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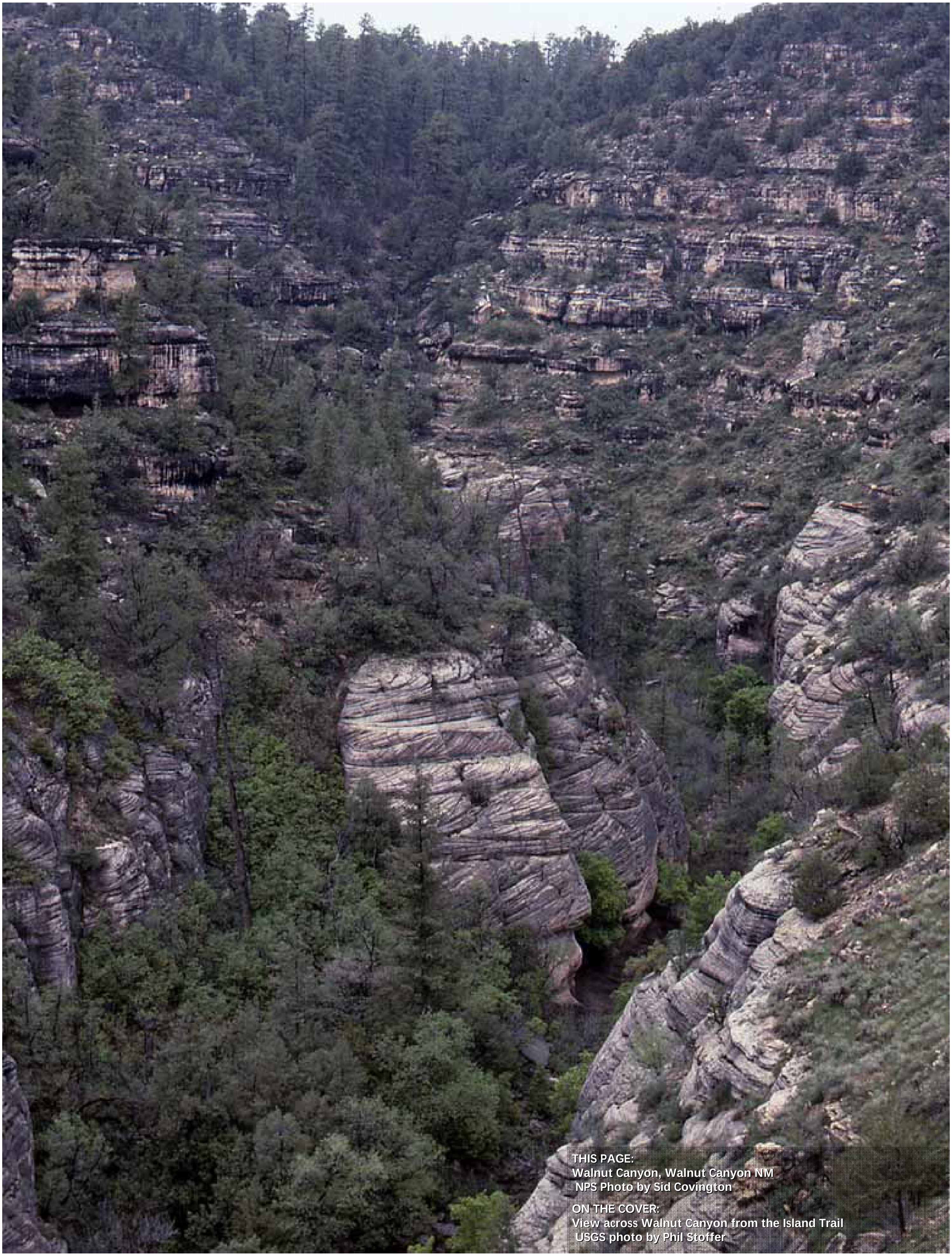
Natural Resource Program Center

Walnut Canyon National Monument
Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/040



THIS PAGE:
Walnut Canyon, Walnut Canyon NM
NPS Photo by Sid Covington

ON THE COVER:
View across Walnut Canyon from the Island Trail
USGS photo by Phil Stoffer

Walnut Canyon National Monument

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Geologic Resources Division
Natural Resource Program Center
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Executive Summary

This report accompanies the digital geologic map for Walnut Canyon 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.

Walnut Canyon National Monument was established in 1915 to protect and preserve the cliff dwellings of the Sinagua culture. The Sinagua occupied the region from about 1100 to 1220 A.D., and constructed their dwellings in alcoves eroded into relatively soft sandstone layers beneath harder, resistant limestone ledges. The cliff dwellings are in the upper third of Walnut Canyon, which Walnut Creek has incised into relatively horizontal layers of Paleozoic limestone and sandstone.

The primary geologic issue facing Walnut Canyon resource management is rockfall. Rockfall is a natural process that has shaped Walnut Canyon for thousands of years. However, rockfall can have a significant impact on visitor and staff safety, park infrastructure, and archaeological resources in the park. There is a specific hazard within the canyon along the Island Trail where climate related factors contribute to the timing of rockfall events. In addition, large, angular blocks of limestone from the Kaibab Formation have narrowed the canyon floor in places.

Another important geologic resource management issue is the combined geomorphic and hydrogeologic response to decreased water flow in Walnut Creek. Decreased sediment input reduced streambed scouring and recharge from alluvial aquifers. In the monument, approximately 80 acres of riparian vegetation grows on the floor of Walnut Canyon. Loss of this native vegetation because of decreased flows would not only eliminate the riparian landscape, indicative of the natural setting at the time of the Sinagua, but also negatively impact the viewshed from primary visitor use areas.

Two dam impoundments upstream of Walnut Creek have altered the character of the stream, the riparian ecosystem, and the limited water resources within the monument. The impoundment and diversion of Walnut Creek since 1941 have negatively affected wetland, floodplain, and riparian habitats that depend on a scoured channel, periodic flooding, and available groundwater. To help assess the sustainability of the riparian corridor within Walnut Canyon, field studies and baseline documentation are needed to identify and monitor geomorphic changes and groundwater flow.

Other geologic issues include volcanic eruptions, seismicity, mass wasting, flash flooding, potential aquifer contamination, and fossil theft. Approximately 1,000 years ago, volcanic eruptions produced the Sunset Crater in the San Francisco volcanic field north of Walnut Canyon. Future eruptions that would produce volcanic ash and cinders are possible, but not predictable with current technology. Earthquakes along local normal faults pose only a minor threat to the infrastructure and archaeological resources at the park. However, the Anderson Mesa fault and the smaller Marshall Lake fault, both located south of the monument, show evidence of recent movement.

Although stream flow has decreased in Walnut Creek, flash flooding remains a potential hazard. Intense thunderstorms may produce flash floods from local tributary canyons. Flooding in Walnut Canyon would also occur if either of the two upstream dams were to catastrophically fail.

Fossils are present in the limestone ledges of the Kaibab Formation outcrop along park trails making them vulnerable to theft. The majority of the paleontological resources at Walnut Canyon are marine invertebrates. Spiral impressions of snails, molds of small clams, and brachiopods are the most common fossils along the trails.

The porous Coconino Sandstone is an important regional aquifer in northern Arizona and provides the only reliable groundwater beneath the monument at a depth of approximately 460 m (1,500 ft). The National Park Service maintains a well into the aquifer, and the water table has remained relatively stable. Under current conditions, there is little threat of contamination or aquifer depletion within the watershed. However, the city of Flagstaff has annexed all lands to the north and west of the monument boundary and any development there could significantly increase non- point source pollution in perched aquifers, springs, and seeps that flow into the canyon.

Introduction

The following section briefly describes the National Park Service Geologic Resource Evaluation Program and the regional geologic setting of Walnut Canyon National Monument.

Purpose of the Geologic Resources Evaluation Program

The Geologic Resource Evaluation (GRE) Program is one of 12 inventories funded under the NPS Natural Resource Challenge designed to enhance baseline information available to park managers. The program carries out the geologic component of the inventory effort from the development of digital geologic maps to providing park staff with a geologic report tailored to a park's specific geologic resource issues. The Geologic Resources Division of the Natural Resource Program Center administers this program. The GRE team relies heavily on partnerships with the U.S. Geological Survey, Colorado State University, state surveys, and others in developing GRE products.

The goal of the GRE Program 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 GRE team is systematically working towards providing each of the identified 270 natural area parks with a geologic scoping meeting, a digital geologic map, and a geologic report. These products support the stewardship of park resources and are designed for non- geoscientists. During scoping meetings the GRE team brings together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes.

The GRE 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. As a companion to the digital geologic maps, the GRE team prepares a park- specific geologic report that aids in use of the maps 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 up to date GRE contact information please refer to the Geologic Resource Evaluation Web site (http://www2.nature.nps.gov/geology/inventory/).

Location and Regional Setting

Walnut Canyon National Monument is located approximately 11 km (7 mi) east of Flagstaff, Arizona. The monument was established in 1915 to protect the areas natural resources and ancient Native American ruins that date from about 1100 to 1220 A.D. Access to the monument is by a paved road to the northern rim of Walnut Canyon from Interstate- 40 and by various unpaved roads from the adjacent Coconino National Forest, managed by the U.S. Forest Service (fig. 1). The park road ends at a visitor center on the northern rim of the canyon. Island and Rim trails are the only two hiking trails managed and maintained by Walnut Canyon National Monument (fig. 2). Public use is limited to these designated trails and adjacent picnic areas (NPS 2003; Hansen et al. 2004).

The monument covers 3,579.46 acres and ranges in elevation from 1,890 to 2,100 m (6,200 to 6,900 ft). The stream and canyon are named after the Arizona walnut trees that grow along the floor of the canyon (Vandiver 1936; NPS 2003).

A moderately hot and moist summer, cool and dry spring and fall, and cold, periodically wet, winter typify the semi- arid, continental climate of Walnut Canyon National Monument (Hansen et al. 2004). Average annual precipitation at the monument headquarters is approximately 51 centimeters (cm) (20 in) (Thomas 2003). Monsoon- like precipitation events occur principally from July through September, often in the form of intense thunderstorms of short duration.

Regional Geology

Walnut Canyon National Monument is part of the Colorado Plateau Physiographic Province consisting of high plateaus, deep narrow canyons, and broad, rounded uplands covering an area of 83,200,000 acres in northern Arizona, northwestern New Mexico, western Colorado, and southeastern Utah. To the south, the Colorado Plateau ends abruptly along the Mogollon Rim, a roughly 320 km (200 mile) long, faulted escarpment that cuts across much of central Arizona.

The main geologic and topographic feature of Walnut Canyon National Monument is Walnut Canyon, an entrenched segment of Walnut Creek. The canyon trends from west to east and is incised into the Coconino

Plateau that extends from the South Rim of the Grand Canyon to Flagstaff. Walnut Canyon averages 402 m (1,320 ft) wide from the north rim to the south rim, 122 m (400 ft) deep at the western (upstream) boundary, and 76 m (250 ft) deep at the eastern (downstream) boundary. Anderson Mesa rises above the Coconino Plateau south of Walnut Canyon (fig. 3). Cherry Canyon is a major drainage to the southeast of Walnut Canyon.

The resistant gray limestone of the Permian Kaibab Formation caps the upper walls of Walnut Canyon (fig. 5). This same formation forms the rims of Grand Canyon and the higher, relatively flat mesas surrounding the narrow canyon within the monument. Locally, more than 111 m (364 ft) of massive, resistant limestone and dolomite of the Kaibab interbedded with thin, less resistant siltstones and sandstones form characteristic ledges and slopes. The ancient dwellings in Walnut Canyon were constructed under the shelter of overhanging ledges of Kaibab limestone 61 m (200 ft) or more above the canyon bottom (fig. 4).

The light- tan Permian Coconino Sandstone underlies the Kaibab Formation (fig. 5). The Coconino Sandstone is a distinctive cross- bedded sandstone unit that formed when the regression of an ancient sea exposed vast tracts of sand to prevailing winds , blowing the sand into large dune fields similar to the modern Sahara. In this area of the Colorado Plateau, the massive cross- bedded sandstones of the Coconino are difficult to differentiate from cross- bedded sandstones of the overlying Toroweap Formation, and so they are mapped as one unit in Walnut Canyon area. However, careful field examination reveals that a truncation surface marked by vegetation in outcrop exposures typically separates Toroweap beds from the underlying Coconino Sandstone (Turner 2003). Within Walnut Canyon, the combined Coconino and Toroweap unit is 225 m (738 ft) thick (Rowlands et al. 1995).

The Coconino Sandstone is the primary aquifer in the region. Local fractures, parting along bedding planes, and limestone dissolution allows precipitation to percolate through the Kaibab Formation to the underlying Coconino Sandstone recharging this regional aquifer (Paul Whitefield, NPS WACA, written communication November 30, 2005).

Uplift of the Colorado Plateau in the Cenozoic Era and regional erosion removed most of the Mesozoic and Cenozoic rocks from the Walnut Creek area. Although the siltstones, mudstones, and sandstones of the Triassic Moenkopi Formation have been mostly eroded, they do outcrop locally, ranging in thickness from 0 to 120 m (0 to 394 ft) (Rowlands et al. 1995). Patchy outcrops occur along the upthrown side of the Anderson Mesa normal fault. The Moenkopi also outcrops in narrow structural basins oblique to the Anderson Mesa Fault in Walnut Canyon.

Tertiary and Quaternary basaltic lava flows locally cap the sedimentary strata. The Anderson Mesa Basalt caps Anderson Mesa immediately south of Walnut Canyon (fig. 3). Basaltic lava flows within the Lake Mary Graben are approximately 38 m (125 ft) thick, covered by Quaternary alluvium (Rowlands et al. 1995). Like the Kaibab Formation, these fractured basalts act as recharge zones for many local perched aquifers.

Quaternary alluvial (stream) and lacustrine (lake) deposits are as thick as 23 m (75 ft) (Rowlands et al. 1995). Colluvial (slope) deposits of talus at the base of slopes occur along the downthrown sides of faults, in canyons, and along margins of lava flows.

Faults and fractures that strike perpendicular to the trend of Walnut Canyon across Anderson Mesa and along the Lower Lake Mary shoreline are the dominate the geologic structures of the area (fig. 3). The major fault is the Anderson Mesa Fault - a normal fault that forms the southwest boundary of Anderson Mesa and the northeast boundary of the Lake Mary basin (Rowlands et al. 1995).

Park History

The earliest evidence of humans living in Walnut Canyon dates back to 4,000 B.C. (Hansen et al. 2004). However, the highest density of prehistoric people living in the area was from 600 A.D. to 1250 A.D. when a prehistoric farming culture flourished in the Flagstaff area (Hansen et al. 2004; http://www.nps.gov/waca/index.htm, accessed October, 2004). The Spanish named these people the Sinagua culture, a name taken from “Sierra Sinagua” meaning “mountain range without water” (NPS 2003; Hansen et al. 2004; http://nps.gov/waca/index.htm, accessed October 2004). Although Noble (1991) refers to the “Sinagua Indians,” Sinagua is not the name of a tribe or clan, but refers to various archeological sites and objects found in this part of Arizona that have similar characteristics. How these people collectively perceived themselves and their neighbors, or what they called themselves is not known (http://www.nps.gov/waca, accessed October, 2004).

The ancient farmers grew corn, squash, and beans above the Walnut Canyon rim. Ash and cinders from the eruptions of nearby Sunset Crater Volcano (the last eruption occurred about 1,000 years ago) enriched the soil, curbed evaporation, conserved soil moisture, and increased productivity of the Sinagua’s fields so that the regional population began to grow. People first moved down into the canyon about 1150 A.D. when they built most of the cliff dwellings that line the canyon walls. Although little water flows in Walnut Creek today because of two upstream dams, Walnut Creek once supported a rich variety of plants and animals (http://nps.gov/waca, accessed October 2004).

The Sinagua culture in Walnut Canyon thrived for about 150 years, but around 1250 A.D., the Sinagua mysteriously abandoned the canyon. Archaeologists are not sure why the Sinagua people left, but probable causes include lack of precipitation, falling water tables, permanent water shortages, resource depletion, repeated crop failures, and rapidly expanding arroyo systems (Schroeder 1977; Rowlands et al. 1995; http://www.desertusa. com/ind1 /du_peo_sin.html, accessed March 2007). Hopi oral histories tell of the Sinagua migrations (http://www.desertusa.com /ind1 /du_peo_sin.html, accessed March 2007; Noble 1991).

The Walnut Canyon cliff dwellings are unique in that they are the only known such remains of the northern Sinagua culture. The site density in the monument averages almost 100 sites per square mile, compared with typical densities of 40 sites per square mile in other areas near Flagstaff (NPS 2003). About 300 rooms are scattered along both sides of Walnut Canyon. In 1885, James Stevenson of the Smithsonian Institution visited the area and noted,

> "The doors are large and extend from the ground up to a sufficient height to admit a man without stooping. The rooms are large and the walls are two to four feet thick. The fireplaces are in one corner of the room on an elevated rock, and the smoke can only escape through the door. The masonry compares favorably with the construction of the best villages in Canyon de Chelly. Many objects of interest were found in the debris around and in these houses. Matting, sandals, spindle whorls, and stone implements of various kinds abound."
>
> (Vandiver 1936, p. 2).

Vandals and thieves removed almost all of the archaeological objects from the cliff dwellings described by Stevenson, and many of the cliff dwellings were broken down and destroyed prior to 1906 when the U.S. Forest Service first protected the area (Vandiver 1936). The dense concentration of prehistoric ruins, their exceptional state of preservation, and their unusual and highly scenic setting in sheltered alcoves, as well as the threat of imminent destruction by commercial looters and misguided tourists were key factors influencing the creation of Walnut Canyon National Monument (NPS 2003).

No large settlements of humans inhabited Walnut Canyon after 1250 A.D., but the surrounding landscape has been altered by historic and modern human activity such as logging, hunting, fire suppression, housing development, water impoundments, and road and utility construction. In 1973, the park installed a fences around protected ruins and prohibited livestock grazing. Grazing continues in areas adjacent to the monument and within the unfenced monument boundary (Hansen et al. 2004).

Figure 1. Regional location map for Walnut Canyon National Monument.

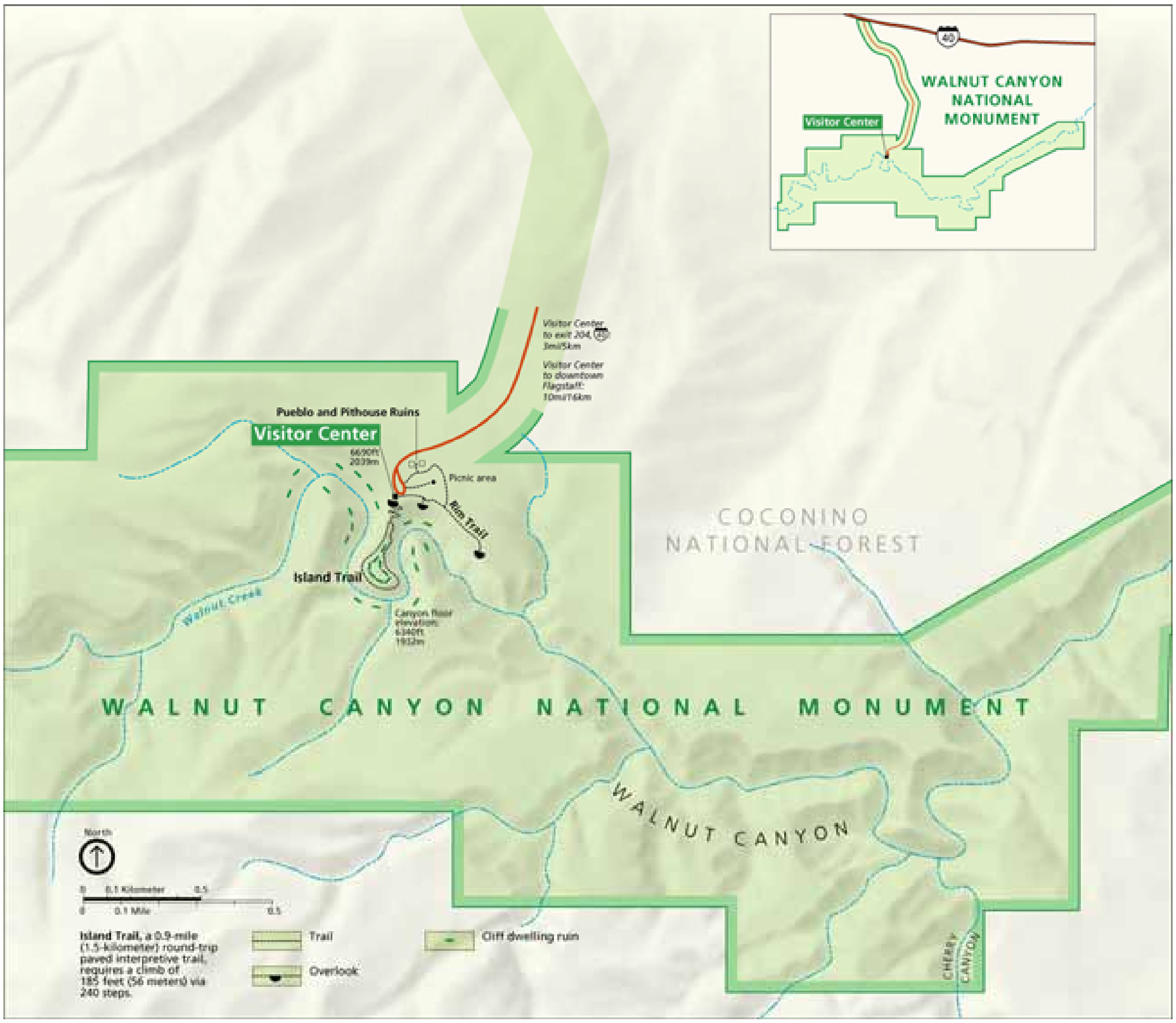

Figure 2 Trails and relief in Walnut Canyon National Monument. Map courtesy of the National Park Service, http://www.nps.gov/waca/planyourvisit/index.htm (Accessed March 2007).

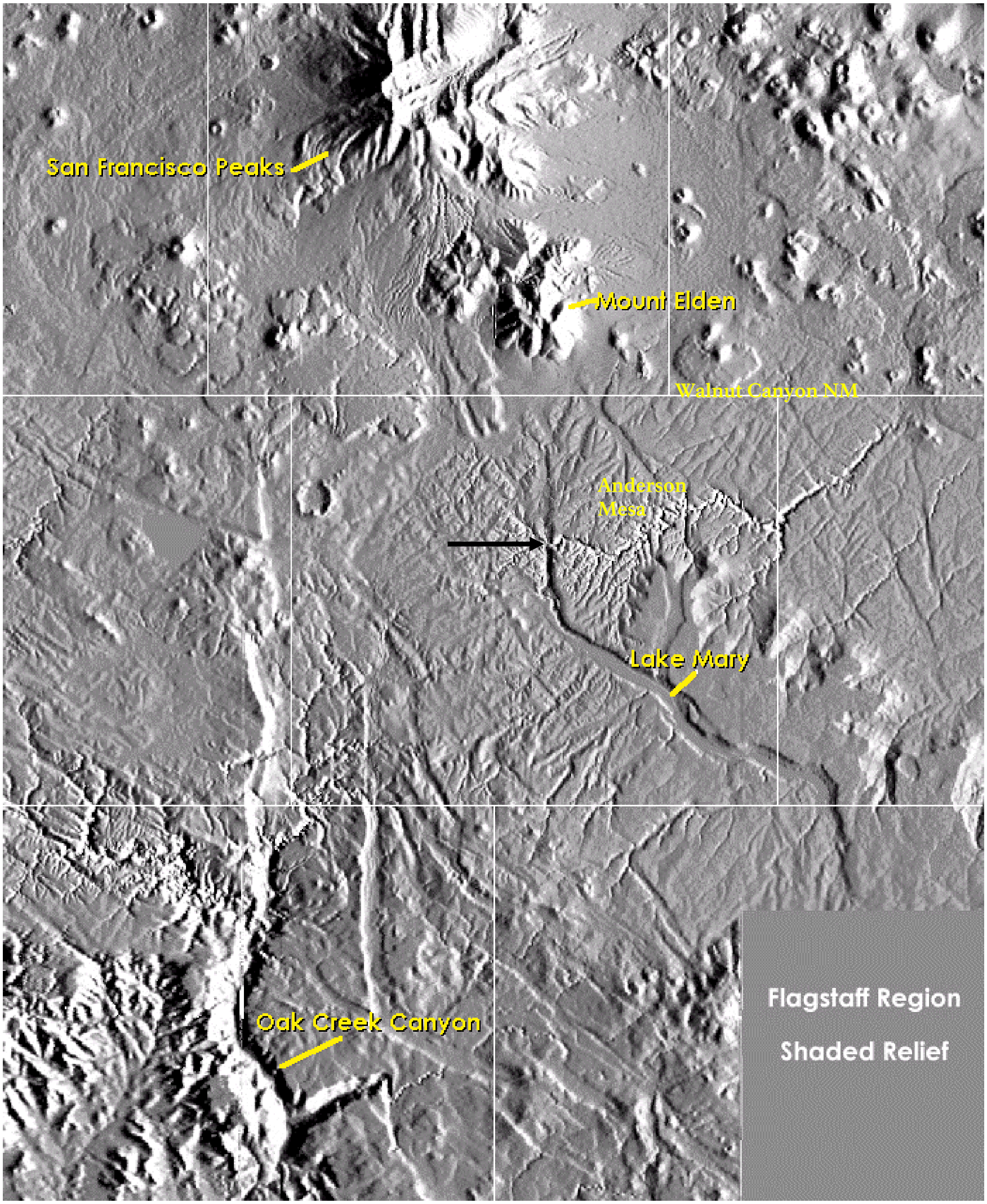

Figure 3. Shaded relief map showing the Walnut Canyon National Monument area. The black arrow points to the escarpment of the Anderson Mesa Fault. Lake Mary lies in the graben formed by the fault. The north-south lineaments that cross Walnut Canyon and the northwest-southeast and northeast-southwest features are faults. The image was generated using 30 meter resolution Digital Elevation Model (DEM) data. Map courtesy of the U.S. Geological Survey, http://terraweb.wr.usgs.gov/projects/Flagstaff/ dem.html (Accessed March 2007).

Figure 4. Cliff dwellings at Walnut Canyon National Monument constructed in an alcove within the Kaibab Formation beneath an overhanging ledge of limestone. Photo courtesy of the USGS; http://3dparks.wr.usgs.gov/walnutcanyon/html2/wc1650.htm (Accessed March 6, 2007).

Period	Formation/Unit	General Lithology
Quaternary	Alluvium	Unconsolidated gravel, sand, silt deposits
	Lacustrine deposits	Fine- grained lake deposits
	Colluvium	Unconsolidated gravel, sand, & basalt
Regional Unconformity		
Triassic	Moenkopi Fm	Mudstone, siltstone, & sandstone
Regional Unconformity		
Permian	Kaibab Fm.	Dolomite, sandy limestone, cherty limestone
	Toroweap Fm. & Coconino Sandstone	Cross- bedded quartz sandstone
Regional Unconformity		
Pennsylvanian/Permian	Supai Group	Not exposed in Walnut Canyon NM

Figure 5. Generalized stratigraphic column for Walnut Canyon National Monument, Arizona.

Geologic Issues

A Geologic Resource Evaluation scoping session was held for Walnut Canyon National Monument on June 28–29, 2001, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. The following section synthesizes the scoping results, in particular those issues that may require attention from resource managers.

Since 1941, flow in Walnut Creek has been severely limited due to two upstream dams. Decreased flow has resulted in reduced sediment input, reduced streambed scouring, reduced recharge of springs and seeps, and a more static channel morphology. Changes in the geomorphic and hydrogeologic character of the canyon bottom and Walnut Creek have caused changes in the riparian habitat flanking the creek, which depends on a scoured channel, periodic flooding, and adequate groundwater. The riparian areas in Walnut Canyon provide an important element of the desired cultural landscape setting for the Sinagua cliff dwellings and enhances the natural viewshed from the primary visitor use areas. Ultimately, the riparian corridor significantly enhances habitat diversity, species richness, cultural resource integrity, and visitor experience (Whitefield 2005). For these reasons, defining the integrated geomorphic and hydrogeologic response to decreased water flow in the canyon is the primary geologic issue facing Walnut Canyon National Monument.

Rockfall

Rockfall is a serious hazard in the rugged canyons of Walnut Canyon National Monument that can impact visitor and staff safety as well as park infrastructure. The Island Trail is the most popular trail at Walnut Canyon National Monument. It descends into a steep, rugged canyon allowing park visitors to hike in a natural environment and view ancient cliff dwellings. On November 30th and December 8th, 2007 two rockfalls damaged large sections of the Island Trail. The initial rockfall blocked the lower section of the trail and the much larger December 8th event took out large sections of a concrete stairway, steel handrails, and a bench. As a result the trail is closed to visitor use pending remediation (Greco 2008).

The natural processes that formed the canyon are still at work and can sometimes produce hazardous conditions. Climate can be a primary driver behind hazards in Walnut Canyon as was the case with recent events. The weathering and erosion of material from slopes is seasonally controlled. Extreme mechanical weathering from freeze- thaw action during the winter months can account for a large portion of the debris moving down slope. During climatic extremes such as drought, heavy snow pack or extreme rainstorms, the erosion cycles can be accelerated. In times of drought, excess debris builds up, then during rainstorms events or snow melt, the amount of material flushed can increase substantially (Greco 2008).

The 2007 rockfall events were not unique in Walnut Canyon National Monument. Rockfall is a natural occurance and a long history of past rockfalls is evident in the talus and large boulders scattered throughout the canyon. Scars on the canyon walls likewise identify where large chunks of rock have previously fallen. Larger size rockfalls occur infrequently and are only addressed when they impact park infrastructure or threaten visitor. Smaller rockfalls occur much more frequently and usually go unreported.

Geomorphology and Hydrogeology

Walnut Canyon National Monument contains 13 linear km (8 linear mi) of Walnut Canyon. The canyon bottom is narrowly- incised into the Coconino Sandstone where the Walnut Creek drainage meanders northeastward through coarse- grained stream terrace deposits and talus blocks from the canyon walls. Water catchment basins of various sizes, scoured into the Coconino Sandstone, provide important water sources for wildlife. Groundwater from numerous fractures and bedding planes seeps from the steep canyon walls and tributary canyons (Chronic 1983; NPS 2003; Whitefield 2005).

The Walnut Canyon watershed drains an area of about 108,800 acres or 170 square miles (440 sq km). Approximately 75%, or 83,200 acres, 130 square miles, (337 sq km) of the Walnut Creek watershed lies upstream of the monument to the south and west in the Coconino National Forest. Walnut Creek headwaters originate in the Mormon Mountain- Mormon Lakes area more than 32 km (20 mi) south of the monument. Prior to the first upstream dam construction in 1904, anecdotal and photographic evidence suggests that Walnut Creek was once an ephemeral stream with an open, rocky bed maintained by seasonal flooding (Rowlands et al. 1995). Reliable flows typically occurred early each year during the seasonal spring snowmelt. Less predictable flows occurred during the summer and fall thunderstorm season. Today, dense stands of invasive, hearty upland woody vegetation choke the bottom of Walnut Creek (Rowlands et al. 1995).

Wetlands, floodplains, and riparian habitats covering about 90 acres within Walnut Canyon National Monument are restricted to the narrow canyon bottom and a number of perennial seeps found in the tributary canyons on the south side of the monument. Riparian vegetation includes a tree canopy of box elder, Arizona walnut, narrow- leaf cottonwood, Rocky Mountain juniper, ponderosa pine, Douglas fir, and Gambel oak.