Geology Fieldnotes

- Park Geology
- Park Maps
- Photo Album
- Books, Videos, CDs
- Geologic Research
- Selected Links
- Teacher Feature

Park Highlights

- Visitor Information

USGS Geology

- USGS Information

NRCS Soils

- Soils Information

Mountains

- Geologic Provinces
- Also see Plate Tectonics Parks
- Mountian Parks Tour

Plate Tectonics

- What on Earth is Plate Tectonics?
- USGS Geologic Time on-line
- Scotese Plate Movement Maps
- Plate Tectonics Parks Tour

Volcanoes

- NPS Volcano Knowledge Center

geology fieldnotes

Bandelier
National Monument
New Mexico

✔ Park Geology


Bandelier Naional Monument, New Mexico

Geology of Bandelier National Monument, New Mexico

Bandelier National Monument lies within an area of great crustal tension with a long history of volcanism; consequently, its surficial geology is predominantly volcanic extrusives (Figure 8). Sedimentary rocks are found on the east edge of the San Miguel Mountains and in the bottom of Capulin Canyon. Quaternary gravels (alluvium) occur in lower reaches of the canyons and along the Rio Grande River. East of the Rio Grande are a group of cinder cone vents forming the Cerros del Rio (Figure 5). These cones erupted 3 million years ago filling ancient valleys with basalt.

The Jemez Mountains are the remnants of a large, collapsed volcano that underwent massive eruptions 1.4 and 1.1 million years ago. The 6-mile wide Valles Grande (central crater) was formed by an explosion believed to have been 600 times as powerful as the Mt. Saint Helens eruption (Barry, 1990). Lava and ash from these eruptions covered the older basalt to a depth of 1,000 feet in some places and formed the Pajarito Plateau. The Rio Grande has cut through the tuff and into underlying units to form White Rock Canyon.

Ash fall, pumice, and rhyolite tuff comprise the Pajarito Plateau and its cliff forming units, and together are referred to as the Bandelier Tuff. Most of the Monument's elongated mesas are comprised of this tuff which is over 1000 ft thick in the western part of the Plateau and thins to about 260 feet eastward near the Rio Grande. To the west, the tuffs overlap onto the Tschicoma Formation, which consist of older volcanics that form the Jemez Mountains (Los Alamos National Laboratory, 1995).

In most areas, the Bandelier tuff is underlain by the Puye Formation. The Puye is primarily a large Pliocene alluvial fan complex derived from the erosion of the Tshicoma highlands in the geologic past (Reneau and McDonald, 1996). In the eastern portion of the Pajarito Plateau, near White Rock Canyon, basalt flows from the Cerros del Rio outcrop and underlie the Bandehier Tuff. In lower Frijoles Creek, channel incision is impeded by the Cerros del Rio basalts such that the middle and upper Frijoles are not directly influenced by changes in Rio Grande base level (Reneau et. al., 1996a). Sedimentary rocks are exposed in the lower elevations of White Rock Canyon and in the canyon floors of the western Monument, and include sandstones and siltstones of the Miocene Santa Fe Group (Cannon, 1997).

The only aquifer capable of producing large-scale municipal water is referred to as the regional, or main aquifer, the surface of which rises westward from the Rio Grande within the Santa Fe Group and into the lower portion of the Puye Formation (Figure 7). The presence of numerous basalt flows interbedded in the Santa Fe Group may account for confining conditions noted in portions of this aquifer. Near the top of the Santa Fe Group and underlying the center of the Pajarito Plateau appears to be a late Miocene trough 3 to 4 miles wide and extending 7 to 8 miles from the northeast to the southwest. It is filled with up to 1500 feet of gravels, cobbles, and boulders and produces the area's only high-yield, low-drawdown water supply wells (Los Alamos National Laboratory, 1998b).

Alpine glaciers did not form in the Jemez Mountains (Allen, 1989a). Rather, streams draining from topographic highs dissected the relatively soft tuff and formed the narrow canyons and valleys of the Monument. Flowing water cut up to 1,000 feet in the tuff, and in places, up to 200 feet into the underlying basalt and sedimentary strata (Barry, 1990).

Major faults along the western boundary of the Monument resulted from crustal adjustments associated with the Rio Grande rift (Purtymun and Adams, 1980). The series of normal faults shown in Figures 7 and 8 are part of the Pajarito fault system, a system of over 65 miles of mapped faults. This concentrated fault zone is 0.25 miles wide and has over 410 feet of displacement, with the down-dropped wall to the east (Los Alamos National Laboratory, l998b). Seismic hazard studies indicate the Pajarito fault system could produce maximum earthquakes with a Richter magnitude of about seven. Although large uncertainties are inherent to such studies, Richter magnitude earthquakes greater than or equal to six were estimated to occur once every 4,000 years along the Pajarito fault zone. Other work indicates additional faulting underlying and pre-dating the Bandelier Tuff (U. S. Department of Energy, 1998).

Physiography

Bandelier lies on the southeast flank of the Valles Caldera, the central feature of the Jemez Mountains (Figure 5). The Jemez Mountains are a complex volcanic pile at the intersection of two regional geologic features: the eastern rim of the Colorado Plateau to the west, and the Rio Grande rift to the east (Christensen, 1980). The Sierra de los Valles are the mountains encircling the caldera's rim. Streams draining the caldera form a radial drainage pattern (Figure 6). Drainage patterns at the scale of the Monument include: dendritic drainage pattern in headwaters; parallel drainage pattern across the Pajarito Plateau; and trellis drainage pattern within individual canyons (White and Wells, 1984).

The east flank of the Sierra de los Valles breaks to the gentler slope of the Pajarito Plateau, on which lies the majority of Bandelier (Figure 7). The Plateau is composed of gently sloping volcanic ash and lava flows and is terminated on the east by the deep canyon of the Rio Grande. The Pajarito Plateau has been dissected (in some places completely) by deep canyons. Between the canyons are elongated mesas, the surfaces of which share a common elevation and slope, and are remnants of the once continuous lava-flow. While the Bandelier country looks rugged and broken, most points have moderate slopes of less than 20 percent, with extremely steep slopes found on the near-vertical canyon and valley walls (Allen, l989a). The San Miguel Mountains are an additional area of steep terrain (Figure 2) formed by an uplifted fault block of volcanic and sedimentary rocks lying southeast of the Valles Caldera.

Soils and Erosion

Several distinct soils have developed as a result of interactions between bedrock, topography, and localized climatic conditions. Soil orders found at Bandelier include Entisols, Inceptisols, Alfisols, Mollisols, and Aridisols (Allen, 1989a). General soil surveys have been conducted by Earth Environmental Consultants (1978) for Bandelier, and specific soil surveys have been completed at a watershed erosion monitoring site located on the mesa south of the headquarters (Davenport, 1997). Detailed soil mapping has been completed for Los Alamos County, the adjoining Santa Fe National Forest, and Los Alamos National Laboratory (see references in Mathien et. al., 1993; and Allen, 1989a), but not for Bandelier National Monument.

The two most important properties of soils at the watershed scale are their infiltration rate and erodability. Soils in the area generally have a moderate to high infiltration rate due to the widespread occurrence of pumaceous and other highly porous parent material. Kearl et al. (1986) determined that pumaceous and other highly porous units within the tuffs of the Pajarito Plateau "act like a sponge", and require a quantity of water equal to approximately 1/4 of the rock volume to satisfy capillary forces and permit movement of water. Erosion hazard ranges from moderate to severe depending on soil characteristics, slope, effective ground cover, and overstory vegetation conditions (Cassidy et al., 1996). When soil infiltration thresholds are exceeded, sheet and nh runoff can cause widespread soil erosion augmented by the intensity of the area's thunderstorms and the low specific gravity of pumice (i.e. pumice floats).

Soil loss at Bandehier has been estimated at nearly one inch per decade; an unsustainable rate given soil depth in piñon-juniper woodlands is only one to three feet to bedrock (National Park Service, l995b). Piñon-juniper woodlands cover 40 percent of the Monument and their high erosion rates are apparently due to their degraded state (Allen, 1989a). At least 80 percent of Bandelier's archeological sites within the pinyon-juniper zone are being damaged by accelerated erosion (National Park Service, 1995a).

Re-establishment of herbaceous ground cover in degraded piñon-juniper woodland areas is extremely difficult due to soil movement, soil loss, unreliable precipitation and an inadequate seed source. Major factors limiting restoration include: 1) restrictions on methodology as imposed by cultural, natural and wilderness values; 2) poor site conditions characterized by sparse vegetative cover, organic and nutrient poor soils prone to frost heave and high rates of erosion, depleted soil seed bank and limited seed source; 3) unreliable growing season precipitation or protective winter snow pack; and, 4) heavy utilization of existing herbaceous vegetation by wildlife ranging from ants to elk (National Park Service, 1995a).

Current and abandoned roads and trails can be focal points for accelerated erosion throughout the watersheds. The infiltration capacity of road and trail surfaces is low, and little precipitation is required to generate runoff. This runoff is often channeled down the surface of the road or trail, or within road ditches, at erosive velocities. Recent studies reviewed by Castro and Reckendorf (1995) reveal the density and extent of a basin's drainage are increased because the roads and trails act as ephemeral tributaries, creating a more efficient sediment delivery system.

Surface Water

The entire Monument drains to the Rio Grande and Cochiti Reservoir (Figure 1). The Rio Grande is the master stream in north central New Mexico and south central Colorado, with a drainage area above Otowi of 14,245 mi2. The discharge at Otowi for 94-years of record (1902-1996) ranged from 60 cfs in 1902 to 24,400 cfs in 1920, with the average flow being 1,530 cfs (U.S. Geological Survey, 1998). As mentioned previously, the eastern boundary of the Monument is defined as the westbank of the Rio Grande; therefore, a detailed discussion of the hydrology of the Rio Grande is immaterial. Alteration of natural flows within the Rio Grande do affect Bandelier's ripanan areas, flood plains, and wildlife, and are discussed in later sections.

Five principal canyons dissect Bandehier' s portion of the Pajarito Plateau in a northwest to southeast alignment (Figure 9). These canyons support various lengths of base flow (Table 2) which originate from springs and seeps along the mountain/plateau interface (Table 3). The two most prominent streams, Capulin and Frijoles, have average base flows of approximately 0.5 and 1.0 cfs, respectively. Only Rito de los Frijoles (translation = Little River of the Beans - referred to in the text as Frijoles Creek) maintains perennial flow to the Rio Grande. In addition to the major canyons, six discrete areas on the western wall of White Rock Canyon drain mesa tops and side slopes directly to the Rio Grande (Stephens, 1982).

Christensen (1980) stated the springs and seeps which supply base flow to Monument streams are recharged from perched water in the Tschirege member of the Bandelier Tuff, or within the underlying Tschicoma formation. These perched bodies are found in fractured or jointed rock, or in a pumice bed at the base of the Tschirege. Recharge is thought to occur on the southeast flank of the Sierra de los Vales. Christensen determined perennial flow in stream channels is maintained when the infiltration rate of water into canyon alluvium does not exceed the amount of water supplied by springs and seeps. Evapotranspiration and loss to underlying formations mainly control stream channel infiltration rates.

Purtymun and Adams (1980) noted that stream flow increased in Fnjoles Canyon from the springs to the crossing of the Pajarito fault line (upper crossing of trail). They attributed this increased flow to return flow from thinning alluvium, seepage from colluvium at the base of the canyon walls, and movement of water through brecciated zones associated with the faults. Surface flow decreased from the fault line to the confluence with the Rio Grande. They also reported intermittent reaches of Frijoles Creek during some summers.

Ground Water

Ground water beneath the Pajarito Plateau occurs in three zones: the shallow alluvium of canyons; perched on relatively impermeable strata; and in the main aquifer (Los Alamos National Laboratory, 1995). The main, or regional, aquifer is the only viable water source on the Pajarito Plateau (Rogers et. al., 1996b). Almost everything that is known about the area's ground water comes from investigations conducted by or for Los Alamos National Laboratory. Despite the millions of dollars and years of effort spent on sampling, modeling, and quantifying subsurface waters, these systems remain a conundrum.

Fluvial Geomorphology

The following discussion focuses on the physical condition of Bandelier's streams. Maintenance of natural physical processes is perhaps the most fundamental component of ecosystem management. The community of organisms inhabiting a stream reach has developed over thousands of years, and changes in physical habitat condition and/or distribution will alter these communities, often over large temporal and spatial scales.

Even a casual observer can perceive the annihilation of habitat (i.e. poois, riffles, and runs) within Capulin Creek most obvious physical alteration is entrenchment which results in the stream channel being down-cut and widened so that subsequent flood flows are confined to a vertically walled trench and no longer spread out upon adjacent flood plains. The process of regaining a stable channel type is impeded by the inability of post-fire bank-full discharges to redistribute the available bedload and form a stable channel cross-section and new flood plain. Close scrutiny of geomorphic parameters in Frijoles reveals physical habitat alterations still exist in some of its reaches 20 years after the La Mesa Fire.

Figure 23 shows the response of a portion of the Capulin channel to Dome Fire induced flooding. Incision in the reach adjacent to Capulin Base Camp was as great as 4.7 feet. Maximum incision observed by the author further upstream was estimated to exceed 8 feet (Photo 1 and 2). In other reaches, cobbles and boulders excavated by the floods were re-deposited, burying the preexisting channel. A striking example of channel response to post-fire flows is shown in Figure 24 and Photo 3. The gauge and flume labeled in Figure 24 can be seen near the center of Photo 3. The flume and gauge were installed in 1985 and passed all flow (except one event in 1988 which overtopped the concrete flume but was less than the elevation of the chart recorder) and sediment until 1996. According to Veenhuis (1998) "During the initial inspection on June 13, 1996, this flume was to be re-instrumented to monitor post-fire runoff, but on June 26, 1996 when the first and largest post-fire flood occurred (2,700 cfs), the flume was inundated with large boulders and debris. Thereafter the stream cut a channel on the right side of the flume wall and began down cutting and widening the channel to accommodate the larger flows." The new channel cross-section is also plotted in Figure 24 and can be seen to the right of the old flume in Photo 3.

Another significant aspect of the incision was the removal of the cobble and boulder armor from the streambed and exposure and incision into the underlying friable sandstone. This easily erodible bedrock is visible in Photo 2 as the white strata rising about 6 feet above the level of the stream. Incision into this unit might be providing a modem analog for processes leading to formation of terraces observed in many Pajarito Plateau Canyons (Reneau et a!., 1996b). Because the intensities of both the Dome and La Mesa fires are believed to be unprecedented in the several-hundred-year long fire record on the Pajarito Plateau, it is possible that the resultant fluvial geomorphic effects are also unprecedented. While historic records show little in the way of large-magnitude floods outside of post-fire years, field evidence indicates catastrophic flooding has taken place in pre-historic times (Reneau et al., 1996b).

Stratigraphic relations and radiocarbon dating indicate that mid- to late-Holocene (within the last 5,000 years) sediments in many canyons recorded repeated episodes of alternating channel aggradation or stability and channel incision, with incision being dominant at an average rate of 4 mm/year (Reneau et a!., 1996a). It is notable that there is abundant evidence for significantly larger floods on the floor of Capulin Canyon, including extensive boulder deposits commonly containing boulders much larger than those transported by recent floods (2,700 cfs). Their presence indicates the potential for significantly larger floods (Reneau, 1996). Depending on the interpretation of the base level of the channel bottom at the time of pre-historic flooding, flow reconstruction estimated a flood magnitude between 9,000 and 10,500 cfs. The cause of these earlier flood peaks is unknown (Veenhuis, 1998).

McCord (1996) examined flood-scars on trees and radiocarbon dates from sediments to reconstruct a record of past flood events on Frijoles Creek. The scar dates ranged in age from 1773 to 1985, with most of the scar dates falling in 1977 and 1978. McCord determined there have been at least four floods comparable to the 1978 flood (greater than 3,000 cfs) in the last two centuries, and at least seven floods as large as the flood of 1977 (653 cfs) during that time. Other than the 1977 scar, only the 1773 flood scar matches a major fire year in the local fire scar record. This suggests one of two possibilities: that fire intensity, rather than fire extensiveness, is the major factor leading to post-fire flooding; or, the occurrence of floods in Frijoles Canyon can be independent of fire (McCord, 1996).

Other potential sources of damaging floods are rain on snow or other anomalous precipitation events; landslides; and, debris flows. Cannon et at., (1998) determined debris-flow and landslide susceptibility in Capulin Canyon was low, but the potential for debris-flow was observed in two tributary canyons. Another potential scenario that could result in catastrophic flooding is an outwash event. As an example, the slope above Capulin Creek shown in Photo 2 has been destabilized by channel incision, and could become further destabilized as the friable sandstone is laterally eroded from the toe of this slope. If slumping occurred during a high-water event, the water could be dammed behind the slump and released as an outbreak event when the slump was overtopped, undermined, or circumvented. According to Allen (1989a), landslides in the Jemez

Mountains occur mainly on steep slopes within canyons. In the Frijoles watershed, a landslide occurred below the lower falls in 1942, destroying about 150 yards of trail. At least three other notable rock-slides/landslides have occurred in the Frijoles watershed since that time (Allen, 1 989a).

Source National Park Service, Water Resources Division

References

Allen, C.D., 1989a, Changes in the Landscape of the Jemez Mountains , New Mexico , Ph.D. Dissertation, University of California at Berkeley , Berkeley , California , 346 pp.

Barry. P., 1990, Bandelier National Monument : Southwest Parks and Monuments Association, Tucson , Arizona , 48 pp.

Cannon, S.H., 1997, Evaluation of the Potential for Debris and Hyperconcentrated Flows in Capulin Canyon as a Result of the 1996 Dome Fire, Bandelier National Monument , New Mexico : U. S. Geological Survey Open File Report 97-136, Denver , Colorado , 20 pp.

Cassidy, R., DeGray, M., McWilliams, S., Reidy, M., Sanchez, J., Skinner, R., and Trujillo , 1996, Dome Fire Assessment, Santa Fe National Forest , Jemez Ranger District: Report on File with Jemez Ranger District, Los Alamos , New Mexico .

Castro, J., and Reckendorf, F., 1995, Effects of Sediment on the Aquatic Environment: Natural Resources Conservation Service, Working Paper No. S, Oregon State University , Department of Geosciences, Eugene , Oregon , 43 pp.

Christensen, P.K., 1980, Base Flow Sources in the Upper Reaches of Rito Dc Los Frijoles, Bandelier National Monument, Southwest Region, National Park Service, Santa Fe, New Mexico, 17 pp.

Davenport , D.W., 1997, Soil survey of three watersheds on South Mesa : Unpublished report, on file at Bandelier National Monument , Los Alamos , New Mexico.

Los Alamos National Laboratory, 1995, Environmental Surveillance at Los Alamos during 1993: Report No. LA-12973-ENV, Los Alamos National Laboratory, Los Alamos , New Mexico .

Los Alamos National Laboratory, 1998b, Hydrogeologic Workplan, Los Alamos National Laboratory: Los Alamos National Laboratory, Los Alamos , New Mexico , multiple sections, appendices, and maps.

McCord, V.A.S., 1996, Flood History Reconstruction in Frijoles Canyon Using Flood-Scarred Trees: : *in* Allen, C.D., Technical Editor, Fire Effects in Southwestern Forests, Proceedings of the Second La Mesa Fire Symposium, Los Alamos, New Mexico, USDA Forest Service, General Technical Report RM-GTR-286, p. 179 -195.

National Park Service, 1995a, Resource Management Plan: Bandelier National Monument , Los Alamos , New Mexico , 371 pp. + App.

National Park Service, 1995b, NBS NRPP Proposal, Watershed Restoration in Degraded PinyonJuniper Woodlands: Bandelier National Monument, Mitigation Proposal updated in Resource Management Plan, 18 pp.

Purtymun, W.D., and Adams, H., 1980, Geohydrology of Bandelier National Monument , New Mexico : Los Alamos Scientific Laboratory, Informal Report LA-8461-MS, Los Alamos , New Mexico , 25 pp.

Reneau, S.L., and McDonald, E.V., 1996, Introductory Section: *in* Reneau, S.L., and McDonald, E.V. editors, Landscape History and Processes on the

Pajarito Plateau, Northern New Mexico, Los Alamos National Laboratory Document No. LA-UR-96-3035, Los Alamos , New Mexico , p. 3.

Reneau, S., McDonald, E., Gardner, J., Phillips, B., Broxton, D., Allen, C., and Kelsom, K., 1996a, Day 2, Ponderosa Campground to Rendija Canyon: *in* Landscape History and Processes on the Pajarito Plateau, Northern New Mexico, Reneau, S.L., and McDonald, E.V. editors, Los Alamos National Laboratory Document No. LA-UR-96-3035, Los Alamos , New Mexico , p. 77 - 143.

Rogers, D.B., Stoker, A.K., Mclin, S.G., and Galiaher, B.M., 1996b, Recharge to the Pajarito Plateau Regional Aquifer System: *in* The Jemez Mountains Region, Goff, F., Kues, B.S., Rogers, M.A., McFadden, Les D., and Gardner, J.N., New Mexico Geological Society Forty-Seventh Annual Field Conference, September 25 -28, 1996, p. 74- 77.

Stephens, K., 1982, Water Resources Management Plan, Bandelier National Monument : Bandelier National Monument , Report on File, Los Alamos , New Mexico .

Survey, 1998, <http://water.usgs.gov/>.

U.S. Department of Energy, 1998, Draft Site-Wide Environmental Impact Statement on the , Continued Operation of the Los Alamos National Laboratory, Los Alamos , New Mexico : U. S. Department of Energy, Albuquerque Operations Office, Albuquerque , New Mexico.

Veenhuis, J., 1998, An Analysis of Flood Hazards for 1998 in Capulin Canyon after the Dome Fire, 1996, and Summary of the Second Year of Data Collection: U. S. Geological Survey, Provisional Report to Bandelier National Monument, on file at Monument Headquarters, Los Alamos, New Mexico.

White, W.D., and Wells, S.G., 1984, Geomorphic Effects of La Mesa Fire: *in* La Mesa Fire Symposium, Los Alamos, New Mexico, October 6 and 7, 1981, compiled by Teralene S. Foxx, pp. 73 -90. Los Alamos National Laboratory Report LA-9236-NERP. Los Alamos National Laboratory, Los Alamos , New

Mexico

Park Geology

Beautiful canyon country containing many cliff and open pueblo ruins of late prehistoric period

Several groups settled on the canyon-slashed slopes of the Pajarito Plateau, in a striking setting characterized by tan cliffs, forested mesas, and deep gorges. The story of these people - their adaptation to their environment and their relationships with other groups - is gradually being brought to light through continuing research by archaeologists, adding to our knowledge of prehistoric Southwestern cultures.

The Pajarito Plateau is of interest geologically as well as archaeologically. It is constituted largely of **tuff** (consolidated volcanic ash) and **basaltic lava** ejected thousands of years ago by a great volcano. The **caldera** (saucer-shaped depression) created by the collapsed summit of the volcano is among the world's largest calderas; its rim forms the Jemez Mountains. Through this highland, running water has cut many steep-walled canyons down to the Rio Grande.

The Geologic Story

Bandelier National Monument is located in north-central New Mexico on the eastern side of the geologically young Jemez (HAY--mez) Mountains. Situated on the gently sloping Pajarito (Pah-hah- REE-toe "little bird") Plateau, Bandelier is bordered on the south by the Rio Grande and to the west by the San Miguel Mountains.

The monument's current serenity hides its turbulent past. In order to understand the forces that created the current landscape, let's go back in time and look below the surface.

Beginning about 30 million years ago, tension caused by movement in the earth's mantle created a huge valley, an immense tear that runs across New Mexico from Colorado to northern Mexico. Now known as the Rio Grande Rift, this pulling apart of the earth's crust resulted from separation along two parallel fault zones.

The area near Bandelier is also crossed by the Jemez Lineament. The lineament is a line of young volcanos that represent a weakness in the earth's crust running from east-central Arizona to northeastern New Mexico. These volcanos include Mt. Taylor, the Jemez Mountains, and Capulin Volcano.

THE VOLCANOS

Bandelier is bordered on the west by St. Peter's Dome and Boundary Peak. These peaks, part of the San Miguel Mountains, are the eroded remains of a group of 8 to 13 million year-old volcanoes. These mountains were slowly built by numerous eruptions along the Jemez Lineament.

Across White Rock Canyon, the monument's southern boundary, lies the exposed portion of the Cerros Del Rio (SER-os del REE--oh "Mountains of the River") Volcanic Field. Active one to three million years ago, this volcanic field features cinder cones, basaltic lava flows, and maar cones. Maar cones form when rising magma encounters water. The resulting steam produces violent eruptions which blow out rock fragments that settle into thin layers. This creates a cone characterized by having many thin layers, a low rim, and a large diameter.

One maar cone that formed during these eruptions is visible along the Falls Trail approximately 1.5 miles from monument headquarters. Inside the monum-ent, most of the Cerros Dei Rio volcanics are covered by subse-quent eruptions originating in the Jemez Mountains to the west.

The Jemez Mountains are located at the junction of the western boundary of the Rio Grande Rift and the Jemez Lineament. The Jemez Mountains are best known for two major volcanic eruptions, the first of which occurred more than 1.4 million years ago, and the second, a little over one million years ago. Together these eruptions were 600 times more powerful than the 1980 eruption of Mount St. Helens. Over 100 cubic miles of material was spewed out, covering over 1500 square miles with volcanic ash that was up to 1,000 feet deep in some areas.

THAT'S TUFF

Hot ash from these eruptions settled and through a process of welding, it consolidated to form tuff, the pinkish-orange rock now visible in Frijoles (free-HOH-leez "Beans") Canyon. These welded layers of ash may have taken up to 10 years to cool. The upper and lower surfaces of a flow cool much more quickly than the center. As a result, the center of a sheet is the most densely welded, while the top and bottom are usually non-welded. Welding also decreases away from the vent due to heat loss. Frijoles Canyon is 10 miles from the vent, too far for the tuff to be densely welded.

The hot ash that flowed down the mountain's side filled in existing canyons, creating a series of gently sloping plateaus around the volcano. Some streams continued to follow their old courses and have re-cut their ancient channels. Some canyons were not re-cut, and one of these can be seen on the Falls Trail.

SWISS CHEESE

Across the Pajarito Plateau, the soft top of the tuff sheet was quickly removed by erosion. Streams cut into the tuff, producing the characteristic mesa and canyon topography of the area. Under-cutting of the softer tuff gives the canyons their steep walls. Variations in welding led to the stepped appearance of the cliff walls; each step marks the top of a resistant layer. Vertical columns in these layers are due to contraction and cracking of the cooling tuff. The "Swiss cheese" appearance of canyon walls is due to weathering-out of loosely consolidated pockets of tuff and pumice. These pockets are more frequent at the bottom of flows and between ash flow layers.

TENT ROCKS

Cone shaped rocks, know as "tent rocks," occur in great numbers throughout this area. These eroded remnants of tuff cliffs show the position of canyon walls at a previous time. There are several possible reasons why they form. Some may have been near an Escape route of hot gases, where the additional heat welded the ash more tightly. Some still bear a capstone of harder material, which has slowed their erosion. Others may be protected from erosion by resistant rind created by minerals deposited by ground water.

WILL IT HAPPEN AGAIN?

With a past this violent, the natural question is "will it happen again?" The presence of hot springs and hot dry rock in the area tell us magma chambers are still active. The Rio Grande Rift continues to widen. This evidence suggests the answer is "YES!"

TOP OF PAGE

✔ Park Maps

The General park map handed out at the visitor center is available on the park's map webpage.

For information about topographic maps, geologic maps, and geologic data sets, please see the geologic maps page.

TOP OF PAGE

✔ Photo Album

A geology photo album has not been prepared for this park.

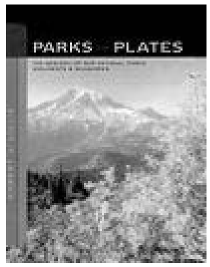
For information on other photo collections featuring National Park geology, please see the Image Sources page.

TOP OF PAGE

✔ Books, Video, CDs

Currently, we do not have a listing for a park-specific geoscience book. The park's geology may be described in regional or state geology texts.

Please visit the Geology Books and Media webpage for additional sources such as text books, theme books, CD ROMs, and technical reports.



Parks and Plates: The Geology of Our National Parks, Monuments & Seashores.
Lillie, Robert J., 2005.
W.W. Norton and Company.
ISBN 0-393-92407-6
9" x 10.75", paperback, 550 pages, full color throughout

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TOP OF PAGE

✔ Geologic Research

For imformation about permits that are required for conducting geologic research activities in National Parks, see the Permits Information page.

The NPS maintains a searchable data base of research needs that have been identified by parks.

A bibliography of geologic references is being prepared for each park through the Geologic Resources Evaluation Program (GRE). Please see the GRE website for more information and contacts.

TOP OF PAGE

✔ Selected Links

Park Highlights

- Visitor Information

NPS Geology Partners

AASG Association of American State Geologists
THE GEOLOGICAL SOCIETY OF AMERICA Geological Society of America
NRCS Natural Resource Conservation Service
USGS U.S. Geological Survey

TOP OF PAGE

✔ Teacher Feature

Currently, we do not have a listing for any park-specific geology education programs or activities.

General information about the park's education and intrepretive programs is available on the park's education webpage.

For resources and information on teaching geology using National Park examples, see the Students & Teachers pages.

National Park Service
Nature & Science

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Search

Search A to Z

Air
Biology
Geology
Natural Sounds
Water

Cave & Karst »
Coastal Geology »
Disturbed Lands »
Geohazards
GeoScientist Jobs »
Inventory & Monitoring »
Minerals »
Paleontology »
Park Geology Tour »
Permits & Planning »
Publications
Site Maps
Nature & Science
Soils
Students & Teachers »
Who We Are »

Explore Geology:

Explore Geology
NPS » Nature & Science » Geology » Tour » Bandelier

Geology Fieldnotes

- Park Geology
- Park Maps
- Photo Album
- Books, Videos, CDs
- Geologic Research
- Selected Links
- Teacher Feature

Park Highlights

- Visitor Information

History

- Geology Documents

USGS Geology

- USGS Information

NRCS Soils

- Soils Information

Mountains

- Geologic Provinces
- Also see Plate Tectonics Parks
- Mountian Parks Tour

Plate Tectonics

- What on Earth is Plate Tectonics?
- USGS Geologic Time on-line

Parks: Nature & Science

- Scotese Plate Movement Maps
- Plate Tectonics Parks Tour

Volcanoes

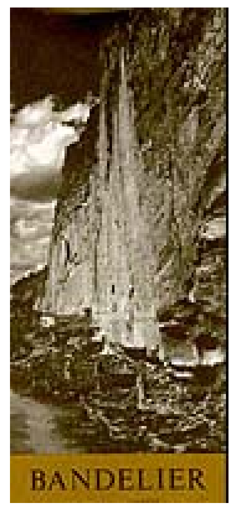
- NPS Volcano Knowledge Center
- U.S. Volcano Observatories
- USGS Photo Glossary of Volcano Terms
- Volcano Parks Tour

geology fieldnotes

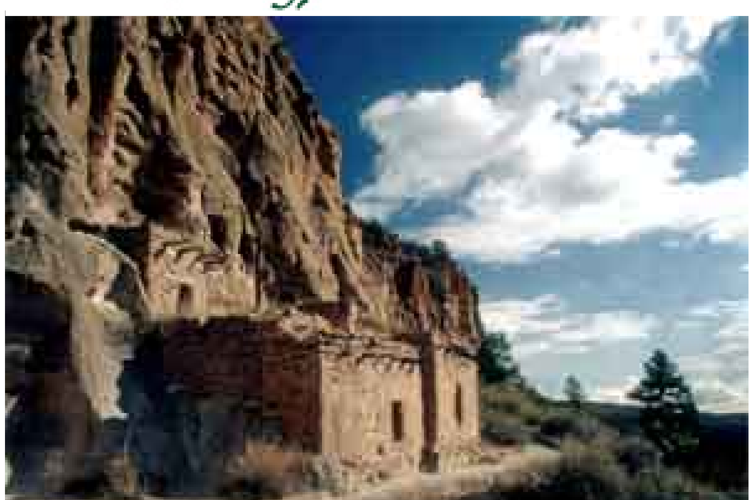
Bandelier

National Monument

New Mexico



✔ Park Geology



Bandelier Naional Monument, New Mexico

Bandelier National Monument lies within an area of great crustal tension with a long history of volcanism; consequently, its surficial geology is predominantly volcanic extrusives (Figure 8). Sedimentary rocks are found on the east edge of the San Miguel Mountains and in the bottom of Capulin Canyon. Quaternary gravels (alluvium) occur in lower reaches of the canyons and along the Rio Grande River. East of the Rio Grande are a group of cinder cone vents forming the Cerros del Rio (Figure 5). These cones erupted 3 million years ago filling ancient valleys with basalt.

The Jemez Mountains are the remnants of a large, collapsed volcano that underwent massive eruptions 1.4 and 1.1 million years ago. The 6-mile wide Valles Grande (central crater) was formed by an explosion believed to have been 600 times as powerful as the Mt. Saint Helens eruption (Barry, 1990). Lava and ash from these eruptions covered the older basalt to a depth of 1,000 feet in some places and formed the Pajarito Plateau. The Rio Grande has cut through the tuff and into underlying units to form White Rock Canyon.

Ash fall, pumice, and rhyolite tuff comprise the Pajarito Plateau and its cliff forming units, and together are referred to as the Bandelier Tuff. Most of the Monument's elongated mesas are comprised of this tuff which is over 1000 ft thick in the western part of the Plateau and thins to about 260 feet eastward near the Rio Grande. To the west, the tuffs overlap onto the Tschicoma Formation, which consist of older volcanics that form the Jemez Mountains (Los Alamos National Laboratory, 1995).

In most areas, the Bandelier tuff is underlain by the Puye Formation. The Puye is primarily a large Pliocene alluvial fan complex derived from the erosion of the Tshicoma highlands in the geologic past (Reneau and McDonald, 1996). In the eastern portion of the Pajarito Plateau, near White Rock Canyon, basalt flows from the Cerros del Rio outcrop and underlie the Bandehier Tuff. In lower Frijoles Creek, channel incision is impeded by the Cerros del Rio basalts such that the middle and upper Frijoles are not directly influenced by changes in Rio Grande base level (Reneau et. al., 1996a). Sedimentary rocks are exposed in the lower elevations of White Rock Canyon and in the canyon floors of the western Monument, and include sandstones and siltstones of the Miocene Santa Fe Group (Cannon, 1997).

The only aquifer capable of producing large-scale municipal water is referred to as the regional, or main aquifer, the surface of which rises westward from the Rio Grande within the Santa Fe Group and into the lower portion of the Puye Formation (Figure 7). The presence of numerous basalt flows interbedded in the Santa Fe Group may account for confining conditions noted in portions of this aquifer. Near the top of the Santa Fe Group and underlying the center of the Pajarito Plateau appears to be a late Miocene trough 3 to 4 miles wide and extending 7 to 8 miles from the northeast to the southwest. It is filled with up to 1500 feet of gravels, cobbles, and boulders and produces the area's only high-yield, low-drawdown water supply wells (Los Alamos National Laboratory, 1998b).

Alpine glaciers did not form in the Jemez Mountains (Allen, 1989a). Rather, streams draining from topographic highs dissected the relatively soft tuff and formed the narrow canyons and valleys of the Monument. Flowing water cut up to 1,000 feet in the tuff, and in places, up to 200 feet into the underlying basalt and sedimentary strata (Barry, 1990).

Major faults along the western boundary of the Monument resulted from crustal adjustments associated with the Rio Grande rift (Purtymun and Adams, 1980). The series of normal faults shown in Figures 7 and 8 are part of the Pajarito fault system, a system of over 65 miles of mapped faults. This concentrated fault zone is 0.25 miles wide and has over 410 feet of displacement, with the down-dropped wall to the east (Los Alamos National Laboratory, l998b). Seismic hazard studies indicate the Pajarito fault system could produce maximum earthquakes with a Richter magnitude of about seven. Although large uncertainties are inherent to such studies, Richter magnitude earthquakes greater than or equal to six were estimated to occur once every 4,000 years along the Pajarito fault zone. Other work indicates additional faulting underlying and pre-dating the Bandelier Tuff (U. S. Department of Energy, 1998).

Physiography

Bandelier lies on the southeast flank of the Valles Caldera, the central feature of the Jemez Mountains (Figure 5). The Jemez Mountains are a complex volcanic pile at the intersection of two regional geologic features:

the eastern rim of the Colorado Plateau to the west, and the Rio Grande rift to the east (Christensen, 1980). The Sierra de los Valles are the mountains encircling the caldera's rim. Streams draining the caldera form a radial drainage pattern (Figure 6). Drainage patterns at the scale of the Monument include: dendritic drainage pattern in headwaters; parallel drainage pattern across the Pajarito Plateau; and trellis drainage pattern within individual canyons (White and Wells, 1984).

The east flank of the Sierra de los Valles breaks to the gentler slope of the Pajarito Plateau, on which lies the majority of Bandelier (Figure 7). The Plateau is composed of gently sloping volcanic ash and lava flows and is terminated on the east by the deep canyon of the Rio Grande. The Pajarito Plateau has been dissected (in some places completely) by deep canyons. Between the canyons are elongated mesas, the surfaces of which share a common elevation and slope, and are remnants of the once continuous lava-flow. While the Bandelier country looks rugged and broken, most points have moderate slopes of less than 20 percent, with extremely steep slopes found on the near-vertical canyon and valley walls (Allen, l989a). The San Miguel Mountains are an additional area of steep terrain (Figure 2) formed by an uplifted fault block of volcanic and sedimentary rocks lying southeast of the Valles Caldera.

Soils and Erosion

Several distinct soils have developed as a result of interactions between bedrock, topography, and localized climatic conditions. Soil orders found at Bandelier include Entisols, Inceptisols, Alfisols, Mollisols, and Aridisols (Allen, 1989a). General soil surveys have been conducted by Earth Environmental Consultants (1978) for Bandelier, and specific soil surveys have been completed at a watershed erosion monitoring site located on the mesa south of the headquarters (Davenport, 1997). Detailed soil mapping has been completed for Los Alamos County, the adjoining Santa Fe National Forest, and Los Alamos National Laboratory (see references in Mathien et. al., 1993; and Allen, 1989a), but not for Bandelier National Monument.

The two most important properties of soils at the watershed scale are their infiltration rate and erodability.

Soils in the area generally have a moderate to high infiltration rate due to the widespread occurrence of pumaceous and other highly porous parent material. Kearl et al. (1986) determined that pumaceous and other highly porous units within the tuffs of the Pajarito Plateau "act like a sponge", and require a quantity of water equal to approximately 1/4 of the rock volume to satisfy capillary forces and permit movement of water. Erosion hazard ranges from moderate to severe depending on soil characteristics, slope, effective ground cover, and overstory vegetation conditions (Cassidy et al., 1996). When soil infiltration thresholds are exceeded, sheet and nh runoff can cause widespread soil erosion augmented by the intensity of the area's thunderstorms and the low specific gravity of pumice (i.e. pumice floats).

Soil loss at Bandehier has been estimated at nearly one inch per decade; an unsustainable rate given soil depth in piñon-juniper woodlands is only one to three feet to bedrock (National Park Service, l995b). Piñon-juniper woodlands cover 40 percent of the Monument and their high erosion rates are apparently due to their degraded state (Allen, 1989a). At least 80 percent of Bandelier's archeological sites within the pinyon-juniper zone are being damaged by accelerated erosion (National Park Service, 1995a).

Re-establishment of herbaceous ground cover in degraded piñon-juniper woodland areas is extremely difficult due to soil movement, soil loss, unreliable precipitation and an inadequate seed source. Major factors limiting restoration include: 1) restrictions on methodology as imposed by cultural, natural and wilderness values; 2) poor site conditions characterized by sparse vegetative cover, organic and nutrient poor soils prone to frost heave and high rates of erosion, depleted soil seed bank and limited seed source; 3) unreliable growing season precipitation or protective winter snow pack; and, 4) heavy utilization of existing herbaceous vegetation by wildlife ranging from ants to elk (National Park Service, 1995a).

Current and abandoned roads and trails can be focal points for accelerated erosion throughout the watersheds. The infiltration capacity of road and trail surfaces is low, and little precipitation is required to generate runoff. This runoff is often channeled down the surface of the road or trail, or within road ditches, at erosive velocities. Recent studies reviewed by Castro and Reckendorf (1995) reveal the density and extent of a basin's drainage are increased because the roads and trails act as ephemeral tributaries, creating a more efficient sediment delivery system.

Surface Water

The entire Monument drains to the Rio Grande and Cochiti Reservoir (Figure 1). The Rio Grande is the master stream in north central New Mexico and south central Colorado, with a drainage area above Otowi of 14,245 mi2. The discharge at Otowi for 94-years of record (1902-1996) ranged from 60 cfs in 1902 to 24,400 cfs in 1920, with the average flow being 1,530 cfs (U.S. Geological Survey, 1998). As mentioned previously, the eastern boundary of the Monument is defined as the westbank of the Rio Grande; therefore, a detailed discussion of the hydrology of the Rio Grande is immaterial. Alteration of natural flows within the Rio Grande do affect Bandelier's ripanan areas, flood plains, and wildlife, and are discussed in later sections.

Five principal canyons dissect Bandehier' s portion of the Pajarito Plateau in a northwest to southeast alignment (Figure 9). These canyons support various lengths of base flow (Table 2) which originate from springs and seeps along the mountain/plateau interface (Table 3). The two most prominent streams, Capulin and Frijoles, have average base flows of approximately 0.5 and 1.0 cfs, respectively. Only Rito de los Frijoles (translation = Little River of the Beans - referred to in the text as Frijoles Creek) maintains perennial flow to the Rio Grande. In addition to the major canyons, six discrete areas on the western wall of White Rock Canyon drain mesa tops and side slopes directly to the Rio Grande (Stephens, 1982).

Christensen (1980) stated the springs and seeps which supply base flow to Monument streams are recharged from perched water in the Tschirege member of the Bandelier Tuff, or within the underlying Tschicoma formation. These perched bodies are found in fractured or jointed rock, or in a pumice bed at the base of the Tschirege. Recharge is thought to occur on the southeast flank of the Sierra de los Vales. Christensen determined perennial flow in stream channels is maintained when the infiltration rate of water into canyon alluvium does not exceed the amount of water supplied by springs and seeps. Evapotranspiration and loss to underlying formations mainly control stream channel infiltration rates.

Purtymun and Adams (1980) noted that stream flow increased in Fnjoles Canyon from the springs to the crossing of the Pajarito fault line (upper crossing of trail). They attributed this increased flow to return flow from thinning alluvium, seepage from colluvium at the base of the canyon walls, and movement of water through brecciated zones associated with the faults. Surface flow decreased from the fault line to the confluence with the Rio Grande. They also reported intermittent reaches of Frijoles Creek during some summers.

Ground Water

Ground water beneath the Pajarito Plateau occurs in three zones: the shallow alluvium of canyons; perched on relatively impermeable strata; and in the main aquifer (Los Alamos National Laboratory, 1995). The main, or regional, aquifer is the only viable water source on the Pajarito Plateau (Rogers et. al., 1996b). Almost everything that is known about the area's ground water comes from investigations conducted by or for Los Alamos National Laboratory. Despite the millions of dollars and years of effort spent on sampling, modeling, and quantifying subsurface waters, these systems remain a conundrum.

Fluvial Geomorphology

The following discussion focuses on the physical condition of Bandelier's streams. Maintenance of natural physical processes is perhaps the most fundamental component of ecosystem management. The community of organisms inhabiting a stream reach has developed over thousands of years, and changes in physical habitat condition and/or distribution will alter these communities, often over large temporal and spatial scales.

Even a casual observer can perceive the annihilation of habitat (i.e. poois, riffles, and runs) within Capulin Creek most obvious physical alteration is entrenchment which results in the stream channel being down-cut and widened so that subsequent flood flows are confined to a vertically walled trench and no longer spread out upon adjacent flood plains. The process of regaining a stable channel type is impeded by the inability of post-fire bank-full discharges to redistribute the available bedload and form a stable channel cross-section and new flood plain. Close scrutiny of geomorphic parameters in Frijoles reveals physical habitat alterations still exist in some of its reaches 20 years after the La Mesa Fire.

Figure 23 shows the response of a portion of the Capulin channel to Dome Fire induced flooding. Incision in the reach adjacent to Capulin Base Camp was as great as 4.7 feet. Maximum incision observed by the author further upstream was estimated to exceed 8 feet (Photo 1 and 2). In other reaches, cobbles and boulders excavated by the floods were re-deposited, burying the preexisting channel. A striking example of channel response to post-fire flows is shown in Figure 24 and Photo 3. The gauge and flume labeled in Figure 24 can be seen near the center of Photo 3. The flume and gauge were installed in 1985 and passed all flow (except one event in 1988 which overtopped the concrete flume but was less than the elevation of the chart recorder) and sediment until 1996. According to Veenhuis (1998) "During the initial inspection on June 13, 1996, this flume was to be re-instrumented to monitor post-fire runoff, but on June 26, 1996 when the first and largest post-fire flood occurred (2,700 cfs), the flume was inundated with large boulders and debris. Thereafter the stream cut a channel on the right side of the flume wall and began down cutting and widening the channel to accommodate the larger flows." The new channel cross-section is also plotted in Figure 24 and can be seen to the right of the old flume in Photo 3.

Another significant aspect of the incision was the removal of the cobble and boulder armor from the streambed and exposure and incision into the underlying friable sandstone. This easily erodible bedrock is visible in Photo 2 as the white strata rising about 6 feet above the level of the stream. Incision into this unit might be providing a modem analog for processes leading to formation of terraces observed in many Pajarito Plateau Canyons (Reneau et a!., 1996b). Because the intensities of both the Dome and La Mesa fires are believed to be unprecedented in the several-hundred-year long fire record on the Pajarito Plateau, it is possible that the resultant fluvial geomorphic effects are also unprecedented. While historic records show little in the way of large-magnitude floods outside of post-fire years, field evidence indicates catastrophic flooding has taken place in pre-historic times (Reneau et al., 1996b).

Stratigraphic relations and radiocarbon dating indicate that mid- to late-Holocene (within the last 5,000 years) sediments in many canyons recorded repeated episodes of alternating channel aggradation or stability and channel incision, with incision being dominant at an average rate of 4 mm/year (Reneau et a!., 1996a). It is notable that there is abundant evidence for significantly larger floods on the floor of Capulin Canyon, including extensive boulder deposits commonly containing boulders much larger than those transported by recent floods (2,700 cfs). Their presence indicates the potential for significantly larger floods (Reneau, 1996). Depending on the interpretation of the base level of the channel bottom at the time of pre-historic flooding, flow reconstruction estimated a flood magnitude between 9,000 and 10,500 cfs. The cause of these earlier flood peaks is unknown (Veenhuis, 1998).

McCord (1996) examined flood-scars on trees and radiocarbon dates from sediments to reconstruct a record of past flood events on Frijoles Creek. The scar dates ranged in age from 1773 to 1985, with most of the scar dates falling in 1977 and 1978. McCord determined there have been at least four floods comparable to the 1978 flood (greater than 3,000 cfs) in the last two centuries, and at least seven floods as large as the flood of 1977 (653 cfs) during that time. Other than the 1977 scar, only the 1773 flood scar matches a major fire year in the local fire scar record. This suggests one of two possibilities: that fire intensity, rather than fire extensiveness, is the major factor leading to post-fire flooding; or, the occurrence of floods in Frijoles Canyon can be independent of fire (McCord, 1996).

Other potential sources of damaging floods are rain on snow or other anomalous precipitation events; landslides; and, debris flows. Cannon et at., (1998) determined debris-flow and landslide susceptibility in Capulin Canyon was low, but the potential for debris-flow was observed in two tributary canyons. Another potential scenario that could result in catastrophic flooding is an outwash event. As an example, the slope above Capulin Creek shown in Photo 2 has been destabilized by channel incision, and could become further destabilized as the friable sandstone is laterally eroded from the toe of this slope. If slumping occurred during a high-water event, the water could be dammed behind the slump and released as an outbreak event when the slump was overtopped, undermined, or circumvented. According to Allen (1989a), landslides in the Jemez

Mountains occur mainly on steep slopes within canyons. In the Frijoles watershed, a landslide occurred below the lower falls in 1942, destroying about 150 yards of trail. At least three other notable rock-slides/landslides have occurred in the Frijoles watershed since that time (Allen, 1 989a).

Source National Park Service, Water Resources Division

References

Allen, C.D., 1989a, Changes in the Landscape of the Jemez Mountains , New Mexico , Ph.D. Dissertation, University of California at Berkeley , Berkeley , California , 346 pp.

Barry. P., 1990, Bandelier National Monument : Southwest Parks and Monuments Association, Tucson , Arizona , 48 pp.

Cannon, S.H., 1997, Evaluation of the Potential for Debris and Hyperconcentrated Flows in Capulin Canyon as a Result of the 1996 Dome Fire, Bandelier National Monument , New Mexico : U. S. Geological Survey Open File Report 97-136, Denver , Colorado , 20 pp.

Cassidy, R., DeGray, M., McWilliams, S., Reidy, M., Sanchez, J., Skinner, R., and Trujillo , 1996, Dome Fire Assessment, Santa Fe National Forest , Jemez Ranger District: Report on File with Jemez Ranger District, Los Alamos , New Mexico .

Castro, J., and Reckendorf, F., 1995, Effects of Sediment on the Aquatic Environment: Natural Resources Conservation Service, Working Paper No. S, Oregon State University , Department of Geosciences, Eugene , Oregon , 43 pp.

Christensen, P.K., 1980, Base Flow Sources in the Upper

Reaches of Rito Dc Los Frijoles, Bandelier National Monument, Southwest Region, National Park Service, Santa Fe, New Mexico, 17 pp.

Davenport , D.W., 1997, Soil survey of three watersheds on South Mesa : Unpublished report, on file at Bandelier National Monument , Los Alamos , New Mexico.

Los Alamos National Laboratory, 1995, Environmental Surveillance at Los Alamos during 1993: Report No. LA-12973-ENV, Los Alamos National Laboratory, Los Alamos , New Mexico .

Los Alamos National Laboratory, 1998b, Hydrogeologic Workplan, Los Alamos National Laboratory: Los Alamos National Laboratory, Los Alamos , New Mexico , multiple sections, appendices, and maps.

McCord, V.A.S., 1996, Flood History Reconstruction in Frijoles Canyon Using Flood-Scarred Trees: : *in* Allen, C. D., Technical Editor, Fire Effects in Southwestern Forests, Proceedings of the Second La Mesa Fire Symposium, Los Alamos, New Mexico, USDA Forest Service, General Technical Report RM-GTR-286, p. 179 -195.

National Park Service, 1995a, Resource Management Plan: Bandelier National Monument , Los Alamos , New Mexico , 371 pp. + App.

National Park Service, 1995b, NBS NRPP Proposal, Watershed Restoration in Degraded PinyonJuniper Woodlands: Bandelier National Monument, Mitigation Proposal updated in Resource Management Plan, 18 pp.

Purtymun, W.D., and Adams, H., 1980, Geohydrology of Bandelier National Monument , New Mexico : Los Alamos Scientific Laboratory, Informal Report LA-8461-MS, Los Alamos , New Mexico , 25 pp.

Reneau, S.L., and McDonald, E.V., 1996, Introductory Section: *in* Reneau, S.L., and McDonald, E.V. editors, Landscape History and Processes on the Pajarito Plateau, Northern New Mexico, Los Alamos National Laboratory Document No. LA-UR-96-3035, Los Alamos , New Mexico , p. 3.

Reneau, S., McDonald, E., Gardner, J., Phillips, B., Broxton, D., Allen, C., and Kelsom, K., 1996a, Day 2, Ponderosa Campground to Rendija Canyon: *in* Landscape History and Processes on the Pajarito Plateau, Northern New Mexico, Reneau, S.L., and McDonald, E.V. editors, Los Alamos National Laboratory Document No. LA-UR-96-3035, Los Alamos , New Mexico , p. 77 -143.

Rogers, D.B., Stoker, A.K., Mclin, S.G., and Galiaher, B. M., 1996b, Recharge to the Pajarito Plateau Regional Aquifer System: *in* The Jemez Mountains Region, Goff, F., Kues, B.S., Rogers, M.A., McFadden, Les D., and Gardner, J.N., New Mexico Geological Society Forty-Seventh Annual Field Conference, September 25 -28, 1996, p. 74- 77.

Stephens, K., 1982, Water Resources Management Plan, Bandelier National Monument : Bandelier National Monument , Report on File, Los Alamos , New Mexico .

Survey, 1998, <http://water.usgs.gov/>.

U.S. Department of Energy, 1998, Draft Site-Wide Environmental Impact Statement on the , Continued Operation of the Los Alamos National Laboratory, Los Alamos , New Mexico : U. S. Department of Energy, Albuquerque Operations Office, Albuquerque , New Mexico.

Veenhuis, J., 1998, An Analysis of Flood Hazards for 1998 in Capulin Canyon after the Dome Fire, 1996, and Summary of the Second Year of Data Collection: U. S. Geological Survey, Provisional Report to Bandelier National Monument, on file at Monument Headquarters, Los Alamos, New Mexico.

White, W.D., and Wells, S.G., 1984, Geomorphic Effects of La Mesa Fire: *in* La Mesa Fire Symposium, Los Alamos, New Mexico, October 6 and 7, 1981, compiled by Teralene S. Foxx, pp. 73 -90. Los Alamos National Laboratory Report LA-9236-NERP. Los Alamos National Laboratory, Los Alamos , New Mexico

Park Geology

Beautiful canyon country containing many cliff and open pueblo ruins of late prehistoric period

Several groups settled on the canyon-slashed slopes of the Pajarito Plateau, in a striking setting characterized by tan cliffs, forested mesas, and deep gorges. The story of these people - their adaptation to their environment and their relationships with other groups - is gradually being brought to light through continuing research by archaeologists, adding to our knowledge of prehistoric Southwestern cultures.

The Pajarito Plateau is of interest geologically as well as archaeologically. It is constituted largely of **tuff** (consolidated volcanic ash) and **basaltic lava** ejected thousands of years ago by a great volcano. The **caldera** (saucer-shaped depression) created by the collapsed summit of the volcano is among the world's largest calderas; its rim forms the Jemez Mountains. Through this highland, running water has cut many steep-walled canyons down to the Rio Grande.

The Geologic Story

Bandelier National Monument is located in north-central New Mexico on the eastern side of the geologically young Jemez (HAY--mez) Mountains. Situated on the gently sloping Pajarito (Pah-hah- REE-toe "little bird") Plateau, Bandelier is bordered on the south by the Rio Grande and to the west by the San Miguel Mountains.

The monument's current serenity hides its turbulent past. In order to understand the forces that created the current landscape, let's go back in time and look below the surface.

Beginning about 30 million years ago, tension caused by movement in the earth's mantle created a huge valley, an immense tear that runs across New Mexico from Colorado to northern Mexico. Now known as the Rio Grande Rift, this pulling apart of the earth's crust resulted from separation along two parallel fault zones.

The area near Bandelier is also crossed by the Jemez Lineament. The lineament is a line of young volcanos that represent a weakness in the earth's crust running from east-central Arizona to northeastern New Mexico. These volcanos include Mt. Taylor, the Jemez Mountains, and Capulin Volcano.

THE VOLCANOES

Bandelier is bordered on the west by St. Peter's Dome and Boundary Peak. These peaks, part of the San Miguel Mountains, are the eroded remains of a group of 8 to 13 million year-old volcanoes. These mountains were slowly built by numerous eruptions along the Jemez Lineament.

Across White Rock Canyon, the monument's southern boundary, lies the exposed portion of the Cerros Del Rio (SER-os del REE--oh "Mountains of the River") Volcanic Field. Active one to three million years ago, this volcanic field features cinder cones, basaltic lava flows, and maar cones. Maar cones form when rising magma encounters water. The resulting steam produces violent eruptions which blow out rock fragments that settle into thin layers. This creates a cone characterized by having many thin layers, a low rim, and a large diameter.

One maar cone that formed during these eruptions is visible along the Falls Trail approximately 1.5 miles from monument headquarters. Inside the monum-ent, most of the Cerros Dei Rio volcanics are covered by subse-quent eruptions originating in the Jemez Mountains to the west.

The Jemez Mountains are located at the junction of the western boundary of the Rio Grande Rift and the Jemez Lineament. The Jemez Mountains are best known for two major volcanic eruptions, the first of which occurred more than 1.4 million years ago, and the second, a little over one million years ago. Together these eruptions were 600 times more powerful than the 1980 eruption of Mount St. Helens. Over 100 cubic miles of material was spewed out, covering over 1500 square miles with volcanic ash that was up to 1,000 feet deep in some areas.

THAT'S TUFF

Hot ash from these eruptions settled and through a process of welding, it consolidated to form tuff, the pinkish-orange rock now visible in Frijoles (free-HOH-leez "Beans") Canyon. These welded layers of ash may have taken up to 10 years to cool. The upper and lower surfaces of a flow cool much more quickly than the center. As a result, the center of a sheet is the most densely welded, while the top and bottom are usually non-welded. Welding also decreases away from the vent due to heat loss. Frijoles Canyon is 10 miles from the vent, too far for the tuff to be densely welded.

The hot ash that flowed down the mountain's side filled in existing canyons, creating a series of gently sloping plateaus around the volcano. Some streams continued to follow their old courses and have re-cut their ancient channels. Some canyons were not re-cut, and one of these can be seen on the Falls Trail.

SWISS CHEESE
Across the Pajarito Plateau, the soft top of the tuff sheet was quickly removed by erosion. Streams cut into the tuff, producing the characteristic mesa and canyon topography of the area. Under-cutting of the softer tuff gives the canyons their steep walls. Variations in welding led to the stepped appearance of the cliff walls; each step marks the top of a resistant layer. Vertical columns in these layers are due to contraction and cracking of the cooling tuff. The "Swiss cheese" appearance of canyon walls is due to weathering-out of loosely consolidated pockets of tuff and pumice. These pockets are more frequent at the bottom of flows and between ash flow layers.

TENT ROCKS
Cone shaped rocks, know as "tent rocks," occur in great numbers throughout this area. These eroded remnants of tuff cliffs show the position of canyon walls at a previous time. There are several possible reasons why they form. Some may have been near an Escape route of hot gases, where the additional heat welded the ash more tightly. Some still bear a capstone of harder material, which has slowed their erosion. Others may be protected from erosion by resistant rind created by minerals deposited by ground water.

WILL IT HAPPEN AGAIN?
With a past this violent, the natural question is "will it happen again?" The presence of hot springs and hot dry rock in the area tell us magma chambers are still active. The Rio Grande Rift continues to widen. This evidence suggests the answer is "YES!"

TOP OF PAGE

✔ Park Maps

The General park map handed out at the visitor center is available on the park's map webpage.

For information about topographic maps, geologic maps, and geologic data sets, please see the geologic maps page.

TOP OF PAGE

✔ Photo Album

A geology photo album has not been prepared for this park.

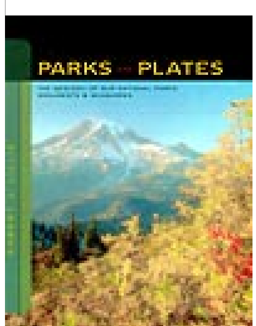
For information on other photo collections featuring National Park geology, please see the Image Sources page.

TOP OF PAGE

✔ Books, Video, CDs

Currently, we do not have a listing for a park-specific geoscience book. The park's geology may be described in regional or state geology texts.

Please visit the Geology Books and Media webpage for additional sources such as text books, theme books, CD ROMs, and technical reports.



Parks and Plates: The Geology of Our National Parks, Monuments & Seashores.
Lillie, Robert J., 2005.
W.W. Norton and Company.
ISBN 0-393-92407-6
9" x 10.75", paperback, 550 pages, full color throughout

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TOP OF PAGE

Geologic Research

For imformation about permits that are required for conducting geologic research activities in National Parks, see the Permits Information page.

The NPS maintains a searchable data base of research needs that have been identified by parks.

A bibliography of geologic references is being prepared for each park through the Geologic Resources Evaluation Program (GRE). Please see the GRE website for more information and contacts.

TOP OF PAGE

Selected Links

Park Highlights

- Visitor Information

NPS Geology Partners

AASG Association of American State Geologists

Geological Society of America

Natural Resource Conservation Service

U.S. Geological Survey

TOP OF PAGE

Teacher Feature

Currently, we do not have a listing for any park-specific geology education programs or activities.

General information about the park's education and intrepretive programs is available on the park's education webpage.

For resources and information on teaching geology using National Park examples, see the Students & Teachers pages.

TOP OF PAGE