Teachers' guide to

BROKEN TOP LOOP

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This guide is designed as a resource for teachers who have attended the teachers' workshop presentation of the loop trail and are now bringing their classes.

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LOGISTICS

Park at the Tree Molds Parking Lot. To guide your students around the Broken Top Loop, including Buffalo Caves, will require a minimum of 2 hours and cover a distance of 1.8 miles. Because none of the loop trail is surfaced, with the exception of the segment along the road, and there are areas where the trail is very steep, the trail is not recommended for students with walking disabilities. Make students aware that they will be gone for over 2 hours and that, other than the vault toilets at the parking lot, there will be no restroom facilities along the route. For safety reasons, as well as for students to see and for the teacher to be heard, it is recommended that groups be kept to 30 students or less.

SAFETY

1 Each person should carry at least a pint of drinking water. **2** A first-aid kit should be carried in the event that a student trips or falls and gets a cut or scrape. **3** Students should wear long pants, which can prevent or reduce the severity of a cut or scrape. **4** Students should wear sturdy shoes, which increase traction and lessen the chance of slipping or turning an ankle; sandals should not be permitted. **5** If you are going into the Buffalo Caves with your group, each person should have a reliable flashlight.

Safety messages throughout the Teachers' Guide are highlighted in **RED**.

THINGS TO BRING ALONG

EACH LEADER
water
first aid kit
map and guide

EACH STUDENT
water
long pants
sturdy shoes

OPTIONS
hand lens
binoculars
camera

RESOURCE PROTECTION

Please help us to protect this resource so that future generations of students can also enjoy it. Insist that students stay on the trail, do not litter or throw rocks, and take only pictures. You can point out that, with about 225,000 visitors per year, it wouldn't take long for the place to look very different if people were allowed to collect things or take home souvenirs from the Monument.

Resource protection messages throughout the Teachers' Guide are highlighted in **BLUE**.

If each visitor took just one hand specimen, 86 small dump truck loads of material (4 cubic yards each) would be leaving the park each year.

HARD AS A ROCK?

While the lava flows seem indestructible, these rocks are very fragile! The crust covering the lava flows is brittle and will fracture and break if you step on it. Any place where the lava is orange instead of black indicates that the crust has been damaged and the oxidized lava underneath is now exposed. Hollow ropy lava, crumbly crater walls, and honeycombed cinders can be destroyed by a careless step. *You* can make a difference.

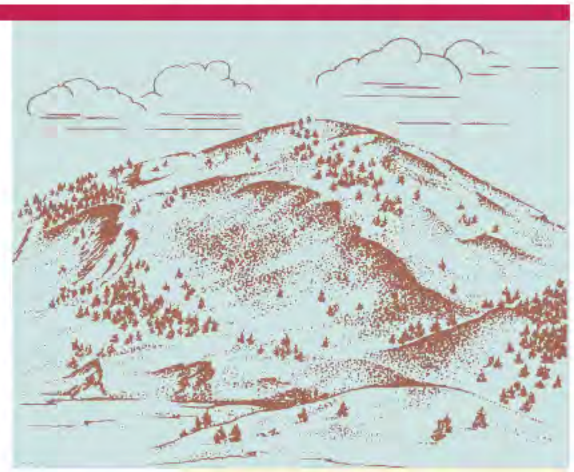
Stay on the trails wherever possible.

If exploring the Monument where there are no trails, please follow these low-impact hiking techniques:

- The first choice is to walk on soil-covered areas, then cinders, then the lava flows.
- Do not climb or walk on fragile features such as the monoliths, spatter cones, or tree molds.

We appreciate your cooperation! Remember,
THE ROCKS ARE FRAGILE!

PARKING LOT



Big Cinder Butte, one of the largest basaltic cinder cones in the world.

Repetition is the mother of learning. Begin by reviewing the geologic setting of Craters of the Moon. Have students summarize what they have learned at the visitor center or previously in school about the Yellowstone Hot Spot (original *source* of heat and molten basaltic material), The Great Rift (*pathway* related to Basin and Range Type Faulting), and the Stages of Eruption.

Because a number of cinder cones are visible from here, it is an excellent place to discuss what happens when **magma*** comes to the surface with a lot of dissolved gasses.

**** If a scientific term is defined in the glossary, it will appear in bold print the first time it is used.***

The Great Rift will be discussed in more detail at Stop 1, Eruptive Fissure, so plan on discussing the Great Rift at that stop. Do the film can eruption again, or ask students to think back to when they saw the demonstration earlier.

FILM CAN EXPERIMENT AND ANALOGIES TO VOLCANIC ERUPTIONS

This simple experiment gives students a tangible model to which to relate volcanic activity:

Fill a plastic film can about 1/3 full with water and then drop in an "Alka-Seltzer" tablet; cap it and make sure it isn't pointing at anyone (the cap may shoot as high as 20 feet in the air). Just like the film can lid, if molten rock comes to the surface with a lot of dissolved gasses it too gets thrown high into the air when the pressure is released. (You can also use a pop or champagne bottle analogy.) As the material rains back down, it can pile up to form cinder cones. Dump what remains of the tablet on the pavement. This represents a later stage when lava pours out more quietly onto the surface. Just like the tablet, which is still fizzing, magma that has had much of the pressure released is free to flow out onto the surface in a more quiet fashion in the form of lava flows. This flowing lava still has gasses left in it, which produces the holes that the students will see in the lava as they walk from the parking lot to where the trail starts up the side of Broken Top (NE of the parking lot).

Big Cinder Butte, SE of the parking lot, is a great example of magma coming to the surface with a lot of dissolved gasses! It is the largest **cinder cone** in the park, and one of the largest basaltic cinder cones in the world. The fountain of fire that produced it was probably greater than 1,000 feet high, and possibly more than 1,500 feet. The cone itself is more than 700 feet high (therefore, the minimum height for the fire fountain had to have been 700 feet). Big Cinder is more than a mile across at the base.

Big Cinder is asymmetrical (lopsided) in shape, which was caused by more material being carried and deposited in the downwind direction by the prevailing winds. (The low hills on the right as you view the cone from the parking lot are also a part of Big Cinder Butte.) Many cones at Craters of the Moon are higher on their NE sides because the prevailing winds in the past, just like today, were out of the SW.

Big Cinder formed about 6,000 years ago and the hill (unnamed cinder cone) rising behind the parking lot is also believed to be of similar age.

STUDY OPTION: PLANTS & SOILS

Look at some of the plants here, while students are taking turns using the restrooms. Have the students examine scorpionweed and dwarf buckwheat with hand lenses and describe what they see. Descriptions, pictures and information on how the plants are adapted to survive in this not only harsh volcanic terrain but also high desert environment can be found in Appendix III. Good plants to study at the parking lot are scorpionweed, dwarf buckwheat, sulfur buckwheat, antelope bitterbrush, rubber rabbitbrush, and sagebrush. Cut bank along sidewalk is also a great place to talk about loess - see page 11 for a description of loess.

In comparison to composite or strato volcanoes, such as those found in the Cascade Range, with which most students are often more familiar, the cinder cones may seem small, but for their type they're really not. Sometimes going over the dimensions of Big Cinder, in addition to telling the students that it is a world-class feature, will leave the students with a more accurate impression.

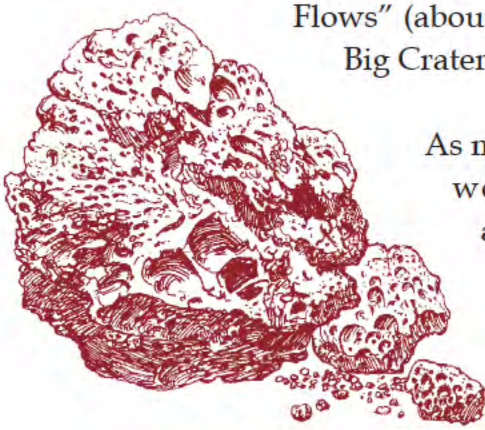
You can ask students to speculate on why Big Cinder is lopsided. Some may be able to guess that the wind did it. This concept can be reinforced at either Stop 2a or 2b when viewing Silent Cone and Big Craters from along the trail. You can also point out to your students that they are drawing conclusions based on concrete evidence to explain what must have gone on in the past—uniformitarianism or the concept that the present is the key to the past.

"Wildflowers of Craters of the Moon National Monument," available in the Natural History Association bookstore, is a useful guide on this subject. Appendix IV is a list of commonly seen plants.

Dward buckwheat.

Follow the paved trail on the south side of the road to where it forms a T intersection with the loop. Turn left.

Point out as students walk by the flows that the lava is filled with gas holes and resembles Swiss cheese. The lava flow that the road passes over is part of the "Blue Dragon Flows" (about 2.1 Ka) that originated in the Big Craters/Spatter Cones Area.



Lava is often filled with gas holes. It reminds many people of Swiss cheese.

As mentioned during the teachers' workshop, the **aa** or rough-appearing material seen along the road is actually slabby pahoehoe (chewed up lava in which the ropey **pahoehoe** nature can still be seen on the tumbled plates and slabs). Slabby pahoehoe is the result of shearing caused by the steepness of the slope it was flowing down or the roughness of the bed surface or possibly both. You can point out where the lava switches back to pahoehoe probably because the slope decreased as the flows came upon the edge of the spatter rampart, the low hill next to the eruptive fissure. It could not switch back to pahoehoe if it was caused by cooling and degassing.

Ma = *million years ago*
Ka = *thousand years ago*

Mother Nature's taffy rapids.

This discussion is probably too complicated for young students, but may be appropriate for earth science students.

PROCEED ...

690 feet to where the trail joins the loop.

ERUPTIVE FISSURE

The depression in this picture is an eruptive fissure. The material that built Broken Top was ejected from this fissure.

The Great Rift, the pathway that allowed molten rock to come to the surface runs from north of the visitor center, through this area, and to the SE, a minimum of 52 miles. As portions of the rift were forced open by rising magma, huge amounts of molten rock were spewed out onto the surface of Craters of the Moon. The steep-walled pit at the start of the trail is one of the eruptive fissures that built the cinder cone we call Broken Top.

You may see one of these yellow pine chipmunks feeding on an antelope bitterbrush.

Because the Blue Dragon Flow wraps around and partially fills in the fissure, the eruptive fissure and the cone that was built from it, i.e. Broken Top, have to be slightly older (>2.1 Ka).

The material that looks like it was flowing down into the fissure on either side is **spatter**, and forms a spatter rampart on the right. This spatter was thick liquid rock that was thrown out. After it landed and while it was still plastic, it crept or flowed back toward the fissure under the tug of gravity.

Point out that both the side of the volcano on the left and the low spatter rampart hill on the right are mantled or covered with numerous volcanic bombs as well as spatter. The main difference between spatter and bombs is that bombs were ejected higher and had more air time.

PROCEED ...

435 feet, about halfway up the slope on the right-hand side. The small limber pine tree here makes a good place to stop for people to catch their breath, to introduce the limber pine, and to make other observations.

LIMBER PINE

Limber pine, the most common tree found in the monument, is a five-needle pine.

Have the students look across at the lava flows on the other side of the road. Ask which seems easier for life to get a foot hold on, the rough or the smooth lava. Both are the same age. It should be obvious to most students that there is more vegetation on the smooth or pahoehoe lava. Most rocks at Craters of the Moon are too young to have broken down and produced much soil. Plant life is dependent on the deposition of wind-blown soil in order to have a growth medium in which to live. In general the older the lava flow or cinder cone, the more wind-blown soil that has been deposited and, therefore, the more plant life that exists.

The pahoehoe has more plant life because the soil that has accumulated is close enough to the surface that if a seed germinates it also has sunlight to conduct photosynthesis.

The slabby pahoehoe or rough lava has less life because the cracks are so deep that when a seed germinates there often isn't any light available. In Hawaii, just the opposite pattern is true. In Hawaii because of the hot moist climate and the greater surface area of the very rough clinkery lavas, known as aa, they break down much more rapidly than pahoehoe. Also, because of our high desert environment we have about the same amount of vegetation after 2,000 years as Hawaiian lava flows do after 40 years.

This is also a good spot to reinforce that winds during cinder cone formation can cause the cone to take on an asymmetrical or lopsided shape.

Have the students look at both Silent Cone and Big Craters as examples.

stop **2**

The limber pine *(Pinus flexilis)* is the most common tree found in the Monument. It is very appropriately named, for you can take a small branch and literally tie it in a knot. Limber pine is a subalpine species (normally found growing just below timberline); however, it finds similar harsh living conditions here because of the strong winds present during the summer, just like the strong winds found near timberline. Being flexible is very important because it allows the tree to bend rather than break or get uprooted by the wind. Its needles have fewer stoma (openings used for respiration) than most pines, which helps it to conserve water, which is very important here in the high desert.

Limber pine represents a relic population that got started here on older cones about the close of the last ice age.

Limber pine is usually found above 8,000 feet in Idaho, about a half mile higher than here.

PROCEED ... ***another 285 feet to the large limber pines at the curve on the trail ahead and continue the discussion there.***

stop **2a**

MISTLETOE

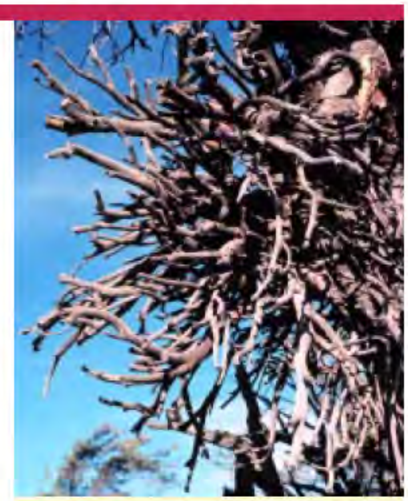
The Clark's Nutcracker is a pigeon-sized bird with a crow-like flight.

It takes 2 years for a limber pine cone to come to maturity, but when it does, it contains large pine nuts that feed many animals here at Craters of the Moon. The seeds are quite obviously too large to be dispersed by the wind, so the tree is dependent upon animals to distribute its seeds. The large gray jay-like bird commonly seen in the park around the limber pines is the Clark's nutcracker. A single Clark's nutcracker may make as many as 30,000 caches of limber pine nuts in a year, but never eats them all and therefore ends up planting new trees. Our pine squirrels also end up planting trees by caching nuts.

Clark's Nutcrackers have a sublingual pouch in which they can carry up to 17 pine nuts, but they usually only make caches of 5-7 nuts so that other animals can't steal all their food (i.e., don't put all your eggs in one basket).

Have a couple of the students pick up one of the cones and find the scars left by the seeds; have them pass it around so that all the students can get an idea of how big the seeds are. If you are lucky and if you look carefully, you may even find a seed on the ground.

The tree on the left side of the trail is a good place to see dwarf mistletoe. Look for yellowish shoots emerging from limbs. In late August, the berries, which look like fluid-filled blisters, swell and burst. The sticky seeds are ejected and carried on the wind to adjacent trees where they adhere to the needles. The mistletoe is a parasitic plant getting both sugars and water from its host tree. The mistletoe injects a hormone into the tree, which tells the tree to send more nutrients, which in turn causes the branch to swell and eventually causes a very dense branching pattern called witches' broom. Dwarf mistletoe rarely kills its host. There is no advantage for a parasite to kill its host because it would end up dying itself.



Witch's broom.

Dwarf mistletoe on a limber pine branch.

Desert parsley is an edible plant that was used as a salad green by the Indians. It looks like the parsley used as a garnish in restaurants. It is best if eaten before it has gone to seed, because afterward it is very bittter.

As you leave this stop, look around. There is usually some desert parsley in this area.

PROCEED ...

350 feet to the area just before the trail turns to the right and enters the open limber pine forest.

LOESS

The wind-blown soil that provides the growth medium for the plants here at Craters of the Moon is well exposed in this area. It is the tan-colored material exposed in the bank on the right side of the trail and has formed the tan mounds around many of the shrubs in this area. The scientific name for this material is **loess**. It is dominantly of silt size (silt is the particle size that falls in between very fine sand and clay-sized particles). The loess is material that was ground up by the glaciers up in the mountains, carried down onto the plains by the rivers that drain them, and subsequently sorted and transported by the wind. The dust that the students have been stirring up as they walked up the trail, unless it has rained recently, is loess.

Have the students take a pinch of the soil, getting the cinders out first, and rub it between their fingers. The tan, powdery-feeling material left on their fingers is the loess. Geologists use this technique as a crude tool to tell particle sizes apart. Sand feels gritty, loess or silt feels like talcum powder, and clay rolls up into little cigars.

Use this as an example of how easy it is to transport silt-sized particles.

It was mentioned earlier that the general pattern observed here at Craters of the Moon is that the older the flow or the cone, the more vegetation it has on it. Broken Top is an exception, one of those examples mother nature throws in to keep us humble, and what makes science more interesting. If you look across at Silent Cone you see a sagebrush steppe community on the south-facing slopes and an open limber pine forest on the north-facing slope. This is typical of a cone that is about 6,000 years old (Silent Cone is 6.5 Ka). Broken Top has this same pattern. You have sagebrush in front of you and as you proceed just a little further you will enter an open limber pine forest. Yet Broken Top is one of the youngest cones in the park. For some reason, a lot of loess has been deposited here in a short period of time. Perhaps Big Cinder and the unnamed cone behind the parking lot interrupted the wind sufficiently to cause a higher rate of deposition? A fire may also have remobilized soil that ended up deposited here.

Ask the students if they noticed that the sagebrush was much more common once they moved onto the lee slopes. As wind speed slowed, particles carried on the wind were deposited in these areas.

View of asymmetrical shape of cinder cones from Big Sink Stop.

stop 2b

Sagebrush requires a deeper soil profile to survive than does rubber rabbitbrush or antelope bitter-brush. Note as you enter the forest that the trail has merged with an old road, which was once used to drive sheep to the Little Prairie to graze.

PROCEED ... *315 feet around the corner into the open limber pine forest and stop at the large stump surrounded by a pile of pine cone debris on the right-hand side of the trail.*

stop 2c

MIDDEN

The pile is an old midden produced by the "chickaree" or "pine squirrel", which is a red squirrel. It is the smallest and most common squirrel throughout the Rocky Mountains. It is rust-red to grayish red above and white or grayish white below. This boisterous squirrel is often heard scolding hikers for being in its territory. The chickarees harvest large numbers of pine cones, which they store in middens for later use. These middens serve as their food banks for the winter; since they do not hibernate they remain active all winter. Chickarees are in competion with the Clark's nutcrackers for the pine nuts and will harvest the cones and put them in their middens before the cones have opened up, giving the birds easy access.

STUDY OPTION: LUPINE AND RYE

Between the midden and the bank of cinders is a good place to point out lupine and giant or Great Basin wild rye. The lupine has lavendar pea-like flowers and distinctive palmately compound leaves, each with 7-9 leaflets that radiate out from the tip of the leaf stalk. Lupine is a legume and fixes nitrogen, which adds to the fertility of the soil. The rye is easily distinguished by its height, between 3 and 4 feet. It was used by Native Americans as a grain and is an important food source for wildlife, especially in winter when other food is under snow.

Lupine.

Wild rye.

PROCEED ... *650 feet to new spur trail.*

stop **3**

BIG SINK SPUR TRAIL

A left turn at this junction will take you to the overlook of Big Sink.

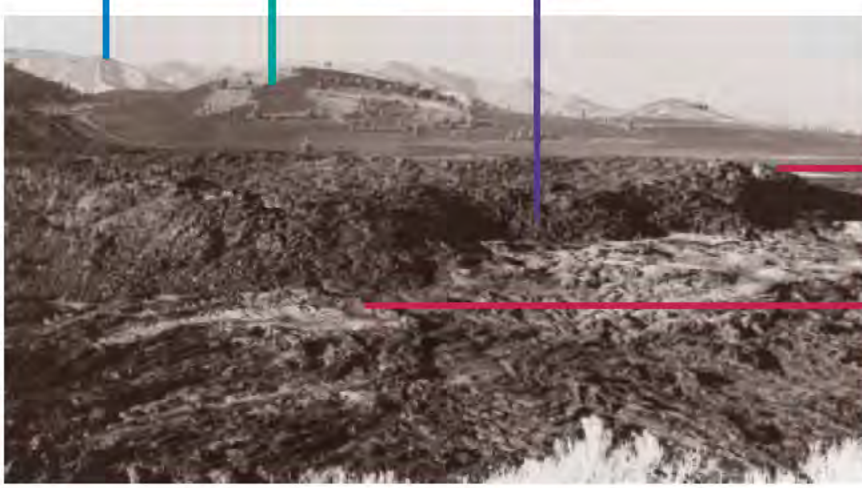
▶ **PROCEED ...**

570 feet to the overlook platform.

stop **3a**

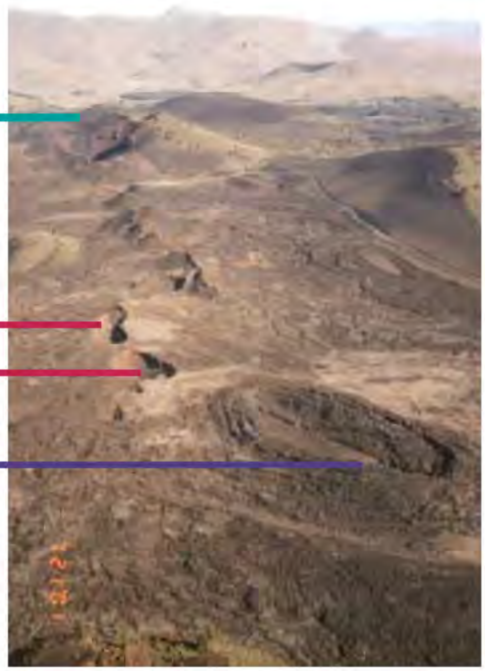
BIG SINK OVERLOOK

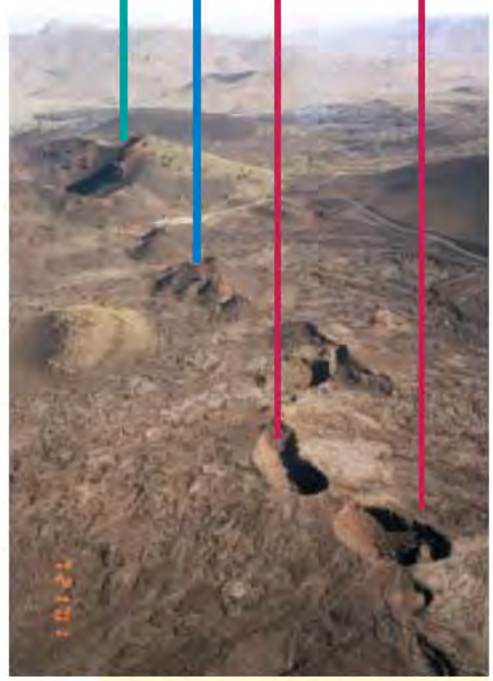
The large bathtub-like structure (3 football fields long and over 50 feet deep) located across the street from here is named Big Sink, and it does look like a basin or washbowl for a giant. Perhaps it started as a tumulus or mound above the tube that ruptured open to form the pond. Lava levels within this pond probably moved up and down and occasionally found weak spots in the levees or dikes that formed from chilled lava at the edges. At various times, the lava broke out forming rivers or streams of lava, and even cascades. Finally, the lava drained back into the tube system and the still plastic crust on top of the pond draped down making a bowl shape.



Big Sink is the raised area in the center of the photo. Behind it is Inferno Cone, and in the far background are the Pioneer Mountains.

Big Sink as it appears from a low-flying aircraft.





Views of features above Big Sink. These aerial photographs, along with the one of Big Sink on page 13, give an idea of some of the plumbing and features that will be talked about in the new waysides. Big Craters, top left, followed by the spatter cones, pit craters (collapses) and Little Sink.

PROCEED ...

570 feet back to the main trail and turn left, then go another 125 feet to the next stop along a large bank of cinders.

CINDER

You are on the far side of this cinder cone from the eruptive fissure out of which this material was ejected or thrown. Material thrown from a volcano is also known as ejecta or **pyroclastic** material. If the wind is blowing, lighter material is carried further downwind than heavier material. Many students will be amazed at just how light some of these cinders are. These cinders were highly gas charged and can be thought of as a froth, not unlike frothy slag which floats to the top in a blast furnace. These cinders can be thought of as volcanic slag from mother nature's blast furnace. Some of the cinders are light enough to float on water, but because the pores are usually fairly well interconnected they eventually fill with water, causing the cinders to sink. Pumice, on the other hand, which is frozen volcanic froth of a granitic rather than basaltic composition, usually has poorly interconnected pores and therefore can float almost indefinitely. In addition to being very light, many of the cinders in this bank exhibit a play of colors or an iridescence. The play of colors is believed to be caused by a very thin layer of glass on the surface of the cinder material, which refracts light much like an oil film on water.

Not all material thrown from a volcano is light in weight. Between here and the next stop keep an eye out for fragments of breadcrust bombs to show the students. Even though these bombs contain a lot of gas holes they are considerably denser than cinders. Breadcrust bombs form when globs of molten rock are thrown out and cool as they fly through the air. After a crust has formed on the glob, the gasses inside the bomb continue to expand, enlarging the bomb as it flies through the air and cracking the previously formed crust. This is very similar to what happens to bread that continues to rise in the oven as it bakes. Continued rising produces the cracked pattern in the crust. These bombs were named breadcrust bombs by volcanologists.

Iridescent cinder.

Have students examine some of the cinders to see how light they are and look for cinders with a play of colors on them.

MAKE SURE THAT THE STUDENTS TOSS THE SPECIMENS THAT THEY HAVE BEEN LOOKING AT BACK ONTO THE BANK. This might be a good time to remind them of how many visitors we get (~225,000) and what would happen if people were allowed to collect and take home souvenirs. Or bring it closer to home by asking students to imagine what this cinder bank would look like if each of the more than 4,000 school students that come here each year were to take a specimen. How many colorful cinders would be left? Would the bank change shape?

PROCEED ...

590 feet to where the trail turns and goes down the hill.

VISTA

Crescent-shaped spindle bomb.

Look behind the shrubs on the left side of the trail. You should find a spindle bomb with a crescent shape hidden behind one of them. Spindle bombs are globs of molten rock that were ejected just like breadcrust bombs, but got twisted during their flight. Some take on a spiral or football shape, some end up looking like a star or sunburst, some look like giant twisted ribbons or other bizarre shapes, and some take on a crescent shape like the one you are looking at.

SAFETY MESSAGE

Be careful when you pick the spindle bomb up, it is heavy.

Please put the bomb back out of sight after you have shown it to the students to reduce the chance of vandalism.

From the time you left the open limber pine forest you have been walking across a different terrain, an area of hummocks and hollows. What caused this to happen to the cone? This is not the way cinder cones normally look. Also, look off to the north and notice that there are lava beds that are tilted up sharply. Examination of these lava beds shows that they were laid down flat and were tilted up later. There are two hypotheses that explain both the hummocky topography and the tilted lava beds. The first hypothesis is that collapse back into the magma chamber after it emptied produced these features. It is easy to picture producing the hummocks and hollows from collapse, but not so easy to picture it causing the lava beds to be tilted. An analogy that might help the students is that the collapse is similar to pushing down on a balloon with your hand; it causes a raised edge to form around your hand. The second hypothesis is that some reinflation of the cone occurred associated with the Broken Top flows. The reinflation was not uniform and this chopped up part of the cone, producing the hummocky terrain and also tilting up the lava beds around the edge of part of the cone. An analogy of this might be inflating a rubber glove and where the fingers poked up you got hummocks.

Tilted lava beds that were originally laid down flat.

The large mountain rising from the floor of the plain about 25 miles to the east of here is Big Southern Butte. It is a different kind of volcano than those we have here at Craters of the Moon. It is a rhyolite dome that formed as rhyolitic magma slowly rose up through the layers of older basalt. The magma pushed the overlying layers upward, broke through, and flowed slowly onto the surface; Big Southern Butte is 300 Ka in age. East Butte, which is closer to Idaho Falls and has an assortment of radio and TV broadcast antennas on it, is 600 Ka in age. Some layers of basalt on Big Southern Butte were broken and carried up as the dome grew. These can be seen as you drive along HWY 20 to Idaho Falls. All that you can see on Middle Butte, which lies between Big Southern and East Buttes is domed-up basalt; it is believed to be the same age as East Butte.

The parent material for the rhyolite was basalt. It was separated off much like grease flating to the top of a pot of stew. The process is called fractionation or extreme differentiation.

Another kind of volcano is visible from this vista as well. Just this side of Big Southern Butte where the sky and land meet you can see several small shield volcanoes. They are convex up, gently arched structures that reminded early geologists of a knight's shield laying on the ground, hence the name shield volcano. Shield volcanoes are mostly made up only of lava flows; usually very little ash or cinders is erupted from the vent that produces them. As the lava continues to pour from the vent over a long period of time, the gently sloped mounds you see near the horizon are formed. As shield volcanoes go, these are small ones, particularly in comparison with the Hawaiian Islands, which are huge shield volcanoes.

Big Southern Butte.

The Eastern Snake River Plain is believed to be made up of about 8,000 shield volcanoes.

Look over at Big Cinder and you can see discrete layers of rock. These layers are not lava flows, but rather agglutinated cinders. Sometimes the cinders are so hot when they land that they weld or sinter themselves together in a process that geologists call agglutination. Notice that some of these layers have failed in landslide, not unlike a slab release avalanche. Based on the vegetation growing below these failures, they must have occurred long ago.

The densely (relatively speaking) vegetated lava flow before you is the Broken Top Flow and it is the youngest one in the park (~2 Ka). This is another of the exceptions to the general pattern of older volcanic features having more vegetation than younger ones. A geologic explanation will be given later in this guide when we talk about the Broken Top Flow again.

Ask the students to come up with an explanation.

Watch for deer tracks along the way.

PROCEED ...

580 feet down the trail and stop at the tall boulders covered with lichens on the right side of the trail.

stop 5a

LICHEN

Lichen-encrusted boulder.

Lichens are the first organisms that are able to colonize the rocks after they have cooled. Lichens are made up of two organisms that have a **symbiotic** relationship with each other: an algae and a fungus. There are 26 different algae (17 green, 8 blue-green, and 1 yellow-green) that can combine with either Ascomyocetes (tube fungi) or Basidiomyocetes (stem fungi) to produce every color of the rainbow. Lichens are very hardy and can survive up to 5 years in a dehydrated state. They start the soil-forming process by secreting an acid which breaks down the rock. Because all of these rocks are so young geologically, there has been very little time for either chemical or mechanical weathering to have produced soil. In addition, because of the desert environment, the action of the lichens is also a very slow process and has yielded a negligible amount of soil in contrast to that brought in by the wind.

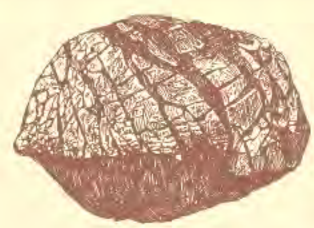
Many-colored lichen.

PROCEED ... *44 feet further and stop at the large breadcrust bomb on the right.*

stop 6

BOMB

This intact breadcrust bomb, which weighs well over one hundred pounds, should give students an idea of the force needed to throw something this large and heavy through the air. Some of the cow pie bombs the students will see later are more than 12 feet across. If you look around, you will see a number of bombs in this area. Some show a hybrid of both breadcrust and spindle characteristics.



Breadcrust bomb.

PROCEED ... *38 feet further and examine the surface texture of the Broken Top Flow on the left side of the trail.*

stop **6a**

BROKEN TOP FLOW

When you study the surface of the Broken Top Flow, you will find that the surface is covered with spherical or round pits generally less than a 1/4 inch across. They were caused by gas bubbles and the shape tells us that the lava had to be very hot and fluid in order for the surface tension to keep them round as the lava flowed. Each one of these pits had a bubble above it. From Hawaii we know that the surface of these bubbles is a thin film of glass. Within the first hour of cooling, contraction causes the bubbles to break, flinging glass shards outward. As these glass shards break down (a process called devitrification), they can form clay minerals (soil). Thus, a possible geologic explanation for why the youngest flow in the park has some of the densest vegetation is that the flow made its own soil. If you look to the East, you can see that the flow in this area was sufficiently gas-charged to produce small open tubes, blishters, and thin crusts (about 10 cm thick) and is known as shelly pahoehoe.

Ask the students to visualize miniature light bulbs.

PROCEED ... 43 feet further and look at the lava toes on the right side of the trail.

stop **6b**

LAVA TOES

The lava toes look like distal appendages of some huge monster that Medusa has turned to stone. These lava toes are the

"toe" of this breakout flow from the main body of the Broken Top Flow (further discussion of the Broken Top Flow will be provided at Stop 14, Buffalo Caves). These toes have a beautiful blue-glassy crust. Where this crust has been broken a reddish oxidized material is exposed.

This glassy layer is fragile and most of the damage exposing the red coloration has been caused by people either walking or climbing on these toes. Please keep everyone off of them.

Compare the picture of relatively undamaged lava toes at left with the toes you are looking at here.

PROCEED ... *52 feet further and move up onto the pressure ridge.*

PRESSURE RIDGE

Edge of pressure ridge. Move up onto the ridge on the left-hand side.

Pressure or flow ridges like this one are common throughout the park. Once a crust has formed on the surface of a lava flow and more material is added to the base of the crust (because it is the main cooling surface) the cross-sectional area that the stream or river of lava has to flow through is diminished. If the same volume of flow is going to be maintained, the pressure and speed of flow must increase. The increase in pressure often causes the crust to rupture, because the solidified crustal material can no longer stretch. Stretching is a tensional or pulling apart force and the prominent fracture seen running along the crest or top of most pressure ridges is a tension fracture. These fractures widen and propagate down as more and more material is added to the crust. The fracutres also widen with cooling. If pressure becomes sufficient at some time after the tension fracture has formed, molten rock can be forced or squeezed up through the fracture to spill down the sides of the ridge in what is called a squeeze up (there is a great example on the North Crater Flow Trail).

See p. 5 of Appendix II for a picture of a squeeze up.

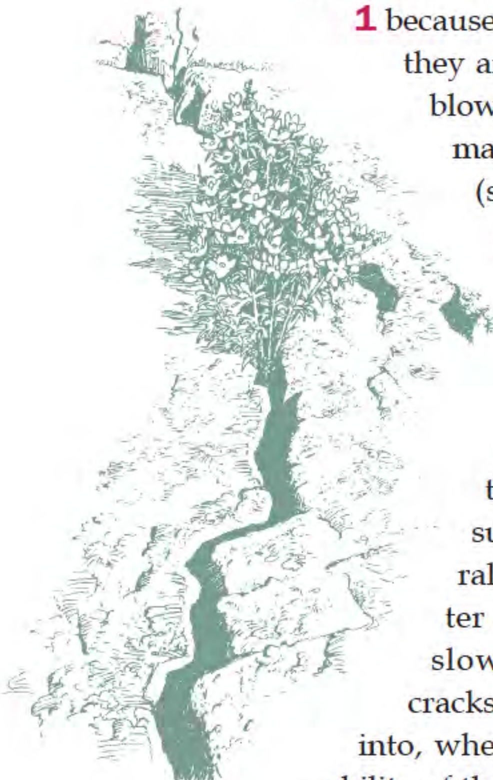
The outstanding "Dragon's Teeth" or saw-edge fractures, which can be seen so well here (some of the best in the park), are a cooling phenomenon. Many materials, including rock, expand when they are heated and contract when they are cooled, and rock when it contracts usually produces polygonal patterns of fractures or joints. You can see this polygon pattern on the surface near the "Dragon's Teeth." In thick flows this phenomenon produces columnar structures (columnar joints), often referred to as "Devil's post piles." If they are exposed in a cliff face they are called pali-

Dragon's teeth.

Students can count the number of sides that these polygons have. If your students have been to Yellowstone National Park near the Tower Fall area, they may have seen some good examples of this type of feature.

sades or colonnades. Mud cracks that form as mud desiccates or dries out are analogous to these cooling cracks and are also caused by contraction (in this case however, the contraction is caused by the clay minerals dewatering and shrinking in size rather than by cooling).

This is also a good spot to discuss where and why plant life gets its first foothold. The cracks are where the plants get their foothold. Cracks offer a lot of advantages: **1** because the wind speed is less in them they are sites of deposition of wind-blown soil; even at low wind speeds material being rolled or bounced (saltation) along can fall into them; **2** large cracks provide shelter from the wind, which can rob moisture from plants; **3** cracks can also provide shade, making it cooler – the sun can heat these black rocks to more than 150ºF during the summer; and **4** cracks are natural traps for moisture, e.g., in winter cracks fill with snow, which slowly melts in the spring, and cracks are low spots for water to flow into, when the rain is heavier than the ability of these porous rocks to absorb it.



Syringa – state flower of Idaho – growing in a tension fracture.

Have the students look around. Ask them to identify where most of the plants seem to be growing.

This a good area to study 3 of our prominent shrubs: syringa, fern bush, and rockspirea. Look for them in the big cracks. Descriptions are found in Appendix II.

PROCEED ...

370 feet toward Buffalo Caves, stopping to look into some of the small lava tubes and stop where the ferns are growing.

FERN

Christmas fern gets its name because it is evergreen and is used as a Christmas decoration.

Ferns are not a plant one expects to see in the desert, because their leaves have too much surface area from which to lose moisture. Here at Craters of the Moon, ferns tend to be found in either very deep cracks that provide shade almost the entire day, shelter from the wind, and moisture from the melting snows that filled them during the winter, or in cracks that have a connection to lava tubes. Many lava tubes accumulate ice during the winter, which melts very slowly over the summer. Some of the lava tubes here at Craters of the Moon (e.g. Boy Scout Cave) hold ice all summer long and you can still see ice in them in the fall. When the wind blows across cracks, it can pull cool moist air from the lava tubes creating a micro or small environment which can sustain the ferns. The ferns growing at this stop are Christmas ferns.

PROCEED ... 204 feet to Buffalo Caves.

BUFFALO CAVES

Buffalo Caves with Big Cinder Butte in the background.

Lava tubes are the main way in which pahoehoe lavas get distributed. Once a stream or river of lava crusts over, the crust acts like an insulator reducing the heat loss to the air, and allows the molten rock to be carried further from the vent before it solidifies. Much like ice on a river with water flowing beneath the ice. The crust also makes the river of lava into a tube in which the crust serves as the pipe within which the molten rock is flowing. As the volume of lava being released from the vent vacillates, the tube may sometimes be filled to the top and at other times be only partially filled. When the vent stops feeding the tube, and if the tube has an opportunity to drain, then the tube is left behind as a cave.

Cross to the far side of the collapse and sit down on the ledge formed by the collapse and leave the students standing on the collapse. Ask the students if they know what they are standing on.

Buffalo Caves is a series of lava tubes that got their name from a bison bone that was found in one of them. The ultimate fate of all lava tubes is to collapse. The students are standing on top of a hot collapse where the ceiling of the tube collapsed and fell the distance from where you are sitting to where your feet are. The ceiling was hot enough to drape down in a plastic fashion, as opposed to the collapse (rubble pile) just to the north of this one that collapsed after the ceiling was cool enough (solid enough) to break in a brittle fashion. Water freezing and expanding in cracks, the action of plant roots, or a major earthquake are the most likely agents that will lead to the eventual collapse of the lava tubes here at Craters of the Moon. A section of Buffalo Cave is closed because of freeze-thaw action has weakened the ceiling and colapse has begun. *Do not go beyond warning signs within the cave.*

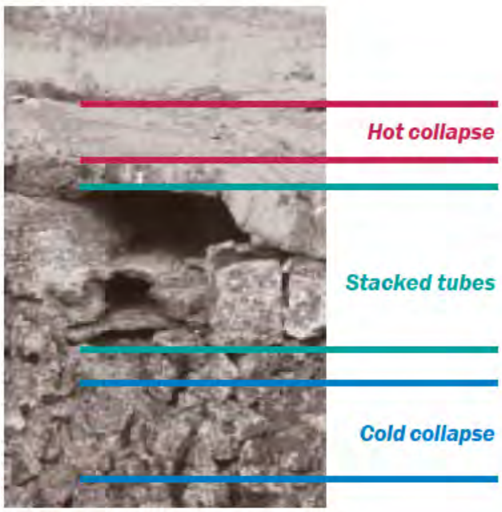
A number of bones can still be found in Buffalo Caves. Please leave them where they are so that others can also enjoy the thrill of discovery in the future.

PROCEED ... ***clockwise around the edge of the collapses until you can see the lava curbs and stacked tubes.***

The series of rock shelves along the far wall of the tube, which here are about a foot wide, are called lava curbs or bathtub rings. The curbs represent a level at which the lava flowed for a long enough period of time for ropes or ripples of congealing lava moving along the surface of the flow to accumulate at the edges of the stream of molten rock producing the curbs.

SAFETY MESSAGE

If you go down to where the curbs are, please ask students not to climb on them!



Stacked tubes.

Lava curbs.

If lava flows at a lowered level within a tube for a long enough period of time, a new internal ceiling can form. If the flow from the vent feeding the tube drops in increments, a whole series of new ceilings can be formed internal to the original tube producing a series of stacked tubes. A tube that flows for a long time can also soften the floor it is flowing over and gradually erode its way down, which also can generate new curbs and ceilings.

If you would rather go through a lava tube that is much larger and easier to travel through, we recommend visiting either Indian Tunnel or Beauty Cave, which are located in the Caves Area, a five-minute drive from where you are now parked.

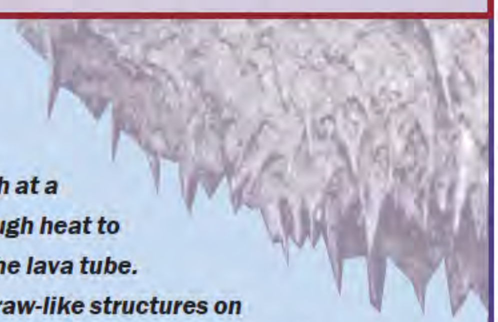
Vault near lava curbs.

The lava stalactites or "lava icicles" hanging from the ceiling form as molten rock clinging to the ceiling flows and drips towards the floor under the tug of gravity, while the tube is draining or splashed there to do the same thing. Once formed, these stalactities do not continue to grow as do the stalactictes in limestone caves. Lava stalagmites are very rare because the floor of the tube is a stream of moving lava, and when it stops moving the ceiling is usually too cool for lava to drip down and form stalagmites.

Some coatings and crystals are still forming or growing today. Water percolating through cracks and pores in the lava dissolves very tiny amounts of the rock over time and precipitates it as it evaporates on the inside of the lava tube. The white coatings that you see in places on the ceiling and walls of the lava tube are such material. The composition of the material has been identified as sulfate compounds. In some places you can see delicate flower-like crystals of sulfate. The sulfate is made up of a metalic ion, like iron, plus the SO_4 radical.

There are also some tan stains near some of the large cracks in the roof. The tan is some of the loess we discussed earlier. It has been physically brought in as water infiltrated along the cracks and carried the loess with it.

REMELT STRUCTURES



There are times when the inside of a lava tube can remelt. A stream of lava sometimes flows long enough at a lower level and radiates enough heat to remelt the top and sides of the lava tube. Remelting produces soda-straw-like structures on the tips of the lava stalactites. Remelted basalt when it recrystallizes takes on a submetallic or silvery appearance because of lack of dissolved gases. Good examples of remelt can be seen in Beauty Cave at the Caves Area.

FOR SAFETY, SERIOUS CAVING, SUCH AS IN CRAWLS REQUIRES:

1. **Minimum party of three**
2. **Three independent sources of light**
3. **Hard hats**
4. **Knee pads**
5. **Work gloves**

Please ask students not to touch any of the crystals. The crystals are fragile and the oils from human skin can stop them from growing.

The most common mineral is believed to be sodium sulfate. Small amounts of calcium carbonate may also be leached from some of the loess and deposited in the tubes.

SAFETY MESSAGE

NO CAVE IS A 100% SAFE! You know your students and their abilities. Factors to consider include the size of your group, the ability to provide close supervision in a cave, and having the proper equipment. If you do not think that every student will have a safe trip through the lava tube, you should not enter the cave.

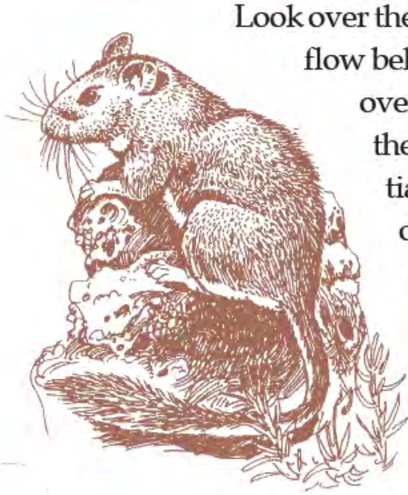
Throughout Buffalo Caves there are a lot of pack rat droppings, which look similar to cocoa crispies. Pack rats are common in many of the lava tubes, because the tubes afford them some of their favorite habitat, i.e., caves.

After you leave Buffalo Caves proceed out onto the flow so that students can get a nice feel for the Broken Top Flow (BTF). BTF was a sheet flow; look toward Big Cinder (south) and imagine a lake of lava sitting here. Picture the lava coming to the surface a few hundred feet in front of you, then fanning out, including flowing back to where you are now standing. Sheet flows usually start out somewhere between knee and waist deep in these continental basalts and, as more and more lava feeds into them, they get thicker and thicker. Look over the edge of the flow behind you; the total thickness of the BTF is over twice the thickness that you see here on the east side of Half Cone. As the BTF initially came up against the edge of the cone of Broken Top, it couldn't go any further and the surface solidified. As more and more lava inflated the sheet flow, the already solidified crust at the edge was tilted up.

SAFETY MESSAGE

Caution students not to hit their heads or backs. Although the incidence of pack rats carrying Hantavirus is very low, do not allow any of the students to handle the feces or kick them into the air.

View of Broken Top Flow from Big Cinder Butte.



Pack rats like to gather stray objects – particularly shiny things.

Edge of Broken Top Flow east of Half Cone.

PROCEED ...

310 feet back and pick up any gear you left outside the entrance to Buffalo Caves and pick up the trail, which is marked by rock cairns. Walk until you get to the limber pine with the incredible exposed root.

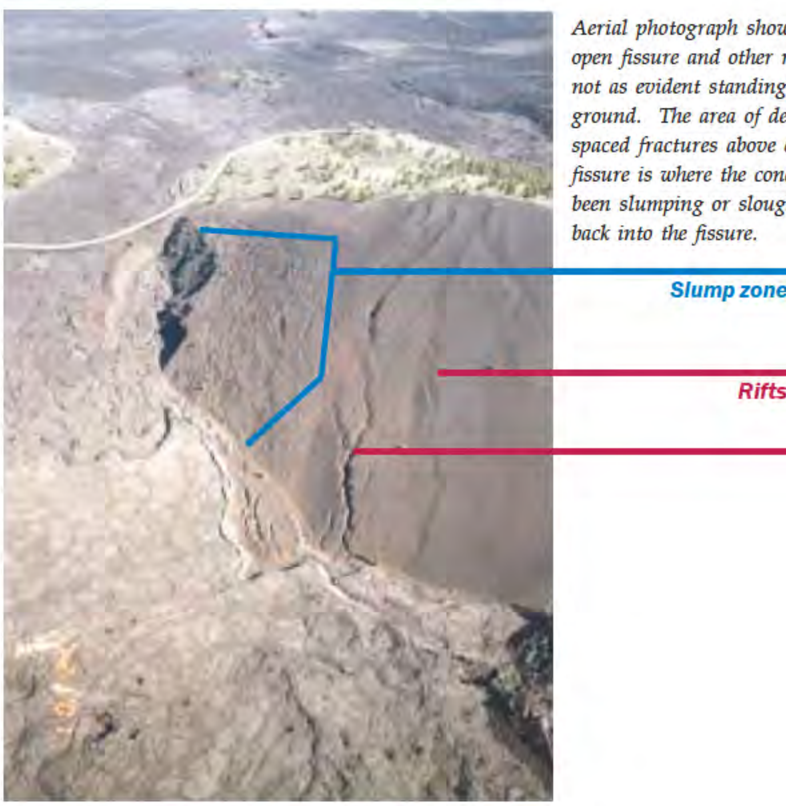
ROOT

The root of this limber pine is a testimony to the will to survive and the tremendous quest for water that these trees have. You can have a student "heel-toe-it" to measure the length of the root that is visible, and should come up with about 40 feet.

Just a little beyond the root on the side of the cone is an open fissure. This fissure has opened since Broken Top Cone was deposited. Perhaps it will be the weak spot magma will follow to the surface in the future.

This side of Broken Top Cone is covered with volcanic bombs that flattened on impact. Because they went splat on impact they are called cow-pie bombs. They were at the least still plastic when they landed and many probably contained a fluid core. Some are as much as 12 feet across. The surface of some of them show both ripples and also breadcrust textures.

Open fissure. View from trail.



Aerial photograph showing open fissure and other rifting not as evident standing on the ground. The area of densely spaced fractures above eruptive fissure is where the cone has been slumping or sloughing back into the fissure.

stop **8a**

As you proceed on down the trail you will be passing a finger of lava. It is estimated that it took between 10 and 20 minutes for this small stream of lava to flow to where it stopped. In general the smaller the stream of lava the slower it flows. Even very large tubes like Indian Tunnel were probably flowing at less than 10 miles per hour. This finger of lava is very special; it is covered with a natural bonsai-like garden. Stunted by the harsh growing conditions, dwarf goldenweed, limber pines, and others look like miniatures of giant trees.

Please do not let students climb, walk, stand, or sit on the finger of lava, so that this bonsai garden will be here for future generations to enjoy.

Lava finger.

PROCEED ...

315 feet to where the steeply dipping edge of the sheet flow has been lifted up and lava fingers have poured out from beneath. Remind students to stay on the trail.

stop 9

BREAKOUT

Breakouts from the sheet flow or lava lake occurred at the end of the Broken Top Flow eruption. Because of its plateau-like appearance, another name for the feature before you is a pressure plateau. It is produced by the sill-like injection of new lava beneath the crust of an earlier flow that has not completly solidified. Lava found a weak spot here and was forced up the steeply dipping plate at the edge of the flow and escaped. Because of its proximity to the flank of the cinder cone, the lava from this breakout had only two possible ways to flow. Facing the breakout from the trail, the lava flowed downhill to both the right and the left, producing the blue, glass-covered lava fingers and toes.

West side of pressure plateau as seen from the air. Note steep edge of pressure plateau.

Students can easily see the sharp contrast between the nearly vertical plates along most of the edge and the almost horizontal segment here.

Keep an eye out for yellow-bellied marmots.

PROCEED ...

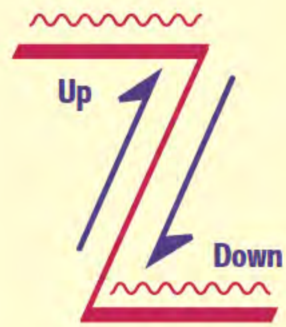
375 feet to the fenced viewing area for the inflation structure.

INFLATION

Inflation structure with reverse fault type movement. Note how ropes have been offset on the left.

Inflation structure is common throughout the pahoehoe flows in the park. The one seen here is a textbook example that is easy for students to see. Lava may have hit a topographic high or an obstacle and couldn't flow any further because it didn't have enough energy to flow over or around it. (Remember, the primary force that causes lava to flow is gravity.) But that doesn't mean that all the forces acting on the lava have been neutralized. The vent may still have poured out more lava, and gasses dissolved in the lava may have continued to come out of solution. Either or both of these events can exert tremendous pressure on an already solidified crust. These pressures can cause the crust to rupture and very slowly rise, not unlike the crust of a casserole in the oven when water in the casserole changes to steam.

Geologists in Hawaii, watching these structures form, report a glowing line at the fracture and a growth rate or movement rate which can be as little as a fraction of an inch an hour. What you see before you may have taken days to form! Because this is an expansive or growth process the normal observed sense of motion along the fracture is that of a reverse fault with the up-thrown side slightly overhanging the other. As the structure grows and the one side grinds past the lip of the original crust, vertical scratches or striations are often left on the up-thrown segment, as can be seen here. The pahoehoe ropes that were on the surface of the original crust are nicely offset on the left side of this inflation structure.



PROCEED ... *130 feet to the viewing area for the pahoehoe ropes.*

stop **10**

ROPE

For a good analogy for these beautiful pahoehoe ropes, compare them to a thick cake or brownie mix. When the batter is poured into a baking pan from the mixing bowl, it also forms ropes. The ropes form because, while the batter in the center of the pan flows rather quickly, the batter at the edges of the pan is slowed by the friction developed as it drags on the pan's sides.

Perhaps the students could make brownies in school the day before the trip and bring them as a snack.

Ropes are useful to a geologist because they provide a direction of flow at the time the crust solidified. The convex arch points in the direction of flow. Younger students are not going to be familiar with what convex means, so the following analogy should be useful: pretend each rope is an archer's bow and if you attach an imaginary string and drop in an arrow, the direction the arrow would fly is the direction the lava was flowing.

Keep in mind that after a section of ropy pahoehoe forms it can be broken and spun around like ice bobbing in a river.

Ropy pahoehoe.

PROCEED ... *60 feet to the next viewing area along the lodgepole pine barrier.*

stop **10a**

CONTACT

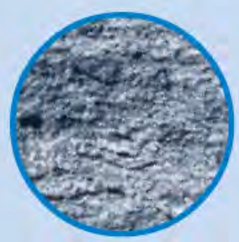
The lava toes with the pale to dark-blue glass (breakouts from the Broken Top Sheet-Flow or lava lake) clearly have flowed out on top of the Blue Dragon Flow. Besides the nice sharp contact between the two flows there is also a marked difference in their surface textures, which is a reflection of their viscosities. The Blue Dragon Flow was very thick and pasty, probably close to becoming aa. The flow was so thick and pasty that gas bubbles that came to the surface coalesced and were stretched into elongate ovals up to 4 or more inches in length. This kind of pahoehoe is known as spiny pahoehoe. Just a little shearing will cause it to change into slabby pahoehoe(discussed in the section between the parking lot and eruptive fissure stops). In contrast the gas bubbles on the surface of the lava toes from the Broken Top Flow breakouts are usually only stretched an inch or less, indicating that it was much more fluid than the Blue Dragon Flow.

This is a great place to review or reinforce the law of superposition, which you may have discussed with either older students or with earth science students.

LAVA TEXTURES

As you have made your way around the loop, you have seen 3 distinctly different surface textures representing 3 different viscosities of pahoehoe lava: 1 spherical gas bubbles on the Broken Top Flow — hot and very fluid or low-viscosity pahoehoe; 2 slightly stretched gas bubbles on the Broken Top Sheet-Flow breakouts — relatively fluid or intermediate-viscosity pahoehoe; and 3 highly stretched and elongated bubbles on the Blue Dragon Flow — very thick and pasty or high-viscosity pahoehoe on the verge of becoming aa that can shear, producing slabby pahoehoe.

1


2


3


PROCEED ...

205 feet to the fenced off lava billows at the top of the hill across the way, noting the many fine examples of pahoehoe ropes along the way.

BILLOWS

The lava here had just the right taffy-like quality to fold into these remarkable billows. The lava here got stopped as it ran into a barrier and, as material continued to move toward that barrier, bunched up into tight folds. The lava was not so hot and fluid that it flowed back together and not so thick that the forward motion caused it to shear and chew itself up.

An analogy to help students envision this happening: Ask them to think of a table cloth on a polished table. If they anchor the table cloth with one hand and with the other hand push the table cloth toward their anchored hand, it will glide and fold into billows. Or, have them think of their dog running across the kitchen floor and suddenly hitting a throw rug and bunching it up.

PROCEED ...

160 feet to the overlook into the eruptive fissure just above the small switchback in the trail.

WRAP UP

Look back toward the east between Broken Top and Big Cinder Butte and you will see a crescent-shaped volcano. It is called Crescent Butte and it is the oldest (~ 15 Ka) volcano on the surface here at Craters of the Moon. Big Cinder Butte on your right is the largest volcano in the park and Broken Top on your left is one of the youngest volcanoes (~ 2.1-2.2 Ka).

The sequence of events in this immediate area was as follows: **1** the eruptive fissure you are standing next to opens along the Great Rift and Broken Top Cone is built from material ejected from it; **2** the Blue Dragon Flow comes from the north-west, sweeps around, and partially fills in the eruptive fissure; **3** the Broken Top Sheet-Flow is poured out onto the surface (this is the smooth, level area visible to the east); and **4** breakouts from the Broken Top Sheet-Flow / Lava Lake / Pressure Plateau occur. The breakouts as seen from here form the contorted (jumble of lava toes and fingers) level between the Blue Dragon Flow and the Broken Top Flow.

Eruptive fissure.

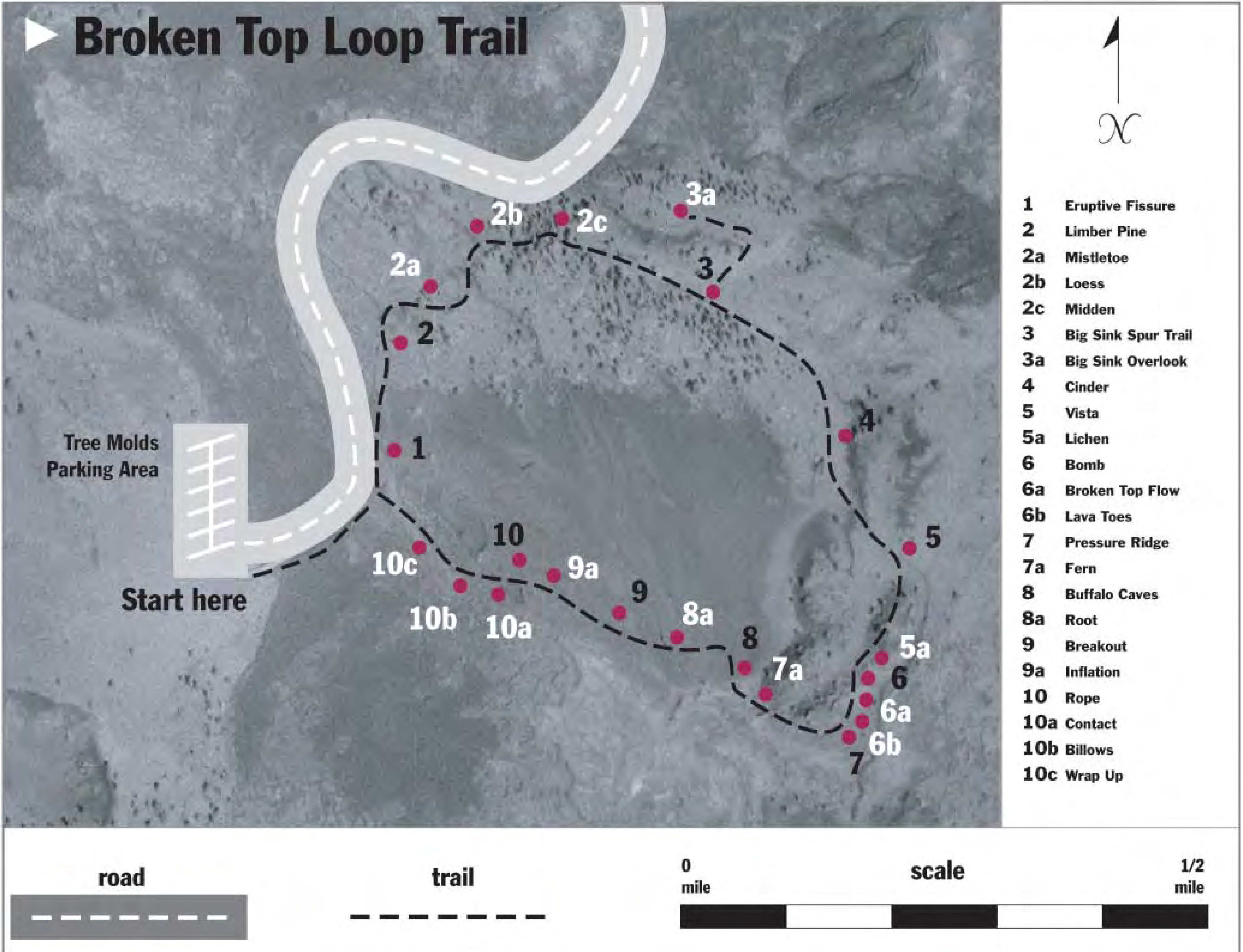
In 310 feet, the trail to the parking lot will intersect with the loop. Turn left and walk another 690 feet to the lot.

THANKS!

We hope you had a safe and rewarding educational experience.

MAPS

Orthographic version
Topographic version


Broken Top Loop Trail
Tree Molds Parking Area
Start here
1
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3a
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7a
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8a
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9a
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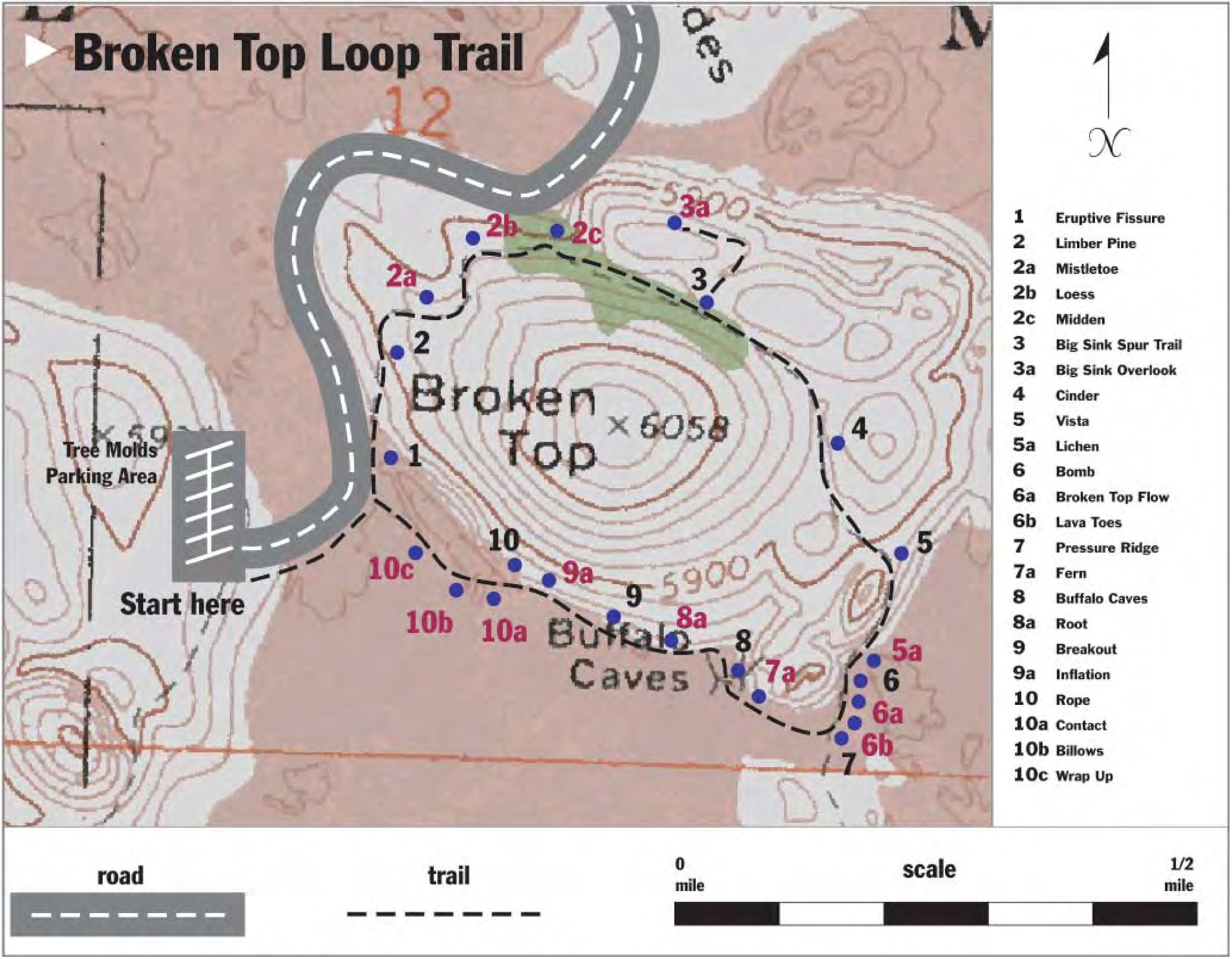
10a
10b
10c
1 Eruptive Fissure
2 Limber Pine
2a Mistletoe
2b Loess
2c Midden
3 Big Sink Spur Trail
3a Big Sink Overlook
4 Cinder
5 Vista
5a Lichen
6 Bomb
6a Broken Top Flow
6b Lava Toes
7 Pressure Ridge
7a Fern
8 Buffalo Caves
8a Root
9 Breakout
9a Inflation
10 Rope
10a Contact
10b Billows
10c Wrap Up
road
trail
scale
0 mile
1/2 mile


Broken Top Loop Trail
Tree Molds Parking Area
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Broken Top
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Buffalo Caves
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1 Eruptive Fissure
2 Limber Pine
2a Mistletoe
2b Loess
2c Midden
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3a Big Sink Overlook
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7 Pressure Ridge
7a Fern
8 Buffalo Caves
8a Root
9 Breakout
9a Inflation
10 Rope
10a Contact
10b Billows
10c Wrap Up
road
trail
scale
0 mile
1/2 mile

APPENDIX I

GEOLOGY OF CRATERS OF THE MOON NM (simple version)

Craters of the Moon

National Monument
U.S. Department of the Interior

Geology

Big Cinder Butte

WHAT MAKES CRATERS OF THE MOON SO SPECIAL GEOLOGICALLY?

Craters of the Moon is an outdoor classroom in which to study volcanic geology. It is the largest and most complex of the late Pleistocene (the last Ice Age) and Holocene basaltic lava fields of the Eastern Snake River Plain. In the past 15,000, years eight major eruptive periods formed the Craters of the Moon Lava Field. During this time the Craters of the Moon Lava Field grew to cover 618 square miles. In contrast, most of the other lava fields on the Eastern Snake River Plain (including the Kings Bowl and Wapi Lava Fields) represent single eruptions. The Craters of the Moon Lava Field consists of up to 60 lava flows and 25 cones.

rafted blocks

WHAT IS THE GREAT RIFT?

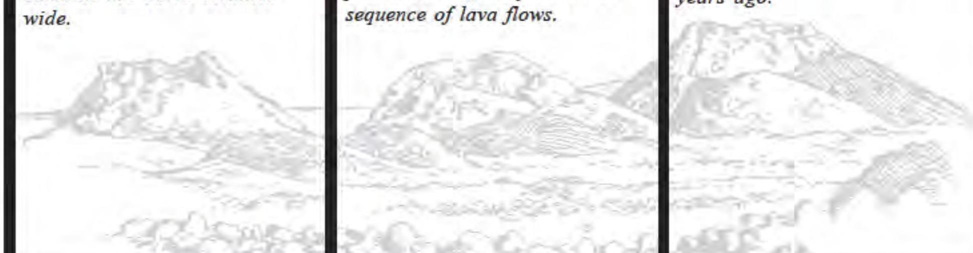
The Great Rift is a long line of fractures in the Earth's crust. It begins at the base of the Pioneer Mountains (north of the park's visitor center) and extends for over 50 miles to the southeast. The Craters of the Moon Lava Field is the northernmost of the 3 lava fields found along the Great Rift. The Craters of the Moon Lava Field formed from magma (molten rock below the surface of the earth), which pushed up along the Great Rift. The magma that formed the Kings Bowl and Wapi Lava Fields also came up along the Great Rift, but originated in a different magma chamber.

TIMELINE OF GEOLOGIC EVENTS

*The Yellowstone Hotspot was beneath Craters of the Moon. This time was characterized by violent eruptions and formation of huge craters called **calderas**. Some calderas are 10 to 40 miles wide.*

Numerous basaltic eruptions produced a 4,000-foot-thick sequence of lava flows.

The Craters of the Moon Lava Field formed during eight major eruptive periods. The Wapi and Kings Bowl lava fields formed about 2,200 years ago.



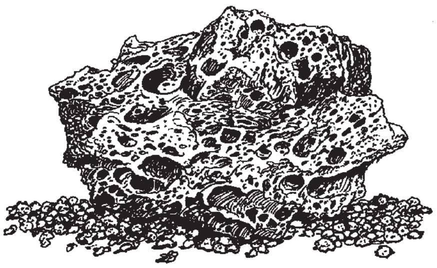
~8 MILLION TO 10 MILLION YEARS AGO

6 MILLION TO 15 THOUSAND YEARS AGO

15 THOUSAND TO 2 THOUSAND YEARS AGO

WHAT IS THE YELLOWSTONE HOTSPOT?

The Yellowstone Hotspot is a column of hot rock flowing up from the Earth's upper mantle. The hotspot has a plume shape, just like the wax in a "lava lamp."



cinder

The column flows upward until it hits the overlying North American Plate, which is colder. The plate consists of the crust and the uppermost mantle. Periodically, blobs of iron-rich basaltic magma rise up into the crust from a depth of about 50 miles. In the crust, these molten blobs melt overlying rocks and form sponge-like magma chambers. About 100 times in the past 16.5 million years, catastrophic eruptions of huge volumes of granitic magma have taken place along the Eastern Snake River Plain. Although some of the mountain ranges that existed on the Eastern Snake River Plain before the hotspot may have been blown away by the eruptions, it is more likely that they were swallowed up as the floor of the caldera sank during the violent explosions. The hotspot itself is stationary. Rather, it is the North American Plate that has been moving in a southwesterly direction over the hotspot. The plate's movement has produced the progressively younger trend of eruptions to the northeast. Imagine the burn mark left by a candle as a sheet of paper is moved across the flame.

WHAT KINDS OF LAVA ARE FOUND AT CRATERS OF THE MOON?

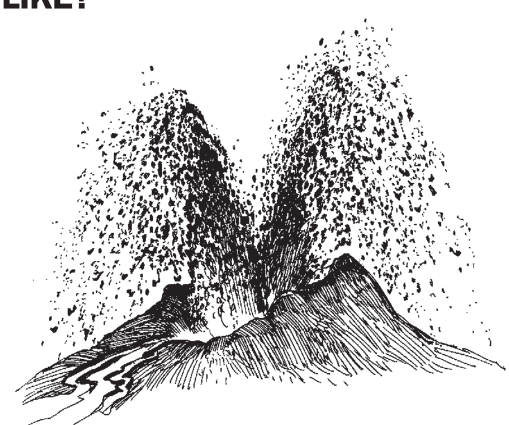
Molten rock on the Earth's surface is called ***lava***. Of the 60 lava flows visible on the surface of the Craters of the Moon Lava Field today, 20 have been dated. The oldest is about 15,000 years old and the youngest about 2,000.

Some lava flows are very dense and have a surface of angular blocks—***block lava***. Others have a rough, jagged, or clinkery surface—***áa lava.*** Still others have a smooth, ropy, or billowy surface—***pahoehoe lava***.

áa lava

HOW LIKELY IS ANOTHER ERUPTION AT CRATERS OF THE MOON? WHAT WILL THIS ERUPTION BE LIKE?

The interval between eruptive periods in the Craters of the Moon Lava Field averages 2,000 years and it has been more than 2,000 years since the last eruption. The area's geologic record suggests that future eruptions will begin along the central portion of the Great Rift in the Craters of the Moon Lava Field, but they may well travel to the northern part of the monument in the proximity of the loop drive. The nature of the area's volcanism suggests that slightly over one cubic mile of lava will be erupted during the next eruption period. Initial flows, based on past performance, will probably be relatively non-explosive and produce large-volume pahoehoe flows. Eruptions from potential vents on the northern part of the Great Rift may be comparatively explosive, produce significant amounts of cinder, lava bombs, and spatter, destroy cinder cones by both explosion and collapse, and build new ones.



erupting cinder cones

Only time will tell for sure.

WHAT KIND OF FEATURES ARE BUILT BY ERUPTIONS?

When magma emerges at the Earth's surface along a segment of a rift, it often begins by producing a curtain of fire and a line of low eruptions. As portions of the segment become clogged the fountains jet higher. If magma emerges at the surface highly charged with gas it sprays high in the air, like taking the cap off a shaken bottle of soda pop. The highly gas-charged molten rock cools and solidifies during flight and rains down to form cinders. When enough cinder piles up, a ***cinder cone*** is formed. If you look closely at cinders you will see that they are laced with gas holes and resemble a sponge or a piece of Swiss cheese. Cinders are very lightweight because of these gas holes. The fire fountains that produced many of the Craters of the Moon cinder cones were probably over 1,000 feet high. Big Cinder Butte, the tallest cinder cone at Craters of the Moon, is over 700 feet high.

Lava tubes are hollow spaces beneath the surface of solidified lava flows. They are formed by the withdrawal of molten lava after the formation of the surface crusts. Indian Tunnel in the northern area of the park has a 40-foot-high ceiling and is 800 feet long. Bear Trap Cave, which lies between the Craters of the Moon and Kings Bowl Lava Fields, is about 15 miles long, but is not continuously passable.

Some vents along the rift eject very fluid particles (spatter) that accumulate to form steep-sided ***spatter cones***. Stop and visit the Spatter Cone exhibit along the loop drive.

During some eruptions, pieces of crater walls are carried off like icebergs by lava flows. These wall portions are known as ***rafted blocks***. The monoliths on the North Crater Flow Trail across from the visitor center are excellent examples of these volcanic formations. Go to Devils Orchard to see more examples of rafted blocks.

pahoehoe lava

For further information, check out the following websites:

WWW.NPS.GOV/CRMO/

WWW2.NATURE.NPS.GOV/GRD/PARKS/CRMO/

WWW.ID.BLM.GOV/CRATERS/

HTTP://VULCAN.WR.USGS.GOV/VOLCANOES/IDAHO/CRATERSMOON/DESCRIPTION_CRATERS_MOON.HTML

HTTP://IMNH.ISU.EDU/DIGITALATLAS

APPENDIX II

GEOLOGY OF CRATERS OF THE MOON NM
(more technical version)

GEOLOGY

OF CRATERS OF THE MOON NATIONAL MONUMENT

Compiled and interpreted from current literature by
Doug Owen, Park Geologist

BRIEF CHRONOLOGY OF GEOLOGIC EVENTS

- Between approximately 8 and 10 million years ago the Yellowstone Hotspot was beneath Craters of the Moon. This time was characterized by violent rhyolite eruptions and caldera formation.
- Between 6 million and 15,000 years ago numerous basaltic eruptions produced a 4,000-foot-thick sequence of lava flows.
- Between 15,000 and 2,000 years ago the Craters of the Moon Lava Field formed during eight major eruptive periods. During this time the Craters of the Moon lava field grew to cover 618 square miles. The Wapi and Kings Bowl lava fields formed contemporaneously about 2,200 years ago.

DESCRIPTION

The Craters of the Moon Lava Field, a composite field, is made up of about 60 lava flows and 25 cones. It is the largest and most complex of the late Pleistocene (the last Ice Age, from 1 million to 10,000 years ago) and Holocene (10,000 years ago to the present) basaltic lava fields of the Eastern Snake River Plain. The flows of the Craters of the Moon Lava Field have parent magma similar to that in the rest of the plain, but exhibit a wide range of chemical compositions. This wide range is caused in one of two ways: (1) by crustal contamination from assimilating older rocks, which produces lava with silica (SiO_2) ranges of ~49% to 64%, or (2) by crystal fractionation, which produces lava with silica ranges of ~44% to 54%.

In the past 15,000 years eight major eruptive periods formed the Craters of the Moon Lava Field. In contrast, most of the other lava fields on the Eastern Snake River Plain (including Kings Bowl and Wapi) represent single eruptions. Although these eruptions were widely scattered in space and time, they share nearly identical chemical composition (producing lava with silica ranges of ~45% to 48%). The typical Eastern Snake River Plain basalts are classified as diktytaxitic olivine tholeiite lavas or simply olivine basalts.

What makes Craters of the Moon so special geologically?

Craters of the Moon is an outdoor classroom in which to study volcanic geology. The Craters of the Moon Lava Field is the largest basaltic, dominantly Holocene (dating from the past 10,000 years) lava field in the lower 48 states. It has nearly every type of feature associated with basaltic systems and park trails give convenient access to most of them. So, short of travelling to Alaska or Hawaii, this is one of the best places in the United States to study this type of volcanism.

What is the Great Rift?

The Great Rift is a system of crustal fractures. It begins at the base of the Pioneer Mountains (north of the park's visitor center) and extends for over 50 miles to the southeast. The Craters of the Moon Lava Field is the northernmost of the 3 lava fields found along the Great Rift. The Wapi Lava Field is the southernmost. The Craters of the Moon Lava Field formed from magma (molten rock below the surface of the earth), which pushed up along the Great Rift. The magma that formed the Kings Bowl and Wapi Lava Fields also came up along the Great Rift, but originated in a different magma chamber. The Great Rift and other volcanic rifts on the Eastern Snake River Plain are generally parallel to but not necessarily collinear with basin and range faults north and south of the plain.

What is the Yellowstone Hotspot? When did it form? How did it move?

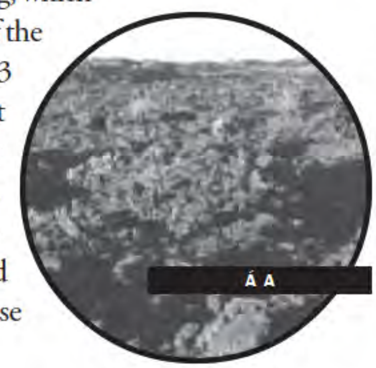
Many geologists think the Yellowstone Hotspot formed just 17 to 18 million years ago; a few think it is much older. More and more evidence is pointing to the hotspot having formed in the Earth's upper mantle at a depth of about 125 miles, rather than being a mantle plume from the core/mantle boundary. The hotspot has a plume shape, just like the wax in a "lava lamp," but the plume is probably not completely molten. It is a column of hot rock, which may have been produced by radioactive decay, in which some of the molten rock flows upward. The column flows upward until it hits the overlying North American Plate, which is colder. The plate consists of the crust and the uppermost mantle. Periodically blobs of iron-rich basaltic magma rise up into the crust from a depth of about 50 miles. In the crust these molten blobs melt overlying silica-rich rocks and form sponge-like magma chambers of partly molten rhyolite.

About 100 times in the past 16.5 million years catastrophic eruptions of huge volumes of rhyolitic magma have taken place along the Eastern Snake River Plain. These eruptions often produced huge craters called calderas; some are 10 to 40 miles wide. Many of the approximately 100 calderas overlapped and may be broken down into 7 to 13 volcanic centers. Although some of the mountain ranges that existed on the Eastern Snake River Plain before the hotspot may have been blown away by the eruptions, it is more likely that they were swallowed up as the floor of the caldera sank during the violent explosions.

The hotspot itself is stationary. Rather, it is the North American Plate that has been moving in a southwesterly direction over the hotspot. The plate's movement has produced the progressively younger trend of rhyolitic eruptions to the northeast. Imagine the burn mark left by a candle as a sheet of paper is moved across the flame.

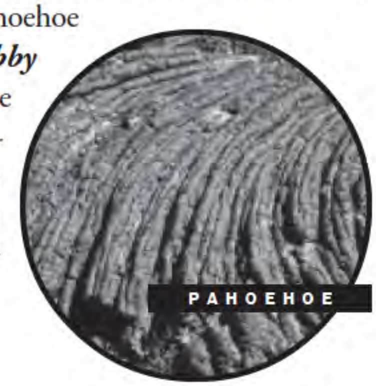
If the Yellowstone Hotspot was here so long ago and is now so far away, why have the eruptions continued?

Recent seismic data suggest that the Yellowstone Hotspot left behind a slab of basalt 6 to 10 miles thick. This slab is poised in a mid-crustal position and some of it is thought to contain partial melt. It is believed that this slab represents the slag left in the bottom of the numerous magma chambers spawned by the hotspot. This region is experiencing basin and range type faulting, which is stretching or pulling apart the crust. The Lost River Range north of the town of Arco is good evidence that these forces are still active. In 1983 these forces caused a magnitude 7.3 earthquake, during which Mount Borah rose up about 1 foot and the entire Lost River Valley in that vicinity dropped about 8 feet. On the Eastern Snake River Plain, instead of producing mountain ranges, the tensional forces have created decompression melting, which results in dike emplacement and periodic eruption of molten rock onto the surface. As long as these forces continue to act, more eruptions will eventually occur.



What kind of lava is found at Craters of the Moon?

Molten rock on the surface is called ***lava***. Of the 60 lava flows visible on the surface of the Craters of the Moon Lava Field today, 20 have been dated. The oldest is about 15,000 years old and the youngest about 2,000. Some lava flows were very dense and had a surface of angular blocks—***block lava***. Others had a rough, jagged, or clinkery surface—***áa lava***. Still others had a smooth, ropy, or billowy surface—***pahoehoe lava***. Three special kinds of pahoehoe may be observed in the Craters of the Moon Lava Field: (1) ***slabby pahoehoe***, is made up of jumbled plates or slabs of broken pahoehoe crust; (2) ***shelly pahoehoe***, which forms from gas-charged lava, contains small open tubes, blisters, and thin crusts; and (3) ***spiny pahoehoe***, which is very thick and pasty, contains elongated gas bubbles on the surface that form spines. Both slabby and spiny pahoehoe are transition phases to áa.



What are volcanic bombs?

Four kinds of bombs are found at Craters of the Moon, all of which start off as globs of molten rock thrown into the air. If the glob gets twisted during its flight it is called a ***spindle bomb*** and typically extends from a few inches to several feet in length. If it is very tiny and twisted it is called a ***ribbon bomb***. When a glob forms a crust as it flies through the air and if the gases inside continue to expand and crack that crust, it is called a ***breadcrust bomb***. The outer surface texture is similar to bread rising in the oven. If the glob does not completely solidify during flight, so that it goes splat and flattens on landing, it is called a ***cow-pie bomb***. Some cow-pie bombs are over 10 feet long.

What are lava tubes?

Lava tubes are hollow spaces beneath the surface of solidified lava flows. They are formed by the withdrawal of molten lava after the formation of the surface crusts. Indian Tunnel in the northern area of the park has a 40-foot high ceiling and is 800 feet long. Bear Trap Cave, which lies between the Craters of the Moon and the Kings Bowl Lava Fields, is about 15 miles long, but is not continuously passable.

What kind of features are built by eruptions?

Most of the Craters of the Moon lava flows are pahoehoe and were fed through tubes and tube systems, although there are some sheet flows. At Craters of the Moon structures representing both inflation and deflation of the lava surface can be seen along with hot and cold collapses of the roofs of lava tubes. Inside lava tubes one can see lava stalactites, remelt features, and lava curbs. In other places lava flows formed ponds, built levees, and produced lava cascades. Some lava flows produced small mounds (***tumuli***) or elongated ridges (***pressure ridges***) on their crusts. In some places ***squeeze-ups*** formed when pressure was sufficient to force molten lava up through tension fractures in the top of pressure ridges or cracks in the solidified crust of lava ponds. ***Pressure plateaus*** were produced by the sill-like injection of new lava beneath the crust of an earlier flow that has not completely solidified.

When magma emerges at the surface along a segment of a rift, it often begins by producing a curtain of fire and a line of low eruptions. As portions of the segment become clogged the fountains jet higher. If magma emerges at the surface highly charged with gas it sprays high in the air, like taking the cap off a shaken bottle of soda pop. The fire fountains that produced many of the Craters of the Moon cinder cones were probably over 1,000 feet high.

Big Cinder Butte, the tallest cinder cone at Craters of the Moon, is over 700 feet high. The highly gas-charged molten rock cools and solidifies during flight and rains down to form ***cinder cones***. If you look closely at cinders you will see that they are laced with gas holes and resemble a sponge or piece of Swiss cheese. Cinders are very lightweight because of these gas holes.

Some vents along the rift ejected very fluid particles (***spatter***) that accumulated to form steep-sided ***spatter cones***. Along eruptive fissures where a whole segment erupted, spatter accumulated to produce low ridges called ***spatter ramparts***. ***Hornitos***, also known as rootless vents, are similar in appearance to spatter cones. Hornitos form from spatter ejected from holes in the crust of a lava tube instead of directly from a feeding fissure. Craters of the Moon also has collapses known as ***sinks*** or ***pit craters***. During some eruptions pieces of crater walls were carried off like icebergs by lava flows. These wall chunks are known as ***rafted blocks***; the monoliths on the North Crater Flow Trail are excellent examples of these volcanic formations.


SHIELD VOLCANO

How many volcanoes lie on the Eastern Snake River Plain? What is the most common type? What was the average volume of material erupted?

The most common type of volcano is a shield volcano. Shield volcanoes are gently sloping, like a knight's shield lying on the ground, or like a flattened dome built by fluid lava flowing away from the vent. There are believed to be about 8,000 on the Eastern Snake River Plain and an average volume of 1.2 cubic miles of material erupted from them.

Why has Crater of the Moon Lava Field had multiple eruptive periods when most other areas have not?


SQUEEZE UP

One hypothesis is that basin and range faulting is having a hard time moving into the Idaho Batholith, a mass of granitic bodies that covers over 15,000 square miles in central Idaho. Stress that would otherwise be released in the Idaho Batholith is possibly being accomodated along the Great Rift, thus resulting in more volcanic activity here.

How likely is another eruption at Craters of the Moon? What will this eruption be like?

Very likely. The recurrence interval for eruptive activity in the Craters of the Moon Lava Field averages 2,000 years and it has been more than 2,000 years since the last eruption. We are now at the end of a normal repose interval. The constancy of the most recent volcanic output rate suggests that slightly over one cubic mile of lava will be erupted during the next eruption period.

In the past, eruptions in the Craters of the Moon Lava Field have generally shifted to the segment of the Great Rift with the longest repose interval. Therefore, the next eruptive period should begin along the central portion of the Great Rift in the Craters of the Moon Lava Field, but may well propagate to the northern part of the monument in the proximity of the loop road. Initial flows, based on past performance, will probably be relatively non-explosive and produce large-volume pahoehoe flows. Eruptions from potential vents on the northern part of the Great Rift may be comparatively explosive and may produce significant amounts of ***tephra*** (airfall material ejected from a volcano), destroy cinder cones by both explosion and collapse, and build new ones. Only time will tell for sure.

SUGGESTED READING

Smith, Robert B. and Siegel, Lee J. Windows into the Earth. Oxford University Press, 2000 (242 pp).
Read chapters 1 and 2 for a description of the Yellowstone Hotspot and the development of the Eastern Snake River Plain. Written for the layperson.

Kuntz, Mel A., Champion, Duane E., Spiker, Elliot C., and Lefebvre, Richard H. "Contrasting magma types and steady-state, volume-predictable, basaltic volcanism along the Great Rift, Idaho." Geological Society of America Bulletin, vol. 97, pp. 579-594.
Good technical summary paper that includes speculations on future eruptive activity.

Decker, Robert and Decker, Barbara. Volcanoes In America's National Parks. W.W. Norton & Company, New York, 2001 (256 pp).
Good general reference book on volcanic parks in the U.S.; Craters of the Moon is on pages 190 to 195. Written for the layperson .

WEBSITE INFORMATION SOURCES

National Park Service
www.nps.gov/crmo/

NPS Geological Resources Division
www2.nature.nps.gov/grd/parks/crmo/

Bureau of Land Management
www.id.blm.gov/craters/

U.S. Geological Survey
http://vulcan.wr.usgs.gov/volcanoes/idaho/cratersmoon/description_craters_moon.html

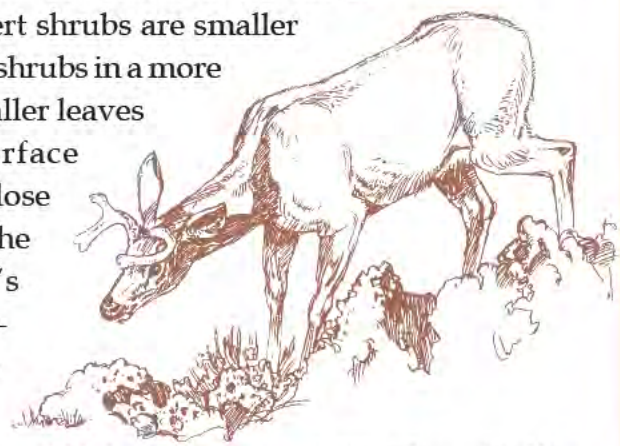
Digital Atlas of Idaho
http://imnh.isu.edu/digitalatlas

APPENDIX III

SOME COMMON PLANTS OF CRATERS OF THE MOON

Antelope Bitterbrush – This shrub is a major food source for wildlife at Craters of the Moon. It is the primary food source for the deer. Because our soils are young (i.e., dominantly brought in by the wind since the ice age) and there is so little rain to leach nutrients and carry them below the root zone, the nutrients are available for the shrub to take them up. This uptake makes the shrub very nutritious, so nutritious in fact that the deer here often have twins or triplets instead of just a single fawn, as is the norm elsewhere. In spring, after the shrub flowers, each of the small fruits that form contain a drop or two of purple juice. This juice is a source of water for small animals and you will often see chipmunks up in the shrubs eating the fruits. Later, inside each of the fruits, a nice size black seed develops that many of the small animals also eat. In a very dry year, as an adaptation to survive, the shrub will drop its leaves to conserve water and not grow them back until after a good rain. The leaves of this shrub and most other desert shrubs are smaller than those found on shrubs in a more humid climate. Smaller leaves have a smaller surface area from which to lose water to the air. The buds for next year's leaves are an important food source during the winter for animals such as the rabbits.

Ask students who have been to more humid climates to compare the size of the leaves of this shrub to shrubs in that more humid climate.



Mule deer often have twins or triplets at Craters of the Moon because the antelope bitterbrush here is so nutritious.

Dwarf Buckwheat — This small, low-growing, whitish-colored plant ubiquitous to the cinder areas in the park is one of the plants most often asked about by visitors. A 10- or 20-power hand lens makes it easier to see the wool-like hairs that reflect light and help create dead air space next to the plant tissue. Cinders can be heated to over 150ºF by the sun, so reflecting light and keeping the soil immediately below the plant cooler is a real advantage for survival. Both the hairs and the color of the foliage help to do this. The dead air space created by the hairs helps to reduce moisture loss to wind. This plant is highly competitive for water and puts out a remarkably extensive root system. Roots from a single small plant have been measured to extend as far as 110 cm vertically and horizontally. The even spacing between plants is caused by the competition between plants for water and not, as many visitors think, because they were planted that way by man (*we have not planted any of them*). The typical life span of the plant is unknown, but observations have indicated that it is many years. Living multiple years gives it a big advantage over plants that have to come up from seed every year. The longer life span allows it to establish an extensive root system. Also, the plant maintains its foliage under the snow and does not have to waste energy growing new foliage the following spring. In the spring this plant puts out pom-pom like flowers.

Hand lenses are available for sale at the Visitor Center bookstore.

Rockspirea — This plant has grayish-red bark and wedge-shaped leaves with a toothed margin. The flowers are borne in dense terminal clusters that make the shrub look like a mass of cream- or coral-colored foam when it is in bloom.

Rubber Rabbitbrush — This plant has gray-green linear leaves and produces a burst of yellow when it flowers in the late summer and fall. It is a prodigious pollen producer and affects many people who suffer from allergies. The plant is a host for numerous insects. It contains a natural latex and was chewed by the Indians to help quench thirst, much like people use chewing gum today.

Sagebrush — This pungent-smelling shrub has grayish-green wedge-shaped leaves with 3 prominent teeth at the end. It is not the same as the herb called sage. Today the plant is generally considered to be toxic, but the Indians used it stop internal bleeding, boiled it to produce an antiseptic, because of the plant's strong bacteriostatic quality. Sage requires a deep soil profile and usually is found on older deposits where there has been more time for soil to accumulate. One of sagebrush's adaptations to living in the desert is that it also grows larger leaves in the spring to make more food when moisture is more readily available. Then, as the soil dries out, the large leaves are replaced by small leaves to reduce water loss through evaporation. Smaller leaves have less surface area to lose moisture from and is a common characteristic of desert plants.

Sagebrush (close-up).

Scorpionweed — This fascinating plant has hairs that are easily seen under low magnification. The hairs do several things that enable this plant to survive here. They reflect light to help keep the plant cooler (which often makes the leaves appear as if they have frost on them), they help create a dead air space next to the plant tissue that prevents the loss of moisture to the wind. The hair also serve as traps for dew. Students may have also noticed that the veins on the leaves all point toward the center of the plant; this helps roll any moisture that accumulates or falls on the plant back toward its tap root. The plant gets its name from the seed bodies that form, which look like the hooked tail of a scorpion.

Scorpionweed (close-up). Note the hairs on the leaves.

Ask students beforehand if they see any plants that remind them of a funnel.

Sulfur Buckwheat — This plant is somewhat shrubby and forms mats of red and green leaves (this is probably the best clue for students to look for in order to recognize the plant). Flowering stalks are much taller than on the dwarf buckwheat, but still are usually less than 10 inches tall.

Syringa — This flower, also called Lewis mockorange, is the state flower of Idaho. The shrub has gray-brown bark and bright green oval leaves that are borne opposite each other on the branches. The flowers are very fragrant and measure about 1 inch in diameter. The petals are white.

Fern bush — This shrub has very distinctive leaves that are pinnately dissected and remind many people of ferns. The leaves are sticky to the touch, the oils being a strategy to reduce moisture loss. The Native Americans found that these same oils had a very beneficial quality, i.e., they are a natural insect repellent, and would rub the aromatic leaves of this plant over their skin. The flowers are about 1/2 inch in diameter with 5 creamy white petals.

APPENDIX IV

COMMONLY SEEN PLANTS OF CRATERS OF THE MOON (list)

Commonly Seen Plants

Craters of the Moon
NATIONAL MONUMENT

Compiled by Doug Owen, Park Naturalist

yellow flowers

Common name	Scientific name	Family
☐ Arrow-Leaved Balsamroot	Balsamorhiza sagittata	Sunflower
☐ Hawksbeard	Crepis (3 species)	Sunflower
☐ Mountain Dandelion	Agoseris glauca	Sunflower
☐ Salsify	Tragopogon dubius	Sunflower
☐ Groundsel	Senecio (5 species)	Sunflower
☐ Buckwheats	Erigonum (11 species)	Buckwheat
☐ Desert Parsley	Cymopterus terebinthinus	Carrot
☐ Gland Cinquefoil	Potentilla glanulosa	Rose
☐ Leopard Lily	Fritillaria atropurpurea	Lily
☐ Wayside Gromwell	Lithospermum ruderale	Borage
☐ Hairy Golden-Aster	Heterotheca villosa	Sunflower
☐ Sukdorf's Monkeyflower	Mimulus suksdorfii	Snapdragon
☐ White Stem Stickleaf	Mentzelia dispersa	Loasa
☐ Yellow Wood Violet	Viola orbiculata	Violet
☐ Blazingstar	Mentzelia laevicaulis	Loasa
☐ Prickly Pear cactus	Opuntia polyacantha	Cactus
☐ Mullein	Verbascum thapsus	Snapdragon

red / purple / blue flowers

☐ Indian Paintbrush	Castilleja chromosa	Snapdragon
☐ Dwarf Monkeyflower	Mimulus nanus	Snapdragon
☐ Wild Onion	Allium (8 species)	Lily
☐ Scarlet Gilia	Gilia aggregata	Phlox
☐ Wire Lettuce	Stephanomeria tenuifolia	Sunflower
☐ Joe Pye Weed	Eupatorium occidentale	Sunflower
☐ Hoary Aster	Machaeranthera canescens	Sunflower
☐ Fernleaf Fleabane	Erigeron compositus	Sunflower
☐ Blue Penstemon	Penstemon cyaneus	Snapdragon
☐ Lupine	Lupinus (4 species)	Pea
☐ Anderson Larkspur	Delpinium andersonii	Buttercup
☐ Scorpionweed	Phacelia hastata	Waterleaf
☐ Blue-eyed Mary	Collinsia parviplora	Snapdragon
☐ Rockcress	Arabis (5 species)	Mustard
☐ Spiney Skeleton Plant	Stephanomeria spinosa	Sunflower

Common name	Scientific name	Family

white flowers

Common name	Scientific name	Family
☐ Bitterroot	Lewisia rediviva	Purslane
☐ Sego Lily	Calochortus nuttallii	Lily
☐ Cryptantha	Cryptantha (8 species)	Borage
☐ Scabland Penstemon	Penstemon deustus	Snapdragon
☐ Lava Phlox	Leptodactylon pungens	Phlox
☐ Dusty Maiden	Chaenactis douglasii	Sunflower
☐ Western Yarrow	Achillea millefolium	Sunflower
☐ Slender Woodland Star	Lithophragma tenella	Saxafrage
☐ Ground Smoke	Gayophytum (5 species)	Primrose
☐ Coyote Tobacco	Nicotiana attenuata	Nightshade

trees

Common name	Scientific name	Family
☐ Limber Pine	Pinus flexilis	Pine
☐ Douglas Fir	Pseudotsuga menziesii	Pine
☐ Quaking Aspen	Populus tremuloides	Willow
☐ Rocky Mtn. Juniper	Juniperus scopulorum	Cedar

shrubs

Common name	Scientific name	Family
☐ Antelope Bitterbrush	Purshia tridentata	Rose
☐ Rubber Rabbitbrush	Chrysothamnus nauseosus	Sunflower
☐ Fern Bush/Tansy Bush	Chamaebatiaria millefolium	Rose
☐ Sagebrush	Aretmisia (6 species)	Sunflower
☐ Syringa	Philadelphus lewisii	Hydrangea
☐ Squaw Currant	Ribes cereum	Currant
☐ Golden Currant	Ribes aureum	Currant
☐ Serviceberry	Amelanchier alnifolia	Rose
☐ Rockspirea	Holodiscus dumosus	Rose
☐ Choke Cherry	Prunus virginiana	Rose
☐ Dwarf Goldenweed	Haplopappus nanus	Sunflower

ferns

Common name	Scientific name	Family
☐ Christmas Fern	Polystichum scopulinum	Fern
☐ Brittle Bladder Fern	Cystopteris fragilis	Fern
☐ Male Fern	Dryopteris felix-mas	Fern

grasses, etc.

Common name	Scientific name	Family
☐ Dwarf Mistletoe	Arceuthobium cyanocarpum	Mistletoe
☐ Great Basin Wildrye	Elymus cinereus	Grass
☐ Bottle Brush/Squirreltail Grass	Sitanion hystrix	Grass
☐ Cheat Grass	Bromus tectorum	Grass
☐ Indian Rice Grass	Oryzopsis hymenoides	Grass
☐ Gray-Green Thistle	Cirsium canovirens	Aster
☐ Tumbleweed	Salsola kali	Goosefoot
☐ Sandberg Bluegrass	Poa secunda	Grass
☐ Needlegrass	Stipa (5 species)	Grass

APPENDIX V

WILDLIFE CHECKLIST

Craters of the Moon

National Monument
U.S. Department of the Interior

Wildlife Checklist

At first glance, Craters of the Moon seems a lifeless place. The young lava flows and cinder cones are indeed inhospitable. During summer as little as one inch of rain may fall. This moisture drains quickly into the porous rock and out of reach of animals. Air temperatures soar into the 90's and the lava surface may reach over 150° F. Drying winds of over 20 miles per hour are common in summer.

Despite the harsh conditions, many creatures eke out a living here. Animals escape the summer heat in different ways. Most, like the mountain lion, venture forth in search of food only at night. Others, like the pika, are active at dusk and dawn. Those that are out during the day often seek shelter in the hottest hours. Marmots take more extreme measures to escape heat. They enter a hibernation-like state called estivation, during which their metabolism and body temperature drop. They estivate until cooler, moister conditions return.

Since there are no streams and few water holes in the lava fields, animals must get the moisture they need directly from their food. Mule deer munch bitterbrush leaves. Violet-green swallows snatch insects from the air. Rattlesnakes inject their venom and swallow their prey, such as chipmunks, whole. Each of these foods contains water essential to life.

The following list should assist you in identifying the animals you see during your visit. Even if you do not see animals, be alert to evidence of their presence: tracks, trails, nests, burrows, gnawed cones and twigs, fur, feathers, bones, droppings, calls, and smells.

All animals have been classified in one of two categories:

I: Quite common at some time during the year and may include resident, migrant, or breeding animals.

II: Has been observed within the monument only infrequently. Sightings of these animals should be reported at the visitor center.

Reptiles and Amphibians

- [ ] Gopher Snake – I
- [ ] Rubber Boa – I
- [ ] Western Rattlesnake – II
- [ ] Western Garter Snake – II
- [ ] Western Yellow-Bellied Racer – II
- [ ] Long-nosed Leopard Lizard – II
- [ ] Sagebrush Lizard – II
- [ ] Desert Horned Lizard – II
- [ ] Short-Horned Lizard – II
- [ ] Western Skink – I
- [ ] Western Toad - II
- [ ] Boreal Chorus Frog – II

Mammals

- [ ] Dusky Shrew – II
- [ ] Vagrant Shrew – II
- [ ] Merriam's Shrew – II
- [ ] Little Brown Myotis – I
- [ ] Long-eared Myotis – II
- [ ] Long-legged Myotis – II
- [ ] Small-footed Myotis – II
- [ ] Fringed Myotis – II
- [ ] California Myotis – II
- [ ] Big Brown Bat – II
- [ ] Hoary Bat – II
- [ ] Townsend's Big-eared Bat – II
- [ ] Pika – I
- [ ] Pygmy Rabbit – I
- [ ] Mountain Cottontail – II
- [ ] Snowshoe Hare – II
- [ ] White-tailed Jackrabbit – I
- [ ] Black-tailed Jackrabbit – II
- [ ] Least Chipmunk – II
- [ ] Yellow-pine Chipmunk – I
- [ ] Yellow-bellied Marmot – I
- [ ] Columbian Ground Squirrel – II
- [ ] Great Basin Ground Squirrel – II
- [ ] Golden-mantled Ground Squirrel – I
- [ ] Red Squirrel – I
- [ ] Northern Pocket Gopher – II
- [ ] Great Basin Pocket Mouse – I
- [ ] Ord's Kangaroo Rat – II
- [ ] Western Harvest Mouse – II
- [ ] Deer Mouse – I
- [ ] Bushy-tailed Woodrat – I
- [ ] Montane Vole – I
- [ ] Long-tailed Vole – II
- [ ] Sagebrush Vole – II
- [ ] Western Jumping Mouse – II
- [ ] Muskrat – II
- [ ] Beaver – II
- [ ] Porcupine – II
- [ ] Coyote – I
- [ ] Red Fox – I
- [ ] Kit Fox – II
- [ ] Black Bear – II
- [ ] Raccoon – II
- [ ] Short-tailed Weasel – II
- [ ] Long-tailed Weasel – I
- [ ] Badger – I
- [ ] Western Spotted Skunk – II
- [ ] Striped Skunk – II
- [ ] Mountain Lion – II
- [ ] Bobcat – II
- [ ] Elk – II
- [ ] Mule Deer – I
- [ ] White-tailed Deer – II
- [ ] Pronghorn – I
- [ ] Moose - II

APPENDIX VI

BIRD CHECKLIST

Craters of the Moon

National Monument
U.S. Department of the Interior

Bird Checklist

Birding Watching at Craters of the Moon

While stark, barren lavas are the focal point of the 1100-square mile monument, other habitats are well represented: limber pine forest; pockets of Douglas fir and aspen; extensive tracts of sagebrush, other shrubs, and grasses; and a few small riparian zones and wetlands. These attract a variety of birds, and the monument's proximity to other ecosystems — marshes, mountains, forests, and lakes — brings a wide spectrum of migrants and accidentals to the area. A surprising 184 species of birds have been reported at Craters of the Moon.

Few birds remain during the harsh winter. However, some are far northern species, difficult to find in the U.S. and therefore of interest to birders. Spring migrants reach a peak in May, and as summer progresses, more than 80 species may nest. By mid-August, southbound migrants are visible, pausing here to rest and forage.

Sightings by visitors are important additions to our wildlife records. Please report unusual bird sightings at the visitor center or write to:

Craters of the Moon National Monument
Resource Management Division
P.O. Box 29
Arco, ID 83213

Codes

These codes reflect the likelihood of finding a given species in appropriate habitat throughout a given season.

A	Abundant	Hard to miss		Sp	Spring	late March-early June
C	Common	Seen most days, easy to find		S	Summer	early June-late August
F	Fairly Common	Seen annually, but not daily		F	Fall	late August-November
U	Uncommon	A few are seen most years		W	Winter	November-March
O	Occassional	Not present most years				
X	Accidental	Not expected; 3 records		*	Nesting species	Has nested at Craters of the Moon
H	Hypothetical	An unverified record exists				
R	Rare	Scarce, not seen yearly				

Checklist

	Grebes	**Sp**	**S**	**F**	**W**
	Pied-billed Grebe	O	O		
	Eared Grebe	O	O	O	
	Western Grebe	X	X		
	Pelicans and Cormorants	**Sp**	**S**	**F**	**W**
	American White Pelican			X	
	Herons and Egrets	**Sp**	**S**	**F**	**W**
	Great Blue Heron	O	O		
	Vultures	**Sp**	**S**	**F**	**W**
	Turkey Vulture	C	C		
	Ducks and Geese	**Sp**	**S**	**F**	**W**
	Snow Goose	O			
	Canada Goose	U	R		
	Gadwall	F			
	American Wigeon	F			
	Mallard *	F	O		
	Northern Shoveler	U			
	Cinnamon Teal	U	U		
	Northern Pintail	F			
	Blue-winged Teal		X		
	Green-winged Teal		X		
	Tundra Swan	F			
	Hawks, Eagles, Falcons	**Sp**	**S**	**F**	**W**
	Osprey			R	
	Bald Eagle			R	R
	Northern Harrier *	U	F	R	
	Sharp-shinned Hawk *	U	U	U	
	Copper's Hawk *	O	O	O	
	Northern Goshawk			O	
	Swainson's Hawk.	O	R		
	Red-tailed hawk *	U	U		
	Rough-legged Hawk				U
	Ferruginous Hawk *	O	O		
	Golden Eagle *	U	U	U	U
	American Kestrel *	F	F	U	
	Merlin	O	X	O	
	Peregrine Falcon	O		O	
	Prairie Falcon *	R	U	U	R
	Gallinaceous Birds	**Sp**	**S**	**F**	**W**
	Chukar *		O	O	
	Gray Partridge *		O	O	
	Ring-necked Pheasant	X		X	
	Ruffed Grouse			O	
	Greater Sage Grouse *	U	U	U	U
	Blue Grouse *		U	U	
	Wild Turkey		X		
	Rails and Cranes	**Sp**	**S**	**F**	**W**
	American Coot	C	C	C	
	Sora			X	
	Sandhill Crane	O		O	

	Shorebirds	**Sp**	**S**	**F**	**W**
	Killdeer	R	R	R	
	Spotted Sandpiper	O	O		
	Long-billed Curlew		O		
	Common Snipe			O	
	Wilson's Phalarope			X	
	Ring-billed Gull	O			
	Herring Gull		O		
	California Gull	O			
	Forster's Tern		O		
	Black Tern		O		
	Doves and Pigeons	**Sp**	**S**	**F**	**W**
	Rock Dove *	U	F	F	R
	Band-tailed Pigeon		O		
	Mourning Dove *	C	C		
	Owls	**Sp**	**S**	**F**	**W**
	Great Horned Owl *	U	U	U	U
	Snowy Owl				X
	Burrowing Owl		O		
	Long-eared Owl *	R	R	O	
	Short-eared Owl *	R	U	R	
	Northern Saw-whet Owl *	R	R	R	R
	Nightjars	**Sp**	**S**	**F**	**W**
	Common Nighthawk *		F		
	Common Poorwill *		U		
	Swifts	**Sp**	**S**	**F**	**W**
	White-throated Swift	O			
	Hummingbirds	**Sp**	**S**	**F**	**W**
	Black-chinned Hummingbd	R	R		
	Calliope Hummingbird	R	U		
	Broad-tailed Hummingbird		O		
	Rufous Hummingbird *	R	F		
	Kingfishers	**Sp**	**S**	**F**	**W**
	Belted Kingfisher	O			
	Woodpeckers	**Sp**	**S**	**F**	**W**
	Lewis' Woodpecker *	R	U		
	Red-headed Woodpecker		X		
	Red-naped Sapsucker *	F	R	U	
	Williamson's Sapsucker	R			
	Downy Woodpecker *	R	R	R	R
	Hairy Woodpecker *	U	U	U	U
	Northern Flicker *	C	C	C	U
	Flycatchers	**Sp**	**S**	**F**	**W**
	Olive-sided Flycatcher *		U		
	Western Wood-pewee *		U		
	Willow Flycatcher		X		
	Hammond's Flycatcher	R			
	Gray Flycatcher		O		
	Ducky Flycatcher *	R	F		
	Cordilleran Flycatcher		O		

Checklist

Flycatchers (continued)	**Sp**	**S**	**F**	**W**
Say's Phoebe *	U	U		
Ash-throated Flycatcher	X			
Western Kingbird	R		R	
Eastern Kingbird		O		
Shrikes	**Sp**	**S**	**F**	**W**
Loggerhead Shrike *	R	U	R	
Northern Shrike				U
Vireos	**Sp**	**S**	**F**	**W**
Plumbeous Vireo *	R	R	R	
Cassin's Vireo *	R	U		
Warbling Vireo *	U	U		
Jays and Crows	**Sp**	**S**	**F**	**W**
Steller's Jay	O		O	
Pinyon Jay			O	O
Clark's Nutcracker *	C	C	A	C
Black-billed Magpie *	R	R	U	R
American Crow *	U	R		
Common Raven *	C	C	C	C
Larks	**Sp**	**S**	**F**	**W**
Horned Lark		R	F	F
Swallows	**Sp**	**S**	**F**	**W**
N. Rough-winged Swallow	R			
Tree Swallow		O		
Viloet-green swallow *	F	A	U	
Barn Swallow *	C	C	F	
Chickadees	**Sp**	**S**	**F**	**W**
Black-capped Chickadee *	C	C	F	R
Mountain Chickadee *	C	C	F	F
Nuthatches	**Sp**	**S**	**F**	**W**
Red-breasted Nuthatch	U	U	U	R
White-breasted Nuthatch	R	R	R	
Creepers	**Sp**	**S**	**F**	**W**
Brown Creeper	R		R	R
Wrens	**Sp**	**S**	**F**	**W**
Rock Wren *	C	C	R	
House Wren *	U	U	R	
Winter Wren	R		R	R
Dippers	**Sp**	**S**	**F**	**W**
American Dipper			X	
Kinglets, Gnatcatchers	**Sp**	**S**	**F**	**W**
Golden-crowned Kinglet	R	R	R	R
Ruby-crowned Kinglet	C	U	C	
Blue-gray Gnatcatcher *	R	R	R	
Thrushes	**Sp**	**S**	**F**	**W**
Western Bluebird		X		
Mountain Bluebird *	C	C	F	
Townsend's Solitaire	R		R	
Swainson's Thrush	R		R	
Hermit Thrush	U		U	
American Robin *	C	A	F	
Varied Thrush	O			
Thrashers, Mockingbirds	**Sp**	**S**	**F**	**W**
Gray Catbird	O	O		
Sage Thrasher *	R	U	F	
Brown Thrasher		X	X	
Starlings	**Sp**	**S**	**F**	**W**
European Starling *	C	C	C	U
Pipits and Wagtails	Sp	S	F	W
American Pipit			O	
Waxwings	**Sp**	**S**	**F**	**W**
Bohemian Waxwing			O	U
Cedar Waxwing	U	R	U	

Warblers	**Sp**	**S**	**F**	**W**
Tennessee Warbler	X		X	
Orange-crowned Warbler *	U	F	R	
Nashville Warbler			X	
Yellow Warbler *	U	F		
Yellow-rumped Warbler	C	U	F	
Townsend's Warbler	R		R	
American Redstart	X			
Northern Waterthrush	X		X	
MacGillivray's Warbler *	U	F	R	
Wilson's Warbler *	U	F	R	
Yellow-breasted Chat	X		X	
Tanagers	**Sp**	**S**	**F**	**W**
Western Tanager *	F	U		
Sparrows	**Sp**	**S**	**F**	**W**
Green-tailed Towhee *	C	F	U	
Spotted Towhee *	C	C	U	
Chipping Sparrow *	U	F		
Brewer's Sparrow *	A	A	C	
Vesper Sparrow *	F	F	F	
Lark Sparrow	R	U		
Black-throated Sparrow		X		
Sage Sparrow	R	R		
Lark Bunting *		R		
Savannah Sparrow	O	O		
Grasshopper Sparrow *	U	U		
Fox Sparrow *	U	U		
Song Sparrow *	F	F	F	
Lincoln's Sparrow	O			
White-throated Sparrow			X	
White-crowned Sparrow	F	U	F	
Golden-crowned Sparrow			X	
Dark-eyed Junco	C	F	F	
Snow Bunting				U
Cardinals and Allies	**Sp**	**S**	**F**	**W**
Black-headed Grosbeak *	U	U		
Lazuli Bunting *	F	C	F	
Blackbirds and Orioles	**Sp**	**S**	**F**	**W**
Red-winged Blackbird *	F	F	F	
Western Meadowlark *	F	F	U	
Yellow-headed Blackbird *	C	C	C	R
Brewer's Blackbird	C	A		
Common Grackle		X		
Brown-headed Cowbird *	C	C		
Bullock's Oriole *	U	U		
Baltimore Oriole	X			
Finches	**Sp**	**S**	**F**	**W**
Gray-crowned Rosy-Finch	R			U
Black Rosy-Finch				R
Pine Grosbeak			O	
Cassin's Finch *	C	A	U	
House Finch	U	R	U	
Red Crossbill		O	O	
Hoary Redpoll				X
Common Redpoll				R
Pine Siskin *	F	C	F	U
American Goldfinch	R		R	
Evening Grosbeak	U	U	U	
Weaver Finches	**Sp**	**S**	**F**	**W**
House Sparrow *	C	C	C	

APPENDIX VII

WEATHER INFORMATION

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Average Max. Temperature (F)	28.9	34.1	41.5	53.4	64.5	74.4	84.3	82.7	71.6	59.1	40.4	29.9	55.4
Average Min. Temperature (F)	10.3	14.3	20.4	28.2	36.9	44.6	51.9	50.2	40.9	31.3	20.5	11.3	30.1
Average Total Precipitation (in.)	2.17	1.61	1.28	1.04	1.74	1.27	0.69	0.85	0.87	0.90	1.36	1.80	15.58
Average Total SnowFall (in.)	22.5	17.8	9.8	4.6	2.2	0.0	0.0	0.0	0.5	1.7	10.9	19.6	89.5
Average Snow Depth (in.)	20	26	19	3	0	0	0	0	0	0	2	11	7

Percent of possible observations for period of record.

Max. Temp.: 95.2% Min. Temp.: 95.5% Precipitation: 96.6% Snowfall: 95.7% Snow Depth: 91.9%

APPENDIX VIII

GLOSSARY OF TERMS NOT DEFINED IN THE TEXT

aa — a Hawaiian term for lava flows typified by a rough, jagged, spinose, clinkery, or fragmental surface.

cinder — a fragment of lava from an erupting volcano, often very porous and filled with gas holes.

cinder cone — a steep, conical hill formed by the accumulation of cinders and other loose material expelled from a volcanic vent by escaping gasses.

Ka — one thousand years.

lava — magma or molten rock that has reached the surface of the earth.

loess — wind-blown silt.

Ma — one million years.

magma — molten rock below the surface of the earth.

pahoehoe — a Hawaiian term for lava typified by a smooth, billowy, or undulating surface.

pyroclast — an individual particle ejected during a volcanic eruption.

spatter — an accumulation of very fluid pyroclasts.

symbiotic — the intimate living together of two dissimilar organisms in a mutually beneficial relationship.

vent — the opening at the earth's surface through which gasses and other volcanic materials issue.