

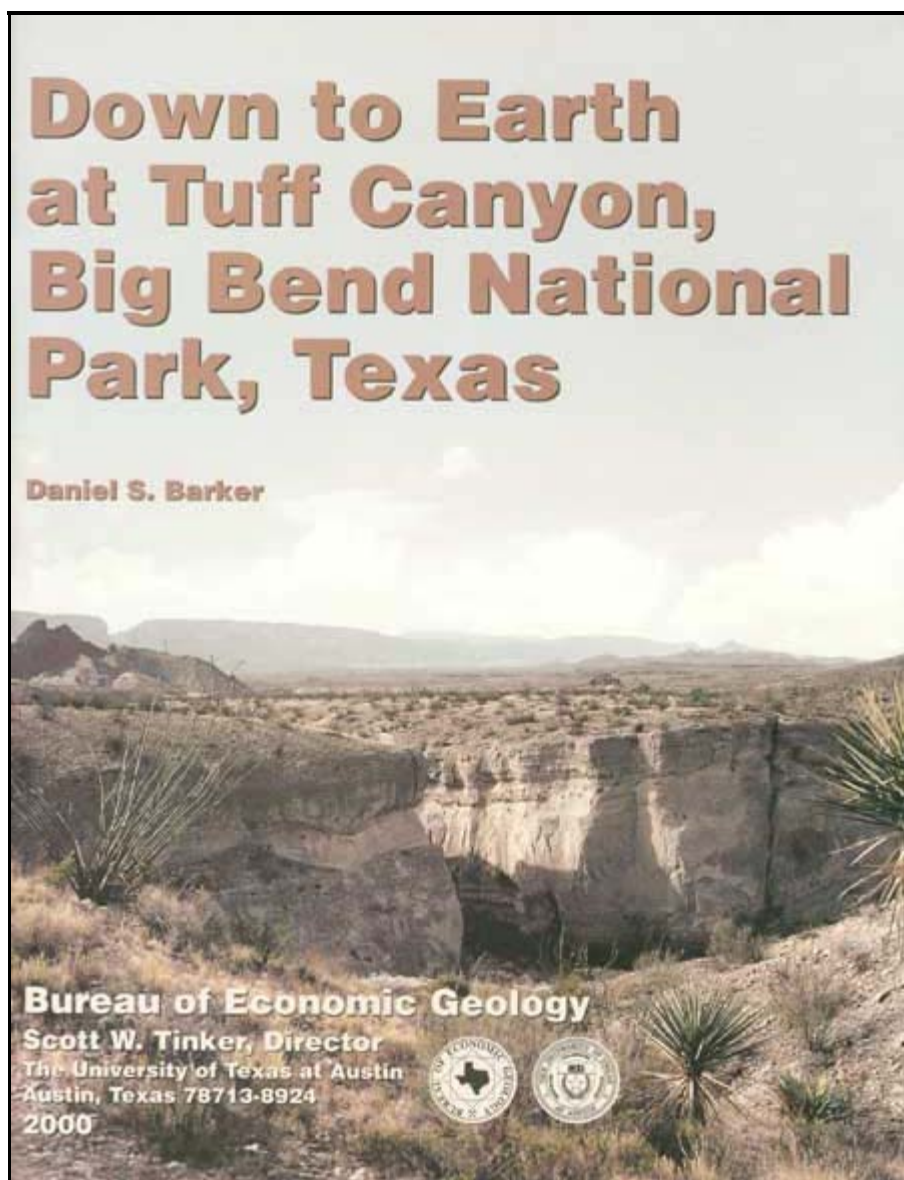


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Down to Earth at Tuff Canyon, Big Bend National Park, Texas

DOWN TO EARTH AT TUFF CANYON, BIG BEND NATIONAL PARK, TEXAS

By
Daniel S. Barker



BUREAU OF ECONOMIC GEOLOGY

Bureau of Economic Geology
Scott W. Tinker, Director
The University of Texas at Austin
Austin, Texas 78713-8924

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HOWDY FROM TUFF CANYON IN BIG BEND!

Just visiting? Hope the visit is fun AND educational. This guidebook ought to help with both. It will lead you down some exciting paths in some beautiful scenery, at the same time helping you understand how that scenery came to have the shape it has today. It will also tell you how scientists use the clues they have found in the rocks to tell the history of the canyon and its surroundings. Some of the explanations might get a tad technical, so whenever you see a word in **boldface**, look it up in the glossary in the back. Oh, and because topographic maps of the Big Bend area show elevations above sea level in feet, and because odometers in U.S. motor vehicles still register in miles, in this guidebook contour lines are labelled in feet and road distances in miles. In fact, taking a cue from the first book in this series, *Down to Earth at McKinney Falls State Park, Texas*, by Jay A. Raney, I have set down ALL measurements according to the English system.



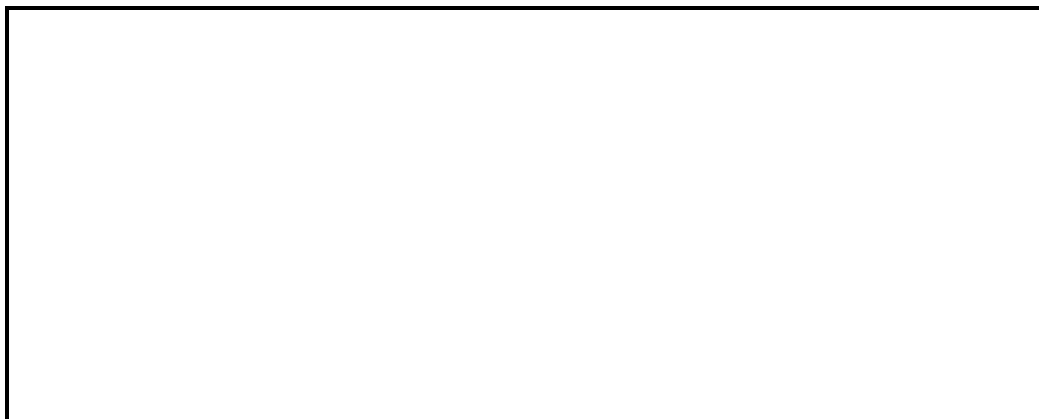
Of course part of the scenery is the incredible flora and fauna of the area. Depending on the time of year (and day!) you might be visiting, you may happen to run across any number of critters, birds, and plants. Coyotes, collared peccaries (javelinas, wild pigs), jackrabbits, skunks, and snakes all hunt at night, but the coachwhip snake, kangaroo rat, and earless lizard might be encountered during the day. More than 434 species of birds have been identified within Big Bend, for the park lies right on the flyway for birds winging north out of Mexico. Tuff Canyon's bird life is limited, however, to only a handful of species. These include residents of the nearby desert that may visit the canyon in search of food, shelter, or water; those that might be considered transients only; at least one neotropical migrant that nests on the canyon walls some years. This latter species is the cliff swallow, which takes advantage of the canyon walls for a place to build its nest of mudballs. During years of adequate rain, cliff swallows take mud from wet areas, roll the mud into tiny balls, and construct a narrow-mouthed nest on the canyon walls (see photo). Another nesting bird of the canyon is the rock wren, a year-round resident. It utilizes crevices in the walls or other flat surfaces. Rock wren males build tiny ridges, in which they add rocks, bones, and other tiny objects, in front of their nest sites, just to impress the female rock wrens! Other feathered desert creatures that are apt to visit Tuff Canyon at one time or another include the black-throated sparrow, black-tailed gnatcatcher, *Pyrrhuloxia*, cactus wren, canyon towhee, and common raven. Any number of transients could visit the area as well, even some of the neotropical migrants such as vireos, warblers, tanagers, grosbeaks, and sparrows. These northbound and southbound migrants are constantly in need of food and water, and Tuff Canyon, because of its shade and potential for holding water for a longer period than the open desert, is always worth checking. (For further reading on the birds of Big Bend, see *Heralds of Spring in Texas* by Roland Wauer or any of four other of Wauer's books on birds, all available at park headquarters.)

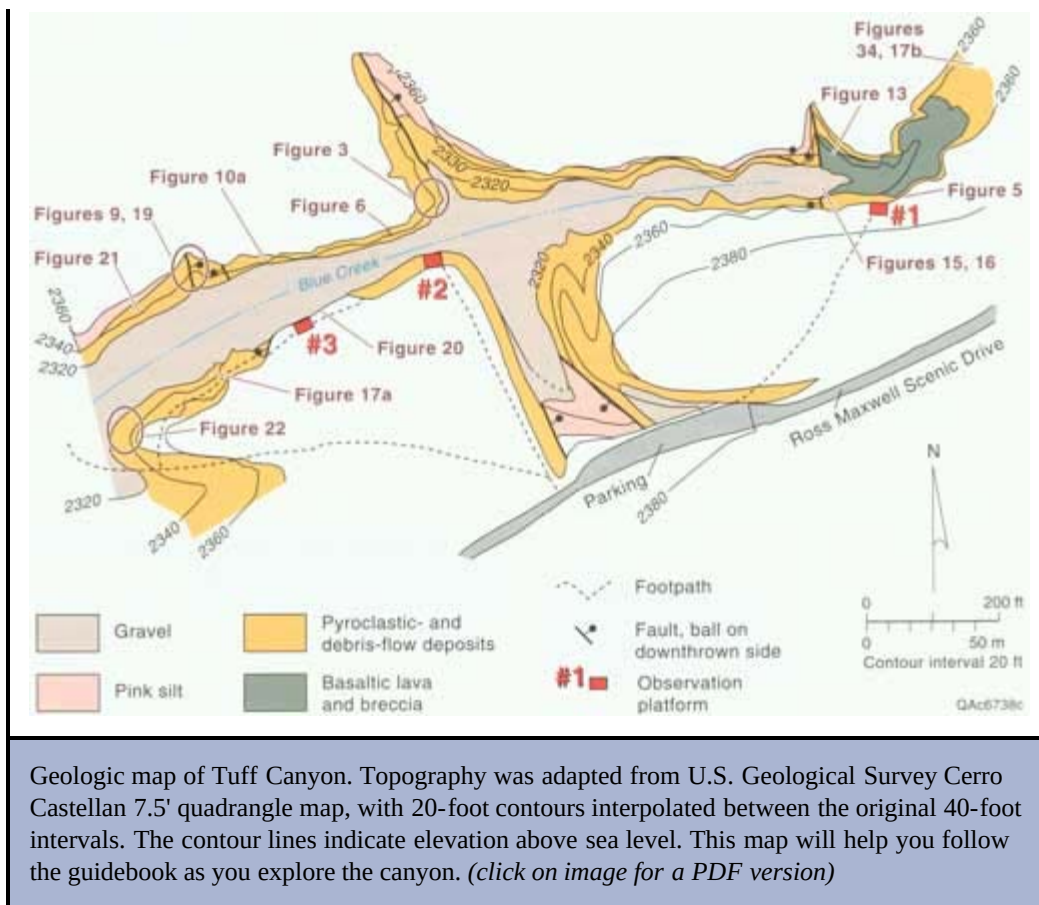


The kangaroo rat and the roadrunner exemplify adaptations to the arid climate of Big Bend because neither drinks water. They rely instead on their diets and specialized digestive systems for survival. Many critters get along in the desert by coming out only at night, however. Most snakes do so because summer temperatures during the day in the desert would kill them within minutes. Some Big Bend lizards, though, brave that heat to hunt during the day. Most often you'll see the western whiptail. The greenish lizard may be seen running on its hind legs like a miniature out of Jurassic Park. Lizards are about the biggest ground critters you scare up on a noontime walk, unless you run across a lizard eater, such as the big pink western coachwhip snake. Critters of the smaller variety include tarantulas, scorpions, and millipedes, but they're rare.

Many species of cactus grow in Big Bend, as well as candelilla, ocotillo, creosote, Chisos agaves, mesquite (see fig. 21, a little farther on in the book) and a number of yuccas, most noticeably the dagger yucca. Wildflowers such as Texas bluebonnets, narrow-leaf globe mallow, and prickly poppy bloom into late spring. (For a more in-depth discussion of flora of Big Bend, see Ross Maxwell's *The Big Bend of the Rio Grande*, available at the park headquarters.)

Please enjoy our National Park, but also please remember that *disturbing or removing rocks, plants, animals, or artifacts is prohibited within National Park boundaries*. To get permission to conduct scientific research, including sampling, you must write a research proposal and submit it to the Superintendent, Big Bend National Park, National Park Service, Big Bend National Park Texas 79834-0129.





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BEFORE HITTING THE TRAIL

As you stand in Big Bend National Park and look around you, the scenery is changing. Gravity, water, and wind are shaping the landscape of the park even as you read this. These are agents of **erosion**, and they are carving and moving rocks that were formed on the floor and shoreline of an ancient shallow sea, or laid down by streams and windstorms, or erupted from volcanoes, or solidified from hot molten rock (**magma**) beneath the Earth's surface. In Big Bend National Park you can actually stand on **lava** from a volcano or on rocks that were laid down on the bottom of an ocean! Many of the common products of volcanic eruptions are easily spotted in Tuff Canyon, a small gorge cut by Blue Creek in its course to the Rio Grande (see the map at the back of the book).

Blue Creek starts high on the western slopes of the Chisos Mountains below Emory Peak and flows southwestward (fig. 1). About 3 miles northeast of its junction with the Rio Grande, Blue Creek has cut Tuff Canyon in a gently southwest sloping surface covered by **gravel**. This gravel layer, difficult to wash away because the boulders and cobbles are large and tightly interlocked, overlies **sedimentary** and **igneous rocks**. Where the creek *has* cut through the gravel, the underlying rocks are soft and easily eroded by running water, and the smaller particles (**silt** and **sand**) are carried away to the Rio Grande. As a result, the stream has cut a narrow, steep-walled valley (fig. 2). For erosion to have created a wide valley with gently sloping sides, much more gravel would have had to be removed. But in this arid climate, there is rarely enough water in Blue Creek to carry away much material.



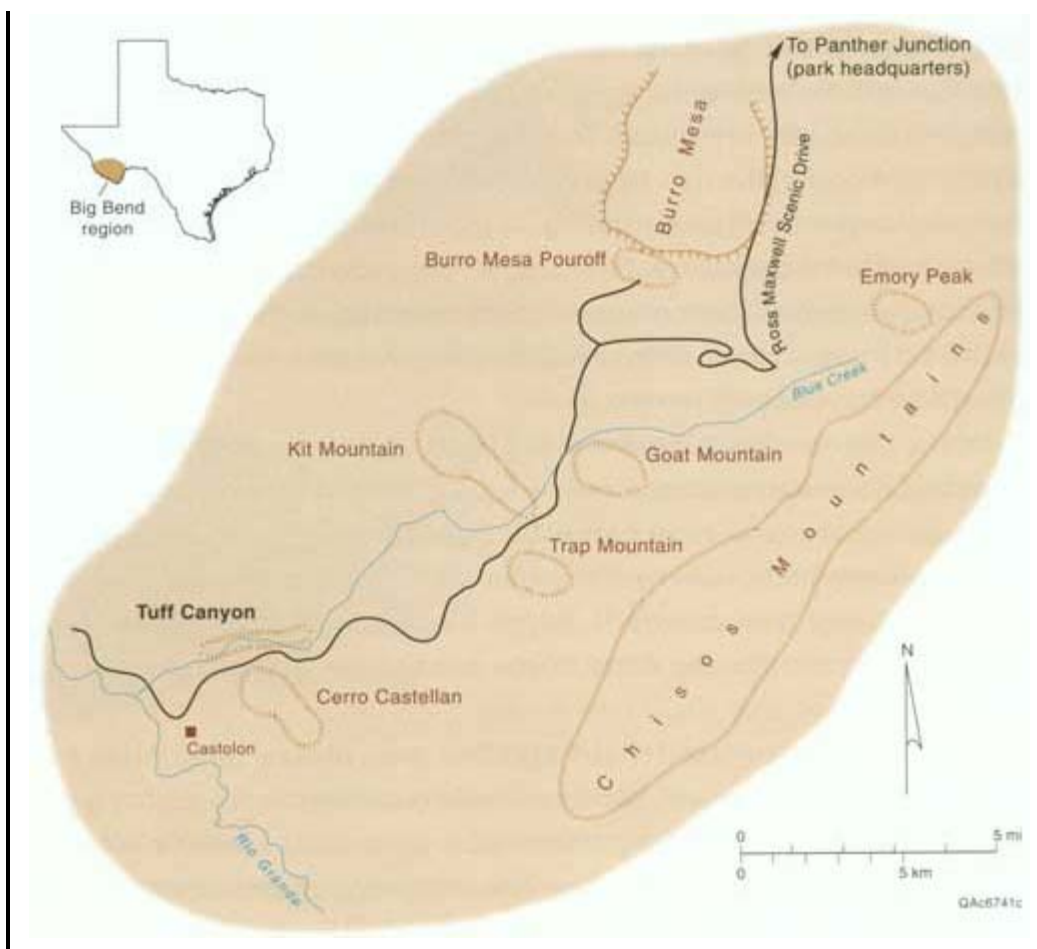


Figure 1. Map of part of Big Bend National Park, showing Tuff Canyon and other places mentioned in this guidebook. This map will help you find your way around this part of the park. A detailed map of Tuff Canyon is found at the back of this book.

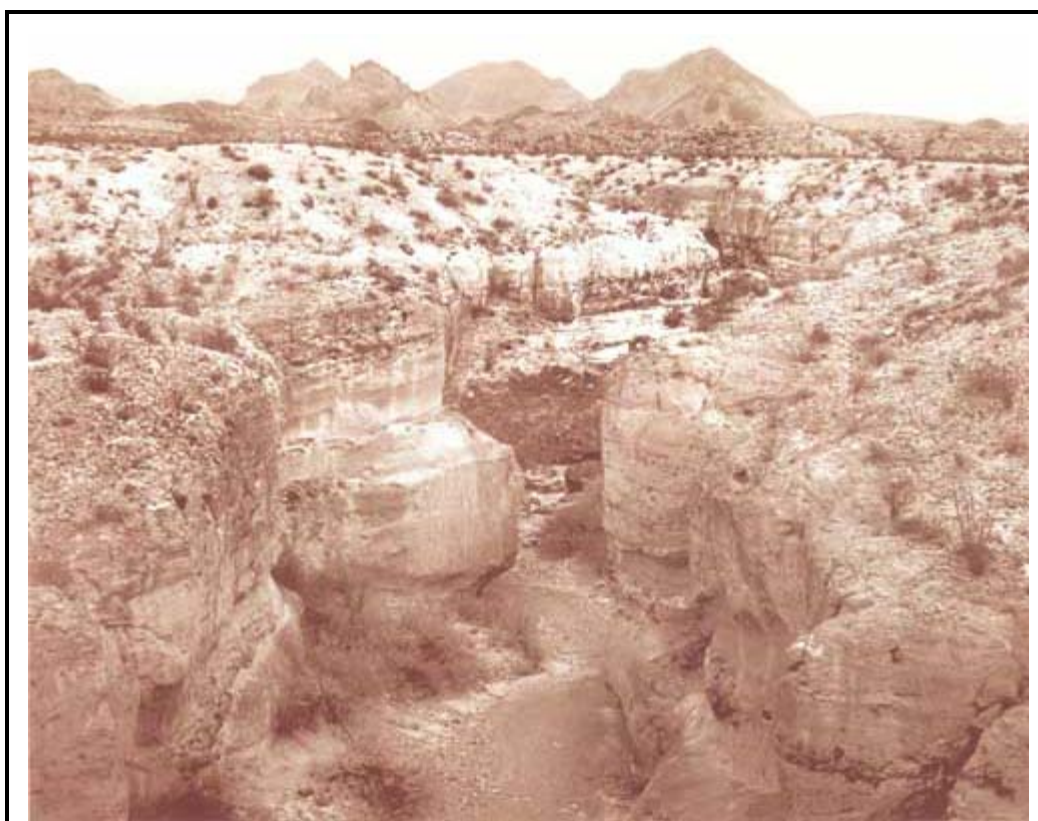


Figure 2. Looking upstream at Tuff Canyon from central observation platform (see map in back of book). This guidebook describes features visible from the three observation platforms, as well as along the canyon floor as you walk toward the dark area in the center of the photo.

Use the map at the back of this book to get started exploring the canyon. The guidebook begins with descriptions of views from the observation platforms above Tuff Canyon that you see on the map. Most of the guidebook, however, describes features you can see on a walk through the canyon, starting with a detailed look at features in the canyon walls below the easternmost observation platform (#1) and continuing roughly 1,300 feet westward to the canyon mouth.

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VIEW FROM THE PARKING AREA

You get to the Tuff Canyon parking area by taking Ross Maxwell Scenic Drive; the parking area on the north side of the road is well marked, and is about 2 miles north of Castolon and 9 miles south of the turn for the Burro Mesa Pouroff (fig. 1). As you look northwest from the parking area, you see Tuff Canyon running parallel to the road and side valleys pointing toward you and away from you (fig. 3). Where the side valleys intersect Tuff Canyon, it is wider. Rapid **weathering** and erosion along a **fault** have loosened and removed more material to widen the canyon here. The fault is buried in the floor of the side canyon farthest from you, and it runs along the base of the left (southwest) wall of the side canyon just below the parking area. The rocks on the east (upstream) side of the fault have dropped farther down than those on the west side. Because the rock exposed on the west side of the fault is more resistant to weathering and erosion than the rock on the east side, the west banks of the side canyons form higher and steeper cliffs than those on the east banks. A short trail leads from the parking area down into the southern side canyon, but because this trail ends in a steep scramble to the canyon floor, it is not recommended. Instead, let's take the easternmost trail, up the gentle slope from the parking area, to the east observation plat form (#1 on the map at the back of the book). It's about a 5-minute walk.

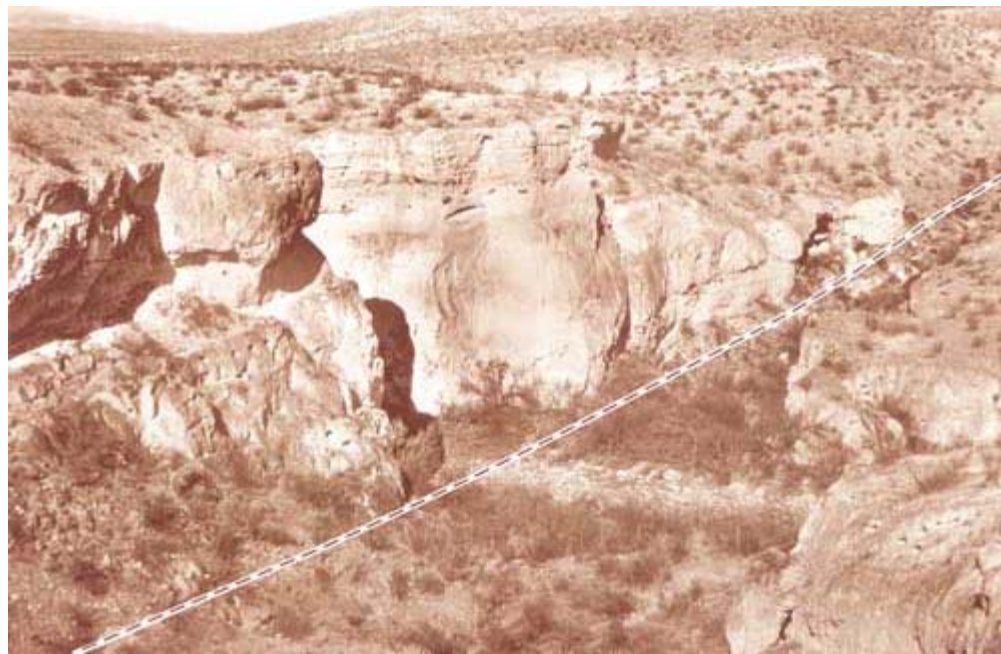


Figure 3. View from Tuff Canyon parking area to the north-northwest, looking at the cross-canyon fault. The high-standing area on the left (west) is more resistant rock that has moved up higher than the rock on the right, along a fault (dashed line). The fault runs parallel to the cliffs.

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VIEW FROM THE EAST OBSERVATION PLATFORM

Once you're standing on the observation platform and looking upstream (to the right) (fig. 4), you can see a lip of rock about 10 feet high. On the rare occasions when water flows in Blue Creek, a wide waterfall runs down this rock face. Below it lies a broad surface of dark **volcanic rock** (if you want another view, it's the darker patch in the center of figure 2). That surface is the top of a once-buried **lava** flow that was uncovered when the soft overlying rock was worn away by erosion. This **basalt** lava resists weathering and erosion because it does not break into small particles as easily as does the overlying **pyroclastic** rock (the light-colored layers). Pyroclastic (literally "fire-broken") products of explosive volcanic eruptions are generally called "volcanic ash," but, scientifically speaking, **ash** simply means loose pyroclastic particles less than approximately 0.1 inch across. **Tuff** is rock made up mostly of hardened ash. So the name "Tuff Canyon" is not correct because the deposits here are made up mostly of particles much larger than 0.1 inch. The pyroclastic particles in this canyon, furthermore, do not stick tightly together, as they must in tuff. It's probably a little late in the game to change Tuff Canyon's name, and I doubt that the scientifically correct "**Pumice Lapilli** Canyon" would catch on.



As you stand here on the east observation platform, you can't help but wonder how this vista came to be. Perhaps a story can help. Once upon a time, before a volcano began to erupt the pyroclastic particles you see, an earlier eruption from a different volcano had covered this part of the park in basalt lava, which formed a fairly smooth and hard surface. How do we know? Look at any pile of layers that have formed on the Earth's surface. The top layer is younger than the one below it. In fact, ANY layer is younger than the one below it and older than the one above it. This rule holds true unless the entire pile of layers has been turned over. The only place in the park where overturned rock layers can be seen is on the mountainside just east of the Persimmon Gap ranger station at the northern park entrance.





Figure 4. View of upper part of Tuff Canyon from the east observation platform, showing dry waterfall in center and dark lava surface under lighter colored pyroclastic deposits.

In Tuff Canyon the dark lava (named the Bee Mountain Basalt) is about 34 million years old. Scientists calculated this age by measuring the proportions of a radioactive isotope of potassium and its decay product, argon. The smaller the ratio of potassium to argon, the older the rock, because there has been more time for more potassium to decay into argon.

Using the layering rule then, we know that the pyroclastic deposits lying on the Bee Mountain Basalt (fig. 5) must be younger than 34 million years old. But how much younger? An answer can be found in another canyon about 1,600 feet east-southeast of Tuff Canyon. There, these same pyroclastic layers are overlain by lava called the Burro Mesa **Rhyolite**, which has been calculated by the potassium-argon method to be 29 million years old. This lava, having the same makeup as the pyroclastic material, is thought to be the result of the same volcanic eruption. The pyroclastic rocks in Tuff Canyon are therefore thought to be 29 million years old!



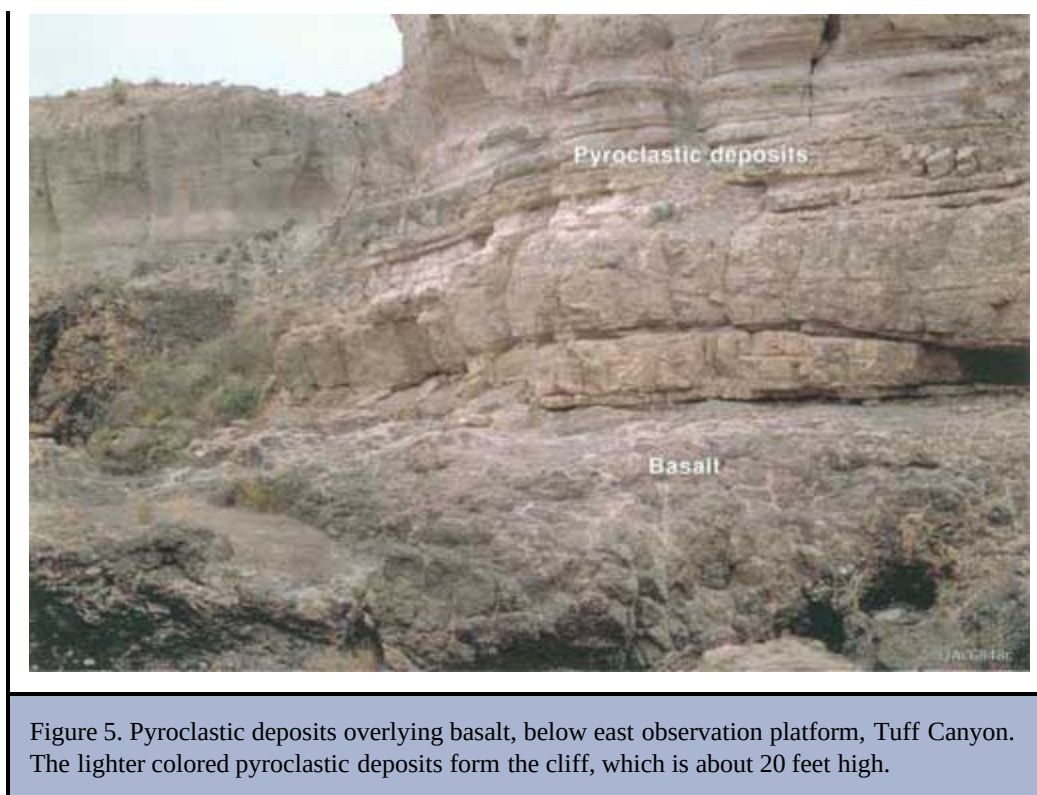


Figure 5. Pyroclastic deposits overlying basalt, below east observation platform, Tuff Canyon. The lighter colored pyroclastic deposits form the cliff, which is about 20 feet high.

The landscape today does not look the same as it did at the time of the eruption; 29 million years is enough time for high-standing areas to erode, low places to fill by **deposition** of **sediment**, and displacement by faults to occur. Those features that are high today owe their height to combinations of hard, resistant rocks and uplift along faults, and not to the piling up of volcanic rocks by eruptions. Some faults may still be active, but earthquakes in West Texas are rare events. In modern times, the only damaging quakes to have occurred happened about 115 miles northwest of Tuff Canyon in 1931 and about 100 miles north-northwest in 1995.

Well, time to mosey. You've seen enough at this platform, but there's more! Retrace your steps to the parking area. From the west end of the parking area, walk north on the trail along the west rim of the side valley to the central observation platform (#2 on the map at the back of the book). It's another 5-minute walk.

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VIEW FROM THE CENTRAL OBSERVATION PLATFORM

It's good to have a new perspective here on this platform. From here you can look to the right, back at the place you just came from, to the left at the third platform, and down to the canyon floor. Looking eastward (back upstream, to your right) you can easily see the dark basalt lava on the farthest part of the canyon floor that is still visible (fig. 2). Look at the contrast between the gentle slopes of the upper canyon walls and the vertical lower walls. The walls of the upper canyon are silt and gravel; the walls of the lower canyon are pyroclastic material. Also note the layers in the pyroclastic material; these are easily seen in the canyon wall opposite the observation platform (fig. 6) and to your left (downstream). The lower wall, a smooth gray rock, has near its top an irregular layer containing large pieces of dark lava in a light-colored **matrix**. This layer is a **debris-flow** deposit, formed when a torrent of rocks, mud, and water flowed rapidly over the pyroclastic deposit and was then buried by more pyroclastic material. Debris flows commonly accompany explosive volcanic eruptions because abundant loose material lies on the surface of a volcano, waiting to be washed downslope. Also, heavy rainfall can be concentrated near the volcanic **vent** because water vapor is a large part of the gas emitted by a volcanic eruption. Water droplets condense on ash particles in the eruption cloud and fall as dirty rain, which gathers in channels and picks up loose material to become thick but fast-moving mud. Debris flows leave their record as poorly **sorted** mixtures of large and small rock fragments that look like concrete. In fact, when the debris flows were moving they must have behaved like concrete being poured; they were thick, heavy, and could knock over trees and erode older rocks and soil as they ran down gullies.

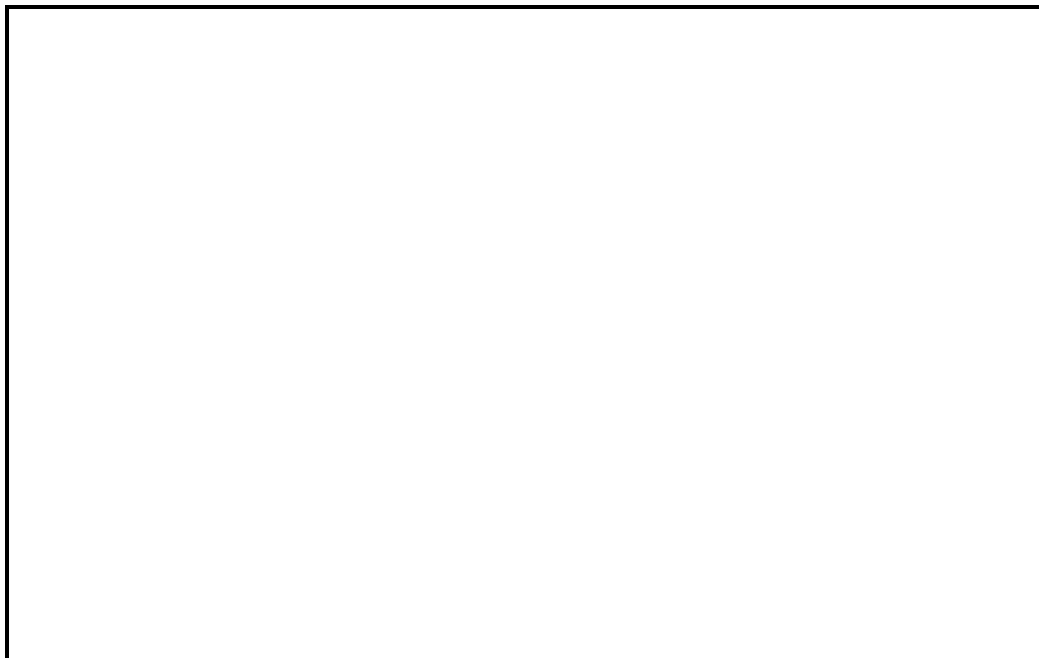
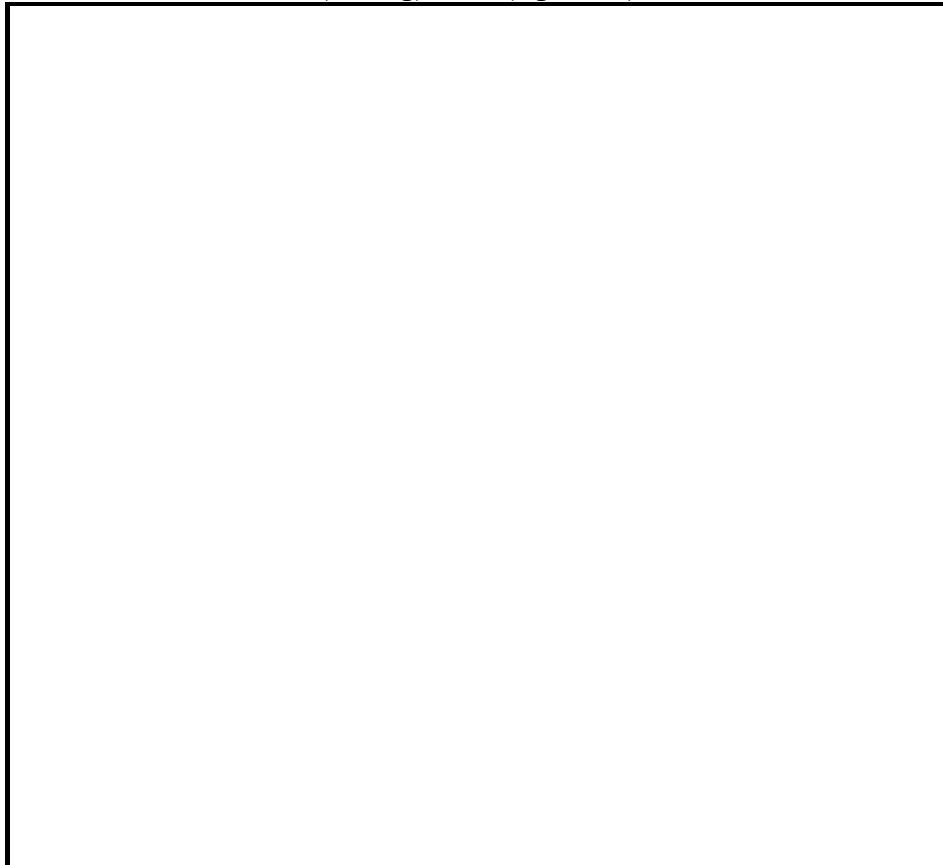
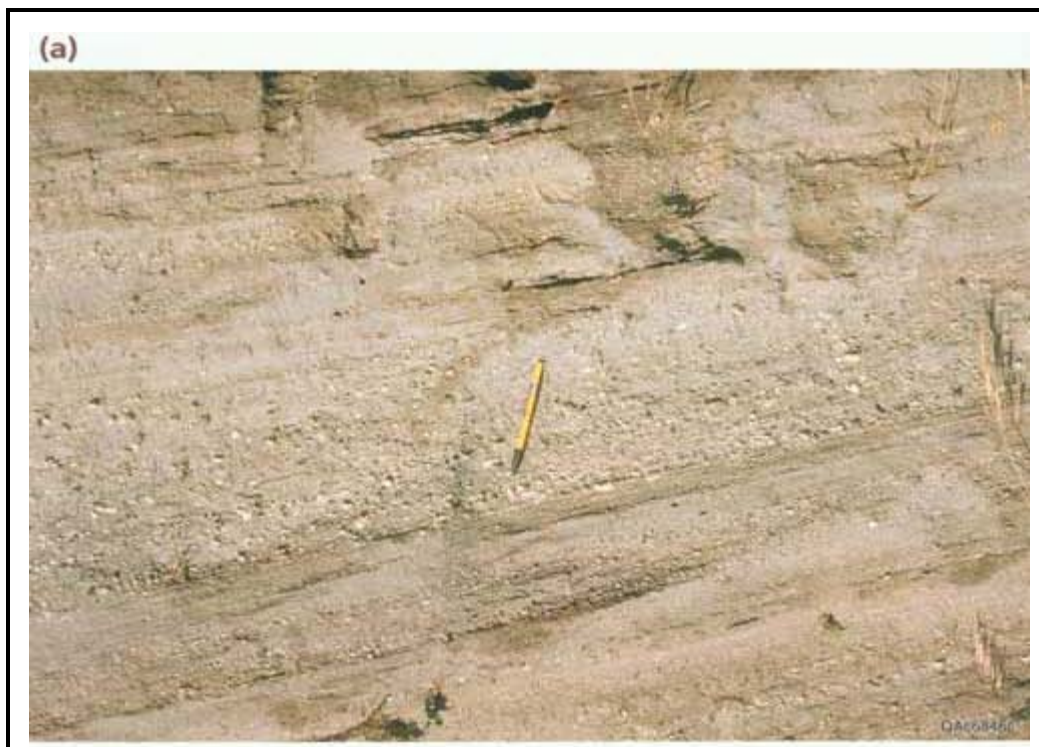
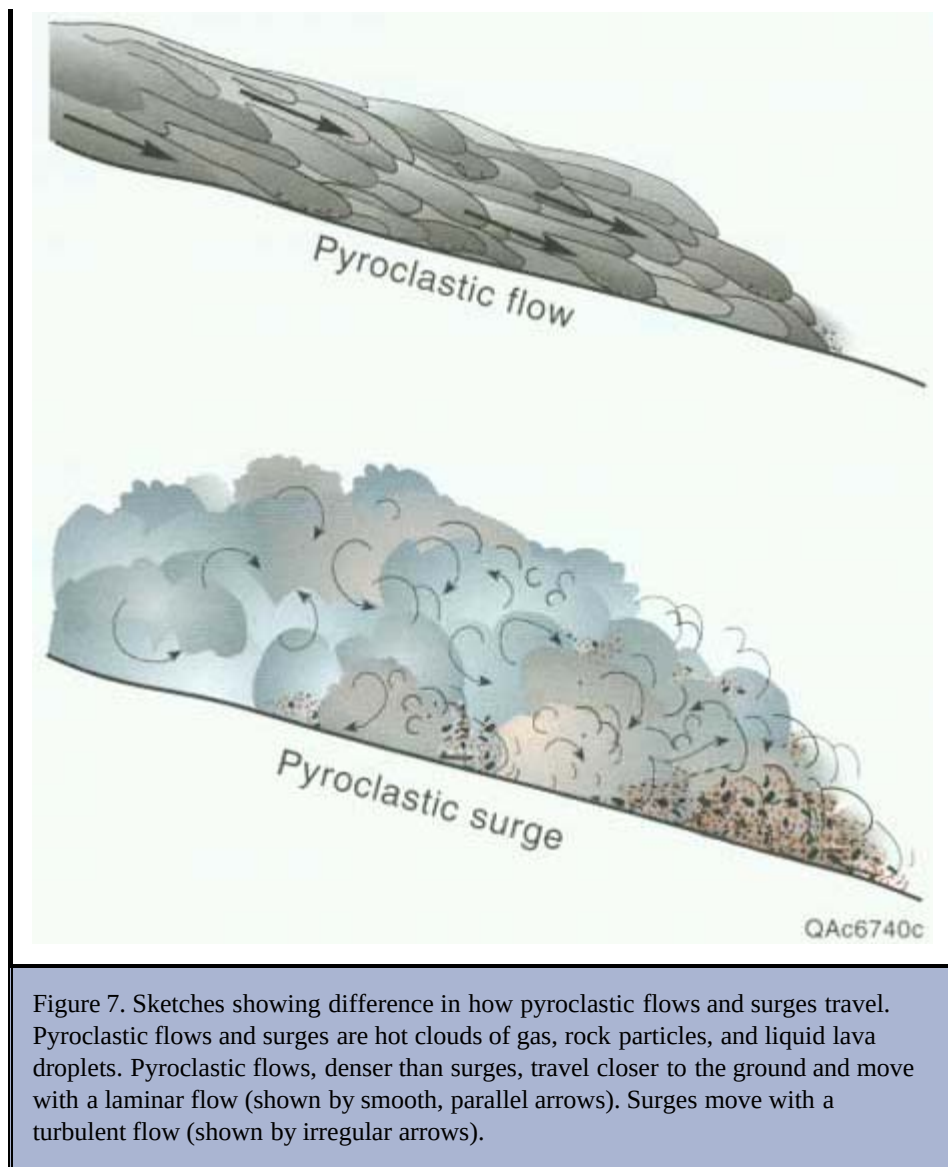


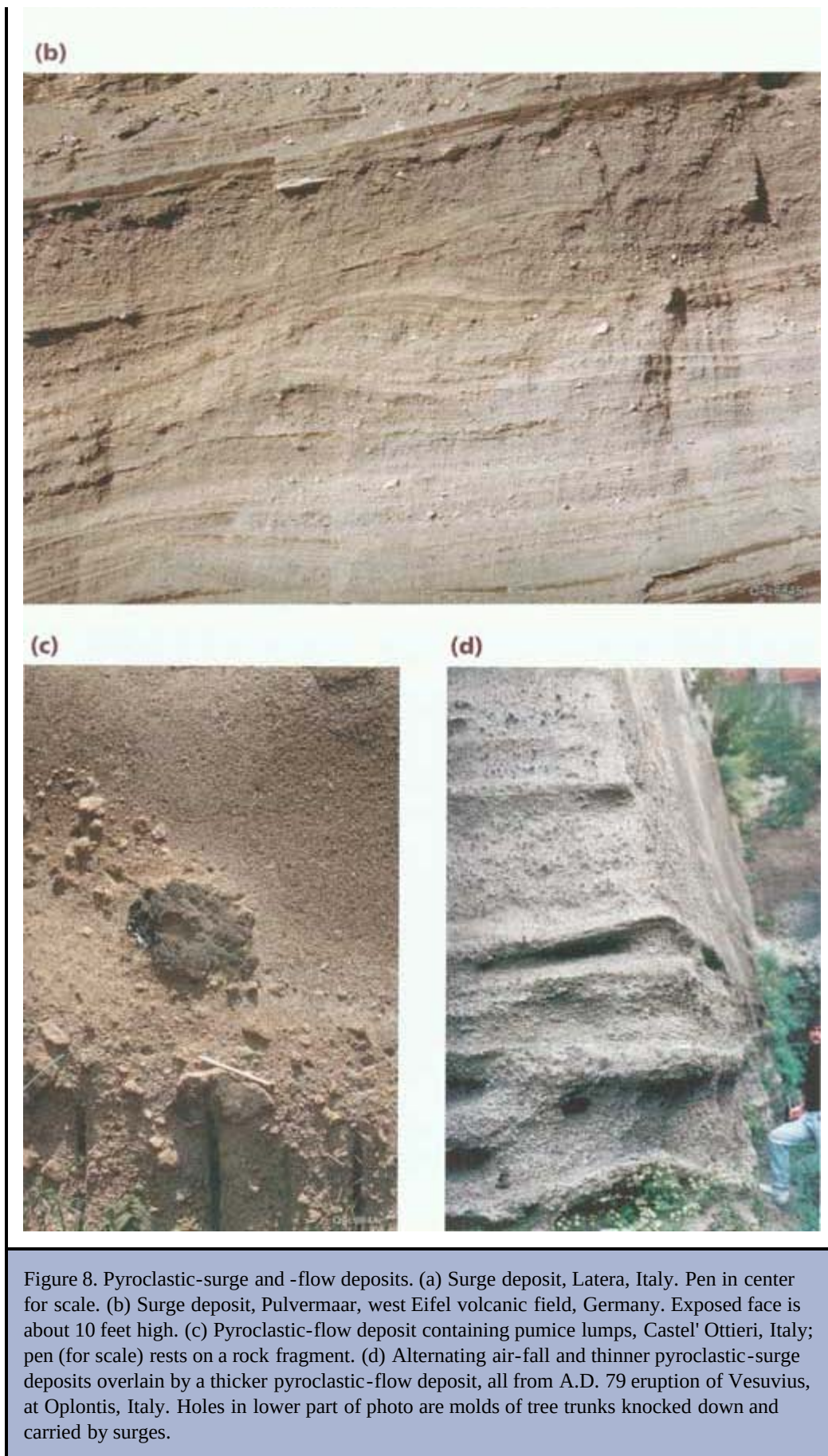


Figure 6. Wall of Tuff Canyon opposite central observation platform. A coarse debris-flow deposit about 3 feet thick fills a channel in the lower part of the photo.

Near the top of the canyon wall is a more colorful stack of layers. As with any kind of deposit, this layering tells the story of how conditions changed during deposition. In this case, the layers were dumped from **pyroclastic surges**, hot clouds of particles and gas that swept over the ground surface rapidly in a **turbulent** (tumbling) flow. In contrast, the thick layer of more uniform gray rock below was deposited by **pyroclastic flows**, hot clouds of particles and gas that were denser than surges (because of a higher proportion of particles to gas) and that moved in a **laminar** (sliding) **flow** (figs. 7, 8).







Pyroclastic flows and surges result in dramatic, scenic vistas, but they are also extremely destructive. They are hot; they carry rock fragments at high speed; and they can burn, kill,

and bury any plants or animals in their way. Pyroclastic-flow and -surge deposits from Mount Vesuvius, for example, buried Pompeii and Herculaneum in A.D. 79. Today the Roman buildings there are still fairly well preserved because they were rapidly filled with pyroclastic material. If these cities had been overrun by lava flows, walls would have been pushed over, wood and wall paintings would have been burnt, and everything would have been buried under hard rock, making excavation much more difficult and expensive. On the other hand, advancing lava flows would have moved so slowly that people would have had plenty of time to escape, and thousands of lives would not have been lost to pyroclastic flows and surges on that long-ago day in Italy.

Worldwide, among the most destructive volcanic eruptions of the last 100 years have been those involving pyroclastic surges and flows at Mont Pelee, Martinique, West Indies, in 1902; Mount Saint Helens, Washington, northwestern U.S., in 1980; El Chichon, Chiapas, Mexico, in 1982; and the Soufriere Hills volcano on the island of Montserrat, West Indies, starting in 1995. In early June 1991, two friends of mine were killed by a pyroclastic surge. Katia and Maurice Krafft were at Mount Unzen in Japan videotaping the eruption from what they thought was a safe place. They were well aware of the dangers and had been filming volcanic eruptions for 20 years. As a matter of fact, they were at Unzen to get new footage of pyroclastic flows and surges for a United Nations video designed to warn people of volcanic hazards. A pyroclastic flow came down a valley and followed a turn in the valley, but a pyroclastic surge above the flow did not turn, and overwhelmed the Kraffts and 39 other people on level ground above the valley. Ironically, an earlier video that they had made for the United Nations is credited with saving thousands of lives at Mount Pinatubo in the Philippines only 2 weeks after the Kraffts died; this video convinced people living on the flanks of Pinatubo to leave for safer places.

So what triggers this destruction? Two processes can generate pyroclastic flows and surges. First, during an explosive eruption a heavy, hot cloud composed of hot particles and gas forms above the volcanic vent. Air mixes with the other two constituents, becomes heated, and expands rapidly. If the cloud is hot enough and contains a small proportion of particles, it is less dense than the surrounding air and rises like a hot-air balloon. In some cases the volcanic cloud can climb into the stratosphere (more than 6 miles!). But if the cloud is heavily loaded with particles, it may rise only a short distance, driven only by the force with which it was expelled from the volcano. Gravity then forces the cloud to fall back onto the ground surface, where it rapidly spreads as a dense pyroclastic flow or surge. A second process that generates flows and surges is the collapse of the steep front of a lava flow; the crumbling hot lava can rapidly release its dissolved gas, which mixes with air to form a violently expanding, dense cloud loaded with lava particles. These two processes produce different characteristics in pyroclastic deposits, especially the sizes of particles and the proportions of particles and gas. The rather small size and extremely frothy nature of the particles in Tuff Canyon indicate that these pyroclastic flows and surges formed by the first process, collapse of an eruption cloud.

It's hard to believe that this quiet spot was once the scene of such violence. You may want to take a few minutes to absorb what you have seen at this platform, but don't take too long. It's time to move on. You're headed west again. From the central observation platform take the trail to the west for a short distance (about a 3-minute walk). You have now reached the third observation platform (#3 on the map).

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VIEW FROM THE WESTERN OBSERVATION PLATFORM

To the west you can see pyroclastic layers in the vertical walls of the canyon (fig. 9). The layers tilt gently toward the mouth of the canyon, and farther to the west they are hidden beneath much younger **alluvium**. The pyroclastic-flow deposit in the opposite wall is lower than it was at the central observation platform because of the westward slope of the layers and because a fault, just west of the central platform, has dropped the rocks down to the west. The pyroclastic-flow deposit is overlain by surge and debris-flow deposits. **Channels** that were eroded and then filled by debris flows are especially visible in the wall opposite this platform; here, some have cut into the top of the pyroclastic-flow deposits, and other channels are at higher levels, within the surge deposits (fig. 10).



Figure 9. View of Tuff Canyon, looking west from west observation platform. Pyroclastic surge, -flow, and debris-flow deposits slope gently toward the mouth of the canyon.

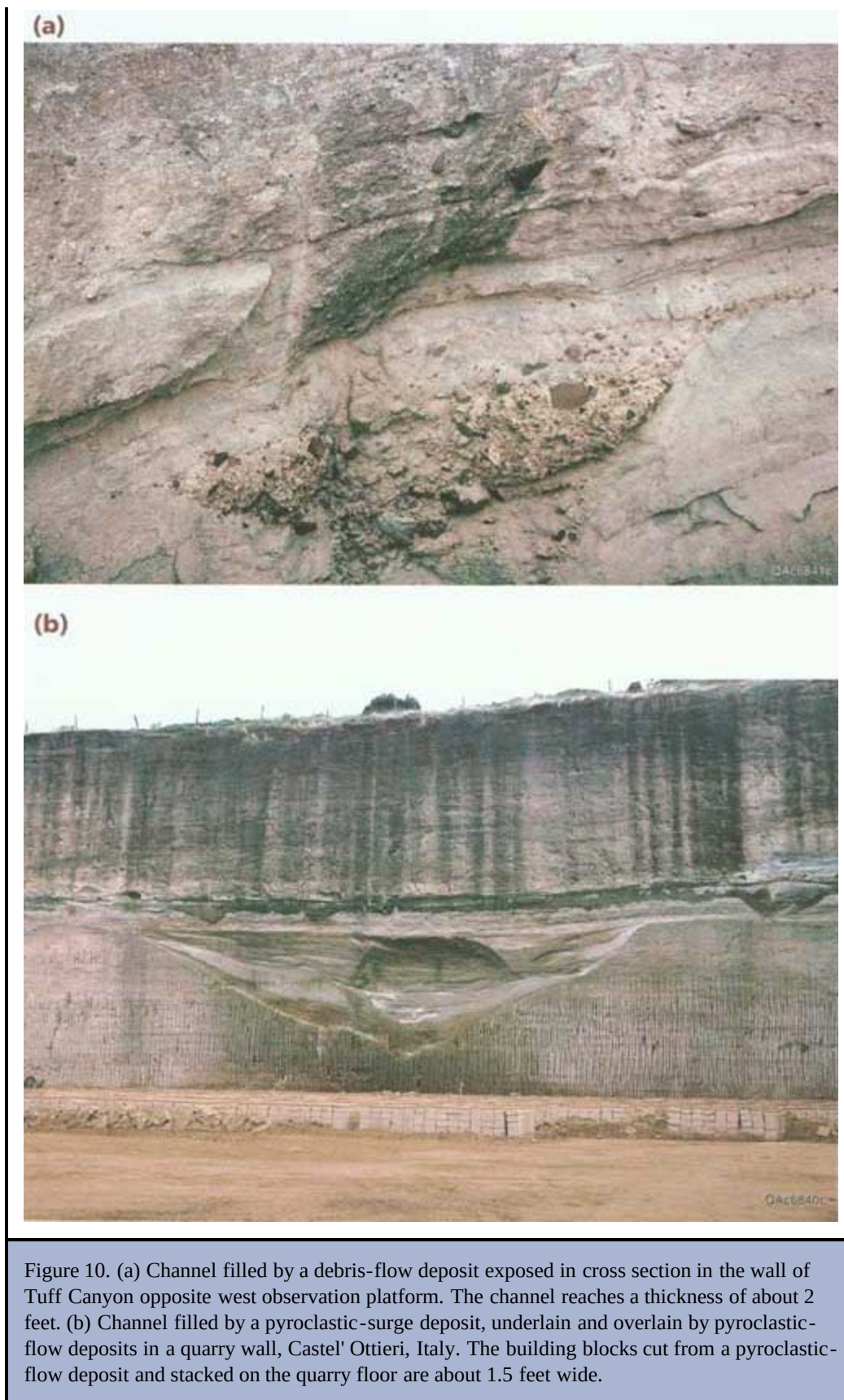


Figure 10. (a) Channel filled by a debris-flow deposit exposed in cross section in the wall of Tuff Canyon opposite west observation platform. The channel reaches a thickness of about 2 feet. (b) Channel filled by a pyroclastic-surge deposit, underlain and overlain by pyroclastic-flow deposits in a quarry wall, Castel' Ottieri, Italy. The building blocks cut from a pyroclastic-flow deposit and stacked on the quarry floor are about 1.5 feet wide.

To the southwest is Cerro Castellan (fig. 1), a prominent landmark visible from many places in the park. It is a stack of pyroclastic rock layers capped by a rhyolite **lava dome**. This dome was fed by the dike exposed on the north flank (fig. 11). Other dikes are well exposed east of Ross Maxwell Scenic Drive in the western slopes of the Chisos Mountains, from 13 to 16 miles north of the Tuff Canyon parking area. Look for sharp "walls" as much as 30 feet

high and 10 feet thick. The dike rocks resist weathering and erosion much more than do the soft rocks that the dikes cut. By the way, the rock layers at Cerro Castellan are higher than they are at Tuff Canyon because of uplift on a fault between Cerro Castellan and where you are now standing.

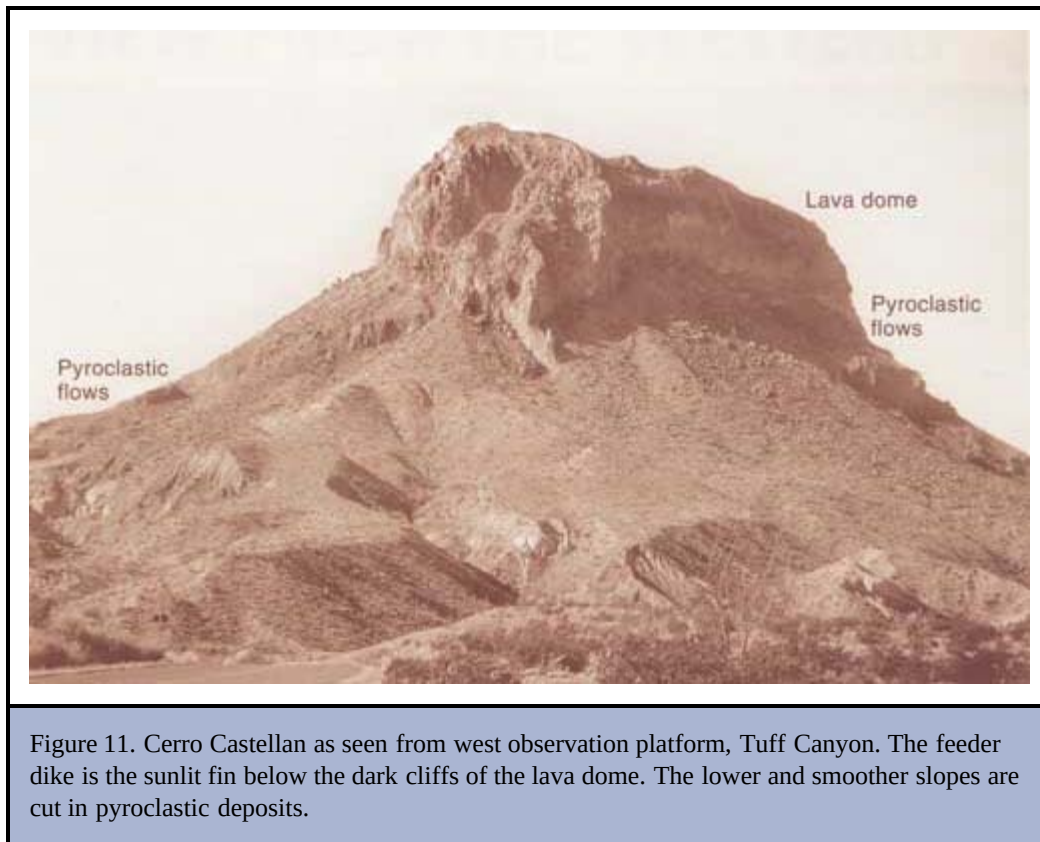
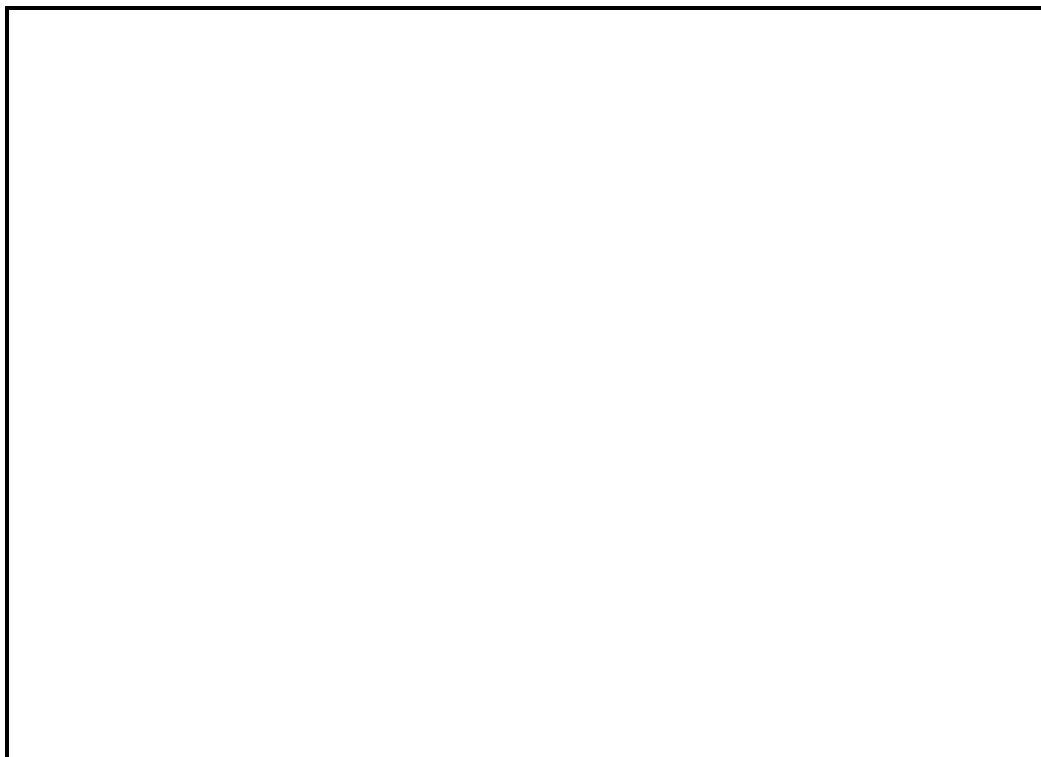


Figure 11. Cerro Castellan as seen from west observation platform, Tuff Canyon. The feeder dike is the sunlit fin below the dark cliffs of the lava dome. The lower and smoother slopes are cut in pyroclastic deposits.

Small **intrusive rock** plugs of rhyolite (including the so-called "petrified tree," fig. 12) poke through white **air-fall** deposits on the north side of Ross Maxwell Scenic Drive northwest of Cerro Castellan (fig. 1).



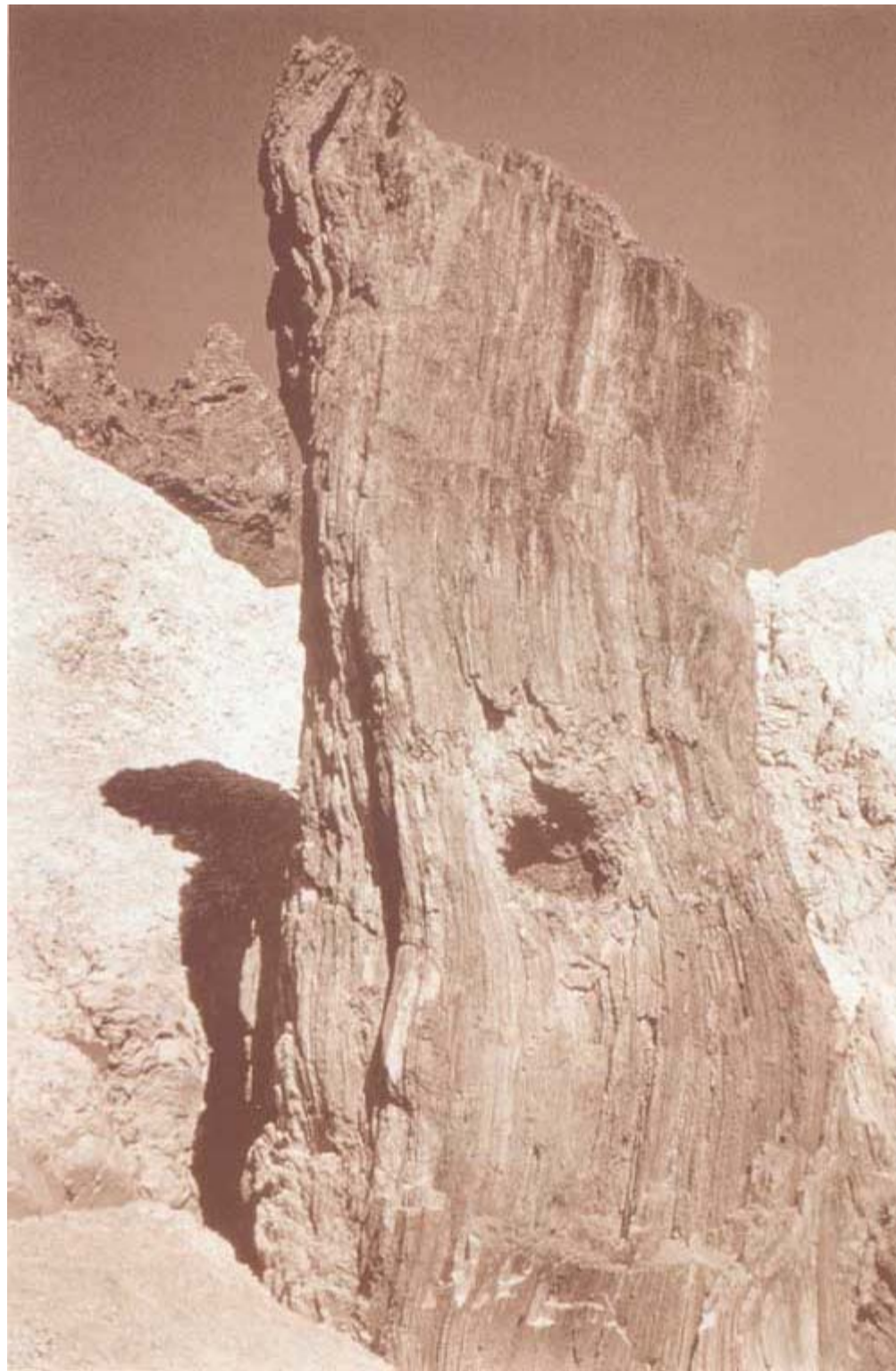


Figure 12. The so-called "petrified tree" northwest of Cerro Castellan; actually an intrusive plug formed by rhyolite magma pushing up through white air-fall tuff. The exposed part of the plug is about 20 feet high. The "knot hole" once held a boulder (Maxwell, R. A., 1968, *The Big Bend of the Rio Grande: The University of Texas at Austin, Bureau of Economic Geology, Guidebook 7*, figure 90).

Now it is time to get a close-up view of the rocks. Take the trail (see map at the back of the book) into Tuff Canyon from the southwest end. After you get down to the canyon floor, you will be walking on fairly level ground, but there is soft sand in places. Give yourself at least 45 minutes for the walk into Tuff Canyon and back. **CAUTION:** do not enter the canyon if

rain is falling anywhere upstream of Tuff Canyon; flash floods can move rapidly through a narrow canyon such as this one.

Once you are in the canyon, note the sand and gravel bars banked against the walls. They are rearranged by every flash flood. Even the boulders on the canyon floor were carried there by running water. Rocks that make up some of these boulders came from miles upstream in the Chisos Mountains, moving perhaps only a short distance during each flood.

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ON THE CANYON FLOOR

You will walk upstream once you're on the canyon floor, because you'll want to do your close inspection of the canyon's geology as you retrace your steps downstream. "Why not pay more attention to the rocks as I walk upstream?" You may wonder. It's because if you start at the upstream end of the hike, you will be able to follow events in the rocks in sequence, from oldest to youngest. The rocks are faulted and gently tilted so that the oldest layers are at the east end of the path, and the younger ones are closer to the canyon mouth. It is easier to understand (and tell) the story if we proceed from early to late events.

Start walking eastward (upstream) until your progress is slowed by large masses of dark rock. Here is where we stop and begin to look at the rocks carefully. This dark rock is one of many lava flows making up the Bee Mountain Basalt, and it is underlain by **breccia** and **pillow lava**. The breccia consists of lava fragments in a much finer matrix; the lava cooled quickly when it flowed into water and was shattered into fragments by steam explosions as the water absorbed heat from the lava and boiled violently (fig. 13). Pillow lavas form during less violent encounters between lava and water; the pillows are smooth, round masses (fig. 14) held together by thin skins of lava that quickly cooled against water. The skins remained soft enough to bend, and they provided enough insulation that the hot interiors of the pillows cooled more slowly. As a result, a pillow could sag and mold itself around underlying pillows. Pillow lavas are the most widespread volcanic features on Earth; they cover enormous areas on the ocean floors.



Figure 13. Breccia produced by steam explosions where basalt lava flowed into water, Tuff Canyon. Pen (center) for scale.

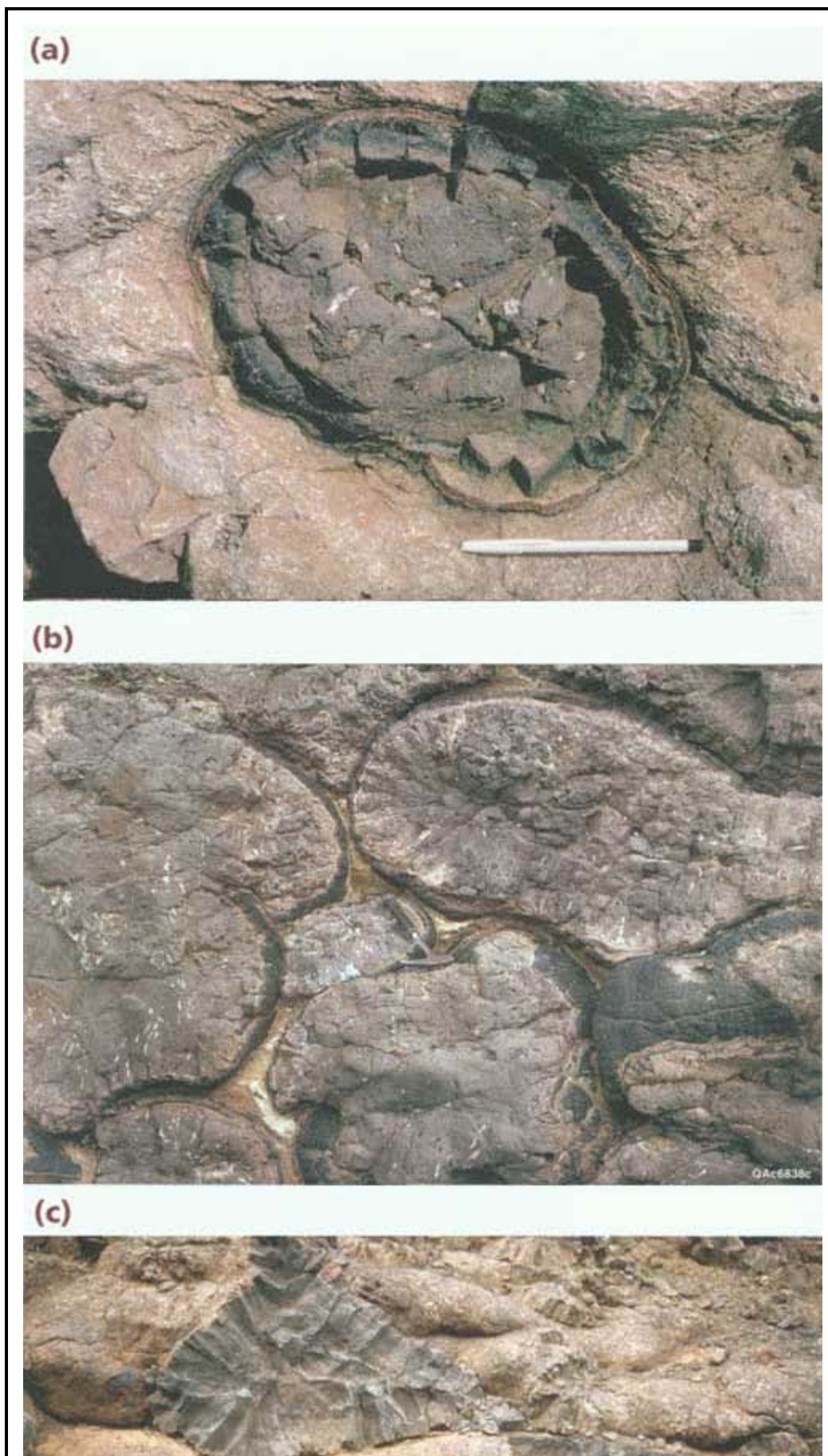




Figure 14. (a) Lava pillow in breccia, Oamaru, New Zealand. Pen for scale. (b) Pillows, Oamaru, New Zealand. Hammer for scale. (c) Pillows, Badsvellir, Iceland. Pen for scale.

The breccia and pillow lava are two results of lava flowing into a body of standing water. Geologists are sure that this body of water was not a shallow arm of an ocean because the youngest fossils of ocean-dwelling animals in the sedimentary rocks of Big Bend National Park are about twice as old as the 34-million-year-old basalt. Fossils younger than 65 million years in this region record only critters that lived on land or in shallow lakes or rivers. Perhaps ponds formed where streams were dammed by basalt lava flows. Later basalt lava, arriving at the water's edge, formed breccia and lava pillows until all the water was displaced or evaporated. Still later, basalt lavas formed more massive (unbroken) flows as they moved over dry ground. The top surface of the dark basalt lava, directly below the pyroclastic rocks, is decorated by a network of pale veins. These had to have formed when pyroclastic material from the later rhyolite eruptions lodged in cracks in the already old and weathered basalt.

On the south edge of the canyon floor, west of the east observation platform, a large block of basalt has preserved the original surface of a lava flow (fig. 15). Although the block is not in its original position after being tumbled downstream by floodwaters, it does show some significant features that are worth a closer look. The lava flow top is smooth to gently rolling or bulging and spotted by elongated holes (fig. 16). The holes were formed by gas bubbles that rose through the hot liquid lava but were caught in the cooler skin of the flow and then stretched into long shapes as the lava flow continued to move. These ancient holes that were formed by trapped bubbles are called **vesicles**.

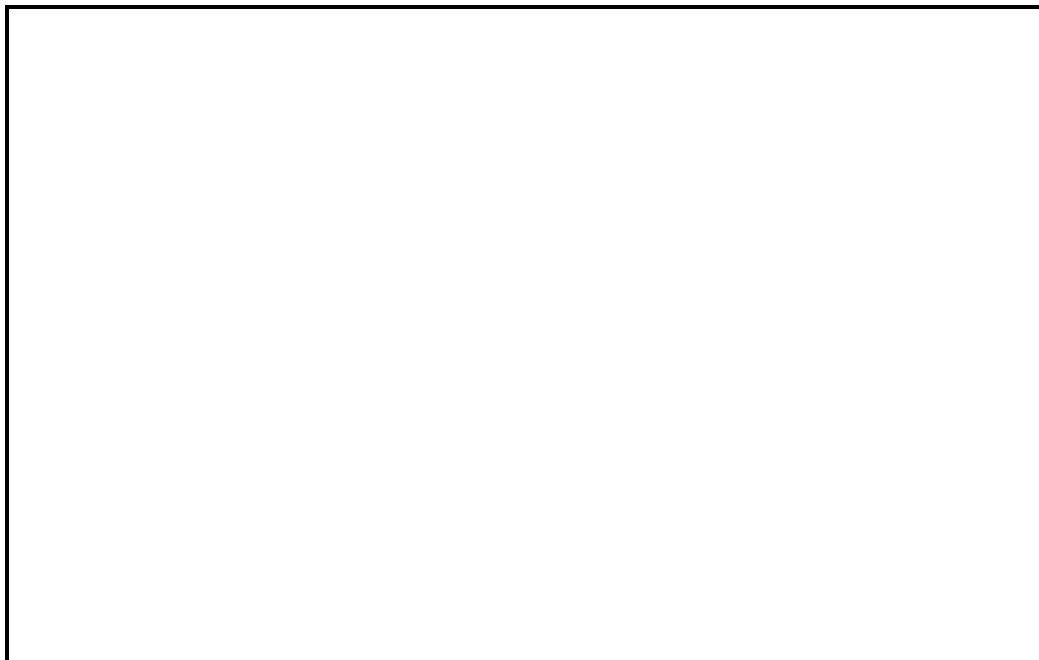




Figure 15. Lava with original flow surface preserved, Tuff Canyon.



Figure 16. Close-up of surface of lava in figure 15, showing stretched gas bubbles (vesicles).

Now how did this scene come to be? Let's do a little detective work. The basalt and breccia, at least 33 feet thick, do not reveal whatever rock lies under them, so the older history of the Tuff Canyon rocks remains hidden. But you can see that directly overlying the basalt are pyroclastic-surge deposits containing channels that run roughly east-west. The surge deposits also contain **ballistic blocks** with **impact sags** (fig. 17). The ballistic blocks are all basalt, although basalt was only a passive victim of the explosions, not a cause of them. The basalt was old and cold by the time rhyolite magma approached the Earth's surface, resulting in volcanoes that erupted explosively to form pyroclastic deposits in this part of the park. Some basalt had even become weathered and eroded, judging from the rounded basalt fragments in

the overlying pyroclastic deposits and from the pyroclastic-filled cracks in the upper part of the basalt. These rounded chunks of basalt had their corners and edges smoothed long after the basalt cooled and were not molten blobs or **bombs** when they were thrown out. From the shape of its impact sag, we can make a rough estimate of the direction from which a ballistic block came. And from the size of a block, we can calculate the maximum distance from the volcanic vent to the impact site. The vent for these blocks was probably north or east of Tuff Canyon and less than 2 miles away. Note that some of the rock fragments in the Tuff Canyon surge deposits overlap one another like shingles on a roof. This **imbrication** indicates motion from the northeast to the southwest, in agreement with the evidence from the impact sags.

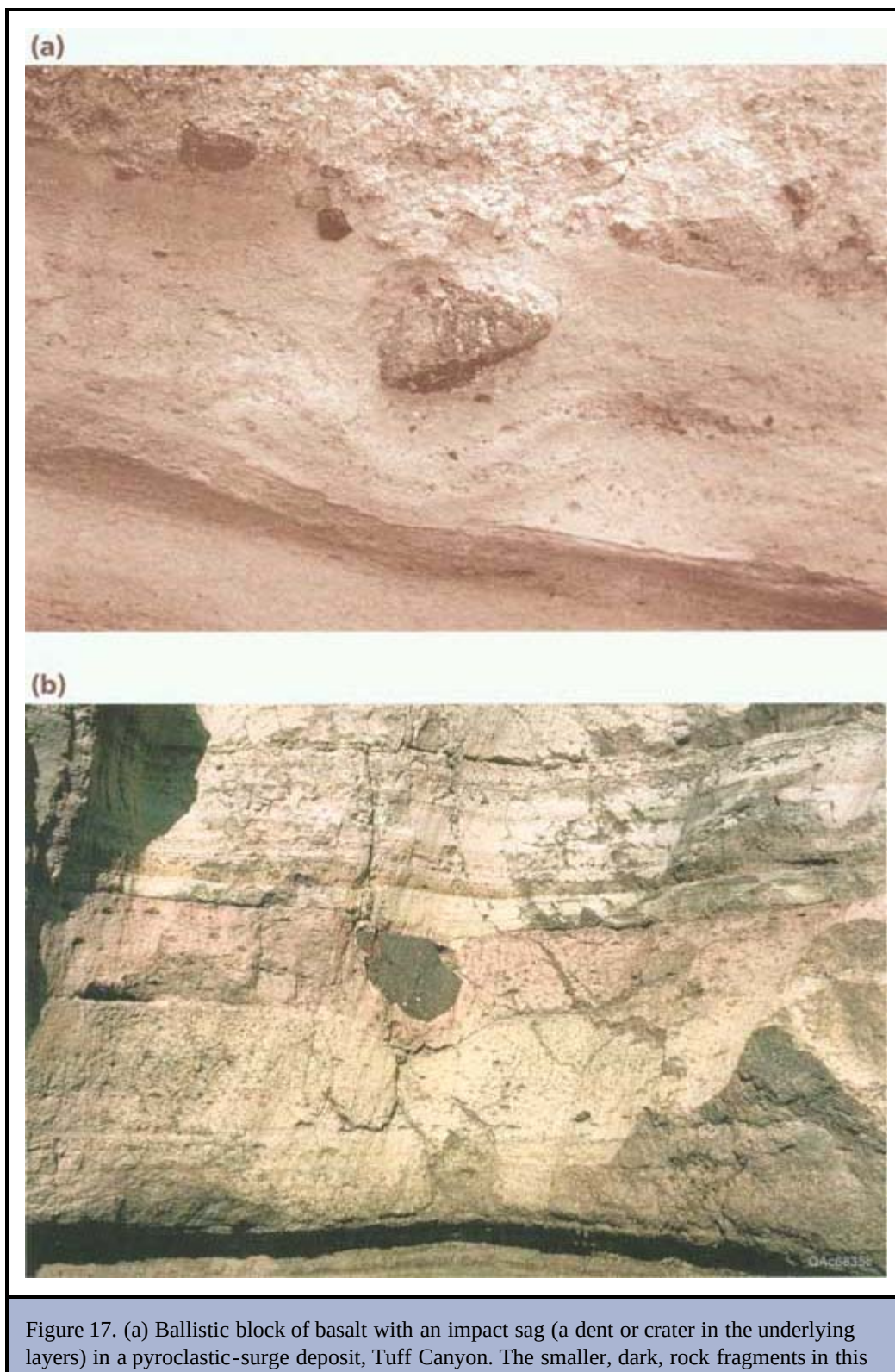


Figure 17. (a) Ballistic block of basalt with an impact sag (a dent or crater in the underlying layers) in a pyroclastic-surge deposit, Tuff Canyon. The smaller, dark, rock fragments in this

photo did not make impact sags because they were swept along the ground in a surge cloud, but the biggest one fell in on a steeper trajectory after being blown out of a volcanic vent. (b) Ballistic block with an impact sag in a surge deposit under the dry waterfall of figure 4. The block is about 10 inches in diameter.

But why are the layered deposits interpreted as products of pyroclastic surges? Good question. The strongest evidence is that fragments of **pumice** and basalt as much as 2 inches in diameter were dumped side by side in a single layer in spite of their density differences. The density of basalt is about three times that of pumice, which can sometimes even float on water. These fragments could therefore not have been carried or dumped by water, but by something having a density much lower than that of either basalt or pumice. That something was most likely a fast-moving cloud of gas, dust, and rock fragments. The cloud or surge moved with hurricane force over the land surface, although it may have been only a few feet deep. Some big rock fragments were deposited without impact sags, having been swept into the surge along with smaller particles. However, some blocks right beside these big fragments do have impact sags, and these show that explosions were occurring at the same time as these layers were being deposited. Chunks of basalt, torn from older layers as the rhyolite magma approached Earth's surface and exploded, flew in an arc through the air, thudded into surge deposits that had just stopped moving, and finally became buried by more surge-carried particles.

See the pumice-rich pyroclastic-flow deposit lying above the surge deposits? Let's get a closer look.

Turn around and begin retracing your route back down the canyon floor. About 50 feet downstream from the basalt lava with the stretched vesicles, a fault has dropped the rocks on the west by at least 50 feet. The pyroclastic-flow deposit that lies at the top of the south wall, directly under the east observation platform, is at the level of the canyon floor on the west side of the fault. Looking at this rock layer closely, you can see that it is a pyroclastic-flow deposit composed mostly of **lapilli** of **silky pumice** between 0.1 and 0.8 inch in diameter, along with less abundant rock fragments of many types (basalt, other lavas, and, more rarely, limestone). Some of these fragments may have been picked up as the pyroclastic flow moved along the ground; others were blown out when the vent cleared its throat.

Above the pyroclastic-flow deposit is a surge deposit less than 3 feet thick, containing rock fragments less than 0.4 inch to 4 inches in diameter. The surge deposit is overlain by an unstratified, very poorly sorted debris-flow deposit about 6 feet thick, containing rock fragments reaching 20 inches in diameter. That deposit in turn is overlain by a pyroclastic-flow deposit about 16 feet thick, and above this lies another surge deposit. Pyroclastic flows are more tightly controlled by topography than are surges because the denser flows tend to move down valleys, whereas surge clouds can billow out of valleys and cover neighboring highlands.

As you walk downstream toward the cross canyon, look for more faults exposed in the canyon walls. Many have displaced the rock layers on either side by only a few feet. Compare what you see in the canyon walls with the generalized sketch in figure 18. Look how quickly you have learned how to tell pyroclastic-flow, -surge, and debris-flow deposits apart! About 425 feet downstream from the basalt, the canyon floor widens into the cross arms that you saw from the parking area, but you should continue walking downstream, toward the canyon mouth. The surge and debris-flow deposits are close to the floor of the canyon. Look for ballistic blocks with impact sags.



Figure 18. Sketch showing distribution of four kinds of deposits in south wall of Tuff Canyon. For simplicity, the floor of the canyon is shown as being smooth and level; in reality it slopes gently but unevenly to the southwest.

About 80 feet downstream from the west observation platform, a fault in the north wall of the canyon shows displacement of about 6 feet, down to the northeast. At and below eye level you can see **gas escape pipes** (fig. 19) in the pyroclastic-flow deposit in the north wall just west of the fault. These are approximately vertical, about 3 feet high and a few inches wide, and spaced a few inches to 3 feet apart. These pipes cut upward through several **flow units**, which average less than 1 foot in thickness and which are distinguished by a coarser pumice concentration at the top of each flow unit. Why are the bigger pieces at the top? Why didn't they sink to the bottom of each flow unit? The explanation in terms of physics is complex, so let's use an analogy instead; if you shake a container of mixed nuts, the larger ones (such as Brazil nuts) rise to the top not because they are lighter than the others, but because the bigger pieces go to the surface where they can move more freely without bumping into others.



Figure 19. Gas escape pipes cutting through thin flow units in a pyroclastic-flow deposit, Tuff Canyon. The pipes are the vertical dark streaks. The height shown is about 6.5 feet.

What can we deduce about the flow units? They were probably not deposited after separate volcanic eruptions. Instead, they record unsteady but continuous flow, and all accumulated within a relatively short time (otherwise a gas escape pipe would be cut off abruptly at the top of a flow unit). The reasoning goes this way: observations of explosive eruptions show that pyroclastic-flow and -surge deposits can accumulate very rapidly, thickening at rates of feet per second. If the lower flow units were old enough to be cool, gas would not still be escaping from them after the upper flow units were deposited. Instead, a gas escape pipe would begin and end within a single flow unit. This evidence, that the pipes cut upward through more than one flow unit, is important because it suggests that all the pyroclastic deposits preserved in the walls of Tuff Canyon may have formed in hours or, at most, a few days.

In this section of the canyon, also notice the **case hardening** on the higher parts of the walls (fig. 20). There, rainwater percolating through pumice has dissolved some of the volcanic

glass. The dissolved silica was carried downward in the water and then was deposited when the water evaporated, leaving a harder crust on the surface. This more resistant coating forms the rock draperies that decorate the upper walls of Tuff Canyon.

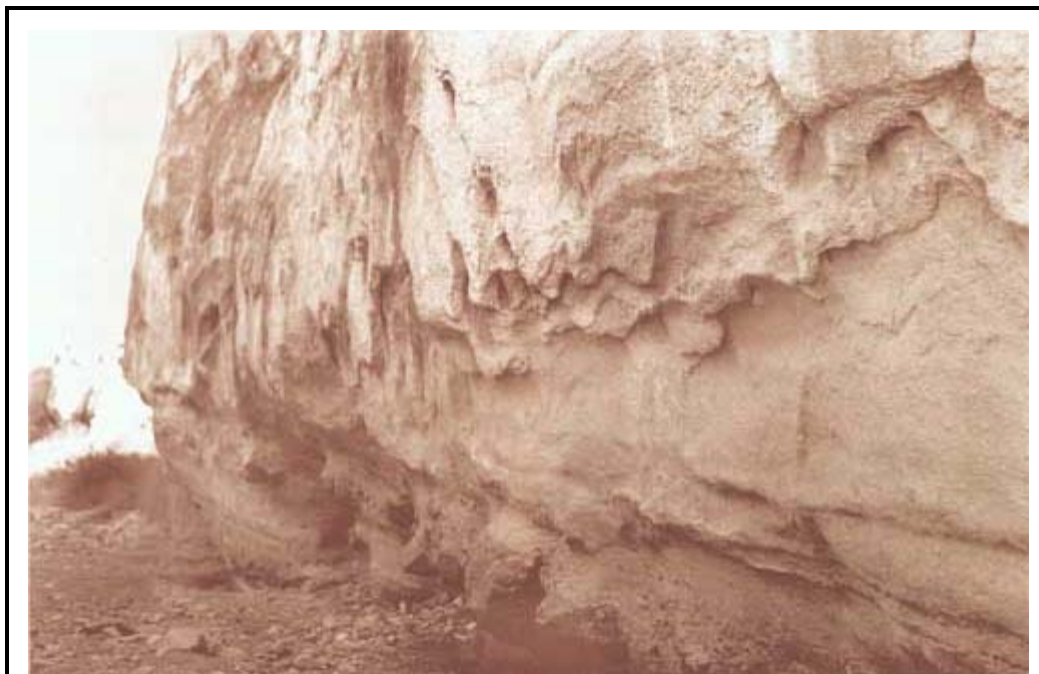


Figure 20. Case hardening has formed rock draperies on the surface of a pumice rich deposit in a wall of Tuff Canyon. The height shown is about 13 feet.

About 150 feet west of the gas escape pipes, a mesquite tree clings to the north wall, its root system partly exposed (fig. 21). This tree probably started growing on the canyon floor, which has since been lowered about 13 feet by erosion. This unusually rapid rate of down-cutting by a stream records perhaps the effects of overgrazing by cattle from about 1900 until the 1940's. When herds removed much of the vegetation in the upper valley of Blue Creek, rain that could not soak into the soil ran off, causing greater water discharge through streams and more rapid erosion.



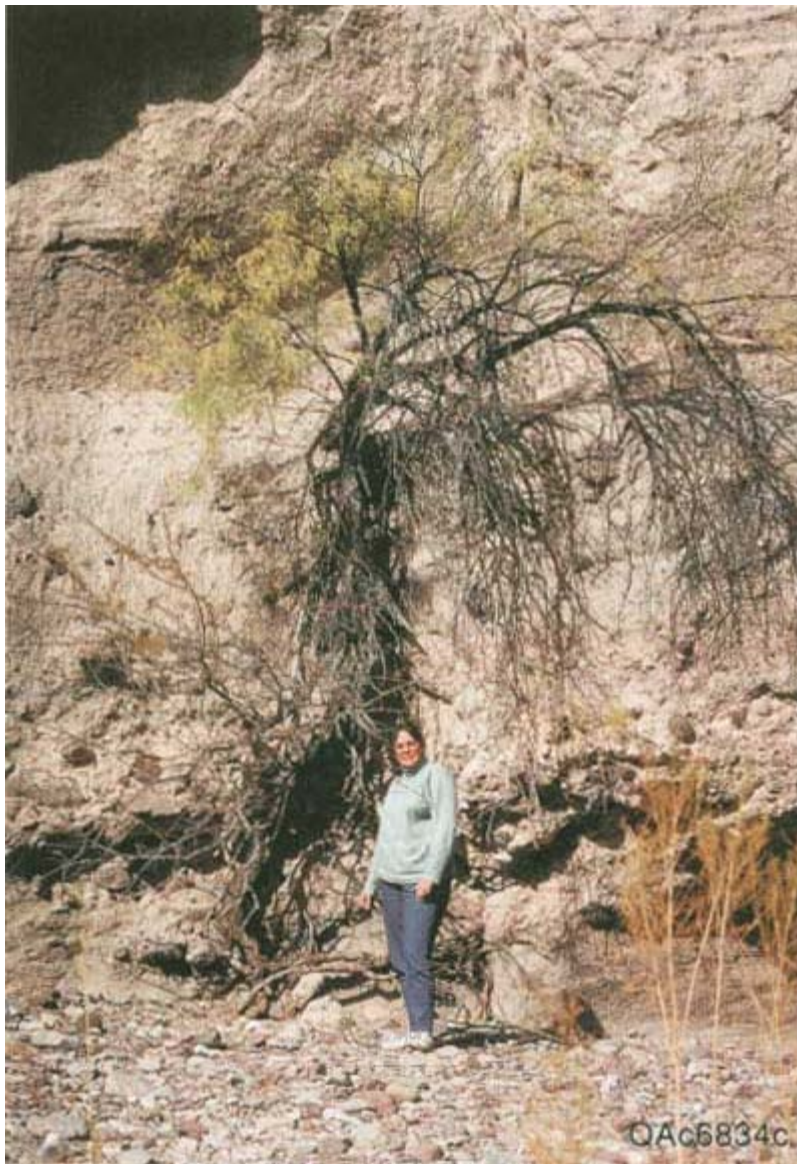


Figure 21. Mesquite tree clinging to the north wall of Tuff Canyon. The original ground surface on which the tree started to grow was about 13 feet above the present-day canyon floor. That's my wife Rosemary Barker 5'8" in the foreground to indicate scale.

In the cliff by the mesquite tree, the top of the pyroclastic flow is only about 1 foot above the canyon floor, and surge and debris-flow deposits make up most of the canyon walls. Just to remind you, we have looked at the rocks while walking downstream because faulting and tilting of the layers have brought progressively younger layers to your eye level. We end the tour by looking at some of the youngest features.

About 160 feet west of the clinging mesquite tree, near the mouth of Tuff Canyon and on the south wall about 10 feet above the floor are some smoothly rounded **potholes** (fig. 22). Some of these contain pebbles or cobbles. The potholes were cut into the soft pyroclastic surge deposits when sand and gravel swirled in eddies at the edge of a flooded stream. After the potholes formed, the canyon was cut deeper by later floods, leaving the potholes above the reach of floodwaters. No modern potholes are visible in the floor of the canyon, probably because the sand and gravel there are moved by each flood.



Figure 22. Potholes near the mouth of Tuff Canyon. The lowest pothole is about 1.5 feet wide.

Well, it's time to head on back. You can return to the parking area via the trail out of the canyon (see the map at the back of the book). It's uphill, so take your time.

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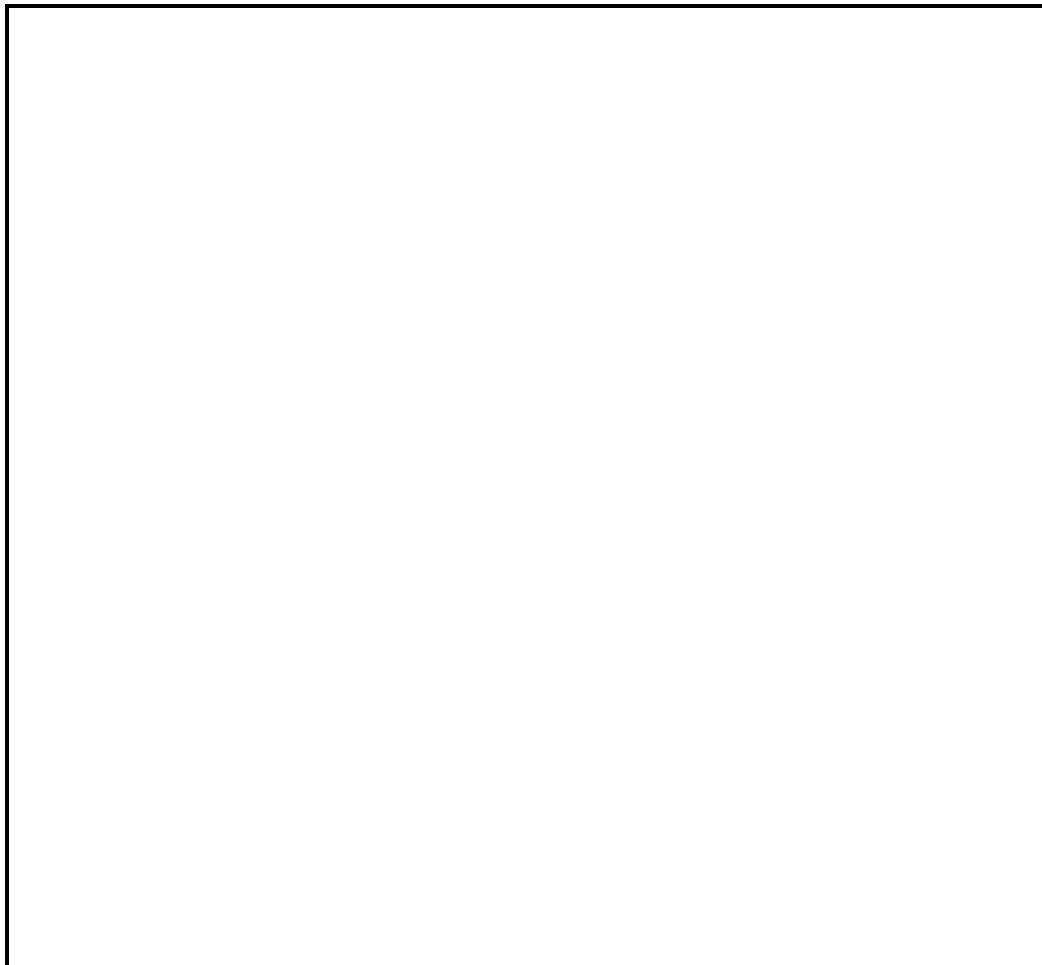


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THE BIG PICTURE

There has been a lot to take in during the tour of Tuff Canyon today, but before reflecting on all that you have seen, take time to consider the canyon in its wider setting. For example, where did the pyroclastic flows and surges come from? Well, the same sequence of rock layers seen from the east observation platform, for instance, is found in a canyon 1,600 feet east-southeast of Tuff Canyon (fig. 23). There, basalt lava is overlain by surge and debris-flow deposits, and these in turn are covered by pumice-rich pyroclastic-flow deposits, all containing abundant blocks of the underlying basalt. The pyroclastic-flow deposits are capped by more surge and debris-flow deposits and then, unlike those in Tuff Canyon, by **welded** rhyolite **spatter** (fig. 24), and finally by a thick rhyolite lava flow. Most rhyolite lava flows have high **viscosity** and therefore don't travel very far from their volcanic vents. In this case, a vent had to have been nearby. There is no marked trail to this vent area, so a visit is not recommended. Among other unpleasant surprises if you were to try it, the flat surface of the rhyolite lava flow ends suddenly at cliffs that drop vertically into a deep pool of water below.



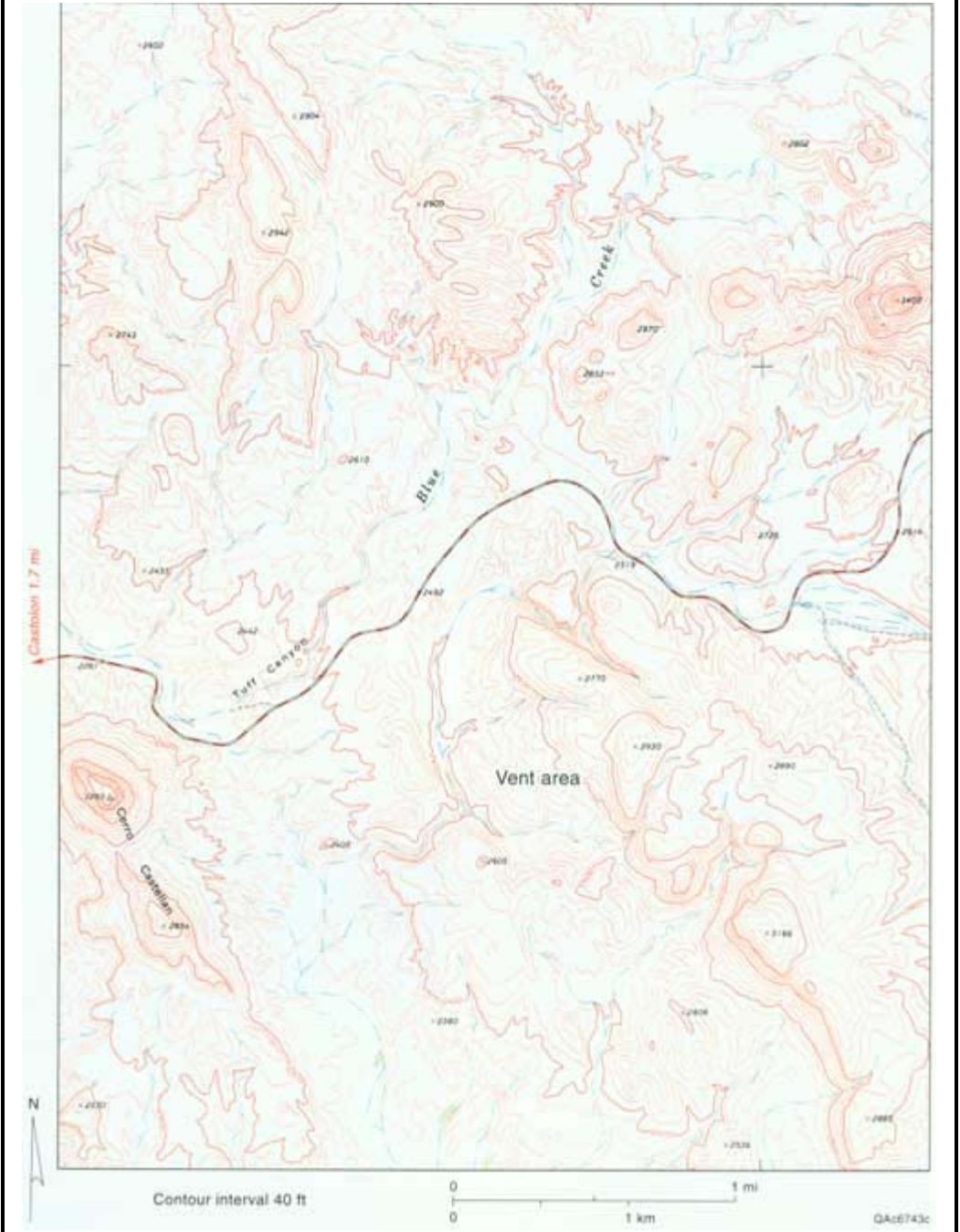
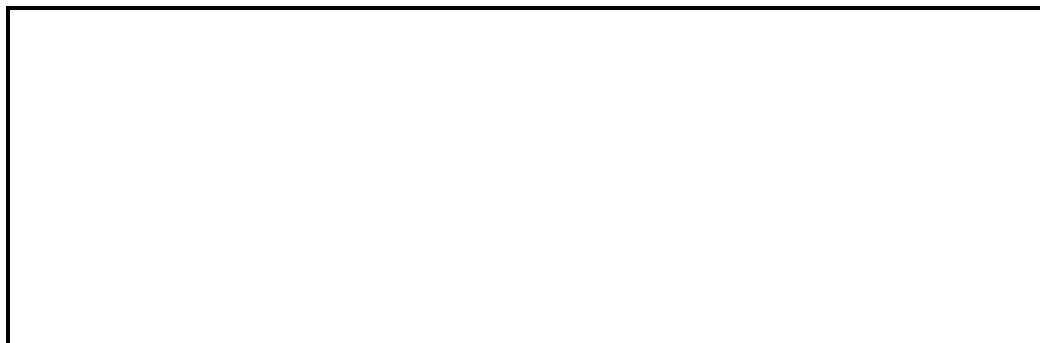


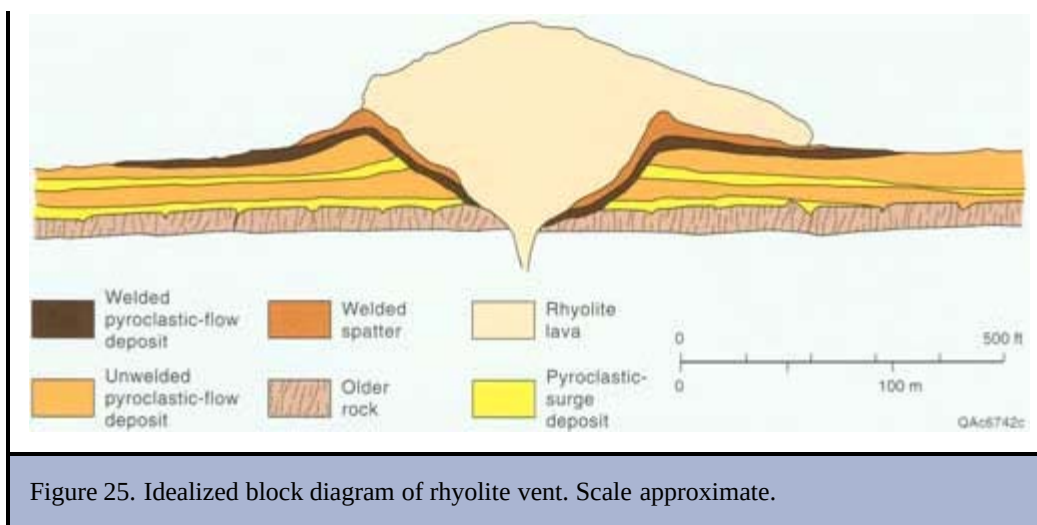
Figure 23. Topographic map (from U.S. Geological Survey, Cerro Castellan 7.5'-quadrangle map), indicating vent area east-southeast of Tuff Canyon and positions of Tuff Canyon and Cerro Castellan. *(click on image for a PDF version)*



Figure 24. Welded rhyolite spatter in vent area of figure 23. Dark, flattened blobs are pumice fragments from which most of the vesicles were squeezed out; light-colored rock fragments were cooler and more rigid, so they were not flattened. Pen for scale.

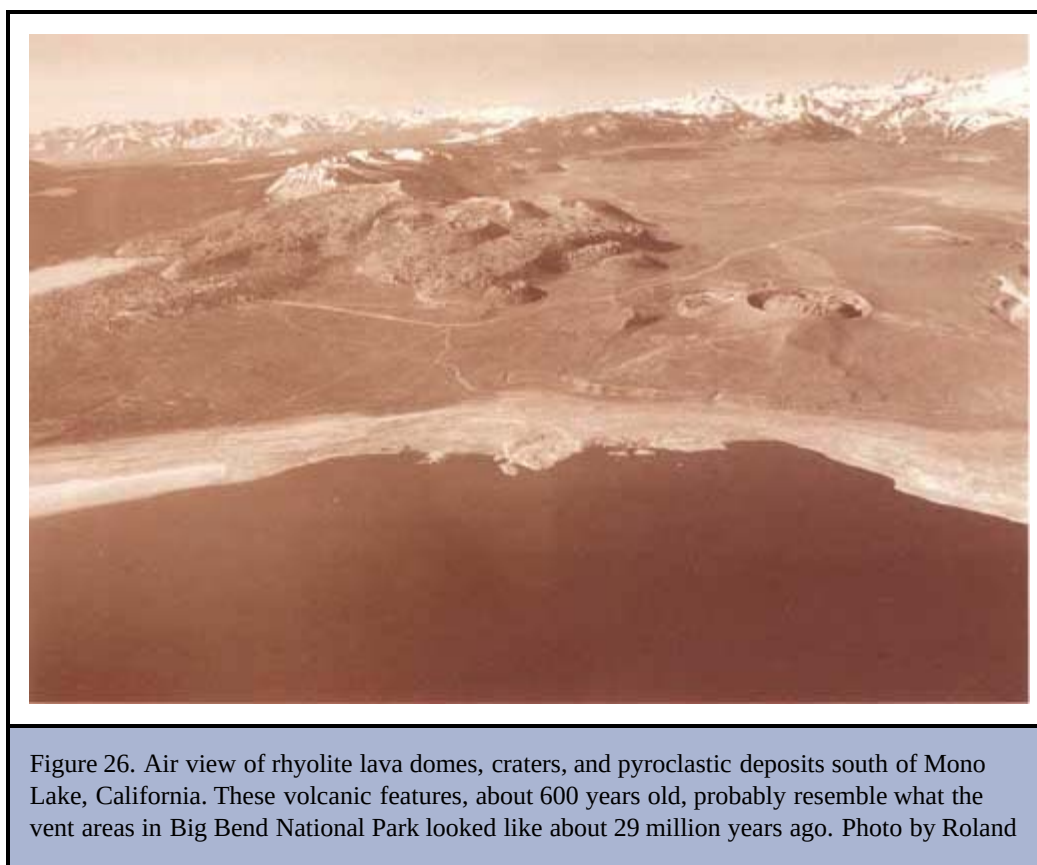
But volcanic vent areas do not have to be tall mountains. Some very energetic eruptions leave no accumulation of lava or pyroclastic material near the vents, which are just holes in the centers of shallow basins. Small accumulations of spatter can form around vents, while the pyroclastic material moves farther outward and spreads more thinly. In this part of the park, rhyolite magma broke through the surface at several vents (perhaps all the rhyolite eruptions happened at the same time or perhaps there were tens of thousands of years between them; we just don't know!) and expelled pyroclastic material before highly viscous lava came out to build domes and flows. In an idealized rhyolite vent (fig. 25), the sequence of deposits from the bottom upward is (1) surge deposits and unwelded pyroclastic flows, then (2) welded pyroclastic flows, (3) welded spatter, and, finally, (4) lava. This progression is caused by decreasing gas content of the magma; in effect, it is a case of foamy magma going flat like a carbonated drink as bubbles burst and gas escapes. As explosive behavior wanes, the amount of remaining gas decreases and the proportion of rock fragments does too. The latter part of such a sequence is most easily seen close up at Burro Mesa Pouroff (fig. 1). Although pyroclastic-flow deposits at Tuff Canyon are not welded, some are at the pouroff. Those at Tuff Canyon possibly travelled farther from their vent and cooled below the welding temperature before they stopped moving, or perhaps the eruption clouds were too cool, when they came out, to permit welding. Anyway, a visit to Burro Mesa Pouroff is worthwhile. From Ross Maxwell Scenic Drive, a well-marked road to the pouroff branches off about 9 miles northeast of Tuff Canyon.





Stacks of rock layers similar to that at Burro Mesa Pouroff can also be seen on Goat Mountain and Cerro Castellan from Ross Maxwell Scenic Drive. Other, less obvious vents occur at Kit Mountain and Trap Mountain (also visible from the road), and there are at least two others along the length of Burro Mesa, but these require hiking on the west slope of the mesa. These locations are shown in figure 1. Several other probable volcanic vents for the rhyolite are needed to explain its distribution but remain unidentified. In general, welded spatter and rhyolite lava do not travel far from vents, but in a few places (one is 3.1 miles north of the Tuff Canyon parking area on Ross Maxwell Scenic Drive), rhyolite lava lies directly on clay, without any pyroclastic deposits in between.

Shortly after the eruptions ended, this part of the park probably looked a lot like the chain of craters and lava domes you can see today south of Mono Lake, California (fig. 26). Here, pumice forms low rings around the volcanic vents, some of which are plugged by lava domes that formed when rhyolite lava oozed out but could not move far.



von Huene, U.S. Geological Survey.

The walls of Tuff Canyon record some violent days in this region's past, although the last volcanic eruption in any part of Texas occurred about 17 million years ago. In Big Bend country in the geologically foreseeable future, we expect no new volcanoes to be born, nor old ones to wake up, for perhaps the next million years at least. Weathering, erosion, and deposition will nevertheless continue to move rocks and change the landscape, some of which we have explored today.

A postscript: some people are worried that volcanic eruptions and earthquakes are happening more and more often. Is the Earth falling apart? There is absolutely no evidence to support this concern. Eruptions and earthquakes *are* being reported more often, but this is because there are more people in more places around the planet and these people have more technology to help them send their news to other places.

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ACKNOWLEDGMENTS

Challenging questions from visitors to Big Bend National Park made me realize that people would welcome a detailed guidebook for a specific area in the park. Suggestions from Pat W. Dickerson, Fred W. McDowell, William R. Muehlberger, Don F. Parker, Doug Smith, and John A. Wolff greatly improved early drafts. At the Bureau of Economic Geology, Jay Raney, Susie Doenges, Becky Smyth, Eddie Collins, and Kirt Kempter gave encouragement and guidance. Sue Hovorka offered suggestions in a final reading of the guidebook. Thanks to Roland Wauer (via Kitty Coley), who provided the information on birds of Tuff Canyon and gave us permission to use a photo, as well as a painting by Howard Rollin, that appeared in a book of his. Kirt and Chris Henry offered their input on critters, too. We found other critter info at <http://www.nps.gov/bibe/> and http://gorp.away.com/gorp/resource/us_national_park/tx_big_b.htm. DesertUSA (<http://www.desertusa.com>) allowed us the use of some of their critter and plant photos, too. Because she lives in Big Bend, Betty Axley took photos of purple prickly pear cactus for us, and cover photos are by Kerza Prewitt.

Lana Dieterich thoroughly reworked my writing, always achieving greater clarity, and Susan Lloyd did the word processing. Figures were drafted by Jamie H. Coggin, David M. Stephens made my photos and slides into text figures, and Jamie also adapted the critter photos and designed the book and its handsome cover, all under the supervision of Joel L. Lardon, Graphics Manager. Last but by no means least, Rosemary Brant Barker sustained me in the field, office, and at home.

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ABOUT THE AUTHOR

Dr. Dan Barker, currently Professor Emeritus in the Department of Geological Sciences at The University of Texas at Austin, retired in 1999 after 36 years with the Department. During his tenure at UT, Dan conducted research on igneous rocks and provinces throughout Texas, from the Big Bend area, to the Llano uplift, to the Balcones province. His research extended well beyond Texas, however, including projects in southern Africa and the Aeolian Islands of Italy. Dan's keen perspective on igneous rocks has given him widespread recognition in the geologic community, and he has participated in international congresses in Africa, Greenland, and Japan. Never one to remain idle for long, Dan continues to conduct research, publish, and attend meetings, oftentimes accompanied by his wife Rosemary.

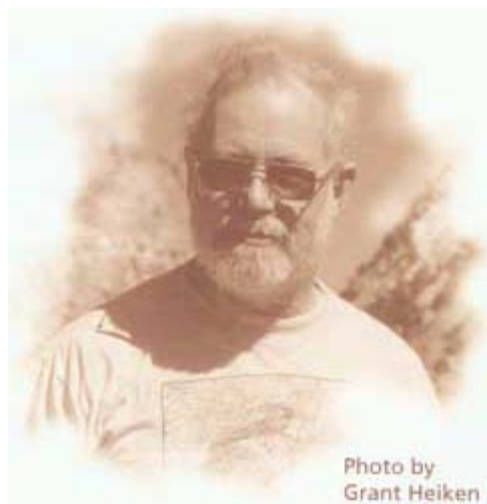


Photo by Grant Heiken

Dan's teaching awards at UT equal his impressive research record. Always extremely popular among students, Dan received the Knebel Distinguished Teaching Award in 1976, 1980, and 1987. In 1983 he published an undergraduate textbook, *Igneous Rocks*, which was reprinted in 1990. Recognition of his teaching contributions at UT culminated at the University of Texas Club on April 25, 1999, when Dean Mary Ann Rankin presented him with the College of Natural Sciences Teaching Excellence Award.

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GLOSSARY

Italicized words are cross-referenced to terms defined elsewhere in this glossary.

air-fall deposit material that falls out of an eruption cloud particle by particle, like rain drops or snow flakes, and accumulates on the Earth's surface. Has not been identified in Tuff canyon, probably because small, loose particles were easily picked up by *debris flows* and by *pyroclastic flows* and *surges*.

alluvium *silt, sand* and *gravel* deposited by running water.

ash *pyroclastic* particles that are not stuck together and that are smaller than roughly 0.1 inch in average diameter.

ballistic block fragment that is blown out of a volcanic *vent* and travels in a parabolic trajectory like an artillery shell or rocket.

basalt dark, fine-grained, *igneous rock*.

blocks and **bombs** rock fragments larger than an orange in a *pyroclastic* deposit. A *bomb* has a round, smooth outline and was probably molten when it was thrown out. A *block* has an angular outline (straight edges, sharp corners) and was solid when it was thrown out. Many blocks can be seen in Tuff canyon, but no bombs.

breccia rock containing angular fragments of older rock in a finer *matrix*.

case hardening process by which the outer part of a rock is made more resistant to *erosion* by precipitation of minerals from water that percolated through the rock and then evaporated, leaving the minerals behind.

channel small valley, formed by *erosion*. It may be preserved by being filled by *alluvium* or *debris-flow* deposits. A channel filling is usually recognizable because it has different particle sizes than do the deposits above and below.

debris flow moving mixture of rock particles and water, commonly having the consistency of freshly mixed concrete ready to be poured. Also called a "mud flow," but that name is not correct because some of the rock particles can be the sizes of cars or houses.

deposition laying down of rock particles.

dike *intrusive igneous rock* body shaped like a wall or a knife blade and formed by *magma* filling a crack.

erosion process by which material on Earth's surface is loosened and carried away. Running water is the most influential erosional agent on Earth, even in deserts.

fault break in Earth's crust, along which displacement has occurred; rock on one side of a *fault* slides past rock on the other side.

flow unit in *pyroclastic-flow* deposits, a layer or group of layers that can be distinguished from those above or below by *sorting*, degree of *welding*, or proportions of rock and *pumice* fragments. It may have been deposited only seconds before the one above it.

gas escape pipe narrow, vertical tube formed in a still-hot *pyroclastic-flow* deposit by gas moving rapidly upward and carrying away smaller particles in such a way that the pipe has a higher proportion of large particles than does the surrounding deposit.

glass in *volcanic rocks*, material that forms naturally when the liquid in *lava* cools before the atoms within it can organize into crystals.

gravel sediment having particle sizes larger than roughly 0.1 inch.

igneous rock rock that was once molten (*magma* or *lava*). The two general kinds are *intrusive* and *volcanic*.

imbrication leaning or shingling of flat rock or *pumice* fragments; the higher ends point the direction the depositing current was moving. Imagine a row of closely spaced dominoes all standing on end; if the domino at one end of the row is toppled so that it falls against another, the *imbrication* shows the direction the toppling wave moved.

impact sag dent left in the surface of the ground by a *ballistic* fragment.

intrusive rock *igneous rock* injected below Earth's surface as *magma*, which cooled and became solid long before it was exposed by *erosion* of overlying rock.

laminar flow fluid motion in which suspended particles follow smooth, parallel paths, like racehorses going around a track. Contrasts with *turbulent flow*.

lapilli *pyroclastic* particles having diameters between 0.01 and 2.6 inches.

lava *igneous* rock material so hot that it is partly or wholly liquid when it flows onto Earth's surface. Term used for both the hot liquid and the rock that forms when the liquid freezes.

lava dome steep-sided pile of *lava* having such high *viscosity* that it did not flow far from its *vent*. *Lava domes* can act as plugs in *vents*, holding in gas until an explosive eruption results. They can also build up so high that their sides collapse, triggering *pyroclastic flows* and *surges*.

magma rock material, partly or wholly liquid, within the Earth. When it erupts on the surface, it becomes *lava*.

matrix finer grained part of a *breccia*, between larger rock fragments. Particles in the matrix may or may not be the same kinds of rock as those making up larger fragments.

pillow lava rounded masses, a foot to several feet long, formed by the quick cooling of an outer skin of *lava* in water or wet mud. The hot interior of a pillow cools more slowly, allowing the still pliable skin to sag and mold itself around any underlying pillows.

pothole deep, smooth hole worn in a rock surface by the grinding of suspended *sediment* that moved in a tight orbit in a water eddy near the edge of a stream.

pumice volcanic *glass* that is so full of gas bubbles that it is frothy and of low density. Some floats on water.

pyroclastic "Fire-broken" (literally) *volcanic* material that was blown out of a *vent* as solid fragments and/or liquid droplets during an explosive eruption. The other kind of volcanic material is *lava*, which flowed out onto the surface of the ground as a liquid.

pyroclastic flow dense cloud of hot particles and gas, moving by *laminar flow* close to the ground surface. Pyroclastic flows travel at 22 to perhaps more than 600 miles per hour.

pyroclastic surge hot cloud, less dense than a *pyroclastic flow*, moving with *turbulent flow* close to the ground surface, commonly leaving a stratified deposit. The layering is produced by the unstable and pulsating motion of the surge cloud; within seconds the sizes of particles being deposited at any one place can change from large to small and back again.

rhyolite fine-grained, generally light colored, *igneous rock* with the chemical composition of granite; when liquid, it has a much higher *viscosity* than does *basalt*.

sand *sediment* composed of particles between 0.002 and 0.1 inch in diameter.

sediment loose particles freed by *weathering* from older rocks and deposited on Earth's surface (including the bottoms of streams, rivers, lakes, and oceans).

sedimentary rock consolidated (hardened) sediment. If you can dig into a deposit with your fingers or with a garden trowel, the deposit is not consolidated.

silky pumice frothy volcanic *glass* in which the gas bubbles have been drawn out into long thin tubes.

silt an unconsolidated sedimentary deposit dominated by particles smaller than 0.002 inch but large enough to have a gritty feel.

sorting process by which particles of a specific shape or size are selectively separated from others of different shape and size. The result of *sorting* is a more uniform population of particles.

spatter *pyroclastic* accumulation of hot globs of *lava* that flattened on impact and partly stuck together. It builds mounds close to volcanic *vents* and forms no more than a few hundred feet from them.

tuff rock composed of consolidated *pyroclastic* particles (*ash*) that are less than 0.1 inch in diameter.

turbulent flow fluid motion in which suspended particles follow erratic paths, like roaches scattering when you turn on the kitchen light at night. Contrasts with *laminar flow*.

vent opening in Earth's surface from which volcanic (*lava* or *pyroclastic*) material erupts.

vesicle hole in an *igneous rock*, formed by the trapping of a gas bubble as *lava* or *magma* froze. It is commonly less than 1 inch in diameter.

viscosity resistance to flow or to stirring. *Basalt* liquid has low viscosity (as low as that of motor oil) and therefore can form thin, rapidly moving *lava* flows. *Rhyolite* lava has high viscosity (similar to that of cold honey) and tends to form thick, slowly moving lava flows or to pile up as a lava dome over the volcanic *vent*. High-viscosity liquids, which can trap more

gas bubbles, are more likely to form *pumice* and to erupt explosively. On the other hand, some *rhyolite* lavas have lost their dissolved gas while sitting at or near Earth's surface.

volcanic rock *igneous rock* formed when *magma* breaks through Earth's surface and pours out, forming *lava*, or is blown out as particles, forming *pyroclastic* material.

weathering process by which rock is mechanically or chemically broken down, at or near Earth's surface.

welding high-temperature process by which *glass* particles in a *pyroclastic* deposit are stuck together and most *vesicles* are pinched shut. *Welding*, which occurs within the first few days or weeks after pyroclastic material is deposited, is most common in *pyroclastic-flow* deposits because these were hotter and commonly thicker than *surge* and *air-fall deposits*. Thickness is important because it helps hold heat in, and the weight of the overlying deposit promotes *welding* of the material below.

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