Guide to Geologic Features at

Petrified Forest National Park

Arizona Geological Survey
Down-to-Earth 10

John V. Bezy
National Park Service

Arthur S. Trevena

Photographs by Larry D. Fellows

Revised with permission from "Guide to Twenty Geological Features at Petrified Forest National Park" by John V. Bezy and Arthur S. Trevena. Published by Petrified Forest Museum Association, 1975, Holbrook, Arizona 86025

416 W. Congress St., Suite 100, Tucson, AZ 85701
(520) 770-3500
www.azgs.state.az.us

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John C. Dohrenwend graciously granted permission to use his satellite images in the design of this publication. Poster-sized satellite image maps (1:100,000) of the Petrified Forest National Park region can be ordered from John C. Dohrenwend, P.O. Box 141, Teasdale, UT 84773; Phone: (435) 425-3118; E-mail: dohrenwend@rkymtnhi.com.

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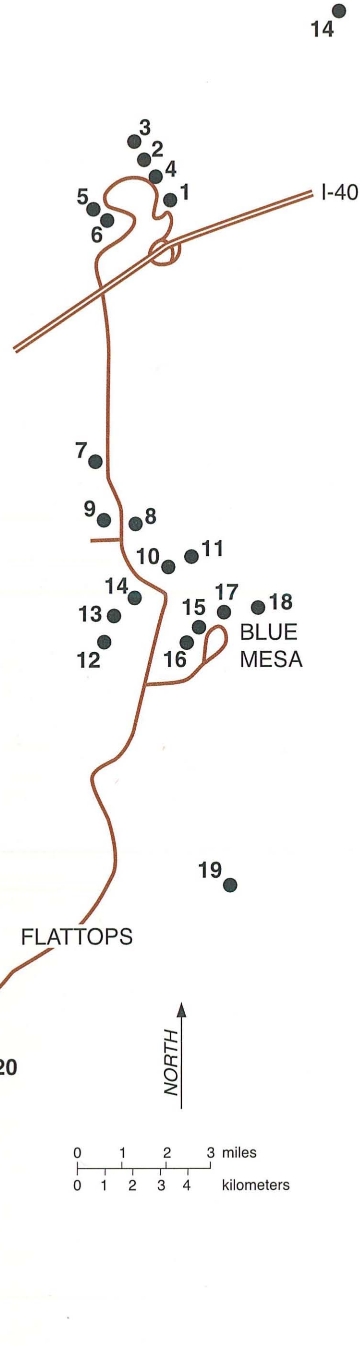


Figure 1. Contents and locations.

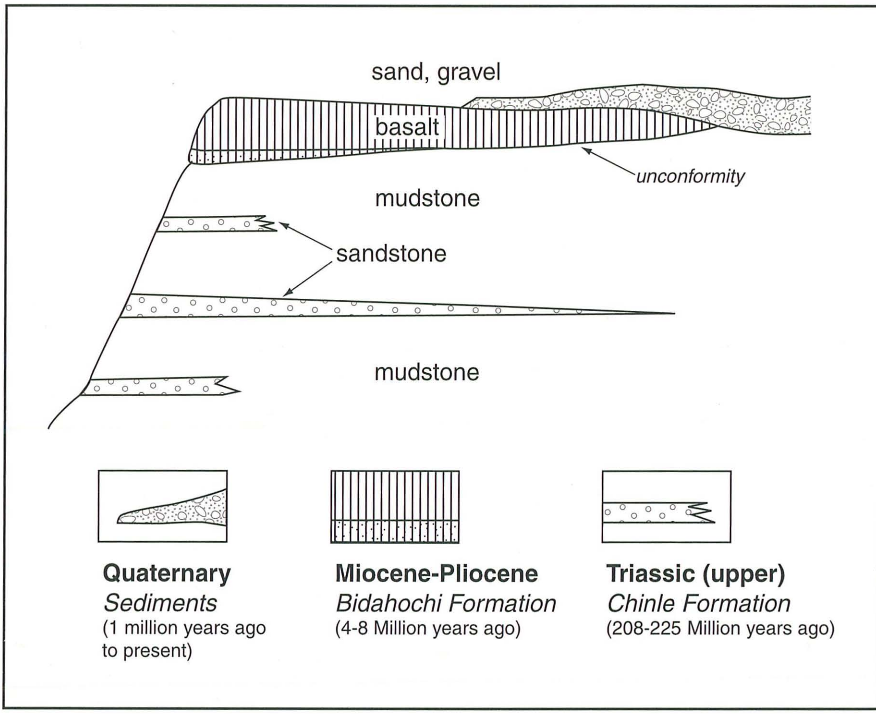


Figure 2. General geologic section for the Petrified Forest National Park area.

INTRODUCTION

Visitors to Petrified Forest National Park may view the 21 significant geologic features that are described in this field guide (Figure 1). Many of the features and processes discussed in the Guide are not restricted to the Park; most are common throughout the American Southwest and many are found all over the world.

This booklet is written for the Park visitor who is interested in geology, but does not necessarily have training in the subject. It may also be of value to the visiting geologist because the authors have described features that otherwise might be overlooked.

A REMINDER

The present and future success of our National Parks depends upon the unselfish cooperation of all visitors. Please help us preserve the geologic features at Petrified Forest by not disturbing rock and mineral specimens. **Federal law prohibits removal of any natural or cultural objects from the National Parks.**

GENERAL GEOLOGY

The rocks exposed within the Petrified Forest National Park were deposited during three different geologic time intervals (Figure 2). Mudstones and sandstones of the Upper Triassic Chinle Formation were deposited as mud and sand on a low-lying river (alluvial) plain about 208 to 225 million years ago. Most of these sediments were deposited by rivers, which originated in highlands in what is now southern Arizona and New Mexico. These rivers flowed toward a sea, which covered large areas of California and western Nevada. Other Chinle sediments were deposited in lakes. The Chinle Formation contains the fossil wood and erodes to form the Painted Desert.

Since the deposition of the Triassic rocks, northeastern Arizona has been uplifted at least a vertical mile. Any rocks of Jurassic and Cretaceous age that may have been present in the Petrified Forest were removed by erosion.

Sedimentary and volcanic rocks of the Miocene-Pliocene Bidahochi Formation cap the higher mesas in the Painted Desert area. These sediments and basaltic volcanic rocks were deposited on an erosion surface cut into the Chinle Formation.

Sediments of the Quaternary Period consist of river-deposited sand and gravel as well as wind-deposited sand. Quaternary sediments cover the older Miocene-Pliocene and Triassic rocks throughout much of the Park.

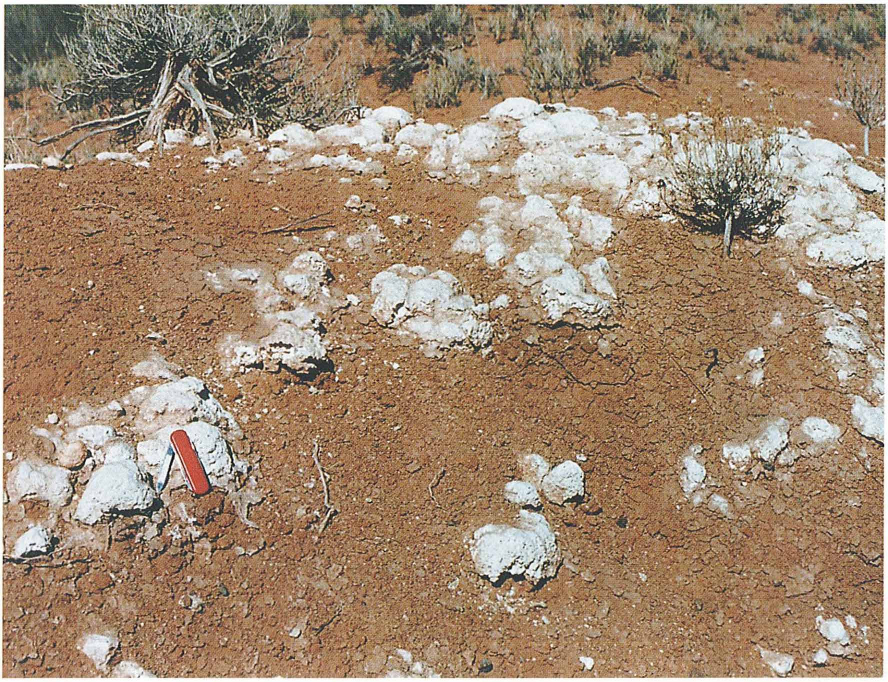


Figure 3. Lime nodules near Tiponi Point, Petrified Forest National Park.

Figure 4. Lime tubes near Tiponi Point, Petrified Forest National Park.

Feature 1

CALICHE (TUBES AND NODULES)

Location: *Follow the park tour road from the Painted Desert Visitor Center to Tiponi Point. The caliche is exposed in ravines 250 yards (230 meters) west-northwest of Tiponi Point, on the east side of the road.*

Discussion: Concentrations of calcium carbonate ($CaCO_3$), called "caliche", are common in arid lands where rainfall is insufficient to flush calcium salts from the soil. Lime nodules (Figure 3) form when calcium carbonate precipitates from downward percolation of soil water, or less commonly, from moisture brought up from below by evaporation and capillary rise. Silt and dust from the atmosphere are also an important source of carbonate. Lime tubes (Figure 4) occur when calcium carbonate coats and eventually replaces plant roots.

Well-developed caliche can form a thick hardpan beneath vast tracts of desert soil. Some buried caliche zones in deserts may have formed during past periods of greater rainfall or increased accumulation of carbonate from the atmosphere.

Figure 5. Gypsum (photo by A. Trevena).

Figure 6. Interbedded gypsum and mudstone below Kachina Point. Canteen (at arrow) for scale. (Photo by A. Trevena).

Feature 2

GYPSUM

Location: *Follow the park tour road to Kachina Point. The gypsum is exposed in the cliff 110 yards (100 meters) down the wilderness trail at Kachina Point. The layers persist laterally around the cliff.*

Discussion: The clear or translucent mineral gypsum ($CaSO_4$-$2H_2O$) (Figure 5) may form at the surface from evaporating bodies of standing water (such as playa lakes or lagoons) or below the surface as a cementing and/or fracture-filling mineral in older rocks. When evaporation in a lake or lagoon exceeds "fresh" water recharge, calcium and sulfate ions may become so highly concentrated that they are no longer soluble. Small crystals form and settle slowly to the bottom. After prolonged settling, a thick gypsum layer is left on the floor of the lake or lagoon. Alternatively, gypsum can be deposited underground from calcium and sulfate-bearing waters within open spaces (pores) or fractures in mudstone, sandstone, and limestone. Gypsum may also replace previously formed minerals such as pyrite (FeS_2) or anhydrite ($CaSO_4$).

The gypsum along the Kachina Point trail is interlayered with red mudstones in the Triassic Chinle Formation (Figure 6). This interlayering probably indicates deposition in a lake under arid to semi-arid conditions during part of the late Triassic period. These gypsum and mudstone cycles may represent alternating dry and wet seasons. Some of the gypsum exposed here may also be secondary, having been dissolved and redeposited by groundwaters.

Figure 7. Slumpage terraces below Kachina Point.

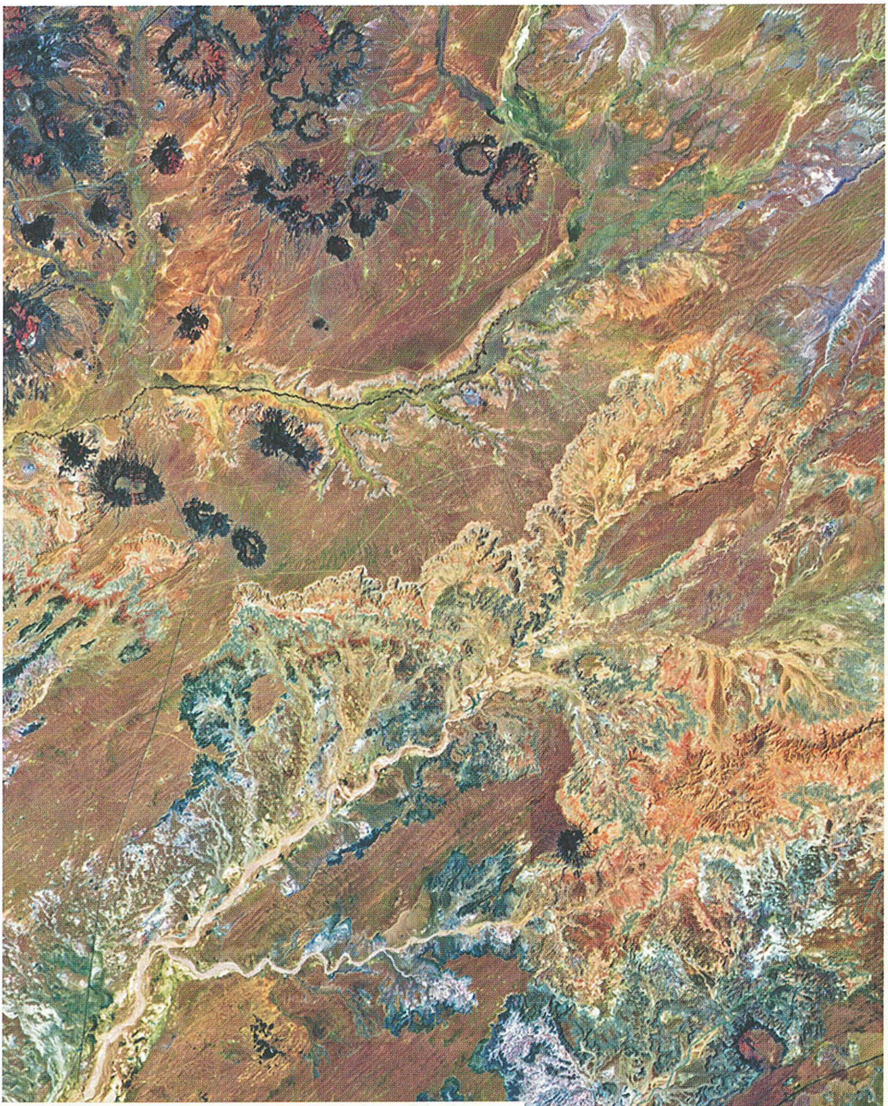
Feature 3

MASS FLOWAGE

Location: *Kachina Point Overlook*

Discussion: The small, terrace-like features in the badlands just below the overlook (Figure 7) are the result of mass downslope flowage of mudstone in the Chinle Formation. These rocks are called bentonitic mudstones, having formed from alteration of volcanic ash. They contain water-absorbing, expandable clays of the smectite group. During summer downpours the clay in the outer layer absorbs water and the mudstone becomes plastic. Surface layers of the saturated bentonitic mudstone then creep downslope under the influence of gravity.

This process, important in the wearing down of mudstone hills, speeds the process of erosion in the badlands.



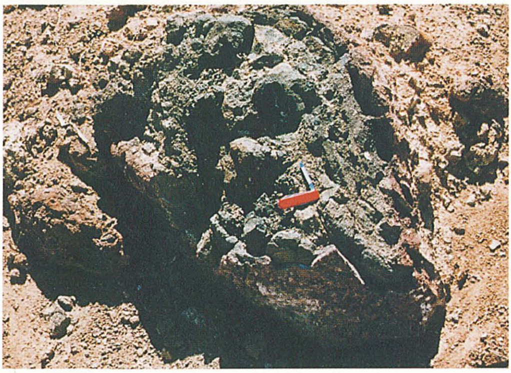


Figure 8 (top). Satellite image of the Hopi Buttes volcanic field and part of Petrified Forest National Park.

Figure 9 (left). A volcanic bomb in agglomerate.

Feature 4

BASALTIC AGGLOMERATE

Location: *This rock is exposed in road cuts 200 yards (183 meters) east of Kachina Point and along the Tawa-Kachina Point Rim trail.*

Discussion: The brown rock here is a basaltic volcanic agglomerate in the Miocene-Pliocene age Bidahochi Formation. The basalt flow beneath it has been dated at 6.8 million years. This agglomerate consists of large boulder-, cobble-, and pebble-sized fragments of basalt which were violently ejected from a nearby volcanic vent and cemented together with similarly ejected finer grained volcanic ash. This erosion-resistant caprock is only one of the numerous erosional remnants of the Hopi Buttes volcanic field (Figure 8) that can be seen on the northwestern horizon.

The angular-shaped fragments were thrown out of the vent in the solid state. Ellipsoidal or football-shaped fragments were ejected as blobs of molten rock that were molded by rotation during flight through the air prior to cooling and impact. These ellipsoidal objects (Figure 9), are called "volcanic bombs" by geologists. Their shapes are determined primarily by the viscosity of the molten rock.

This volcanic agglomerate contains boulders as large as 4 feet (1.2 meters) in diameter. Fragments this large could not possibly have been ejected far from the source, indicating that the explosive volcanic eruption was from a nearby, unknown volcanic vent.

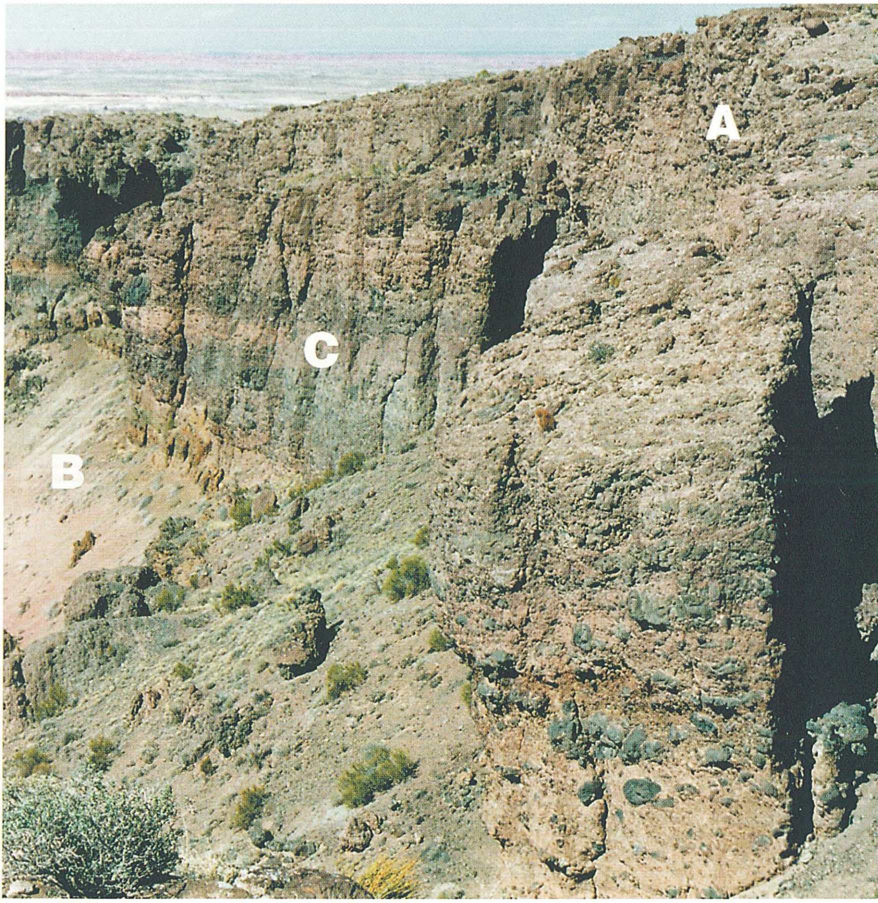


Figure 10. Slump-block near Pintado Point.

Feature 5

SLUMP BLOCK

Location: *Follow the park tour road to Pintado Point. This feature is located about 1000 yards (900 meters) west of Pintado Point along the cliff.*

Discussion: The plateau here is capped by resistant basalt (A) underlain by softer clay (B) (Figure 10). When saturated, the clay loses its supportive strength and causes great blocks (C) of the protective overlying rim rock to break off and slide downslope in a backward, rotating movement.

Called slumping, this type of action tremendously increases the rate of cliff retreat and valley-widening in the Southwest.

Figure 11. The unconformity (at arrow) between the Bidahochi and Chinle Formations; view is from Whipple Point.

Feature 6

UNCONFORMITY

Location: *Follow the park tour road to Whipple Point. Look north-northwest to the line of cliffs along the mesa side.*

Discussion: The nearly-horizontal surface on the photograph (Figure 11, at arrow) separates the black basalt and the yellowish-gray-colored sandstone above from the red colored mudstone below. This surface marks a time gap in the geologic record (an unconformity). The sedimentary rocks below this surface belong to the 208-225 million year old, Upper Triassic Chinle Formation. The sedimentary and volcanic rocks above this surface belong to the 4-to-8 million year old Bidahochi Formation. More than 200 million years of geologic history are not represented by rock at this locality.

An unconformity indicates that either (1) sediment was never deposited in this area during the missing interval, or (2) that sediment was deposited but was later removed by erosion. The latter possibility is more likely here, because the missing time interval is great. Unconformities of this type imply uplift and erosion of the land. Regional studies indicate that more than 1000 feet (305 meters) of rock were stripped off at this locality.

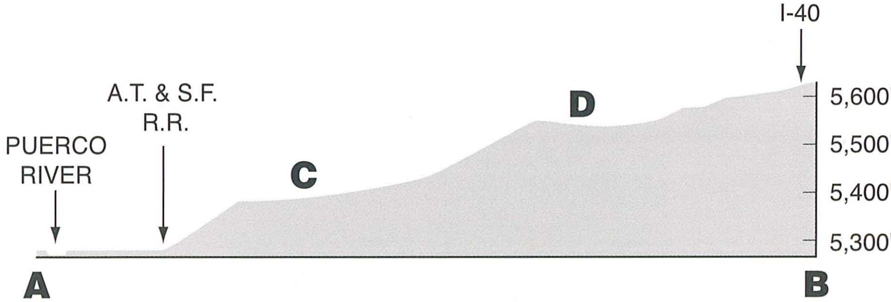


Figure 12. A cross-sectional profile of stream terraces between the Puerco River and Interstate Highway 40.

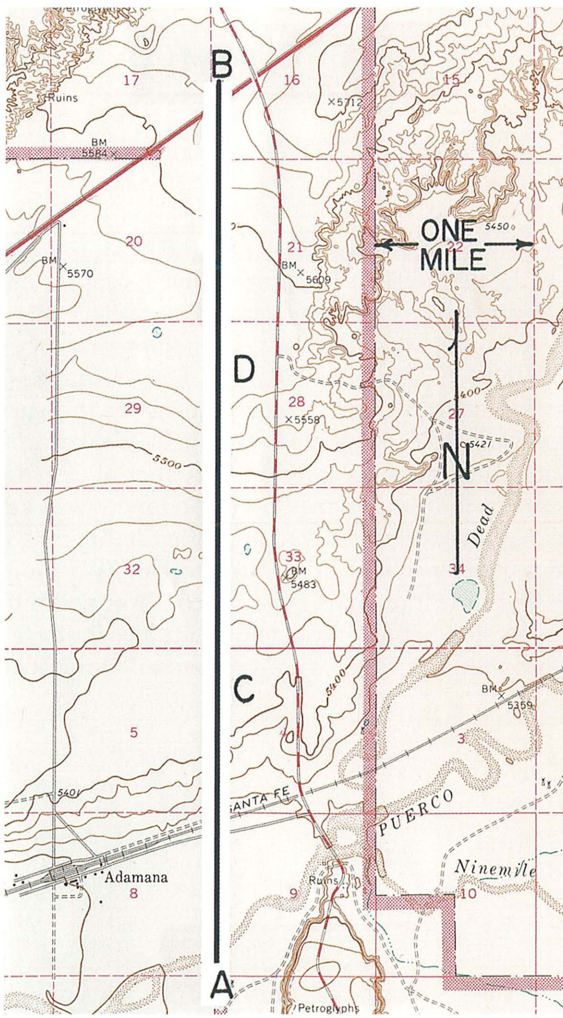


Figure 13. The location of stream terraces on a topographic map of Petrified Forest National Park. Contour interval is 25 feet.

Feature 7

STREAM TERRACES

Location: *Follow the park tour road south for approximately 3 miles (4.8 kilometers) past the Interstate 40 overpass. The terraces are cut into the north flank of the Puerco River Valley.*

Discussion: The two large step-like surfaces (C and D) in figures 12 and 13 are stream terraces. Hundreds of feet above the Puerco River that cut them, these benches are remnants of the river's former floodplains. During at least two episodes of erosion the river cut down its channel and, by shifting from one side of the valley to the other, removed all but these vestiges of the former valley floors.

Stream terraces record changes in the geologic history of a river valley. Here they represent either repeated uplift of the land or climatic change, and the resultant downcutting by the river.

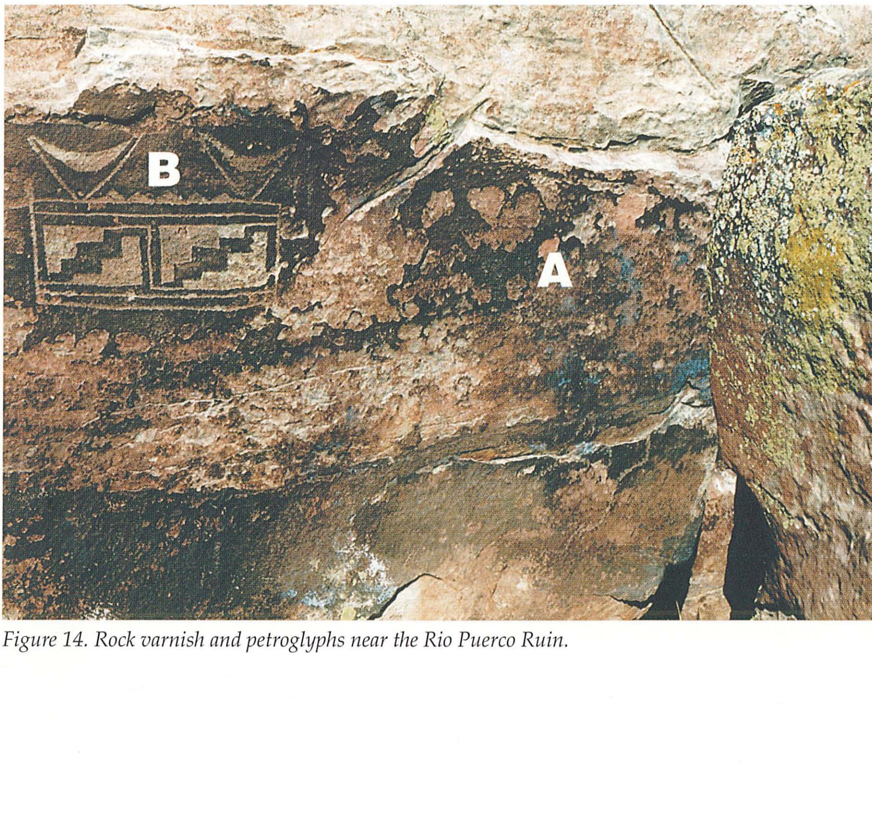


Figure 14. Rock varnish and petroglyphs near the Rio Puerco Ruin.

Feature 8

ROCK VARNISH

Location: *Follow the park tour road south to the Puerco Pueblo Ruin and walk to the end of the walkway.*

Discussion: The brown and black surface stains (Figure 14, A) on this sandstone are called rock varnish. Chemical analysis shows the varnish to be a thin coating of clay minerals (illite, smectite and kaolinite) that is colored by heavy concentrations of iron and manganese oxides. The clay settles as dust from the atmosphere. Manganese, also derived from windborne dust and rain, produces a black to dark brown coloration. Micro-colonies of lichens and bacteria gain energy by oxidizing the manganese. The micro-colonies anchor themselves to rock surfaces with the clay particles, which provide protection against extremes in temperature and humidity. In the process, manganese becomes firmly attached to and darkens the clay. Each time the rock surface is wetted, more manganese and clay are brought in to sustain the slowly growing colony.

"Varnished" rocks are typical of all Earth's deserts. In the Southwest these rocks have a special archaeological significance because of the prehistoric petroglyphs (B) pecked through the mineral skin to the fresh rock below. Because rock varnish forms at variable rates, it cannot be reliably used to date the inscriptions.

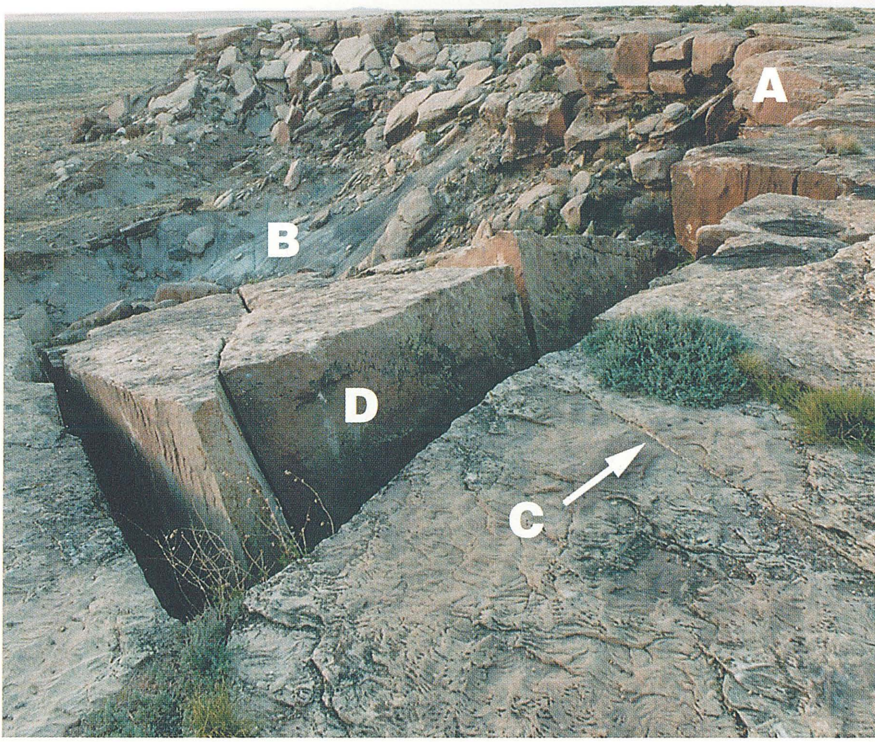


Figure 15. Retreating cliff at Newspaper Rock overlook.

Feature 9

CLIFF RETREAT

Location: *Follow the park tour road to the Newspaper Rock parking lot and walk to the overlook.*

Discussion: This cliff (Figure 15), like other seemingly permanent features of the landscape, is constantly retreating due to erosion. The hard, but highly fractured, Newspaper Rock Sandstone (A) caps the mesa and is underlain by mudstone (B). Rain and meltwater remove the supporting mudstone. This causes fractures (C) in the sandstone above to widen into gaping crevasses (D), and rock slabs to break off and topple to the slopes below. In 1984 the trail that once descended to Newspaper Rock was destroyed by the movement of large sandstone slabs.

Particularly in the Colorado Plateau region, undermining of cliffs is a major process that reduces extensive sandstone plateaus to mesas and buttes.

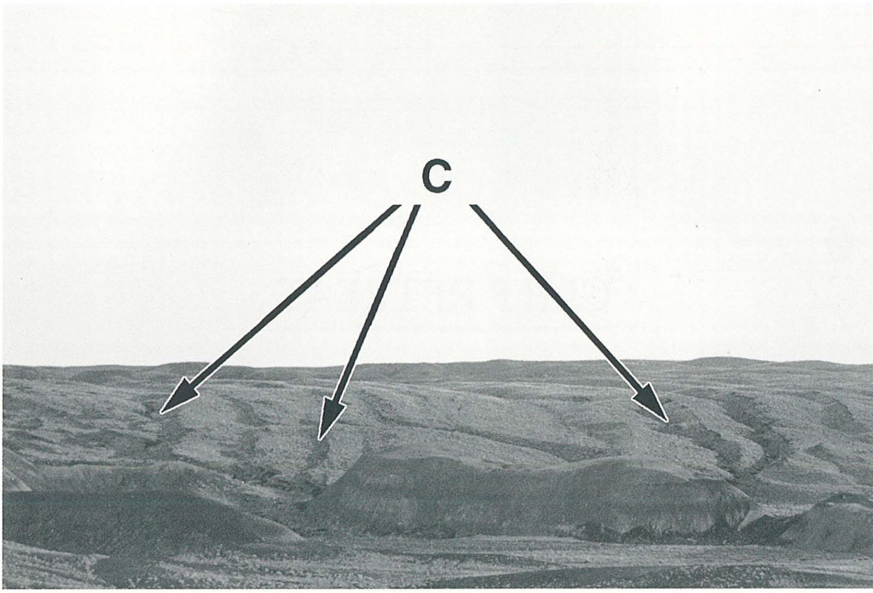


Figure 16. Aligned drainages cut into gently folded sandstones and mudstones of the Chinle Formation.

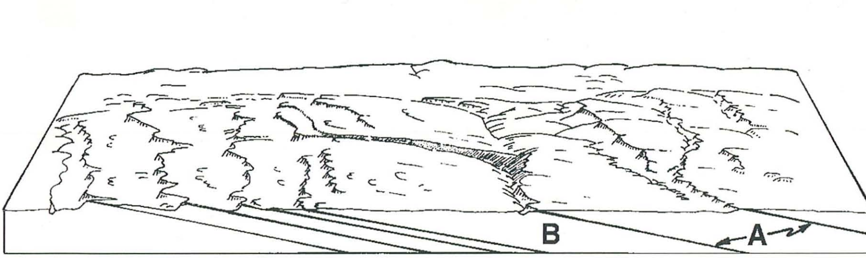


Figure 17. Block diagram of Figure 16.

Feature 10

ALIGNED DRAINAGES

Location: *Follow the park tour road south to the Tepees parking area and walk north for about 3/4 mile (1,200 meters).*

Discussion: Aligned drainages (Figure 16,C) in this area occur in folded layers of sandstone (Figure 17,A) and mudstone (Figure 17,B). Gullies are cut into the soft mudstone, leaving the harder sandstone layers standing in ridges. These gullies are alligned at right angles to the tilt of the rock layers and, on a larger scale, are called strike valleys.

These features show how an ancient geologic structure, such as a fold, can control modern drainage patterns.

Figure 18. Downwarp (syncline) in sandstones and mudstones of the Chinle Formation.

Feature 11

DOWNWARP

(syncline)

Location: *Walk to the prominent ridge located one mile (1.6 kilometers) northeast of Tepees parking area.*

Discussion: The sandstone and mudstone layers that form this ridge were deposited by streams during the Triassic Period as nearly horizontal bodies of sediment. Since then stresses within the earth have folded them into a downwarp or syncline. Rocks along the northeastern end of the ridge (Figure 18, A) dip 5 degrees, whereas those layers in the southwestern part (B) dip as much as 17 degrees in the opposite direction.

This feature is one of several folds in the immediate area. They imply that instability in the earth's crust prevailed here sometime after the deposition of these Triassic sediments. This instability may have been related to either 1) lateral compression associated with plate tectonics or 2) collapse caused by the dissolution of underground salt beds.

Figure 19. Desert pavement near the Tepees parking area.

Feature 12

DESERT PAVEMENT

Location: *This feature is located 1/2 mile (800 meters) southwest of Tepees parking area (see Figure 21).*

Discussion: This flat, rocky surface (Figure 19, A) is covered with cobbles, pebbles, and petrified wood fragments that were left behind when strong winds swept the fine sands into dunes (B). This "desert pavement", especially when cemented with mineral salts such as calcium carbonate, protects the finer material underneath from wind erosion.

Another factor that contributes to the formation of stone pavements is the wetting and drying of the desert surface. When certain clays (smectites) in desert soils absorb rain water they expand to many times their dry volume. This swelling gradually moves the pebbles and cobbles within the soil to the surface. Drying and contraction produces cracks in the soil that quickly fill with sand and silt. Over time, heaving from these repeated cycles of expansion and contraction produces a tightly fitted mosaic of stones on the desert surface.

Desert pavement is common to deserts everywhere and covers thousands of square miles of the earth's surface.

Figure 20. Ventifacts found near the Tepees parking area (photo by J. Erickson).

Feature 13

VENTIFACTS

(venti=wind, fact=made)

Location: *These features are located one-half mile (800 meters) southwest of the Tepees parking area (see Figure 21).*

Discussion: Examine the pebbles and petrified wood fragments that cover the ground here. Many are polished and have sharp edges cut by natural sandblasting (Figure 20). Sparse vegetation, abundant sand, and persistently strong winds create perfect conditions for the shaping of ventifacts, which these abraded rocks are called.

Many pebble-sized ventifacts have two or three facets (cut faces) caused by overturning and swivelling of the stone. Closer examination reveals that most of the wind-cut facets also have small flutes and pits, believed to be caused by wind-driven dust.

Ventifacts, which illustrate the cutting power of wind-driven sand in arid lands, are geologically valuable as indicators of past windy, barren environments.

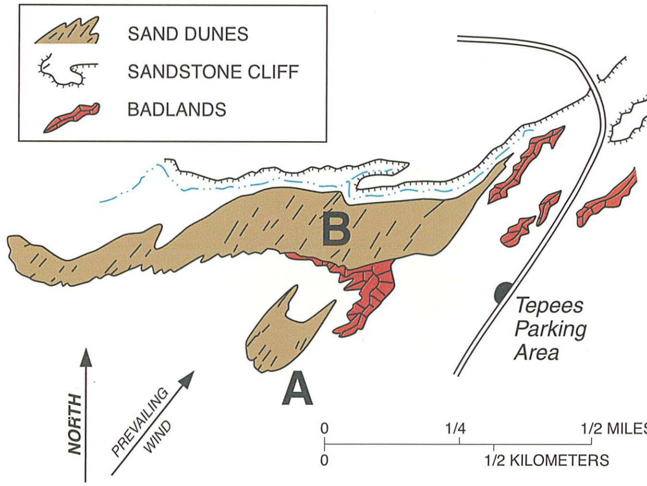


Figure 21. Barchan and transverse dune near the Tepees parking area.

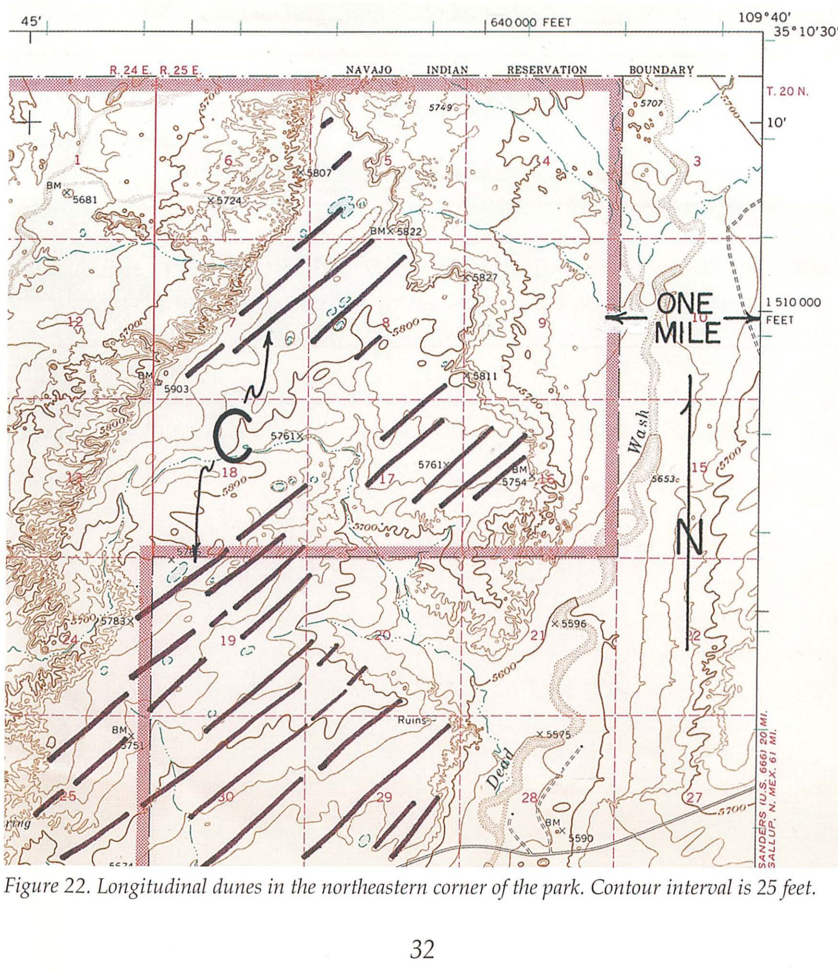


Figure 22. Longitudinal dunes in the northeastern corner of the park. Contour interval is 25 feet.

Feature 14

SAND DUNES

Locations: *Barchan – This type of dune is located about 1/3 mile (500 meters) west-southwest of the Tepees parking area (Figure 21). Transverse dune – This type of dune is located about 1/3 mile (500 meters) west-northwest of the Tepees parking area (Figure 21). Longitudinal dunes – These dunes are located in the northeastern corner of the park (Figure 22).*

Discussion: Constancy, velocity, and direction of the wind, abundance of sand, and density of vegetation all contribute to the shape sand dunes acquire. The barchan (Figure 21,A) is a crescent-shaped dune, the "horns" of which point downwind. A transverse dune (Figure 21,B) trends at right angles to the prevailing wind, and has steep downwind and gentle upwind slopes. Longitudinal dunes (Figure 22,C) are long, narrow, symmetrical ridges of sand that parallel the prevailing winds. All three are distinctive forms that are present in dune fields throughout the world.

All of the dunes at these locations have been stabilized by vegetation for some time and are quite old. The longitudinal dunes in the northeastern corner of the Park are at least 100,000 years old and perhaps as old as 500,000 years. The barchan and transverse dunes near the Tepees parking area are 5,000 years old and younger. Calcium carbonate and clay cementation, development of rudimentary soil, incised gullies, iron-oxide staining, and weathering of individual grains reveal the antiquity of these features. At times during and since the last Ice Age, moving sand dunes were an important part of the landscape of northeastern Arizona.

From sand deposits such as these geologists can interpret ancient wind directions and climatic fluctuations.

Pre-Columbian Native Americans farmed some of the sand dunes in this part of northeastern Arizona. The Hopi Indians still do.

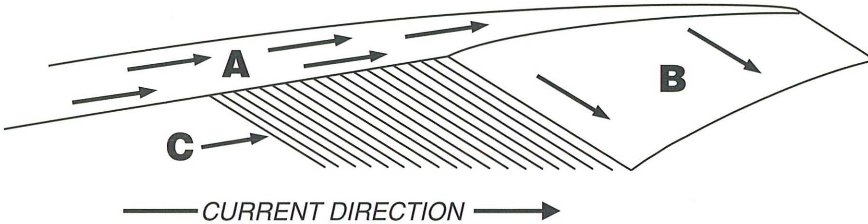


Figure 23. Diagram of a typical sand bar.

Figure 24. Cross-bedded sandstone near the Blue Mesa trail head.

Feature 15

CROSS-BEDDED SANDSTONE

Location: *Follow the park tour road and the Blue Mesa access road to the Blue Mesa trail head. This sandstone caps the mesa and is best examined along trail cuts at the beginning of the walkway.*

Discussion: The layering of sandstone at an angle to the horizontal (cross-bedding) forms by either (a) the downcurrent movement of underwater sand bars in a river channel or shallow sea, or (b) by the downwind migration of sand dunes.

Sand grains move across the gently sloping upstream side of a sand bar (Figure 23,A) and "avalanche", coming to rest on the steep downcurrent side (B). As inclined layers of sand (C) are added to the downcurrent side, the bar or dune advances downstream or downwind. The resulting set of inclined layers of sand, given the right geologic conditions, may be preserved as cross-bedded sandstone (Figure 24). In this case, the cross-bedded sand was deposited in an ancient river.

Cross-bedding can be used to determine the direction and strength of ancient wind and water currents and to estimate minimum water depth and dune height.

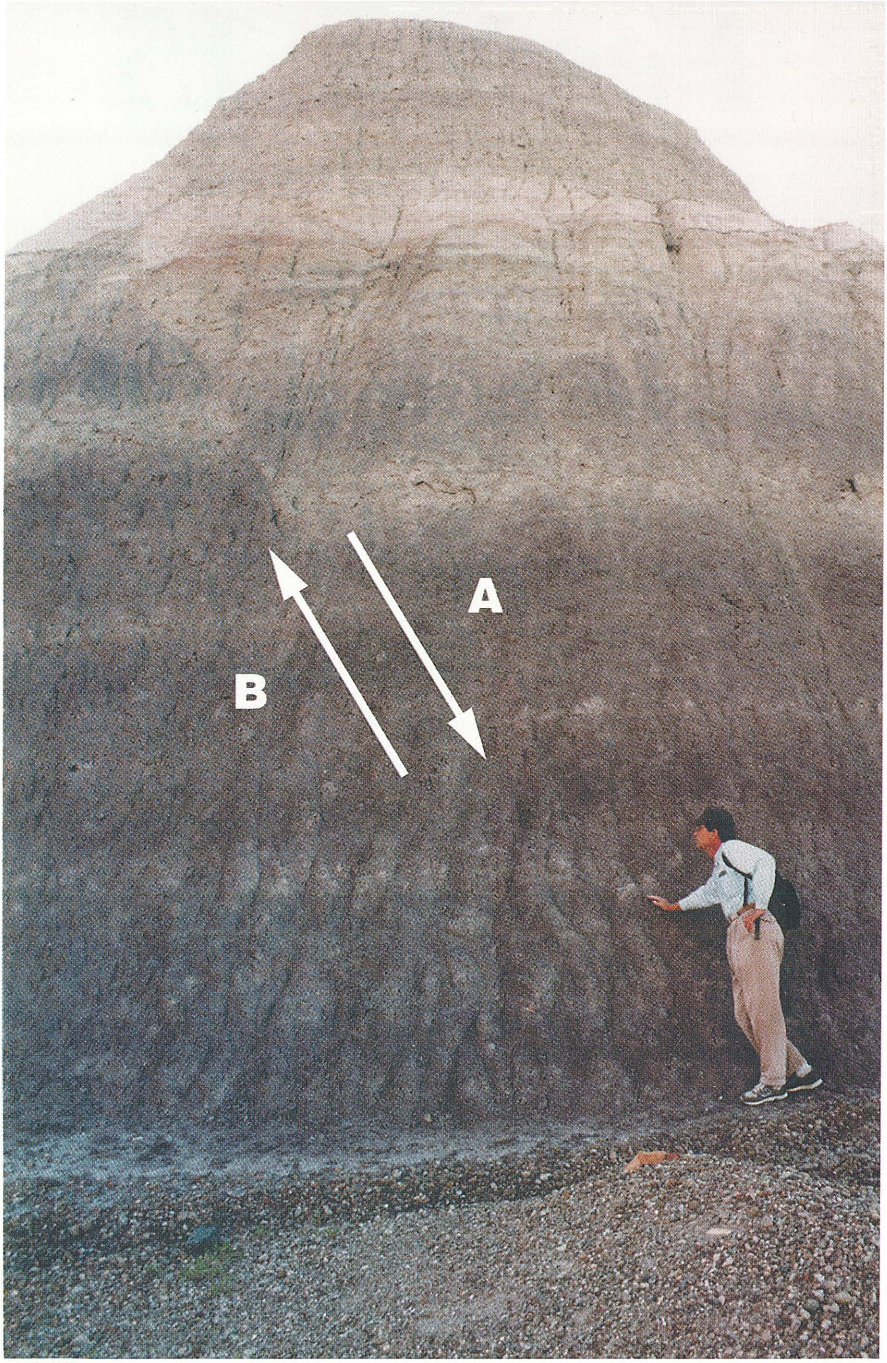


Figure 25. Normal fault (arrows) along the Blue Mesa trail.

Feature 16

NORMAL FAULT

Location: *As you walk down the Blue Mesa trail, this feature is located on the left side, 50 feet (15 meters) before the trail splits to form a loop.*

Discussion: A fault is a fracture in the earth along which movement has occurred. The direction and amount of movement along the fracture may be revealed by the displacement of rock layers on opposite sides of the fault. In this case (Figure 25) notice that rocks of the upper fault block (A) have moved down relative to the rocks of the lower block (B). Such a fault is called a normal fault.

Faults are a sign of instability in the Earth's outer layer at some time in the past. An earthquake is a common sign of fault movement. A normal fault may originate from stretching of the Earth's outer layer or it may result from movement under the influence of gravity.

Figure 26. Closeup view of "frothy" texture of bentonite mudstone.

Figure 27. Unweathered bentonite.

Feature 17

BENTONITE WEATHERING

Location: *This feature can be observed on any slope surface of the badland hills along the Blue Mesa trail.*

Discussion: Note the cracked and loose surface (Figure 26) of the badland hills, which are composed of layered mudstone (Figure 27) that is rich in altered volcanic ash, called bentonite.

Bentonite contains clay minerals of the smectite group (such as montmorillinite) that have the unusual property of absorbing water and swelling to as much as seven times their dry volume. During summer downpours the outer rind of mudstone expands. The hot sun quickly dries this rind and the bentonite shrinks, forming cracks.

The loose and cracked outer surface is easily penetrated by running water and may permit the initiation of piping (see Feature 18).

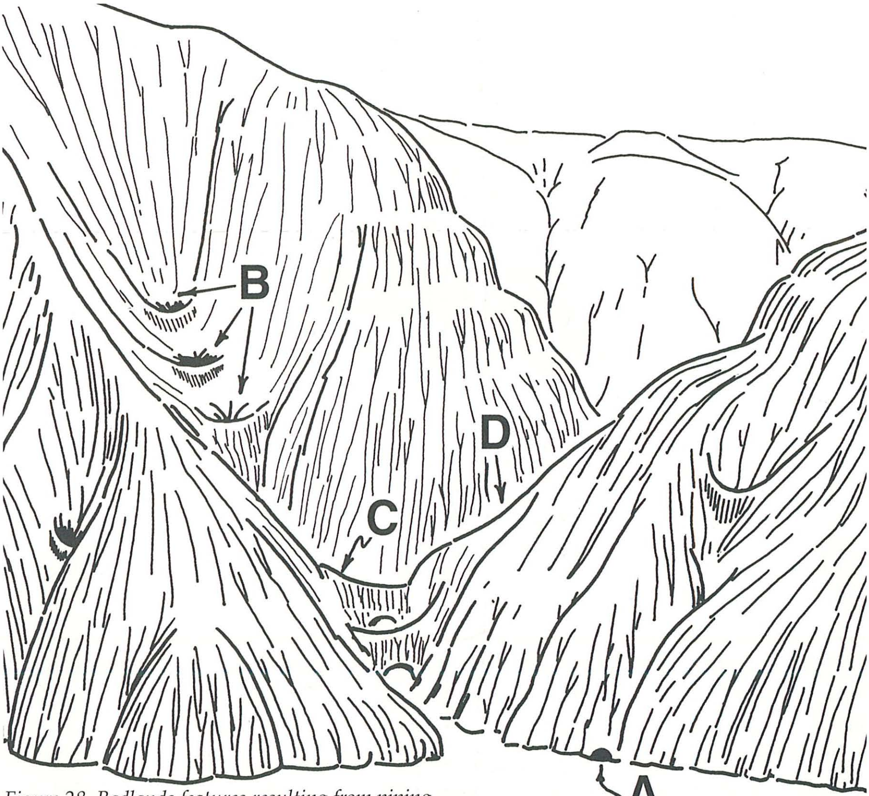


Figure 28. Badlands features resulting from piping.

Figure 29. Piping.

Feature 18

PIPING

Location: *This feature is located along the Blue Mesa trail, where the trail splits to form a loop*

Discussion: Water from summer storms penetrates shrinkage cracks (see Feature 17) in these mudstone badlands and erodes small underground tunnels called pipes (Figure 28). Pipes usually emerge as seeps and springs (A) at the base of the clay hills. Additional hard rains enlarge pipes and erode support of the roofs along their courses. Weakened areas of the roofs collapse, forming aligned sinks (B) which, in turn, funnel more water to the greatly expanding pipes below. Between sinks, natural bridges (C) span the subterranean channels until they too collapse, leaving only steep-walled gullies (D).

Piping indicates the presence of one of the swelling clay minerals of the smectite group. It is also an important type of desert erosion leading to gully formation and the development of badlands (Figure 29).

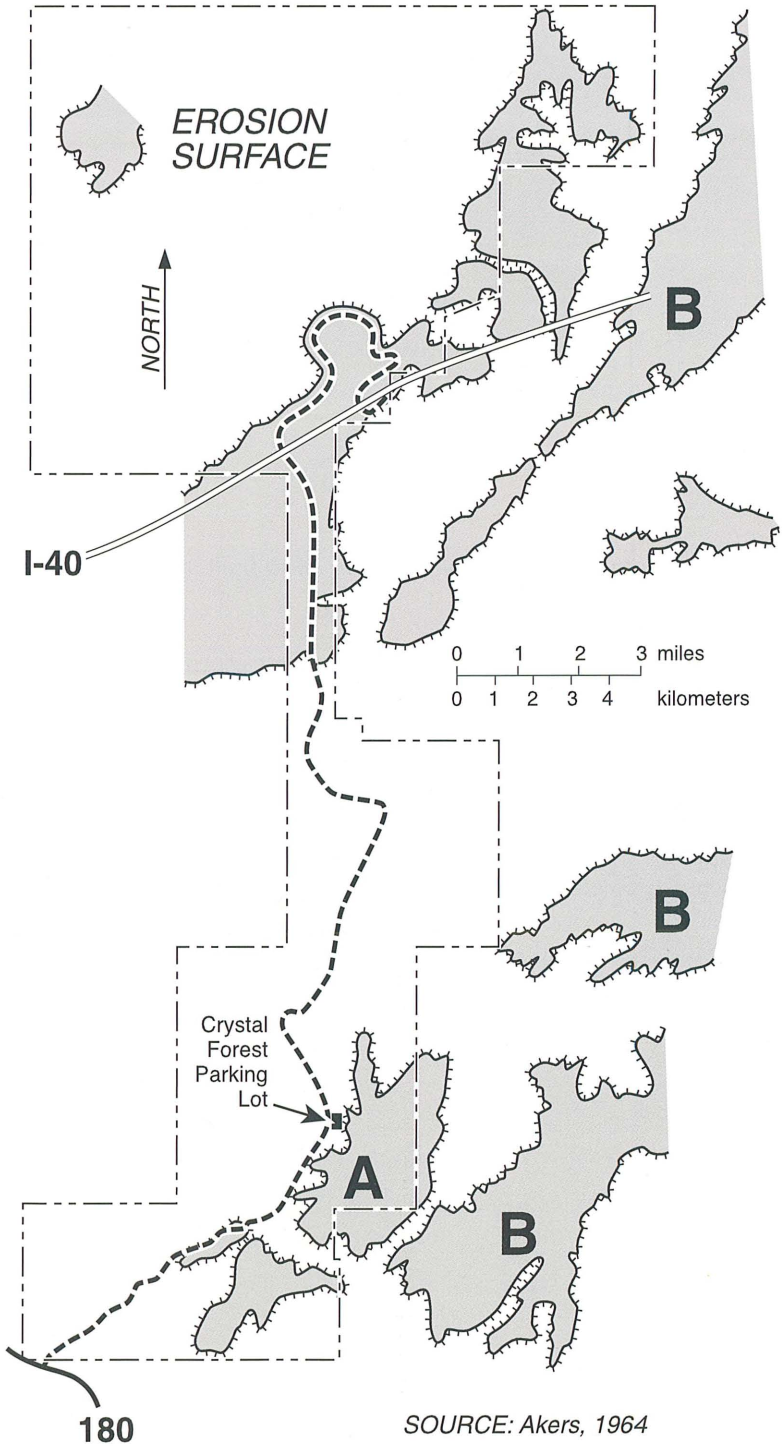


Figure 30. Remnants of Pliocene erosion surfaces at Petrified Forest National Park.

Feature 19

EROSION SURFACE

Location: *This feature is located two miles (3.2 kilometers) east of the Crystal Forest parking lot.*

Discussion: This mesa surface (Figure 30,A) was once connected with those in the distance (B) to form an extensive erosion surface. It was planed off by Pliocene to Early Pleistocene age (5 million to 1/2 million years ago) rivers that eroded the drainage divides and caused the floodplains to merge. The rivers later downcut their courses, leaving these mesas as high remnants of the ancient plain.

Erosion surfaces illustrate on a small scale that, were it not for uplift and mountain building, erosion would reduce the Earth's continents to vast, monotonous plains.

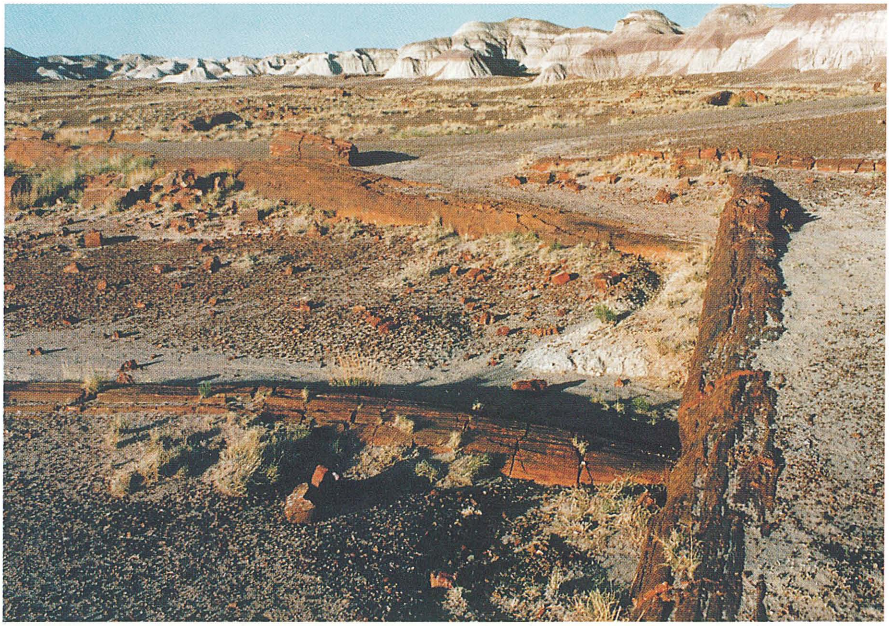


Figure 31. Wood deposited as a log jam and subsequently petrified, Long Logs trail.

Figure 32. Segmented petrified tree trunk, Long Logs trail.

Feature 20

PETRIFICATION

Location: *Petrified wood is best seen along the Long Logs trail.*

Discussion: Many of the petrified tree trunks (Figure 31) along this trail were deposited as log jams in stream channels during the Triassic Period (approximately 208 to 225 million years ago). Logs were buried quickly in the relatively oxygen-poor sand before much of the wood could decay. Ground water became saturated with silica (at about 140 parts per million), due to dissolution and alteration of volcanic ash contained within the river-deposited sediments. Silica-laden ground water percolated through tissue and open spaces in the buried wood. Over time, the silica came out of solution and replaced individual cell walls with microscopic quartz crystals (silicon dioxide), thereby preserving in rock the original tissue structure of the wood. In most logs, however, the cell walls were destroyed and the microscopic structure of the wood was lost as petrification proceeded.

The rainbow of colors in the logs is due to small amounts of mineral oxides in the silica. Various iron compounds impart reds, yellows, and browns; copper oxides produce blue and blue-green colors; manganese and carbon are black. Where cavities in the logs permitted the growth of large crystals, semi-precious gemstones of citrine, amethyst, and rose and smoky quartz can be found.

These petrified wood deposits provide valuable information about the environmental conditions that existed during the Triassic Period and the species of plants that were living at this time.

Many of the logs appear to have been cut into almost measured segments (Figure 32). Some geologists believe that this is the result of earthquake-generated shock waves traveling along the brittle logs when they were still buried in sediment. Note that numerous logs are elliptical in cross-section, indicating that they were deformed by the weight of overlying sediments before becoming petrified. 31

Figure 33. Arroyo south of Rainbow Forest Museum parking lot.

Feature 21

ARROYO

Location: *This feature is located 0.7 mile (1.1 kilometers) south of the Rainbow Forest Museum parking lot, on the east side of the park tour road.*

Discussion: Steep-walled, flat-bottomed desert drainages (Figure 33) are called "arroyos" in the Southwest. Torrential floods shape the channel by undercutting soft banks and scouring the arroyo bottom with gravel.

Before European settlement, many Southwestern drainages contained permanent streams. But by the end of the 19th century these drainages had entrenched their channels and assumed an intermittent flow. Livestock overgrazing, clear-cutting of mountain forests, and changes in seasonal rainfall are some of the theories that attempt to explain this change in stream flow that triggered the accelerated erosion of arroyos.

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