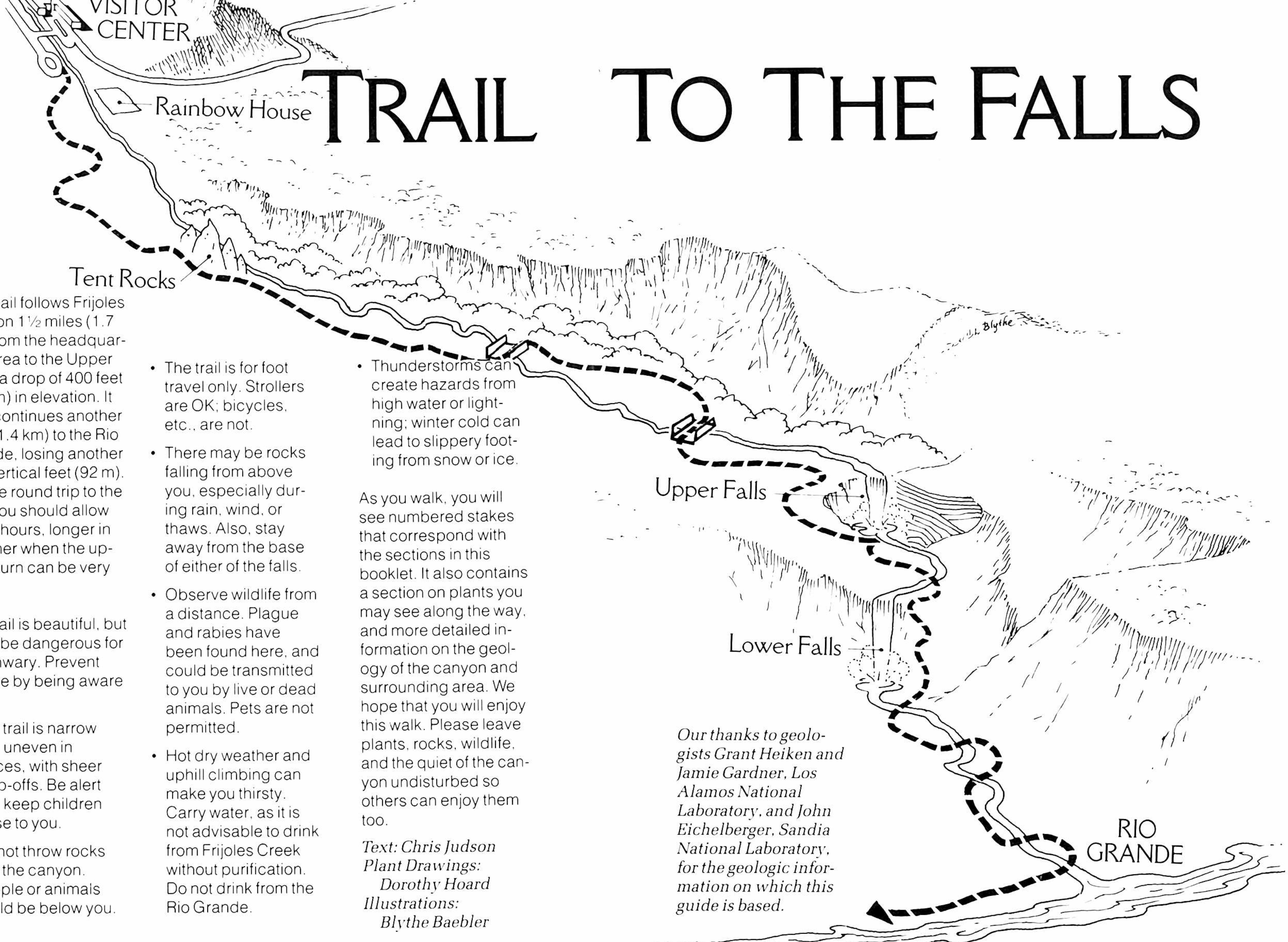
A GUIDE TO THE FALLS TRAIL

BANDELIER NATIONAL MONUMENT

TRAIL TO THE FALLS



This trail follows Frijoles Canyon 1½ miles (1.7 km) from the headquarters area to the Upper Falls, a drop of 400 feet (122 m) in elevation. It then continues another mile (1.4 km) to the Rio Grande, losing another 300 vertical feet (92 m). For the round trip to the falls you should allow 2½-3 hours, longer in summer when the uphill return can be very hot.

The trail is beautiful, but it can be dangerous for the unwary. Prevent trouble by being aware that:

- The trail is narrow and uneven in places, with sheer drop-offs. Be alert and keep children close to you.
- Do not throw rocks into the canyon. People or animals could be below you.
- The trail is for foot travel only. Strollers are OK; bicycles, etc., are not.
- There may be rocks falling from above you, especially during rain, wind, or thaws. Also, stay away from the base of either of the falls.
- Observe wildlife from a distance. Plague and rabies have been found here, and could be transmitted to you by live or dead animals. Pets are not permitted.
- Hot dry weather and uphill climbing can make you thirsty. Carry water, as it is not advisable to drink from Frijoles Creek without purification. Do not drink from the Rio Grande.
- Thunderstorms can create hazards from high water or lightning; winter cold can lead to slippery footing from snow or ice.

As you walk, you will see numbered stakes that correspond with the sections in this booklet. It also contains a section on plants you may see along the way, and more detailed information on the geology of the canyon and surrounding area. We hope that you will enjoy this walk. Please leave plants, rocks, wildlife, and the quiet of the canyon undisturbed so others can enjoy them too.

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Plant Drawings: Dorothy Hoard
Illustrations: Blythe Baebler

Our thanks to geologists Grant Heiken and Jamie Gardner, Los Alamos National Laboratory, and John Eichelberger, Sandia National Laboratory, for the geologic information on which this guide is based.

STOPS ALONG THE TRAIL

1 About 1.4 and again 1.1 million years ago, there was a tremendous series of volcanic eruptions (600 times as large as the Mount St. Helens explosion in 1980) from the Jemez (*HAY-mez*) Mountains just northwest of here. They covered a wide area with thick layers of volcanic ash, creating the Pajarito (*Pah-hah-REE-toe*) Plateau. The pinkish-tan cliffs above you are this ash, consolidated into a rock known as tuff. Tuff is porous and relatively soft. Running water erodes it quickly, creating deep, steep-walled canyons like this one.

More of the Plateau can be seen on the drive between here and Santa Fe or Española.

2 Across the creek is Rainbow House, one of thousands of ruins found in and around Bandelier National Monument. The Indians who lived here about 500 years ago were almost completely dependent on their immediate environment for everything they needed, including food, clothing, shelter, and medicine. Here they could make shelter by carving a cave into the soft tuff cliffs, or building a home of stone blocks cut from tuff. They could grow beans, corn, and squash in the canyon bottom or in rain-watered fields on the mesa tops. Looking around, do you think you could grow, find, or make everything you would need?

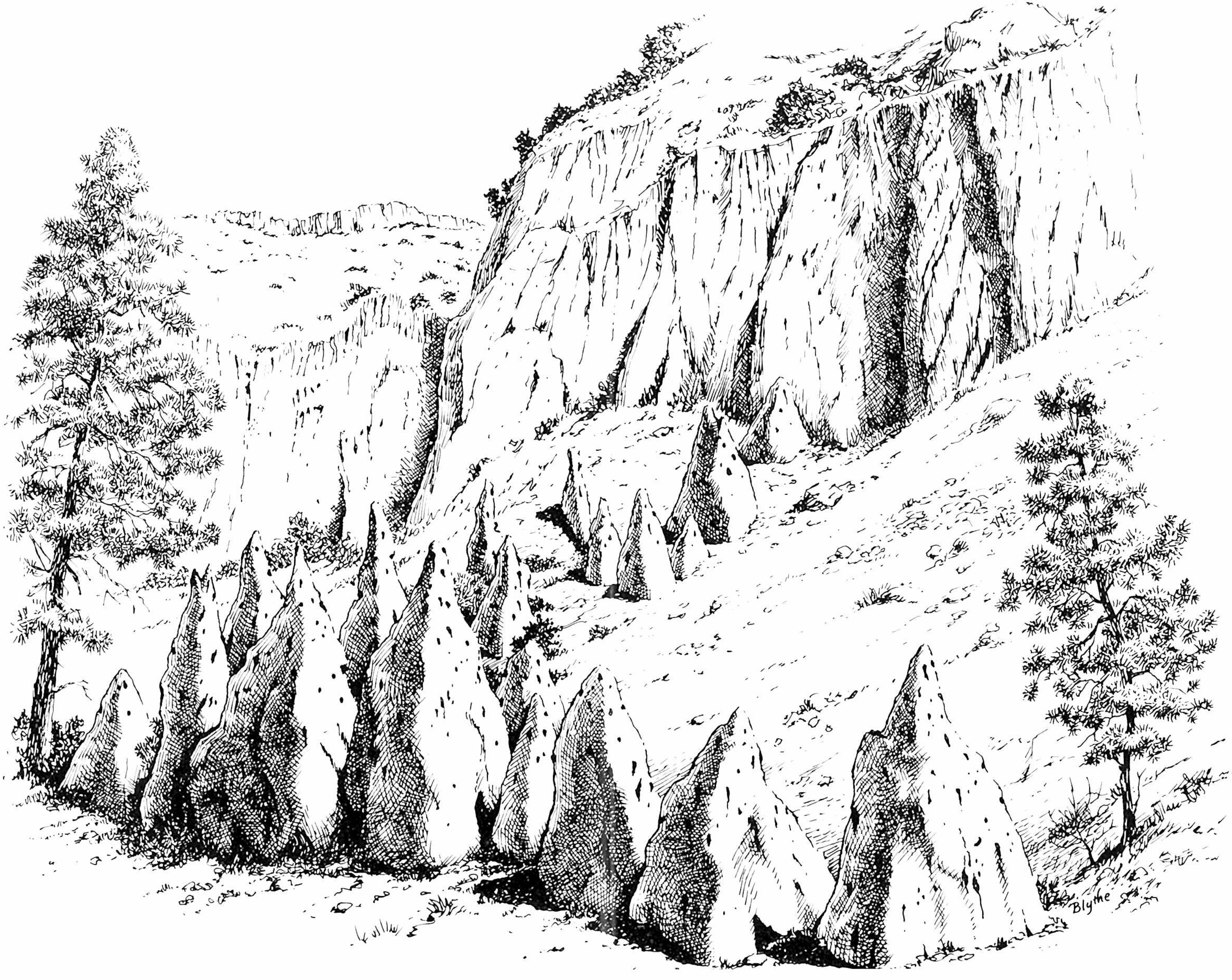
3 Before the eruptions of the Jemez volcanic field created the tuff plateau, smaller volcanos here and to the east had covered a wide area with basalt lava flows. A creek was flowing here then, and eventually carved a canyon into the basalt. The later ash flows filled the canyon, but the creek continued flowing in about the same course, eroding away the tuff and again exposing the basalt. At this moment in geologic time Frijoles Creek has once again cut down to the level in the basalt where it was flowing over a million years ago!

You can see the dark basalt on the far side of the canyon, but the stream has not yet removed all the tuff from the side on which you are standing. In contrast to the tuff, basalt is hard, dense, and usually dark colored. Small gas bubbles that were in the lava caused the holes in basalt; holes in this tuff are usually caused by erosion. As you walk, notice where basalt appears below the overlying tuff.

4 Besides the big things like volcanos and ashflows, there are plenty of small things of interest along this trail. On many boulders there are bright splashes of color — mosses and lichens (*LYE-kens*). The ones that look like greenish-gray furry bumps are mosses. If the moss is dry and you have a canteen along, try watering it with a few drops and see how it reacts.

Lichens come in many colors and forms, and live on trees and rocks, in the soil, and on almost anything else that will stand still long enough. A lichen is actually a combination of two plants, an alga and a fungus, and lichens can withstand conditions that neither of the two could survive alone. Choose a good-sized rock and see how many different lichens are growing there. Did you see any of the kind that grows in the tiny spaces between rock particles? You will find more forms on trees, especially on dead branches.

5 These eroded remnants of tuff are called tent rocks. There are many different kinds of tent rocks in the Jemez Mountains, and several possible reasons why they form. In tuff, some may contain cracks which were the escape route for hot gasses; the additional heat allowed particles to weld together more firmly than in nearby portions of the ash. Ash particles are also cemented by minerals precipitated from escaping vapors. Many tent rocks still bear a cap stone of harder material; these protective caps may have slowed erosion of the soft rock below. Some seem related to fractures in the tuff layer. In some, minerals leached from flowing ground water have


Blythe

formed a resistant rind which protects the "tents" from eroding. How long do you think it will take for erosion to remove the graffiti left here by a few inconsiderate visitors?

6 Here along the creek it is hard to remember that you are really in a desert in New Mexico. During the summer the leaves, shrubs, and vines form a thick, shady woods. If the air is warm there will be many rich fragrances in the air. Can you tell what they come from?

Unfortunately for hikers, this lush streamside environment, especially from here to the Rio Grande, and above Ceremonial Cave, is ideal for two plants you'll want to avoid: poison ivy and stinging nettle. The resin of poison ivy can cause an itchy rash. Scratching can spread the irritating resin to other parts of the body, so wash skin areas that have brushed against the leaves. Nettle leaves have sharp hairs that inject tiny amounts of formic acid into the skin. This feels much like an ant bite (they use formic acid too), leading to the local Spanish nickname, *yerba de la hormiga* — ant weed.

Begining on page 9 of this booklet is a section identifying some of the other plants commonly found along the trail. Please remember to leave the flowers unpicked!

7 With elevations ranging from 10,000′ in the Jemez Mountains down to 5,000′ along the Rio Grande, Bandelier contains habitats for a great variety of plants. Canyon walls and mesa tops nearby receive only about 15″ of precipitation per year, so plants living there must adapt to retain moisture. Those that live in rare canyons such as this that offer water throughout the year can afford large, water-losing leaves.

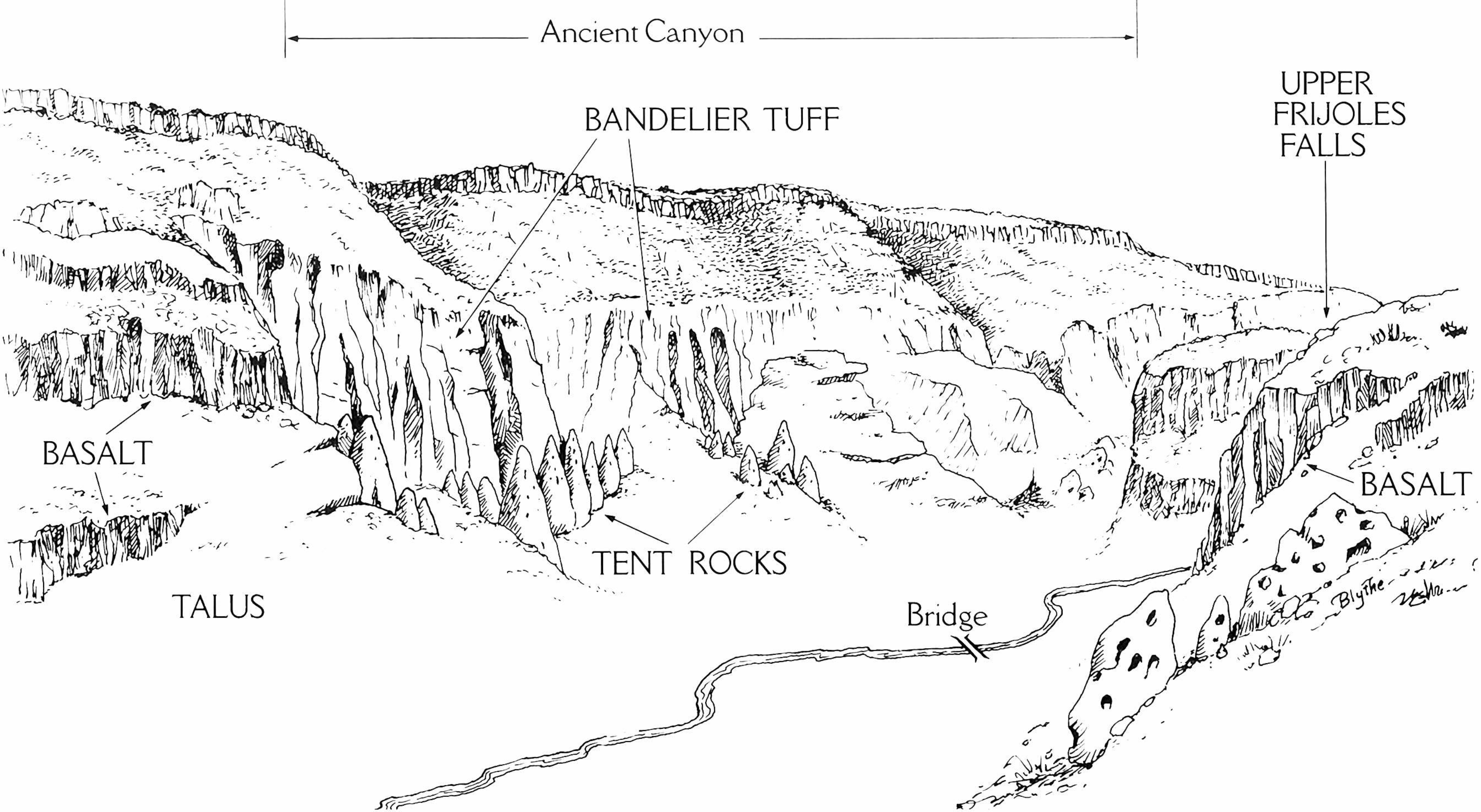
8 This little creek, El Rito de los Frijoles (El REE-toe day los Free-HOH-lees, Little River of the Beans) has been a very important force here for many years. Over a million years ago, it was cutting into the old basalt layers. As the layers of tuff were deposited it continued cutting, maintaining this deep canyon. The presence of year-around water made an environment suitable for many plants and animals that are not found on drier mesas. A relatively short time ago, perhaps only a few thousand years, man began coming into this area, attracted by the water, game, and plants. Later, prehistoric Pueblo Indians, the Anasazi, came and settled, building their homes a little way up the canyon and using the water to irrigate their crops. Today, the stream is enjoyed by many visitors every day, and supports a variety of plants and wildlife.

But, the stream also continues cutting. The La Mesa Fire of 1977 burned over 15,000 acres including areas in the upper parts of this canyon, removing soil-retaining plant cover. Following the fire, heavy rains, especially summer thunderstorms, turned the usually-quiet creek into a muddy, raging torrent carrying rocks and trees. Debris you may see piled against trees was left by these floods.

9 Here you have a chance to take a close look at basalt. This rock was a valuable source of tools for Indians living in the canyon. Manos (*MAH-nose*) and metates (*muh-TAH-tays*) for grinding corn, picks for carving out caves, and axes, hammers, and other tools that had to stand up to heavy use could be made of basalt.

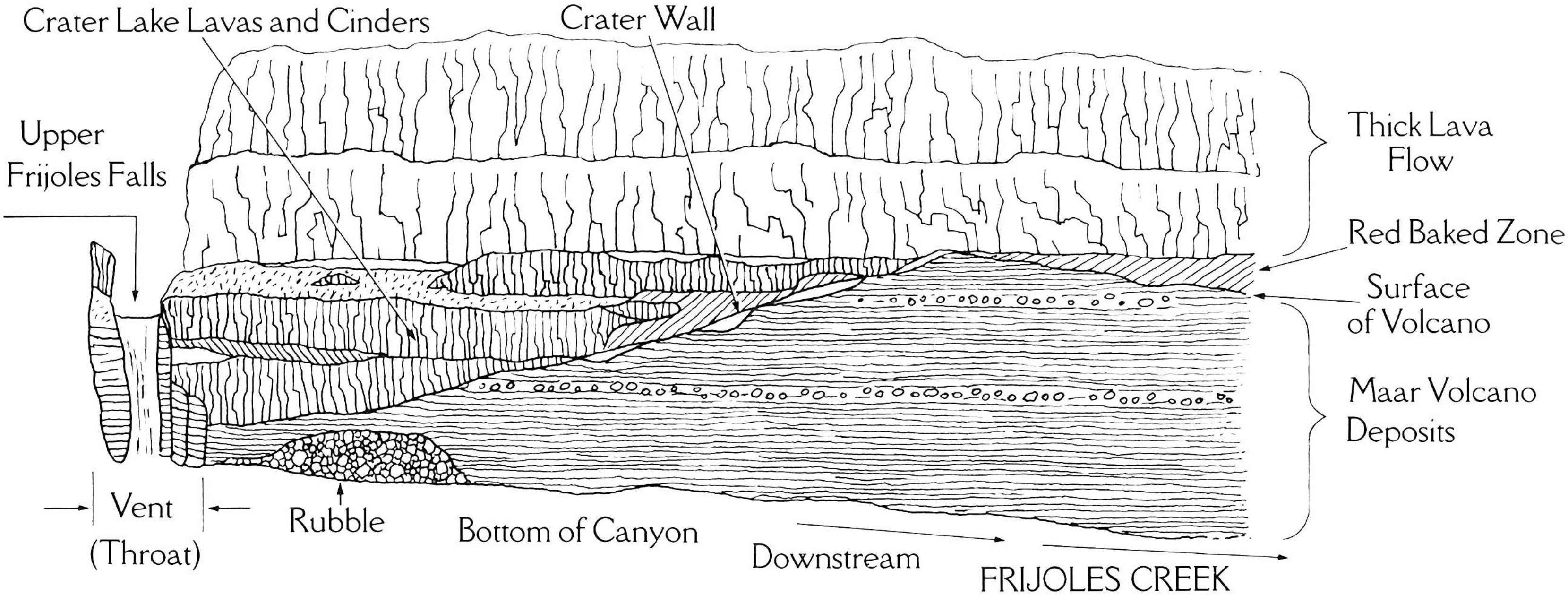
On this large boulder, surfaces sparkle with small flecks of olivine, a green iron and magnesium silicate crystal formed underground before basalt lavas were erupted. Although uncommon on the earth's surface, olivine is an important mineral constituent of the interior. The earth is green inside!

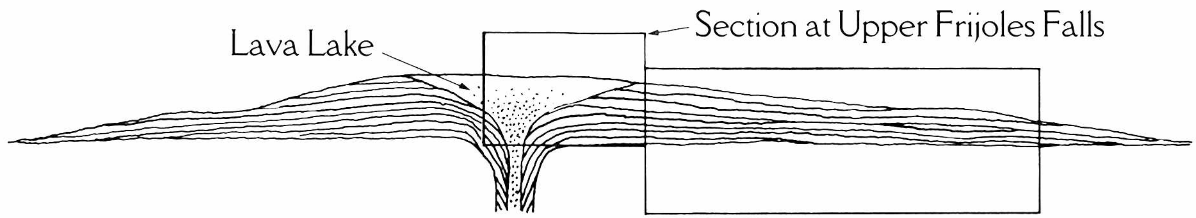
10 Have you seen any wildlife today, or any tracks on the trail? You may even have seen "scat" left on rocks, which is how some animals mark their territory. National parks and monuments like Bandelier are places where native plants and animals are protected by law. This is one of the reasons pets are not permitted on any of the trails. Hunting is prohibited, and other regulations are often necessary. For example, the upper reaches of Frijoles Canyon are home to an endangered species of salamander, and for its protection only day use is allowed in that area. But even with Park Service protection, the ecosystem here is not complete, for several native species, including wolves, river otters, and grizzly bears, were eliminated from all of New Mexico years ago. Burros, exotic plants, and even the management of fires are other problems to be dealt with to keep Bandelier in as natural and healthy a condition as possible.



The Indians of this area depended on their crops, but they also gathered wild food and hunted game. Considering the nature of the area, including plants, rainfall, altitude, and terrain, can you guess what animals might live here? Lists of mammals, birds, reptiles and amphibians are available at the Visitor Center, and the Rangers welcome reports of interesting sightings.

11 On the canyon wall ahead you can see where a tributary creek used to enter Frijoles Creek. Its canyon was filled by the ash flows at the same time as Frijoles Canyon, but was not re-cut afterward. You can see the wide V-shape of the pink tuff filling the dark basalt walls of the old canyon.


Crater Lake Lavas and Cinders
Crater Wall
Upper
Frijoles Falls
Thick Lava
Flow
Red Baked Zone
Surface
of Volcano
Maar Volcano
Deposits
Vent
(Throat)
Rubble
Bottom of Canyon
Downstream
FRIJOLES CREEK


Lava Lake
Section at Upper Frijoles Falls
Section visible in canyon wall from Lower
Frijoles Falls to the Rio Grande

12 As you turn the corner ahead, notice the difference in plants, air temperature, wind direction, even the smell of the air. You can tell that the environment is drier, for the plants are ones that tolerate hot, arid surroundings. The 700 foot change in elevation between the Visitor Center and the canyon bottom here causes spring to arrive there about 2 weeks later than here, while in the fall, color changes here are about two weeks later than up above.

13 Ahead you can see where the creek joins the Rio Grande, which is partway along its journey from Colorado through New Mexico, Mexico, and Texas to the Gulf of Mexico. The river flows through basins resulting from spreading of the earth's crust along the Rio Grande Rift, a feature at least 30 million years old. Like Frijoles Creek, the Rio has stayed in nearly the same place, carving its deep canyon, while the landscape has changed around it. The mountains on the far side of the river are the Cerros del Rio (*SER-ose del REE-oh, Mountains of the River*). They are volcanos that, over the last 1–3 million years, produced the basalt through which you have been walking.

In many places on the sides of the canyon you may notice evidence of passage of time between eruptions. Here and there a layer of very red dirt appears. This is soil that formed on top of the surface of one flow, and then was covered by the next one. The heat of the new flow "baked" the soil, producing the red color.

14 Here and across the canyon you can see layers of what looks like sandstone. Actually you are standing in the mouth of a maar volcano, a type of volcano that erupted through water from a stream or lake. Molten rock coming up and meeting the water caused steam explosions, and the rock fragments were blown out and deposited as thin layers. Larger pieces of rock, called bombs, sometimes landed on these layers; you can see the "dent" at impact points. This volcano was low and wide: about 2 miles across and only about 100 feet high. You can see more of the deposits farther down the canyon.

****Please be very careful not to kick or throw anything into the canyon; someone might be below****

15 After the volcano's cone built up above the level of the water, the eruption changed to more typical cinders and lava flows. Eventually activity ceased, and lava still in the throat of the volcano slowly hardened in place. Upper Falls drops over this resistant rock. If you would like to know more about the geologic history of this area, turn to "Digging Deeper" on page 12 of this booklet.

As you walk from here back to the Visitor Center, or continue down to the Rio, you might think about all the changes that have occurred in this apparently placid little canyon. Volcanos erupted basalt flows and the little creek gradually cut a canyon into them; then huge eruptions from the Jemez Mountains covered the landscape with tuff and filled the canyon, and the creek again cut its slow way down through the rock, this time tuff. Century to century, year to year, season to season, the canyon is always changing. A big rock slide, or even another volcanic eruption, could happen at any time. And almost constantly a pebble somewhere is sliding an inch or so lower, or a grain of sand is being washed into the Rio. The geologic processes continue. Take a little time to enjoy this never-to-be-repeated moment.

IF YOU CONTINUE DOWN THE TRAIL

In about ⅓ mile you will reach a viewpoint for the Lower Falls, and another ⅔ mile takes you to the Rio Grande. Please remember to stay out of the area at the base of each falls, due to the danger of falling rocks.

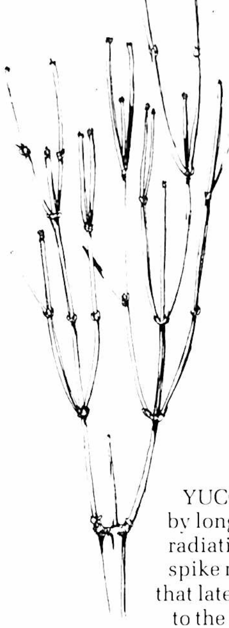
The winter and spring of 1985 brought very heavy snowpack to the watershed of the Rio Grande. During spring runoff, the floodpool of Cochiti Dam, downstream from Frijoles, was allowed to back up much higher than its usual level. This caused over 200 acres of Bandelier along the river to be under lake waters for a year and a half. You may notice effects from this inundation, including drowned plants and a thick layer of silt left behind as the water receded. This lake level may be repeated in any year with heavy runoff. In addition, the trail along the Rio has had to be abandoned, and may or may not be passable at any given time.

WHEN YOU RETURN TO THE VISITOR CENTER

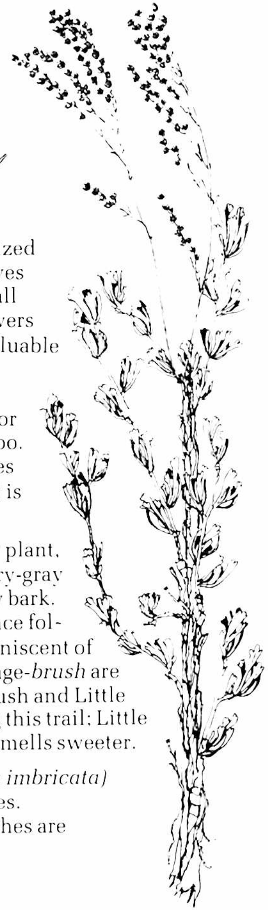
Take your time going up the trail, as it can be hot and tiring. Do not be tempted to drink out of the creek unless you purify the water. The next section of this booklet will highlight species of plants commonly found in various trailside environments. "Posey peeping" (but *not picking*!) will give you a good reason to stop often and get your breath along the way.

FALLS AREA

** plants that tolerate arid conditions **



MORMON TEA *(Ephedra sp.)* This shrubby plant has slender, bunched, jointed stems, leading to a common name, Jointfir. Leaves are reduced to scales. Male and female flowers are borne on separate plants.



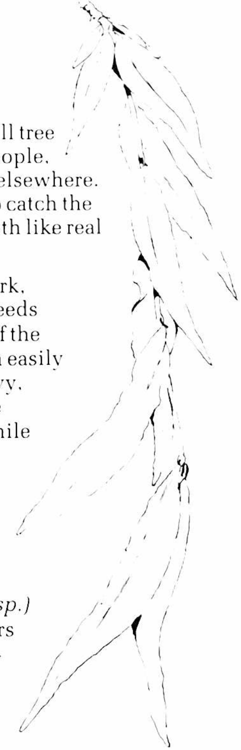
YUCCA *(Yucca sp.)* Yucca is characterized by long, narrow, stiff, sharp-pointed leaves radiating out from the base. In spring a tall spike may form, bearing large white flowers that later become fruit. Yucca was very valuable to the Indians, the leaves being used for weaving baskets, sandals, and mats, the fiber used for ropes, cord, and turkey feather or rabbit skin blankets, and the roots for shampoo. Both broad-leaved and narrow-leaved species are found here. Yucca is not a cactus, rather it is similar to lilies.

SAGEBRUSH *(Artemesia sp.)* A shrubby plant, one to twelve feet high with silvery-gray leaves and dark purplish shaggy bark. You may notice the spicy fragrance following a rain; although it is reminiscent of sage used for cooking, sage and sage-*brush* are in different families. Big Sagebrush and Little Sagebrush are both found along this trail; Little Sagebrush is smaller, lacier, and smells sweeter.

WALKINGSTICK CHOLLA *(Opuntia imbricata)* A tall, skinny cactus with long branches. Yellow growths on the ends of branches are the fruits; flowers are dark purple.

ALONG THE STREAM

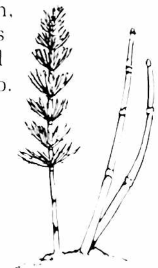
** plants that require moisture **

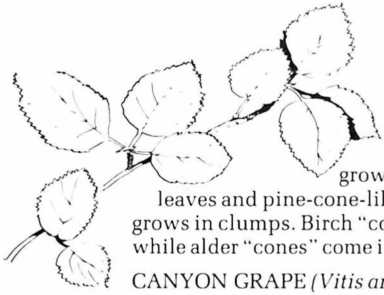


NARROWLEAF COTTONWOOD *(Populus angustifolia)* A tall tree with gray furrowed bark. The narrow leaves surprise many people, being so different from the Rio Grande Cottonwood common elsewhere. Cotton-like filaments, appearing in early summer, function to catch the wind and transport the seed, but are not usable for making cloth like real cotton.

BOX ELDER *(Acer negunda)* This tree with grayish-brown bark, leaflets of three, and winged seeds is not an elder, but a member of the maple family. Young plants can easily be mistaken for poison ivy, but box elders have opposing leaves while those on poison ivy are alternating.

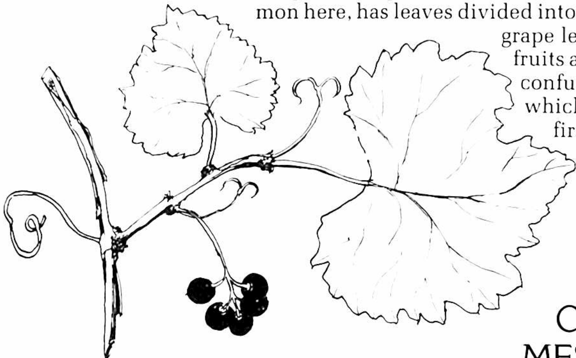
HORSETAIL *(Equisetum sp.)* This water-loving plant appears in two forms. One has green segmented reedy stems and a lack of conspicuous leaves; spores spread from the conelike structure at its tip. The other is a bundle of slender green upright branches, which led to the name "horsetail." A common name, scouring rush, comes from the silica-rich stems that work well as pan scrubbers. Giant, tree-sized species of this plant were common millions of years ago.





THINLEAF ALDER *(Alnus tenuifolia)* and Water Birch *(Betula occidentalis)* These slender-trunked trees look similar and are found in like habitat, along the creek. They grow up to 30 feet tall and both have oval, toothed leaves and pine-cone-like fruit. Alder bark has warts; birch usually grows in clumps. Birch "cones" are solitary and fall apart in autumn, while alder "cones" come in groups and are harder and more permanent.

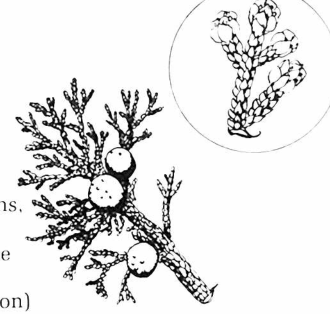
CANYON GRAPE *(Vitis arizonica)* This vine can be seen climbing on shrubs and trees. It has large (1½"–3½") maple-like leaves and coiling tendrils. Virginia Creeper *(Parthenocissus inserta)* another vine common here, has leaves divided into five to seven leaflets, while grape leaves are undivided. Grape fruits are edible, but very easily confused with those of the creeper, which are not. Creepers are the first leaves to change color in the fall, often turning to a deep purplish red.



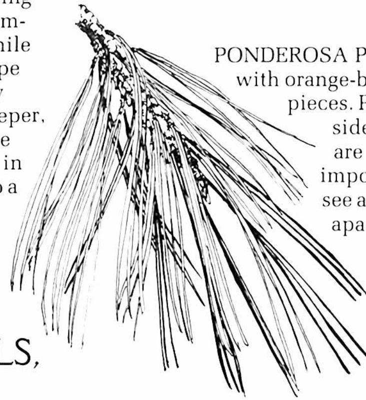
CANYON WALLS, MESA TOPS

* *plants that survive on rainfall alone* *

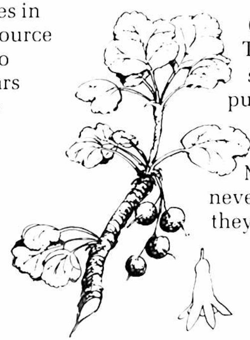
PIÑON PINE *(Pinus edulis)* A rounded-top tree with short needles in bundles of two. The rich nuts have long been a favorite food source for people and animals. It costs the tree so much energy to produce seeds that in this area it is as many as seven years between good crops. Along with juniper, this tree is so characteristic of this plant community that this is known as the piñon-juniper woodland.



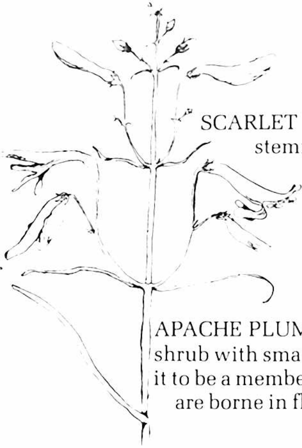
ONE-SEED JUNIPER *(Juniperus monosperma)* A shrubby tree with scale-like leaves, shreddy bark, and small dark blue or purple berry-like cones. The "berries" taste somewhat like turpentine, but are important winter food for robins, bluebirds, coyotes, and others. Male trees disperse great amounts of pollen by the wind in the spring, and may make you sneeze! Three other species (alligator, Rocky Mountain, and common) are also found in Bandelier.



PONDEROSA PINE *(Pinus ponderosa)* A tall, straight pine, with orange-brown bark that looks like jigsaw puzzle pieces. Put your nose to the bark on the sun-warmed side to enjoy the sweet fragrance. The needles are long and in bundles of three. The seeds are important food for squirrels and birds; you may see an Abert (tassel-eared) squirrel tearing apart a cone to get them out.



CURRANT *(Ribes cereum)* and Gooseberry *(Ribes inerme)* These two plants are very similar, but the gooseberry has spines, small white flowers in May, and the berries are purple when ripe; wax currant has no spines, golden flowers early in spring, and red berries. Gooseberries are often the first shrubs to have leaves in the spring. Many inedible berries resemble those that are harmless — never sample wild plants or fruits unless you are *positive* that they are what you think they are!

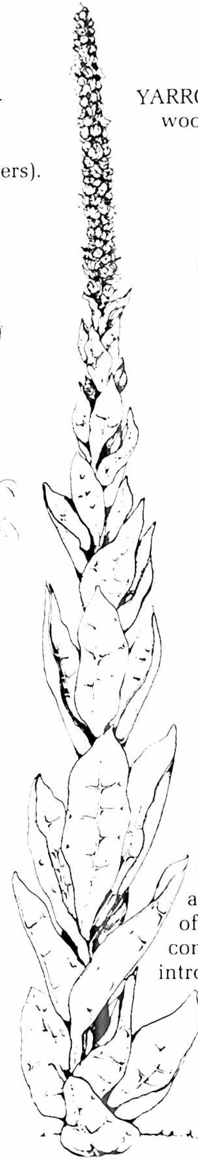


SPRING FLOWERS

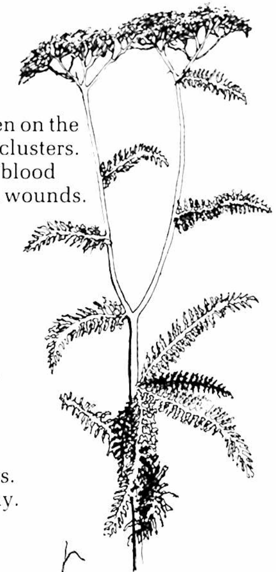
SCARLET PENSTEMON *(Penstemon barbatus)* A straight-stemmed plant with scarlet tube-shaped flowers which are favorites of hummingbirds. Easily confused with Scarlet Gilia (see Summer Flowers).

APACHE PLUME *(Fallugia paradoxa)* A woody shrub with small white flowers that clearly show it to be a member of the rose family. The seeds are borne in fluffy pink bundles that provide the name "plume."

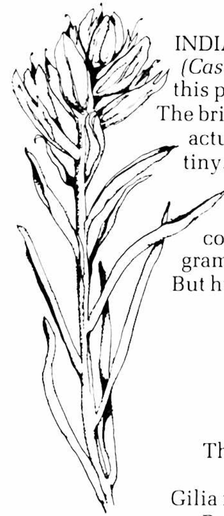
NEW MEXICO LOCUST *(Robinia neomexicana)* This thorny shrub sometimes grows to the size of a small tree. The sweet-pea-shaped flowers are large, showy, and lavender. It is a favorite deer browse.



SUMMER FLOWERS



YARROW *(Achillea lanulosa)* Fern-like leaves often seen on the woodland floor give rise to white, flat-topped flower clusters. Yarrow is widely regarded as useful for stopping blood flow in wounds.



INDIAN PAINTBRUSH *(Castilleja sp.)* In several ways this plant is not what it seems. The bright-red "flowers" are actually bracts that surround tiny, inconspicuous white true flowers. It is semi-parasitic, needing to grow in conjunction with sagebrush, grama grass, or some other hosts. But hummingbirds like it anyway.

SCARLET GILIA *(Ipomopsis aggregata)* The star-shaped ends and yellow speckles differentiate the Gilia flowers from the similar Scarlet Penstemon. The name, *Ipomopsis*, means "resembling a worm." It takes the Gilia two years to go from sprouting to producing seeds.

MULLEIN *(Verbascum thapsis)* Fuzzy leaves in a cabbage-like bunch produce a tall stalk with small yellow flowers that often bloom one ring at a time (leading to the common name, "King's crown"). It is an exotic, introduced from the Mediterranean and now growing commonly throughout the area, thanks to the tremendous number of seeds produced by the numerous flowers on each stalk.

FALL FLOWERS

RABBITBRUSH *(Chrysothamnus nauseosus)* A silvery-gray shrub crowned in late summer with bunches of feathery golden flowers. Locally known as chamisa. Hillsides covered with the golden flowers, glowing in fall light, are a hall-mark of the Southwest.

PURPLE ASTER *(Aster sp.)* These purple daisy-like flowers with yellow centers stand in bright contrast to the golden chamisa and other yellow fall-blooming plants.

DIGGING DEEPER

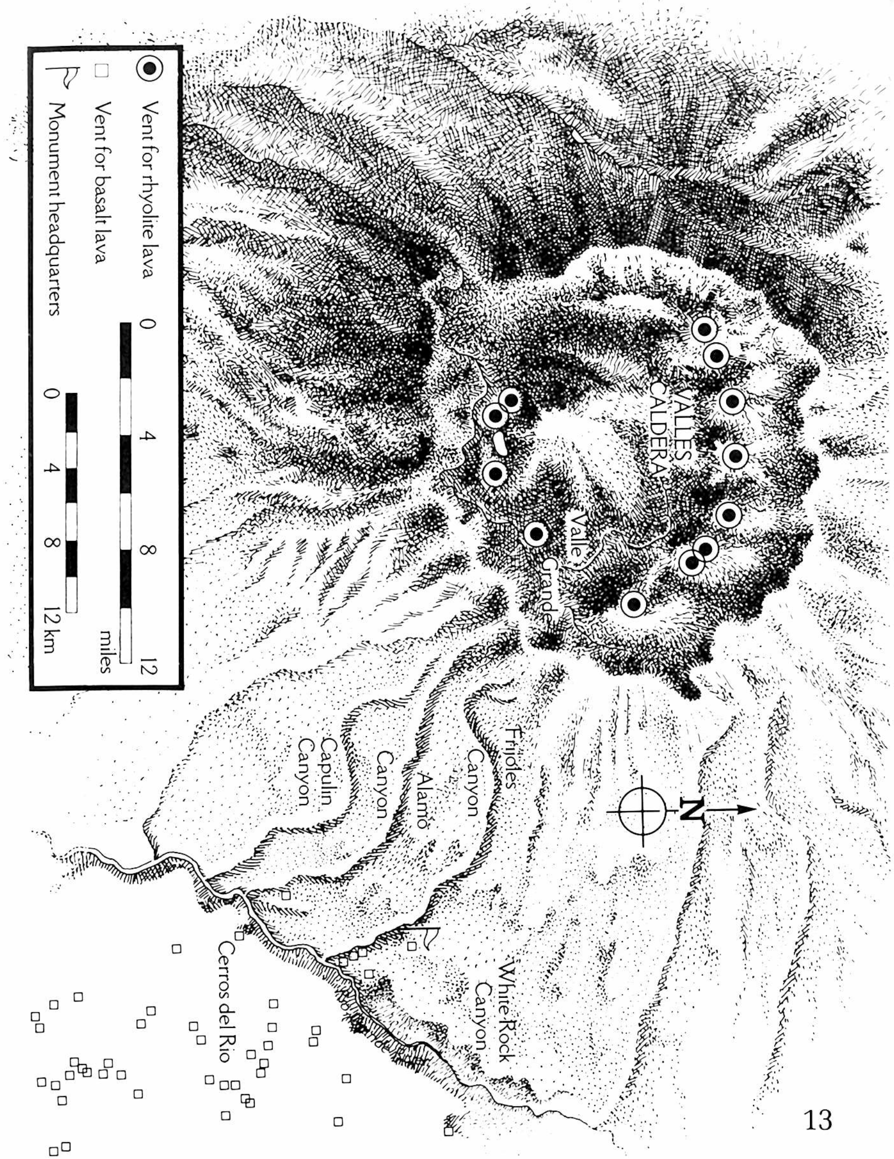
Although the canyon walls and Anasazi ruins give an impression of antiquity, the Pajarito Plateau is actually very young, geologically speaking. Our planet is about 4.6 billion years old, and the hard "basement" rocks which form some of the nearby mountains and underlie the plateau formed about 1.7 billion years ago. Yet the oldest rocks in Frijoles Canyon are about two *million* years old, and many are only half that.

Because the rocks of Frijoles Canyon represent such a small portion of geologic time, the history of the canyon is relatively simple. The canyon is cut into the flank of a large volcanic mass known as the Jemez Volcanic Field, which includes the 14 mile diameter Valles caldera, as well as a wide variety of volcanic vents, lavas, and ash deposits. Cinder and spatter cones and basalt lava flows underlie southern Frijoles Canyon and are exposed in the Cerros del Rio, east and southeast of Bandelier. Eruptions within the Jemez Volcanic field span a time period from more than 16.5 million to less than 100 thousand years ago.

The Cerros del Rio vents were active about three million years ago and erupted mostly basalt. The nature of the eruptions and the shape of the resulting mountains were consequences of the composition of this basalt. All lava contains some gas dissolved within it before eruption. Lava beneath the surface is under pressure and, as the lava rises in a volcano, this pressure decreases and the gas begins to come out of solution and form bubbles. The same process occurs when the top is removed from a bottle containing soda pop. Because these bubbles tend to accumulate at the top of the rising lava and because gas can escape from the vent more easily than the lava can, the beginnings of eruptions are often very gas rich. Frequently, basalt eruptions begin with violent ejections of gas and molten blobs of lava. The blobs land around the vent to form a giant anthill structure called a cinder cone. Many of the hills in the Cerros del Rio are cinder cones, in various stages of erosion. Some still have a conical outline and remnants of a summit crater.

As the gas content decreases, the vertical blast dies and lava breaks through the side of the weak cone and flows over the surrounding region. Because of its silica-poor composition and because it is very hot when molten (about 2200° F), basaltic lava is the most fluid of lavas and moves in thin tongues. Although very fluid for lava, basalt is still a great deal more viscous than any liquid in our ordinary experience, such as water or even molasses. In fact, it requires most of a person's weight to thrust a stick even a few inches into an active basalt flow. As the lava moves, a crust forms where it touches cold ground or air. This crust is continually being broken into rubble by the movement of the flow, so that the rubble travels like the tread of a bulldozer. Rubble on top is carried forward, down the front of the tongue in a continuous avalanche of red-hot blocks, and is then covered by the advancing flow. A typical cross section through a frozen flow shows a solid interior, often with an accumulation of gas-bubble holes near the top. These holes, known as vesicles, can be seen in numerous outcrops along the trail. The top and bottom edges of the flow may consist of a rubble layer. Where there was a substantial interval (hundreds or thousands of years) between flows, a soil layer may have formed only to be covered by a later flow. Such layers appear prominently in several places on the canyon wall as a line of soft red material beneath a flow.

Above the basalt flows rise the impressive buff-colored cliffs of the Bandelier Tuff which makes up the walls of most of Frijoles Canyon. It was in this soft rhyolite rock that the Indians dug their dwellings. We can see that the tuff must be younger than the basalt flows because it lies on top; from radiometric dating we know that this tuff is only 1.1 million years old. What we can't see from the canyon bottom is the source of the tuff. For over 16 million years, activity from over 100 vents west and northwest of here formed a complex volcanic field that was



composed of lava domes, volcanic ash deposits, and stratovolcanos (volcanos that explosively erupt ash, cinders, and lava flows).

Unlike basalt, rhyolite is rich in silica. Had it cooled slowly underground instead of erupting, it would have been granite. Because of the silica content and relatively cool temperature (1500–1700° F) when it flows, the tongues may be as much as 100 yards thick — as thick as a football field is long.

Most of the peaks of the Valles caldera are rhyolite domes and flows. This lava was so viscous that movement away from the vent would have been imperceptibly slow.

Rhyolite lava is usually gas-rich, but since it is so viscous, the gas contained in it cannot escape as easily as that in basalt lava. Consequently, rhyolite eruptions are often very explosive, blowing out a mixture of gas and fragmented melt (volcanic ash). There are two common kinds of explosive rhyolite volcanism, both of which have occurred in the Jemez Volcanic Field. One type is similar to basalt cinder cone eruptions and produces frothy pumice which may pile up in a cone around the vent or blanket the landscape like snow. Airborne deposits like this are not exposed in Frijoles Canyon, but can be found overlying a basalt flow on State Route 4, about 2 miles north of White Rock. The second form of explosive eruption, ash flows, produced most of the Bandelier Tuff. Lava particles, gas and air mix in the eruption cloud to form a dense, hot slurry that sweeps down the flanks of the volcano at hurricane velocity — as much as 100 miles per hour. Each individual ash flow may leave a deposit from a few inches to tens of yards thick.

About 1.4 and again 1.1 million years ago, major eruptions occurred during which over 450 cubic miles of material were spewed out. The ash produced was 600 times that ejected from Mount St. Helens in 1980, and deposits have been found in Nebraska, Kansas, Oklahoma, Texas, and Iowa. Successive ash flows covered the surrounding area up to 1000 feet thick in some places.

Both times, so much ash was erupted that the volcano collapsed, leaving nearly circular craters known as calderas. The Valles caldera and remnants of the earlier Toledo caldera are located west of Bandelier. You can see the Valle Grande (VI-yā GRAHN-day, big valley) a portion of the Valles Caldera, on State Route 4 between Bandelier and Jemez Springs. The collapsed crater is up to 10,000 feet (2 miles) deep, but was filled with ash from the eruptions. It is 14 miles in diameter. Although other calderas in southwestern New Mexico, Yellowstone, and elsewhere are larger, this is definitely considered a major volcanic feature.

The layers of ash that had flowed down the mountain's sides changed character as they cooled. At first the sheet consisted of a mixture of hot lava particles, larger chunks of pumice, some dark rock fragments ripped from the throat of the volcano during eruption, and a large volume of gas and air trapped between the grains. Tuffs may contain about 50 percent gas-and air-filled holes when first deposited, but the longer it takes the tuff to cool and harden, the greater the percentage of gas that escapes or is forced out. As long as the particles are very hot and in the form of glass, they flow under the weight of the tuff sheet itself and fill the spaces between them. This process is called welding because it makes the grains bond together, producing a hard, dense, gray rock called welded tuff. Welding requires both heat and time, but because tuff sheets are often very thick, they stay hot for a long time; the Bandelier tuff may have taken over 10 years to cool. Since heat is lost rapidly to the cold ground below the sheet and to the atmosphere above, the upper and lower surfaces of a flow cool much more quickly than the center. As a result, the center of a tuff sheet is the most densely welded, while the top and bottom are usually nonwelded. Welding also decreases away from the vent since heat is lost during movement of ash flows. The lower section of Frijoles Canyon is 10 miles from the vent, too far for the tuff to be densely welded. Moderately welded tuff, a fairly hard but lightweight pinkish rock, and nonwelded tuff, a white crumbly "ash," can be seen along the trail. Densely welded tuff can be seen in a road cut on the steep grade on State Route 4, just west of the Jemez Springs-Los Alamos junction. There the tuff is purple gray in color and nearly as dense and hard as granite.

Across the Pajarito Plateau, the soft, nonwelded top of the tuff sheet was quickly removed by erosion. Thus, the present surface is the top of the partly welded interior of the last tuff flow. Very few remnants of the nonwelded tuff remain above this zone. Streams easily cut through the soft, nonwelded tuff; this leads to the characteristic mesa and canyon topography of the area. Variations in welding produce the stepped appearance of the cliff walls; each bench marks the top of a resistant layer. Vertical columns in these layers are due to contraction and cracking of the tuff when cooling.

During its major eruptions,

the volcano covered over 400 square miles around it with tuff. The flows poured down the mountain, following the canyons and ridges much as a massive flood would have done. They filled in low areas, covered high spots, and left a fairly uniform surface sloping away from the mountain, the basis of the present-day Pajarito Plateau. The tuff was deeper where it filled canyons than where it covered ridges. So as it welded and compacted, it settled more where it was deeper. Low spots appeared over the old canyons. Because rain and snow falling on the mountain accumulated in basically the same watersheds as before, melt water drained down the low areas where the canyons had been. This resulted in the canyons being re-eroded in generally the same locations as before.

Over much of this trail, Frijoles Creek is now flowing at the base of the tuff, the top of the basalt layer. It has again reached the level where it was flowing before the tuff flows intervened. Is it a coincidence that you happened to come along when the stream has just regained its old level? Probably not. The creek would have cut through the relatively soft tuff quickly (in geological terms); it will be working on the harder basalt for a long time. In human terms, even cutting through the tuff took awhile. Figuring the depth of the canyon where the stream has just arrived at the basalt (near the Visitor Center) and allowing for the missing nonwelded top section of the tuff, we can say that the stream has cut at an average rate of a few inches per hundred years — 1000 feet in the 1 million years since the eruptions.

Below the tuff and basalt flows, there is another type of basalt formation that bears little resemblance to either lava flows or cinder cone deposits. The formation in the vicinity of the Upper Falls is well bedded (layered) with fragments varying widely in size. Layers vary in color, giving the canyon wall a striped appearance. This wall is a cross section of a maar volcano, a type that forms when water — from a lake, stream, or ground water — flows into a volcanic vent. Contact with the water causes the magma (molten rock) in the vent to chill and fracture into small glassy particles. At the same time, great quantities of steam are generated and the explosive interaction discharges a mixture of glass particles, steam, and rocks torn from the walls of the vent.

The numerous thin layers accumulated as airborne deposits or were laid down by clouds of steam and ash which shot out from the maar vent and, being denser than air, swept across the surface. This low-rimmed volcano was constructed layer-by-layer by thousands of steam explosions. In maar volcanos which have been witnessed, there may be as many as 10 to 20 steam explosions per minute.

As the volcano grew, it rose above the water source and the explosive eruptions ceased. Volcanic activity continued in the form of lava fountains and flows which ponded within the crater to form a lava lake. When the flows ceased, lava froze in the vent where we now see the Upper Falls.

Downcanyon from the maar, Frijoles Creek joins the Rio Grande in spectacular White Rock Canyon. This canyon is cut nearly 1000 feet into basalts of the Cerros del Rio. An ancestral river followed this course, flowing along the Rio Grande Rift, long before those volcanos became active. This major crustal spreading feature, which extends from central Colorado to northern Mexico, shows up as sediment-filled basins; the San Luis Valley in Colorado and the Española and Albuquerque-Belen basins of New Mexico are the best defined. It has been active for at least 30 million years, and like other rift areas is characterized by active faulting and volcanism. Thus, the river has stayed where it is, following the rift, while surrounding volcanic activity has built up the plateau around it.

Seeing evidence of volcanic activity over such a long period of time in this area, it seems only natural to wonder if there is likely to be more. On a geologic time scale the answer would likely be yes — sometime. But in human terms, the chances are low that you would see tuff or basalt being erupted from the Jemez Volcanic Field. However, hot springs in the Jemez Mountains (outside of the park) show that heat is still present, and seismic activity continues along the Rio Grande Rift. In the meantime, researchers continue to study this area to learn more about the forces that created the very special landscapes in and around Bandelier National Monument.

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7.5M/SPMA/1989