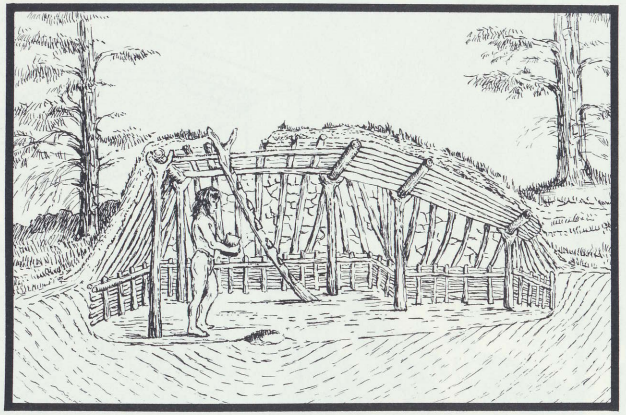
When magma surfaces, the result is an eruption of lava and gas. Most of the gas dissipates into the air while the lava remains on the surface.

PEOPLE OF SUNSET

The present is the key to the past. **Sir A. Geike**

Buried under Sunset Crater cinders are perhaps dozens of pit houses belonging to the Sinagua (Sin-now'-a), a group of people who inhabited the Flagstaff area between A.D. 500 and 1300. Before Sunset Crater's eruption, the Sinagua lived in small groups (probably single families) in pit house villages.

Pit houses excavated in the 1930s contained few artifacts; even most of the building timbers had been removed. This suggests that the people had enough warning of the impending eruption to gather their belongings and move to new areas before the destruction began.



Pre-eruptive Sinagua pithouse built with wood and clay.

Effect on Crops

As Sunset Crater erupted, forest fires, noxious gases, and hot ash destroyed nearby vegetation. Beyond the center of volcanic activity, however, plants cultivated by the Sinagua (such as corn) may have benefited from the light ash fall. Experiments show that a light blanket of ash can retain soil moisture, promote germination, and possibly add more days to the growing season due to the dark, heat-retaining color of the ash. Ash from Sunset Crater may have covered over 800 square miles.

Dating the Eruption

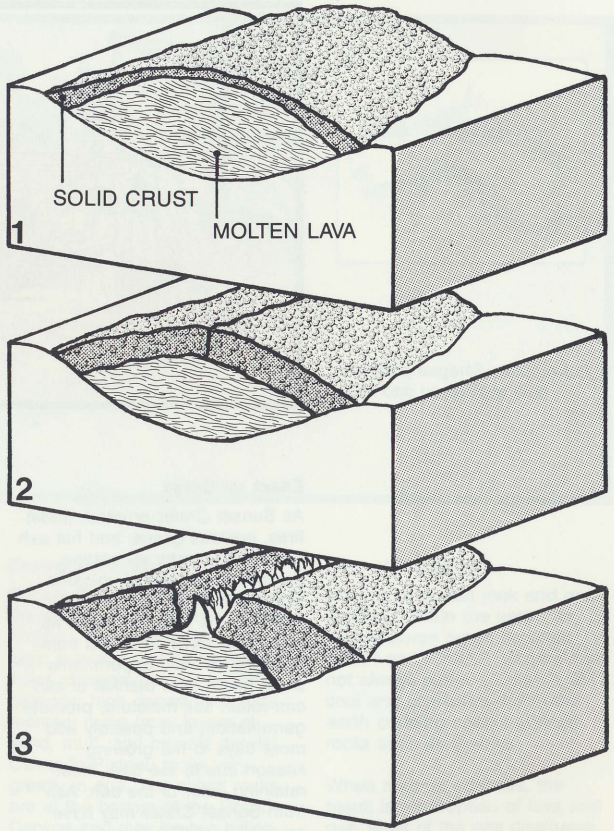
The Sinagua indirectly provided the first information used to date Sunset Crater. Trees in the area that survived the eruption acquired several years of stunted growth rings caused by the adverse conditions of heat and falling cinders from the volcano. Some of these trees were later harvested and used to build Wupatki Pueblo. When archeologists found these timbers and matched their growth ring pattern against a master chart, they discovered that the stunted growth began in A.D. 1064 or 1065. This process of dating from tree ring patterns is called dendrochronology.

SQUEEZE-UPS

Every rock should be regarded as leaverite; leave it right where it is.

Edward Abbey

The standing section of lava ahead of you is an *anosma* or squeeze-up. Squeeze-ups form when molten lava from the interior of a lava flow oozes out through a crack in the solid lava shell. The pressed-up lava is very plastic, like clay, and is molded into a wedge-shaped mass as it rises from the crack. As the squeeze-up grows, gravity causes it to bend. On the face of the squeeze-up are vertical grooves or striations caused when the molten mass scraped against the walls of the crack.



(1) Thin crust develops over molten lava.

(2) Crust thickens. Lava beneath crust continues to move about causing crust to crack.

(3) Crack widens. Thick lava still in molten state under the crust oozes out through crack.

CHANGING LIFE FORMS

Observe always that everything is the result of change, and get used to thinking that there is nothing Nature loves so well as to change existing forms and to make new ones like them.

Marcus Aurelius

Whatever vegetation existed within what is now Sunset Crater National Monument was destroyed by the volcanic eruption. Today plants still struggle to grow. Unlike Hawaii where abundant moisture promotes plant growth soon after eruptions, Sunset Crater averages only 16 inches of precipitation a year, most of it being quickly absorbed by the cinders. Only where the cinder layer is thin or where wind had deposited soil and plant matter can plants survive. Along the trail are signs identifying the common plants of the Bonito Flow.

Volcanic Specializations

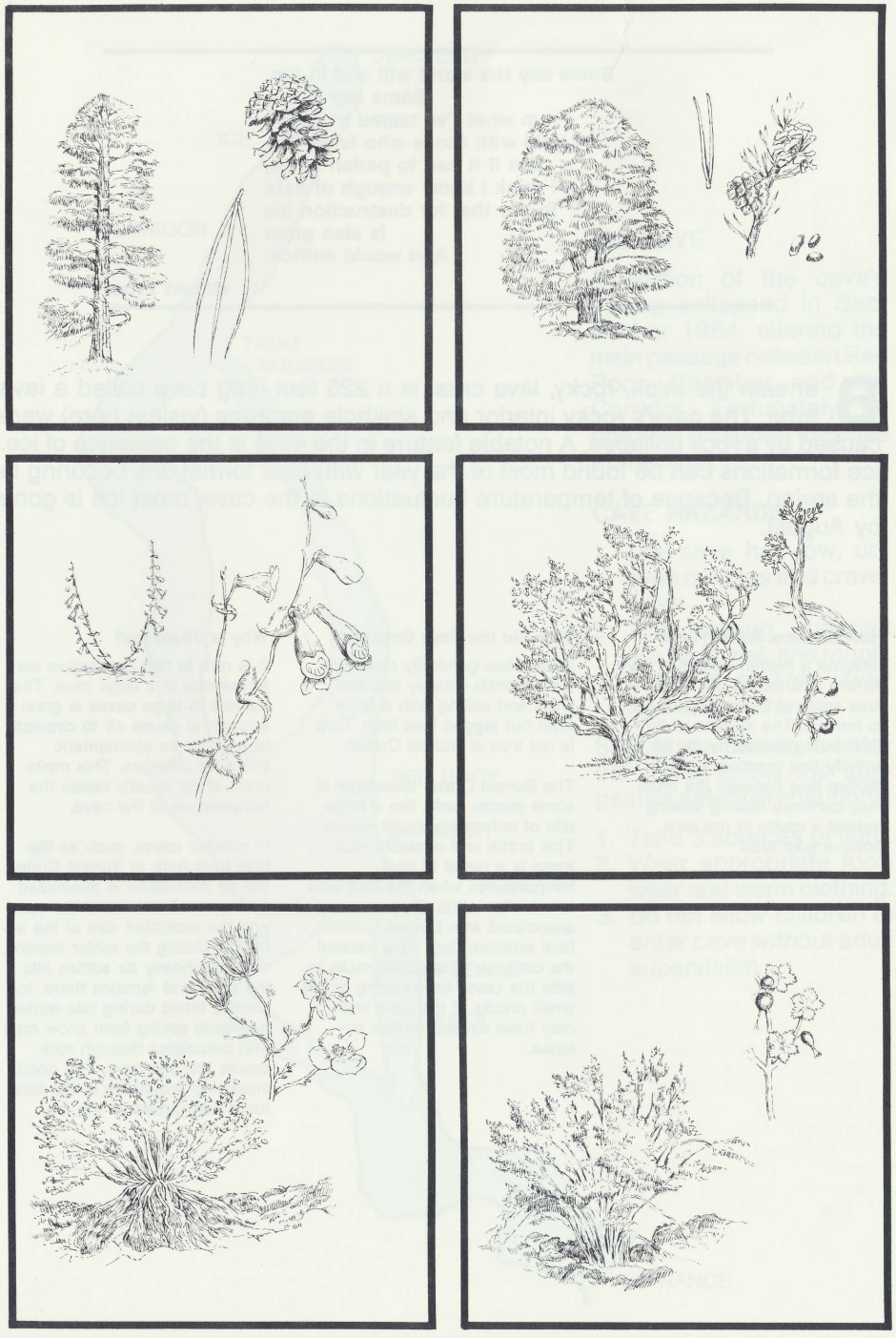
If you visit Sunset Crater in June or July, you may notice a lovely pink tubular flower. It is the pink penstemon *(Penstemon clutei)*, an endangered plant restricted to the area around Sunset Crater. The pink penstemon has a larger floral tube than its nearest relative in Oak Creek Canyon 45 miles south of Sunset Crater. The difference in the two flowers may be a gradual adaptation to a different insect pollinator after Sunset Crater's eruption.

Please don't pick the pink penstemon or any other plants you find blooming in the park during your visit. Every flower picked means fewer seeds to produce more flowers.

Succession

Plant succession starts with the creation of soil. Lichens, a partnership between an alga and a fungus, begin the process by producing an acid which breaks down rocks. Lichens live a very long time and those on the rocks around Sunset Crater may have begun forming not long after the lava cooled. Lichens eventually produce tiny pockets of soil in which mosses take hold. Small plants follow and finally trees whose roots crack and break up the rock.

Vegetation you may see growing along the trail includes ponderosa pine, quaking aspen, pinyon pine, juniper, Apache plume, and wax currant.



(Clockwise from upper left) Ponderosa pine, pinyon pine, one-seed juniper, wax currant, Apache plume, pink penstemon.

UNDERCURRENTS

Some say the world will end in fire,
Some say in ice.
From what I've tasted of desire
I hold with those who favor fire.
But if it had to perish twice,
I think I know enough of hate
To say that for destruction ice
Is also great
And would suffice.

Robert Frost

Beneath the thick, rocky, lava crust is a 225 foot long cave called a lava tube. The cave's rocky interior and sinkhole entrance (visible here) were caused by a rock collapse. A notable feature in the cave is the presence of ice. Ice formations can be found most of the year with best formations occuring in the spring. Because of temperature fluctuations in the cave, most ice is gone by August.

How Do Lava Tubes Form?

Imagine a molten stream of lava. As the lava moves along, it will lose some of its heat and begin to harden. The surface of the flow, being cooled by the air, will solidify first creating a crust. The molten lava beneath the crust may continue flowing leaving behind a cavity in the lava flow—a lava tube.

Why Did the Cave Collapse?

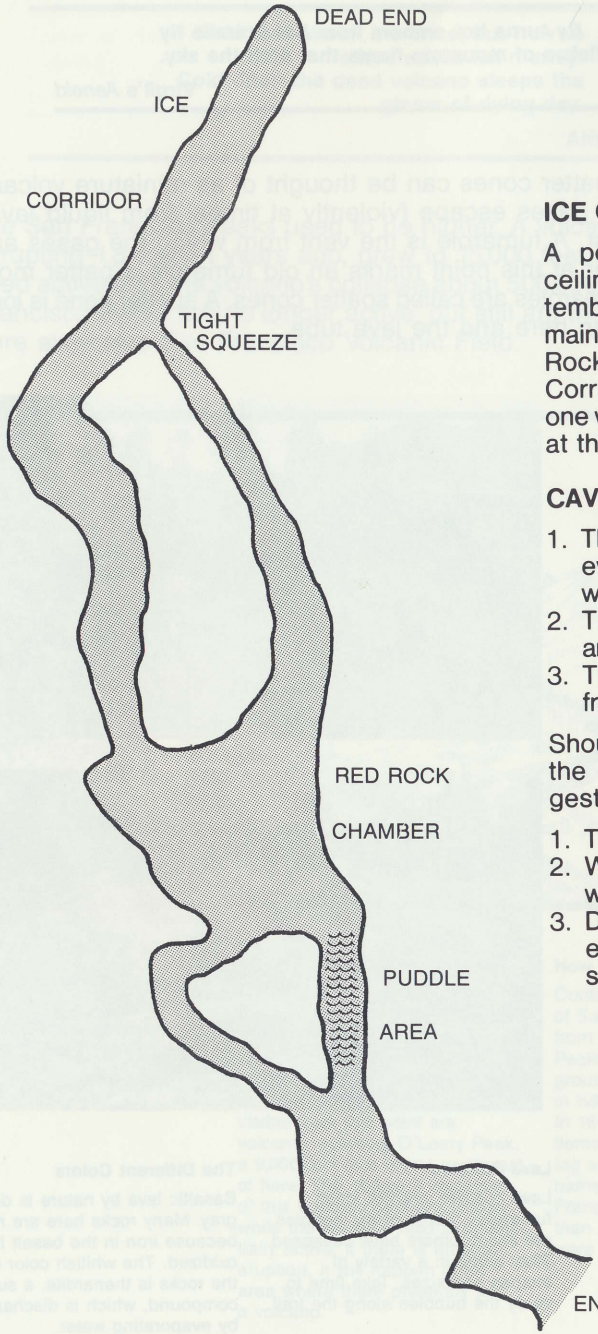
Lava tubes generally resemble train tunnels—nicely rounded walls and ceiling with a fairly level but jagged lava floor. This is not true at Sunset Crater.

The Sunset Crater lavascape in some places looks like a huge pile of unfused volcanic rubble. This brittle and unstable rock mass is a result of cool temperatures when the lava was in a molten state. Tremors associated with Sunset Crater's final eruption may have caused the collapse of unstable rocks inside the cave. Ice wedging in the small cracks of the cave walls may have caused further collapse.

Why is There Ice?

It is rare to find impressive ice formations in a large cave. The volume in large caves is great enough to cause air to circulate in and out as atmospheric pressure changes. This movement of air usually raises the temperature of the cave.

In smaller caves, such as the lava tube here at Sunset Crater, the air circulation is minimized by the small interior of the cave and the restricted size of the entrance. During the winter months, cold and heavy air settles into the cave and remains there. Ice usually forms during late winter and early spring from snow melt that percolates through rock cracks into the cave. The good insulating properties of the lava rocks help preserve the ice.



ICE CAVE

A portion of the cave's ceiling collapsed in September 1984, altering the main passage between Red Rock Chamber and Ice Corridor. Fortunately no one was exploring the cave at the time.

CAVE HAZARDS

1. The cave has low, uneven ceilings and crawlways.
2. The walking surfaces are slick, wet, and rough.
3. There is no light away from the entrance.

Should you decide to enter the cave, follow the suggested safety precautions:

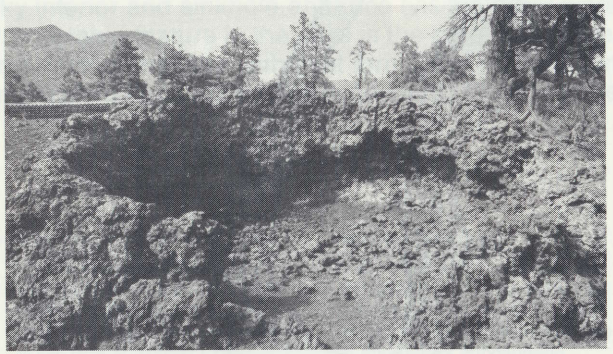
1. Take 3 sources of light.
2. Wear appropriate footwear and warm clothing.
3. Do not allow children to enter cave without adult supervision.

MINIATURE VOLCANOES

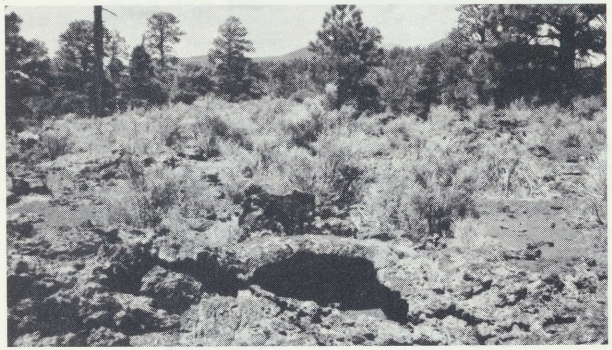
By turns hot embers from her entrails fly
And flakes of mountain flame that arch the sky.

Virgil's *Aeneid*

Fumaroles and spatter cones can be thought of as miniature volcanoes. They form when gases escape (violently at times) from liquid lava beneath the cooling crust. A fumarole is the vent from which the gases are released. The little crater at this point marks an old fumarole. Spatter mounds that build up around fumaroles are called spatter cones. A spatter cone is located along the path between here and the lava tube.



Fumarole with spatter build up.



Lava bubble.

Lava Bubbles

Lava bubbles are like small fumaroles. Some of the bubbles are intact, others have collapsed. They come in a variety of shapes and sizes. Take time to study the bubbles along the trail.

The Different Colors

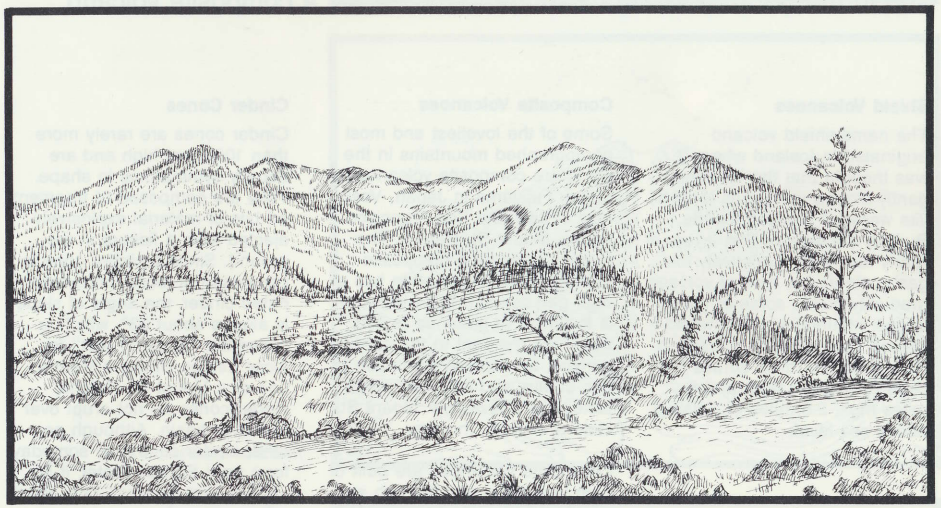
Basaltic lava by nature is dark gray. Many rocks here are red because iron in the basalt has oxidized. The whitish color on the rocks is thenardite, a sulphur compound, which is discharged by evaporating water.

THE PEAKS

Fires that shook me once, but now to
silent ashes fall'n away.
Cold upon the dead volcano sleeps the
gleam of dying day.

Alfred Tennyson

The San Francisco Peaks used to be higher. A volcano, the Peaks began erupting 1.8 million years ago, grew to 15,000 feet above sea level, and remained active until the volcano's collapse about 500,000 years ago. Today the San Francisco Peaks are no longer active, but still are the dominant feature of the more extensive San Francisco Volcanic Field.



The San Francisco Peaks. Left to right: Fremont Peak (11,969), Doyle Peak (11,460), Agassiz Peak (12,356), Humphreys Peak (12,633), Rees Peak (11,474).

San Francisco Volcanic Field

The San Francisco Peaks are the nucleus of the San Francisco Volcanic Field, a 2,200 square mile landscape of lava flows, cinder cones, and other volcanic wonders. All hills and mountains visible from this point are volcanic including O'Leary Peak, a 9,000 foot lava dome northwest of here. The 400-plus volcanoes of this volcanic field are extinct while the volcanic field is potentially active. If there is another eruption, it will happen in an area where there presently isn't a volcano.

How Did They Get Their Name?

Contrary to local stories, the city of San Francisco cannot be seen from the top of the Peaks. The Peaks were named in 1629 by a group of Franciscan missionaries in honor of St. Francis of Assisi. In 1847, a small west coast settlement on the verge of becoming a boom town changed its name from Yerba Buena to San Francisco. This happened more than 200 years after the Peaks were christened.

MAKING A MOUNTAIN

In nature things move violently to their place and calmly in their place.

Francis Bacon

Volcanoes form when hot gases and molten rock (magma) inside the earth break through the earth's surface. Thin and runny magma with little gas produces a quiet eruption and a shield volcano will result. Magma containing minerals which make it thicker and cooler or magma with a high gas content results in an explosive eruption creating either a composite volcano or cinder cone. Of these three types of volcanoes, only cinder cones and a composite volcano can be found in this area. Behind you is Sunset Crater, a cinder cone, and in the distance are the San Francisco Peaks, a composite volcano.

Shield Volcanoes

The name shield volcano originated in Iceland where it was thought that the rounded, gently sloped volcanoes looked like warriors' circular shields. Built by successive thin layers of runny lava with a relatively low gas content, this type of volcano gradually builds some of the largest mountains in the world. Mauna Loa, a shield volcano in Hawaii, is 120 miles across the base on the sea floor and 6 miles high, 2.5 miles of it rising above sea level.

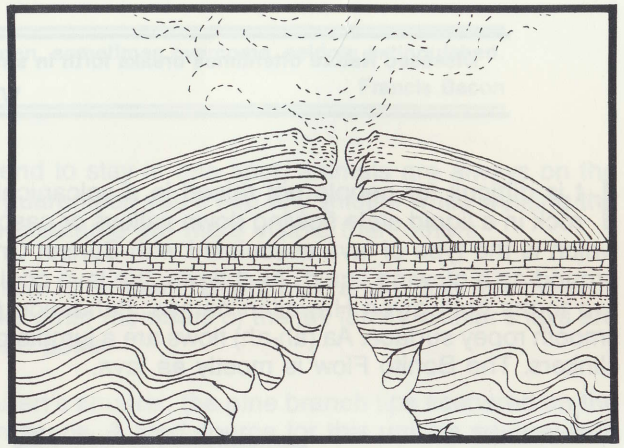
Composite Volcanoes

Some of the loveliest and most photographed mountains in the world are composite volcanoes: Mount Fujiyama in Japan, Vesuvius in Italy, the San Francisco Peaks, Mount St. Helens. The magma beneath a composite volcano is thick and often has a high gas content. If the magma is too thick or gaseous to flow freely out the vent to the earth's surface, an explosive eruption of bits of lava and ash may result instead of a lava flow. Mount St. Helens erupted this way.

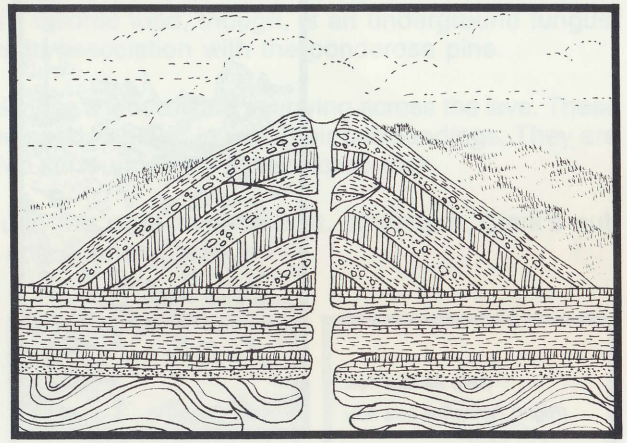
Composite volcanoes are built of both lava flows and the ash and small bits of explosive (pyroclastic) eruptions. Composite volcanoes also alternate between periods of fierce activity and dormancy for many years. Mount St. Helens, for example, rested for 123 years before this latest burst of activity.

Cinder Cones

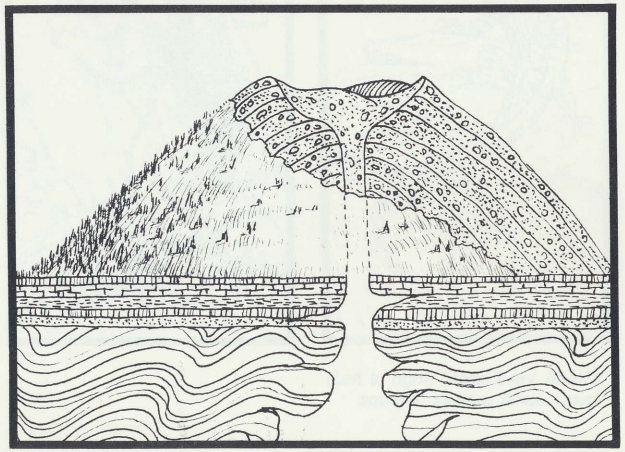
Cinder cones are rarely more than 1000 feet high and are usually symmetrical in shape. They are composed of fragmented bits of material explosively ejected from a fissure in the ground. Since a cinder cone is composed of loose, unconsolidated cinder, the angle of slope is always about 33°, which is called the "angle of rest" for loose cinder. Unlike a Mauna Loa or a Mount St. Helens, cinder cones do not erupt over and over again. Although another cinder cone may someday form near Sunset Crater, it is unlikely that Sunset Crater itself will erupt again.



A shield volcano.



A composite volcano.

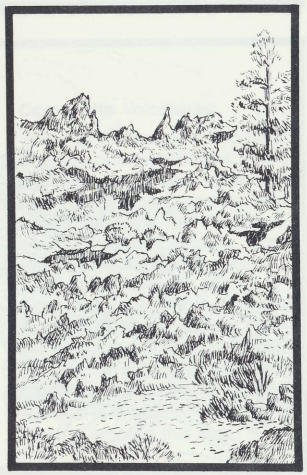


A cinder cone volcano.

ROPES AND CLINKERS

Diseased Nature oftentimes breaks forth in strange eruptions.
William Shakespeare

It is difficult for people not raised in a volcanically active area to imagine rock in a liquid state flowing down valleys or cascading over ridges. Basalt, which is the type of lava associated with Sunset Crater, emerges from below ground as a glowing liquid. As it flows, the lava cools and hardens into one of two forms both given Hawaiian names. Pahoehoe (pa-hoy-hoy) flows have a smooth ropey surface. Aa (ah-ah) flows are a jumble of jagged blocks and sharp clinkers. The Bonito Flow is mostly aa lava.



(Left) Aa lava flow.
(Right) Pahoehoe lava flow.

Why Different Flows?

There seems to be no chemical difference between aa and pahoehoe lava. Usually basaltic lava flows start as pahoehoe, thin and runny. As the lava cools and becomes more viscous, it can change into an aa flow.

There is some indication that gas content of the lava also influences the type of flow. More gaseous lava is often more fluid and tends to solidify more often as pahoehoe.

FEATHERS AND FUR

Nature is often hidden, sometimes overcome, seldom extinguished.
Francis Bacon

Unlike plants, which tend to stay in one spot, animals are always on the move. There are no guarantees you'll see any wildlife while walking the Lava Flow Trail, but some creatures are more visible than others.

The Steller's jay is most likely to be seen. Bright blue and black, it is the only crested jay in the West. Like other members of the jay family, Steller's jays are bold and noisy campground pests.

Even if you don't see an Abert's squirrel, the pine branch tips scattered on the trail are evidence of its presence. A food source for this unique squirrel with large pointed ears and fluffy tail is the inner layer, the cambium, of the branch ends. The Abert's squirrel's favorite food, though, is an underground fungus, a sort of truffle, that grows in association with the ponderosa pine.

On warm days you might glimpse a fence lizard scurrying across the lava. These lizards have gradually developed to blend in with their surroundings. They are darker than lizards who live surrounded by light-colored rock.

Other creatures here include the mule deer, bobcat, chipmunk, Clark's nutcracker, pygmy nuthatch, and gopher snake.

(Left to right) Steller's jay, Abert's squirrel, eastern fence lizard.

VOLCANIC FORECASTING

Come out, come out wherever you are.

Anonymous Kid

If you study the lava piles around you, can you conclude with certainty that that they are harmless or the next Mount St. Helens? Volcano watchers warn that too little is known about volcanic behavior to make accurate predictions of eruptions. Still, progress is being made. At Mount St. Helens, between 1980 and 1983, 13 minor eruptions were predicted with surprising accuracy. Because of Mount St. Helens, volcanologists are more optimistic about their ability to make accurate, short-term predictions.

Probing the Earth

Rising magma is often accompanied by a swarm of small (many times unfelt) local earth movements. The movements, which can be detected by seismometers at the volcanic site, help scientists locate the elusive magma in this geologic game of hide and seek. Information from seismometers goes to seismographs where the tremor's "signature" is written down on paper. Besides giving information on the size, location and frequency of earth movements, earthquake signatures also help scientists locate bodies of magma within the earth. This information is important for determining the chances of a possible volcanic eruption. A harmonic tremor, a continuous earthquake lasting a few minutes to many days, is a good sign that an eruption is about to begin.

On display at the Sunset Crater visitor center is a seismograph used for recording earthquakes. Take time during your visit to see the display.

Stay Tuned...

...there's more action to come! In 1983 the U.S. Geological Survey published a list of 35 volcanic sites in the western United States, Alaska, and Hawaii that are likely to erupt again. In the western states, there are seven volcanic sites that erupt about every 200 years or less. They are, in order of decreasing concern: Mount St. Helens (WA), Mono-Inyo Craters (CA), Lassen Peak (CA), Mount Shasta (CA), Mount Rainier (WA), Mount Baker (WA), and Mount Hood (OR). Also of concern is the Long Valley Caldera (near Mammoth Lakes, CA) where rising magma is causing the earth to bulge. The San Francisco Volcanic Field is near the bottom of the U.S.G.S. list.

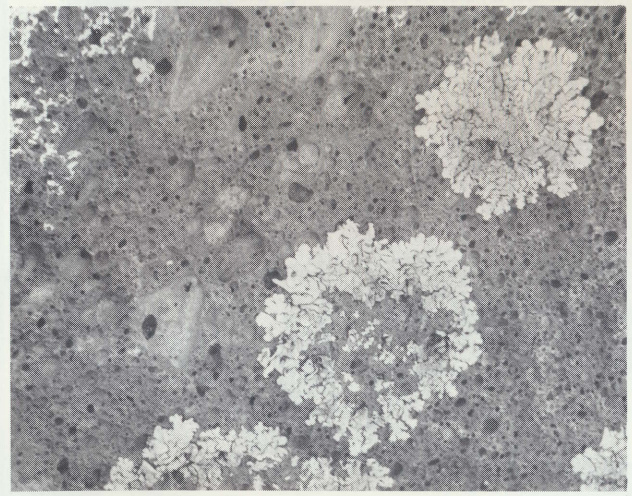
COLORS OF SUNSET

The contrast in the colors is so great that on viewing the mountain from a distance the red cinders seem to be on fire. From this circumstance the cone has been named Sunset Peak. When distant from it ten or twenty miles it is hard to believe that the effect is produced by contrasting colors for the peak seems to glow with a light of its own.

John Wesley Powell

At first glance, Sunset Crater's basaltic lava flows appear to be a mass of gray volcanic rubble, in some places as fresh-looking as the day they poured from the earth. A closer inspection reveals distinctive colors. Along the lava wall, about 130 feet east of here, are rocks stained by a chemical residue left from gases escaping the lava flow. A variety of lichens also color the rocks.

On the rim of Sunset Crater are the red cinders the volcano is noted for. The cinders were colored by the oxidation of iron particles in the basaltic rocks. On the east rim of the crater (not visible from here) are yellow, purple, and green deposits of gypsum, sulphur, and limonite that evaporated out from hot gases and steam. The vari-colored rocks of the volcano reminded explorer John Wesley Powell of the colors of the sunset—hence the name.



Lichen covered rocks add color to the volcanic landscape.

What's in Basalt?

Rocks are made of minerals, minerals of elements. The lava and cinder rocks around you are basaltic. Minerals common in basalt crystallize from molten rock containing a group of elements said to be mafic (calcium, iron, and magnesium). When iron-rich basaltic rocks are exposed to air and moisture during extrusion, the iron oxidizes and turns the rocks rusty red. It should be noted that black basalt and oxidized red basalt have the same composition.

SUNSET CRATER

THE ERUPTION OF SUNSET CRATER

On the following day the smoke arising from the San Francisco Peaks seemed to be threatening, and those that were considered the better class of people became alarmed.

Hopi Legend

Sunset Crater grew up around a weak spot along a four mile fissure that extended through an area surrounded by older volcanoes. Tremors preceded the eruption. In A.D. 1064 or 1065, the fissure opened, volcanic fragments called *pyroclastics* shot upward, and a new volcano was born. The cinder cone grew as the shower of cinder and ash continued. Activity was minor after 1090, but the volcano wasn't dead. Starting in 1150 and again in 1220, lava flowed from the base of the volcano—first from its east base and then from its west base. Finally Sunset Crater's chain of volcanic events came to an end. In 1250, the crater coughed out its last cinders—the red cinders that are its trademark.

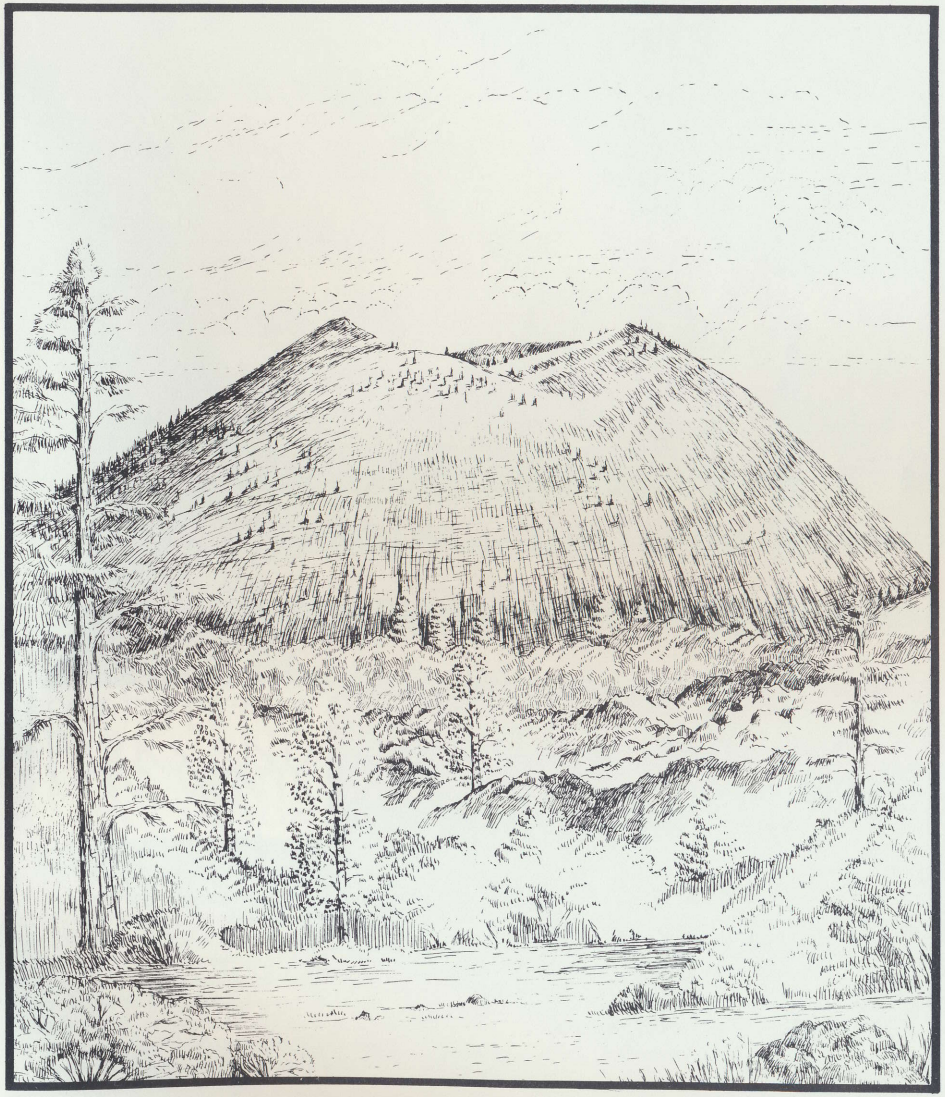
Sunset in the News

Sunset Crater was one of the training sites for the Apollo 17 crew. Part of the monument was used to test an electric-powered lunar vehicle called a "grover."

Also, Sunset Crater was almost in the movies. In 1928, a movie company wanted to dynamite the crater to simulate an eruption. This near destruction of the volcano was instrumental in gaining it protection as a national monument.

Sunset Crater Data

Height: 1,000 ft. (305 m.) high
Diameter at base: 1 mile (1.6 km.)
Diameter at top: 2,250 ft. (868 m.) from rim to rim
Weight: approximately ½ billion tons
Depth of crater: 300 ft. (91.4 m.) deep

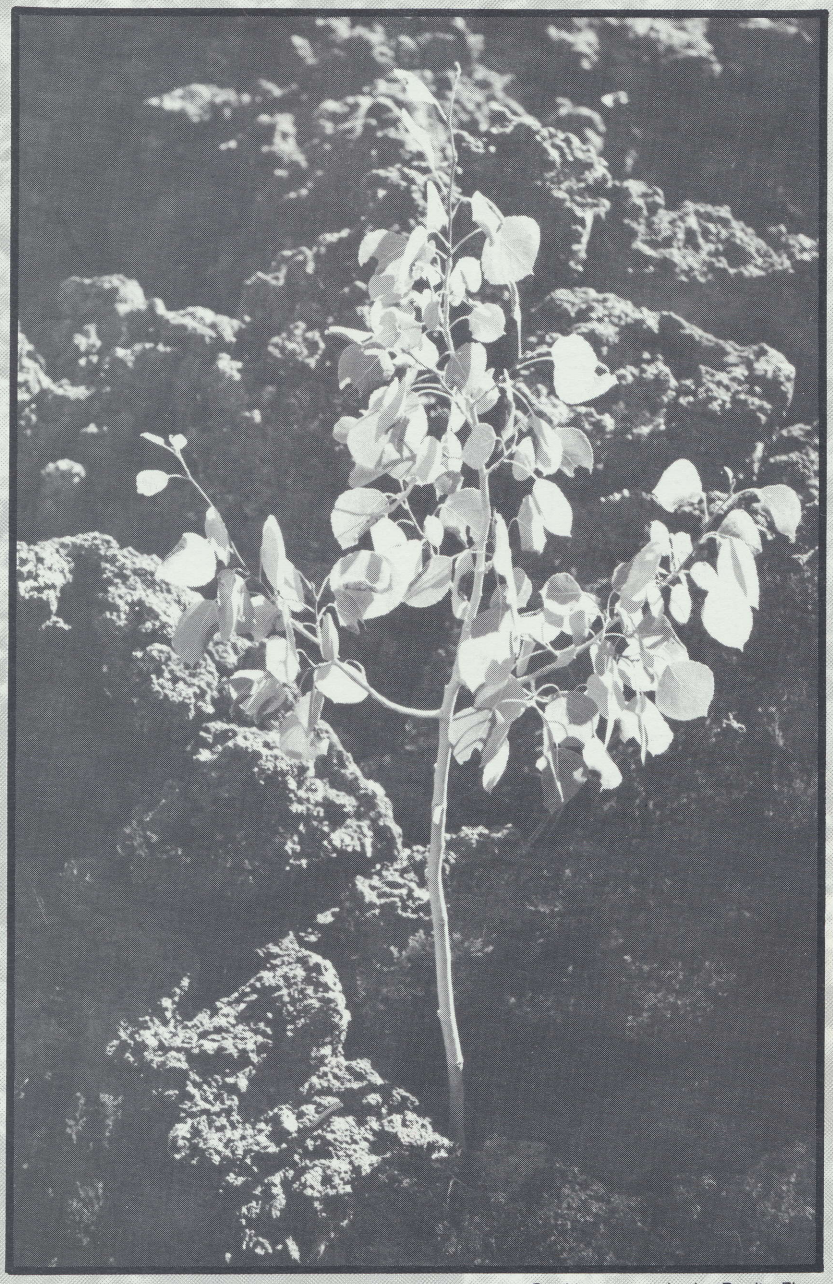


Sunset Crater

NOTES

SOUTHWEST PARKS AND MONUMENTS ASSOCIATION

Southwest Parks and Monuments Association was founded in 1938 to aid and promote the educational and scientific activities of the National Park Service. As a nonprofit organization authorized by Congress, it makes interpretive material available to visitors by sale or free distribution. All net proceeds support the interpretive and research programs of the National Park Service.



Quaking aspen in the Bonito Flow.

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