

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science Directorate
Geologic Resources Division



Walnut Canyon National Monument

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic
Data for Walnut Canyon National Monument

waca_geology.pdf

Version: 5/7/2019

Geologic Resources Inventory Map Document for Walnut Canyon National Monument

Table of Contents

Geologic Resources Inventory Map Document.....	1
About the NPS Geologic Resources Inventory Program.....	3
GRI Digital Map and Source Map Citation.....	5
Index Map	5
Map Unit List	6
Map Unit Descriptions.....	7
Qcc - Volcanic ash (Quaternary).....	7
Quaternary and Tertiary Deposits.....	7
Qal - Alluvium (Quaternary).....	7
Ql - Lacustrine deposits (Quaternary).....	7
Qc - Sandstone and limestone colluvium (Quaternary).....	7
Qbc - Basalt colluvium (Quaternary).....	7
Qb - Lower Lake Mary Flow, basalt (Pleistocene).....	8
Tb - Anderson Mesa Flow, basalt (upper Miocene to Pliocene).....	8
Mesa Gravels.....	9
TRm - Moenkopi Formation (Triassic).....	9
Pkt - Kaibab Formation (Lower Permian).....	11
Pc - Coconino Sandstone and Toroweap Formation, undivided (Lower Permian).....	12
Geologic Cross Section.....	13
Cross Section A-A'.....	13
GRI Ancillary Source Map Information.....	14
Greater Walnut Canyon National Monument Area.....	14
Location Map of Walnut Canyon National Monument.....	14
Photograph 1: Typical outcrop of cross-bedded Coconino Sandstone in Walnut Canyon.....	15
Photograph 2: Typical outcrop of the Kaibab Formation in Walnut Canyon.....	16
References.....	16
GRI Digital Data Credits.....	18

Geologic Resources Inventory Map Document



Walnut Canyon National Monument, Arizona

Document to Accompany Digital Geologic-GIS Data

[waca_geology.pdf](#)

Version: 5/7/2019

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Walnut Canyon National Monument, Arizona (WACA).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

This document contains the following information:

- 1) **About the NPS Geologic Resources Inventory Program** – A brief summary of the Geologic Resources Inventory (GRI) Program and its products. Included are web links to the GRI GIS data model, and to the GRI products page where digital geologic-GIS datasets, scoping reports and geology reports are available for download. In addition, web links to the NPS Data Store and GRI program home page, as well as contact information for the GRI coordinator, are also present.
- 2) **GRI Digital Map and Source Map Citation** – A listing of all GRI digital geologic-GIS maps produced for this project along with sources used in their completion. In addition, a brief explanation of how each source map was used is provided.
- 3) **Map Unit List** – A listing of all geologic map units present on maps for this project, generally listed from youngest to oldest.
- 4) **Map Unit Descriptions** – Descriptions for all geologic map units. If a unit is present on multiple source maps the unit is listed with its source geologic unit symbol, unit name and unit age followed by the unit's description for each source map.
- 5) **Geologic Cross Section** – The A-A' geologic cross section graphic with horizontal scale bar and note.
- 6) **Ancillary Source Map Information** – Additional source map information presented by source map. This includes a location map, two photographs, and references cited by the source map.
- 7) **GRI Digital Data Credits** – GRI digital geologic-GIS data and ancillary map information document production credits.

For information about using GRI digital geologic-GIS data contact:

Stephanie O'Meara
Geologist/GIS Specialist/Data Manager
Colorado State University Research Associate, Cooperator to the National Park Service
Fort Collins, CO 80523
phone: (970) 491-6655
e-mail: stephanie.omeara@colostate.edu

About the NPS Geologic Resources Inventory Program

Background

Recognizing the interrelationships between the physical (geology, air, and water) and biological (plants and animals) components of the earth is vital to understanding, managing, and protecting natural resources. The Geologic Resources Inventory (GRI) helps make this connection by providing information on the role of geology and geologic resource management in parks.

Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel with information that can help them make informed management decisions.

The GRI team, working closely with the Colorado State University (CSU) Department of Geosciences and a variety of other partners, provides more than 270 parks with a geologic scoping meeting, digital geologic-GIS map data, and a park-specific geologic report.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: <https://www.nps.gov/articles/gri-geodatabase-model.htm>

Geologic Reports: Park-specific geologic reports identify geologic resource management issues as well as features and processes that are important to park ecosystems. In addition, these reports present a brief geologic history of the park and address specific properties of geologic units present in the park.

For a complete listing of Geologic Resource Inventory products and direct links to the download site visit the GRI publications webpage: http://go.nps.gov/gri_products

GRI geologic-GIS data is also available online at the NPS Data Store Search Application: <http://irma.nps.gov/App/Reference/Search>. To find GRI data for a specific park or parks select the appropriate park(s), enter □GRI□ as a Search Text term, and then select the Search Button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: <https://www.nps.gov/subjects/geology/gri.htm>, or contact:

Jason Kenworthy
Inventory Coordinator
National Park Service Geologic Resources Division
P.O. Box 25287
Denver, CO 80225-0287
phone: (303) 987-6923
fax: (303) 987-6792
email: Jason_Kenworthy@nps.gov

The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division.

GRI Digital Map and Source Map Citation

The GRI digital geologic-GIS map for Walnut Canyon National Monument, Arizona (WACA):

Digital Geologic-GIS Map of Walnut Canyon National Monument, Arizona (GRI MapCode WACA)

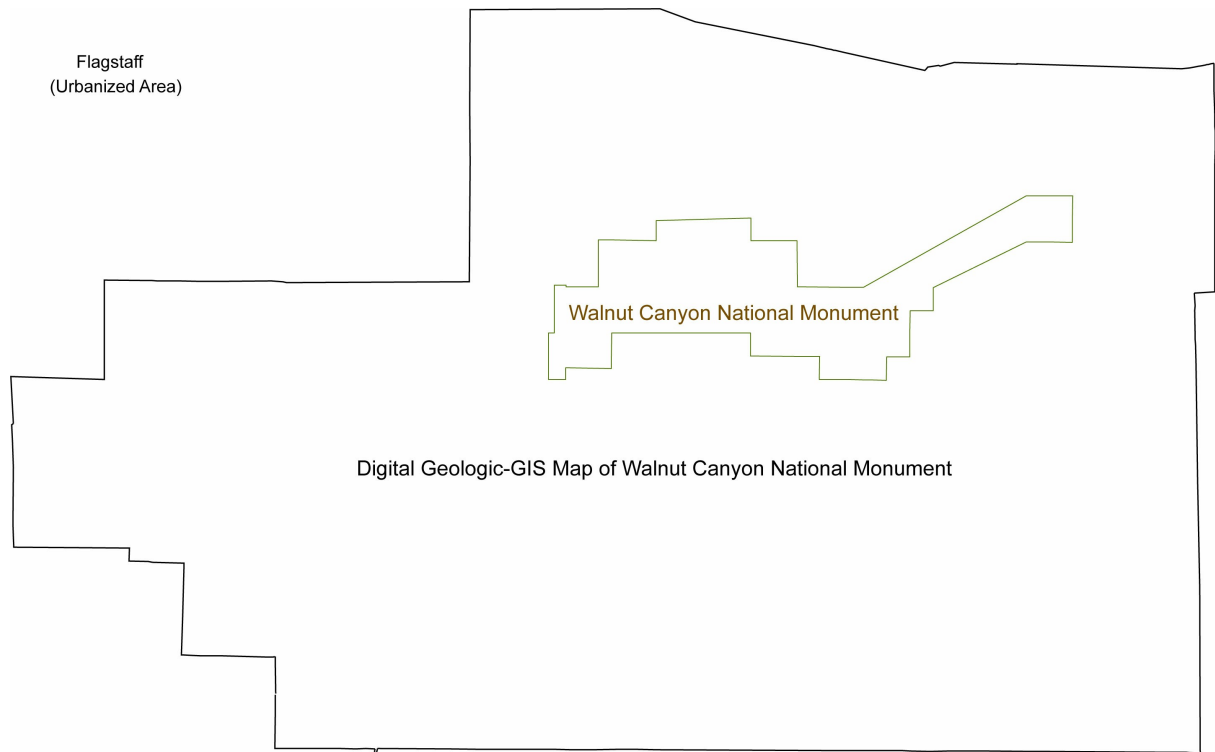
The map was produced from the following source map.

Raucci, J., Blythe, N., Ort M., and Manone, M., 2004, Geologic Map of the Greater Walnut Canyon National Monument Area: Northern Arizona University, unpublished digital data, scale 1:12,000 ([Greater Walnut Canyon National Monument Area](#)). (GRI Source Map ID 4146).

Additional information pertaining to each source map is also presented in the GRI Source Map Information (WACAMAP) table included with the GRI geologic-GIS data.

Index Map

The following index map displays the extent (in black) of GRI digital geologic-GIS map for Walnut Canyon National Monument, as well as the boundary of the monument (in dark green, as of May, 2019). The urbanized area of the city of Flagstaff is to the west and northwest of the monument.



Index map graphic by Stephanie O'Meara (Colorado State University).

Map Unit List

The geologic units present in the digital geologic-GIS data produced for Walnut Canyon National Monument, Arizona (WACA) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qcc - Volcanic ash). Units are listed from youngest to oldest. Information about each geologic unit is also presented in the GRI Geologic Unit Information (WACAUNIT) table included with the GRI geologic-GIS data.

Cenozoic Era

Quaternary Period

[Qcc](#) - Volcanic ash

[Qal](#) - Alluvium

[Ql](#) - Lacustrine deposits

[Qc](#) - Sandstone and limestone colluvium

[Qbc](#) - Basalt colluvium

Pleistocene Epoch

[Qb](#) - Lower Lake Mary Flow, basalt

Tertiary Period

[Tb](#) - Anderson Mesa Flow, basalt

[Mesa Gravels](#) (unmapped unit)

Mesozoic Era

Triassic Period

[TRm](#) - Moenkopi Formation

Paleozoic Era

Permian Period

[Pkt](#) - Kaibab Formation

[Pc](#) - Coconino Sandstone and Toroweap Formation, undivided

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below. Unit descriptions were taken from the source map, [Greater Walnut Canyon National Monument Area](#).

Qcc - Volcanic ash (Quaternary)

No additional unit description present on source map.

The unit Qcc is present in the Ash Units (WACAASH) feature class in the GRI digital geologic-GIS data.

Quaternary and Tertiary Deposits

Several distinct Tertiary to Quaternary surficial units are present within the map area, typically covering bedrock exposures of the Kaibab Formation, Moenkopi Formation, and the basalt sheet flows.

These deposits include Quaternary surficial deposits, [Qal](#), [Ql](#), and [Qc](#), as well as the unmapped Miocene-age (Tertiary) [Mesa Gravels](#).

Qal - Alluvium (Quaternary)

These deposits form the youngest unit in the map area, covering the active drainage channels and incised terraces of broader valleys. The unit is nonlithified sand and gravel alluvial and fluvial deposits and is generally <1 m thick in the map area. These deposits were derived from the surrounding Permian to Tertiary bedrock, as well as older surficial deposits, and include sandstone and siltstone of the Moenkopi Formation, limestone of the Kaibab Formation, and Tertiary to Quaternary basalt.

Ql - Lacustrine deposits (Quaternary)

This unit is Quaternary to Recent lake deposits of Marshall Lake and Lower Lake Mary, both dry at the time of this study. These lake deposits are typically nonlithified silt and mud and are of unknown thickness.

Qc - Sandstone and limestone colluvium (Quaternary)

This Quaternary unit is a localized occurrence of angular sandstone and limestone cobble clasts covering the Lake Mary Fault in the southwestern portion of the map area. This deposit is <10 m thick and is derived from local outcrops of the Kaibab Formation and the Moenkopi Formation along the fault scarp.

Qbc - Basalt colluvium (Quaternary)

This Quaternary deposit is typically angular basalt pebble and cobble clasts shed from the basalt flow of Anderson Mesa. These debris deposits are generally a few centimeters to <2 m thick. The pebble-cobble clasts cover outcrops of the upper Moenkopi Formation on the east-facing and northeast-facing slopes of Anderson Mesa in the central and southeast portion of the map area.

Qb - Lower Lake Mary Flow, basalt (Pleistocene)

This unit shares a unit description with unit Tb.

Two separate basalt sheet flows occur in the area, the upper Miocene to Pliocene Anderson Mesa basalt (Tb), which caps Anderson Mesa, and the Pleistocene Lower Lake Mary basalt (Qb), occurring as a valley fill in the extreme western portion of the mapping area. Both flows unconformably overlie the Moenkopi Formation and are similar to one another in mineral assemblage. These basalts are ~30% plagioclase feldspar and ~10% olivine. These two basalts are distinguished, however, by the differing sizes of the dominant minerals. The Anderson Mesa basalt has large (~1 mm diameter), altered olivine and smaller (~0.5 mm diameter) acicular plagioclase crystals while the Lower Lake Mary basalt has larger plagioclase crystals 1-2 mm in diameter. In thin section, the feldspar is typically acicular and demonstrates good albite twinning. The plagioclase forms the trachytic texture of the rock. The olivine occurs as euhedral crystals, commonly fractured, with rare twinning. Olivine crystals in the Anderson Mesa basalt commonly possess altered clay pellicles, visible in thin section. The basalts are typically gray to brown, aphanitic to vesicular, with visible oxidized olivine crystals. The Lower Lake Mary flow is no greater than 37 m thick, determined from well data reported by Kelly (2000), and the Anderson Mesa flow is no greater than 40 m thick within the map area.

Damon et al. (1974) reported a K/Ar isotopic age on the Anderson Mesa basalt flow in the mapping area, distal from the vent at Mormon Lake, of 6.39 Ma (+/- 0.30 Ma), while Holm and Shafiqullah (1994) reported a K/Ar age of 4.38 Ma (+/- 0.20 Ma) from a small lava shield on top of the sheet flow. Holm and Shafiqullah (1994) reported a K/Ar date of 0.859 Ma (+/- 0.055 Ma) from the intracanyon basalt flow in Walnut Creek, which is correlative to the Lower Lake Mary flow within the mapping area. All ages are by K/Ar whole-rock methods.

Tb - Anderson Mesa Flow, basalt (upper Miocene to Pliocene)

This unit shares a unit description with unit Qb.

Two separate basalt sheet flows occur in the area, the upper Miocene to Pliocene Anderson Mesa basalt (Tb), which caps Anderson Mesa, and the Pleistocene Lower Lake Mary basalt (Qb), occurring as a valley fill in the extreme western portion of the mapping area. Both flows unconformably overlie the Moenkopi Formation and are similar to one another in mineral assemblage. These basalts are ~30% plagioclase feldspar and ~10% olivine. These two basalts are distinguished, however, by the differing sizes of the dominant minerals. The Anderson Mesa basalt has large (~1 mm diameter), altered olivine and smaller (~0.5 mm diameter) acicular plagioclase crystals while the Lower Lake Mary basalt has larger plagioclase crystals 1-2 mm in diameter. In thin section, the feldspar is typically acicular and demonstrates good albite twinning. The plagioclase forms the trachytic texture of the rock. The olivine occurs as euhedral crystals, commonly fractured, with rare twinning. Olivine crystals in the Anderson Mesa basalt commonly possess altered clay pellicles, visible in thin section. The basalts are typically gray to brown, aphanitic to vesicular, with visible oxidized olivine crystals. The Lower Lake Mary flow is no greater than 37 m thick, determined from well data reported by Kelly (2000), and the Anderson Mesa flow is no greater than 40 m thick within the map area.

Damon et al. (1974) reported a K/Ar isotopic age on the Anderson Mesa basalt flow in the mapping area, distal from the vent at Mormon Lake, of 6.39 Ma (+/- 0.30 Ma), while Holm and Shafiqullah (1994) reported a K/Ar age of 4.38 Ma (+/- 0.20 Ma) from a small lava shield on top of the sheet flow. Holm and Shafiqullah (1994) reported a K/Ar date of 0.859 Ma (+/- 0.055 Ma) from the intracanyon basalt flow in Walnut Creek, which is correlative to the Lower Lake Mary flow within the mapping area. All ages are by K/Ar whole-rock methods.

Mesa Gravels

A nonconsolidated pebble gravel mantles weathered Moenkopi Formation outcrop and occurs within basalt colluvium throughout the map area, most abundantly in the northeast. These gravel deposits consist of sub-rounded to very well-rounded quartz and quartzite pebbles and sub-angular to sub-rounded chert pebbles. The quartz pebbles are pink to red and are 2-5 cm long. The quartzite pebbles are pink to red and are 2-4 cm long. The chert pebbles are red and black and are 2-5 cm long. These pebbles are associated with red to tan, angular pieces of petrified wood, ranging in size from 2-5 cm diameter. These gravels occur as a discontinuous, <20 cm thick surficial cover, and were not mapped at 1:24,000 scale. These gravels were first reported by Price (1950), who termed them Type B gravels of his study, and were subsequently termed Mesa Gravels by Holm (2001). Holm (2001) interpreted these gravels to be deposits of Miocene age derived from outcrops of the Shinarump Conglomerate of the Upper Triassic Chinle Formation. He describes their occurrence at the contact between Miocene basalt sheet flows and the underlying Moenkopi Formation as a lag veneer deposited on the eroded sandstone/siltstone of the Moenkopi Formation prior to being covered by lava flows.

Text from source map: [Greater Walnut Canyon National Monument Area](#)

Mesa gravels were unmapped on the source map, and thus are not present in the GRI digital geologic-GIS data. Nevertheless, as mentioned in the above unit description these deposits are present in the mapped area.

TRm - Moenkopi Formation (Triassic)

The Lower to Middle Triassic Moenkopi Formation unconformably overlies the Kaibab Formation and is composed of four discernible units within the mapping area: a conglomerate at the base, the siltstone-mudstone of the Wupatki Member, the lower massive sandstone, and the cross-bedded sandstone of the Holbrook Member.

Basal Conglomerate

A conglomerate facies at the base of the Moenkopi Formation is exposed in a few areas within the southern portion of the mapping area. This conglomerate is a red, well-consolidated, poorly-sorted, sub-angular pebble-clast conglomerate with a medium sandstone to pebbly sandstone matrix. It is matrix-supported, with approximately 20% clasts of sub-angular red to tan limestone, 0.25 to 3 cm long; white to brown, sub-rounded coarse sand size quartz; and black, sub-angular, ~1-2 mm diameter chert fragments, with minor coarse sand size chalcedony. The matrix consists of very fine grained quartz and sub-rounded chert, euhedral plagioclase and calcite grains, with a minor population of curvilinear muscovite and sub-rounded chalcedony grains, cemented by calcite. The limestone clasts are derived from the underlying Kaibab Formation and support the interpretation of this facies as a rip-up clast conglomerate. This unit is no greater than 5 m thick in the map area. Basham (1990) reported the occurrence of a similar conglomerate near the contact with the underlying Kaibab Formation in exposures north of Flagstaff, Arizona. Cook (1989) reported exposure of this conglomerate unit up to 2 m thick near Gray Mountain and interpreted these deposits as debris flows transported down the flanks of a structure associated with the present-day Gray Mountain Monocline.

Wupatki Member

The Wupatki Member conformably overlies the lower conglomerate facies and is the most common member of the Moenkopi Formation in the map area. This unit consists of siltstone and mudstone interbeds. The siltstone and mudstone are thinly bedded, well sorted and quartz dominant; the quartz grains are sub-rounded to sub-angular. A minor component of calcite is present, both as angular grains and minor cement; minor muscovite is present as angular laths. Ripple marks and mudcracks are common. This unit is typically 20 m thick, although only a few complete sections of the member are exposed in the southern portion of the area. The base and upper portions are commonly obscured

by Quaternary basalt colluvium. Basham (1990) reported ripple and climbing-ripple cross-stratification in this unit in northeastern and north-central Arizona, with both straight-crested and sinuous-crested ripples common. He also reports local occurrences of soft-sediment deformation structures such as ball and pillow and flame structures within this unit and favors a marine tidal flat origin. This environmental interpretation is supported in part by evidence of bimodal paleocurrent distribution within the ripple cross-stratification, a strong suggestion of tidal action (Baldwin, 1973).

Lower Massive Sandstone

A prominent, massive red sandstone serves as a marker bed throughout the Moenkopi Formation in Arizona. This sandstone is typically a well-sorted subarkose, with sub-rounded, fine-sand-size grains. Mineral composition includes ~60-% monocrystalline quartz, 5-% plagioclase and microcline feldspars, 10-% calcite grains and minor cement, and ~25-% chert. Sedimentary structures within this sandstone in the map area include small-scale trough and planar cross-stratification and localized crinkle laminations, typical of a drying dune surface. In the map area, this sandstone is 5 to 10 m thick and occurs within the middle to upper portion of the Wupatki Member; its exact stratigraphic location is unknown due to poor outcrop.

In northeastern and north-central Arizona, Basham (1990) reported local climbing ripple stratification and trough and planar cross-strata in the lower massive sandstone and noted that large-scale sets are rare. He interpreted this unit to be of an eolian origin, based upon the presence of climbing translent strata and southeasterly paleoflow directions (in opposition to the dominant fluvial flow directions for the Triassic). Basham (1990) also reported a series of fluvial sandstones overlying the lower massive sandstone in outcrops to the north of Flagstaff, Arizona, typically possessing low-angle trough and ripple cross-stratification. This additional upper fluvial facies was not observed in the sparse and covered outcrops of the map area, but may be present.

Holbrook Member

The Holbrook Member conformably overlies the Wupatki Member and the lower massive sandstone. The unit is a tan to red, cross-bedded to thinly bedded fine-grained sandstone. The sandstone is well sorted, with grain-to-grain contacts of sub-angular to angular, very-fine-sand-size grains. The grains are ~60% monocrystalline quartz, 30% calcite, 5% chert, 5% plagioclase feldspar, with a minor component of biotite and muscovite laths and zircon crystals. The member has small channels <0.5 m thick with mudstone rip-up clasts, as well as 0.5 to 1 m thick cross-bed sets with minor mud rip-up clasts. Horizontal and trough-, planar-, and ripple-cross-stratification are common in this unit. The unit is exposed as a 10-m-thick incomplete section in a single location in the south-central portion of the map area. It is assumed this member represents ~80 m of the upper Moenkopi Formation outcrop. Traces of red, weathered sandstone mixed with basalt colluvium on slopes beneath the Anderson Mesa basalt indicate that the Holbrook Member is probably present throughout the map area beneath a basalt colluvium cover.

In northeastern and north-central Arizona, Basham (1990) described this unit as "fine- to medium-grained sheet and ribbon-shaped sandstone bodies set in dark reddish-brown, horizontally laminated to structureless mudstone." He reported similar cross-strata within the sandstone as observed in the Walnut Canyon area, as well as architectural elements such as channel deposits, barforms, and dune and sand wave bedforms, leading to an interpreted fluvial depositional environment. Basham (1990) described this fluvial system as a braided system with large flood plains, with a west to northwest paleoflow direction. Blakey et al. (1993) suggested that the Holbrook Member represents a depositional environmental change from the strongly ephemeral streams of the lower Moenkopi Formation to more dominantly perennial, strong-flowing streams. Stratigraphically, this member has been shown to be equivalent to the Upper Red Member of the Moenkopi Formation, present from southwest Utah to east-central Arizona.

Poor exposure throughout the map area does not allow for consistent mapping of the four members of the Moenkopi Formation individually. The most complete exposures of the Moenkopi Formation occur only in the southern portion of the mapping area. The upper portion of the Wupatki Member and the Holbrook Member are typically covered by basalt colluvium. Stewart et al. (1972) place the lower

massive sandstone marker bed within the upper to middle Wupatki Member in the Flagstaff area. Due to predominantly covered outcrop throughout the map area, the exact stratigraphic position of this unit is unknown; however, given observations from a single outcrop in the southcentral portion of the map area, we consider the lower massive sandstone to be near the top of the Wupatki Member. The entire Moenkopi Formation attains a maximum mappable thickness of no greater than 110 m in this area, consistent with the 120 m thickness estimate from Stewart et al. (1972) for this region. The Moenkopi Formation is dominantly siltstone to fine-grained sandstone, cemented by red matrix, suggesting a widespread, fine-grained, recycled sedimentary rock source (Blakey et al., 1993). These authors suggested that dissected Permian redbeds, present across much of central North America, provided the bulk of the siliciclastic material for the Moenkopi Formation.

Pkt - Kaibab Formation (Lower Permian)

The Lower Permian Kaibab Formation unconformably overlies the Coconino Sandstone and is exposed throughout the map area. The Kaibab Formation in the Walnut Canyon area is characterized by distinct outcrop ledges (Figure 2) of tan, silty and dolomitic fossiliferous limestone interbedded with calcereous siltstone and sandstone, with bedded and discontinuous chert and minor limestone conglomerate beds typical of the Fossil Mountain Member. The chert within the discontinuous layers are cream-colored nodules, 2-10 cm in diameter. Ripple laminations and cross-stratification characterize the unit in the Walnut Canyon area. There is a considerable degree of interfingering between carbonate and siliciclastic compositions of the Kaibab Formation, as well as pervasive diagenetic silicification and dolomitization. These compositional variations were also documented by Hopkins (1986) in the eastern Grand Canyon and confirm similar descriptions by Chronic (1952) of the Walnut Canyon section.

Regionally, a wide variety of paleofauna have been preserved within the Fossil Mountain Member of the Kaibab Limestone, including fish, sponges, brachiopods, bryozoans, crinoids, ammonoids and trilobites. These assemblages are generally characteristic of the unit within the map area. Chronic (1952) described in detail the molluscan fauna of the Fossil Mountain Member in Walnut Canyon; McKee (1938) described in detail the brachiopod fauna and other fauna of the Kaibab Formation in northern Arizona and southern Utah; and Miller and Furnish (1958) described the ammonoid population of the member. Recent biostratigraphic studies of the Fossil Mountain Member, based on several different paleofaunal assemblages, have narrowed the age of the unit to the very latest Early Permian epoch (Thompson, 1995).

In central Arizona, the Kaibab Formation is divided into the Fossil Mountain and Harrisburg Members and overlies the Toroweap Formation and Coconino Sandstone. Distinguishing stratigraphic location within the Kaibab Formation in the map area is difficult; however, it appears that the best exposure within Walnut Canyon is within the Fossil Mountain Member. Its greatest mapped thickness in the area is 160 m with the best exposure present in the walls of Walnut Canyon above the Coconino Sandstone. The upper contact of the Kaibab Formation is commonly covered by colluvium derived from the Moenkopi Formation.

Regionally, the Kaibab Formation was deposited within a broad shelf, or ramp, that was stable to gently subsiding. Changes in lithofacies and increased open-marine fauna indicate that deeper water environments existed to the west during deposition. The Fossil Mountain Member of the formation represents a transgressive sequence (relative sea-level rise) punctuated by small regressions (relative sea-level fall) within this shelf environment. Distribution of lithofacies within the Fossil Mountain Member are consistent with deposition within subtidal to near-shore environments (Hopkins, 1986).

Pc - Coconino Sandstone and Toroweap Formation, undivided (Lower Permian)

Coconino Sandstone (Pc)

The Lower Permian Coconino Sandstone unconformably underlies the Kaibab Formation and is the oldest exposed unit in the mapping area. In Walnut Canyon, the unit is a white to gray, fine-grained, cross-bedded sandstone. The unit is well sorted and is composed of ~90% well-rounded quartz grains cemented by silica with minor potassium feldspar grains, clay, and lime carbonate. Cross-bed sets of the unit are 5 to 10 m thick and grain size within the individual laminae of the cross-bedded strata is generally uniform. Large-scale planar-tabular, planar-wedge, and compound cross-stratification, horizontal stratification, ripple marks, and raindrop impressions are common in the unit. Outcrops of the Coconino Sandstone are the cliff-forming basal portion of Walnut Canyon, with the best and thickest exposures in the area occurring within the Walnut Canyon Monument. The maximum thickness of Coconino Sandstone outcrop mapped in Walnut Canyon is 60 m (Figure 1, typical outcrop in Walnut Canyon). Exposures in Walnut Canyon are similar to exposures at the Grand Canyon to the northwest, described by McKee (1933) and Middleton et al. (2003). Middleton et al. (2003) reported that the silica cement in the Coconino Sandstone occurs primarily in the form of quartz overgrowths. Smaller scale features, such as wind-ripple laminations, sandflow strata and minor grainfall laminae, observed by Middleton et al. (2003) in the Grand Canyon section suggest an eolian depositional environment; observed paleocurrent trends of the same study support a northern source for the wind-blown sands. The Middleton et al. (2003) study also reported the presence of invertebrate and vertebrate trace fossils, predominantly tracks, in the Grand Canyon.

Toroweap Formation (not mapped as a separate unit)

The Lower Permian Toroweap Formation is present above the Coconino Sandstone in the Grand Canyon, northward into southern Utah, and southward to the Mogollon Rim. In Walnut Canyon, the Toroweap Formation is horizontally bedded, tan, medium-grained, calcareous quartz sandstone. It resembles the overlying Fossil Mountain Member of the Kaibab Formation, illustrating a gradational vertical change from dominantly siliciclastic to sandy limestone facies. The Toroweap Formation and Kaibab Formation contact is difficult to determine in the best exposures in Walnut Canyon, and is unmappable at 1:24,000 scale. For simplicity, the Toroweap Formation and Kaibab Formation are considered a single unit in this study; the sandstone of the Toroweap Formation, however, represents no more than the lower 10-15 m of the mapped Kaibab Formation. The contact of the Toroweap Formation with the underlying Coconino Sandstone is sharp in Walnut Canyon, demonstrated by a change from the cross-bedded sandstone of the Coconino Sandstone to the horizontally bedded sandstone of the Toroweap Formation.

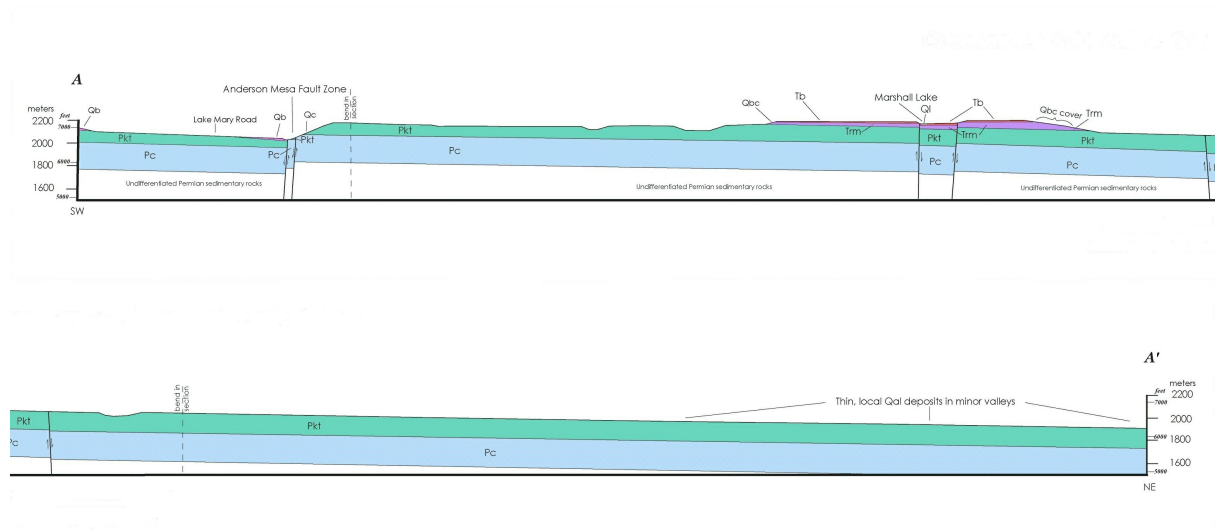
Regionally, the unit is sandstone, but varies from gypsum and limestone interfingering with sandstone in western exposures of the Colorado Plateau, to horizontally bedded sandstone and cross-bedded sandstone in exposures in east-central Arizona (Turner, 2003). Turner (2003) reported a similar gradational relationship between the Toroweap and Kaibab Formations in Sycamore Canyon to the southwest of the map area, where the upper portion of the Toroweap Formation resembles the sandstone of the lower Fossil Mountain Member of the Kaibab Formation. Turner (2003) described a different problem in Oak Creek Canyon, along the Mogollon Rim to the southwest of the map area, where the Toroweap Formation is entirely cross bedded, making it difficult to distinguish from the underlying Coconino Sandstone. The thickness of the Toroweap Formation varies regionally from 183 m in the central portion of the Grand Canyon, thinning to 17 m in eastern and northern Arizona, and thickening to 305 m south of Flagstaff, Arizona, along the Mogollon Rim (Turner, 2003).

Geologic Cross Section

The geologic cross section present in the GRI digital geologic-GIS data produced for Walnut Canyon National Monument, Arizona (WACA) is presented below. The cross section graphic was scanned at a high resolution and can be viewed in more detail by zooming in (if viewing the digital format of this document).

Cross Section A-A'

Cross Section A-A', Walnut Canyon Region, Coconino County, Arizona



For display purposes the cross section graphic is split into two graphics because of its length. No vertical exaggeration indicated on source map.

1 0.5 0 1 kilometer
Cross section constructed at scale = 1:20000 (1 cm = 200 m)

Graphic(s) from source map: [Greater Walnut Canyon National Monument Area](#)

GRI Ancillary Source Map Information

The following section present ancillary source map information associated with source used for this project.

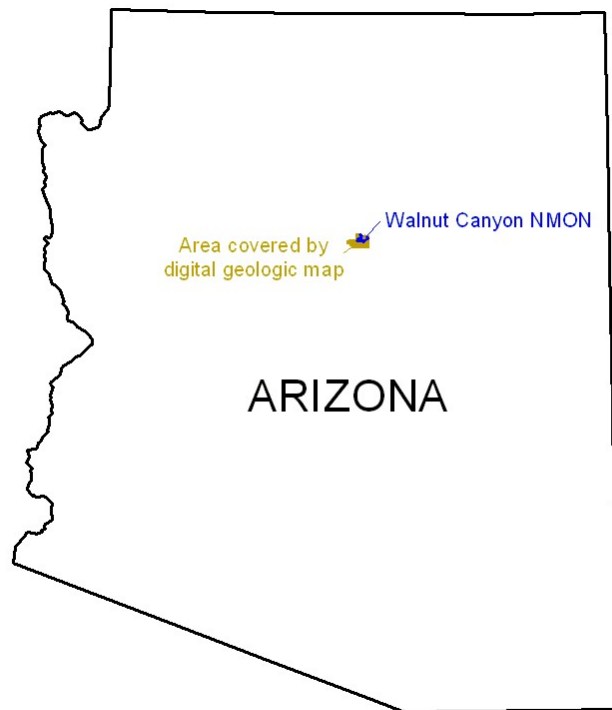
Greater Walnut Canyon National Monument Area

The formal citation for this source.

Raucci, J., Blythe, N., Ort M., and Manone, M., 2004, Geologic Map of the Greater Walnut Canyon National Monument Area: Northern Arizona University, unpublished digital data, scale 1:12,000 (*GRI Source Map ID 4146*).

Prominent graphics and text associated with this source.

Location Map of Walnut Canyon National Monument



Graphic from source map: [Greater Walnut Canyon National Monument Area](#)

Photograph 1: Typical outcrop of cross-bedded Coconino Sandstone in Walnut Canyon



Graphic from source map: [Greater Walnut Canyon National Monument Area](#)

Photograph 2: Typical outcrop of the Kaibab Formation in Walnut Canyon

The red line shows contact with underlying Coconino Sandstone.

Graphic from source map: [Greater Walnut Canyon National Monument Area](#)

References

- Baldwin, J.E., 1973, The Moenkopi Formation of north-central Arizona: an interpretation of ancient environments based upon sedimentary structures and stratification types: *Journal of Sedimentary Petrology*, v. 43, p. 92-106.
- Basham, E.L., 1990, Fluvial architecture of the Wupatki and Holbrook Members of the Lower/Middle Triassic Moenkopi Formation: northeastern and north-central Arizona: M.S. Thesis, Northern Arizona University, Flagstaff, Arizona, 178 p.
- Blakey, R.C., Basham, E.L., and Cook, M.J., 1993, Early and Middle Triassic paleogeography of the Colorado Plateau and vicinity: *in* Morales, M., ed., *Aspects of Mesozoic geology and paleontology of the Colorado Plateau*: Museum of Northern Arizona Bulletin 59, p. 13-26.
- Chronic, H., 1952, Molluscan fauna of the Permian Kaibab Formation, Walnut Canyon, Arizona: *Geological Society of America Bulletin*, v. 63, no. 1, p. 95-166.
- Cook, M.J., 1989, Depositional and architectural analysis of the lower massive sandstone (Triassic Moenkopi Formation) of north-central Arizona: Unpublished M.S. Thesis, Northern Arizona University, Flagstaff, Arizona, 147 p.
- Damon, P.E., Shafiqullah, M., and Leventhal, J.S., 1974, K-Ar chronology for the San Francisco

volcanic field and rate of erosion of the Little Colorado River, *in* Karlstrom, T.N.V., et al., eds., *Geology of northern Arizona: Flagstaff, Arizona: Geological Society of America Rocky Mountain Section Guidebook*, p. 221-235.

Holm, R.F., 2001, Cenozoic paleogeography of the central Mogollon Rim – southern Colorado Plateau region, Arizona, revealed by Tertiary gravel deposits, Oligocene to Pleistocene lava flows, and incised streams: *Geological Society of America Bulletin*, v. 113, no. 11, p. 1467-1485.

Holm, R.F. and Shafiqullah, M., 1994, K-Ar ages of late Cenozoic basaltic rocks in northern part of the Mormon volcanic field, north-central Arizona: *Isochron/West* no. 61, p. 21-24.

Hopkins, R.L., 1986, Depositional environments and diagenesis of the Fossil Mountain Member of the Kaibab Formation (Permian), Grand Canyon, Arizona: M.S. Thesis, Northern Arizona University, Flagstaff, Arizona, 244 p.

Kelly, S.E., 2000, Ground water flow simulation and recharge sources for a fractured sandstone aquifer, Coconino County, Arizona: M.S. Thesis, Northern Arizona University, Flagstaff, Arizona, 145 p.

McKee, E.D., 1933, The Coconino Sandstone – its history and origin: *Contributions to Paleontology*, No. 7: Carnegie Institution of Washington Publication No. 440, p. 77-115.

Middleton, L.T., Elliot, D.K., and Morales, M., 2003, Coconino Sandstone: *in* Beus, S.S. and Morales, M. eds., *Grand Canyon Geology*, 2nd edition, Oxford University Press, p. 163-179.

Miller, A.K. and Furnish, Jr., W.M., 1958, Permian ammonoids from the Kaibab Formation, *Journal of Paleontology*, v. 32, no. 4, p. 553-557.

Price, W.E., 1950, Cenozoic gravels on the rim of Sycamore Canyon, Arizona: *Geological Society of America Bulletin*, v. 61, p. 501-508.

Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972, Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region: *U.S. Geological Survey Professional Paper* 691, 195 p.

Thompson, K.L., 1995, Paleoecology and biostratigraphy of the Fossil Mountain Member, Kaibab Formation, northwest Arizona: M.S. Thesis, Northern Arizona University, Flagstaff, Arizona.

Turner, C.E., 2003, Toroweap Formation: *in* Beus, S.S. and Morales, M. eds., *Grand Canyon Geology*, 2nd edition, Oxford University Press, p. 180-195.

Text from source map: [Greater Walnut Canyon National Monument Area](#)

GRI Digital Data Credits

This document was developed and completed by Stephanie O'Meara (Colorado State University) for the NPS Geologic Resources Division (GRD) Geologic Resources Inventory (GRI) Program. Quality control of this document by Stephanie O'Meara.

The information in this document was compiled from GRI source map, and is intended to accompany the digital geologic-GIS map and other digital data for Walnut Canyon National Monument, Arizona (WACA) developed by Anne Poole (NPS GRD) and Stephanie O'Meara (see the [GRI Digital Map and Source Map Citation](#) section of this document for all sources used by the GRI in the completion of this document and the related GRI digital geologic-GIS map).

GRI finalization by Stephanie O'Meara.

GRI program coordination and scoping provided by Bruce Heise and Tim Connors (NPS GRD, Lakewood, Colorado).