National Park Service
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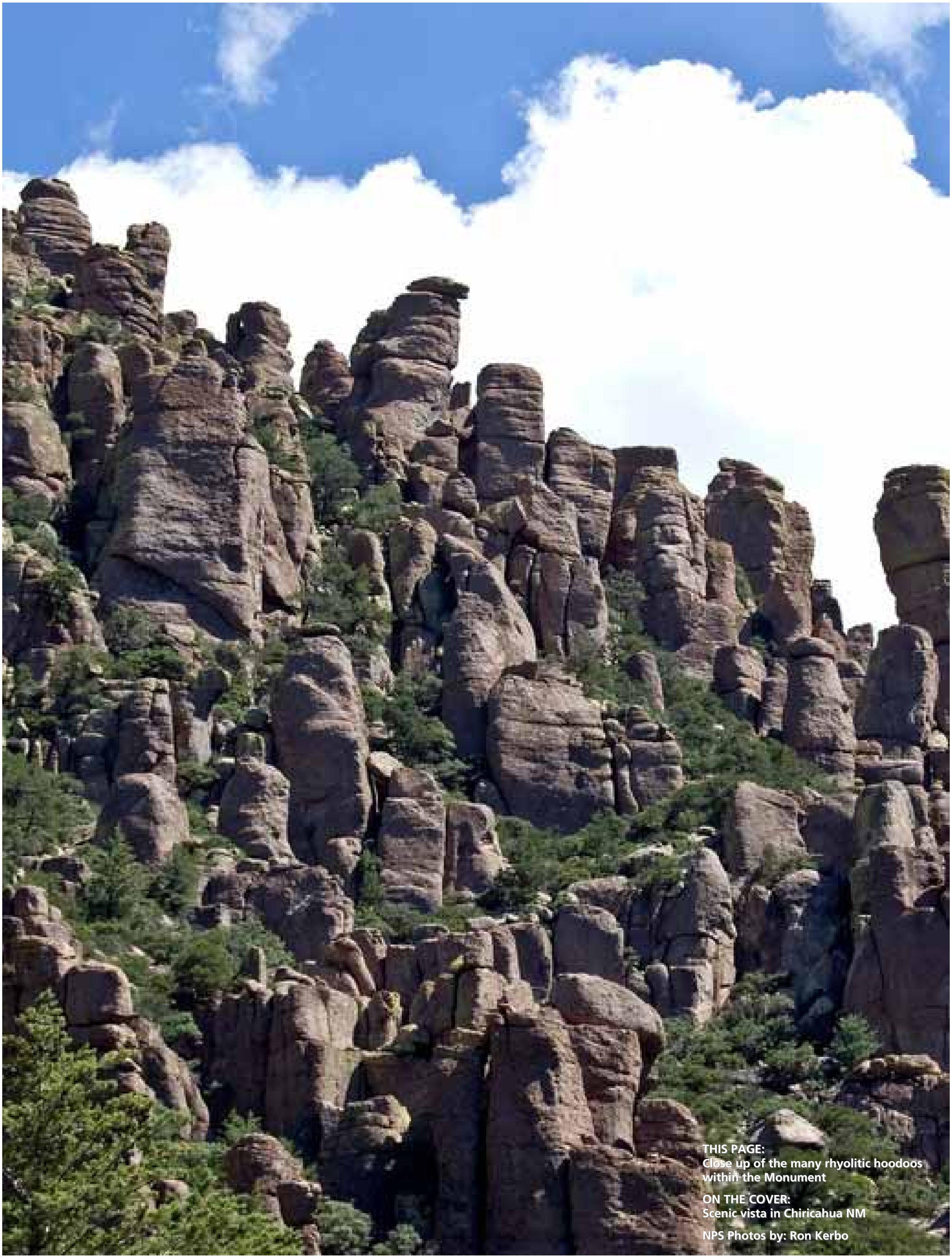
Natural Resource Program Center

Chiricahua National Monument

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2009/081



THIS PAGE:
Close up of the many rhyolitic hoodoos within the Monument

ON THE COVER:
Scenic vista in Chiricahua NM

NPS Photos by: Ron Kerbo

Chiricahua National Monument

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Natural Resource Program Center
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June 2009

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Please cite this publication as:

Graham, J. 2009. Chiricahua National Monument Geologic Resources Inventory Report. Natural Resource Report NPS/NRPC/GRD/NRR—2009/081. National Park Service, Denver, Colorado.

NPS D-94, June 2009

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Executive Summary

This report accompanies the digital geologic map for Chiricahua National Monument in Arizona, which the Geologic Resources Division produced in collaboration with its partners. It contains information relevant to resource management and scientific research. This document incorporates preexisting geologic information and does not include new data or additional fieldwork.

The geologic features preserved in Chiricahua National Monument are spectacular examples of physical and chemical weathering processes. The Monument was established in 1924 to protect its distinctive pinnacles, columns, spires, and balanced rocks that seem to defy gravity. The remarkable rock spires, known as 'hoodoos,' are erosional features formed in the Rhyolite Canyon Tuff. The volcanic eruption that produced the abundant Rhyolite Canyon Tuff ejected more than a thousand times the amount of material than was ejected during the May 1980 Mount St. Helens eruption in Washington State. The explosion and collapse of the magma chamber formed the giant Turkey Creek caldera, a depression 19 km (12 mi) across and 1,500 m (5,000 ft) deep. In addition to the unusual erosional features, Chiricahua National Monument preserves and protects geologically significant remnants of the Turkey Creek caldera.

Located in southeastern Arizona, the Chiricahua Mountain Range is an inactive volcanic range 32 km (20 mi) wide and 64 km (40 mi) long. It lies within the Basin and Range physiographic province of mountain ranges separated by fault-bounded, sediment-filled basins. Although Paleozoic and Mesozoic sedimentary rocks are exposed in Chiricahua National Monument, Cenozoic volcanic rocks dominate the landscape. These volcanic rocks, weathered into a maze of pinnacles and passageways, provided an impenetrable stronghold for the Chiricahua Band of the Apache Indian Nation during the nineteenth century.

The most significant geologic issues facing resource management at Chiricahua National Monument include flooding, mass wasting, and information for interpretation. The Visitor Center and the Bonita Creek Campground are located at the head of Faraway Meadow, a narrow canyon surrounded by steep slopes. They lie within the floodplain and are susceptible to flooding. The flash flood risk is monitored on a day-by-day basis and the campground is closed periodically in response to predicted weather conditions.

Mass wasting occurs along the Sugarloaf Mountain Trail. An easily eroded volcanic ash layer undercuts a cliff of densely welded tuff, causing potential collapse of the overlying rock. Slumps and landslides may present safety and maintenance issues for the park.

In the past, interpretation focused almost exclusively on the pinnacles, hoodoos, and unusual geologic formations in the Monument, ignoring the dynamic history of the Turkey Creek caldera. This report provides information that may be used to help develop programs and exhibits that better explain the whole geologic story at Chiricahua National Monument. The interpretive displays at Sugarloaf Mountain, for example, could be revised to more accurately explain the exceptional volcanic eruption that produced the Rhyolite Canyon Tuff.

Additional geologic issues include acid mine drainage from the King of Lead Mine, illegal mineral and specimen collecting, and soil and groundwater contamination from an underground storage tank that leaked in 1994. Stability of the pinnacles and balanced rocks is not an issue for management. Although the slender pinnacles appear ready to collapse, studies show that the hoodoos and spires are remarkably stable.

Features associated with volcanic activity, regional tectonic deformation, and weathering processes are displayed in Chiricahua National Monument. Weathering and erosion processes have created slot canyons, slumps, a natural bridge, solution pans, rock varnish, tafoni, spherulites, and inverted topography in addition to the Monument's distinctive pinnacles, spires, balanced rocks, and columns. Volcanic features, primarily related to the Turkey Creek caldera, include the caldera, welded tuff of the Rhyolite Canyon Tuff, fiamme, fumarole pipes, moat deposits, surge deposits, and igneous dikes. The volcanic features were displaced and fractured by steep normal faults that resulted from crustal extension during the past 20 million years.

While much of the geologic history of the Precambrian, Paleozoic and Mesozoic eras is absent in Chiricahua National Monument, the rocks that are exposed record a dynamic Cenozoic history of volcanic eruptions. Remnants of the Turkey Creek caldera provide evidence for three successive large volcanic eruptions beginning about 26.9 million years ago that blasted more than 400 km^3 (100 mi^3) of magma from a buried magma chamber and covered a region of at least 3,100 km^2 (1,200 mi^2) with pyroclastic debris. Volcanic ash, glowing gas cloud deposits, steam vents, lava flows, and high-velocity surge deposits can be found in Chiricahua National Monument. Hot glass shards fused together to form the welded tuff of the Rhyolite Canyon Tuff, a deposit at least 490 m (1,600 ft) thick. Upon cooling, vertical joints formed in the erosion-resistant Rhyolite Canyon Tuff and provided conduits for water. Continual freezing and thawing expanded the joints and dislodged pieces of the rock. Over time, chemical and physical weathering processes acted together to carve the pinnacles, spires, and columns for which the Monument is known.

Introduction

The following section briefly describes the National Park Service Geologic Resources Inventory and the regional geologic setting of Chiricahua National Monument.

Purpose of the Geologic Resources Inventory

The Geologic Resources Inventory (GRI) is one of 12 inventories funded under the National Park Service (NPS) Natural Resource Challenge designed to enhance baseline information available to park managers. The program carries out the geologic component of the inventory effort. The Geologic Resources Division of the Natural Resource Program Center administers this program. The GRI team relies heavily on partnerships with the U.S. Geological Survey, Colorado State University, state surveys, and others in developing GRI products.

The goal of the GRI is to increase understanding of the geologic processes at work in parks and provide sound geologic information for use in park decision making. Sound park stewardship relies on understanding natural resources and their role in the ecosystem. Geology is the foundation of park ecosystems. The compilation and use of natural resource information by park managers is called for in section 204 of the National Parks Omnibus Management Act of 1998 and in NPS-75, Natural Resources Inventory and Monitoring Guideline.

To realize this goal, the GRI team is systematically conducting a scoping meeting for each of the identified 270 natural area parks and providing a park-specific digital geologic map and geologic report. These products support the stewardship of park resources and are designed for nongeoscientists. Scoping meetings bring together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes.

The GRI mapping team converts the geologic maps identified for park use at the scoping meeting into digital geologic data in accordance with their innovative Geographic Information Systems (GIS) Data Model. These digital data sets bring an exciting interactive dimension to traditional paper maps by providing geologic data for use in park GIS and facilitating the incorporation of geologic considerations into a wide range of resource management applications. The newest maps come complete with interactive help files. This geologic report aids in the use of the map and provides park managers with an overview of park geology and geologic resource management issues.

For additional information regarding the content of this report and current GRI contact information please refer to the Geologic Resources Inventory Web site (http://www.nature.nps.gov/geology/inventory/).

Regional and Geologic Setting

Chiricahua National Monument was established in 1924 to protect and preserve the exceptional geologic features found in the Monument including pinnacles, columns, spires and balanced rocks (fig. 1). While these features are spectacular examples of physical and chemical weathering processes, the monument also preserves remnants of the 19-km- (12-mi) diameter Turkey Creek caldera that formed about 26.9 million years ago. Eruption of the associated volcano produced a volume of volcanic material a thousand times larger than that produced by the 1980 eruption of Mount St. Helens and five to ten times the volume produced by the great volcanic explosion of Krakatoa in 1883. The amount of molten material erupted from a shallow reservoir in the crust was so large that the ground surface collapsed into the resulting void, thereby creating the Turkey Creek caldera (Pallister et al. 1997).

The Monument's 4,850.22 hectares (11,984.73 acres) are in the Chiricahua Mountains of extreme southeastern Arizona (fig. 2). Chiricahua National Monument is a biological crossroads where four different ecological regions meet. The convergence of the Sonoran desert, Chihuahuan desert, the Rocky Mountain biome, and the Sierra Madre biome makes this region unusually diverse in both flora and fauna. In 1976, 86% of the Monument (4,164 hectares; 10,290 acres) received Wilderness designation from Congress.

The Chiricahua Mountains, a range of inactive volcanoes 32 km (20 mi) wide by 64 km (40 mi) long, are part of the Mexican Highland section of the Basin and Range province. Although part of a desert landscape, the ranges and basins are relatively higher than those to the west in the Sonoran Desert Section of the Basin and Range province. Peaks as high as 2,986 m (9,796 ft) receive both snow and rain sufficient to support a dense growth of vegetation, especially in shaded canyons (Kiver and Harris 1999).

The oldest rocks in the Monument are late Paleozoic, Permian limestones about 280 million years old that are exposed in fault blocks in the northeast corner of the Monument (fig. 3). Volcanic ash and welded tuff deposits record a series of explosive eruptions that shook the area during the Tertiary and buried Paleozoic and Mesozoic sedimentary rocks. Although rocks of the same age exist elsewhere in Arizona, the volcanic rocks that resulted from eruption of the Turkey Creek volcano are found only in the Chiricahua Mountains and immediately adjacent areas.

The complex geologic history of southeastern Arizona includes not only volcanic events but also episodes of tectonic compression and extension. Convergence of lithospheric plates during the Late Cretaceous to middle-Tertiary cuased the regional folding and thrust faulting found in the Chiricahua and Dos Cabezas Mountains to the north. Crustal extension during the Cenozoic produced normal faults, which border the structural basins as well as blocks within the mountain ranges, and gave rise to today's basin and range topography.

Weathering and other erosion processes over the past two million years, especially during the wetter Pleistocene Ice Ages, carved the volcanic deposits into the maze of columns and passageways that characterize Chiricahua National Monument. Chemical and physical weathering processes continue to shape the landscape.

Park History

The Chiricahua Mountains were part of the traditional homeland of the Chiricahua Band of the Apache Indian Nation. The Apaches called this part of the Chiricahua Mountains "The Land of Standing-Up Rocks." During the conflicts of the nineteenth century between the Apaches and the U.S. military, the labyrinth of rock pillars and passageways provided an essentially impenetrable stronghold for the skillful and effective Apache warriors Cochise and Geronimo (Kiver and Harris 1999; http://www. nps.gov/chir, accessed March 2007).

Upon surrendering at Fort Bowie in 1886, Geronimo and the other Apaches were exiled to Florida. Along the way, one of his lieutenants, "Bigfoot" Massai, leapt from the train and returned to the Chiricahua Mountains where he eluded his pursuers for more than 20 years in the maze of pinnacles in what is now Chiricahua National Monument. He was never caught. Massai Canyon and Massai Point derive their names from him.

After Geronimo surrendered, Swedish immigrants Neil and Emma Erickson settled in Bonita Canyon and operated the Faraway Ranch, which is now on Monument property. Their closest neighbors were the Stafford family, whose cabin can be found farther up the canyon. Rumor has it that Bigfoot Massai stole a horse from the Staffords, rode to Massai Point, and was never seen again.

The Erickson's daughter and her husband turned Faraway Ranch into a guest ("dude") ranch and worked toward making the area into a national park. In 1924, President Calvin Coolidge designated Chiricahua National Monument. In 1976, Congress designated 86% of the monument as Wilderness. When the Faraway Ranch property was sold to the National Park Service in 1979, it became a historic district within the Monument.

Figure 1. Pinnacles, columns, and balanced rocks in the Rhyolite Canyon Tuff in Chiricahua National Monument, Arizona. Photograph by John Graham (Colorado State University), April 5, 2006.

Figure 2. Location map for Chiricahua National Monument. Wilderness areas extend north and south of Bonita Canyon Road. The Visitor Center and Bonita Canyon campground are located at the mouth of Rhyolite Canyon and Bonita Canyon, respectively. NPS Graphic.

Era	Period	Formation/Unit	General Lithology
CENOZOIC	Quaternary	Alluvium, colluvium	Various subdivisions of sand, silt, and gravel
	Tertiary	Conglomerate	Poorly sorted fine- and coarse-grained sediments
		Rocks of the Turkey Creek Caldera	Moat deposits: mostly rhyolite lava flows Dacite of Sugarloaf Mountain: dacite lava flow Rhyolite Canyon Tuff: welded-ash-flow deposit
		Jesse James Canyon Tuff	Welded ash-flow deposit
		Faraway Ranch Formation	Assemblage of rhyolite, dacite, and andesite lavas & pyroclastic rocks
		Sedimentary rocks of Bonita Park	Red-weathering clay-rich sandstone, siltstone, and claystone
		Welded tuff of Joe Glen Ranch	Welded rhyolite ash-flow deposit
		Volcanic flows and dikes	Andesite and dacite lava flows; rhyolite dikes
		Regional Unconformity	
MESOZOIC	Cretaceous	Bisbee Group Mural Limestone	Tan, thin-bedded silty limestone
		Bisbee Group Morita Formation	Siltstone, sandstone, shale, conglomerate
		Glance Conglomerate	Cobble, pebble, & boulder conglomerate
		Volcaniclastic and volcanic rocks	Metamorphosed greywacke, andesite, and basalt
		Regional Unconformity	
PALEOZOIC	Permian	Concha Limestone	Dark-gray, cherty, fossiliferous limestone
		Scherrer Formation	Light-gray fine-grained sandstone and quartzite
		Epitaph Dolomite and Colina Formation	Dark-gray, coarse-grained slightly cherty limestone and light-gray, fine-grained dolomite
		Earp Formation	Pale-red siltstone and argillaceous limestone
		Horquilla Limestone	Upper member: limestone and siltstone

Figure 3. General stratigraphic column for Chiricahua National Monument. Regional unconformities represent major gaps in time within the geologic record at the Monument.

Geologic Issues

The National Park Service held a Geologic Resources Inventory scoping session for Chiricahua National Monument on April 5, 2006, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. This section synthesizes the scoping results, in particular those issues that may require attention from resource managers.

Narrow canyons, intense rainfall events, and easily eroded volcanic rock layers contribute to significant geologic issues facing Chiricahua National Monument resource management. Geological research in the last 15 years has also exposed a need for improved interpretive materials to explain the geologic history of the Monument.

Flooding

Bonita Canyon, Rhyolite Canyon, Newton Canyon, and their tributary canyons drain into Faraway Meadow, located in a narrow canyon surrounded on three sides by steep slopes (fig. 2) (Pallister and du Bray 1997). Both the Chiricahua National Monument Visitor Center and the Bonita Creek Campground at the head of Faraway Meadow lie within the floodplain (fig. 4).

Precipitation within the Monument averages 49.58 cm (19.52 in) a year, most of which falls during the summer monsoons from July through mid-September. Rainfall events occur as high intensity thunderstorms. Rocky slopes encourage runoff. Because the slopes are so steep, any flooding will be sudden and likely preclude evacuation (Carrie Dennett, NPS Chiricahua National Monument ecologist, personal communication, April 5, 2006).

Chiricahua National Monument managers have no plans to relocate facilities that currently lie within the floodplain, but the Monument may identify areas prone to flooding and avoid constructing new facilities in these areas. In the past, the campground has been closed due to flooding. The flash flood risk will continue to be monitored on a daily basis, and selective closures of the Bonita Creek Campground will be based on seasonal and predicted weather conditions at Chiricahua National Monument (National Park Service 2001).

Mass Wasting and Hoodoo Stability

Landslides

An ash-rich, white-to-light gray bed forms a conspicuous layer at the contact of the Upper and Middle Members of the Rhyolite Canyon Tuff along Sugarloaf Mountain Trail (figs. 5). The ash layer is soft and more easily eroded than the overlying layers of welded tuff. During wet years, water moves along joints and saturates the white ash, thereby reducing its strength and causing slumping. With undercutting, the overlying cliff becomes unstable and collapses (fig. 6) (Pallister and du Bray 1997; Bezy 2001). Destabilized blocks in the overlying cliffs break loose and tumble down the slopes of Sugarloaf Mountain.

A February 2001 landslide closed the Sugarloaf Mountain Trail for a year and a half. Management may wish to consult a rockfall expert such as Gerry Wieczorek (USGS), who has worked with NPS personnel on large rockfalls in Yosemite National Park (Ed du Bray, USGS geologist, written communication, March 12, 2009). Re-routing the trail onto the southern, gentler slopes may be an alternative, also.

The Upper Member of the Rhyolite Canyon Tuff is only found atop Sugarloaf Mountain in the Monument. Landslide deposits are also mapped in the northeastern part of the Monument along East Whitetail Trail (Pallister and du Bray 1997). However, these are older, relatively stable deposits (Ed du Bray, USGS geologist, written communication, March 12, 2009). Landslide potential is further reduced because the terrain isn't too steep in this area. In this remote part of the Monument, infrastructure is relatively minor and hikers are few.

Extensive landslide deposits in Pinery Canyon are located adjacent to the southeastern boundary of Chiricahua National Monument (Pallister and du Bray 1997). These older deposits lie outside the Monument on relatively gentle topography.

Hoodoo Stability

Tall, slender pinnacles, like those in Chiricahua National Monument, are known as hoodoos and look as if they could easily collapse. Balanced rocks, notched where horizontal joints have weathered, appear ready to topple. However, studies show that the pinnacles could withstand 12–13 times their weight in stress before they would collapse (Bezy 2001). Engineering analysis of the columns shows that the columns are quite strong and well within their mechanical failure limits for static load (Hall 1996). In fact, columns supporting balanced rocks above V-shaped incuts have been shown to be more stable than those columns that do not have necks. Neither they nor the balanced rocks are about to fail under their own weight (Pallister et al. 1997). Even the Totem Pole (height 57 m [187 ft]) could be suspended upside-down without breaking.

Dynamic failure, which involves seismic shaking by a lateral force, is more likely to topple columns than gravity. Earthquakes produce lateral forces, but the 7.2-M Pitaycachi earthquake in 1887 did relatively little damage to the columns in Chiricahua National Monument (Hall 1996). The Pitaycachi earthquake, whose epicenter was located approximately 120 km (75 mi) south-southeast of Chiricahua National Monument, shook all of southeastern Arizona and caused rockslides as far away as the Santa Catalina Mountains north of Tucson but did not destabilize the hoodoos.

When a large rock fell onto the main road after a rainstorm, seismometers were placed to monitor vibrations from heavy equipment and small dynamite charges (Alan Whalon, Chiricahua National Monument superintendent, personal communication, April 5, 2006). Road maintenance did not destabilize the pinnacles and other rock structures, but the study did show that climbing on the rocks promoted rockfall. Chiricahua National Monument does not allow rock climbing, and the study offered additional evidence to support a ban on rock climbing in the Monument.

Information for Interpretation

At the scoping session, Ed du Bray, U.S. Geological Survey geologist, emphasized the need to update the interpretive displays at Sugarloaf Mountain. Displays currently represent the Turkey Creek volcano as a stratovolcano with steep slopes, similar to Mount Rainier, for example. However, the Turkey Creek caldera resulted from an entirely different type of volcanic eruption.

The Turkey Creek caldera is a product of a large mass of rhyolite magma that accumulated near the surface in the area south of the Monument. Eventually, the overlying rock ruptured, resulting in a decrease in confining pressure. As pressure decreased, volatiles (mostly water and carbon dioxide) separated from the magma and formed gas bubbles. The frothy magma expanded as much as 50 times in volume, causing a series of large explosive eruptions of pumice and ash (Pallister and du Bray 1997). Clouds of ash blanketed a vast area of what is today southern Arizona and New Mexico. Dense, hot clouds of pumice, ash, and volcanic gases filled the Monument valley to a depth of more than 490 m (1,600 ft). More than 400 km^3 (100 mi^3) of molten rock erupted from the volcano. In comparison, Mount St. Helens produced 0.4 km^3 (0.1 mi^3) of magma, and the 1991 eruption of Mount Pinatubo in the Philippines, which was one of the largest eruptions of the 20^{th} century, produced only about 4 km^3 (1 mi^3) of magma (Pallister et al. 1997). When the magma erupted from Turkey Creek volcano, the magma chamber collapsed and the floor of the volcano subsided, forming the 19-km (12-mi) diameter Turkey Creek caldera.

The extraordinary volume of volcanic material produced by the Turkey Creek volcano is typically associated with catastrophic eruptions from stratovolcanoes, such as the Mount Mazama eruption that produced the Crater Lake caldera, or the more recent eruptions from Mount Pinatubo and Mount St. Helens. However, the Turkey Creek magma erupted explosively through ring fractures, not through a central vent as in a stratovolcano.

In the past, interpretation at Chiricahua National Monument focused on the pinnacles and other unusual geological formations rather than the history of the Turkey Creek caldera. This report may help the interpretive staff at the Monument develop materials and programs that present a more accurate and complete geologic story.

Other Issues

King of Lead Mine

The King of Lead Mine is located adjacent to the northeast boundary of Chiricahua National Monument. The mine has four patented mining claims and was active until 1984 when access to the mine through the Monument became an issue (see Appendix B). The primary ore deposits are lead-zinc deposits that formed when magma that may be associated with an unknown caldera at Cochise Head, northeast of the Monument, reacted with Paleozoic rocks.

The King of Lead Mine and smaller lead-zinc deposits in the area cannot be extracted economically in today's market. If economic conditions change and the extraction of lead from this mine becomes economic, the park may need to work with GRD staff to address impacts from adjacent mining. Although this is unlikely to occur in the near future, potential impacts from renewed mining may include acid mine drainage, impacts to the Monument's viewshed, and access issues.

The King of Lead Mine drains to Bonita Creek, but there is no surface flow for most of the year. Water-quality tests of Bonita Creek showed no impacts from acid mine drainage, but hydrologist Mike Martin of the NPS Water Resources Division was skeptical of these results. Groundwater and surface-water sampling may provide more definitive information for use in land-use planning for the Monument.

About 13 years ago, old mines presented safety and bat habitat issues for Chiricahua National Monument management. Today, however, there are no safety or bat habitat issues related to these old mines in the Monument (Alan Whalon, Chiricahua National Monument superintendent, personal communication, April 5, 2006).

Mineral Specimen Collecting

Mineral specimens are non-renewable resources that require park protection. Collecting, rockhounding, and gold panning of rocks, minerals, and paleontological specimens, for either recreational or educational purposes is generally prohibited in all units of the National Park System (36 C.F.R. § 2.1(a) and § 2.5(a)). Violators of this prohibition are subject to criminal penalties.

Collecting rock specimens is an issue for park management. Visitors collect samples of galena and sphalerite (lead-zinc minerals) as well as spherulites along Monument trails. The marble-like spherulites, known as "hailstones," weather out of volcanic tuff, especially along Hailstone Trail. The number of specimens removed from the Monument has not been documented, and it is unclear how large a problem mineral theft is for the Monument. Nevertheless, improving visitor education regarding the prohibition against collecting may help to reduce mineral theft.

Subsurface Contamination/Decontamination

Soil and groundwater were contaminated in 1994 when an underground storage tank leaked. The tank was pulled, and decontamination at the site is ongoing because the contaminant plume is difficult to define and mitigate (see Appendix B).

Sewer and Septic Problems

The septic system for Chiricahua National Monument is old and deteriorating, but issues associated with the system are related more to park finances than to geology (see Appendix B). Management of Monument finances is beyond the scope of this report. The septic system that serves the campground is often used to capacity (National Park Service 2001). Because Faraway Meadow is narrow and much of the area is within the floodplain, a good location for a new septic system is difficult to identify. Issues concerning the hydrology of Chiricahua National Monument may be addressed to the Water Resources Division of the National Park Service.

Figure 4. The Visitor Center at Chiricahua National Monument lies within Faraway Meadows and is susceptible to flash flooding. Photograph courtesy of the National Park Service, http://www.nps.gov/chir/planyourvisit/hours.htm.

Figure 5. Surge deposits (white) and welded tuff deposits (brown) along Sugarloaf Mountain Trail pose a landslide hazard at Chiricahua National Monument. Photograph by John Graham (Colorado State University), April 5, 2006.

Figure 6. Landslide potential. Erosion of the soft, ash-rich white layer at the base of the Upper Member of the Rhyolite Canyon Tuff causes undercutting of the more resistant welded tuff and subsequent cliff collapse.

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Chiricahua National Monument.

Weathering, volcanic activity, and faulting combined to form the principal geologic features found within Chiricahua National Monument. The unusual pinnacles, columns, and balanced rocks owe their origin to differential weathering processes and are the reason for the Monument. Other equally outstanding geologic features resulted from volcanic episodes that impacted the southeastern Arizona area and from regional tectonics associated with the western margin of North America.

Features Related to Differential Weathering and Erosion

Hoodoos, Balanced Rocks, and Slot Canyons

The pinnacles and balanced rocks, for which the Monument is best known, are exposed in what look like organ pipes about 0.8 km (0.5 mi) from the Visitor Center, along the main park road, and in the Heart of Rocks area (fig. 1) (Pallister and du Bray 1997; Pallister et al. 1997; Bezy 2001). The spires are particularly abundant in canyons on the west side of the Chiricahua Mountains (Chronic 1983). Few columns are present on the eastern slope due to the lack of vertical fractures in the rocks in that area. These hoodoos are erosional features that formed as the Rhyolite Canyon Tuff was dissected by water and wind (Pallister et al. 1997). Weathering along horizontal fractures in the welded tuff is responsible for the irregular profiles.

Chemical and physical weathering processes are commonly concentrated along joints in the rock. In the volcanic rocks at Chiricahua National Monument, joints intersect one another at high angles to form rectangular blocks. Along Sugarloaf Mountain Trail, the average spacing between extensive 'master' joints is 4.3–5.5 m (14–18 ft) (Bezy 2001). Water from rain or snowmelt seeps into fractures. When the water freezes, the increase in volume exerts sufficient pressure to shatter rock through a process called 'frost wedging.' When the ice thaws, pieces of shattered rock that were held in place by the ice collapse and are washed away, thereby widening fractures.

Plant roots also seek water in joints. Their continued growth exerts pressures that also lead to rock degradation along joints. The slightly acidic water can also cause chemical degradation of rock along joint walls. Over hundreds of thousands of years, weathering and erosion have widened and deepened crevices developed along joints, leading to the formation of rectilinear ridges, pinnacles, and slot canyons.

The hoodoos are relict landforms from the Pleistocene ice ages (approximately 1.6 million to 10,000 years ago). Frost wedging during the wetter glacial climate sculpted the bedrock into angular columns. During the last 10,000 years, the pinnacles have been smoothed to their present cylindrical and hourglass shapes by chemical weathering, repeated freezing and thawing, lichen attack, and other processes. Wind erosion helps shape the balanced rocks. Sand grains, blown by the wind, act like sandpaper or sand blasting to effectively round the corners of the columns.

Slot canyons can be found along Echo Canyon Loop Trail. These canyons are commonly as much as 40 times deeper than they are wide. Cut into the rhyolite, they are almost exclusively controlled by rectilinear joint sets. These narrow canyons and the fin-like, pinnacle-lined walls that separate them are the result of repeated freezing and thawing and subsequent flushing away of rock fragments by running water.

Natural Bridge

A natural bridge with a 9-m (30 ft) span of welded tuff can be seen from the overlook at the end of the Natural Bridge Trail. The trailhead is located approximately 2 km (1.25 mi) from the Visitor Center along the Bonita Canyon scenic drive. The trail traverses the Middle Member of the Rhyolite Canyon Tuff and climbs to a high plateau where piñon pine and alligator juniper rise above a chaparral community of manzanita, bear grass, and yucca. High on the far wall of the canyon, the natural bridge crosses a narrow gulch lined by oak trees.

Natural bridges differ from arches, such as those at Arches National Park in Utah, in that they are formed by flowing water. The natural bridge in Chiricahua National Monument probably formed during the wetter Pleistocene glacial period when flowing water eroded the weaker rock beneath the bridge.

Case Hardening

Case hardening is the process that has caused the surfaces of most of the pinnacles and cliffs in Chiricahua National Monument to develop a protective mineral rind. Ongoing water evaporation at the rock's surface draws moisture from pore spaces within the rock. This water is re-precipitated on the surface and evaporates. As the water evaporates, it leaves behind, or deposits, a durable film of amorphous silica. The silica accumulates, hardens, and enhances rock strength, thereby protecting the surface from chemical weathering and low energy erosion. However, the rock beneath the surface becomes weaker than the case-hardened surface so that once the protective outer surface is broken, the softer, weathered zone is exposed to differential erosion and develops tafoni, which are commonly referred to as 'stonepecker holes' (Bezy 2001).

Tafoni

Tafoni are cavernous openings or pits that are common along joints, bedding planes, or other zones of weakness in the bedrock. These openings can range from the size of bottle caps up to several meters in diameter. The word comes from spectacular honeycomb structures that form in granite along the coast of Sicily. Tafoni are the result of several processes acting together. Differential erosion causes small depressions to form adjacent to surfaces hardened by mineral crusts. These openings enlarge as erosive agents attack the more porous interior rock adjacent to case-hardened zones. Resulting shaded cavities have higher humidity and lower temperatures than adjacent rock and experience continued differential erosion as a consequence, resulting in accelerated disintegration.

Desert Varnish

Desert varnish (also called 'rock varnish') consists of brown and black blotches on the buff-colored rock pinnacles in the Monument. Sandstone, basalt, and many metamorphic rocks have hard, erosion-resistant surfaces that promote the formation of rock varnish. Typically less than a quarter of a millimeter (a hundredth of an inch) thick, desert varnish is a coating formed by colonies of microscopic bacteria. The bacteria absorb trace amounts of manganese and iron from the atmosphere and precipitate the minerals as a black layer of manganese oxide or reddish iron oxide on the rock surface. The thin layer of desert varnish also includes clay particles that help shield the bacteria against desiccation, extreme heat, and intense solar radiation.

Solution Pans

Flat-bottomed solution pans form on many relatively horizontal surfaces, including the level tops of many hoodoos. These circular, dish-shaped depressions may reach 1 m (3 ft) in diameter and 10 cm (4 in) in depth and can hold water for weeks after rain or snowmelt (Bezy 2001). Chemical and physical weathering processes, similar to those responsible for tafoni formation, attack the rock at points of weakness. An orange, iron-rich rock varnish coats the rims of many solution pans. The orange tint results from the oxidation (rust) of small quantities of iron (Bezy 2001).

Horizontal Ribs

Horizontal ribs appear as small-scale ridges exposed on the surface of rock pinnacles. The ribs and adjacent depressions vary from about 1 to 10 cm (0.5 to 4 in) in width and are as much as 20 cm (8 in) long. The depressions between the ribs are cavities formed by weathering of softer ash layers and fiamme (pumice blocks flattened and deflated during welding of rhyolite). The welded tuff composing the ribs is more resistant to weathering than the ash layers, and consequently forms positive features on the rock.

Talus Cones

Steep, triangular piles of rock rubble, known as talus cones, are common landforms in high mountains and deserts. Talus cones form from the accumulation of fallen, angular rock fragments dislodged by ice wedging, plant roots, chemical decomposition, and other weathering processes.

In the Chiricahua Mountains, talus cones may be relict features produced during the cooler and wetter climate of the Pleistocene ice ages (1.6 million to 10,000 years ago) when freeze-thaw cycles were more frequent (Bezy 2001). Talus rocks are encrusted with lichen and have been partially stabilized by vegetation, which indicates minor recent movement. Talus cones can be seen along the Hailstone segment of Echo Canyon Loop Trail.

Most slope angles are near their upper limit (angle of repose) and can be very unstable. Climbing on the cones can trigger rockslides.

Exfoliation Shingles

Blocky features that resemble small, overlapping shingles cover the narrow necks of many pinnacles along Echo Canyon Loop Trail. Shingles extend only a few inches into the bedrock. Desert varnish coats the exfoliation shingles, which are case hardened. The origin of these weathering features is still unknown (Bezy 2001).

Chicken Heads

Knobby or plate-like protrusions called 'chicken heads' have developed on otherwise smooth rock surfaces near the base of many pinnacles. These features contain remnant coatings of rock varnish and lichen, have been case hardened, and are more resistant to weathering than the surrounding rock surfaces. Once the protective coating is worn away, the chicken heads weather to a smooth surface.

Inverted Topography

Inverted topography represents a large-scale geomorphic feature that formerly was a topographic low but presently is a topographic high that reflects the difference in erosion resistance between adjacent rock bodies. For example, the Rhyolite Canyon Tuff flowed into a valley when it erupted from the Turkey Creek caldera. However, over the past 26.9 million years, the welded tuff did not erode as quickly as the surrounding rocks. Now, because of its relative resistance to erosion, the Rhyolite Canyon Tuff stands above the surrounding terrain.

Sugarloaf Mountain is another excellent example of inverted topography. The dacite that caps the mountain once filled a valley eroded into the Rhyolite Canyon Tuff. Dacite is more resistant to erosion than the tuff, so as erosion continued to degrade the tuff, the top of Sugarloaf became a prominent knob above the surrounding landscape. What was once a valley bottom is now a mountaintop.

Lichens

Lichen colonies are common features on rocks at Chiricahua National Monument. These colonies of algae and fungi weather rocks by both chemical and physical processes. Acids produced by lichens etch minerals such as feldspar and quartz. Lichens, attached firmly to rock surfaces, expand and shrink when they are wet and dried, and in doing so, they exert enough pressure to dislodge mineral grains, chip off rock flakes, and enlarge cracks. The process is slow but relentless. Over time, the rock disintegrates grain-by-grain.

Volcanic Features Related to the Turkey Creek Caldera

Turkey Creek Caldera

Visible on the southern skyline from the top of Sugarloaf Mountain, the highest peaks of the Chiricahua Mountains represent remnants of the Turkey Creek caldera. Magma, water vapor, carbon dioxide, and other gases accumulated in a massive magma chamber a few miles below the land surface and erupted explosively 26.9 million years ago. More than 400 km^3 (100 mi^3) of pumice and ash were blown into the atmosphere. The pyroclastic material blanketed more than 3,100 km^2 (1,200 mi^2) and compacted to become the Rhyolite Canyon Tuff. The magma chamber collapsed following the explosion and formed the Turkey Creek caldera, a giant depression 19 km (12 mi) across and 1,500 m (5,000 ft) deep (Pallister et al. 1997; Bezy 2001). Subsequent burial by additional pumice and ash, faulting, and erosion have obscured the circular form of the caldera.

As mentioned in the Geologic Issues section, the volume of material from the Turkey Creek volcano was much greater than 19^{th} and 20^{th} century stratovolcano eruptions. In addition, the Turkey Creek eruption did not proceed from a central vent but from a series of vents that ruptured the land surface. Although larger than Krakatoa, Mount St. Helens, and Mount Pinatubo, the Turkey Creek eruption is not the biggest known. Similar types of eruptions in the San Juan Mountains of Colorado and in what is now Yellowstone National Park each vented more than 2,000 km^3 (500 mi^3) of magma (Pallister et al. 1997). Still, the Turkey Creek caldera remains an excellent example of this style of volcanic eruption.

Rhyolite Canyon Tuff

When the Turkey Creek volcano erupted, the liberated gas produced both ash clouds and pyroclastic flows. The ash clouds consisted of billions of microscopic shards of volcanic glass, fragments of crystals, and microscopic rock fragments. Boiling clouds of very hot (> 540 °C [1,000°F]) ash, pumice, rock fragments and gas were blown into the atmosphere and propelled across the land surface at speeds of 80 to more than 160 km/hr (50 to more than 100 mi/hr) (Pallister et al. 1997). The intense heat scoured everything in its path. Pyroclastic flows developed as the ash clouds lost gas and deflated. The pyroclastic flows ponded in valleys to form thick deposits of steaming ash and pumice. A 'tuff' is a volcanic rock composed primarily of ash and pumice, and if the shards of volcanic glass and the pumice fragments are still hot when deposited, they fuse together and compact under their own weight to form a rock called 'welded tuff.'

Before the Turkey Creek eruption, the Chiricahua National Monument area was a valley. Pyroclastic flows from the caldera-forming eruption filled the valley to a depth of at least 490 m (1,600 ft) (Pallister et al. 1997). The deposit was named the Rhyolite Canyon Tuff for the excellent exposures in Rhyolite Canyon. Primary components of the tuff include pumice, ash, rock fragments, and crystals of feldspar and quartz. Most of the Rhyolite Canyon Tuff is densely welded, but some layers of poorly welded ash and pumice and surge beds of ash form horizontal white bands within the unit.

The white, poorly welded layers are visible in the cliffs of the Monument and mark contacts between distinct sequences of pyroclastic flows (fig. 5). In Chiricahua National Monument, two such contacts divide the Rhyolite Canyon Tuff into three members. Contacts between each member are defined by white, ash-rich surge beds formed from material that was blasted from the volcano at high velocity. The surge beds are poorly welded relative to the densely welded pyroclastic flows that subsequently buried them.

The three members of the Rhyolite Canyon Tuff represent three giant eruptions that occurred in rapid succession and that dwarf historic eruptions (Pallister et al. 1997; Kiver and Harris 1999). The Middle Member alone is a startling 268 m (880 ft) thick. Each member consists of densely welded pyroclastic flows composed of pumice, ash, rock fragments, and crystals of feldspar and quartz.

Welded Tuff and Fiamme

Both the welded tuff and the unwelded tuff layers in the Rhyolite Canyon Tuff are well preserved along Sugarloaf Mountain Trail. White streaks in the rock are flattened pumice fragments, called 'fiamme.' Pumice, a soft volcanic material permeated by formerly gas-bubble-filled cavities was compressed, while still hot, and the bubbles were deflated by the weight of overlying volcanic ash. Volcanic rock that encloses fiamme is composed of microscopic pieces of volcanic glass and crystal fragments.

Surge Beds, Liesegang Bands, and Fumarole Pipes

The only location in the Chiricahua Mountains where the contact between the Upper Member and the Middle Member of the Rhyolite Canyon Tuff is exposed is along Sugarloaf Mountain Trail (fig. 5). White, ash-rich surge beds at the base of the Upper Member mark the dynamic contact between these pyroclastic flows and the ash-fall layers of the Middle Member.

Surge beds are a type of pyroclastic flow deposit that record lateral explosions that blasted ash from the volcano at high velocity. As gases escaped from the violent explosions that propelled ash clouds down the slopes of the Turkey Creek caldera, a frothy ash cloud, flowed, or surged, from the volcano and settled in topographically low areas. The surge beds intersect one another at low angles, producing cross-bedding. In some places, coarser grained beds overlie finer grained beds to form a feature called 'inverse graded bedding.'

Volcanic ash subsequently settled on top of the pyroclastic flows and fused into thick layers of welded tuff. The soft, ash-rich, white- to- light gray surge layers contribute to mass wasting along Sugarloaf Mountain Trail (fig. 6) (Pallister et al. 1997; Bezy 2001).

Secondary chemical processes produced features called 'Liesegang bands' in the surge beds along Sugarloaf Mountain Trail. These bands formed when water in the ash boiled and precipitated less-soluble minerals (Pallister et al. 1997; Bezy 2001). They can be found at the base of some preserved fumarole pipes and within the surge deposits (fig. 7).

When water in the ash boiled, the resulting steam blasted to the surface through the overlying ash-flow tuff to form irregular vertical conduits. These features, called 'fumarole pipes,' are preserved in the ash and the overlying welded tuff along Sugarloaf Mountain Trail (fig. 8) (Pallister et al. 1997; Bezy 2001). Fine-grained ash was blown out of the fumarole pipe, leaving behind coarser ash and crystals in the pipe-like conduit. The preserved fumarole pipes suggest that the top of the Middle Member of the Rhyolite Canyon Tuff and/or the overlying basal white ash were wet prior to deposition of the hot ash of the Upper Member (Pallister and du Bray 1997).

Moat Deposits and Flow Ramps
Following the eruption of the Rhyolite Canyon Tuff, the central part of the caldera depression was uplifted south of the Monument, forming a feature known as a resurgent dome. A circular valley, or moat, formed between the resurgent dome and the edge of the caldera depression. Highly viscous rhyolite lava leaked into the moat, piled up on itself, and solidified into vertical features called 'flow ramps.' Visible from the lookout atop Sugarloaf Mountain, moat lava rock forms the east-west ridgeline south of Pinery Canyon and extends to the south along the crest of the Chiricahua Mountains. The hillside above and just south of Downings Pass on the Methodist Camp road, a side road south of the Pinery Canyon road between the Monument and Portal, Arizona, contains an excellent exposure of flow-ramped moat lava (Pallister et al. 1997).

Columnar Joints
Columnar-jointed rocks that have not weathered to hoodoos form cliffs of Rhyolite Canyon Tuff north of Picket Canyon. The columns are parallel cracks that formed as the volcanic ash beds cooled and contracted. These contraction joints form at right angles to cooling surfaces of lava flows or tuffs. The intersection of the joint sets form rock columns, or 'columnar joints.' Columnar joints are also well developed at Devils Postpile National Monument in California.

Dacite Caprock
Sugarloaf Mountain is capped by a dacite lava flow that weathers to form a blocky, rubbly surface. Dacite contains about 63-70% silica compared to rhyolite, which contains about 77% silica. Magma of this composition resided in the lower part of the magma chamber and was erupted after the Rhyolite Canyon Tuff. It did not erupt as violently as the rhyolite because it contained less water and volatiles. Most of the dacite lava flowed into the caldera depression although some of the lava flowed out of the caldera and down the former valley into the area of the Monument. The dacite contains large crystals of feldspar. A rock in which large crystals are surrounded by fine-grained groundmass, such as this dacite, is called a 'porphyry' and the large crystals are called 'phenocrysts.'

Igneous Dikes
Not all of the magma was extruded onto the surface. Rhyolite magma that intruded into pre-Turkey Creek caldera rocks and formed tabular features called 'igneous dikes.' Igneous dikes form discordant to the bedding or layering of the rocks they intrude. The igneous dike near the King of Lead Mine is visible from Sugarloaf Mountain Trail. This dike and others like it stand out from the surrounding topography because they are more resistant to weathering than the rocks that they intruded.

Spherulites
Rounded spherulites, found along Hailstone Trail, formed as volcanic ash cooled and began to crystallize. The spheroidal, marble-like shape resulted from radial growth of secondary needle-shaped crystals of quartz and feldspar around a common center. At one time, they were thought to be volcanic hailstones formed by repeated accumulation of concentric ash layers around water droplets or crystals rising and falling through volcanic ash clouds (Chronic 1983; Kiver and Harris 1999). However, the pellets along Hailstone Trail contain radiating crystals, lack concentric layering, and except for being harder, are similar in composition to the surrounding tuff. Evidence suggests an origin following deposition of the tuff (Pallister and du Bray 1997; Bezy 2001).

Features that Predate the Turkey Creek Caldera

Volcanic Features
The hills north and south of Faraway Ranch consist of rhyolite formed from lava in that pooled around eruption vents prior to the Turkey Creek caldera eruptions. Rhyolite of Erickson Ridge, a unit in the Faraway Ranch Formation, contains phenocrysts of plagioclase and biotite. Dark colored andesite and basalt, which form from magma low in silica, are exposed in road cuts uphill from Bonita Park on the road to Sugarloaf Mountain and Massai Point (Pallister et al. 1997).

A vertical flow ramp in Faraway Ranch Formation rhyolite lava is exposed in the cliff north of the Faraway Ranch parking lot (Pallister et al. 1997; Pallister and du Bray 1997). Thin beds of rhyolite ash and rock debris in the Faraway Ranch Formation represent small explosions that accompanied the eruption of rhyolite lava and produced swiftly flowing, turbulent gaseous clouds of pyroclastic material called 'nuée ardente' (glowing cloud and avalanche) deposits.

Sedimentary Features
The Tertiary-age, red-weathering beds of sandstone and conglomerate of Bonita Park underlie the Faraway Ranch Formation (fig. 3). These sedimentary rocks

represent stream deposits laid down along the floor of the ancient Monument valley about 30 million years ago (Pallister et al. 1997).

Features in the Lower Permian limestones in the northeastern section of the Monument provide evidence of a time when marine environments transgressed into southeastern Arizona. Productid brachiopods (brachiopods with long spines to attach to the substrate), echinoids (related to modern sea urchins and sand dollars), and other marine invertebrates inhabited offshore, well-oxygenated marine environments. Tweet et al. (2008) summarized the paleontological resources (fossils)of Chiricahua National Monument and the other parks of the Sonoran Desert Inventory and Monitoring Network.

Structural Features

During the Miocene (20-15 million years ago), rising heat from the mantle began to thin the crust beneath the southwestern United States, causing the crust to bulge upward. The crust began to stretch or pull apart, and as it stretched, steeply-dipping normal faults developed to accommodate the extension. Uplifted blocks of crust called 'horsts' (German for 'heap') developed into today's fault-bounded, north-south trending mountain ranges. Downdropped blocks filled with sediment to form relatively flat, fault-bounded valleys, or 'grabens' (German for 'ditch'). San Simon Valley to the east and parts of Sulphur Springs Valley to the west are normal-fault-bounded grabens.

At the eastern boundary of Chiricahua National Monument, where the paved road to Sugarloaf Mountain and Massai Point turns south after ascending Bonita Canyon, the steep-sided Whitetail Valley is parallel to a fault zone across which distinct rock masses have been juxtaposed (Pallister et al. 1997). The most recent movement along the fault dropped the block east of the fault down relative to the rocks west of the fault, forming Whitetail Valley; these fault displacements dragged and folded the Rhyolite Canyon Tuff down into the valley. Formerly horizontal welded- pumice fiamme are now steeply tilted into the valley.

Figure 7. The "boiling pot" at the base of a fumarole pipe (arrow). Concentric layers are Liesegang bands. The light-gray layers below the fumarole pipe are surge beds, which were deposited from horizontally directed explosive blasts of ash, crystals, and rock debris. Liesegang bands also overprint these layers. Photograph by John Graham (Colorado State University), April 5, 2006.

Figure 8. A fumarole pipe preserved in the Rhyolite Canyon Tuff, Sugarloaf Mountain Trail. Photograph by John Graham (Colorado State University), April 5, 2006.

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resources Inventory digital geologic map of Chiricahua National Monument. The accompanying table is highly generalized and for background purposes only. Ground-disturbing activities should not be permitted or denied on the basis of information in this table.

Geologic maps facilitate an understanding of Earth, its processes, and the geologic history responsible for its formation. Hence, the geologic map for Chiricahua National Monument informed the "Geologic History," "Geologic Features and Processes," and "Geologic Issues" sections of this report. Geologic maps are essentially two-dimensional representations of complex three-dimensional relationships. The various colors on geologic maps illustrate the distribution of rocks and unconsolidated deposits. Bold lines that cross or separate the color patterns mark structures such as faults and folds. Point symbols indicate features such as dipping strata, sample localities, mines, wells, and cave openings.

Incorporation of geologic data into a Geographic Information System (GIS) increases the usefulness of geologic maps by revealing the spatial relationships to other natural resources and anthropogenic features. Geologic maps are indicators of water resources because they show which rock units are potential aquifers and are useful for finding seeps and springs. Geologic maps do not show soil types and are not soil maps, but they do show parent material, a key factor in soil formation. Furthermore, resource managers have used geologic maps to make connections between geology and biology; for instance, geologic maps have served as tools for locating sensitive, threatened, and endangered plant species, which may prefer a particular rock unit.

Although geologic maps do not show where earthquakes will occur, the presence of a fault indicates past movement and possible future seismic activity. Geologic maps do not show where the next landslide, rockfall, or volcanic eruption will occur, but mapped deposits show areas that have been susceptible to such geologic hazards. Geologic maps do not show archaeological or cultural resources, but past peoples may have inhabited or been influenced by various geomorphic features that are shown on geologic maps. For example, alluvial terraces may preserve artifacts, and formerly inhabited alcoves may occur at the contact between two rock units.

The geologic units listed in the following table correspond to the accompanying digital geologic data. Map units are listed in the table from youngest to oldest. Please refer to the geologic timescale (fig. 9) for the age associated with each time period. This table highlights characteristics of map units such as susceptibility to hazards; the occurrence of fossils, cultural resources, mineral resources, and caves; and the suitability as habitat or for recreational use.

The GRI digital geologic maps reproduce essential elements of the source maps including the unit descriptions, legend, map notes, graphics, and report. The following reference is source data for the GRI digital geologic map for Chiricahua National Monument:

Pallister, J. S., and E. A. du Bray. 1997. *Interpretive map and guide to the volcanic geology of Chiricahua National Monument and vicinity, Cochise County, Arizona*. Scale 1:24,000. Miscellaneous Investigations Series Map I-2541. Reston, VA: U.S. Geological Survey.

The GRI team implements a geology-GIS data model that standardizes map deliverables. This data model dictates GIS data structure including data layer architecture, feature attribution, and data relationships within ESRI ArcGIS software, increasing the overall quality and utility of the data. GRI digital geologic map products include data in ESRI shapefile and coverage GIS formats, Federal Geographic Data Committee (FGDC)-compliant metadata, a Windows help file that contains all of the ancillary map information and graphics, and an ESRI ArcMap map document file that easily displays the map with appropriate symbology. GRI digital geologic data are included on the attached CD and are available through the NPS Data Store (http://science.nature.nps.gov/nrdata/).

Map Unit Properties Table

Age	Unit Name (Symbol)	Features and Description	Erosion Resistance	Suitability for Development	Hazards	Paleontological Resources	Cultural Resources	Mineral Occurrence	Habitat	Recreation	Geologic Significance
QUATERNARY (Holocene)	Alluvium (Qal)	Unconsolidated to poorly consolidated silt, sand, & gravel. Found in valley bottoms.	Low	High except in flood- prone areas	Flooding	None	Possible Native American sites	Sand & Gravel	Grasslands: >50 grass species, yucca, cactus, agave, scrub oak	Bonita Creek & Silver Spring hiking trails; campground; Visitors Center	None
QUATERNARY (Pleistocene–Holocene)	Aluvial- fan deposits (Qaf)	Poorly sorted deposits of silt- to boulder- size material. Aprons adjacent to topographic highlands. Limited exposures in the Monument.	Variable but relatively low	High	None documented	None	Possible Native American sites	None	Yucca, cactus	Bonita Creek Trail	None
	Colluvium (Qc)	Poorly sorted silt- to boulder- size material. Mostly gentle slope deposits.	Fine sediment are less resistant than boulders	Contains the road into the Visitor Center	None documented	None	Possible Native American sites	None	Yucca, cactus	Whitetail Trail in NE; roadside scenery	None
QUATERNARY & TERTIARY	Landslide deposits (QTls)	Deposits formed by gravity sliding or flowing. Cuspate breakaway scarps (hachured on map) exposed at heads of some deposits. Degree of erosion & alteration, as well as proximity to Tertiary faults & to margin of Turkey Creek caldera, suggests a Tertiary age for some deposits. Found primarily in NE part of Monument & SE of the Monument.	Depends on slope stability & slide reactivation potential	Designated as wilderness areas	Potential for large landslides	None	Unknown	None	Blocks encrusted with lichen; habitat for small animals	Climbing may trigger rock slides	None
TERTIARY (Oligocene)	Conglomerate (Tcg)	Weakly indurated, poorly sorted conglomerate & gritty sandstone. Clasts are principally derived from the underlying Rhyolite Canyon Tuff. Form fan deposits NW of Chiricahua National Monument.	Moderate. Not exposed in the Monument.	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument
	ROCKS OF THE TURKEY CREEK CALDERA Mainly lava flows, relatively thin ash- & pumice- rich deposits (pyroclastic flows or tuffs), & lesser amounts of sed rocks deposited within the Turkey Creek caldera, between the uplifted central region & the caldera wall (the moat of the caldera). Divided into 3 eruptive units on the basis of stratigraphic position, petrographic differences, & distinct trace- element geochemistry.										
	Moat deposits (Tmt3, Tmr2, Tmt2, Tmr1, Tmt1)	Tmt3: Rhyolite tuff. Lavender to reddish- gray rhyolite ash- flow tuff; fine- grained or aphanitic & lithic- poor, except near the base where quartz, sanidine, & plagioclase xenocrysts & rhyolitic lithic fragments are found; 24–79 m (80–260 ft) thick. Exposed S & SW of the Monument.	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Rhyolite composition. Rocks originally made of volcanic glass that contained few crystals; now mainly light gray, rather than black (like obsidian), because glass crystallized to fine- grained minerals. Tmr1: Two $^{40}Ar/^{39}Ar$ ages on sanidine: 26.64±0.13 million years & 26.93±0.17 million years
		Tmr2: Rhyolite lava. Light- gray to reddish- gray, phenocryst- poor rhyolite lava; flow layered & intricately flow folded, locally massive; aphanitic or sparsely porphyritic with small (less than 1 mm) phenocrysts of sanidine, qtz, & opaque oxide minerals; accessory biotite & zircon; devitrified, except at basal flow contact where black or green glassy breccia or flow- layered perlite is locally exposed; secondary qtz & feldspar crystals. Maximum thickness about 300 m (980 ft). Forms ledges & massive cliffs in the exhumed moat S & SW of the Monument.	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	
		Tmt2: Tuff. Ash- flow deposits & intercalated air- fall tuff & volcaniclastic sedimentary rocks. Light- gray to orange or pink, poorly to densely welded, crystal- poor rhyolite ash- flow tuff; very sparsely porphyritic; phenocrysts are quartz & sanidine (both <1 mm); similar to Tmr2 but some ash flows have more abundant (about 1%) phenocrysts, including plagioclase, sanidine, opaque oxides, & biotite; individual ash flows & intercalated volcaniclastic sedimentary beds range from < 1 m (3 ft) to about 30 m (100 ft) thick. Max thickness about 100 m (330 ft). Forms multiple low- relief cliffs or slopes below the steeper cliffs of Tmr2 S & SW of the Monument.	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	
		Tmr1: Rhyolite lava. Light- gray to reddish- gray or brown rhyolite lava; typically aphanitic; contains sanidine, quartz, & opaque oxide minerals; local xenocrysts of plagioclase, hornblende, & clinopyroxene; similar to Tmr2, except for more variable phenocryst assemblage, less evolved trace- element composition & stratigraphic position; devitrified, except at basal flow contact where perlitic glass locally contains spherulitic zones & geodes; breccia locally exposed at margins of lava flows; flow interiors recrystallized to granophyre & contain quartz & feldspar in amygdules. Flow layered & intricately flow- folded but locally massive. Maximum thickness 150 m (490 ft). Exposed S & SW of the Monument.	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	

Age	Unit Name (Symbol)	Features and Description	Erosion Resistance	Suitability for Development	Hazards	Paleontological Resources	Cultural Resources	Mineral Occurrence	Habitat	Recreation	Geologic Significance
		Tmt1: Tuff. Pyroclastic flow & surge deposits. Gray to dark- brown or purplish- brown, densely to poorly welded, typically aphanitic rhyolite ash- flow tuff & light- gray surge beds; basal vitrophyre grades upward into devitrified rheomorphic tuff with convoluted flow banding; thickness 0–30 m (0–100 ft). Exposed S & SW of the Monument.	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	Not exposed in the Monument	
	Dacite of Sugarloaf Mountain (Tdpl)	Dacite porphyry lava; black to gray lava- flow; equivalent of dacite that forms lava flows at the base of the moat sequence as well as the resurgent intrusion within the Turkey Creek caldera; 10- 15% small (< 2 mm) phenocrysts (mainly plagioclase, clinopyroxene, & minor orthopyroxene); formerly glassy groundmass is variably devitrified; thickness about 70 m (230 ft). Preserved only as the remnant of a lava flow atop Sugarloaf Mountain.	High	Limited exposures; foundation for Sugarloaf Mountain lookout	None documented	None	None documented within the Monument	Crystal clots to 1 cm (0.4 in) across of plagioclase, clinopyroxene, & opaque oxides; sparse, large 2–5 mm (0.08–0.2 in) alkali feldspar & small 0.5 mm (0.02 in) quartz xenocrysts	Grasses at summit; scrub oak, manzanita, cactus on slopes	Sugarloaf Mountain hiking trail	26.9 million years old; may have flowed down an ancient valley from near Barfoot Peak, SE of the Monument
	Outflow facies of the Rhyolite Canyon Tuff (Trco, Trcu, Trcm, Trd, Trcv, Trca)	Light- gray, welded ash- flow deposit; rhyolite ash, pumice, crystals, & rock fragments erupted from Turkey Creek caldera & transported by hot ash- rich clouds (ash flows); divided into intracaldera (exposed S of the Monument) & outflow facies; Lower, Middle, & Upper Members of outflow facies separated by ash- cloud & surge deposits; abundant white streaks represent flattened pumice blocks (fiamme); small quartz & feldspar crystals (forms subhedral, lath- shaped phenocrysts, typically 1–4 mm (0.04–0.16 in) in length). Phenocrysts of sanidine (feldspar) & quartz; sanidine has a bluish luster in sunlight (chatoyant); quartz is rounded & embayed, 1–3 mm (0.04–0.12 in) diameter; also contains accessory opaque oxide minerals & trace amounts of clinopyroxene, biotite, hornblende, zircon, & apatite; eutaxitic & vitroclastic; locally spherulitic; composite thickness of entire outflow facies in Chiricahua National Monument about 490 m (1,600 ft). Trco (undivided): Most exposures probably equivalent to Middle Member (Trcm). Trcu: Upper Member. White, ash- rich surge beds overlain by gray, densely to mod welded tuff; surge beds cut by vertical fossil fumarole pipes & over- printed by low- angle secondary Liesegang bands; trace augite, zircon, & biotite tend to be more common than in most samples of Lower & Middle Members; welded tuff has both white fiamme & dark- gray to maroon lensoidal masses of sanidine-megacrystic rhyolite, thought to represent poorly vesiculated magma clots; upper 6 m (20 ft) is moderately to poorly welded & poorly exposed; thickness 24 m (80 ft) at Sugarloaf Mt. Exposed as erosional outlier near the top of Sugarloaf Mt & isolated outcrop NW of the Monument. Trcm: Middle Member. Voluminous, gray, densely welded, pumiceous ash- flow tuff; prominent vertical columns (hoodoos); jointing attributed primarily to contraction related to cooling; internally homogeneous; but, slight variation in welding & weathering profile suggest multiple ash flows erupted in rapid succession & cooled together; base locally marked by a 0–1 m (0–3 ft) thick section that consists of pumiceous ash- flow, ash- cloud, & surge deposits that were welded as a result of emplacement of the overlying main body; overlies the white, poorly welded, top of Lower Member; thickness 320 m (1,050 ft) at Sugarloaf Mountain where top exposed. Forms hoodoos; primary rock unit exposed in Chiricahua National Monument. Trcl: Lower Member. Pumiceous & locally lithophysal ash- flow tuff & related ash- cloud deposit. Red- brown densely welded lower zone & gray moderately welded middle zone. Middle zone grades upward into white, pumice- bearing, poorly welded ash- cloud deposit. 0–180 m (0–600 ft) thick. Forms a wedge that thickens to South & East of the Monument. Trcv: Vitrophyre. Black perlitic glass locally exposed at base of the Middle Member where it directly overlies basement rocks of Faraway Ranch Fm (Tfr) in W part of the Monument. Not present at base of Middle Member in central part of outcrop area where Middle Member is thick & overlies Lower Member; typically < 3 m (10 ft) thick. NOTE: No letter symbol is used on the source map. Trca: Basal ash. Line on map denotes top of white, crystal- poor ash found locally at the base of Trcl. NOTE: No letter symbol is used on the source map.	Dense, welded tuff is highly resistant to erosion, but the white ash bed at the base of Trcu is easily eroded, undercuts cliff, & causes slumps; a recent slump closed Sugarloaf Mountain Trail for 1.5 years	Trails, roads, buildings, parking areas are presently developed in unit	Potential for rockfall & slides on scree slopes	None	Potential Native American sites	Trcm/Trcl: marble- like spherulites called "hailstones" weather out of volcanic tuff along the Hailstone Trail	Exposed at an elevation of 1,500–2,000+ m (5,000–7,000+ ft): pine- fir forests whose prominent species are manzanita, Arizona Sycamore, alligator juniper, oaks, pines, Arizona cypress, madrone, acacia. Cottonwoods, sycamores, willows along narrow riparian corridor in canyon bottoms Trcm: lichen on hoodoos	No climbing is allowed in the Monument, including the hoodoos (Trcm). Many hiking trails: Natural Bridges Trail, Sugarloaf Trail, Echo Canyon Trail, Massai Point Trail, Inspiration Point Trail, Heart of Rocks Loop Trail, Hailstone Trail, Sarah Deming Trail, Rhyolite Trail	Chiricahua National Monument is the type locality for the Rhyolite Canyon Tuff Radiometric ages for sanidine samples show 26.94±0. 16 million years for the Upper Member (Trcu) & 26.93±0.12 million years for the Lower Member (Trcl)
	ROCKS THAT PREDATE THE TURKEY CREEK CALDERA										

Age	Unit Name (Symbol)	Features and Description	Erosion Resistance	Suitability for Development	Hazards	Paleontological Resources	Cultural Resources	Mineral Occurrence	Habitat	Recreation	Geologic Significance
	Jesse James Canyon Tuff (Tjj, Tjjf)	Tjj: Light- gray or pinkish- gray, lithic poor, mod crystal poor, biotite- bearing quartz- sanidine rhyolite ash- flow tuff from undetermined source; similar to Trcm, & Trcl; distinguished by trace amounts of bronze biotite & sphene, smaller & less abundant phenocrysts of sanidine & quartz, higher ratio of sanidine to quartz (3:1 or greater), forms a simple cooling unit; poorly welded upper zone grades downward into densely welded, eutaxitic lower zone; basal vitrophyre exposed locally. About 240 m (790 ft) thick near Jesse James Canyon; thins to N, NW, & NE. Forms steep slopes beneath Trcl (S & SW); bounded by normal faults in NE Chiricahua National Monument. Tjjf: Found locally at top of Tjj; overlain by about 1.5 m (5.0 ft) of white, crystal poor, biotite- bearing ash where present. NOTE: No letter symbol is used on the source map.	Variable: densely welded part is more resistant than poorly welded part of unit	Forms steep slopes; most exposures are within wilderness boundary	Rockfall & scree slide potential on steeper slopes	None	Potential Native American sites	None documented	Exposed at an elevation of 1,720–1,900 m (5,640–6,200 ft); sparsely vegetated; transition zone from interior chaparral shrubland to pine–fir forests	Steep slopes; crossed by Rhyolite Trail	Type locality is in the Monument. Deposited in an ancient valley shortly before Tr deposition
	Faraway Ranch Formation (Tfre, Tfpe, Tfrh, Tfph)	An assemblage of interfingering rhyolite, dacite, & andesite lava flows, near- source pyroclastic rocks, & clastic sedimentary rocks. Exposed in W part of Chiricahua National Monument. Tfre: Rhyolite of Erickson Ridge. Light- gray or red- brown (devitrified) to black (glassy) biotite rhyolite; phenocrysts of plagioclase (3–7%) & biotite (1–2%); trace sphene forms euhedral phenocrysts; prominent flow layering; thickness variable; as much as 150 m (500 ft) thick near Faraway Ranch. Forms small lava domes & flows with black glassy breccias as well as ridges & cliffs. Tfpe: Pyroclastic flow deposits of Erickson Ridge. Light- gray to orange block- &- ash flow, ash- fall & surge deposits, & ash- rich lahars interbedded with Tfre; locally includes reworked volcaniclastic sedimentary deposits; thickness 0–60 m (0–200 ft). Tfrh: Rhyolite of Hands Pass. Light- gray, qtz- sanidine rhyolite; subhedral sanidine & quartz phenocrysts & accessory biotite & opaque oxide minerals, typically in a spherulitic to granophyric devitrified groundmass; thickness 0–130 m (0–430 ft). Forms a prominent lava dome overlain by Trc near Hands Pass. Tfph: Pyroclastic flow deposits of Hands Pass. Light- gray to orange block- &- ash- flow, ash- fall, ash- rich lahar, & volcaniclastic sed deposits; 0- 70 m (0- 230 ft) thick. Forms a pyroclastic apron next to Tfrh.	High	Some exposures in wilderness designation; forms slopes on either side of Faraway Meadow	Rockfall potential beneath cliffs	None	Potential Native American sites	Phenocrysts of plagioclase, biotite, sphene	Exposed at an elevation of 1,600–1,800 m (5,200–5,860 ft): chaparral shrubland; desert plants; pointleaf manzanita, scrub oak	Ridges & slopes border Faraway Meadow; low elevation hiking	Type locality: W side of the Monument in section 27, T16S, R29E Age dated at 28–32 million years old
	ROCKS THAT PREDATE THE FARAWAY RANCH FORMATION										
	Sedimentary rocks of Bonita Peak (Tbp)	Distinctly red- weathering, poorly sorted, clast- supported conglomerate, & interbedded volcaniclastic arenite, siltstone, & claystone; contains gypsum veinlets near Bonita Park; graded beds & channel deposits common; poor sorting, hematitic alteration, & channel bedding consistent with alluvial- fan deposition; forms red clay- rich soil; underlies QTls deposits in Bonita Park & W of Whitetail Pass; less than 49 m (160 ft) thick. Limited exposures in Bonita Park; well exposed in road cuts.	Variable due to differing rock types	Limited exposures; partially in wilderness designation	None	None	None documented; most exposures are in road cuts	Extensively altered to clay minerals & hematite	Limited exposures in fault slices in Bonita Park, NE part of the Monument	Accessible roadside exposures	Deposited from streams flowing on the floor of an ancient basin
	Welded tuff of Joe Glen Ranch (Tjg)	Gray to pink, lithic- poor (<10% lithics) & moderately crystal- rich biotite- quartz- sanidine rhyolite ash- flow tuff; 10–15% sanidine, 5–7% quartz, 1- 3% biotite, & about 1–2% plagioclase; stratigraphic assignment made on basis of similarity in mineral assemblage & chemical composition to exposures of welded tuff of Joe Glen Ranch in the southern Chiricahua Mountains & in the Pedregosa Mountains; thickness about 130 m (430 ft); top eroded. Forms moderately welded remnant of outflow sheet atop ridges SW of Riggs Spring at Pinery Creek, S of Monument.	Exposed S of the Monument in Pinery Canyon	Exposed S of the Monument in Pinery Canyon	Exposed S of the Monument in Pinery Canyon	Exposed S of the Monument in Pinery Canyon	Exposed S of the Monument in Pinery Canyon	Exposed S of the Monument in Pinery Canyon	Exposed S of the Monument in Pinery Canyon	Exposed S of the Monument in Pinery Canyon	Exposed S of the Monument in Pinery Canyon
	Intermediate & mafic lava flows (Tim)	Interfingering lava flows, flow breccia, & near- source pyroclastic rocks; red to brown, hornblende- & biotite- bearing plagioclase porphyritic dacite that locally overlies Tbp & dark- gray aphanitic to glassy, clinopyroxene- bearing andesite & basalt; thickness >120 m (400 ft) locally, base not exposed. Underlie Tfre & most rhyolitic rocks in the Chiricahua Mountains and exposed around perimeter of Monument & in NE fault block. Timp: Spheroidal weathering & curvilinear vesicle trains in celadonitic plagioclase- clinopyroxene basaltic andesite suggest pillow basalt (eruption underwater). Exposed SE of Bonita Park. Tims: Zones of silicification. NOTE: No description or letter symbol is on the source map. Tq: Quartz vein. Occurs only within Tim. NOTE: Not shown on the source map.	High	Few exposures in Chiricahua National Monument; gentle slopes support roads	None documented	None	Potential Native American sites	None documented	Desert plants & grasses on alluvial fans	Most accessible exposures are along the road through Faraway Meadow; alluvial fan hiking	Erupted before most rhyolitic rocks of the Chiricahua Mts; range in age from about 28 million years to about 34 million years old
	Rhyolite dikes (Tr)	(Oligocene?) Light- gray to pink or tan aphanitic or quartz & (or) feldspar porphyritic rhyolite dikes; intrude pre- Turkey Creek caldera rocks. Form narrow, vertical, tabular sheets of rhyolite.	High	Low since exposures are linear features	None	None	None documented	None documented	Linear exposure in NE part of the Monument	Near unmaintained trail in NE part of Monument	Cut across other map units

Age	Unit Name (Symbol)		Features and Description	Erosion Resistance	Suitability for Development	Hazards	Paleontological Resources	Cultural Resources	Mineral Occurrence	Habitat	Recreation	Geologic Significance
CRETACEOUS (Lower)	Bisbee Group	Mural Limestone (Kbls)	Tan, thin- bedded, laminated silty limestone, interbedded with siltstone & shale. Too few exposures to map in Chiricahua National Monument.	Moderate	Insignificant exposure	Insignificant exposure	Insignificant exposure	None documented	None documented	Exposures too limited to map	Exposures too limited to map	None
		Morita Formation (Km)	Maroon- weathering siltstone, sandstone, shale, & conglomerate. Limited exposures in fault slices in the NE part of Chiricahua National Monument.	Monderate	Wilderness designation	None	None	Unknown	None documented	Exposed at elevations of 1,770–1,840 m (5,800–6,040 ft): pine- fir forests	Unmaintained hiking trail	Bounded by normal faults
		Glance Conglomerate (Kg)	Cobble, pebble, & boulder conglomerate composed of subrounded to subangular clasts of Paleozoic limestone, sandstone, & quartzite; thickness 0–200 m (0–660 ft). Exposed in NE Chiricahua National Monument in slopes & fault slices.	High, but less resistant where influenced by faults	Wilderness designation	None	None	Unknown	None documented	Upper elevation vegetation (2,000–2,400 m; 7,000–7,800 ft)	NE boundary; off- trail hiking	Very few exposures
CRETACEOUS & JURASSIC	Volcaniclastic &volcanic rocks (KJv)		Dark- green to gray volcanic & sedimentary rocks—lava flows & sedimentary rocks rich in volcanic debris (metagraywacke, meta- andesite & metabasalt); variably metamorphosed to green- schist- facies assemblages of chlorite, calcite, albite, epidote, & magnetite; metagraywacke is typically siltstone & fine- to medium- grained volcanic sandstone, but coarse- grained sandstone & breccia beds are near inferred volcanic centers; metabasalt forms lava flows, which are locally pillowed, dikes, & possibly sills in exposures to the SE; overlies Kbls but recent work to SE suggests a Jurassic age for at least part of unit; thickness greater than 300 m (980 ft). Forms slopes & ridges in NE part of the Monument; well exposed along the road to Onion Saddle, SE of the Monument.	High	Mostly in wilderness designation; has one unimproved road	Rockfall, scree slopes	None	Potential Native American sites	King of Lead Mine (sec 18, T16S, R30E) at contact with Phu; NE border; galena, & sphalerite specimens	Upper elevation vegetation (about 2,000–2,100 m; 5,900–7,000 ft): pine- fir forests	Traversed by 4WD road to King of Lead Mine	Contact with Kbls poorly exposed so not known if units are in depositional or structural contact
PERMIAN (Lower)	Concha Limestone (Pcn)		Dark- gray, thick- bedded, fossiliferous, cherty limestone; thickness 190–200 m (620–660 ft). Form steep slopes in NE part of Monument.	High	Wilderness designation	Rockfall, scree slopes	Large productid brachiopods	Unknown	None	Upper elevation vegetation	Limited exposures on slopes	About 265–270 million years old
	Scherrer Formation (Ps)		Light- gray to pinkish- gray, fine- grained, nearly massive sandstone & quartzite; thickness greater than 49 m (160 ft). Form steep slopes in NE part of Monument.	High	Wilderness designation	Rockfall, scree slopes	None	Unknown	None	Upper elevation vegetation	Limited exposures on slopes	About 270–272 million years old
	Epitaph Dolomite & Colina Limestone, Undivided (Pec)		Dark- gray, coarse- grained, sparsely fossiliferous, slightly cherty limestone & local light- gray, fine- grained, limy dolomite; thickness 160 m (540 ft). Form steep slopes in NE part of Monument.	High	Wilderness designation	Rockfall, scree slopes	Large echinoid spines & gastropods	Unknown	None	Upper elevation vegetation	Limited exposures on slopes	About 272–275 million years old
	Earp Formation (Pea)		Pale- red siltstone & argillaceous limestone; interbedded with light- gray to yellowish- gray limestone; thickness >300 m (>1,000 ft). Very limited exposures on steep slopes in NE edge of the Monument.	High	Wilderness designation	Rockfall, scree slopes	Marine invertebrate fossils (fusulinids)	Unknown	None	Upper elevation vegetation	Very few exposures in the Monument	About 280–299 million years old
	Horquilla Limestone (Upper Member) (Phu)		Light- gray, thin- to thick- bedded, fine- grained calcilutite, coarse- grained bioclastic & fossiliferous cherty limestone, & inter- bedded pink siltstone; thickness about 400 m (1,300 ft). Very limited exposures on steep slopes in NE edge of the Monument.	High	Wilderness designation	Rockfall, scree slopes	Marine invertebrate fossils (fusulinids)	Unknown	King of Lead Mine (sec 18, T16S, R30E) at contact with KJv; NE border; galena & sphalerite specimens	Upper elevation vegetation	Very few exposures in the Monument	About 285–299 million years old

Interpretive map and guide to the volcanic geology of Chiricahua National Monument and vicinity, Cochise County, Arizona

Geologic History

This section describes the rocks and unconsolidated deposits that appear on the digital geologic map of Chiricahua National Monument, the environment in which those units were deposited, and the timing of geologic events that created the present landscape.

Paleozoic rocks about 280 million years old are the oldest rocks exposed in Chiricahua National Monument (Pallister and du Bray 1997). However, the oldest rock in southeastern Arizona is the Pinal Schist that formed about 1.7 billion years ago during Precambrian time (fig. 9). This metamorphic rock is exposed in the Dos Cabezas Mountains, between Chiricahua National Monument and Willcox, Arizona. At the time of its deposition, the Southwest may have looked like today's western Pacific, where numerous volcanic belts are separated by seas (Hoffman 1989; Pallister et al. 1997).

During Precambrian time, the southwestern coastline of North America paralleled the present border of Wyoming and Colorado. A sequence of volcanic belts, or island arcs, were plastered, or accreted, onto the margin of North America in a process of continental growth that is part of the global process of plate tectonics. By 1.4 billion years ago, most of what is now the Arizona land surface had been added to the North American continent, forming a new coastal province.

New masses of molten rock then intruded the accreted coastal province. The granodiorite in Fort Bowie National Historic Site, for example, intruded the Pinal Schist about 1.375 billion years ago (Drewes 1981). Another example of these Precambrian granitic intrusions can be found in nearby road cuts on Arizona highway 181, about 2.4 km (1.5 mi) east of Dos Cabezas, Arizona (Pallister et al. 1997). This granite contains feldspar crystals 2.54 cm (1 in) or more across.

The next 800 million years of the geologic history of southeastern Arizona are a mystery. Erosion has removed any rocks that were deposited during this time, leaving an unconformity in the geologic record that separates the 1.4-billion-year-old Precambrian rocks from the 510–542-million-year-old Cambrian rocks (fig. 9). This remarkable unconformity is exposed in road cuts 5.6 km (3.5 mi) east of Dos Cabezas (Pallister et al. 1997).

Paleozoic History

Throughout the Paleozoic (542–251 million years ago), southeastern Arizona was covered by an ancient sea. Thick layers of carbonate and siliceous sediments accumulated on the sea floor.

Ranging in age from 299 to 265 million years old, Permian-aged strata on the rugged flank of Timber Mountain are the only Paleozoic rocks exposed in Chiricahua National Monument. Fossil brachiopods, echinoid spines, and gastropods are abundant in the Concha Limestone, Colina Limestone, Epitaph Dolomite, Earp Formation, and Horquilla Limestone (fig. 3). These Permian strata record shallow-water coral reef environments (fig. 10) (Pallister et al. 1997). Also in the Permian, a shallow marine embayment encroached into southeastern New Mexico from the south. This embayment produced the Permian reef complex, exposed today in Guadalupe National Park and Carlsbad Caverns National Park.

During the Permian (about 275 million years ago), what is now Wyoming and eastern Utah was located near the equator along the western margin of Pangaea (Biek et al. 2000; Morris et al. 2000). Pangaea was the supercontinent that formed during the late Paleozoic as the globe's landmasses sutured together. A dry, high atmospheric pressure climatic belt prevailed in this western part of Pangaea and resulted in restricted marine evaporitic conditions (Peterson 1980). Warm, shallow seas and sabkhas (broad, very flat surfaces near sea level) covered the area.

At the close of the Permian, continental shelf and slope rocks were compressed against the western continental margin in the vicinity of what is now Nevada. Southeast of Arizona, the South American tectonic plate collided with the North American plate and closed the proto-Gulf of Mexico. The collision caused the uplift of the northwest-southeast-trending Ancestral Rocky Mountains in Colorado, the northeast-southwest-trending Sedona Arch in central Arizona, and the Mogollon Rim, an uplift in east-central Arizona. South of the Mogollon Rim, an offshore carbonate shelf developed in southeastern Arizona (Blakey 1980; Peterson 1980).

The close of the Permian brought the third, and most severe, major mass extinction of geologic time. This extinction marked the end of the Paleozoic Era. Much more extensive than the extinction event that terminated the dinosaurs at the end of the Mesozoic, the end of the Permian extinction eliminated approximately 96% of all species (Raup 1991). There are a number of hypotheses regarding the processes that could cause such an extinction. One recent extinction hypothesis suggests that a comet, about 6–13 km (4–8 mi) in diameter, slammed into Earth (Becker et al. 2001). Such an impact could have triggered vast volcanic eruptions that spread lava over an area two-thirds the size of the United States.

Powerful updrafts would have carried dust and grit swirling into the upper atmosphere. Particulate matter would have reflected and scattered sunlight, resulting in years of global cooling with freezing temperatures even during summertime. A recent example of this type of global cooling occurred in 1816, called "the year without a summer," following an 1815 volcanic explosion in Tambora, Indonesia. Sulfuric emissions from the eruptions would have mixed with atmospheric water to produce downpours of corrosive acid rain. During the end of the Permian extinction, thousands of species of insects, reptiles, and amphibians died on land while in the oceans, coral formations vanished, as did snails, urchins, sea lilies, some fish, and the once-prolific trilobites. Five million years later, at the dawn of the Mesozoic Era, the oceans began to evolve into the chemistry of the modern oceans, and on land, the first mammals and dinosaurs emerged.

Mesozoic History

The next 150–180 million years of local geologic history is not represented in Chiricahua National Monument. The Permian Concha Limestone (about 280 million years old) is overlain by conglomerate and sandstone of the Cretaceous Bisbee Group (about 100 million years old) (fig. 11). The unconformity represents a period of uplift and erosion in southeastern Arizona.

From middle Paleozoic through Mesozoic time, the western margin of North America was an active plate margin where dense oceanic crust was subducted beneath lighter continental crust. In plate tectonic theory, spreading ocean ridges and subduction zones act as "conveyer belts" that move lithospheric plates around the globe. As plates collide, sediments deposited in the trench that forms at the juncture of the two plates, as well as bits of oceanic crust (including islands like Hawaii and island arcs like Japan), are scraped off the top of the "conveyor belt" and accreted onto the edge of the continent, thereby contributing to continental growth.

As oceanic crust sinks beneath continental crust, overlying rocks melt and begin to rise through the crust, becoming enriched in volatiles and melting some continental rocks. Magma may ascend directly to the surface and erupt as a volcano, or it may pond beneath the surface to form subterranean reservoirs of molten rock, known as magma chambers. Magma in these reservoirs cools slowly and eventually forms coarse-grained igneous rocks such as granite.

During much of the Mesozoic Era, subduction zones underlay southeastern Arizona (Pallister et al. 1997). Volcanoes are common above subduction zones, and during the Mesozoic Era a volcanic island arc, similar to those that formed in the Precambrian and Paleozoic, formed off the coast of western North America. Magma chambers developed, forming island arc volcanoes and the Sierra Nevada batholith (including the granitic masses in Yosemite National Park) in California. About 165 million years ago, huge volcanic eruptions in southeastern Arizona formed calderas in the Huachuca and southern Dragoon Mountains.

During the Early Cretaceous in southern Arizona, the tectonic regime was dominated by rifting along the northwest-southeast-trending Bisbee Basin, which was located near the southwestern margin of the North American tectonic plate (fig. 11) (Elder and Kirkland 1994; Dickinson and Lawton 2001; Haenggi and Muehlberger 2005). Rather than accreting land to the continent in this region, tectonic forces were pulling the land apart. Rifting associated with the Mojave-Sonora megashear, a strike-slip fault with horizontal displacement measured in tens to hundreds of kilometers, tilted the Mogollon slope towards the northeast and opened a series of local pull-apart basins (Elder and Kirkland 1994; Anderson and Nourse 2005).

The Glance Conglomerate, the basal unit of the Bisbee Group in this area, represents proximal deposits of alluvial fan systems that rimmed local fault-block mountain ranges and basins (Bilodeau and Lindberg 1983). Conglomerate beds in the Bisbee Group, which are widely exposed in the hills east of Whitetail Pass, contain cobbles of fossil-rich limestone shed from uplifted mountains composed of the underlying Paleozoic rocks. Fine-grained sedimentary rocks and lava flows overlie the conglomerate beds. Some sandstone beds contain petrified wood from fossilized trees while other beds are colored dark green or gray from abundant volcanic fragments. Lava that flowed into water formed pillow-like shapes ("pillow lava") that can be seen along the road across Onion Saddle, between Chiricahua National Monument and Portal, Arizona. The Bisbee Group rocks record deposition in a shallow inland sea that extended from southeastern Arizona across southern New Mexico and to the Gulf of Mexico (fig. 11) (Pallister et al. 1997).

During the Late Cretaceous, southeastern Arizona formed part of the western border of the most extensive interior seaway ever recorded in North America (fig. 12). As mountains rose in the west, the Gulf of Mexico continued to rift open in the south, and seawater encroached northward into an elongate depression forming in the western interior of North America. Marine water also began to transgress southward from the Arctic region. The seas advanced and retreated many times during the Cretaceous until a seaway extended from today's Gulf of Mexico to the Arctic Ocean, a distance of about 5,000 km (3,000 mi) (Kauffman 1977).

At the close of the Mesozoic Era, about 65 million years ago, another burst of volcanic activity and faulting in southeastern Arizona resulted from the Laramide orogeny (about 75–35 million years ago), an episode of tectonic compression and mountain-building that is responsible for the modern Rocky Mountains and most of the ores of copper, silver, and gold deposited in the southwestern United States (Pallister et al. 1997). Welded tuff that forms the summit of the Dos Cabezas Mountains erupted during this period, also.

Cenozoic History

Volcanism continued during the first half to two-thirds of the Tertiary because a subduction zone was present beneath the southwestern United States (fig. 13). The Santa Catalina Mountains of southern Arizona contain at least 12 plutons that can be divided into three intrusive epochs: (1) 70-65 million years ago (Latest Cretaceous to Paleocene), (2) 50-44 million years ago (Eocene), and (3) 29-25 million years ago (Oligocene) (Anderson 1988). In the Chiricahua Mountains, most of the volcanic activity occurred between about 35 and 25 million years ago, primarily in the Oligocene epoch (fig. 13).

Dark andesitic and basaltic lava flows, exposed in the road cuts uphill from Bonita Park on the road to Sugarloaf Mountain and Massai Point, erupted from scattered volcanoes. Viscous rhyolite flows erupted from small volcanoes and were accompanied by nuée ardente (glowing cloud and avalanche) deposits consisting of thin beds of rhyolite ash and rock debris. Viscous rhyolite accumulated to form vertical flow ramps. Sedimentary rocks near Bonita Park were deposited by streams along the floor of the ancient Chiricahua National Monument valley about 30 million years ago (Pallister et al. 1997).

About 32–28 million years ago, an assemblage of rhyolite, dacite, and andesite lavas and pyroclastic rocks were erupted into the area of Chiricahua National Monument. These became the Faraway Ranch Formation and underlie the Jesse James Canyon Tuff and Rhyolite Canyon Tuff in the Monument area (Pallister et al. 1997). This formation also includes the ash-rich deposits of the rhyolite on Erickson Ridge.

As much as 240 m (790 ft) of rhyolite ash-flow tuff (the Jesse James Canyon Tuff) was deposited in an ancient valley in Chiricahua National Monument shortly before the Rhyolite Canyon Tuff was erupted. Since their compositions are similar, the Jesse James Canyon Tuff can be difficult to distinguish from the Rhyolite Canyon Tuff.

As described in the Features and Processes section, the eruption that produced the Turkey Creek caldera occurred about 26.9 Ma. More than 400 km^3 (100 mi^3) of magma was erupted from vents above the extensive pool of rhyolite magma and buried a region of at least 3,100 km^2 (1,200 mi^2) under a thick blanket of ash and pumice. The roof of the magma chamber collapsed, producing the Turkey Creek caldera (Pallister et al. 1997).

During the caldera-forming eruption, pyroclastic flows filled valleys adjacent to the volcano, including the valley where Chiricahua National Monument is today. Because of its dense welding and great thickness, this valley-filling deposit has not completely eroded away during the past 26.9 million years. After millions of years, at least 490 m (1,600 ft) of pyroclastic flows still remain in the Monument.

The dacite lava atop Sugarloaf Mountain records the final chapter in the volcanic history of Chiricahua National Monument. The source of this flow was about 10 km (6 mi) southeast of Sugarloaf Mountain.

Although the dacite atop Sugarloaf Mountain is the youngest volcanic rock in Chiricahua National Monument, caldera development continued in the area south of the Monument, where the central part of the caldera depression was uplifted to form a resurgent dome. Rhyolite lavas leaked out to fill the moat surrounding the dome.

Faulting and erosion have dramatically changed the topography of the Chiricahua Mountains over the past 27 million years. About 20 million years ago, subduction off the southwestern coast of North America ceased as the former East Pacific Ocean spreading ridge ran into the subduction zone (Pallister et al. 1997; Kiver and Harris 1999). Plate motion shifted to strike-slip faulting, initiating the San Andreas Fault system of California. When subduction ceased, volcanism waned in the Chiricahua region. Strike-slip faulting and high heat flow beneath the southwestern region of the United States combined to cause the crust to stretch, or pull apart. Large crustal blocks were downdropped along high-angle normal faults, creating grabens, while other blocks were uplifted into mountain ranges, known as horsts. This type of regional faulting produced the Basin and Range Province of today's southwestern landscape.

Nearly vertical normal faults separate the Chiricahua Mountains from the San Simon Valley to the east and parts of the Sulphur Springs Valley to the west (Pallister et al. 1997). In some areas, such as in the Pinaleno and Rincon–Santa Catalina Mountains, low-angle faulting also accommodated crustal extension. During this extension process, small amounts of basalt magma leaked from the underlying mantle to form the San Bernadino volcanic field along the southeastern flank of the Chiricahua Mountains.

Downward-cutting streams, faulting, and erosion exposed the rocks in the Chiricahua Mountains as uplift of southeastern Arizona continued into the Quaternary. Sediments flushed from the canyons during flash floods have formed alluvial fans along the mountain fronts and continue to fill the basins adjacent to the mountain ranges. Focused along joint planes, wind and water erosion proceeded to dissect the welded tuff into the extraordinary pinnacles and columns characteristic of Chiricahua National Monument today.

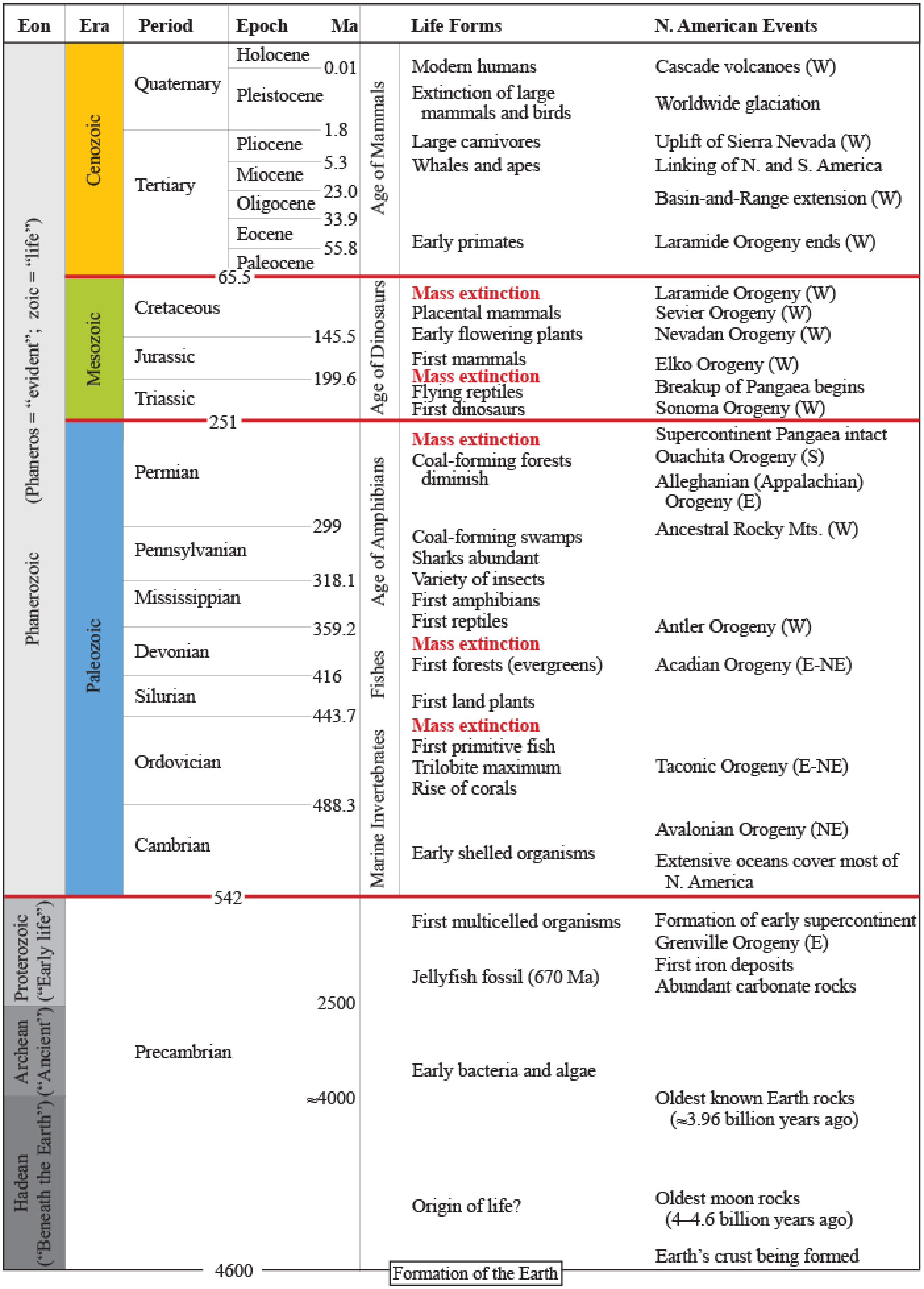

Figure 9. Geologic Timescale. Adapted from the U.S. Geological Survey (http://pubs.usgs.gov/fs/2007/3015/). Red lines indicate major unconformities between eras. Included are major events in the history of life on Earth and tectonic events occurring on the North American continent. Absolute ages shown are in millions of years (Ma). Compass directions in parentheses indicate the regional location of individual geologic events.

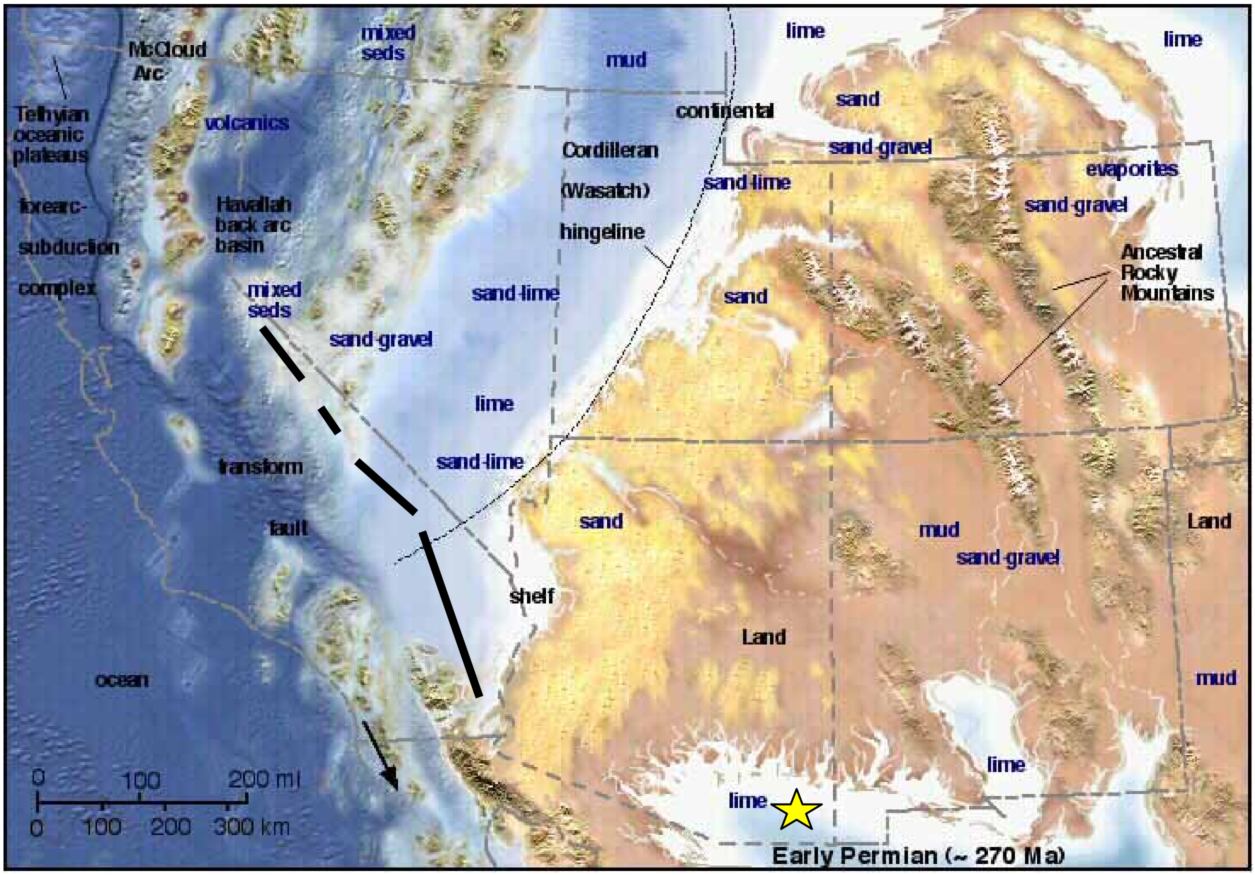

Figure 10. Early Permian paleogeographic map of the southwestern United States. About 270 million years ago, a shallow sea encroached into southeastern Arizona. The yellow star is the approximate location of today's Chiricahua National Monument. Browns and yellows denote land, light blue represents shallow marine, and dark blue represents deeper marine environments. The arrow in the lower left corner of the map shows the relative direction of movement of the offshore land masses relative to the North American margin. The "transform fault" marks the suture zone between the oceanic plate and the North American plate, although Permian plate boundaries are not well defined. The "Cordilleran (Wasatch) hingeline" marks the location of the future Wasatch Mountains. Map modified from Dr. Ron Blakey (Northern Arizona University), http://jan.ucc.nau.edu/~rcb7/perpaleo.html, accessed February 2007.

Figure 11. Early Cretaceous paleogeographic map of the southwestern United States. The yellow star is the approximate location of today's Chiricahua National Monument. About 130 million years ago, the shallow marine Bisbee Basin in southeastern Arizona was the site of tectonic rifting in which lithospheric plates are in the process of splitting apart. An epicontinental seaway encroached from the north. The "transtensional basin," "accretionary prism mélange," "fore arc basin," and "fore-arc subduction complex" are associated with the oceanic-continental (Andean-style) subduction zone between the North American Plate and the Farallon Plate. The thick, black line marks the approximate location of the subduction zone. Basins in southern Arizona and California formed due to strike-slip, extensional faulting (dashed lines) and were the sites of thick marine and continental deposition. Map modified from Dr. Ron Blakey (Northern Arizona University), http://jan.ucc.nau.edu/~rcb7/crepaleo.html, accessed March 2007.

A) Western Interior Seaway of North America (light blue)

B) Depositional patterns in the southwestern United States during the Late Cretaceous

Figure 12. Late Cretaceous paleogeographic map of North America. (A) About 80 million years ago, an inland seaway (light blue) extended from the Gulf of Mexico to the Arctic Ocean. Map courtesy of Dr. Ron Blakey (Northern Arizona University), http://jan.ucc.nau.edu/rcb7/namK85.jpg. (B) Vast alluvial plains formed in the southwest as the seaway slowly retreated to the northeast about 75 million years ago. The yellow star is the approximate location of today's Chiricahua National Monument. Mountains rose from compression of the Cordilleran arc along the western margin of North America, marked by the thick, dashed lines. Transform faults, caused by oblique collision with the Farallon Plate, transported pieces of the western margin northward along the edge of North America. Map modified from Dr. Ron Blakey (Northern Arizona University), http://jan.ucc.nau.edu/rcb7/crepaleo.html, accessed February 2009. .

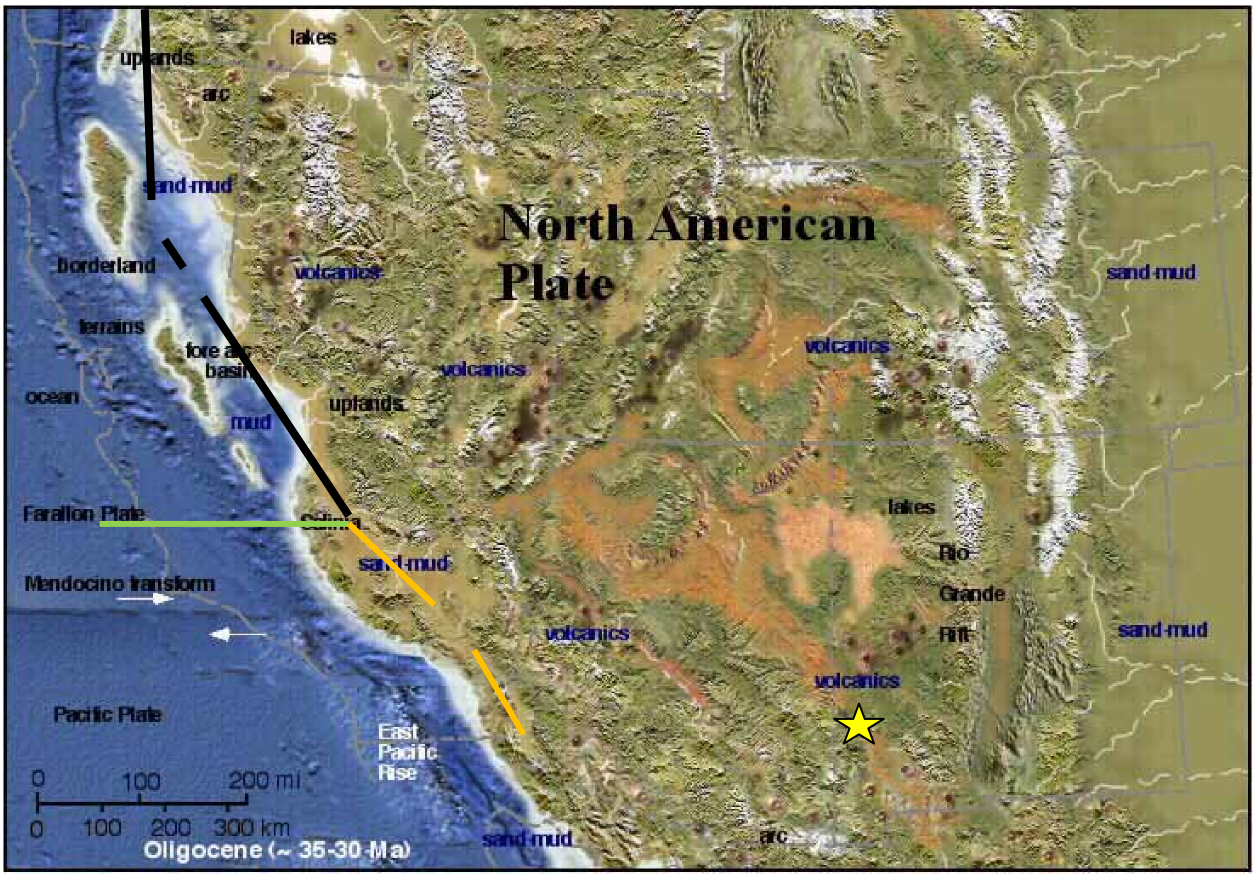

Figure 13. Oligocene paleogeographic map of the southwestern United States. About 30-35 million years ago, volcanism was widespread across much of the Western Interior of North America. The first stages of the Rio Grande Rift in New Mexico and southern Colorado developed as parts of western North America changed from compressional tectonics to extensional tectonics. The East Pacific Rise (orange line), a Pacific spreading center, neared the coast of southwestern North America. Its impending collision would cause subduction to cease and initiate strike-slip faulting and the San Andreas Fault system. The arrows in the lower left corner show the direction of movement along the Medocino transform fault (green line), which separated the Pacific Plate (south of the fault) from the Farallon Plate (north of the fault). The thick, black line represents the boundary between the North American Plate and the Farallon Plate. The yellow star is the approximate location of today's Chiricahua National Monument. Map modified from Dr. Ron Blakey (Northern Arizona University), http://jan.ucc.nau.edu/~rcb7/terpaleo.html, accessed February 2009.

Glossary

This glossary contains brief definitions of technical geologic terms used in this report. Not all geologic terms used are referenced. For more detailed definitions or to find terms not listed here please visit: http://wrgis.wr.usgs.gov/docs/parks/misc/glossarya.html.

absolute age. The geologic age of a fossil, rock, feature, or event in years; commonly refers to ages determined radiometrically.

accreted. The process by which continental crust grows thorugh the addition of smaller fragments of crust to its margins.

alluvial fan. A fan-shaped deposit of sediment that accumulates where a high-gradient stream flows out of a mountain front into an area of lesser gradient.

alluvium. Stream-deposited sediment that is generally rounded, sorted, and stratified.

amygdule. A gas cavity or vesicle in an igneous rock, which is filled with minerals.

andesite. A volcanic rock with about 52–63% silica.

anhedral. A grain lacking well-developed crystal faces.

aphanitic. Fine-grained igneous rock whose components are not distinguishable with the unaided eye.

ash (volcanic). Fine pyroclastic material ejected from a volcano (also see tuff).

ash flow. A dense cloud composed predominantly of hot ash and pumice. Moves rapidly due to liberation of gas from pumice and to ingestion of air at flow front. A type of pyroclastic flow.

asthenosphere. Weak layer in the upper mantle below the lithosphere where seismic waves are attenuated.

basalt. A dark-colored volcanic rock low in silica (<52%).

basement. The undifferentiated rocks, commonly igneous and metamorphic, that underlie the rocks at the surface.

basin (sedimentary). Any depression, from continental to local scales, into which sediments are deposited.

basin (structural). A regional depression bounded on at least one side by a fault zone.

batholith. A massive, discordant pluton, greater than 100 km^2 (40 mi^2), and often formed from multiple intrusions.

bed. The smallest lithostratigraphic unit, distinguishable from beds above and below, and commonly ranging in thickness from 1 cm (0.4 in) to 1–2 m (3–6 ft).

bedding. Depositional layering or stratification of sediments.

block (fault). A crustal unit bounded by faults.

breccia. A coarse-grained, generally unsorted, sedimentary rock with cemented angular clasts.

calcilutite. A limestone consisting predominantly (>50%) of detrital calcite particles of silt and/or clay size; a consolidated carbonate mud.

caldera. A large bowl- or cone-shaped depression in the summit of a volcano formed by explosion or collapse.

celadonite. A soft, green or gray–green, earthy, dioctahedral mineral of the mica group.

chatoyant. The property of some minerals to produce a distinct reflected color or luster. The feldspar mineral sanidine in the Rhyolite Canyon Tuff shows this property.

cementation. The process by which clastic sediments are converted into rock by precipitation of mineral cement among the grains of the sediment.

chemical weathering. Chemical breakdown of minerals at Earth's surface via reaction with water, air, or dissolved substances; commonly results in a change in chemical composition more stable in the current environment.

chicken head. Knobby or plate-like protrusions that are case-hardened and developed on otherwise smooth rock.

clastic. Rock or sediment made of fragments of pre-existing rocks.

columnar joints. Planar or curvilinear fractures that bound polygonal columns of rock. Typically form due to contraction during cooling of volcanic rocks.

conglomerate. A coarse-grained sedimentary rock with clasts >2 mm (0.08 in) in a fine-grained matrix.

continental crust. The type of crustal rocks underlying the continents and continental shelves; having a thickness of 25–60 km (16–37 mi)and a density of approximately 2.7 grams per cubic centimeter.

cordillera. A Spanish term for an extensive mountain range; used in North America to refer to all of the western mountain ranges of the continent.

craton. The relatively old and geologically stable interior of a continent (also see "continental shield").

cross-bedding. Uniform to highly varied sets of inclined sedimentary beds deposited by wind or water.

crust. Earth's outermost compositional shell, 10–40 km (6–25 mi) thick, consisting predominantly of relatively low-density silicate minerals (also see oceanic crust and continental crust).

dacite. A volcanic rock with about 63–69% silica.

debris flow. A moving mass of rock fragments, soil, and mud; more than half the particles being larger than sand size.

deformation. A general term for the process of faulting, folding, shearing, extension, or compression of rocks as a result of various Earth forces.

devitrification. Conversion of glass to crystalline material.

dike. A tabular, discordant igneous intrusion.

dip. The angle between a structural surface and a horizontal reference plane measured normal to their line of intersection.

distal. A sedimentary deposit consisting of fine clastics that formed farthest from the source area.

dolomite. A carbonate sedimentary rock consisting of >50% of the mineral dolomite (calcium-magnesium carbonate).

epicontinental. Situated on the continental shelf or on the continental interior, as a epicontinental sea.

euhedral. A grain bounded by perfect crystal faces.

eutaxitic. Said of the banded structure in certain extrusive rocks, resulting from the parallel arrangement and alteration of layers of different textures, mineral composition, or color.

extrusive. Of or pertaining to the eruption of igneous material onto Earth's surface.

facies (metamorphic). Rocks of any origin formed within certain pressure-temperature conditions.

fault. A subplanar break in rock along which relative movement occurs between the two sides.

feldspar. The most common mineral group in the shallow levels of Earth's crust. Composed of combinations of potassium, sodium, and calcium combined with aluminum and silica.

fiamme. Italian for "flame." Refers to lens-shaped, flattened pumice fragments in a welded tuff. In cross-section such fragments commonly have jagged terminations, giving the appearance of flames.

flow ramp. A sequence of layers in a lava flow that ramp abruptly upward. Most common in high-silica (rhyolite) lavas due to their high viscosity.

footwall. The mass of rock beneath a fault, orebody, or mine working, especially the wall rock beneath an inclined vein or fault.

formation. Fundamental rock-stratigraphic unit that is mappable and lithologically distinct from adjoining strata and has definable upper and lower contacts.

fracture. Irregular breakage of a mineral; also any break in a rock (e.g., crack, joint, or fault).

frost wedging. The breakup of rock due to the expansion of water freezing in fractures.

fumarole pipes. Steam vents within volcanic rocks that result from degassing after deposition of ash-flow deposits, or from steam from underlying wet ground.

graben. A down-dropped structural block bounded by steeply dipping, normal faults (also see horst).

graded bedding. The result of gravitational settling of particles in a fluid which results in larger and heavier grains being concentrated at the base of a deposit..

granite. A high-silica rock (typically more than 70% silica) composed mainly of coarse-grained crystals of quartz and feldspar.

granophyre. An irregular microscopic intergrowth of quartz and alkali feldspar.

hanging wall. The overlying side of an orebody, fault, or mine working, especially the wall rock above an inclined vein or fault.

hoodoo. A pillar of rock developed by erosion of horizontal strata of varying hardness. Typically found in climatic zones where most rainfall is concentrated during a short period of the year.

horst. An uplifted structural block bounded by high-angle normal faults (also see graben).

igneous. Refers to a rock or mineral that originated from molten material; one of the three main classes of rocks—igneous, metamorphic, and sedimentary.

intrusion. A body of igneous rock that invades older rock. The invading rock may be a plastic solid or magma that pushes its way into the older rock.

inverse grading. Graded bedding in which larger grains settle above smaller ones. Indicates rapid lateral flow. A characteristic feature of surge beds.

island arc. A line or arc of volcanic islands formed over and parallel to a subduction zone.

joint. A semi-planar break in rock without relative movement on either side of the fracture surface.

lahar. A mudflow composed chiefly of volcaniclastic materials on the flank of a volcano.

landslide. Any process or landform resulting from rapid, gravity-driven mass movement.

lava. Fluid rock that issues from a volcano or fissure; also, the same material solidified by cooling.

Liesegang bands. Secondary, nested rings or bands caused by chemical deposition from a fluid that migrated through the pore space of the rock.

limestone. A sedimentary rock consisting chiefly of calcium carbonate.

lithology. The physical description of a rock, especially its color, mineralogic composition, and grain size.

lithophysa. A hollow, bubble-like structure composed of concentric shells of finely crystalline alkali feldspar, quartz, and other minerals; found in volcanic rocks containing abundant silica.

lithosphere. Earth's relatively rigid outmost shell, 50–100 km (30–60 mi) thick that encompasses the crust and uppermost mantle.

magma. Molten rock capable of intrusion and extrusion.

magma chamber. A reservoir of molten rock beneath Earth's surface.

mantle. The zone between Earth's crust and core.

matrix. The groundmass of an igneous rock or the finer grained material enclosing the larger grains in a sedimentary rock; also the rock or sediment in which a fossil is embedded.

mechanical weathering. The physical breakup of rocks without change in composition.

megashear. A strike-slip fault with a horizontal displacement measured in tens to hundreds of kilometers.

member. A lithostratigraphic unit with definable contacts; a member subdivides a formation.

metamorphic. Pertaining to the process of metamorphism or its results.

metamorphism. Literally, "change in form." Metamorphism occurs in rocks through mineral alteration, genesis, and/or recrystallization from increased heat and pressure.

mineral. A naturally occurring, inorganic crystalline solid with a definite chemical composition.

moat. An annular depression between the central resurgent dome and the edge of a caldera depression.

neck (volcanic). An eroded, vertical, pipe-like intrusion that represents the vent of a volcano.

normal fault. A dip-slip fault in which the hanging wall moves down relative to the footwall.

nuée ardente. A "glowing cloud" of hot ash that rises from an avalanche of volcanic ash and rock fragments. A type of pyroclastic flow.

oceanic crust. Earth's crust formed at spreading ridges that underlie the ocean basins. Oceanic crust is 6–7 km (3–4 mi) thick and generally of basaltic composition.

orogeny. A mountain-building event.

outcrop. Any part of a rock mass or formation that is exposed or "crops out" at Earth's surface.

paleogeography. The study, description, and reconstruction of the physical geography from past geologic periods.

parent (rock). The original rock from which sediments or other rocks are derived.

perlitic. Said of the texture of glassy volcanic rocks characterized by numerous curving cracks roughly concentric around closely spaced centers.

phenocryst. A coarse crystal in a porphyritic igneous rock.

pillow lava. Lava that flowed under water and formed pillow-shaped masses as a consequence of chilling and solidification of the outer surface while the inner part of the lava flow was still flowing.

plate tectonics. The theory that the lithosphere is broken up into a series of rigid plates that move over Earth's surface above a more fluid aesthenosphere.

pluton. A body of intrusive igneous rock.

porphyry. An igneous rock with abundant coarse crystals in a fine-grained groundmass.

proximal. A sedimentary deposit consisting of coarse clastics that formed nearest the source area.

pumice. A gas-bubble-rich volcanic rock typically with enough bubbles to allow it to float in water.

pyroclastic. Clastic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent; also pertaining to rock texture of explosive origin.

pyroclastic flow. A dense could of hot ash, rock debris, pumice, and gas that moves rapidly downslope from a volcano and leaves an ash-rich deposit.

radioactivity. The spontaneous decay or breakdown of unstable atomic nuclei.

radiometric age. An age in years determined from radioisotopes and their decay products.

relative dating. Determining the ageof rocks, events, or fossils without reference to their absolute age.

resurgent dome. A region of domal uplift within a caldera depression.

reverse fault. A contractional, high-angle ($>45^{\circ}$), dip-slip fault in which the hanging wall moves up relative to the footwall (also see "thrust fault").

reomorphic. Said of a rock whose form and internal structure indicate that it was subjected to ductile flow; also, the phenomena causing such a rock.

rhyolite. A silica-rich volcanic rock or magma (>70% silica).

sandstone. Clastic sedimentary rock of predominantly sand-sized grains.

schist. A metamorphic rock that is rich in the platy mineral mica.

sediment. An eroded and deposited, unconsolidated accumulation of lithic and mineral fragments.

sedimentary rock. A consolidated and lithified rock consisting of detrital and/or chemical sediment(s).

shale. A clastic sedimentary rock made of clay-sized particles that exhibit parallel splitting properties.

sierra. An often used Spanish term for a rugged mountain range.

sill. A tabular, igneous intrusion that is concordant with the country rock.

siltstone. A variably lithified sedimentary rock composed of silt-sized grains.

slope. The inclined surface of any geomorphic feature or rational measurement thereof (syn: gradient).

slump. A generally large, coherent mass movement with a concave-up failure surface and subsequent backward rotation relative to the slope.

spherulites. A spherical mass produced by crystallization of volcanic glass at high temperature and typically composed of minute crystal fibers of feldspar that radiate from a common point.

spreading ridges. The globe-encircling submarine mountain ranges where the oceanic sea floor and crust is created by upwelling and eruption of basalt magma..

strata. Tabular or sheet-like masses or distinct layers of rock.

stratigraphy. The geologic study of the origin, occurrence, distribution, classification, correlation, and age of rock layers, especially sedimentary rocks.

strike. The compass direction of the line of intersection that an inclined surface makes with a horizontal plane.

strike-slip fault. A fault with measurable offset where the relative movement is parallel to the strike of the fault.

structure. The attitude and relative positions of the rock masses of an area resulting from such processes as faulting, folding, and igneous intrusions.

subduction zone. A convergent plate boundary where oceanic lithosphere descends beneath a continental or oceanic plate and is carried down into the mantle.

subhedral. A grain partly bounded by crystal faces; intermediate between euhedral and anhedral.

surge beds. Ash-rich beds that result from laterally-directed volcanic blasts. Characterized by inverse grading and low-angle cross-bedding.

tectonic. Relating to large-scale movement and deformation of Earth's crust.

thrust fault. A contractional fault with a shallowly dipping fault surface ($<45^{\circ}$) where the hanging wall moves up and over relative to the footwall.

topography. The general morphology of Earth's surface, including relief and location of natural and anthropogenic features.

trace (fault). The exposed intersection of a fault with Earth's surface.

transform fault. A strike-slip fault that links two other faults or two other plate boundaries (e.g. two segments of a mid-ocean ridge).

trend. The direction or azimuth of elongation of a linear geologic feature.

tuff. Generally fine-grained, igneous rock formed of consolidated volcanic ash.

unconformity. A surface within sedimentary strata that marks a prolonged period of nondeposition or erosion.

uplift. A structurally high area in the crust, produced by movement that raises the rocks.

vent. An opening at Earth's surface through which volcanic materials are extruded.

vitrophyre. Dense volcanic glass produced by extreme welding at the base of a welded tuff deposit.

volcanic. Related to volcanoes; describes igneous rock crystallized at or near Earth's surface (e.g., lava).

volcaniclastic. All clastic volcanic materials formed by any process of fragmentation, dispersed by any kind of transporting agent, deposited in any environment, or mixed in any significant proportion with nonvolcanic fragments.

weathering. The set of physical, chemical, and biological processes by which rock is broken down in place.

welded tuff. A pyroclastic rock that has been hardened by the welding together of its glass shards under the combined action of heat, pressure, and hot gases.

xenocryst. A crystal that resembles a phenocryst in igneous rock but is a secondary mineral, forming after solidification of the rock in which it occurs.

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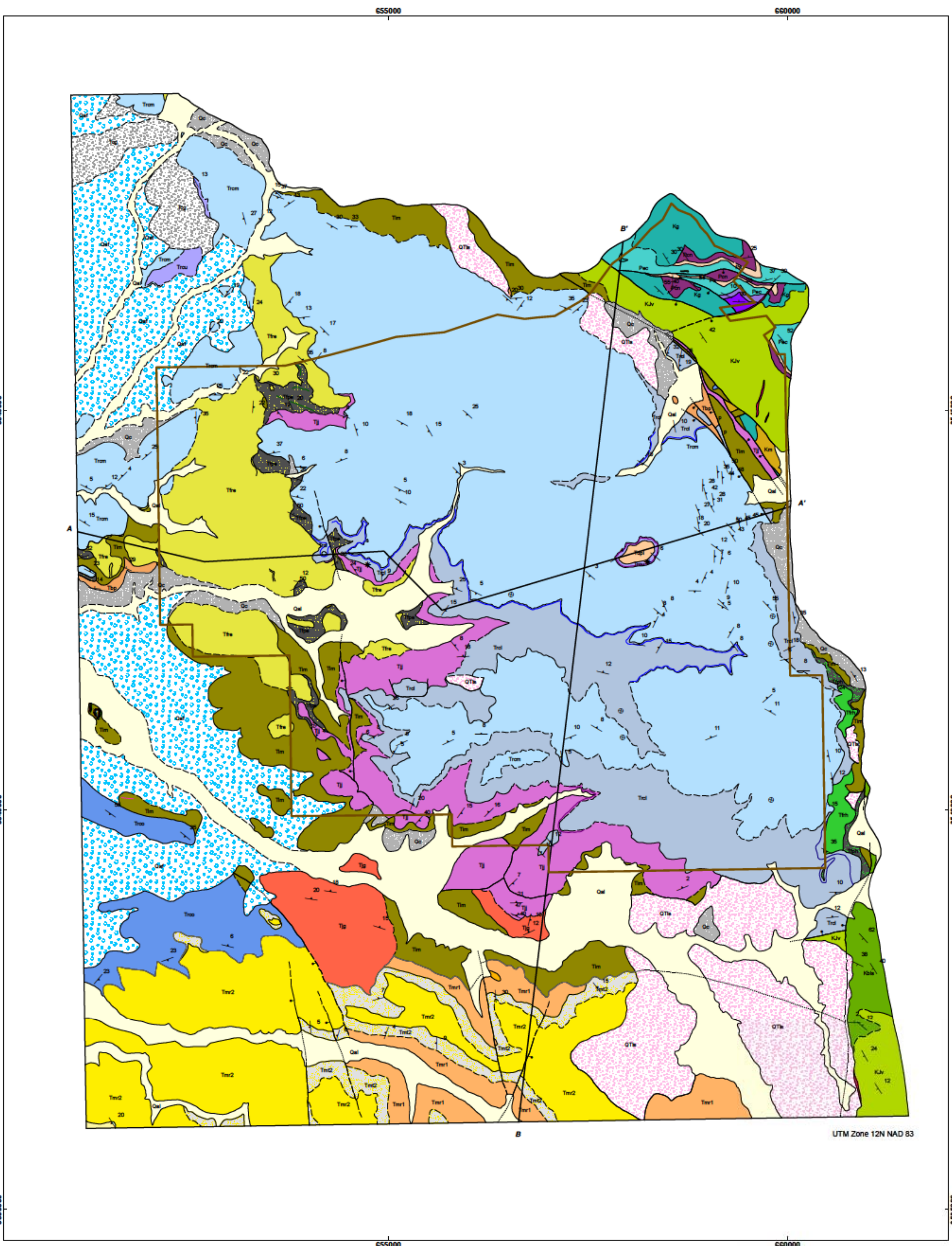
Appendix A: Geologic Map Graphic

The following page is a snapshot of the geologic map for Chiricahua National Monument. For a poster-size PDF of this map or for digital geologic map data, please see the included CD or visit the Geologic Resources Inventory publications Web page (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm).

Geologic Map of Chiricahua National Monument



NPS Boundary

Geologic Cross Section Lines

Geologic Attitude Observation Localities
- strike and dip of bedding
- strike and dip of foliation
- horizontal foliation
- downthrown side of fault

Geologic Age-Date Localities
- 40Ar/39Ar radiometric sample locality
- K/Ar radiometric sample locality

Linear Geologic Hazard Features
- landslide

High-Angle Fault
- known
- approximate
- concealed

Linear Volcanic Features
- prominent flow layering in Tfre
- trend of bedding in Tfpe
- base of ash cloud deposit in Trcl
- top of surge beds in Trcu

Unconformities
- unconformity, known
- unconformity, concealed

Geologic Point Units
- Timp - possible pillow basalt

Linear Geologic Units
- Trcv - Rhyolite Canyon Tuff, virtophyre
- Trca - Rhyolite Canyon Tuff, basal ash
- Tjjf - Jesse James Canyon Tuff, lithic-rich pyroclastic flow
- q - quartz vein

Geologic Contacts
- contact, known
- contact, approximate
- contact, gradational
- map extent

Geologic Units
- Qal - alluvium
- Qaf - alluvial fan deposits
- Qc - colluvium
- QTls - landslide deposits
- Tcg - conglomerate
- Tmt3 - moat deposits, Unit 3 (rhyolite tuff)
- Tmr2 - moat deposits, Unit 2 (rhyolite lava)
- Tmt2 - moat deposits, Unit 2 (tuff)
- Tmr1 - moat deposits, Unit 1 (rhyolite lava)
- Tmt1 - moat deposits, Unit 1 (tuff)
- Tdpl - dacite porphyry lava
- Trco - Outflow facies Rhyolite Canyon Tuff, undivided
- Trcu - Outflow facies Rhyolite Canyon Tuff, upper member
- Trcm - Outflow facies Rhyolite Canyon Tuff, middle member
- Trcl - Outflow facies Rhyolite Canyon Tuff, lower member
- Tjj - Jesse James Canyon Tuff
- Tfre - Rhyolite of Erickson Ridge
- Tfpe - Pyroclastic flow deposits of Erickson Ridge
- Tfrh - Rhyolite of Hands Pass
- Tfph - Pyroclastic flow deposits of Hands Pass
- Tbp - Sedimentary rocks of Bonita Park
- Tjg - Welded tuff of Joe Glen Ranch
- Tim - Intermediate and mafic lava flows
- Tims - areas of silicification
- Tr - rhyolite dikes
- Kbls - Bisbee Group, Mural Limestone
- Km - Bisbee Group, Morita Formation
- Kg - Glance Conglomerate
- KJv - volcaniclastic and volcanic rocks
- Pcn - Concha Limestone
- Ps - Scherrer Formation
- Pec - Epitaph Dolomite and Colina Limestone
- Pea - Earp Formation
- Phu - Horquilla Limestone, upper member

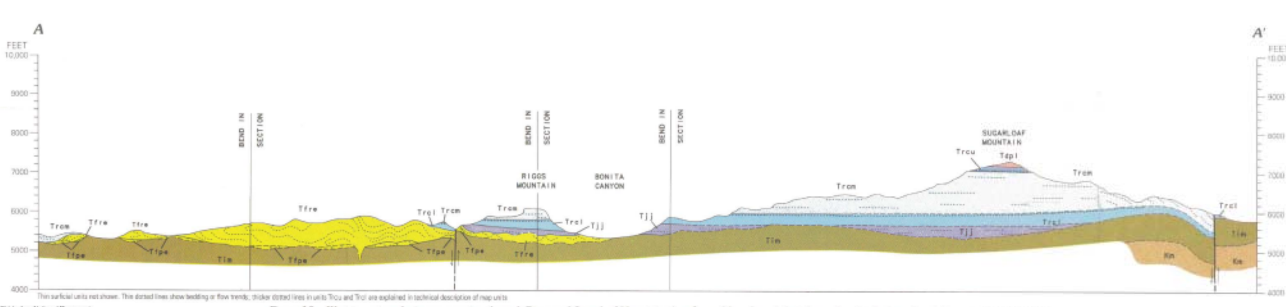
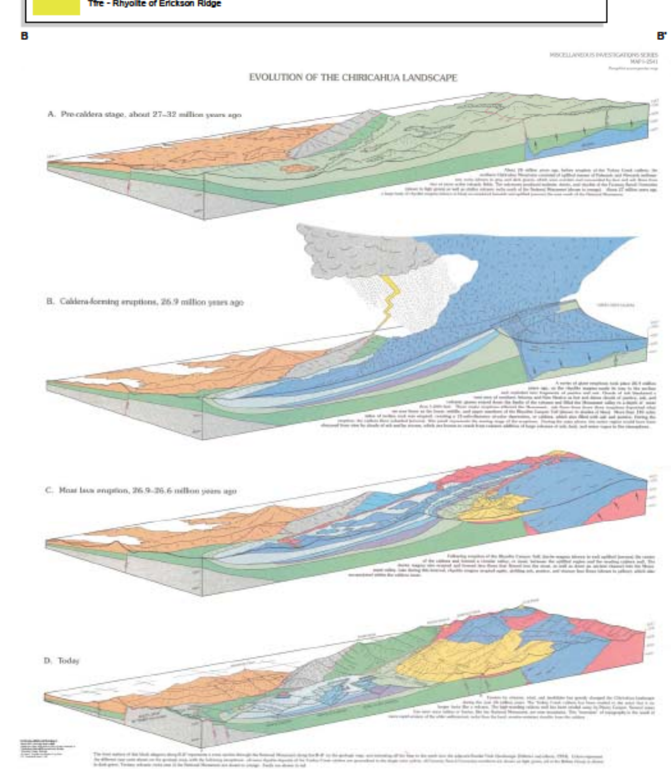


Figure 12. West to east geologic cross section through Riggs and Sugarloaf Mountains (see figure 11 and map) that shows the distribution of rock layers in the subsurface.



N

0 1 2 Kilometers

0 1 2 Miles

This map graphically presents digital geologic data prepared as part of the NPS Geologic Resources Division's Geologic Resources Inventory. The source map used in creation of the digital geologic data product was:

Pallister, J.S., E. A. Du Bray. 1997. Interpretive Map and Guide to the Volcanic Geology of Chiricahua National Monument and Vicinity, Conchise County, Arizona. Scale 1:24,000. Miscellaneous Investigations Series Map I-2541. U.S. Geological Survey.

Digital geologic data and cross sections for Chiricahua National Monument and all other digital geologic data prepared as part of the Geologic Resources Inventory, are available online at the NPS Data Store: http://science.nature.nps.gov/nrdata/

Produced by the Geologic Resources Inventory

January 2009

Appendix B: Scoping Summary

The following excerpts are from the GRI scoping summary for Chiricahua National Monument. The contact information and Web addresses in this appendix may be outdated. Please contact the Geologic Resources Division for current information.

The National Park Service held a GRI scoping meeting for Chiricahua National Monument (CHIR) on April 5, 2006, at park headquarters. Participants at the meeting included NPS staff from the park, Geologic Resources Division, and the Intermountain Region and cooperators from the United States Geological Survey (USGS), Arizona Geological Survey (AZGS), and Colorado State University (CSU) (see scoping table 3).

Park and Geologic Setting

Chiricahua National Monument was proclaimed a national monument on April 18, 1924, and transferred from the U.S. Department of Agriculture, Forest Service to the National Park Service on August 10, 1933. It presently encompasses 11,984.73 acres in extreme southeastern Arizona. In 1976, Congress designated 10,290 acres as Wilderness (86% of the Monument). Chiricahua NM was established to protect and preserve the exceptional geologic features in the Monument including pinnacles, columns, spires and balanced rocks.

Geologic Mapping for Chiricahua National Monument

The NPS GRI Geology-GIS Geodatabase Data Model incorporates the standards of digital map creation set for the GRI Program. Staff members digitize maps or convert digital data to the GRI digital geologic map model using ESRI ArcMap software. Final digital geologic map products include data in geodatabase, shapefile, and coverage format, layer files, FGDC-compliant metadata, and a Windows HelpFile that captures ancillary map data.

When possible, the GRI program provides large scale (1:24,000) digital geologic map coverage for each park's area of interest, which is often composed of the 7.5-minute quadrangles that contain park lands (fig. 1). Maps of this scale (and larger) are useful to resource management because they capture most geologic features of interest and are positionally accurate within 12 m (40 ft). The process of selecting maps for management use begins with the identification of existing geologic maps and mapping needs in the vicinity of the park. Scoping session participants then select appropriate source maps for the digital geologic data to be derived by GRI staff.

Map coverage for Chiricahua NM consists of 4 quadrangles of interest mapped at a 1:24,000 scale (scoping fig. 1): Cochise Head, Bowie Mountain South, Rustler Peak, and Fife Peak. These quadrangles are located on the Wilcox and Chiricahua Peak 30' x 60' sheets. Table 1 lists the source maps chosen for Chiricahua National Monument.

GRI staff have digitized GMAP 1120:

Pallister, J. S., and E. A. du Bray. 1997. *Interpretive map and guide to the volcanic geology of Chiricahua National Monument and vicinity, Cochise County, Arizona*. Scale 1:24,000. Miscellaneous Investigations Series Map I-2541. U.S. Geological Survey.

GMAP 1120 covers to the park boundary. The four intersecting 7.5' quadrangles do have complete geologic map coverage, and if it is desired to have more of a buffer around the park, they could be digitized to enhance the existing digital geologic map.

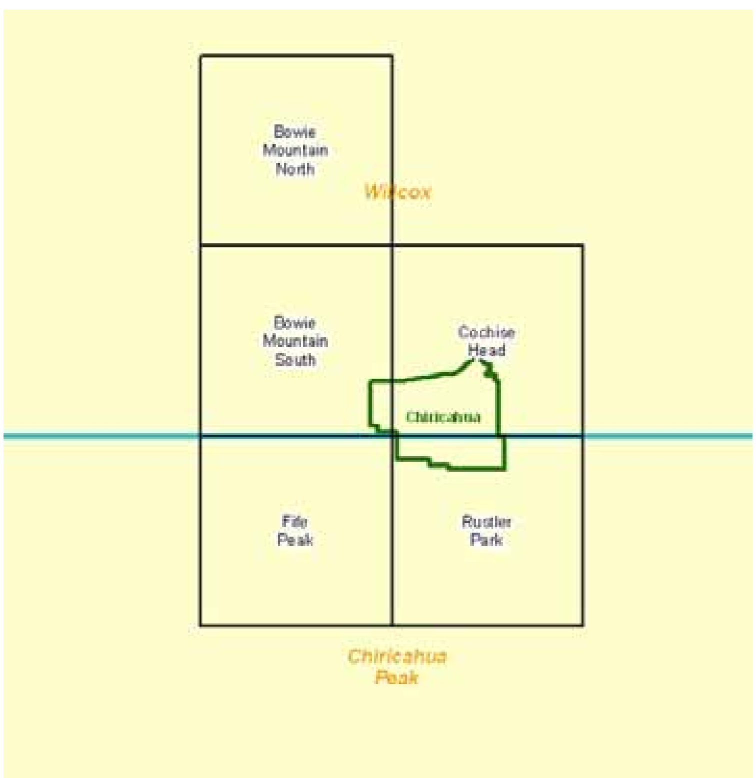
GMAP 1120 is probably the best map available (Ed du Bray). The map focuses on the Turkey Creek caldera and surrounding area and contains an interpretive pamphlet suitable for the non-geologist. Ed du Bray considers GMAP 1120, however, to be a map that simply lays out the geologic framework of the park. More detailed mapping and subsequent research could be done, for example, on the world-class tuff deposits in Chiricahua. GMAP 1120 is sold at the Visitor Center.

Both the Paleozoic rocks in the northeastern part of Chiricahua NM and the Mesozoic rocks were difficult to map (Ed du Bray). Harald Drewes mapped the Paleozoic rocks in detail, but structural relations among these strata could probably be refined.

Scoping table 1. GRI Mapping Plan for Chiricahua National Monument.

Covered Quadrangles	GMAP*	Citation	Scale	Format	Assessment	GRI Action
Parts of Bowie Mountain South, Cochise Head, Rustler Park, Fife Peak	1120	Pallister, J. S., and E. A. duBray. 1997. *Interpretive map and guide to the volcanic geology of Chiricahua National Monument and vicinity, Cochise County, Arizona*. Scale 1:24,000. Map I-2541. Reston, VA: US Geological Survey.	1: 24,000	paper	GMAP 1120 covers the park boundary	Conversion of digital data to geodatabase data model will integrate into either FY06 or FY07 projects.
Rustler Park	8436	Pallister, J. S., E. A. duBray, and J. S. Latta. 1994. *Geologic map of the Rustler Park quadrangle, Cochise County, Arizona*. Scale 1:24,000. Geologic Quadrangle Map GQ-1696. Reston, VA: US Geological Survey.	1: 24,000	paper and digital	Maps Rustler Peak quadrangle and includes southeastern part of Monument	Conversion of digital data to geodatabase data model/ will integrate into either FY06 or FY07 projects.
Fife Peak	8439	Pallister, J. S., and E. A. duBray. 1994. *Geologic map of the Fife Peak quadrangle, Cochise County, Arizona*. Scale 1;24,000. Geologic Quadrangle Map GQ-1708. Reston, VA: US Geological Survey.	1: 24,000	digital	Maps Fife Peak quadrangle, the quadrangle bordering the monument to the southwest	Conversion of digital data to geodatabase data model/ will integrate into either FY06 or FY07 projects.

* GMAP numbers are unique identification codes used in the GRI database



Scoping figure 1. Quadrangles of Interest for Chiricahua National Monument, Arizona. The 7.5-minute quadrangles (scale 1:24,000) are labeled in black; names in yellow indicate 30-minute by 60-minute quadrangles (scale 1:100,000). Green outline indicates the boundary of the Monument.

Quaternary, surficial deposits at Chiricahua NM have not been mapped in detail although most every structure in the Monument is built on Quaternary deposits (Todd Shipman, AZGS; Ed du Bray). The Monument has a soils map, but the map has not been digitized (Carrie Dennett, NPS CHIR). Rhyolitic volcanic ash deposited in water alters to bentonite, a clay that has shrink and swell properties. Soils with shrink and swell characteristics and thin soils both could impact septic systems and the structural integrity of facilities so a soils map is important to the park. Pete Biggam (NPS GRD) should be consulted for questions regarding soils.

Because of the flooding potential at the Visitor Center expansion and campgrounds, a map of the Quaternary showing potential flood areas would be beneficial. Mike Martin (NPS WRD) visited Chiricahua NM and generated a 100-year flood map. Stephanie will contact Mike to see about digitizing his map for Chiricahua. Colleen Filippone (NPS Intermountain Region) also would like a copy of the map for the Chiricahua NM library.

Increased runoff and flooding associated with recent fires is an issue at the Monument (Carrie Dennett). Fire increases the potential for slope erosion, and hazard maps showing areas prone to mass slippage would be useful for management. Hazard maps showing rock outcrops as natural fire barriers and areas of recent burns could also be helpful to park staff. Ed du Bray suggested that remote sensing could be used for this.

Colleen Filippone expressed an interest in more map coverage in Pine Canyon because of high visitation. Pine Canyon is located along the southern edge of GMAP 1120.

GRI mapping action planned for FY 2006 or FY 2007 includes:

- The GRI will convert existing digital data for GMAP 1120 from the GRI coverage and shapefile data model to the GRI geodatabase data model. This is required, as integration of newly acquired digital data will need to be in the same GIS format for edge-matching and compilation, and because the geodatabase format is now the standard GRI supported deliverable format.
- Ed du Bray of the USGS has recently supplied the GRI (acquisition date of April 17, 2006) with digital data in Shapefile (.shp) format, as well as digital text of ancillary text including map unit descriptions and references pertaining to GMAP 8436 (Rustler Park) and 8439 (Fife Peak quadrangle). The GRI will evaluate and convert the digital data to the GRI geodatabase data model format. The digital data will then be edge-matched and appended to existing GRI digital data GMAP 1120 to produce one compiled park map for Chiricahua NM. Ancillary text and figures associated with the two quadrangle maps will be formatted and incorporated with existing GRI CHIR project text and figures.
- The GRI will contact Mike Martin (NPS Water Resources Division) in Fort Collins concerning a floodplain map he recently produced for Chiricahua NM. The GRI will then determine if the map can be georeferenced for GIS digitization (this requires coordinate tics and/or features present that can be used to assist georeferencing). If georeferencing is possible then the GRI will digitize the map to the GRI geodatabase data model format.
- The GRI will evaluate a scoping proposal to map Quaternary surficial deposits within the Monument, primarily deposited within drainages. This should prove helpful for debris flow and post-fire management.
- The GRI will evaluate a scoping proposal to re-map the area around the King of Lead Mine in and near the northeast area of the park. Ed du Bray stated that geology of the area was structurally complex and could be re-mapped by a geologist with more structural mapping experience.

Geologic Resource Management Issues

The scoping session for Chiricahua National Monument provided the opportunity to develop a list of geologic issues, features and processes, which will be further explained in the final GRI report. Scoping table 2 presents a summary of potential hazards or features discussed during the scoping meeting and the issues these hazards may present to management.

During the meeting, Alan Whalon (NPS CHIR-FOBO) prioritized the most significant issues as follows:

(1) Flooding
(2) Sewer and septic problems, and
(3) Information for interpretation

Other geologic resource management issues discussed included: mining issues, landslides, mineral specimen collecting, subsurface contamination from a leaking underground storage tank, and rock stability associated with fractures and faults in the rocks.

Scoping table 2: Hazards associated with issues, features, and processes at Chiricahua National Monument.

Hazard	Issues, Feature and Processes
Flooding	Large watershed catchment area; affects Visitor Center & campgrounds
Septic	Thin soils; bentonite; flooding
Shrink and swell soils	Expansive clays; shrink and swell properties
Interpretive needs	Displays are not geologically correct
Landslides	Potential for large landslides in southeast Chiricahua NM & along Sugarloaf Trail
Old mines	Safety issues; acid mine drainage?
Mineral and/or rock collecting	Spherulites – collected by visitors; mineral (Pb/Zn) specimens
Post-fire erosion	Steep slopes denuded by fire tend to erode
Rock climbing	Not allowed in park
Seismicity	Not a significant issue for the pinnacle features and columns
Caves/karst	Not an issue
Geothermal	Not an issue
Active faults	Not an issue

Flooding

Mike Martin advised the Monument that slopes were so steep, flooding would occur too quickly for evacuation (Carrie Dennett). Todd Shipman (AZGS) suggested that rather than developing a warning system, which would not be adequate, the Monument could identify areas prone to flooding and avoid locating facilities in those areas. Carrie Dennett pointed out that, unfortunately, the Visitor Center and campgrounds are located in the floodplain, and the Monument has no plans to relocate those facilities. Campgrounds have been closed in the past due to 100-year floods. Monument management is concerned that visitors new to the area won't recognize the potential for flooding in the campgrounds because they see the area as a "desert" (Alan Whalon).

Sewer and Septic Problems

Issues associated with the sewer and septic system at Chiricahua National Monument may be more related to money than to geology (Alan Whalon). The septic system is old and deteriorating. A good location for a septic system is difficult to find.

Information for Interpretation

The interpretive displays at Sugarloaf Mountain need to be redone (Ed du Bray). These displays show a stratovolcano with steep slopes, but the Turkey Creek caldera was a gently sloping volcano that erupted through ring fractures, not a central vent. Alan Whalon commented that the Monument focused on the pinnacle features, but the whole geologic story is much more interesting. However, a geologist has not been employed by Chiricahua National Monument for some time. Suzanne Moody (NPS CHIR) suggested a need to emphasize the caldera study in their interpretive material. The geology of Chiricahua NM might be used to tie in other themes such as natural history, culture, vegetation, and biology.

Other Issues

The King of Lead Mine, adjacent to the northeast boundary of Chiricahua NM, consists of four patented mining claims. The mine was active up to about 1984 when access to the mine through the Monument became an issue. The lead-zinc deposits of the mine formed as a result of magma interacting with Paleozoic rocks and may be related to an unknown caldera around Cochise Head. Several other small, lead-zinc deposits are associated with Turkey Creek caldera magmatism. These mines, including the King of Lead Mine, are presently not economically exploitable.

Acid mine drainage from mines adjacent to Chiricahua National Monument may be an issue. The King of Lead mine drains to Bonita Creek. There is no surface flow for Most of the year, however. Mike Martin performed some water quality tests and was skeptical of the results, which showed no impacts (Colleen Filippone). If funds for sampling could be found, groundwater sampling might prove beneficial. The mine owner would sell the mine to the Monument for several million dollars. Alan Whalon explained that old mines were an issue about ten years ago, but today there are no safety or bat habitat issues.

Vast landslide deposits of an unknown age are located in the southeastern area of Chiricahua NM (Ed du Bray), creating the potential for large landslides. A slump recently occurred along the Sugarloaf trail closing it for 1.5 years. The slump is associated with a distinctive white volcanic ash zone that is easily eroded, undercuts the overlying cliff, and results in collapse. Washouts along a Civilian Conservation Corps (CCC) trail during trail rehabilitation closed the trail for six months.

Collecting mineral specimens probably is more of a Monument management issue than is hardrock mining for economic mineral deposits. In addition to lead-zinc mineral specimens (galena, sphalerite), spherulite collecting is an issue for management. The marble-like spherulites (nicknamed "hailstones") weather out of volcanic tuff along the Hailstone Trail.

Regarding subsurface contamination (soil and groundwater), an underground storage tank was pulled out in 1994 and found to be leaking. Decontamination continues because the geometry of the contaminant plume is difficult to define and mitigate (Alan Whalon).

Although horizontal and vertical fractures cut the rocks, a study of some of these structures showed that they are stable (Ed du Bray). In 1887, a 7.2 M earthquake (the Pitaycachi earthquake) did not destabilize the columns. During a road project, a large rock fell on the road following a rainfall (Alan Whalon). Seismometers were placed in the area to detect vibrations from heavy equipment and from small dynamite charges. This small but "interesting" study suggested that one of the biggest issues regarding rockfall was climbing on the rocks (Alan Whalon). Chiricahua NM does not allow climbing and the study is additional evidence for not allowing this recreational activity in the Monument.

Features and Processes

Ed du Bray led a field trip to the top of Sugarloaf Mountain to observe features related to the Turkey Creek caldera. Features observed along the Sugarloaf Trail included:

- Pinnacles, columns, spires, and balanced rocks,
- Erosional remnants of igneous dikes exposed near the King of Lead Mine,
- Middle and Upper Members of the Rhyolite Canyon Tuff and associated features,
- Remnants of the slump resulting from erosion of the conspicuous white ash unit and undercutting of the Upper Member,
- Structures that suggest the white ash unit is a surge deposit at the base of the Upper Member rather the an ash cloud deposit at the top of the Middle Member,
- Fumarole pipes,
- The "boiling pot" of a fumaroles,
- Liesegang bands where small amounts of chemical impurities from hot water were precipitated,
- The only place in the Chiricahua Mountains where the dynamic contact between the Middle and Upper Members is exposed,
- An overall panoramic display of the caldera remnants from the top of the mountain.

Other geologic features in Chiricahua National Monument include:

- Columnar joints in the rhyolite,
- Spherulites (marble-like rocks found along Hailstone Trail),
- Vertical volcanic flow structures,
- Landslides and mass wasting features (erosional processes),
- Vertical and horizontal fractures (tectonic and cooling processes),
- Inverted topography.

Recommendations

Recommendations from the scoping meeting include:

- More detailed mapping and research on the tuff deposits,
- Maps showing the relationship between geology and vegetation,
- A map identifying flood prone areas,
- A hazard map showing rock outcrops and potential post-fire slope failure.

Scoping table 3. Scoping Meeting Participants.

Name	Affiliation	Position	Phone	E-Mail
Covington, Sid	Geologist	NPS GRD	303-969-2154	sid_covington@nps.gov
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du Bray, Ed	Geologist	USGS	303-236-5591	edubray@usgs.gov
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Graham, John	Geologist	Colorado State University	970-581-4203	rockdoc250@comcast.net
Kerbo, Ron	Cave specialist	NPS GRD	303-969-2097	Ron_Kerbo@nps.gov
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Shipman, Todd	Geologist	Arizona Geol. Survey	520-770-3500	todd.shipman@azgs.az.gov
Whalon, Alan	Superintendent	NPS CHIR-FOBO	520-824-3560 ext. 202	alan_whalon@nps.gov

Chiricahua National Monument

Geologic Resources Inventory Report

Natural Resource Report NPS/NRPC/GRD/NRR—2009/081

Credits

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NPS D-94, June 2009

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U.S. Department of the Interior

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