Exploring the Geology of Arizona National Parks with Geologic Resource Inventory Products

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Sunset Crater Volcano National Monument

Notable geology of Sunset Crater Volcano

Established by presidential proclamation in 1930, Sunset Crater Volcano National Monument protects and preserves over 3000 acres that represent the Colorado Plateau's most recent volcanic eruption. Located about 15 miles northeast of Flagstaff, Sunset Crater Volcano National Monument protects the 1000-foot-high cinder cone and surrounding features including the Bonito Lava Flow, ice cave, cinder fields, spatter cones, lava tubes, and squeeze ups. The recent nature of the eruption and relatively undeveloped landscape provide outstanding opportunities to study plant succession and ecological change. At first glance, much of the stark, black landscape appears inhospitable. But within the dramatic geologic features, islands of desert shrubs, wildflowers, and trees have created small and unique habitats for wildlife to return.

Covering over 1800 square miles, the San Francisco Volcanic Field, located on the southern border of the Colorado Plateau, contains about 600 volcanoes ranging in age from Miocene to Holocene. Sunset Crater, one of the youngest cinder cones in the contiguous United States and the youngest volcano in the San Francisco Volcanic Field erupted in about 1085 CE. The eruption began with an approximately 7-mile-long fissure of lava fountaining activity called a "curtain of fire" but was quickly localized directly beneath present day Sunset Crater Volcano. Violent, Strombolian-style eruption columns sent molten rock and volcanic ash billowing into the air. When the eruption concluded, the Sunset Crater cinder cone loomed 1000 feet over the dramatically altered landscape. Ash deposits up to 40 feet thick covered almost 900 square miles and 3 separate lava flows extended nearly 7 miles from the source vent.

These events were the only eruptions indisputably witnessed by pre-historic communities in the Southwest and they certainly impacted their way of life. Archeological evidence indicates that native peoples were forced to relocate to nearby areas and there is even evidence of humans interacting directly with the volcano. Pieces of Sunset Crater scoria with impressions of corn kernels have been found within the walls of habitation structures miles away from the closest lava flows. These "corn rocks" are thought to have been formed when people put ears of corn near spattering vents above lava tubes. When the vents erupted, it covered the corn in molten rocks that eventually cooled to create corn molds.

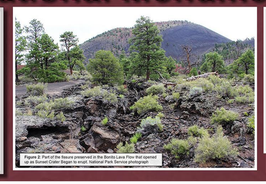


Figure 2. Part of the fissure preserved in the Bonito Lava Flow that spread out as Sunset Crater Began to erupt. National Park Service photograph

Figure 3. Church of Sunset Crater basalt with corn cob impressions. Some archeologists speculate that corn may have been given as an offering to the lava to try and stop the flow or to honor it as a blessing. Photo by Helga Teiste

Figure 1. Sunset Crater Volcano from O'Leary peak. National Park Service photograph

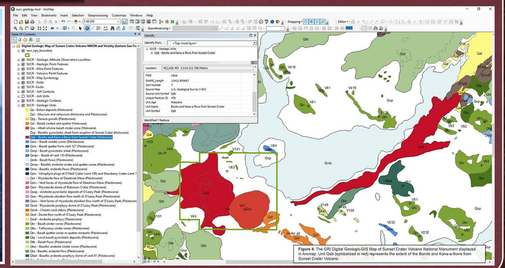


Figure 4. The GRI Digital Geologic-GIS Map of Sunset Crater Volcano National Monument displayed in ArcMap. The pink polygon (exhibited in red) represents the extent of the Bonito and Kana-a flows from Sunset Crater Volcano.

Walnut Canyon National Monument

Notable geology of Walnut Canyon

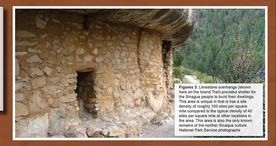
Walnut Canyon National Monument, located roughly 8 miles east of Flagstaff, Arizona, was established by presidential proclamation in 1915 to protect a dense concentration of prehistoric cliff dwellings. The canyon, deeply incised into Permian aged limestone and sandstone, provided a reliable water source and shelter for the people of the Sinagua culture (Sinagua means "without water" in Spanish). Seasonally available water, varied solar exposures and elevations also made this canyon a biologically diverse hotspot of multiple overlapping distinct ecosystems that support a variety of wildlife and plant species.

The people of the Sinagua culture thrived in Walnut Canyon and benefited from the geologic landscape in multiple ways. Less resistant sandstone lenses in the Kaibab Limestone eroded away providing overhanging limestone ledges under which dwellings could be constructed. Ash and cinders from volcanic eruptions in the San Francisco Volcanic Field enriched the soil above the canyon rim where the Sinagua people grew squash, corn and beans. The people of the Sinagua culture thrived in Walnut Canyon for roughly 150 years until about 1250 CE and left behind about 300 rooms along both sides of the canyon and 500 archeological sites along the 10 miles of Walnut Canyon.

Figure 1. Limestone overhangs. National Park Service photograph

Period	Formation	Lithologic Description
Quaternary	Alluvium	Unconsolidated gravel, sand, silt deposits
	Cocoino Deposits	Fine grained lake deposits
	Colluvium	Unconsolidated gravel, sand, & basalt
Triassic	Moenkopi Formation	Mudstone, siltstone, & sandstone
Permian	Kaibab Lim.	Dolomite, sandy limestone, cherty limestone
	Coconino Sd. & Coconino Sandstone	Cross-bedded quartz sandstone
Pennsylvanian/Permian	Supai Group	Sandstone/red & Brown Calcareous Sltst

Figure 2. Generalized stratigraphy for the area. CdP dwellings were built within less resistant layers in the Kaibab Formation. (Graham, 2008)



Figures 3. Limestone overhangs (above) look on the lower Trail (pictured whether for the Sinagua people to build their dwellings. This area is unique in that it has a site density of roughly 150 sites per square mile compared to the typical density of 40 sites per square mile at other locations in the area. This area is also the only known location where the Sinagua cultivated crops. National Park Service photographs

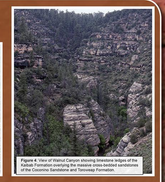


Figure 4. View of Walnut Canyon showing limestone ledges of the Kaibab Formation overlying the massive cross-bedded sandstones of the Coconino Sandstone and Toroweap Formation

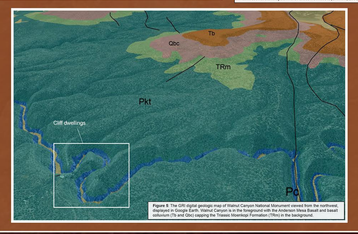


Figure 5. The GRI digital geologic map of Walnut Canyon National Monument viewed from the northwest, displayed in Google Earth. Walnut Canyon is in the foreground with the Anderson Mesa Basalt and basalt outcrops (Tb and Qbc) capping the Triassic Moenkopi Formation (TRm) in the background.

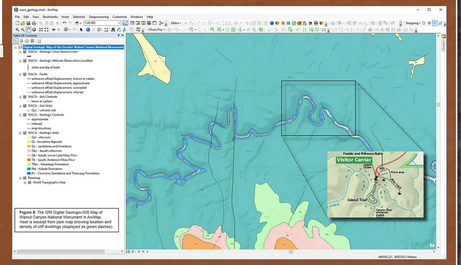
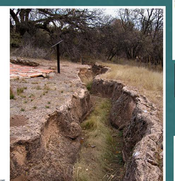


Figure 6. The GRI Digital Geologic-GIS Map of Walnut Canyon National Monument in ArcMap. Polygons of different rock units are displayed in green and density of cliff dwellings (displayed as green dashes).

Montezuma Castle National Monument

Notable geology of Montezuma Castle

Montezuma Castle sits in a sheltered, limestone alcove of the Tertiary Verde Formation. This five-story high, 20-room cliff dwelling was constructed more than 800 years ago by the southern Sinagua people and is now considered one of the best preserved prehistoric structures of the entire southwestern United States. Nearby, Montezuma Well occupies a sinkhole in the travertine of the Tertiary Verde Formation. The well is among the premier natural resources managed by the National Park Service. How did it form and how does it work?



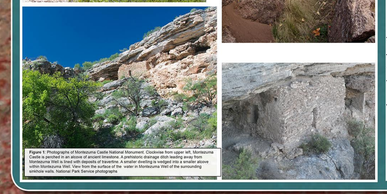


Figure 1. Photographs of Montezuma Castle National Monument. Clockwise from upper left, Montezuma Castle is a 5-story, 20-room dwelling built into a limestone alcove. Middle-ground is Beaver Creek. Montezuma Well is lined with deposits of travertine. A smaller dwelling is wedged into a smaller alcove within Montezuma Well. View from the surface of the water in Montezuma Well of the surrounding sinkhole walls. National Park Service photographs

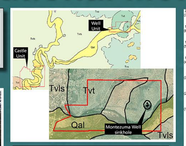


Figure 2. Screen capture images of the GPS GIS data over aerial imagery. Red lines indicate National Park Service boundary of both units of Montezuma National Monument. Geologic units are displayed in Qal (Quaternary Alluvium), TVls (Tertiary Verde Formation; Qal is alluvium; TVls is limestone of the Verde Formation; Tvt and Tvl are Verde Formation, undivided sedimentary rocks and lacustrine rocks, respectively. Aerial imagery from ESRI Arc Image Service, ESRI World Imagery

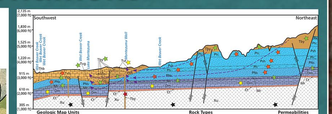


Figure 3. Generalized cross section through Montezuma Well in the travertine of the Verde Formation. Groundwater flows through permeable fractures along and above an impermeable layer of basalt. Water in the well is supersaturated with CO_2 and dissolves travertine and basaltic carbonate minerals along the transport path. The process likely contributed to the formation of the cavity of Montezuma Well. As part of this processes, deep-sourced CO_2 degasses, depositing travertine at the surface. Travertine coats the current irrigation ditch that transports water away from Montezuma Well. (Hallett,pers. planned 2018)

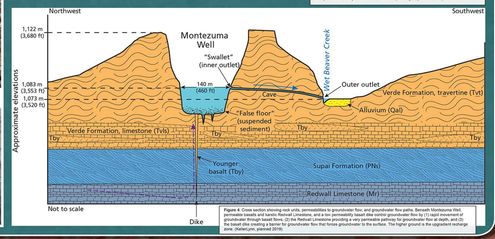


Figure 4. Cross section showing rock units, permeabilities to groundwater flow, and groundwater flow paths. Beneath Montezuma Well, groundwater flows through permeable Verde Formation limestone (Tvl) and Quaternary Alluvium (Qal). Beneath the Verde Formation, groundwater flows through basalt flows, (Tb) the Redwall Limestone providing a very permeable pathway for groundwater flow at depth, and (D) the basalt dike creating a barrier for groundwater flow that forces groundwater to the surface. The highlighted portion is the upgradient recharge zone. (Hallett,pers. planned 2018)

The Geologic Resources Inventory

The Geologic Resources Inventory (GRI) is one of twelve inventories funded under the National Park Service (NPS) Natural Resource Challenge. The goal of the GRI is to increase understanding of the geologic processes at work in parks and provide accurate geologic information for use in park decision-making. Sound park stewardship relies on understanding natural resources and their role in the ecosystem, of which geology is the foundation. The GRI program is a partnership between the NPS and Colorado State University (CSU), and relies heavily upon the U.S. Geological Survey, individual state geological surveys, and other organizations in developing its source map products. CSU research associates work side-by-side with NPS GRI staff to facilitate a scoping meeting that identifies park mapping needs, as well as park-specific geologic issues, features, and processes. Additional information about the GRI program can be found at: https://www.nps.gov/subjects/geology/gri.htm

Overview of GRI Products

The GRI produces several products to assist park staff in the management and protection of their park. These products include a digital geologic-GIS map product that is available in three data formats:

1.) ESRI 10.X file geodatabase and accompanying 10.0 ArcMap document for use with ESRI ArcGIS software
2.) KML/KMZ file for use with Google Earth
3.) ESRI 10.X map service for use with ESRI online web map applications such as ArcGIS Online, or other portal/viewer applications.

Each digital geologic-GIS product also contains an introductory readme file, FGDC-compliant metadata, and an ancillary map information document, which contains unit descriptions and other ancillary source map graphics and information.

In addition to the digital geologic-GIS map product, the GRI also produces a basic cartographic layout and a geologic report. The layout displays a park's geologic map complete with prominent features and localities within and around the park. The report is a comprehensive document that presents a park's:

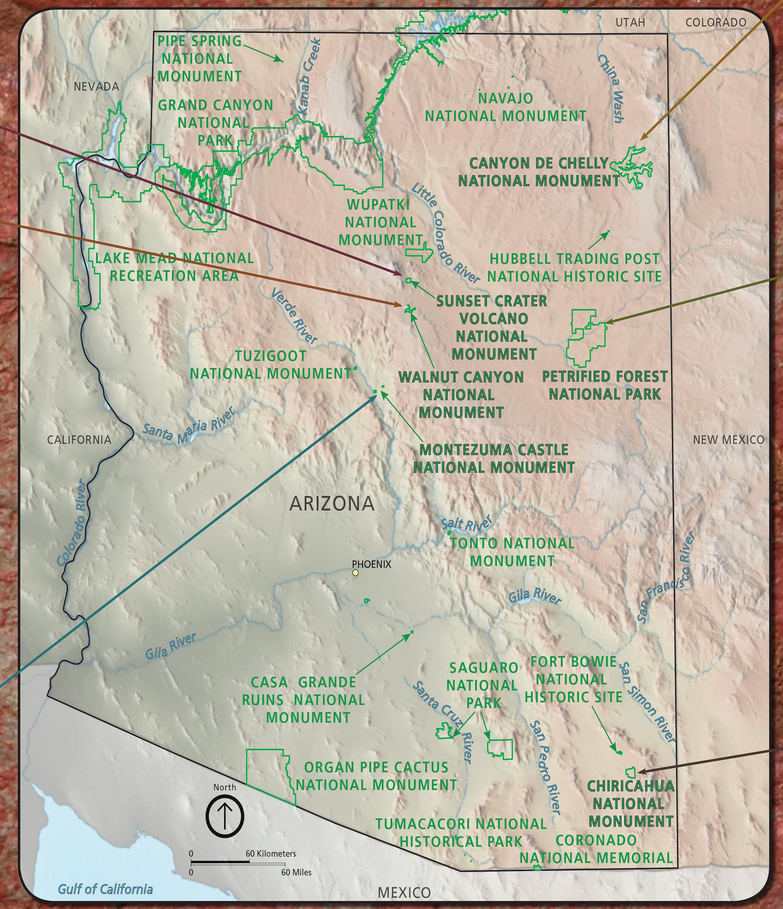
1.) Geologic significance
2.) Geologic history
3.) Discusses prominent geologic features, processes and issues, and presents this in a scientific format directed at park resource managers.

Completed GRI products, digital geologic-GIS maps, layouts and reports, as well as GRI scoping meeting reports, are available online at: https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm

Grand Canyon Centennial

February 26, 2019, the Grand Canyon celebrated 100 years since it's designation as a national park. Grand Canyon welcomes approximately six million visitors each year. After 100 years, whether its hiking a corridor trail, rafting the river, taking a stroll on the rim or enjoying the landscape from an overlook, Grand Canyon continues to provide a space for all visitors to connect with the outdoors.
https://www.nps.gov/grca/getinvolved/centennial.htm

View of Phantom Ranch, the Colorado River, and Bright Angel Creek from the Kaibab Trail, Grand Canyon National Park. Photo by Ron Karpilo



GRI Arizona Park Product Status

GRI product availability for each park service unit in Arizona is presented in the table below. Available products can be acquired online from the GRI Publications site: https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm. Products not yet available are either in-progress, or are planned as future projects to be completed within the next 5 to 6 years.

Park	GDB	KML	Map Service	Layout	Report	Report Year
Canyon de Chelly National Monument	Yes	No	No	No	No	NA
Casa Grande Ruins National Monument	Yes	Yes	No	Yes	Yes	2018
Chiricahua National Monument	Yes	No	No	Yes	Yes	2009
Coronado National Memorial	Yes**	No	No	Yes	Yes	2011
Fort Bowie National Historic Site	Yes	No	No	Yes	Yes	2011
Glen Canyon National Recreation Area-	Yes	Yes	No	Yes	Yes	2016
Grand Canyon National Park	Yes	Yes	Yes	No	No	NA
Hubbell Trading Post National Historic Site	Yes	Yes	No	No	No	NA
Lake Mead National Recreation Area	Yes**	No	No	No	No	NA
Montezuma Castle National Monument	Yes	Yes	Yes	Yes	2019*	2019*
Navajo National Monument	Yes	No	No	Yes	Yes	2007
Organ Pipe Cactus National Monument	Yes	Yes	Yes	No	No	NA
Petrified Forest National Park	Yes	No	No	Yes	Yes	2010
Pipe Spring National Monument	Yes	No	No	Yes	Yes	2010
Saguaro National Park	Yes	No	No	Yes	Yes	2010
Sunset Crater Volcano National Monument	Yes	No	No	Yes	Yes	2005
Tonto National Monument	Yes	No	No	No	No	NA
Tumacacori National Historical Park	Yes	No	No	Yes	Yes	2011
Tuzigoot National Monument	Yes	Yes	Yes	2019*	2019*	2019*
Walnut Canyon National Monument	Yes	No	No	Yes	Yes	2008
Wupatki National Monument	Yes	Yes	Yes	Yes	Yes	2011

Bold text denotes product presented on this poster, *Denotes projected completion date, **Denotes projects that have not been released to the public

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Canyon de Chelly National Monument

Notable geology of Canyon de Chelly

Canyon de Chelly National Monument, in the heart of the Navajo Nation, was established to maintain and preserve an outstanding concentration of archeological resources, representing thousands of years of continuous occupation and agriculture, as well as other significant natural and cultural features. The canyon preserves resources of sacred significance and perpetuates traditions of past and present cultures connected to these landscapes.

Sandstone walls rise in height from 30 feet high near the mouth of Canyon de Chelly to 1,200 feet at the eastern end of the monument. Natural features such as the 825 feet tall towering spires of erosion-resistant sandstone and cap-rock of Spider Rock are physical expressions of the defining stories and events in the history of the Navajo people and retain profound spiritual and sacred significance. Spider Rock is a geologic keystone of the national monument because it displays the three rock formations exposed here: Pennsylvanian sandstone of the Supai Group, Permian De Chelly Sandstone, and the Triassic Shinarump Member of the Chinle Formation. Additionally, Canyon de Chelly is designated as the type section for the De Chelly Sandstone.

Figure 2. Large-scale crossbedding of the De Chelly Sandstone. Photo by Ron Karpilo

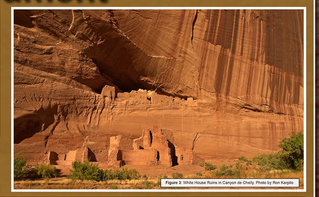

Figure 3. White House Ruins in Canyon de Chelly. Photo by Ron Karpilo

Figure 1. Spider Rock at the junction of Canyon de Chelly and Monument Canyon. Photo by Ron Karpilo

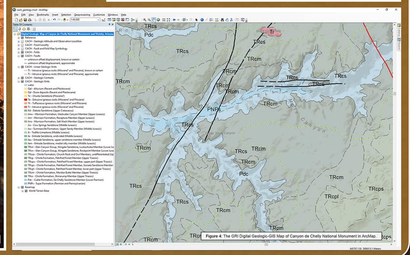

Figure 4. The GRI Digital Geologic-GIS Map of Canyon de Chelly National Monument in ArcMap.

Petrified Forest National Park

Notable geology of Petrified Forest

The first American national park that was set aside specifically for fossil resources is Petrified Forest National Park in northeastern Arizona. The excellent exposures and accessibility of the Upper Triassic Chinle Formation make Petrified Forest National Park a world-renowned natural laboratory for paleontology and other geologic disciplines such as sedimentology, stratigraphy, geomorphology, and structural geology. The park contains one of the largest and most colorful deposits of mineralized wood in the world and scientists now recognize it as one of the best places in the world to study the evolutionary transition of nonmarine animals, especially tetrapods.

Figure 1. Painted Desert. National Park Service photograph

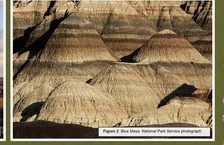

Figure 2. Blue Mesa. National Park Service photograph

Figure 3. Petrified wood. National Park Service photograph

Figure 4. Long Logs Trail. National Park Service photograph

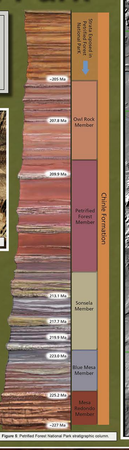

Figure 5. Petrified Forest National Park stratigraphic column.

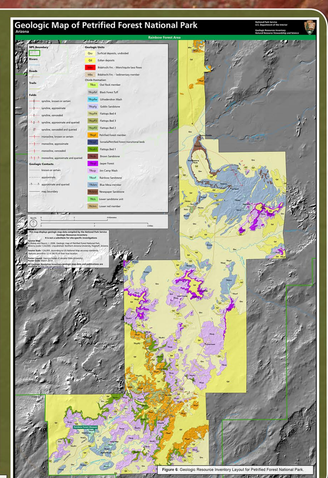

Figure 6. Geologic Resource Inventory Layout for Petrified Forest National Park.

Chiricahua National Monument

Notable geology of Chiricahua

Within the Chiricahua Mountains of southern Arizona are numerous rhyolite rock formations that form an impressive landscape of natural rock columns, balanced rocks and towering pinnacles. The Chiricahua Apache called the region "The Land of Standing-Up Rocks." Today, these rock formations are simply called "the Pinnacles," and they are in part a primary reason why Chiricahua National Monument was created in 1927.

The rhyolite rocks that are "the Pinnacles" were first emplaced approximately 27 million years ago during a period of intense volcanic activity in the American west. Upon cooling, vertical joints formed in the rhyolite, and provided conduits for water. Since their emplacement, these erosion-resistant volcanic rocks have been fractured, displaced, weathered and eroded to form the monument's impressive pinnacles we see today.

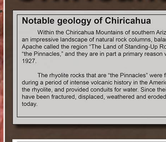

Figure 1. Lizoning process along the Echo Canyon Trail Loop. Photo by Brian Schmid

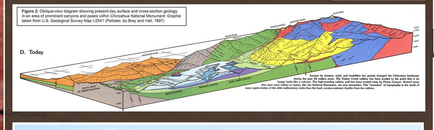

Figure 2. Oblique-view diagram showing present-day surface and cross-section geology in an area of prominent pinnacles and peaks within Chiricahua National Monument. Graphic taken from U.S. Geological Survey Map I-2561 (Pelletier, du Bray and Hart, 1997).

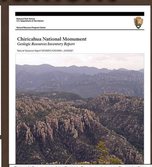

Figure 3. A landscape of pinnacles. National Park Service photograph

Figure 4. Cover page of the Geologic Resources Inventory Report for Chiricahua National Monument. A page of the report's Cenozoic Geologic History section is also presented. Enlarged text is the graph from the report's Geologic History section. This section of the report, which includes a discussion of the Chiricahua Mountains, discusses the emplacement of the park's Tertiary rhyolite. (Graham, 2008)

About 32–28 million years ago, an assemblage of rhyolite, dacite, and andesite lava and pyroclastic rocks were erupted into the area of Chiricahua National Monument. Then became the Fisherman's Ranch Formation and underlie the Jesse James Canyon Tuff and Rhyolite Porphyry of Cave Creek (Pelletier, du Bray and Hart, 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 that was similar in topographic position to today's the Rhyolite Canyon Tuff was erupted. Since their compositions are similar, the Jesse James Canyon Tuff may 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 (Pallister et al. 1992) was the largest and most voluminous eruption of rhyolite magma and buried a region of at least 4000 km² (1500 mi²) in ash-flow tuff and other volcanic ejecta. The roof of the magma chamber collapsed, producing the Turkey Creek caldera (Pallister et al. 1992).

During the caldera-forming eruption, pyroclastic flows filled valleys adjacent to the volcano, including the valley where Chiricahua National Monument is today. Because of the extreme heat of the pyroclastic flows, the deposits erupted here not completely cooled and are dating the past 26.5 million years. After millions of years, at least 450 m (1500 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. Sugarloaf Mountain is about 25 km (16 mi) southeast of Sugarloaf Mountain.

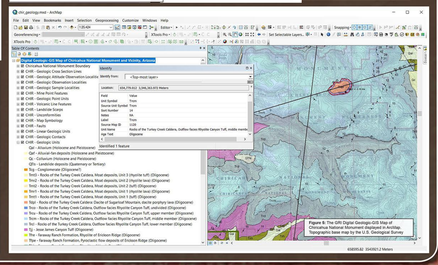

Figure 5. The GRI Digital Geologic-GIS Map of Chiricahua National Monument displayed in ArcMap. Topographic layer courtesy of the U.S. Geological Survey