National Park Service
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Natural Resource Stewardship and Science

Walnut Canyon National Monument

Paleontological Resource Inventory (Non-Sensitive Version)

Natural Resource Report NPS/WACA/NRR—2018/1658

ON THE COVER

Euomphalus kaibabensis, a marine gastropod in the Permian-aged Kaibab Formation of Walnut Canyon National Monument. Scale bar is in cm. Photo by Diana Boudreau (NPS).

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Diana M. Boudreau,[1] Justin S. Tweet,[2] and Vincent L. Santucci[3]

[1]National Park Service
Edwards, Illinois

[2]National Park Service
9149 79th St. S.
Cottage Grove, Minnesota 55016

[3]National Park Service
Geologic Resources Division
1849 “C” Street, NW
Washington, D.C. 20240

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Executive Summary

Walnut Canyon National Monument (WACA) protects a dense concentration of exceptionally well-preserved prehistoric cliff dwellings on the southern Colorado Plateau. Established by presidential proclamation in 1915, the monument contains more than 500 archeological sites along ten kilometers (six miles) of Walnut Creek. WACA is justifiably well-known for its cliff dwellings, built by the Sinagua people hundreds of years ago. These people took advantage of the ledge-and-recess erosion of rock outcrops in Walnut Canyon to make their homes. In addition, the deep pools and reliable flow of the creek made the canyon a rare and valuable home for the Sinagua people and supports the rich biological communities in this dry landscape. After the eruption of Sunset Crater Volcano in the 11th century, the population of the area grew significantly and people began constructing dwellings in the limestone alcoves below the canyon rim.

Walnut Canyon's ancient dwellings and rich assortment of plants, animals, and fossils hold traditional cultural importance for numerous tribes in the Southwest. For the Native American people, whose ancestors occupied the canyon for about 150 years, these sites contain evidence and information that verify oral histories and maintains cultural identities. Volcanic eruptions and other geologic processes, combined with ancient and modern human influences in the area, highlight the dynamic nature and interplay of social and environmental history. Aside from its value as a classroom for science and anthropology, the monument represents an outstanding scenic and recreational attraction for visitors and local residents.

Walnut Canyon cuts through three geologic formations of early Permian age (approximately 275 million years ago), in ascending order the Coconino Sandstone, Toroweap Formation, and Kaibab Formation. They record an environmental transition from a dune field (Coconino Sandstone) to a shallow sea (Kaibab Formation). Quaternary deposits can also be found within the national monument. It is within the limestone and dolomite beds of the Kaibab Formation, which were repurposed by the Sinagua people as roofs and floors, that we can find abundant fossils.

Paleontological resources have been documented in Walnut Canyon as early as 1893. Since that time many publications have touched on WACA's geology and paleontology, but there has never been a formal park-specific paleontological inventory. To address this, in 2017 a field survey of WACA was conducted to revisit previously known fossiliferous sites, document unreported localities, and assess outside collections at WACA repositories. During the 2017 survey, 28 fossil localities were documented in the monument, and collections at Museum of Northern Arizona (MNA) and Western Archeological and Conservation Center (WACC) were assessed. The most common fossils documented from WACA include brachiopods (lamp shells), bivalves (clams, oysters, etc.), and gastropods (snails). Scaphopods (tusk shells), crinoids (sea lilies), and trace fossils were also documented. In addition to backcountry areas, all public trails were surveyed, as they are frequently used by the public and can be utilized for interpretive programs. In addition, these public localities are at a higher risk for unauthorized fossil collection.

Acknowledgments

We would like to thank the staff members at Flagstaff Area National Monuments who aided in the completion of this report. Thanks in particular to Kayci Cook, Flagstaff Area National Monuments Superintendent, and Lisa Leap, Flagstaff Area National Monuments Chief of Resources, for organizing and working with staff to get this project up and running. Additional thanks to Paul Whitefield, Michael Jones, Mark Szydlo, Jordan Thompson, and Jon Hardes for their help during field reconnaissance and providing insight into accessing rocky exposures in WACA.

Assistance provided by Gwenn Gallenstein (Flagstaff Area National Monuments curator) and Janet Gillette at the Museum of Northern Arizona (MNA) was essential in completing a comprehensive report. Many specimens collected from WACA are housed at MNA and were made available and accessible by these individuals. Additionally, they accessed documents and references providing context for the specimen. We thank Kim Beckwith for her support on providing specimens and documents housed at the Western Archeological and Conservation Center (WACC) in Tucson, Arizona.

The continued valuable support and information provided by additional NPS Geologic Resources Division staff, including Dave Steensen, Hal Pranger, Tim Connors, and Jason Kenworthy, is greatly appreciated. This report would not have been possible without the funding from the NPS Geologic Resources Division (GRD) and Flagstaff Area National Monuments and the opportunities available through the partnership with the American Geosciences Institute. Thanks also to Don Weeks from the IMR. We thank Nancy Stamm and Dave Soller from the USGS for providing access to the Examine & Report archives, and their assistance with using these files. Thanks also to Alison Mims who completed earlier work on the Southern Colorado Plateau Network paleontologic report including Walnut Canyon National Monument.

Finally, we would like to thank our peer review team including: program manager Hal Pranger, peer review manager Lisa Leap, and peer reviewers Lynne Murdock (NPS), Dave Elliott (NAU), and Tim Connors (NPS). Their insights helped us improve the final product.

Dedication

We dedicate this report to a woman who had a life deeply embedded within the Arizona landscape, Halka Chronic (February 26, 1923–April 16, 2013; Figure 1). She was born in Tucson, Arizona and attended the University of Arizona for her undergraduate studies. She moved from the area to pursue her master's degree in marine biology at Stanford University and focused her doctoral studies on the marine fossils of Walnut Canyon and the Kaibab Formation in northern Arizona. After a few years raising a family in Colorado, she returned to Arizona amongst the red rock of Sedona. She traveled to distant places and had great adventures, but always returned to Arizona and retired there later in her life. Her adventurous spirit and love for geology, the sea, and Arizona red rock paved the way for her future in geology.

After completing her Ph.D. work, she worked at Stanford's Hopkins Marine Station, the National Center for Atmospheric Research (NCAR) as a writer-editor, and scientific editor for the Geological Society of America, and participated in writing for the Roadside Geology series, including editions for Arizona, Utah, Colorado, and New Mexico. In 2004, she received the Geosciences in the Media Award for her notable journalistic achievement in communications contributing to public understanding of geology. Her contributions to southwestern regional geology are well-known and appreciated. Most notable to this report is her Ph.D. work on fossil molluscan fauna which added greatly to the paleontological knowledge of Walnut Canyon National Monument and the Kaibab Formation. We thank Halka Chronic for her dedication and lifelong contributions to the sciences. Additional thanks to Halka Chronic's family for providing information about Halka's life and the image below.

Figure 1. Halka Chronic (foreground center) sits on a summit in Grand Teton National Park in 1949; photo courtesy Chronic family.

Introduction

Walnut Canyon National Monument (WACA) encompasses 1,448.56 hectares (3,579.46 acres) of land in south-central Coconino County, north-central Arizona, near the southern edge of the Colorado Plateau (Figure 2). 1,330.86 hectares (3,288.62 acres) are under federal administration. WACA was established to protect cliff dwellings constructed in Walnut Canyon by the Sinagua people, who lived in the canyon about 800 years ago. Walnut Creek, an intermittent stream, runs through WACA on its way to the Little Colorado River, forming the titular Walnut Canyon. WACA was proclaimed November 30, 1915; at that time, it was within the U.S. Forest Service. It was transferred to the National Park Service on August 10, 1934. The boundaries of WACA have changed twice, on September 24, 1938 and November 12, 1996; the latter expansion added adjoining areas east and west of the original core. WACA is part of the National Park Service (NPS) Southern Colorado Plateau Inventory & Monitoring Network (SCPN). It is managed collectively with two other NPS units in the vicinity of Flagstaff: Sunset Crater Volcano National Monument (SUCR) and Wupatki National Monument (WUPA). Together, these are the Flagstaff Area National Monuments (FLAG). WACA is roughly 12 km (7.5 miles) east of Flagstaff. Of the other units of FLAG, SUCR is a little over 24 km (15 miles) north of WACA, and WUPA is 43 km (26 miles) north of WACA (Figure 3).

Walnut Canyon is the result of Walnut Creek deeply incising its channel over a period of time. Such entrenched meanders are a common phenomenon in the Colorado Plateau. They occur when sediment input, flow, and bed slope are such that a river cannot maintain a floodplain. Limited to the current course, it begins eroding a canyon. At WACA, the canyon is as much as 123 m (400 ft) deep (Bezy 2003). The downcutting of Walnut Canyon has exposed three Permian bedrock units in the canyon walls (see Appendix E for a geologic time scale), in ascending order the Coconino Sandstone, Toroweap Formation, and Kaibab Formation (Figure 4). These three formations were deposited at the end of the early Permian (Hintze and Kowallis 2009), approximately 275 Ma (million years ago). They represent the replacement of a coastal dune field by a shallow continental sea (Bezy 2003).

The dune rocks of the Coconino Sandstone and the transitional coastal rocks of the Toroweap Formation have yet to produce fossils within WACA, but the overlying shallow marine Kaibab Formation has proven to be extensively fossiliferous in the monument (Figure 5). Natural molds and casts of invertebrate shells are common, including those of brachiopods (lamp shell), bivalves (clams, oysters, etc.), and gastropods (snails), as well as cherty concretions that formed around sponges (Chronic 1983). Variations in Kaibab Formation lithology have produced ledges and recesses that later were exploited by the Sinagua people to make cliff dwellings (Shimer and Shimer 1910). The only formations in WACA that are younger than the Kaibab Formation are Quaternary deposits, although the Lower Triassic Moenkopi Formation is exposed just outside of the monument (Figure 4) (Graham 2008). Erosion has removed any post-Kaibab rocks within WACA itself. The deep incision of Walnut Canyon, like other entrenched meanders in the Colorado Plateau, probably occurred in the Neogene (Bezy 2003), about 23 to 2.6 Ma. Volcanic activity began in the area about 6 Ma and has continued to nearly the present day (Ort et al. 2008a, 2008b). The past few thousand years of biological history near WACA have been recorded in packrat middens (Murdock 1994).

Purpose and Need

The NPS is required to manage its lands and resources in accordance with federal laws, presidential directives, NPS management guidelines and policy, and scientific principles. Those authorities and guidance directly applicable to paleontological resources are cited below. The paleontological inventory was initiated to better understand the scope and significance of fossil resources present within Walnut Canyon National Monument and, therefore, provide a basis to inform decisions and actions that comply with these laws, directives, and policies. See Appendix D for additional information on applicable laws and legislation.

Project Objectives

The project was initiated to provide information to WACA staff for use in formulating management guidelines that would enable compliance with related laws, regulations, policy, and management guidelines. Additionally, this project should make the resources in this monument more accessible to paleontologists, facilitating future work. Tasks addressed in this inventory include: locating, identifying, and documenting paleontological resource localities through field reconnaissance using photography, GPS data, and standardized forms; relocating and assessing historical localities; revisiting collections of WACA fossils at the Museum of Northern Arizona (MNA) and Western Archeological and Conservation Center (WACC); and a thorough search for relevant publications, unpublished geologic notes, and outside collections from WACA.

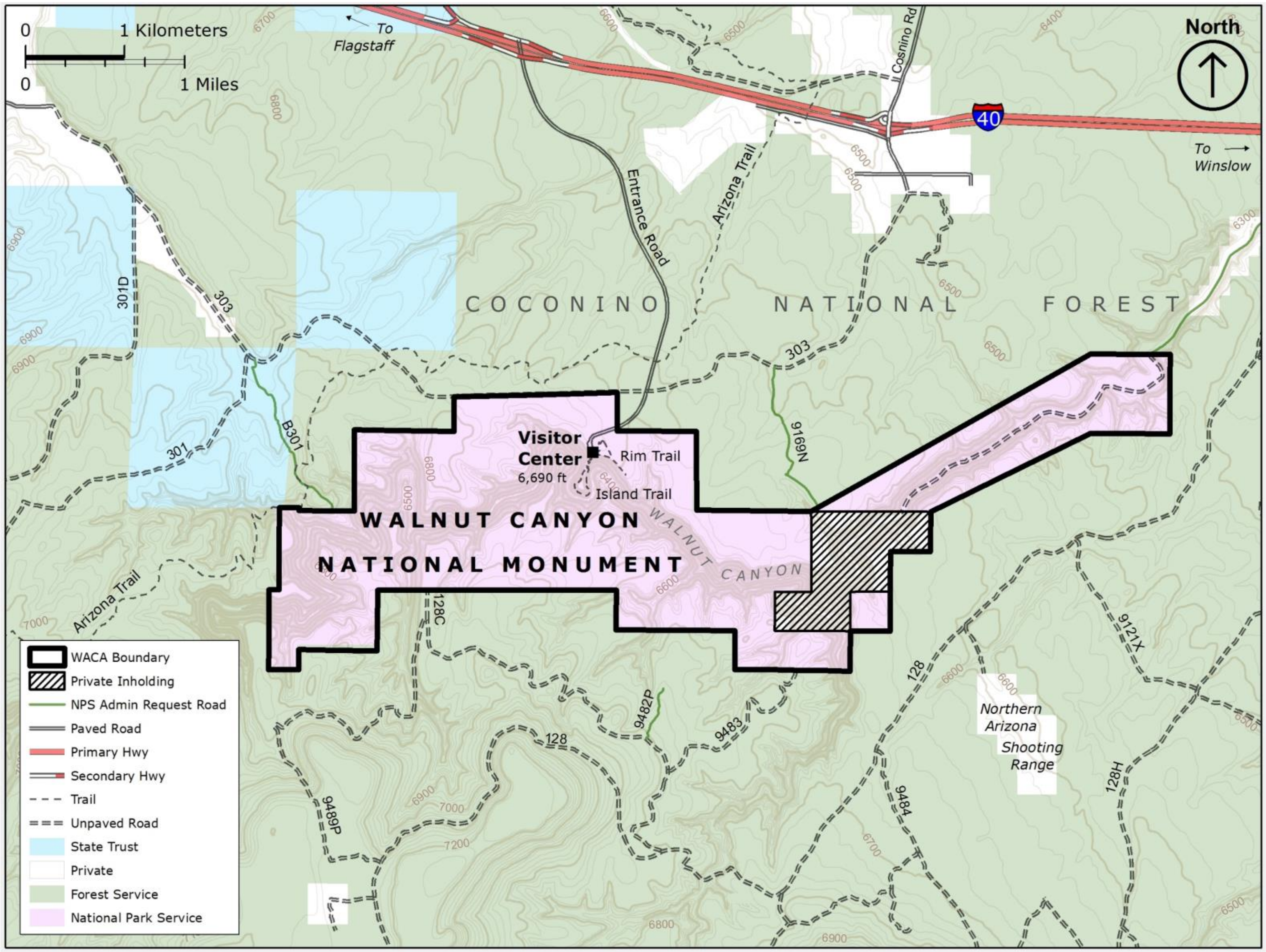


Figure 2. NPS boundary for Walnut Canyon National Monument location just south of Interstate 40 near Flagstaff, Arizona. Much of the monument is inaccessible to the general public. Private inholdings within WACA are indicated by section with black hash marks (NPS map).

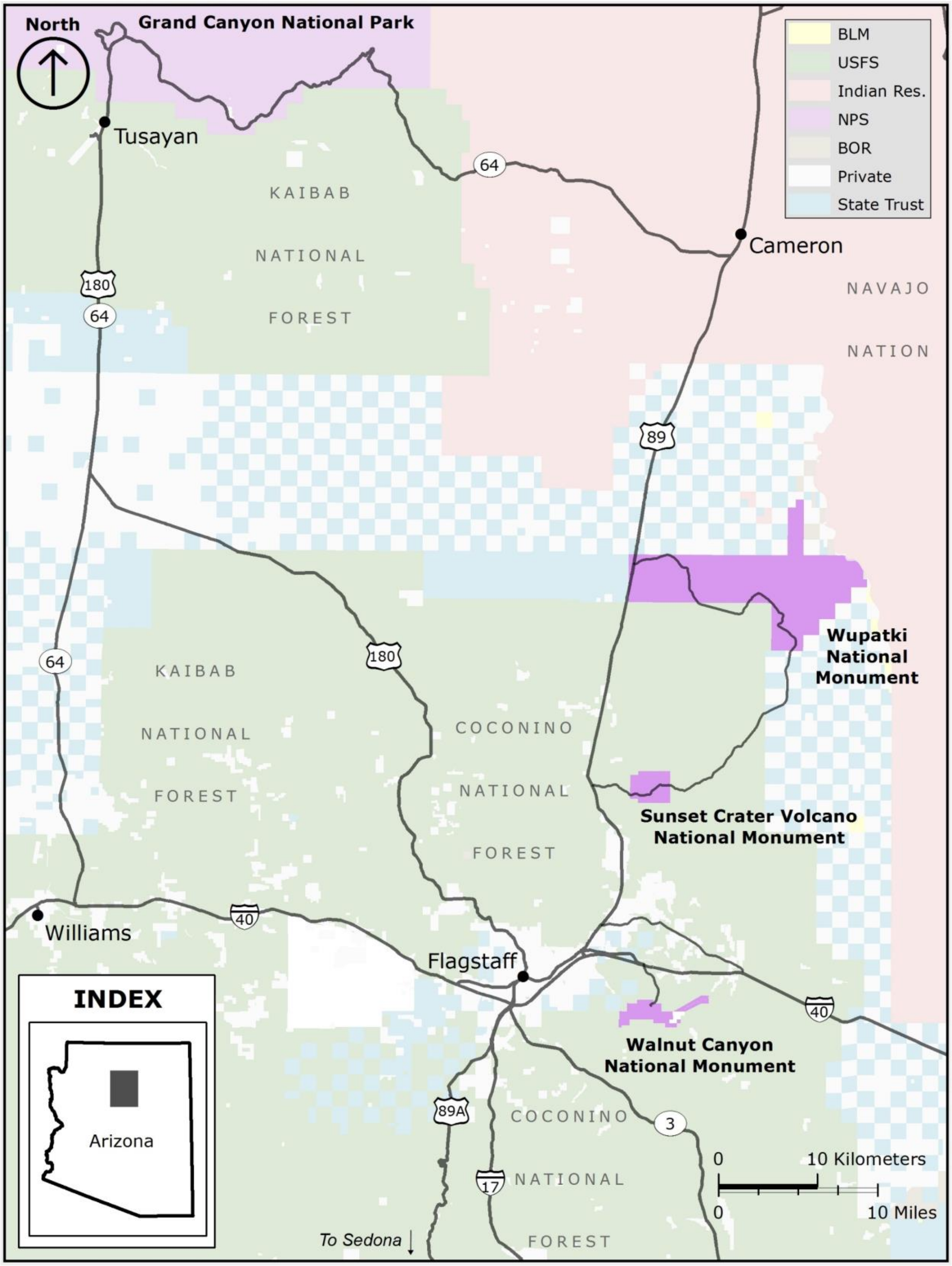


Figure 3. Flagstaff Area National Monuments include Wupatki National Monument, Sunset Crater Volcano National Monument, and Walnut Canyon National Monument. Grand Canyon National Park, Flagstaff, and major highways are also included for geographic reference (NPS map).

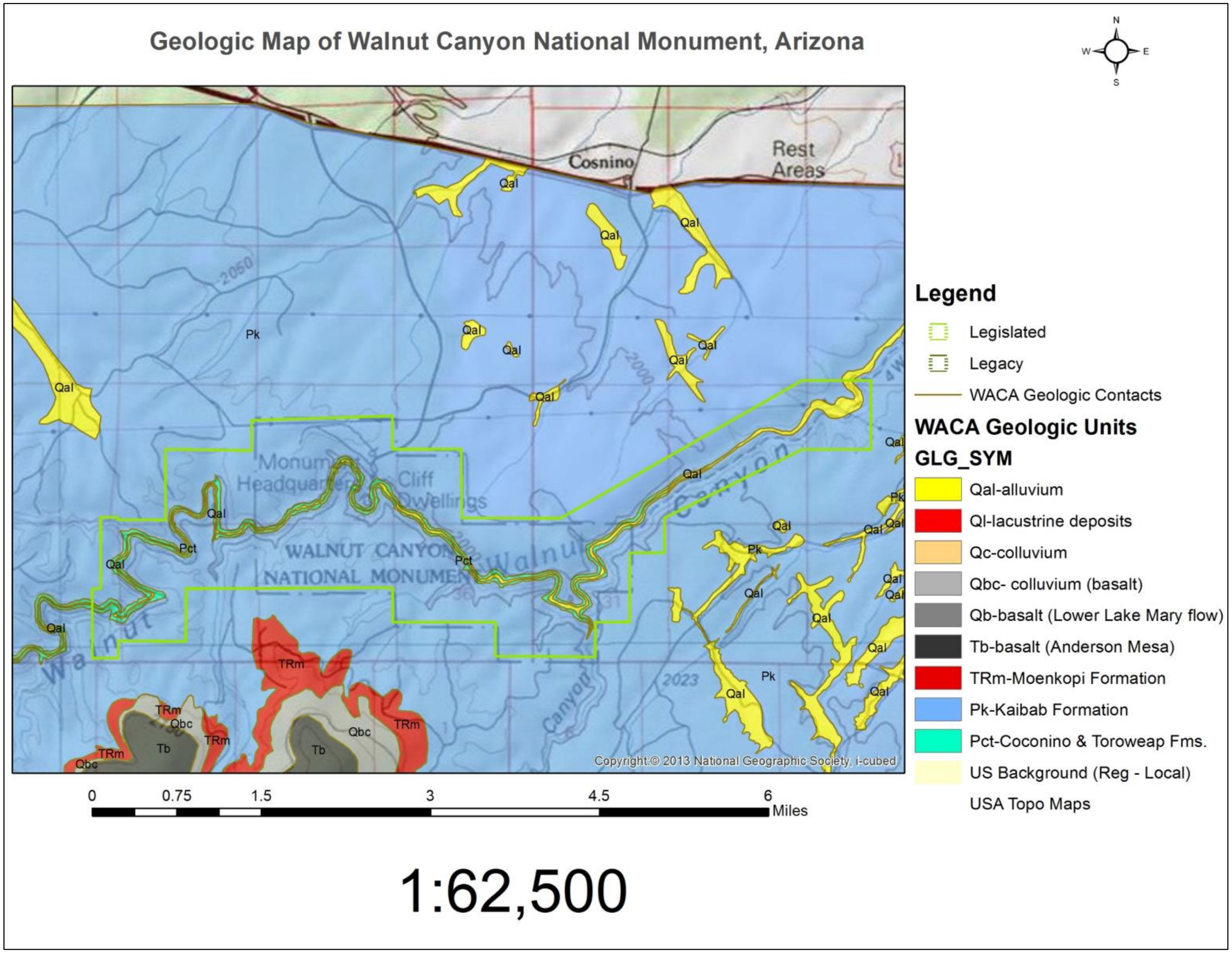


Figure 4. Schematic geological map of WACA (NPS/TIM CONNORS) adapted from digital geologic map data available at the following URL: https://irma.nps.gov/DataStore/Reference/Profile/1045893.

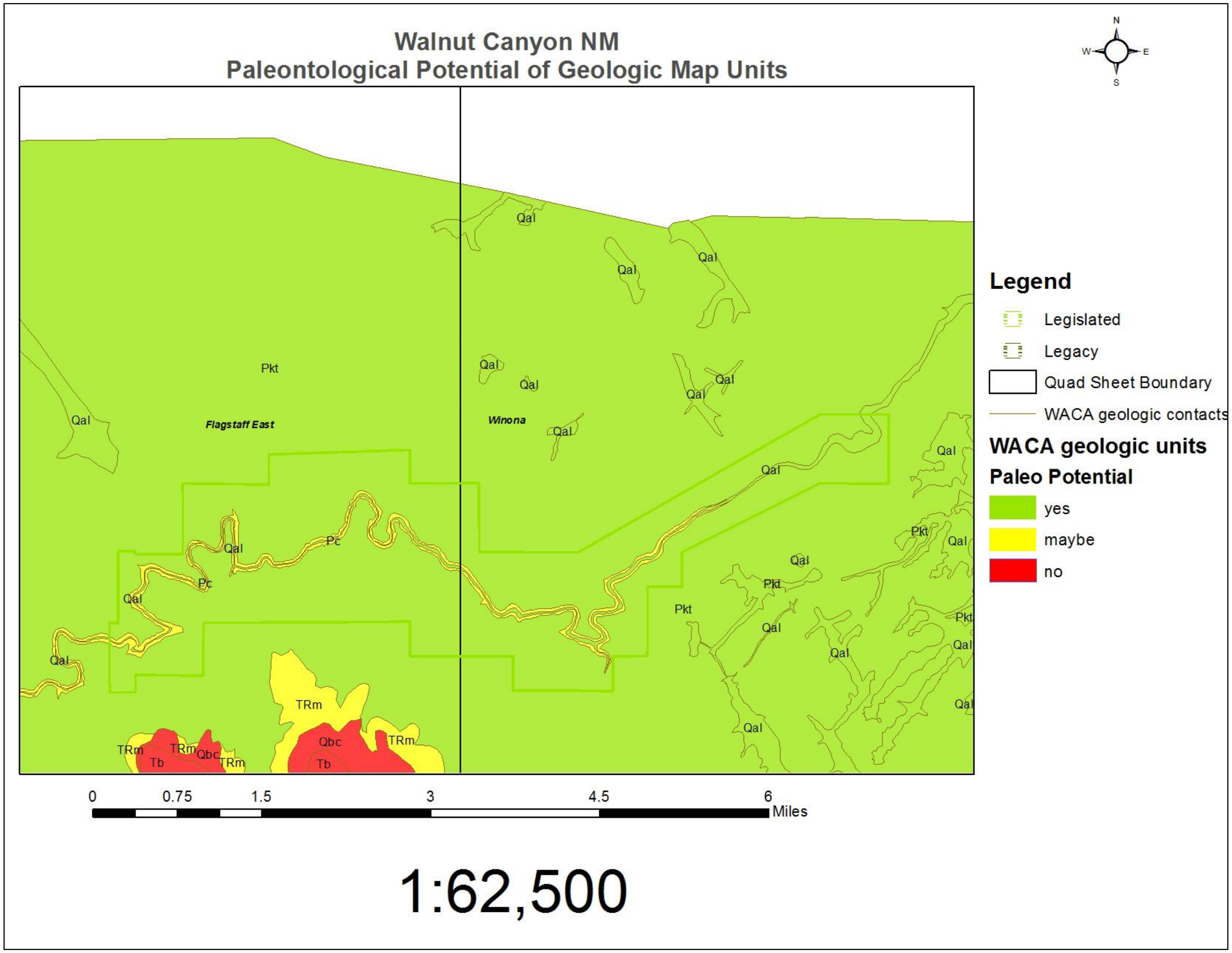


Figure 5. Map indicating paleontological potential of geologic map units (NPS/TIM CONNORS). The Kaibab Formation and Quaternary deposits have yielded fossils within WACA and the Toroweap and Coconino Formations at the base of Walnut Canyon are potentially fossiliferous.

History of Paleontological Work at WACA

Although archeology has been the primary resource focus at WACA, the geology and paleontology of the monument have been described in a few publications. Significant references for WACA's geology and paleontology include Hughes (1893), Frech (1893), Shimer and Shimer (1910), Shimer (1919), Miller and Blanchard ("1927"), Vandiver (1936), McKee (1938), Pattison (1947), Chronic (1952, 1983), Benfer (1971), Lipinski (1976), Murdock (1994), Santucci and Santucci (1999), Bezy (2003), Raucci et al. (2003), Chronic and Chronic (2004), Graham (2008), and Tweet et al. (2009).

The geology of Walnut Canyon began to attract attention by the end of the 19th century. A brief description by Hughes (1893) (Figure 6) and a taxonomic list of fossils by Frech in the same volume may be the earliest geological reports for WACA. The description by Hughes (1893), although featuring now-outdated terminology, still holds as a valid general description. Hughes recognized several features, including the division of the canyon into a lower unit of cross-bedded sandstone and an overlying unit of irregular limestone beds hosting the cliff dwellings, and the presence of upper Paleozoic ("Aubrey or Upper Carboniferous rocks") brachiopods and bivalves. Frech (1893) supplemented this description with an identification of three brachiopod species from the "faint pink-colored dolomite in which are the famous cliff dwellings", the common *Productus ivesii* (now *Peniculauris ivesi*) and rare *Productus* aff. *scabriculus* (species now in *Buxtonia)* and *Spirifer* (*Martinia*) *lineata* (now *Martinia lineata*).

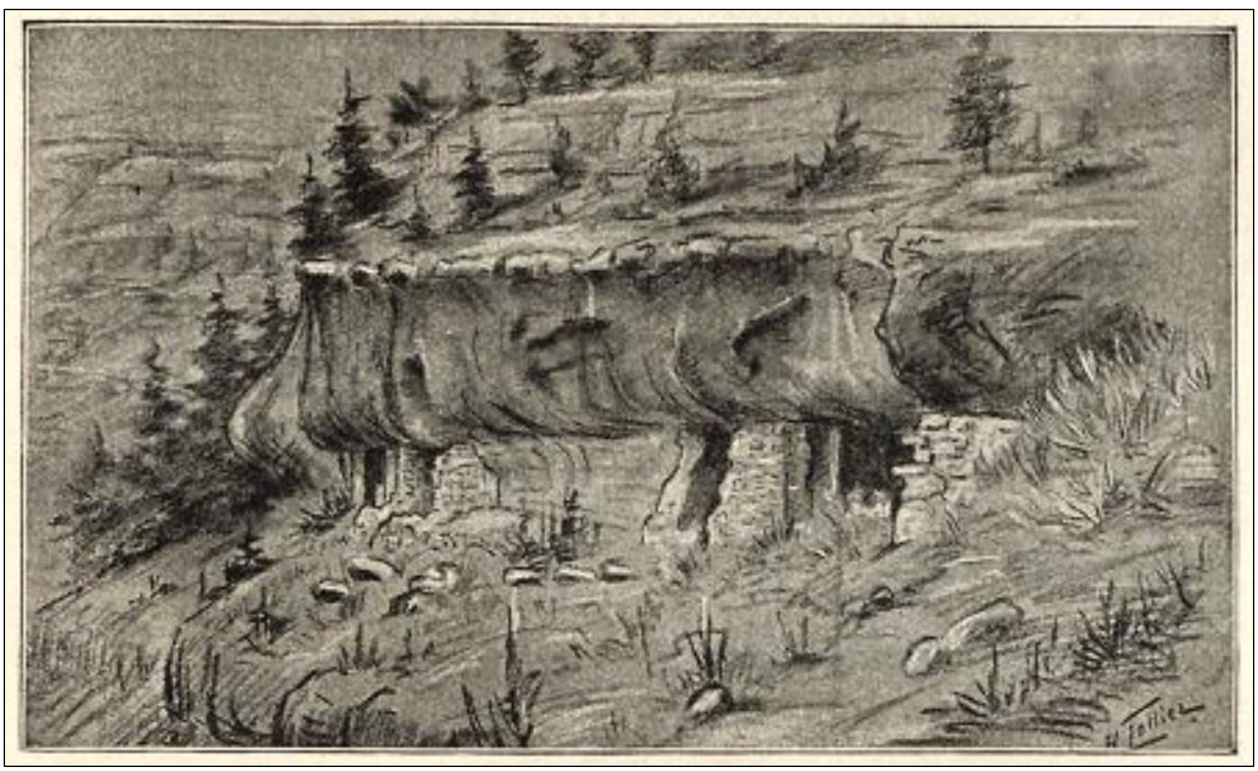
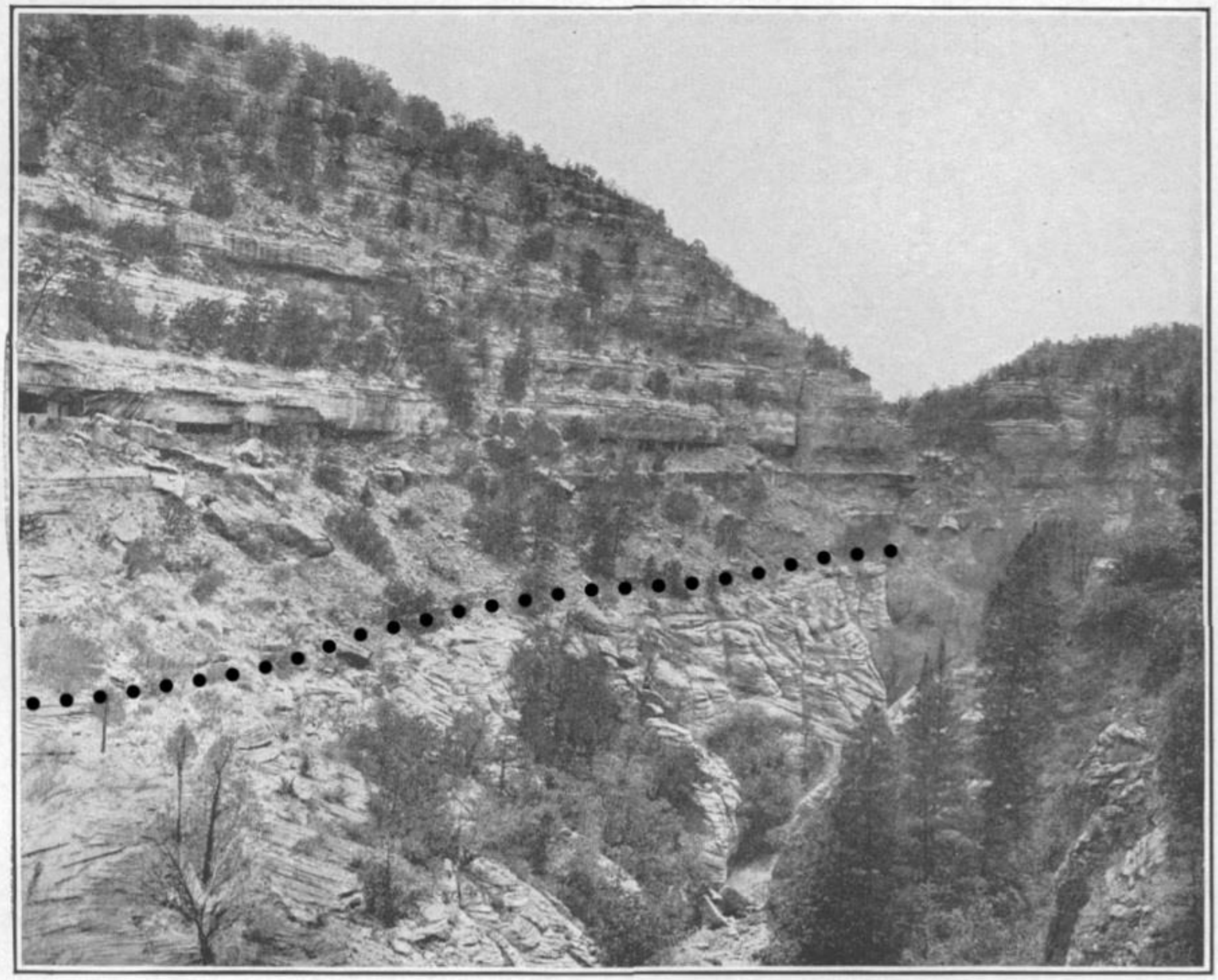


Figure 6. An illustration of Walnut Canyon from Hughes (1893).

Darton (1910) reproduced Frech’s species list and included a photo of the canyon (Figure 7), but more importantly named the Kaibab Formation and Coconino Sandstone, and applied the names to the canyon’s upper limestone and lower sandstone, respectively.



B. COCONINO CROSS-BEDDED SANDSTONE OVERLAIN BY KAIBAB LIMESTONE AT WALNUT CREEK CLIFF DWELLINGS, SOUTHEAST OF FLAGSTAFF, ARIZ.

Figure 7. Photo of Walnut Canyon from Darton (1910), showing the division between the Kaibab Formation, above the dotted line (added 2018), and underlying cross-bedded Coconino Sandstone.

The first detailed geological study of Walnut Canyon was published in 1910 (Shimer and Shimer). They recognized the presence of not only a lower interval of cross-bedded sandstone and an upper interval of alternating limestone and dolomite, but also noticed an intermediate interval of several meters of non-cross-bedded sandstone. They also observed that the cliff dwellings were confined to a sequence of several zones that alternated between resistant and slope-forming carbonate beds. The dwellings were built within the more recessive zones, supported above and below by resistant zones. Shimer and Shimer (1910) only noted fossils in passing, but lead author Hervey W. Shimer later (1919) listed several species from the Kaibab Formation. By this time, Walnut Canyon National

Monument had been established (1915), but was not within the NPS (1934). Nothing of note on WACA's geology appears to have been published from this time until the mid-1930s, but there is an undated and unpublished stratigraphic section composed by an E. F. Miller and S. W. Blanchard in the correspondence collections of the U.S. Geological Survey. Information on these geologists is scarce, but the Arizona Daily Sun reported on February 15, 1927 that "E.F. Miller, field geologist for the Marlin Oil Co. of Denver Colo., and S.W. Blanchard, an assistant, came to Flagstaff last week with a collection of fossils they are sending to Professor A.I. Keyte [Ivy Allen Keyte] of the geology department at Colorado College at Colorado Springs." For convenience, this section is here referred to as Miller and Blanchard "1927." Miller and Blanchard cited a number of different kinds of fossils, including brachiopods, bivalves, and gastropods, as well as "baculites." "Baculites" is an anachronism, because true *Baculites* is an Upper Cretaceous ammonite that lived approximately 200 million years after the deposition of the Kaibab Formation. The name has sometimes been used for mollusk fossils of narrow cylindrical to conical form, and if such is the case here, Miller and Blanchard may have been referring to scaphopods (reported from Walnut Canyon in Chronic 1952 and observed in WACA by lead author D. Boudreau in 2017), poorly preserved "pen shell" bivalve *Pinna* (reported from Walnut Canyon in Shimer 1919), or orthoconic (straight) nautiloids (represented by *Mooreoceras* in the Kaibab Formation; Miller and Youngquist 1949). Miller and Blanchard ("1927") also noted the presence of fossils in the recess holding the majority of the cliff dwellings. Colton (1929) reported on Quaternary mollusks discovered in lacustrine beds just beyond Walnut Canyon, outside of WACA.

NPS-associated geological work at WACA began in the 1930s with Vandiver (1936), who undertook a brief assessment of the monument's geology and archeology. Hargrave (1939) mentioned a few bird bones collected from the monument's Walnut Pueblo. Edwin McKee, noted for his work on the Paleozoic rocks of Grand Canyon National Park (GRCA) and the vicinity, used Walnut Canyon as a study locality for his work with the Kaibab and Toroweap formations. McKee (1938) introduced two notable innovations: he identified the lower sandstone unit as an unusual eastern phase of his new Toroweap Formation instead of the Coconino Sandstone, and he divided the Kaibab Formation into three subunits, in ascending order the gamma, beta, and alpha members.

The longest association any geologist has had with WACA to date has been that of Halka Chronic (née Pattison), who wrote her thesis on the Kaibab Formation of Walnut Canyon (Pattison 1947, results published as Chronic 1952) and later wrote about the monument for the public (Chronic 1983; Chronic and Chronic 2004). Chronic's work included two geologic sections that can now be attributed to WACA, as well as several others in the vicinity.

Since the publication of Chronic (1952), WACA's geology and paleontology have generally only been treated in passing in the literature. (It should be noted that occasionally authors cite Chronic's taxa as from "Walnut Canyon" regardless of the actual locality; e.g., Erwin 1988.) Baars (1961, 1979) commented on the Coconino/Toroweap issue; he regarded the sandstone of Walnut Canyon as the Coconino Sandstone while also noting that the Coconino Sandstone and Toroweap Formation were indistinguishable east of the canyon. Benfer (1971) and Lipinski (1976) wrote theses on the rocks of Walnut Canyon (Toroweap Formation for Benfer, Kaibab Formation for Lipinski), but neither author appears to have formally published results. In another thesis, Murdock (1994) described one packrat midden from Walnut Canyon National Monument and seven others in close vicinity; the results have not been published, but some of her findings were summarized by Rowlands et al. (1995a, 1995b) and Menzel and Covington (1997). The first paleontological inventory for WACA was published by Santucci and Santucci (1999). Similar to Chronic (1983) and Chronic and Chronic (2004), Bezy (2003) touched on WACA in a public outreach context. Raucci et al. (2003) produced a geologic map of the monument, which was used as the basis of NPS (2004). Following a 2001 geologic resources inventory scoping session for all three of the Flagstaff Area National Monuments (NPS 2001), the Geologic Resources Division of the NPS produced a geological inventory for WACA (Graham 2008). Tweet et al. (2009) produced another short paleontological summary of WACA.

Summary of 2017 Paleontological Survey

During October 2017, a week-long field survey for paleontological resources within Walnut Canyon National Monument was conducted by the lead author. The survey work consisted of two phases: assessment of WACA collection housed at the Museum of Northern Arizona and field reconnaissance within WACA to revisit known fossil localities and record new ones. Collaboration and planning between the lead author and members of the National Park Service staff at FLAG area monuments (Lisa Leap, Paul Whitefield, Michael Jones, Mike Szydlo, Jordan Thompson, and Jon Hardes) ensured a successful and safe week of survey.

The first portion of the survey required visiting the collection of fossil specimen from WACA that are housed at the Museum of Northern Arizona (MNA). The collection houses 98 specimen from WACA. Some specimen are from the vicinity, but actual placement within the monument's boundary is uncertain. WACA specimens were photographed, documented, and used as a reference for materials found during the field survey in WACA. General classification for the WACA specimens housed at MNA included conulariids (problematic cnidarians), brachiopods (lamp shells), bivalves (clams, oysters, etc.), cephalopods (nautiloids, squid, etc.), gastropods (snails), and scaphopods (tusk shells). For more detail on WACA museum specimen see the "Paleontological Research and Collections" section.

The second component involved an in-depth field survey within WACA to collect fossil locality data and make field identifications of fossils. Using geologic maps, satellite imagery, and WACA staff knowledge, routes were planned to safely access rocky outcrops within the canyon. Areas were targeted for paleontological survey based on accessibility, topography, rock type present, time constraints, and available rocky outcrop. During the survey, 28 fossil localities were found, photographed, and recorded by GPS. All fossil specimens were identified as invertebrates and found in the lower Permian Kaibab Formation. The most common organisms recorded were gastropods, bivalves, and brachiopods. Fossils were best preserved and most common in rocky alcoves often associated with cultural sites within the cliff walls. In these alcoves, fossils are protected from erosional processes, which likely allowed them to retain their form. Fossil localities were restricted to rock faces within the canyon itself as all other regions of WACA are flat and covered by soil and/or dense vegetation. Sections of the underlying Coconino Sandstone and Toroweap Formation were also surveyed, but yielded no fossils. For a detailed list and specimen images, see the "Taxonomy" section.

In the event paleontology surveys are completed in the future, researchers should examine more outcrops on the eastern section of the monument. Due to the short duration of the survey in 2017, this particular area was not surveyed. In addition, more identifiable outcrops of Toroweap Formation should be examined. Future surveys should also revisit paleontological localities documented in this survey and Chronic (1952).

Geology

Geologic History

The geologic history exposed at WACA is confined to two relatively narrow slices of time, representing the late early Permian (approximately 275 to 272 Ma) and the end of the Cenozoic Era (at least several thousand years ago to the present) (see Appendix E for a geologic time scale). At least some rocks from the intervening 272 million years were probably present at one time, because Triassic rocks can be found just outside of WACA (Raucci et al. 2003), but they were eroded from WACA before the present.

Permian rocks at WACA represent a time when a vast sandy dune field was replaced by a shallow continental sea that advanced and retreated multiple times, becoming less of an influence toward the top of this sequence (Chronic 1952; Blakey and Knepp 1989; Billingsley et al. 2007; Graham 2008). Marine rocks from this sea are also well-exposed to the west and north, in places such as Grand Canyon National Park and Lake Mead National Recreation Area. The area where WACA is located today was typically near the Permian shoreline (McKee 1938; Chronic 1952, 1983), and the shoreline at the greatest extent of the sea may have been approximately 110 km (70 mi) east of WACA (Chronic 1952). Being near the margin of the sea, the rocks and fossils of the WACA/Flagstaff area differ from what is seen with the more strongly marine rocks of places like Grand Canyon (McKee 1938; Nicol 1944; Pattison 1948; Chronic 1952). The presence of Lower Triassic rocks directly overlying the lower Permian sequence just outside of WACA (Raucci et al. 2003) indicates that middle and upper Permian rocks were either not formed in this area or were eroded before the Triassic. There is evidence for faulting, tilting, and uplift in the area where Arizona, Nevada, and Utah meet during the unrepresented Permian time (Nielson 1991). Later uplift, during the mountain-building event called the Laramide Orogeny approximately 75 to 35 Ma, is thought to be responsible for the erosion of most of the Mesozoic record from the area (Graham 2008).

Recent geological history in the Flagstaff area has been active. Several faults cut through WACA, typically running north-south or northwest-southeast (Raucci et al. 2003; Graham 2008). The San Francisco volcanic field, immediately north and northwest of WACA, became active around 6 Ma. To date, it has produced approximately 600 cones, the most recent being Sunset Crater of SUCR, which erupted between 1050 and 1100 AD (Ort et al. 2008a, 2008b). Two dated volcanic flows are present near WACA. The older Anderson Mesa basalt dates to between 6.39 ± 0.30 Ma and 4.38 ± 0.20 Ma, and the younger Lower Lake Mary flow dates to 859,000 ± 55,000 years ago (Raucci et al. 2003). Humans were in the WACA area by 11,000 years ago, and had largely abandoned it by 1300 AD (Grahame and Sisk 2002).

Rock units exposed at WACA include, from oldest to youngest, the Coconino, Toroweap, and Kaibab Formations (all lower Permian), and Quaternary alluvium (Raucci et al. 2003) (Table 1) (Figure 4). The identity of the sandstone unit(s) beneath the Kaibab Formation has proven a point of contention. The initial differentiation of Kaibab and Coconino by Darton (1910) was accepted by Shimer (1919) and Miller and Blanchard (“1927”). McKee (1938), however, interpreted the sub-Kaibab Formation unit as an eastern phase of the Toroweap Formation, which was accepted by

Benfer (1971), but Baars (1961, 1979) and Lipinski (1976) preferred to interpret the rocks as the Coconino Sandstone. Chronic (1983), Bezy (2003), Raucci et al. (2003), Chronic and Chronic (2004), and Graham (2008) interpreted the sandstone as including both the Toroweap Formation and Coconino Sandstone; because this arrangement is used in the GRD report and map (Graham 2008), it is used here. Because WACA includes recently active drainage, nearby formations may erode into the monument. In particular, outcrops of the fossiliferous Moenkopi Formation (Lower–Middle Triassic) are as close as a third of a kilometer (a fifth of a mile) south of WACA (Raucci et al. 2003). To date, the Kaibab Formation is extensively fossiliferous in WACA, with shelled marine invertebrates especially common, and Holocene packrat middens have been found within the monument boundary and other nearby localities (Murdock 1994).

Table 1. Summary of WACA stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text and in Tweet et al. (2009).

Formation	Age	Fossils Within WACA	Depositional Environment
Quaternary sediments	Pleistocene–Holocene	Holocene: packrat midden middens with various angiosperm material, fecal pellets, and minor conifer material, from 760 ± 60 year BP	Dominated by alluvial and fluvial deposits
Kaibab Formation	early Permian	Sponges, conulariids, bryozoans, brachiopods, bivalves, cephalopods, gastropods, scaphopods, unidentified mollusks, crinoids, echinoids, unidentified invertebrate body fossils, and invertebrate burrows	Shallow continental seas, near shore
Toroweap Formation	early Permian	None to date	Transitional
Coconino Sandstone	early Permian	None to date	Eolian sand dunes

Geologic Formations

Coconino Sandstone (lower Permian)

Lithology: The Coconino Sandstone of WACA is composed of white to gray fine-grained, cross-bedded, silica-cemented sandstone (Figure 8). Up to 60 m (200 ft) are exposed in Walnut Canyon, divided into cross-bed sets 5 to 10 m (16 to 33 ft) thick (Raucci et al. 2003). The upper contact with the Toroweap Formation is unconformable (confusingly stated as the Kaibab Formation in Raucci et al. 2003), and the two can be distinguished by the different bedding (cross-bedding in the Coconino Sandstone versus horizontal bedding in the Toroweap Formation). The Coconino Sandstone makes up the lower part of the canyon walls, forming cliffs (Raucci et al. 2003). This formation was deposited as windblown sand in a dune field (Blakey and Knepp 1989). It can be dated to the late early Permian by the ages of overlying and underlying formations (Blakey and Knepp 1989; Hintze and Kowallis 2009), approximately 275 Ma.

Fossils found within WACA: None to date.

Fossils found elsewhere: Trace fossils; invertebrate traces may represent worms, millipedes, isopods, spiders, scorpions (Middleton et al. 1990), and insects (Spamer 1992) and vertebrate tracks appear to have been made by three *Chelichnus* ichnospecies (a synapsid, or early mammal relative) (McKeever and Haubold 1996; Hunt et al. 2005a) and an unnamed form (Hunt et al. 2005b).

Figure 8. Strongly cross-bedded Coconino Sandstone (lower Permian) present in Walnut Canyon National Monument (NPS/DIANA BOUDREAU).

Toroweap Formation (lower Permian)

Lithology: The Toroweap Formation of WACA is composed of horizontally bedded, tan, medium-grained, calcareous quartz sandstone (Raucci et al. 2003). Elsewhere, where there was more marine deposition, limestone and gypsum are significant constituents, but this is not the case at WACA. The Toroweap Formation cannot be mapped in WACA at a 1:24,000 scale, so Raucci et al. (2003) mapped it undivided with the overlying Kaibab Formation. It is perhaps at most 10 to 15 m (33 to 50 ft) thick at WACA and grades into the overlying Fossil Mountain Member of the Kaibab Formation (Raucci et al. 2003). The Toroweap Formation was deposited during a marine transgression-regression cycle (Rawson and Turner 1974), in the late early Permian (Blakey 1990). At WACA, the rocks are part of a nearshore eastern facies, with terrestrial (eolian and fluvial) input (Chronic 1983).

Fossils found within WACA: None to date.

Fossils found elsewhere: The Toroweap Formation has produced a diverse assemblage of marine fossils to the northwest, in the Grand Canyon region (McKee 1938; Rawson and Turner 1974; Spamer 1992), but such fossils are from marine rocks and are unlikely to be found in the thin terrestrially influenced facies present at WACA. The fossils known from the Coconino Sandstone may actually be more appropriate as a point of comparison. If fossils were to be found in the Toroweap Formation at WACA, they would be of interest due to their depositional setting.

Kaibab Formation (lower Permian)

Lithology: The Kaibab Formation of WACA consists of tan, silty and dolomitic fossiliferous limestone interbedded with calcareous siltstone and sandstone, with bedded and discontinuous chert and minor limestone conglomerate beds (Raucci et al. 2003). The different beds of the Kaibab Formation at WACA have eroded into a series of ledges and recessive intervals which provide the basic architecture for the cliff dwellings (Shimer and Shimer 1910) (Figure 9). The Kaibab Formation is up to about 160 m (520 ft) thick in the area (Raucci et al. 2003), and pinches out approximately 80 km (50 miles) east of Flagstaff (Pattison 1948). McKee (1938) divided the Kaibab Formation into three units, in ascending order the gamma, beta, and alpha members, with all three present in WACA. This stratigraphy was later revised, with the gamma and beta members being combined into the Fossil Mountain Member and the alpha member designated as the Harrisburg Member (Sorauf and Billingsley 1991). Raucci et al. (2003) found the two members difficult to distinguish in the WACA area, but reported that the best exposures in Walnut Canyon are probably of the Fossil Mountain Member. The Kaibab Formation was deposited during an extensive early Permian marine transgression (Jenson 1986) at the end of the early Permian (Blakey and Knepp 1989; Hintze and Kowallis 2009), approximately 272 Ma. In the Flagstaff area, the sea was warm, slightly turbid, and 15 to 150 m (50 to 500 ft) deep (Pattison 1948). The Fossil Mountain Member is interpreted as a shallow marine setting, and the Harrisburg Member is interpreted as a shallow marine to evaporitic depositional setting (Jenson 1986). The Fossil Mountain Member records a marine transgression and the Harrisburg Member records an overall regression (Chronic 1952).

Fossils found within WACA: The Kaibab Formation is the most fossiliferous unit in WACA. Fossils include sponges (Vandiver 1936; McKee 1938; Chronic 1983; Bezy 2003; Chronic and Chronic 2004), conulariids (MNA), bryozoans (McKee 1938; Chronic and Chronic 2004), brachiopods (Hughes 1893; Frech 1893; Shimer 1919; Miller and Blanchard “1927”; McKee 1938; Chronic 1952, 1983; Lipinski 1976; Bezy 2003; Chronic and Chronic 2004), bivalves (Hughes 1893; Shimer 1919; Miller and Blanchard “1927”; McKee 1938; Chronic 1952, 1983; Chronic and Chronic 2004), cephalopods (Bezy 2003), gastropods (Shimer 1919; Miller and Blanchard “1927”; McKee 1938; Chronic 1952, 1983; Lipinski 1976; Chronic and Chronic 2004), scaphopods (Chronic 1952), unidentified mollusks (McKee 1938; Chronic 1952), crinoids (McKee 1938), echinoids (McKee 1938; Lipinski 1976), unidentified invertebrate fossils (Lipinski 1976; Chronic and Chronic 2004), unidentified fossils (Miller and Blanchard “1927”; Chronic 1952), and invertebrate trace fossils (Lipinski 1976).

Fossils found elsewhere not represented at WACA: Outside of WACA fossils from the Kaibab Formation include algae (Mather 1970), foraminifera, corals, ostracods, trilobites, conodonts (Kirkland 1963; Hopkins 1990; Spamer 1992), a few reports of chondrichthyan (cartilaginous fish) teeth, spines, and dermal denticles, and ray-finned fish teeth and tooth plates (Hunt et al. 2005a; Hodnett et al. 2012; Elliott and Hodnett 2013; Hodnett et al. 2013). Beus (1965) wrote a short report on the fossils found on Arizona State College campus and reported finding examples of Busyconidae, a gastropod family previously only known from the Cretaceous and Cenozoic. There are distinct mollusk and open marine faunas (Hopkins 1990) and diverse faunas have been reported from the Harrisburg Member's shallow sea deposits in the Flagstaff area (Nicol 1944, as the Alpha Member). Kaibab Formation fossils may also be found in rock fragments incorporated into other formations (McKee 1937).

Figure 9. Alcoves like this one are common in the Kaibab Formation and were often utilized by the Sinagua people as shelters. Fossils are quite common on the ceilings and back walls of these alcoves due to protection from wind and water erosion (NPS/DIANA BOUDREAU).

Quaternary rocks and sediments (Pleistocene–Holocene)

Lithology: Quaternary deposits consist of sand and gravel in alluvial and fluvial deposits, generally less than 1 m (3 ft) thick. Major components include Kaibab Formation limestone, Moenkopi Formation sandstone and siltstone, and Cenozoic basalt (Raucci et al. 2003).

Fossils found within WACA: One packrat midden has been reported that includes fragments of plants such as mountain mahogany, wild rose, serviceberry, sagebrush, yucca, snowberry, elderberry, mutton and blue grama grasses with small amount of conifer needles, and is approximately 760 ± 60 years BP (Murdock 1994). In addition, floral and faunal remains from the time of cliff dwelling occupation include corn cobs, wood, and bones (Shimer and Shimer 1910), with modern turkey, raven, and crow bones reported by Hargrave (1939) and Starkovich (2011).

Fossils found elsewhere: Murdock (1994) documented a few packrat middens in the private inholding within WACA's boundary and just outside WACA's boundary that contained conifer needles, yucca, snakeweed, rabbitbrush, sage, and buckwheat, from approximately 4,000 years ago to nearly the present. Colton (1929) described freshwater bivalves and terrestrial and freshwater gastropods from deposits along Walnut Creek north of WACA near Winona. Other types of fossils that may be found in WACA's Quaternary deposits include isolated durable remains of large extinct mammals, such as limb bones, skull bones, and teeth of mammoths, horses, camels, and bison. Agenbroad and Mead (1989) published a list of mammoth finds in the Colorado Plateau area.

Taxonomy

See Appendix B for full lists of taxa.

Fossil Plants

Plant fossils from WACA are only known from Holocene packrat middens described by Murdock (1994) and further referenced by Rowlands et al. (1995a, 1995b) and Menzel and Covington (1997). Murdock sampled eight middens ranging in age from 3800 BP to 70 BP ("before present", with "present" set as 1950 AD). One of the sampled middens is within the monument near Island Trail (Midden 8), another two are in the private inholdings within WACA (Middens 6 and 7), and the remaining five are outside the WACA boundary (Middens 1–5). Using radiocarbon dating methods on *Juniperus monosperma* and *Pinus edulis* to calculate a date, the age of Midden 6 was 3660 ± 80 yr BP. Fecal pellets were used to date Middens 7 and 8, resulting in ages of 1800 ± 100 yr BP and 760 ± 60 yr BP, respectively. Plants represented in the midden samples include the mountain mahogany, wild rose, serviceberry, sagebrush, snowberry, elderberry, mutton and blue grama grass, a small amount of conifer needs, and yucca. Yucca may have been introduced by the Sinagua people during their occupation, who may have also depleted the conifers (Murdock 1994). No fossil plant material was documented during the 2017 field survey.

Fossil Invertebrates

Most of the fossils reported from WACA are Kaibab Formation invertebrates.

Phylum Porifera (sponges)

Sponges were first reported from the Kaibab Formation of WACA by Vandiver (1936), who noted that silica nodules had formed around sponge fossils. This phenomenon has been noted by several other authors since then (McKee 1938; Chronic 1983; Bezy 2003; Chronic and Chronic 2004). McKee (1938) reported that sponge-bearing chert concretions are a common feature of the Kaibab Formation's beta member throughout its area of deposition. Griffin (1966) identified the sponge in the Kaibab Formation concretions of northern Arizona as *Actinocoelia maeandrina*, so this is the most likely candidate for WACA's sponges. This species, sometimes called cannonball chert, was originally spherical but has been partially flattened by compression, and makes nodules of 5–25 cm (2–10 in) in diameter. No fossil sponges were recorded during the 2017 field survey.

Phylum Cnidaria (jellyfish and corals)

Conulariids are poorly understood possible cnidarians. They have been documented from the Kaibab Formation before (McKee 1935 and Spamer 1992), but not from within WACA boundaries. However, three specimen in the WACA collection at the MNA suggest that conulariids have actually been found in the Kaibab Formation of WACA, although none were documented during the 2017 field survey. See the "Paleontological Research and Collections" section for more details regarding these MNA specimens.

Phylum Bryozoa (moss animals)

McKee (1938) and Chronic and Chronic (2004) reported the presence of bryozoans in the Kaibab Formation of WACA, but the fossils have not been otherwise described. McKee (1938) reported that bryozoans are common in the Kaibab Formation, but had not been described in detail by that point. They are still poorly known, but McKinney (1983) has described several forms from Grand Canyon National Park (GRCA). Bryozoa were not found during the 2017 field survey.

Phylum Brachiopoda (lamp shells)

Brachiopods are among the most abundant fossils of WACA; one form, the genus *Dictyoclostus,* is reportedly the most common fossil along the Island Trail (Chronic 1983). A handful of taxa have been identified from WACA over the years (see Appendix B), although some of these identifications may be of the same taxa, only seen through different eyes at different times. Brachiopods, like bivalve mollusks, have two shells. Fossils of the two groups can be difficult to distinguish, but in a brachiopod the two shells generally have different shapes and sizes, while bivalve shells are often mirror images. Most WACA brachiopods are productid brachiopods, which tend to have a "chunky" shape, bulbous on one side and flattened or concave on the other, and originally with numerous long thin anchoring spines. *Dictyoclostus* is an example. The bulbous side was often towards the sea floor, propped up by the spiny processes, and the flat side was up and left open to allow water to flow through for filter feeding (Grant 1966). Many of the productid brachiopods in WACA were found bulbous side down, which may indicate in situ preservation. However, a lack of spiny processes suggest transportation before burial, snapping the spines (Grant 1966). Brachiopods tend to be of low diversity and abundance in the Kaibab Formation except in a few units: rocks of the open marine facies and a nearshore facies of the beta member, and a lagoonal facies of the alpha member (McKee 1938). Brachiopods were found in abundance during the 2017 field survey. The most common brachiopod was *Dictyoclostus* at sites 15, 20, 23, 24, 25, and 26; however, *Chonetes* internal molds were also recorded at site 12 (Figure 10). Specimens of *Dictyoclostus* (including those identified as *Productus bassi*) and *Chonetes* are housed in the WACA collection at the Museum of Northern Arizona. For more details, refer to the "Paleontological Research and Collections" section.

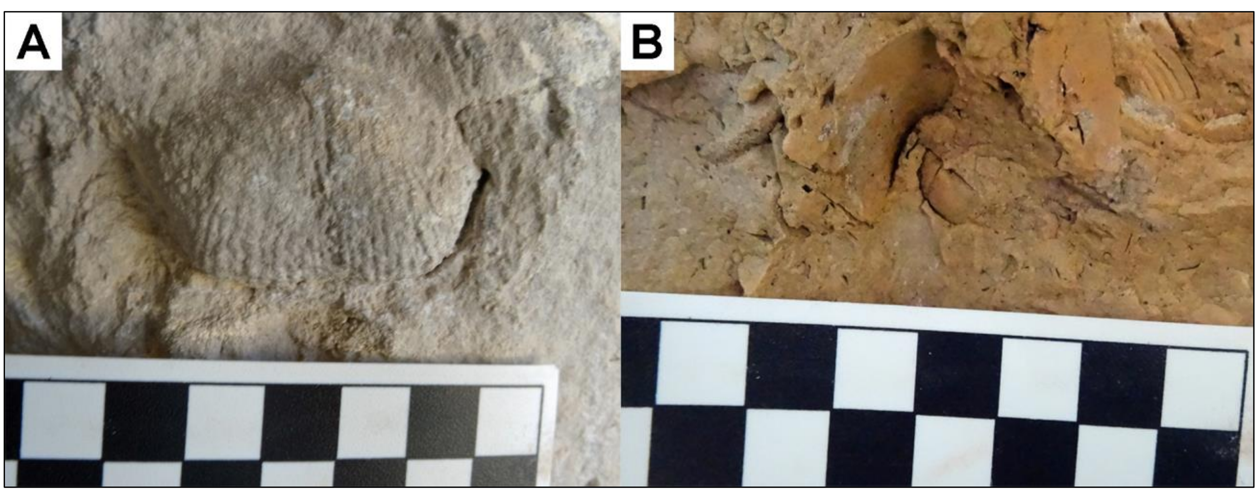


Figure 10. Photos of brachiopods found during the 2017 field survey. (A) A productid brachiopod, likely *Dictyoclostus*, protruding from the ceiling of a rocky alcove at site 24. (B) Internal mold of a brachiopod, *Chonetes*, at site 12. Note the distinctive central groove and small fragment of a bivalve, *Kaibabella,* preserved to the upper right. Scale bar is in cm (NPS/DIANA BOUDREAU).

Phylum Mollusca: Class Bivalvia (clams, oysters, etc.)

True bivalves are also among the more common fossils of WACA, being abundant enough to merit mention in semitechnical descriptions of WACA geology (Chronic 1983; Chronic and Chronic 2004). Chronic (1952) identified most of the known diversity of WACA bivalves, albeit only from the upper Kaibab Formation (see Appendix B). Fragmented bivalves were found in dense fragmented fossil layers in association with scaphopods and gastropods during the 2017 field survey. Specific taxa of bivalves were difficult to determine due to fragmented specimens or partial shell impressions. However, identified specimens from this survey include *Aviculopecten kaibabensis* (site 2) and *Kaibabella* (site 12 and 22) (Figures 10B and 11). Bivalves are common in the collection at the Museum of Northern Arizona, including *Astartella, Aviculopecten kaibabensis,* casts of *Acanthopecten coloradoensis, Nuculopsis, Parallelodon, Pleurophorus, Pseudomonotis, Pteria, Schizodus,* assorted pectinids, and unidentified bivalves. For more details, refer to the "Paleontological Research and Collections" section.

Figure 11. Photos of bivalve shell impressions found during the 2017 field survey. (A) *Aviculopecten kaibabensis* with wings broken or eroded off from site 2. A poorly preserved gastropod, *Euomphalus*, is present to the right of *A. kaibabensis*. (B) Fragment of a ?*Kaibabella* shell preserved in a fossiliferous layer at site 22. Scale bar is in cm (NPS/DIANA BOUDREAU).

Phylum Mollusca: Class Cephalopoda (octopuses, squids, nautiloids, etc.)

Previous published reports of cephalopods from the Kaibab Formation of WACA are questionable. A reference to "baculites" in Miller and Blanchard ("1927") is presumably a mistake for an elongate bivalve, a scaphopod, or an orthoconic nautiloid, as mentioned above. Santucci and Santucci (1999) included cephalopods in their list, but this list includes both WACA and the vicinity, so it is not clear which taxa are from WACA. Bezy (2003) reported unidentified cephalopods as "abundant" at WACA in passing, but no one else has reported abundant cephalopods at WACA, so perhaps something else was intended. In particular, large euomphalid gastropods, which can look like small coiled cephalopods (especially if weathered), are known from WACA (see "Class Gastropoda" below). For reference, the Kaibab Formation includes a small fauna of cephalopods, featuring both ammonites (generally flat-coiled shells) and nautiloids (both coiled like the modern *Nautilus* and straight cones), with lists in McKee (1938) and Miller and Youngquist (1949). One cephalopod was documented during the 2017 field survey at site 27 (Figure 12). Cephalopod material was also recorded from the WACA collection at MNA. Most of the material is fragmentary and labeled as unidentified Nautiloidea or cephalopod. For more details, refer to the "Paleontological Research and Collections" section.

Figure 12. A large, coiled cephalopod documented from site 27 in WACA. Scale bar is in cm (NPS/DIANA BOUDREAU).

Phylum Mollusca: Class Gastropoda (snails)

Gastropod fossils have been frequently reported from the Kaibab Formation of WACA, although as with brachiopods and bivalves only a handful of genera and species have been identified to date. Although some names are outdated, several different basic shapes can be distinguished from the names used, including a tall coiled snail (*Murchisonia terebra* of Shimer 1919), a pyramidal snail (*Pleurotomaria* sp. of McKee 1938), a flat-coiled snail (*Euphemus* sp. or *Euomphalus* sp. of Lipinski 1976), and a bulbous planispiral snail (general "bellerophontid" of Chronic 1952). Kaibab Formation gastropods are most abundant in rocks deposited in near-shore and similar settings (McKee 1938), such as are present at WACA. Gastropods were frequently found during the 2017 field survey. Bellerophontid snail internal molds (sites 3, 5, 7, 8, and 28), silicified pyramidal-coiled snail (*Glabrocingulum laeviliratum*) (site 2), *Euomphalus kaibabensis* (site 21), and *Euomphalus sp.* (sites 1, 2, 6, and 9) were documented during the 2017 survey (Figure 13). Bellerophontid snail internal molds were found individually as well as small fragmented gastropods within fossiliferous layers associated with other fragmented scaphopods and bivalves. The WACA collection at the MNA contains many specimens of fossil gastropods including *Euomphalus, Baylea capertoni, Naticopsis,* and assorted bellerophontid gastropods. See the "Paleontological Research and Collections" section for more details.

Figure 13. Gastropod fossils documented during the 2017 field survey of WACA. (A) Bellerophontid internal mold (site 3); (B) Bellerophontid with two small drill holes on left side (site 28); (C) Flat-coiled gastropod, *Euomphalus*, mostly fragmented showing internal mold shape (site 1); (D) Pyramidal-coiled gastropod, *Glabrocingulum laeviliratum*, shell in fragmented fossiliferous layer (site 2); and (E) *Euomphalus kaibabensis* near the Coconino/Toroweap and Kaibab contact (site 21). Scale bar is in cm (NPS/DIANA BOUDREAU).

Phylum Mollusca: Class Scaphopoda (tusk shells)

Scaphopod mollusks are represented in the Kaibab Formation by a form with a smooth shell (*Plagioglypta*) and a form with longitudinal ridges (*Dentalium*), common in the nearshore facies (McKee 1938). Leaving aside the enigmatic “baculites" of Miller and Blanchard (“1927”), scaphopods were reported from the alpha member of the Kaibab Formation in WACA by Chronic (1952). Many scaphopods were found during the 2017 field survey at sites 1, 4, and 16. They were usually fragmentary and small within fragmented fossil layers of bivalves and gastropods. Shells seem smooth indicating *Plagioglypta*, but they are very fragmentary so any distinguishing ridges or topography of the shell could be lost (Figure 14). MNA collections had a few scaphopod specimens, most commonly *Plagioglypta canna*. For more details, see the “Paleontological Research and Collections” section.

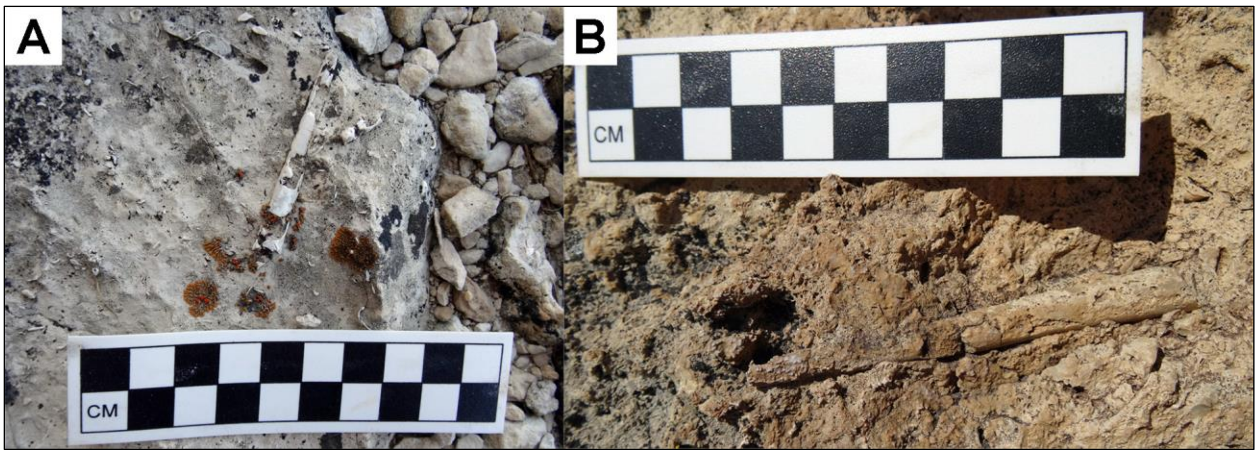


Figure 14. Scaphopod fossils documented during the 2017 field survey of WACA. (A) Fragmented *Plagioglypta* with smooth shell found at site 1 in a layer with fragmented gastropods and bivalves. (B) ?*Plagioglypta*, internal mold from site 4. This specimen is the largest scaphopod documented during the 2017 field survey. Scale bar is in cm (NPS/DIANA BOUDREAU).

Phylum Echinodermata (sea stars, brittle stars, sea lilies, sea urchins, etc.)

Two groups of echinoderms have been reported in passing from the Kaibab Formation of WACA: crinoids and echinoids. Crinoids, also known informally as “sea lilies” when attached to something and “feather stars” when free-floating, were reported from the beta member of WACA by McKee (1938). McKee noted that very little diagnostic crinoid material had been found in the Kaibab Formation in general. Crinoid fossils are frequently fragments of the whole animal, such as ring-shaped or gear-shaped individual columnals of the crinoid stem. Echinoids, also known as “sea urchins”, were reported from the beta member of WACA by McKee (1938), who identified the genus as *Archaeocidaris*. Lipinski (1976) later reported echinoid spines from the beta member. Crinoid columnals or short segments of columns are sometimes used as beads, and WACA collections at WACC include crinoid beads. Crinoids were recorded during the 2017 field survey. A few individual crinoid columnals were documented at sites 2 and 10 within the fragmentary fossil layers associated with bivalves, gastropods, and scaphopods (Figure 15).

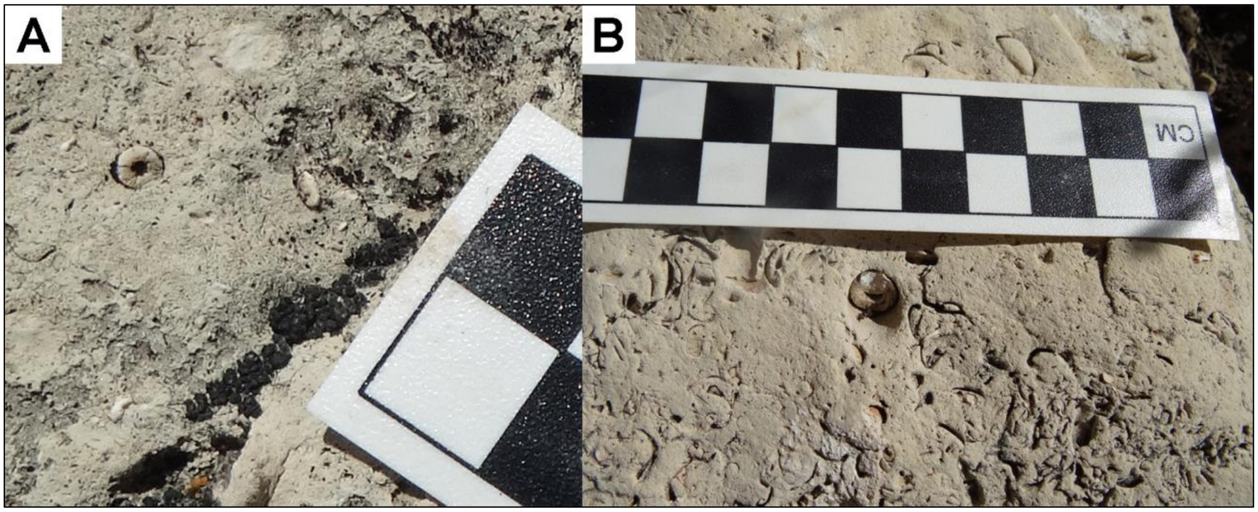


Figure 15. Crinoid stem fragments documented during the 2017 field survey. Crinoid stem segments were found in fragmented fossiliferous layers and were uncommon. Crinoid stems were found at site 2 (A) and site 10 (B). Scale bar is in cm (NPS/DIANA BOUDREAU).

Fossil Vertebrates

Class Aves

Bird bones have been found within cultural sites; however, they are cultural artifacts, not fossilized paleontological specimens. They include two bones of the turkey *Melagris gallopavo* and single bones of the raven *Corvus corax* and crow *Corvus brachyrhynchos* (Hargrave 1939). For more information regarding these specimens consult Hargrave (1939) or Starkovich (2011).

Ichnofossils

Aside from the packrat midden described by Murdock (1994) and detailed above in the “Fossil Plants” section, the only other trace fossils reported from WACA are invertebrate burrows in the Kaibab Formation, noted by Lipinski (1976). Trace fossils were found during the 2017 field survey. Many burrow-like tubes were found on a rock wall at site 16 (Figure 16). In addition, a few fossil specimens from sites 14, 26, and 28 have drill holes in them (Figure 17). These trace fossils are generally made by predatory snails. Snails attach themselves to the shell of an invertebrate and drill a hole through the shell. The snail then injects a substance causing the bivalve or brachiopod to open their shell allowing the snail to enter and consume the organism inside. There has also been documentation that these drill holes were not just predatory in origin, but could have been commensal or parasitic. These types of drill holes are well-known from Mesozoic and Cenozoic periods, but have a sparse record during the Paleozoic (Kowalewski et al. 2000). Therefore, the drill holes preserved in WACA are unique paleontological features. Within the WACA collection at MNA, three fossil burrow casts, each approximately 1 cm in diameter, were cataloged during the Island Trail Rehabilitation Project (Hasbargen 2014). For more details, see the “Paleontological Research and Collections” section.

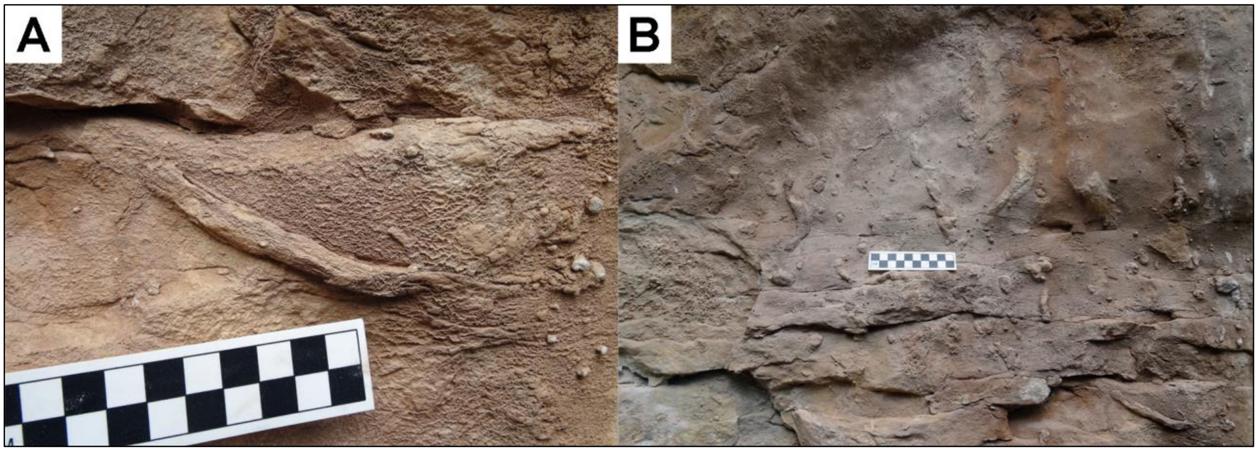


Figure 16. Burrows and traces found at site 16 during 2017 field survey, including low-angle burrows (A) and vertical burrows (B). Scale bar is in cm (NPS/DIANA BOUDREAU).

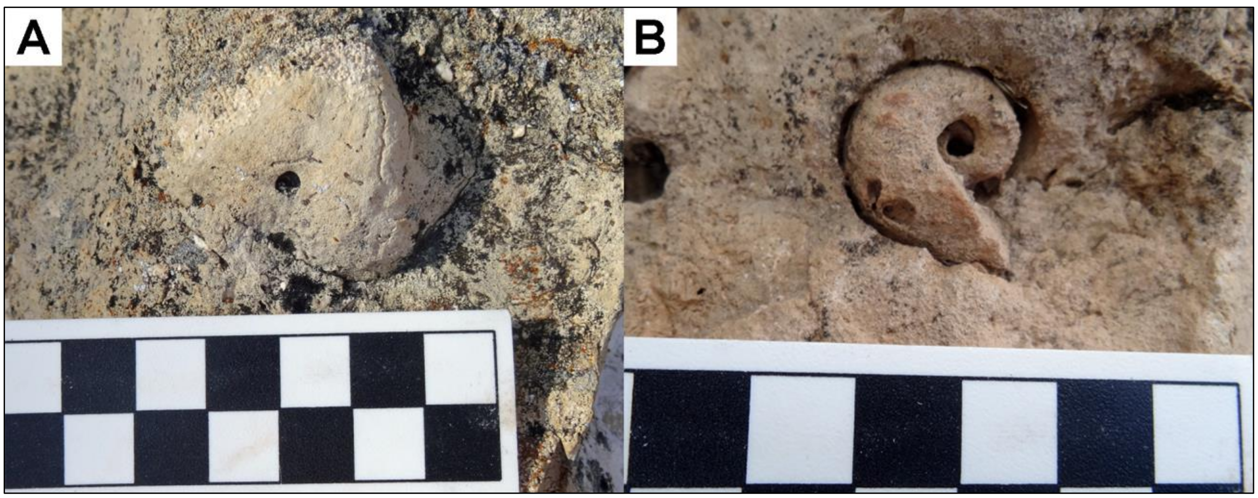


Figure 17. Bored fossils found during 2017 field survey. (A) Single snail borehole in fossil brachiopod, *Dictyoclostus*, at site 26. (B) Two snail boreholes on the side of a bellerophontid gastropod at site 28. Scale bar is in cm (NPS/DIANA BOUDREAU).

Cultural Resource Connections

There are many ways for paleontological resources to have connections to cultural resources. Examples of paleontological resources in cultural contexts include, but are not limited to: fossils used by people for various purposes, such as petrified wood used for tools, spear points, and other artifacts, or fossil shells picked up as charms or simply because they looked interesting; associations of prehistoric humans with paleontological resources, such as kill sites of mammoths, prehistoric bison, and other extinct animals; incorporation of fossils into cultural records, such as fossils in American Indian lore, "tall tales" of mountain men, and emigrant journals; and fossils in building stone. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

At WACA, there are several examples of fossils in cultural contexts. Graham (2008) reported that molds of brachiopods can be seen along the back wall of the cliff dwellings. Additionally, Hasbargen (2014) collected a few brachiopods found in association with cultural sites during a trail rehabilitation project that are now in MNA collections. The Sinagua people are known to have used chert for tools, which can be fossiliferous, although no such tools have been found at WACA. This may be due to artifact looting and collecting that occurred before WACA was proclaimed a national monument. There are, however, a handful of fossils collected from cultural resource contexts at WACA, now reposited at the Western Archeological and Conservation Center (WACC) in Tucson, Arizona (see under "WACA Paleontological Specimens in Museum Collections").

Paleontological Resource Management and Protection

National Park Service Policy

Paleontological resources are non-renewable remains of past life preserved in a geologic context. Fossils possess scientific and educational values and are of great interest to the public; therefore, it is exceedingly important that appropriate management attention be placed on the monitoring, collecting, and curating of these specimens within federal lands. In 2009, the Paleontological Resources Preservation Act (PRPA) was signed into law as part of the Omnibus Public Land Management Act of 2009. The new paleontology-focused legislation includes provisions related to inventory, monitoring, public education, research and collecting permits, curation, and criminal/civil prosecution associated with fossils from designated DOI lands. Paleontological resource protection training is available for NPS staff through the NPS Geologic Resources Division (GRD). GRD is also available to provide support in paleontological resource theft or vandalism investigations.

As of the date of this publication, an interagency coordination team including representatives from the Bureau of Land Management (BLM), Bureau of Reclamation (BOR), National Park Service (NPS) and U.S. Fish & Wildlife Service (FWS) are in the processes of developing Department of Interior (DOI) final regulations for PRPA. Draft DOI regulations were published in the Federal Register in December 2016 and were available for 60 days to allow for public comment. The interagency team are reviewing the public comments and will be drafting the final regulations. For more information regarding this act, visit https://www.nps.gov/subjects/fossils/fossil-protection.htm.

National Park Service management policies state "management actions will be taken to prevent illegal collecting [of fossil resources] and may be taken to prevent damage from natural processes such as erosion. Protection may include construction of shelters over specimens for interpretation in situ, stabilization in the field [which can include reburial] or collection, preparation, and placement of specimens in museum collections. The locality and geologic data associated with a specimen will be adequately documented at the time of specimen collection. Protection may also include, where necessary, the salvage collection of threatened specimens that are scientifically significant."

Effective paleontological resource management serves to protect fossil resources by implementing strategies that mitigate, reduce, or eliminate loss of fossilized materials and their relevant data. Whereas fossils are representatives of adaptation, evolution and diversity of life through deep time, they have intrinsic scientific value beyond that of the physical objects themselves. Their geological and geospatial contexts provide additional critical data concerning paleoenvironmental, paleogeographic, paleoecologic, and a number of other conditions that together allow a more complete interpretation of the physical and biological history of the earth. Therefore, paleontological resource management must act to protect not only the fossils themselves, but to collect and maintain the ancillary data as well.

In general, losses of paleontological resources result from naturally occurring physical processes, by direct or indirect human activities, or by a combination of both. The greatest loss of ancillary data occurs when fossils are removed from their original geological context. Thus, when a fossil erodes from its surrounding sediments and begins to migrate downhill it begins to lose significant ancillary data until, at some point, it becomes more a scientific curiosity than a useful piece of scientific data. Likewise the same can be said of a fossil exhumed during roadway construction or a building excavation. It is not necessary to list here all of the natural geological and anthropogenic activities that can lead to the loss of paleontological resources; rather it is sufficient to acknowledge that anything which disturbs native sediment or original bedrock has potential to result in the loss of the paleontological resources that occur there.

In the course of this inventory, paleontological localities have been evaluated for factors that could cause potential loss of paleontological resources. Their overall conditions are reported as good, fair, or poor based on the situations found at each individual locality. Risks and conditions that influence the degree of potential loss are categorized as Disturbance, Fragility, Abundance, and Site Access. "Disturbance" evaluates conditions that promote accelerated erosion or mass wasting resulting from human activities. "Fragility" evaluates natural conditions that may influence the degree to which fossil transportation is occurring, such as inherently soft rapidly eroding sediment or mass wasting on steep hillsides. "Abundance" judges both the natural condition and number of specimens actually preserved in the deposits as well as the risk of being easily recognized as a fossil-rich area which could lead to the possibility of unpermitted collecting. "Site Access" assesses the risk of a locality being visited by large numbers of visitors or the potential for easy removal of large quantities of fossils or fossil-bearing sediments as a result of convenient transportation corridors.

Each of the factors noted above may be mitigated by management actions. Localities exhibiting a significant degree of disturbance may require either active intervention to slow accelerated erosion, periodic collection and documentation of fossil materials, or both. Localities developed on sediments of high fragility naturally erode at a relatively rapid rate and would require frequent visits to collect and document exposed fossils in order to prevent or reduce losses. Localities with very abundant fossils should be placed on a schedule for periodic visits to collect and document rare or significant specimens as well as to inspect for evidence of unpermitted collecting. Localities that are easily accessible by road or trail would benefit from the same management strategies as those with abundant fossils and by occasional unscheduled visits by monument staff, documentation of in situ specimens, and/or frequent law enforcement patrols.

Alcove localities are in a distinct class for management due to the close connection with archeological resources and unique issues affecting cave resources. See Santucci et al. (2001) for additional discussion of paleontological resources in cave settings.

Management strategies to address any of these conditions and factors could also incorporate the assistance of qualified specialists to collect and document resources rather than relying solely on staff to accomplish such a large task at WACA. Active recruitment of paleontological research scientists should also be used as a management strategy.

Baseline Paleontology Resource Data Inventories

A baseline inventory of paleontological resources is critical for an effective management strategy, as it provides information for decision-making. This inventory report has compiled information on previous paleontological research done in and near WACA, taxonomic groups that have been reported within WACA boundaries, and localities that were previously reported. This report can serve as a baseline source of information for future research, inventory reports, monitoring, and paleontological decisions. The Paleontological Resource Inventory and Monitoring report for the Southern Colorado Plateau Network done by Tweet et al. (2009) and the references cited within were important baseline paleontological resource data sources for this WACA-specific report.

Interpretation and Education

Fossils and paleontology are popular topics with large segments of the public; this is especially true with children. The increased understanding of the paleontological resources at Walnut Canyon National Monument presents many opportunities for public interpretation and education. Fossils possess interesting scientific and educational information about the ancient organisms themselves and often reveal important information about geologic history and paleoenvironments. Whereas fossils are representatives of adaptation, evolution and diversity of life through deep time, they have intrinsic scientific value beyond that of the physical objects themselves. Their geological and geospatial contexts provide additional critical data concerning paleoenvironmental, paleogeographic, paleoecologic, and a number of other conditions that together allow a more complete interpretation of the physical and biological history of the earth.

To begin, interpretation staff could write a short paleontology summary of the monument to post on the WACA website or include in informational brochures, site bulletins, or wayside exhibits and other types of written interpretive media. This would include a brief introduction to the local geology in the canyon, depositional environments of those rock layers, and what fossils are found within them. Text should aim to tie together all of these components to paint a holistic picture of life during the Permian in Walnut Canyon National Monument. Information regarding the history of paleontological exploration in the monument could also be included.

In addition to brochures and site bulletins, a few slabs of representative stone could be bolted to a table in the Visitor Center for a visual-tactile display. This display could also include a paleoartist's reconstruction of the ancient sea that covered northern Arizona during the Permian. Fossil replicas can be obtained by the monument for use in educational outreach, school field trips, or public interpretation.

Walking interpretive programs could also be developed to bring the visitor closer to the resource. Along the Island Trail, many rocky overhangs utilized by the Sinagua people contain fossils. Fossils along the Island Trail include brachiopods (especially *Dictyoclostus*), bivalves, and gastropods (Chronic 1983). In addition, there are multiple views of the Coconino Sandstone from the Island Trail which provide opportunities to talk about the large coastal dune field that covered WACA prior to the shallow sea (Kaibab Formation). The many stairs that lead from the Visitor Center to the Island Trail Loop provide an opportunity to encourage visitors to imagine they are walking back through time. The two suggestions could be intertwined into a longer program covering geology and paleontology or presented separately as shorter programs. See suggested interpretive themes for program ideas.

WACA should be sure to promote their paleontological resources and provide additional opportunities or programs for visitors to learn about fossils on National Fossil Day. The National Park Service coordinates the National Fossil Day partnership (second Wednesday in October) (https://www.nps.gov/subjects/fossilday/index.htm) and hosts fossil-focused events across the country, in conjunction with Earth Science Week. The NPS Geologic Resources Division can assist parks with planning for National Fossil Day activities in the monument and provide supplies of

Junior Paleontologist Program supplies including activity booklets, badges, posters and other fossil-related educational resources (https://www.nps.gov/subjects/fossils/junior-paleontologist.htm).

Suggested Interpretation Themes

I. General Paleontological Information

All of the interpretation topics should include a section instructing visitors how to be paleontologically aware while in the monument. The interpreter will provide the visitor with information regarding why fossils are important, how paleontologists look for fossils, what to do if fossils are found, and reminders to be aware that fossils exist and should be respected within monument boundaries.

- Fossils are non-renewable resources that possess scientific and education information and provide insight into what earth was like thousands and even hundreds of millions of years ago.

- When paleontologists survey for paleontological resources the most important tool is a geologic map. Paleontological resources are more common in certain geologic units, so knowing where those units are exposed is important for a successful search. Other tools that a paleontologist sometimes takes with them include baggies, toilet paper (to wrap the fossil), small picks and brushes, special adhesive called vinac, GPS, camera, topographic maps, and appropriate first aid and safety equipment. It might be helpful to show examples of these items for visitors when giving an interpretive talk. Geologic and topographic maps of Walnut Canyon National Monument are provided in this document and can be provided by FLAG natural resources department.

- If fossils are found in the monument by a visitor, the visitor should photograph it and notify a ranger of where the resource was found, but most importantly, they should leave the fossil where they found it. Removing fossil materials from public lands without permits is a federal offense.

II. Fossils of Walnut Canyon National Monument

A program could be developed to educate the public on what types of fossils are present in WACA and what they tell scientists about Earth’s dynamic history. The goal of this program is to increase visitors’ understanding of local geology and paleontology. Therefore, information regarding fossils from the vicinity of WACA (including but not limited to those in WUPA, GRCA, etc.) can be included.

- Starting with the oldest units (Coconino Sandstone) the interpretive ranger should describe depositional environment and fossils found within those units moving up stratigraphically to the Toroweap Formation, the Kaibab Formation, and finishing with Quaternary deposits. Periods of erosion should be mentioned leading to “gaps” in the geologic record within WACA. If time allows, the interpreter could mention the Moenkopi Formation which is exposed just south of the monument, but is not found within the boundary.

- Discussion of Quaternary deposits should include packrat middens. These middens are commonly found in alcoves of WACA and contain important plant or animal remains which can be scientifically important. The materials incorporated into middens are gathered by the packrats (*Neotoma*) and constructed into elaborate collections of organic material bound together by crystallized packrat urine which slows the decaying process. These organics can be important for environment reconstruction and provide a relatively complete record of vegetation and climate change. Middens are often found in caves or rock shelters where they have been protected from the elements.

Paleontological Research and Collections

Paleontological Research Permits

See the National Park Service Natural Resource Management Reference Manual DO-77 section on Paleontological Resource Management, subsection on Scientific Research and Collection (https://www.nature.nps.gov/rm77/paleo/ProgramGuide.cfm#Research). NPS Management Policies 2006, section 4.8.2.1 on Paleontological Resources, states that "The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit." The NPS maintains an online Research and Collecting Permit (RPRS) database system for researchers to submit applications for research in NPS areas. Applications are reviewed at the park level and either approved or rejected. Current and past paleontological research and collecting permits and the associated Investigator's Annual Reports (IARs) are available on the RPRS website (https://irma.nps.gov/rprs/). Additional information on NPS law and policy can be found in Appendix D.

WACA Paleontological Specimens in Museum Collections

WACA fossils are currently held at the Museum of Northern Arizona (MNA; Flagstaff, Arizona) and the NPS's Western Archeological and Conservation Center (WACC; Tucson, Arizona). Contact information can be found in Appendix C.

Museum of Northern Arizona (MNA)

During the 2017 survey of WACA, the primary author visited the collections housed at the Museum of Northern Arizona (MNA; Flagstaff, Arizona) to document fossil specimen from WACA. Specimens were moved to the MNA from WACA in 2011. The collections include 98 cataloged paleontological specimens. Of the 98 specimens, many have locality information or site descriptions. WACA 419, 421, 424, 425, 426, 427, 1007, and 1650 are cataloged, but are unlikely to be from within WACA boundaries as their provenance is unknown (G. Gallenstein, pers. comm., March 2018).

Seventy-six specimens were collected from localities 60-0 through 60-9. These included: WACA 9885, 9892, 9954, conulariids; WACA 9884, 9891, 9896, 9898, 9901, 9902, 9904, 9906, internal molds of brachiopod *Chonetes* sp.; WACA 9887, 9889, 9897, 9905, 9907, 9918, 9938, *Astartella* sp. bivalves; WACA 9899, 9908, cf. *Aviculopecten kaibabensis* bivalves; WACA 9910, 9940, *Pteria* sp. with *Schizodus* sp. bivalves; WACA 9911, 9914, 9915, 9923, 9926, 9927, 9931, 9941, 9946, *Nuculopsis* sp. bivalves; WACA 9916, 9947, *Pleurophorus* sp. bivalves; WACA 9932, 9936, 9948, *Schizodus* sp. bivalves; WACA 9942, *Parallelodon* sp. bivalve; WACA 9950, *Pseudomonotis sp.* bivalve; WACA 9880, 9881, 9882, 9883, 9886, 9893, 9900, 9903, 9919, 9920, pectinid bivalves; WACA 9894, 9895, unidentified bivalves; WACA 9933, nautiloid with *Plagioglypta, Schizodus,* and *Nuculopsis;* WACA 9888, 9934, 9929, 9939, PN 2.8105, unidentified nautiloid; WACA 9890, 9930, 9953, *Plagioglypta canna* scaphopods; WACA 9937, 9945, *Baylea capertoni* gastropods; WACA 9943, 9944, 9952, *Euomphalus* sp. gastropods; WACA 9909, 9928, 9951, bellerophontid gastropods; WACA 9917, 9925, unidentified gastropods; and WACA 9912, 9913, 9921, 9922, 9924, 9935, 9949, unidentified invertebrate fossils in limestone blocks. A selection of these specimens is pictured in Figures 18 and 19.

The remaining twelve specimens were collected in association with projects or trail maintenance in or near the monument. WACA 436, 437, 438, 439, 440, and 441 are unidentified fossils with provenance likely outside of Walnut Canyon, but collected during R-7 Project by Robert Vicklund. An additional five specimens were collected during a trail work and rehabilitation project by the Coconino Rural Environmental Crew (CREC). The specimens include productid brachiopods WACA 9069, 9961, 10019, and 10032, and WACA 10033, trace fossil casts. These specimens were found near cultural sites in the monument (Hasbargen 2014). An additional brachiopod specimen, WACA 442 (*Productus bassi*) was collected by a seasonal ranger because it was loose on the surface of a heavily trafficked trail.

Additional specimens are listed in MNA collections, but have little to no locality information associated with them. These include: WACA 2218, productid brachiopod; and P2.3136, casts of bivalve *Acanthopecten coloradoensis*.

Western Archeological and Conservation Center (WACC)

The Western Archeological and Conservation Center (WACC; Tucson, Arizona) includes a handful of fossils found in cultural resource contexts. In 2009, WACC registrar Kim Beckwith sent Alison Mims, one of the authors of the 2009 SCPN paleontological inventory, a list of 23 objects under 14 catalog numbers. These included: WACA 436 and 437, unidentified fossils from the R-7 project; WACA 984, 985, 992, and 1000, pieces of petrified wood (four in WACA 1000); WACA 1372, a snail or cephalopod; WACA 1650, an external cast of a brachiopod; WACA 1651, seven drilled crinoid stem fragments, used as beads; WACA 1746, bones from an unknown location; WACA 1802, bones from a gully; WACA 2156, a projectile point variously identified as calcite, chert, or petrified wood; and WACA 2218, a fossil bivalve shell. WACA 436, 437, 984, 985, 992, 1000, and 1650 were in storage, while WACA 663, 1372, 1651, 1746, 1802, 2156, and 2218 were on loan (K. Beckwith, WACC registrar, pers. comm. to A. Mims, June 2009). Justin Tweet visited WACC in March 2015 and observed some of these specimens, as well as a few that weren't included in the 2009 list (Figure 20). WACA 663 and 1372 proved to be bellerophont snails. WACA 1746 included an assortment of true bones and apparent bone-like stones. WACA 1802 appeared to be entirely bone-like stones. WACA 436, 437, 984, 985, 992, 1000, 1650, 2156, and 2218 were not seen. Three catalog numbers not on the 2009 list were seen: WACA 86, nine complete or partial crinoid columnals and four possible bone fragments; WACA 906, six unworked shells, of which the three largest appeared to be fossil bivalves; and WACA 1078, a fossiliferous stone with numerous shell molds and impressions, one of which is clearly a bivalve (J. Tweet, pers. obs., March 2015). All of these fossils are consistent with the kinds of fossils that are known from WACA or the immediate vicinity.

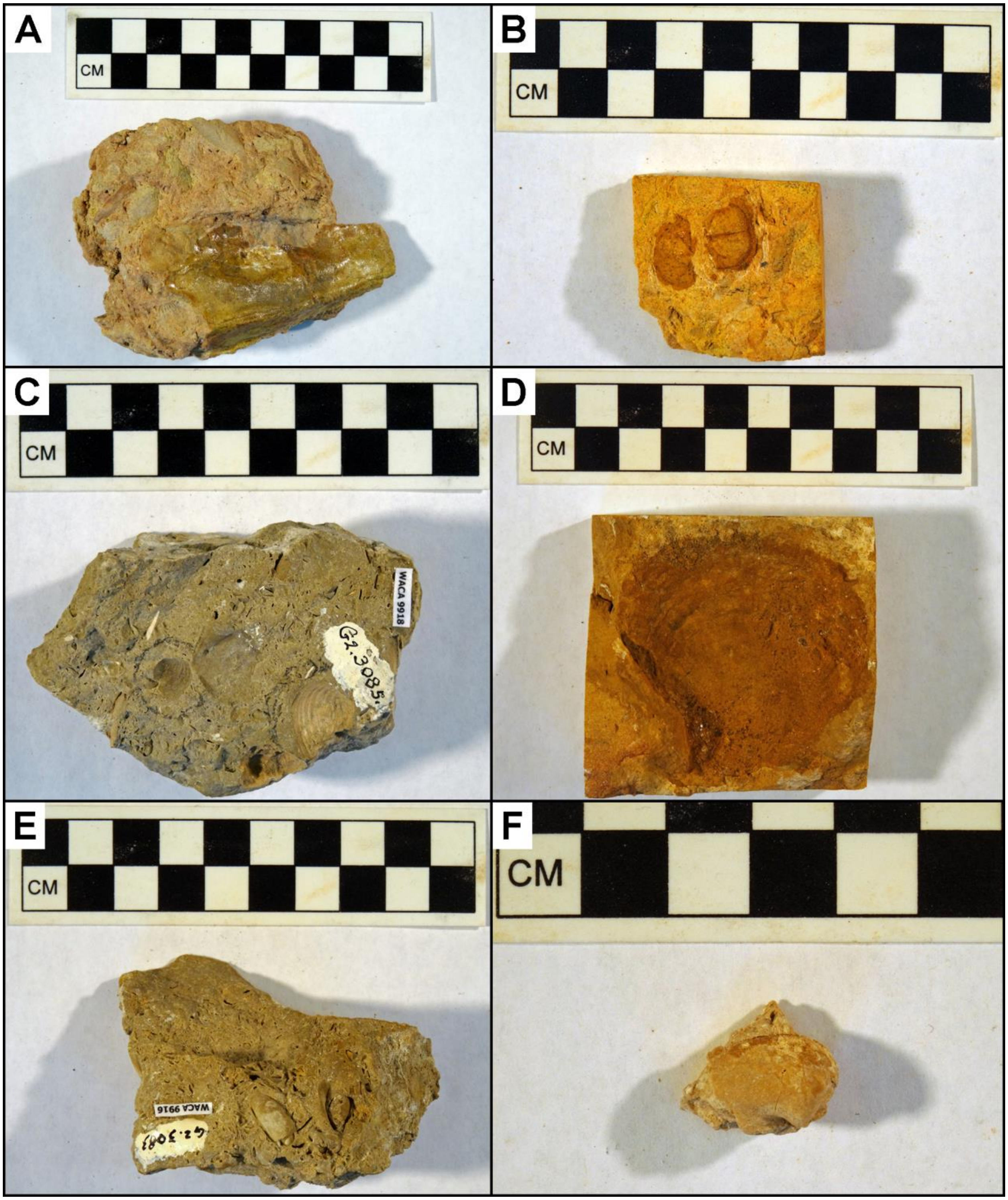


Figure 18. A selection of fossil specimens housed at the Museum of Northern Arizona (MNA) as part of the WACA collection. (A) WACA 9892, conulariid; (B) WACA 9898, *Chonetes sp.* brachiopod internal molds; (C) WACA 9918, *Astartella sp.* bivalve impression circled in graphite; (D) WACA 9908, impression of bivalve *Aviculopecten kaibabensis;* (E) WACA 9916, *Pleurophorus sp.* bivalve; and (F) WACA 9932, *Schizodus sp.* bivalve. Scale bar is in cm (NPS/DIANA BOUDREAU).

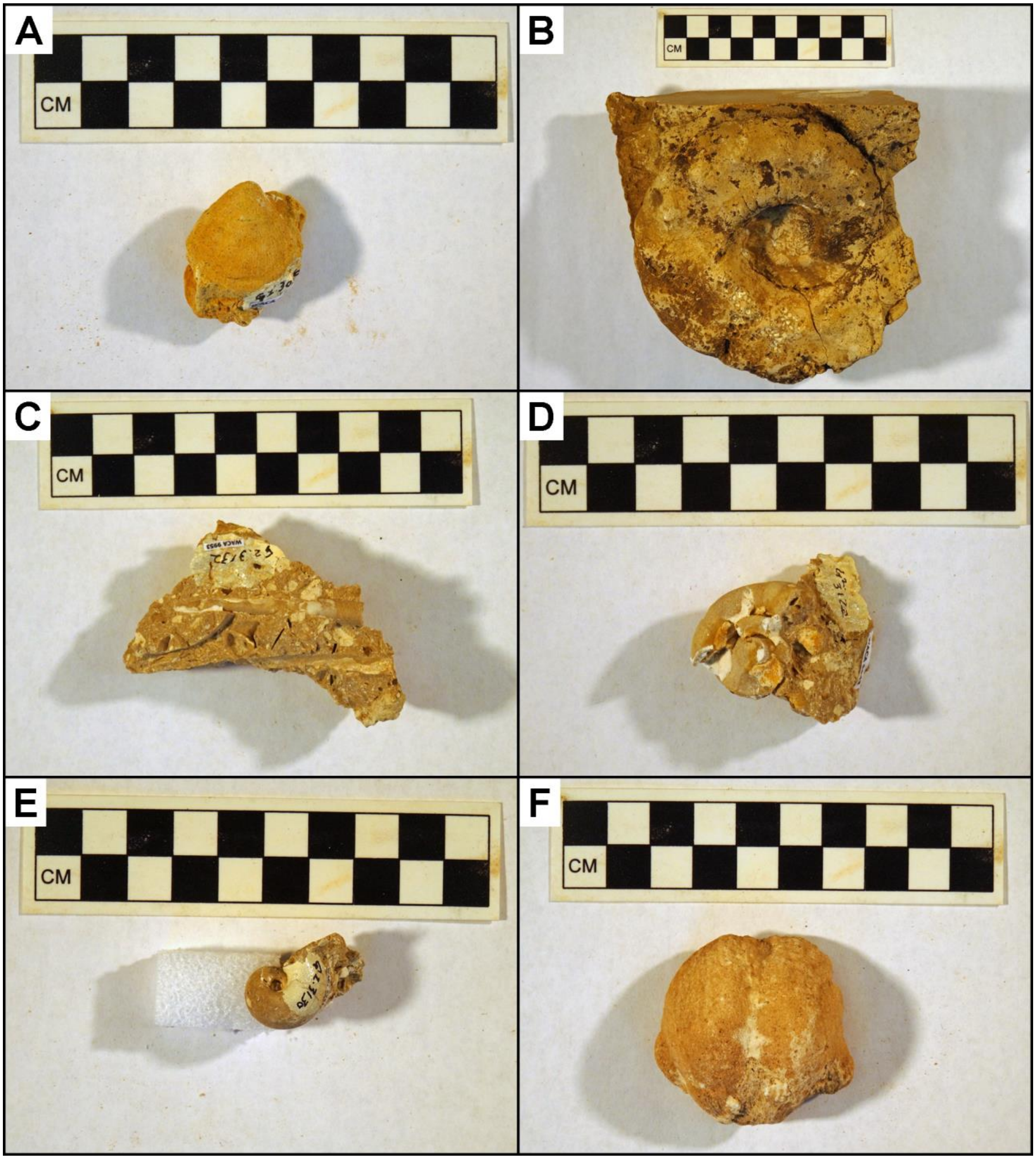


Figure 19. A selection of fossil specimens housed at the Museum of Northern Arizona (MNA) as part of the WACA collection. (A) WACA 9881, unidentified pectinid bivalve; (B) PN 2.8105, unidentified nautiloid; (C) WACA 9953, *Plagioglypta canna* scaphopod; (D) WACA 9943, *Euomphalus sp.* gastropod; (E) WACA 9951, bellerophontid gastropod; and (F) WACA 10032, productid brachiopod. Scale bar is in cm (NPS/DIANA BOUDREAU).

Figure 20. A selection of WACA fossil specimens housed at the Western Archeological and Conservation Center (WACC). (A) WACA 663, bellerophontid gastropod; (B) WACA 906, assorted bivalve shells; (C) WACA 1372, bellerophontid gastropod; (D) WACA 1651, crinoid stem pieces with drill marks indicating use as jewelry; and (E) WACA 86, assorted crinoid stems and fossil bone material. Scale bar is in mm (NPS/JUSTIN TWEET).

Paleontological Resource Management Recommendations

The paleontological resource inventory at WACA has documented rich and previously unrecognized paleontological resources from within monument boundaries. This report captures the scope, significance, and distribution of fossils at WACA as well as provides recommendations to support the management and protection of the monument's non-renewable paleontological resources.

- WACA staff should be encouraged to observe exposed rocks and sedimentary deposits for fossil material while conducting their usual duties. To promote this, staff should receive guidance regarding how to recognize common local fossils. When opportunities arise to observe paleontological resources in the field and take part in paleontological field studies with trained paleontologists, staff should take advantage of them, if funding and time permit.

- WACA staff should photo-document and monitor any occurrences of paleontological resources that may be observed in situ. Fossils and their associated geologic context (surrounding rock) should be documented, but left in place unless they are subject to imminent degradation. A Geologic Resource Monitoring Manual published by the Geological Society of America and NPS Geologic Resources Division (GRD) includes a chapter on paleontological resource monitoring (Santucci et al. 2009). Santucci and Koch (2003) also present information on paleontological resource monitoring.

- Fossil theft is one of the greatest threats to the preservation of paleontological resources and any methods to minimize these activities should be utilized by staff. Graham (2008) reported that fossil theft had occurred at WACA, and a rockhound guide, Ratkevich (1979), included localities in and around the Walnut Canyon area. Any occurrence of paleontological resource theft or vandalism should be investigated by a law enforcement ranger. When possible, the incident should be fully documented and the information submitted for inclusion in the annual law enforcement statistics.

- Geologic units are fairly continuous across Northern Arizona. Therefore, geology and paleontology of WACA can be compared to nearby WUPA, which has the Kaibab Formation and Moenkopi Formation (Henderek et al. 2017), and GRCA, as McKee did in the 1930s.

- Fossil packrat middens are typically found in dry caves and rock shelters and resemble piles or mounds of plant material with a dark glossy coating of crystallized packrat urine. Fossil middens can provide important paleoecological information. If a fossil packrat midden is located, there are several midden researchers in the Southwest who may be contacted. The GRD maintains a list of active researchers and can facilitate communication between the monument and these researchers. Fossil midden studies usually focus on plant fossils, but often also include many other types of fossils, including invertebrate and vertebrate remains. These other types of fossils should not be overlooked in future descriptions.

- Fossils found in a cultural context should be documented like other fossils, but will also require the input of an archeologist or a cultural resource specialist. Any fossil which has a cultural context may be culturally sensitive as well (e.g., subject to NAGPRA) and should be regarded as such until otherwise established. The Geologic Resources Division can coordinate additional documentation/research of such material.

- The monument may fund and recruit paleontology interns as a cost-effective means of enabling some level of paleontological resource support. The Geoscientists-in-the-Parks Program is an established program for recruitment of geology and paleontology interns.

- Contact the NPS Geologic Resources Division for technical assistance with paleontological resource management issues.

If fossil specimens are found by WACA staff, it is recommended they follow the steps outlined below to ensure proper paleontological resource management.

- Photo-document the specimen without moving it from its location, if it is loose. Include a common item, such as a coin, pen, or pencil, for scale if a ruler or scale bar is not available.

- If a GPS unit is available, record the location of the specimen. If GPS is not available, record the general location within WACA and height within the rock wall. If possible, revisit the site when a GPS unit is available.

- Write down associated data, such as rock type, general description of the fossil, type of fossil if identifiable, general location in WACA, sketch of the fossil, position within the rock wall or if it is loose on the ground, any associated fossils, and any other additional information.

- Do not remove the fossil unless it is loose in a heavily trafficked area, such as a public trail, and is at risk of being taken or destroyed. If the fossil is removed, be sure to wrap in soft material, such as toilet paper, and place in a labeled plastic bag with associated notes. Since WACA has many culturally important sites, simply documenting the fossil and leaving it in place is the best course of action until natural resource staff is contacted.

- If fossil resources are found, alert staff at WACA to allow for proper documentation.

Paleontology Archives

All data, references, and information used in the development of this report are in the NPS paleontology archives. If any resources are needed by NPS staff at WACA or additional questions arise regarding paleontological resources, contact Vincent Santucci.

Walnut Canyon National Monument Paleontological Archives
5/1985–present (hard copy data; reports; electronic data; photographs; maps; publications).
Originated by Santucci, Vincent; status: Active.

Literature Cited

Agenbroad, L. D., and J. I. Mead. 1989. Quaternary geochronology and distribution of *Mammuthus* on the Colorado Plateau. Geology 17(9):861–864.

Baars, D. L. 1961. Permian blanket sandstones of Colorado Plateau. Pages 179–207 *in* J. A. Peterson and J. C. Osmond, editors. Geometry of sandstone bodies. American Association of Petroleum Geologists, Tulsa, Oklahoma. Special Publication 22.

Baars, D. L. 1979. The Permian system. Pages 1–6 *in* D. L. Baars, editor. Permianland—A field symposium. Four Corners Geological Society, Durango, Colorado. 9th Field Conference.

Benfer, J. A. 1971. The petrology of the eastern phase of the Toroweap Formation, Walnut Canyon, Arizona. Thesis. Northern Arizona University, Flagstaff, Arizona.

Beus, S. S. 1965. Permian fossils from the Kaibab Formation at Flagstaff, Arizona. Plateau 38:3–5.

Bezy, J. V. 2003. A guide to the geology of the Flagstaff area. Arizona Geological Survey, Tucson, Arizona. Down-to-Earth Series 14. Available at: http://repository.azgs.az.gov/sites/default/files/dlio/files/nid1540/dte-14_guideflagstaffgeology400dpi.pdf (accessed May 2018).

Billingsley, G. H., S. S. Priest, and T. J. Felger. 2007. Geologic map of Wupatki National Monument and vicinity, Coconino County, northern Arizona. U.S. Geological Survey, Reston, Virginia. Scientific Investigations Map 2958. Scale 1:24,000. Available at: https://pubs.er.usgs.gov/publication/sim2958 (accessed May 2018).

Blakey, R. C. 1990. Stratigraphy and geologic history of Pennsylvanian and Permian rocks, Mogollon Rim region, central Arizona and vicinity. Geological Society of America Bulletin 102:1189–1217.

Blakey, R. C., and R. Knepp. 1989. Pennsylvanian and Permian geology of Arizona. Pages 313–347 *in* J. P. Jenney and S. J. Reynolds, editors. Geologic evolution of Arizona. Arizona Geological Society, Tucson, Arizona. Digest 17.

Chronic, H. 1952. Molluscan fauna from the Permian Kaibab Formation, Walnut Canyon, Arizona. Geological Society of America Bulletin 63:95–166.

Chronic, H. 1983. Roadside geology of Arizona. Mountain Press Publishing Company, Missoula, Montana.

Chronic, H., and L. Chronic. 2004. Pages of stone: geology of the Grand Canyon & Plateau country national parks & monuments (2nd edition). The Mountaineers Books, Seattle, Washington.

Colton, H. S. 1929. Fossil fresh water shells from Winona, Coconino County, Arizona. The Nautilus 42(3):93–94. Available at: http://biodiversitylibrary.org/page/8518876 (accessed May 2018).

Darton, N. H. 1910. A reconnaissance of parts of northwestern New Mexico and northern Arizona. U.S. Geological Survey, Washington, D.C. Bulletin 435. Available at: https://pubs.er.usgs.gov/publication/b435 (accessed May 2018).

Elliott, D. K., and J.-P. M. Hodnett. 2013. A new species of *Bransonella* (Chondrichthyes, Xenacanthimorpha, Bransonelliformes) from the Middle Permian Kaibab Formation of Northern Arizona. Journal of Paleontology 87(6):1136–1142.

Erwin, D. H. 1988. Permian Gastropoda of the southwestern United States: Cerithiacea, Acteonacea, and Pyramidellacea. Journal of Paleontology 62(4):566–575.

Frech, F. 1893. Section in Congress Canyon opposite Point Sublime. Pages 476–481 *in* Compte rendu. International Geologic Congress [Congres geologique international], 5th session. Government Printing Office, Washington, D.C. Available at: https://archive.org/details/Geologicalguide00Emmo (accessed May 2018).

Gass, H. L. 1963. A review of the Paleozoic fish of Arizona. Thesis. University of Arizona, Tucson, Arizona. Available at: http://arizona.openrepository.com/arizona/bitstream/10150/551660/1/AZU_TD_BOX241_E9791_1963_152.pdf (accessed May 2018).

Graham, J. 2008. Walnut Canyon National Monument Geologic Resource Evaluation Report. NPS Geologic Resources Division, Denver, Colorado. NPS/NRPC/GRD/NRR—2008/040. Available at: https://nature.nps.gov/geology/inventory_embed/publications/reports/waca_gre_rpt_view.pdf (accessed May 2018).

Grahame, J. D., and T. D. Sisk, editors. 2002. Wupatki and Sunset Crater National Monuments, Arizona. Canyons, cultures and environmental change: an introduction to the land-use history of the Colorado Plateau. Colorado Plateau Land-Use History of North America Project. Northern Arizona University, Flagstaff, Arizona.

Grant, R. E. 1966. A Permian productoid brachiopod: life history. Science 152(3772):660–662.

Griffin, L. R. 1966. *Actinocoelia maeandrina* Finks, from the Kaibab Limestone of northern Arizona. Brigham Young University Geology Studies 13:105–108. Available at: http://geology.byu.edu/home/sites/default/files/actinocoelia-maeandrina-finks-from-the-kaibab-limestone-of-northern-arizona-leland-r.-griffin.pdf (accessed May 2018).

Hargrave, L. L. 1939. Bird bones from abandoned Indian dwellings in Arizona and Utah. The Condor 41(5):206–210. Available at: https://sora.unm.edu/sites/default/files/journals/condor/v041n05/p0206-p0210.pdf (accessed May 2018).

Hasbargen, J. 2014. Artifact analysis from the Island Trail Rehabilitation Project in 2013 and 2014 at Walnut Canyon National Monument, Arizona. P. 23.

Henderek, R., V. L. Santucci, B. Rizner, J. Tweet, and J. Wood. 2017. Wupatki National Monument paleontological resources inventory. Natural Resource Report NPS/WUPA/NRR—2017/1524. National Park Service, Fort Collins, Colorado.

Hintze, L. F., and B. J. Kowallis. 2009. Geologic history of Utah (3rd edition). Brigham Young University Geologic Studies, Special Publication 9.

Hodnett, J.-P. M., D. K. Elliott, T. J. Olson, and J. H. Wittke. 2012. Ctenacanthiform sharks from the Permian Kaibab Formation, northern Arizona. Historical Biology 24(4):381–395.

Hodnett, J.-P. M., D. K. Elliott, and T. J. Olson. 2013. A new basal hybodont (Chondrichthyes, Hybodontiformes) from the Middle Permian (Rodian) Kaibab Formation, of northern Arizona. New Mexico Museum of Natural History and Science Bulletin 60:103–108.

Hopkins, R. L. 1990. Kaibab Formation. Pages 225–245 *in* S. S. Beus and M. Morales, editors. Grand Canyon geology. Oxford University Press, New York, New York.

Hughes, T. McK. 1893. Note on Walnut Canyon and its cliff dwellings. Pages 475–476 *in* Compte rendu. International Geologic Congress [Congres geologique international], 5th session. Government Printing Office, Washington, D.C. Available at: https://archive.org/details/Geologicalguide00Emmo (accessed May 2018).

Hunt, A. P., S. G. Lucas, V. L. Santucci, and D. K. Elliott. 2005a. Permian vertebrates of Arizona. New Mexico Museum of Natural History and Science Bulletin 29:10–15.

Hunt, A. P., V. L. Santucci, and S. G. Lucas. 2005b. Vertebrate trace fossils from Arizona with special reference to tracks preserved in National Park Service units and notes on the Phanerozoic distribution of fossil footprints. New Mexico Museum of Natural History and Science Bulletin 29:159–167. Available at: http://npshistory.com/publications/paleontology/nmmnhs-29-158.pdf (accessed May 2018).

Jenson, J. 1986. Stratigraphy and facies analysis of the upper Kaibab and lower Moenkopi formations in southwest Washington County, Utah. Geology Studies 33(1):21–43. Available at: http://geology.byu.edu/home/sites/default/files/geo-stud-vol-33-jenson.pdf (accessed May 2018).

Kenworthy, J. P., and V. L. Santucci. 2006. A preliminary investigation of National Park Service paleontological resources in cultural context: Part 1, general overview. New Mexico Museum of Natural History and Science Bulletin 34:70–76. Available at: https://www.nps.gov/subjects/fossils/upload/KENWORTHY_SANTUCCI_2006_NPS_FOSSILS_CULTURAL_CONTEXT.pdf (accessed May 2018).

Kirkland, P. L. 1963. Permian stratigraphy and stratigraphic paleontology of a part of the Colorado Plateau. Pages 80–100 *in* R. O. Bass and S. L. Sharps, editors. Shelf carbonates of the Paradox Basin. Four Corners Geological Society, Durango, Colorado. Field Conference Guidebook 4.

Kowalewski, M, M. G. Simoes, F. F. Torello, L. H. C. Mello, and R. P. Ghilardi. 2000. Drill holes in shells of Permian benthic invertebrates. Journal of Paleontology 74(3):532–543.

Lipinski, P. W. 1976. The gamma member of the Kaibab Formation (Permian) in northern Arizona. Thesis. University of Arizona, Tucson, Arizona. Available at: http://arizona.openrepository.com/arizona/bitstream/10150/555070/1/AZU_TD_BOX315_E9791_1976_333.pdf (accessed May 2018).

Mather, T. J. 1970. Stratigraphy and paleontology of Kaibab Formation (Permian), Mogollon Rim region, Arizona. Journal of Sedimentary Petrology 40(2):770–771.

McKee, E. D. 1935. A *Conularia* from the Permian of Arizona. Journal of Paleontology 9(5):427–429.

McKee, E. D. 1937. Triassic pebbles in northern Arizona containing invertebrate fossils. American Journal of Science 33(196):260–263.

McKee, E. D. 1938. The environment and history of the Toroweap and Kaibab formations of northern Arizona and southern Utah. Carnegie Institution of Washington Publication 492. Available at: https://catalog.hathitrust.org/Record/001639438 (accessed May 2018).

McKeever, P. J., and H. Haubold. 1996. Reclassification of vertebrate trackways from the Permian of Scotland and related forms from Arizona and Germany. Journal of Paleontology 70(6):1011–1022.

McKinney, F. K. 1983. Ectoprocta (Bryozoa) from the Permian Kaibab Formation, Grand Canyon National Park, Arizona. Fieldiana Geology 13. Available at: https://www.biodiversitylibrary.org/biblioselect/21597 (accessed May 2018).

Menzel, J. P., and W. W. Covington. 1997. Changes from 1876 to 1994 in a forest ecosystem near Walnut Canyon, northern Arizona. Pages 151–172 *in* C. van Riper, III and E. Deshler, editors. Proceedings of the Third Biennial Conference of Research on the Colorado Plateau. U.S. Department of the Interior, National Park Service, Washington, D.C. National Park Service Transactions and Proceedings Series NPS/NRNAU/NRTP-97/12.

Middleton, L. T., D. K. Elliott, and M. Morales. 1990. Coconino Sandstone. Pages 183–202 *in* S. S. Beus and M. Morales, editors. Grand Canyon geology. Oxford University Press, New York, New York.

Miller, E. F., and S. W. Blanchard. Undated (1927?). Cliff dwellings section on Walnut Creek Canyon, Coconino County, Arizona. In U.S. Geological Survey Examine and Report (E&R) collection.

Miller, A. K., and W. Youngquist. 1949. American Permian nautiloids. Geological Society of America, Boulder, Colorado. Memoir 41.

Murdock, L. 1994. Analysis of woodrat (*Neotoma*) middens found in Walnut Canyon, Coconino County, Arizona. Thesis. Northern Arizona University, Flagstaff, Arizona.

National Park Service, Geologic Resources Division. 2001. Summary of Flagstaff Area NPS Units GRI Meeting June 28-29th. National Park Service, Geologic Resources Division, Denver, Colorado. Available at: https://nature.nps.gov/geology/inventory_embed/publications/s_summaries/SUCR-WACA-WUPA_scoping_summary_20011130.pdf (accessed May 2018).

National Park Service. 2004. Digital geologic map of the greater Walnut Canyon National Monument area, Arizona (NPS, GRD, GRE, WACA). NPS Geologic Resources Inventory Program. Lakewood, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/1045893 (accessed May 2018).

Nicol, D. 1944. Paleoecology of three faunules in the Permian Kaibab Formation at Flagstaff, Arizona. Journal of Paleontology 18(6):553–557.

Nielson, R. L. 1991. Petrology, sedimentology and stratigraphic implications of the Rock Canyon Conglomerate, southwestern Utah. Utah Geological Survey, Salt Lake City, Utah. Miscellaneous Publication 91-7. Available at: https://ugspub.nr.utah.gov/publications/misc_pubs/MP-91-7.pdf (accessed May 2018).

Ort, M. H., M. D. Elson, K. C. Anderson, W. A. Duffield, J. A. Hooten, D. E. Champion, and G. Waring. 2008a. Effects of scoria-cone eruptions upon nearby human communities. Geological Society of America Bulletin 120(3–4):476–486.

Ort, M. H., M. D. Elson, K. C. Anderson, W. A. Duffield, and T. L. Samples. 2008b. Variable effects of cinder-cone eruptions on prehistoric agrarian human populations in the American southwest. Journal of Volcanology and Geothermal Research 176(3):363–376.

Pattison, H. M. 1947. The stratigraphy and paleontology of the Kaibab Formation at Walnut Canyon, Arizona. Thesis. Stanford University, Stanford, California.

Pattison, H. 1948. Life in an ancient Arizona sea. Plateau 21(1):1–6.

Ratkevich, R. P. 1979. Field guide to Arizona fossils. Dinograph Southwest, Incorporated, Alamogordo, New Mexico.

Raucci, J., N. Blythe, M. Ort, and M. Manone. 2003. Geologic map of the greater Walnut Canyon National Monument area. Unpublished digital map, Northern Arizona University, Flagstaff, Arizona. Scale 1:12,000.

Rawson, R. R., and C. E. Turner. 1974. The Toroweap Formation: a new look. Pages 155–190 *in* T. N. V. Karlstrom, G. A. Swann, and R. L. Eastwood, editors. Geology of northern Arizona, with notes on archaeology and paleoclimate. Geological Society of America, Rocky Mountain Section, Flagstaff, Arizona. Guidebook 27, Part 1, regional studies.

Rowlands, P. G., C. C. Avery, N. J. Brian, and H. Johnson. 1995a. Historical flow regimes and canyon bottom vegetation dynamics at Walnut Canyon National Monument, Arizona. NPS report. Available at: https://archive.org/details/historicalflowre00rowl (accessed May 2018).

Rowlands, P. G., H. G. Johnson, C. C. Avery, and N. J. Brian. 1995b. The effect of dewatering a stream on its riparian system: a case study from northern Arizona. Pages 11–23 *in* Proceedings of the 1995 Annual Meeting of the Hydrology Section of the Arizona Nevada Academy of Sciences, Flagstaff, Arizona. Available at: https://arizona.openrepository.com/bitstream/handle/10150/296467/hwr_22-25-011-023.pdf?sequence=1 (accessed May 2018).

Santucci, V. L., and A. L. Koch. 2003. Paleontological resource monitoring strategies for the National Park Service. Park Science 22(1):22–25. Available at: https://www.nature.nps.gov/parkscience/index.cfm?ArticleID=16 (accessed May 2018).

Santucci, V. L., and V. L. Santucci, Jr. 1999. An inventory of paleontological resources from Walnut Canyon National Monument, Arizona. Pages 118–120 *in* V. L. Santucci and L. McClelland, editors. National Park Service Paleontological Research 4. GRD Technical Report, NPS/NRGRD/GRDTR-99/03. Available at: http://npshistory.com/publications/waca/paleontological-resources.pdf (accessed May 2018).

Santucci, V. L., J. Kenworthy, and R. Kerbo. 2001. An inventory of paleontological resources associated with National Park Service caves. NPS Geological Resources Division, Denver, Colorado. Technical Report NPS/NRGRD/GRDTR-01/02. TIC# D-2231. Available at: https://www.nps.gov/subjects/caves/upload/cavepaleo.pdf (accessed May 2018).

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado. Available at: https://www.nps.gov/subjects/fossils/upload/geomon-08.pdf (accessed May 2018).

Shimer, H. W. 1919. Permo-Triassic of northwestern Arizona. Geological Society of America Bulletin 30:471–498. Available at: http://biodiversitylibrary.org/page/35911981 (accessed May 2018).

Shimer, H. W., and F. H. Shimer. 1910. The lithologic section of Walnut Canyon, Arizona, with relation to the cliff-dwellings of this and other regions of northwestern Arizona. American Anthropologist 12(2):237–249. Available at: https://books.google.com/books?id=s44nAQAAIAAJ&pg=PA237 (accessed May 2018).

Sorauf, J. E., and G. H. Billingsley. 1991. Members of the Toroweap and Kaibab Formations, Lower Permian, northern Arizona and southwestern Utah. The Mountain Geologist 28(1):9–24.

Spamer, E. E. 1992. The Grand Canyon fossil record: a source book in paleontology of the Grand Canyon and vicinity, northwestern Arizona and southeastern Nevada. Geological Society of America, Boulder, Colorado. Microform Publication 24.

Starkovich, B. M. 2011. Faunal Analysis of Walnut Canyon, Arizona. Stanley J. Olsen Laboratory of Zooarcheology, Arizona State Museum, and University of Arizona. Tucson, Arizona.

Tweet, J. S., V. L. Santucci, J. P. Kenworthy, and A. L. Mims. 2009. Paleontological resource inventory and monitoring—Southern Colorado Plateau Network. Natural Resource Technical Report NPS/NRPC/NRTR—2009/245. National Park Service, Fort Collins, Colorado.

Vandiver, V. W. 1936. Walnut Canyon geological report. Southwestern monuments special report 7. Available at: https://www.nps.gov/parkhistory/online_books/reports/southwest/sw_mon_rpt/smsr-7-0636.htm (accessed May 2018).

Additional References

Anderson, R. S., J. L. Betancourt, J. I. Mead, R. H. Hevly, and D. P. Adam. 2000. Middle-and late Wisconsin paleobotanic and paleoclimatic records from the southern Colorado Plateau, USA. Palaeogeography, Palaeoclimatology, Palaeoecology 155(1–2):31–57.

Baars, D. L. 1988. Chapter 4—Triassic and older stratigraphy: southern Rocky Mountains and Colorado Plateau. Pages 53–64 *in* L. L. Sloss, editor. Sedimentary cover—North American craton: U.S. In the collection: The Geology of North America. The Geological Society of America, Boulder, Colorado. D-2.

Betancourt, J. L. 1990. Late Quaternary biogeography of the Colorado Plateau. Pages 259–292 *in* J. L. Betancourt, T. R. Van Devender, and P. S. Martins, editors. Packrat middens: the last 40,000 years of biotic change. University of Arizona Press, Tucson, Arizona.

Betancourt, J. L., T. R. Van Devender, and P. S. Martins, editors. 1990. Packrat middens: the last 40,000 years of biotic change. University of Arizona Press, Tucson, Arizona.

DeCourten, F. L. 1978. *Scolecocoprus cameronensis* Brady (1947) from the Kaibab Limestone of northern Arizona: a re-interpretation. Journal of Paleontology 52(2):491–493.

DeCourten, F. L. 1980. The relationship between lithofacies and ichnofauna in shallow marine deposits of the Kaibab Formation, northern Arizona. Abstracts with Programs - Geological Society of America 12(7):410.

Elias, S. A. 1997. The Ice Age history of southwestern National Parks. Smithsonian Institution Press, Washington, D.C.

Hay, O. P. 1927. The Pleistocene of the western region of North America and its vertebrated animals. Carnegie Institute of Washington Publication 322B.

Ironside, K. 2006. Climate change research in National Parks: paleoecology, policy, and modeling the future. Thesis. Northern Arizona University, Flagstaff, Arizona.

Lindsay, E. and N. T. Tessman. 1974. Cenozoic vertebrate localities and faunas in Arizona. Journal of the Arizona Academy of Science 9(1):3–24.

Lucas, S. G. and G. S. Morgan. 2005. Pleistocene mammals of Arizona: an overview. New Mexico Museum of Natural History and Science Bulletin 29:153–158.

Mayor, A. 2005. Fossil legends of the first Americans. Princeton University Press, Princeton, New Jersey.

McKee, E. D. 1954. Stratigraphy and history of the Moenkopi Formation of Triassic age. Geological Society of America, Boulder, Colorado. Memoir 61.

Morales, M. 1993. Tetrapod biostratigraphy of the Lower-Middle Triassic Moenkopi Formation. New Mexico Museum of Natural History and Science Bulletin 3:355–356.

National Park Service. Museum of Northern Arizona Accession Record ledger for fossil specimen. Catalogue Number 407-444.

National Park Service. Museum of Northern Arizona Locality Data Sheets for specimen collected at MNA locality 60.

Nobel, D. G. 1991. Ancient ruins of the Southwest. Northland Publishing, Flagstaff, Arizona.

Pruss, S. B. and D. J. Bottjer. 2004. Early Triassic trace fossils of the western United States and their implications for prolonged environmental stress from the end-Permian mass extinction. Palaios 19(6):551–564.

Snow, J. I. 1945. Trilobites of the Middle Permian Kaibab Formation of northern Arizona. Plateau 18(2):17–24.

Stewart, J. H., F. G. Poole, R. F. Wilson, and R. A. Cadigan. 1972. Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region. U.S. Geological Survey, Washington, D.C. Professional Paper 691. Available at: https://pubs.er.usgs.gov/publication/pp691 (accessed May 2018).

Thornberry-Ehrlich, T. 2005. Sunset Crater Volcano National Monument Geologic Resource Evaluation Report. NPS Geologic Resources Division, Denver, CO. NPS/NRPC/GRD/NRR—2005/004. Available at: https://nature.nps.gov/geology/inventory_embed/publications/reports/sucr_gre_rpt_view.pdf (accessed May 2018).

Appendix A. WACA Locality Information

The 2017 field inventory resulted in 28 fossil site localities in WACA. Additional sites were found in the literature. Further information, including locality forms and condition evaluations, must be requested from the monument.

Appendix B. Paleontological Species List

The following table presents the taxa reported from the Kaibab Formation of WACA in stratigraphic context (Table 2). For ease in referring to the WACA literature, the older divisions of the Kaibab Formation are used. In ascending order, these are Kaibab gamma ("γ") , Kaibab beta ("β"), and Kaibab alpha ("α"). There is a column for each, as well as a column for reports that do not use a divided Kaibab Formation ("Kaibab undiv."). To translate to modern divisions, Kaibab gamma and beta are now included in the Fossil Mountain Member of the Kaibab Formation, and Kaibab alpha is the Harrisburg Member. The column "References" provides citations for the taxa, which can be found in "Literature Cited" above. Aside from providing context, the references are useful to know because taxonomic assignments frequently change, and the names in the oldest references are most likely to be different today. The column "Group" provides a quick visual reference to the higher-level classification of each taxon, with the numeric code as follows:

1. Porifera
2. Cnidaria
3. Bryozoa
4. Brachiopoda
5. Bivalvia
6. Cephalopoda
7. Gastropoda
8. Scaphopoda
9. Mollusca undetermined
10. Crinoidea
11. Echinoidea
12. Invertebrata undetermined
13. Ichnofossil

It is likely that some of the genera and species cited here are actually examples of different authors identifying the same forms using different names. Some of the taxa identified to the species level are now classified under different genera. However, most references to WACA fossils stop at genus or higher classifications. Faced with a choice between changing the handful of species-level entries while leaving the identified genera alone (and presumably at least some of them are also outdated), or using the original terminology for all taxa, it was decided to use the original terminology in this table. Current classifications (as of 2018) are listed after the table.

The taxa listed by Santucci and Santucci (1999) are listed separately at the end of this section. They are not included in the table, because their list is a composite for Walnut Canyon and the area, not the monument specifically, whereas the table is limited to taxa reported from localities that can be placed within WACA.

Table 2. Fossil taxa reported from the Kaibab Formation of WACA in stratigraphic context. References are provided where appropriate. MNA indicates fossil taxa housed at the Museum of Northern Arizona. Personal observation (pers. obs.) denotes fossil occurrences found during the 2017 field survey by Diana Boudreau.

Taxon	Group	Kaibab undiv.	γ	β	α	References
Sponge	1	Y	–	Y	–	Vandiver 1936, McKee 1938, Chronic 1983, Bezy 2003, Chronic and Chronic 2004
Conulariid	2	Y	–	–	–	MNA
Bryozoan	3	Y	–	Y	–	McKee 1938, Chronic and Chronic 2004
Chonetes sp.	4	Y	–	–	–	Pers. obs., MNA
Dictyoclostus sp.	4	Y	–	–	Y	Chronic 1952, Chronic 1983, pers. obs.
Peniculauris sp.	4	–	–	Y	–	Lipinski 1976
Productus bassi	4	–	–	Y	–	McKee 1938, MNA
Productus ivesii	4	Y	–	–	–	Frech 1893, Shimer 1919
Productus aff. *scabriculus*	4	Y	–	–	–	Frech 1893
Productus sp.	4	Y	–	–	–	Hughes 1893, Miller and Blanchard “1927”, Vandiver 1936
Cf. *Pustula nebrascensis*	4	Y	–	–	–	Shimer 1919
Spirifer (*Martinia*) *lineata*	4	Y	–	–	–	Frech 1893
Spirifer sp.	4	Y	–	–	–	Vandiver 1936
Wellerella sp.	4	–	–	–	Y	Chronic 1952
Brachiopod	4	Y	–	–	–	Bezy 2003, Chronic and Chronic 2004, Graham 2008, pers. obs., MNA
Astartella sp.	5	Y	–	–	Y	Chronic 1952, MNA
Aviculopecten sp.	5	Y	–	–	–	Miller and Blanchard “1927”, pers. obs.
Aviculopecten kaibabensis	5	Y	–	–	–	MNA
Kaibabella sp.	5	Y	–	–	–	pers. obs.
Mytiloid bivalve	5	Y	–	–	–	Hughes 1893
Nuculopsis sp.	5	Y	–	–	–	MNA
Palaeonucula sp.	5	–	–	–	Y	Chronic 1952
Parallelodon sp.	5	Y	–	–	–	MNA
Pinna sp.	5	Y	–	–	–	Shimer 1919
Pleurophorus sp.	5	Y	–	–	–	MNA
Pleurophorus albequus	5	–	–	–	Y	Chronic 1952
Pseudomonotis sp.	5	Y	–	–	–	MNA
Pteria sp.	5	Y	–	–	–	MNA
Schizodus sp.	5	Y	–	–	Y	Chronic 1952, MNA
Pectinid bivalve	5	Y	–	–	Y	Chronic 1952, pers. obs., MNA
Bivalve	5	Y	Y	Y	Y	Miller and Blanchard “1927”, McKee 1938, Chronic 1952, Chronic 1983, Chronic and Chronic 2004, pers. obs., MNA
Cephalopod	6	Y	–	–	–	Bezy 2003, pers. obs., MNA
Baylea capertoni	7	Y	–	–	–	MNA
Euomphalus pentangulatus	7	Y	–	–	–	pers. obs.

Taxon	Group	Kaibab undiv.	γ	β	α	References
Euphemus sp. or *Euomphalus* sp.	7	Y	Y	–	–	Lipinski 1976, pers. obs., MNA
Glabrocingulum laeviliratum	7	Y	–	–	–	pers. obs.
Murchisonia terebra	7	Y	–	–	–	Shimer 1919
Naticopsis sp.	7	Y	–	–	–	MNA
Pleurotomaria sp.	7	Y	–	Y	–	McKee 1938, pers. obs.
Bellerophontid gastropod	7	Y	–	–	Y	Chronic 1952, pers. obs., MNA
Spiral gastropod	7	Y	–	–	–	Chronic 1983, pers. obs., MNA
Gastropod	7	Y	Y	–	–	Miller and Blanchard "1927", McKee 1938, Chronic and Chronic 2004, pers. obs., MNA
Plagioglypta canna	8	Y	–	–	–	Pers. obs., MNA
Scaphopod	8	Y	–	–	Y	Chronic 1952, pers. obs., MNA
"Baculites" (scaphopod?)	9	Y	–	–	–	Miller and Blanchard "1927"
Mollusk	9	Y	Y	–	Y	McKee 1938, Chronic 1952, MNA
Crinoid	10	Y	–	Y	–	McKee 1938, pers. obs.
Archaeocidaris sp.	11	–	–	Y	–	McKee 1938
Echinoid	11	–	–	Y	–	Lipinski 1976
Unidentified invertebrate fossils	12	Y	Y	–	Y	Shimer and Shimer 1910, Miller and Blanchard "1927", Chronic 1952, Lipinski 1976, Chronic and Chronic 2004, MNA
Snail drill holes	13	Y	–	–	–	Pers. obs.
Invertebrate trace fossils	13	Y	–	Y	–	Lipinski 1976, pers. obs., MNA

Reassigned species:

- *Murchisonia terebra = Goniasma terebra*
- *Pleurophorus albequus = Permophorus albequus*
- *Productus bassi = Dictyoclostus bassi*, more recently *Peniculauris bassi*
- *Productus ivesii = Dictyoclostus ivesii*, more recently *Peniculauris ivesi*
- *Productus scabriculus = Buxtonia scabricula*
- *Pustula nebrascensis = Parajuresania nebrascensis*
- *Spirifer (Martinia) lineata = Martinia lineata*

Santucci and Santucci 1999

The composite taxa list in Santucci and Santucci (1999) is useful as a reference for fossils in the wider region. The list is reproduced below, reformatted with minor typographic changes.

Phylum Bryozoa

Unidentified fragmentary bryozoans, lower Harrisburg Member

Phylum Brachiopoda

Chonetes sp.
Composita arizonica
Dictyoclostus sp.
Marginifera sp.
Peniculauris bassi
Quadrochonetes kaibabensis
Rugatia paraindica

Phylum Mollusca

Class Pelecypoda

Allorisma sp.
Astartella sp.
Aviculopecten kaibabensis
Dozierella sp.
Edmondia sp.
Grammatodon politus
Janeia sp.
Kaibabella curvilenata
Myalina sp.
Myalinella adunca
Nuculana sp.
Nuculopsis sp.
Palaeonucula levatiformis
Parallelodon sp.
Permophorus albequus (incl. *Pleurophorus albequus*)
Schizodus texanus
Solemya sp.
Solenomorpha sp.

Class Cephalopoda

Aulametacoceras sp.
Metacoceras unklesbayi
Stearoceras sp.
Tainoceras sp.

Class Gastropoda

Baylea sp.
Bellerophon deflectus
Euomphalus sp.
Euphemites sp.
Goniasma sp.
Murchisonia sp.
Naticopsis sp.
Pernotrochus arizonensis
Soleniscus sp.

Busyconid gastropods

Class Scaphopoda

Plagioglypta canna

Phylum Annelida

Unidentified worm tubes on a specimen of the brachiopod *Marginifera*

Phylum Arthropoda

Class Trilobita

Anisopyge sp.

Ditomopyge sp.

Phylum Chordata

Class Chondrichthyes

A variety of shark teeth, including taxa such as *Deltodus*, *Orrodus*, *Petalodus*, *Sandalodus*, *Symmorium*, and phyllodont tooth plates (Gass 1963 is a particularly detailed reference on fish teeth from the Flagstaff area).

Appendix C: Outside Repositories of WACA Fossils

MUSEUM OF NORTHERN ARIZONA
3101 N Fort Valley Rd
Flagstaff, AZ 86001
928-774-5213
https://musnaz.org/

WESTERN ARCHEOLOGICAL AND CONSERVATION CENTER
255 N Commerce Park Loop
Tucson, AZ 85745
520-791-6400
https://www.nps.gov/orgs/1260/index.htm

Appendix D: Paleontological Resource Law and Policy

The following material is reproduced in large part from Henkel et al. (2015) (Henkel, C. J., W. P. Elder, V. L. Santucci, and E. C. Clites. 2015. Golden Gate National Recreation Area: Paleontological Resource Inventory. Natural Resource Report NPS/GOGA/NRR—2015/915. National Park Service, Fort Collins, Colorado.):

In March 2009, the Paleontological Resources Preservation Act (PRPA) (16 USC 460aaa) was signed into law (Public Law 111–11). This act defines paleontological resources as “any fossilized remains, traces, or imprints of organisms, preserved in or on the earth’s crust, that are of paleontological interest and that provide information about the history of life on earth.” The law stipulates that the Secretary of the Interior should manage and protect paleontological resources using scientific principles. The Secretary should also develop plans for “inventory, monitoring, and the scientific and educational use of paleontological resources.”

Paleontological resources are considered park resources and values that are subject to the “no impairment” standard in the National Park Service Organic Act (1916). In addition to the Organic Act, PRPA will serve as a primary authority for the management, protection and interpretation of paleontological resources. Their proper management and preservation should be considered by park resource managers whether or not fossil resources are specifically identified in the park’s enabling legislation.

The Paleontological Resources Management section of NPS Reference Manual 77 provides guidance on the implementation and continuation of paleontological resource management programs. Administrative options include those listed below:

No action—would mean that no action would be taken to collect the fossils as they erode from the strata. The fossils would be left to erode naturally and over time crumble away, or possibly be vandalized, either intentionally or unintentionally by visitors.

Surveys—will be set up to document potential fossil localities. All sites will be documented with the use of GPS and will be entered into the park GIS database. Associated stratigraphic and depositional environment information will be collected for each locality. A preliminary faunal list will be developed. Any evidence of poaching activity will be recorded. Rates of erosion will be estimated for the site and a monitoring schedule will be developed based upon this information. A NPS Paleontological Locality Database Form will also be completed for each locality.

Monitoring—would mean that fossil-rich areas would be examined periodically to determine if conditions have changed to such an extent that additional management actions are warranted. Photographic records should be kept so that changes can be more easily ascertained.

Cyclic prospecting—would mean that areas of high erosion which also have a high potential for producing significant specimens should be examined periodically for new sites. The periodicity of such cyclic prospecting will depend on the abundance of fossils and the rate of sediment erosion.

Stabilization and reburial—would mean that significant specimens which cannot be immediately collected may be stabilized using appropriate consolidants and reburied. Reburial slows down but does not stop the destruction of a fossil by erosion. Therefore, this method would be used only as an interim and temporary stop-gap measure.

Shelter construction—means that fossil sites or specimens which could be exhibited in situ will require protective shelters to protect them from the natural forces of erosion. The use of shelters will likely draw attention to the fossils and increase the risk of vandalism or theft, but also provide an opportunity for interpretation and education.

Excavation—means the partial or complete removal of any or all fossils present on the surface and potentially the removal of specimens still beneath the surface which have not been exposed by erosion.

Closure—means that the area containing fossils may be temporarily or permanently closed to the public to protect the fossil resources. Fossil-rich areas may be closed to the public unless accompanied by an interpretive ranger on a guided hike.

Patrols—may be increased in areas of known fossil resources. Patrols can prevent and/or reduce theft and vandalism. The scientific community and the public expect the NPS to protect its paleontological resources from vandalism and theft.

Alarm systems/electronic surveillance—seismic monitoring systems can be installed to alert rangers of disturbances to sensitive paleontological sites. Once the alarm is engaged, a ranger can be dispatched to investigate. Motion-activated cameras may also be mounted to visually document human activity in areas of vulnerable paleontological sites.

National Park Service Management Policies (2006; Section 4.8.2.1) also require that paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. In 2010, in cooperation with many partners, the National Park Service founded National Fossil Day, a celebration organized to promote public awareness and stewardship of fossils, as well as to foster a greater appreciation of their scientific and educational value (https://www.nps.gov/subjects/fossilday/index.htm).

Related Laws, Legislation, and Management Guidelines

National Park Service Organic Act

The NPS Organic Act directs the NPS to manage units "to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner as will leave them unimpaired for the enjoyment of future generations." (16 U.S.C. § 1). Congress reiterated this mandate in the Redwood National Park Expansion Act of 1978 by stating that the NPS must conduct its actions in a manner that will ensure no "derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress." (16 U.S.C. § 1 a-1). The Organic Act prohibits actions that permanently impair park resources unless a law directly and specifically allows for the acts. An action constitutes an impairment when its impacts "harm the integrity of park resources or values, including the opportunities that otherwise would be present for the enjoyment of those resources and values." (Management Policies 2006 1.4.3).

NPS Management Policies 2006

NPS Management Policies 2006 include direction for preserving and protecting cultural resources, natural resources, processes, systems, and values (NPS 2006). It is the goal of the NPS to avoid or minimize potential impacts to resources to the greatest extent practicable consistent with the management policies.

<u>Paleontological Resources Protection Act (P.L. 111-011, Omnibus Public Land Management Act of 2009, Subtitle D)</u>

Section SEC. 6302 states, "The Secretary (of the Interior) shall manage and protect paleontological resources on Federal land using scientific principles and expertise. The Secretary shall develop appropriate plans for inventory, monitoring, and the scientific and educational use of paleontological resources, in accordance with applicable agency laws, regulations, and policies. These plans shall emphasize interagency coordination and collaborative efforts where possible with non-Federal partners, the scientific community, and the general public."

<u>NPS Director's Order-77, Paleontological Resources Management</u>

DO-77 describes fossils as non-renewable resources and identifies the two major types, body fossils and trace fossils. It describes the need for managers to identify potential paleontological resources using literature and collection surveys, identify areas with potential for significant paleontological resources, and conduct paleontological surveys (inventory). It also describes appropriate actions for managing paleontological resources including: no action, monitoring, cyclic prospecting, stabilization and reburial, construction of protective structures, excavation, area closures, patrols, and the need to maintain confidentiality of sensitive location information.

Excerpt from: Clites, E. C. and V. L. Santucci. 2012. Protocols for paleontological resource site monitoring at Zion National Park. Natural Resource Report NPS/ZION/NRR—2012/595. National Park Service, Fort Collins, Colorado.

<u>Monitoring</u>

An important aspect of paleontological resource management is establishing a long-term paleontological resource monitoring program. National Park Service paleontological resource monitoring strategies were developed by Santucci et al. (2009). The park's monitoring program should incorporate the measurement and evaluation of the factors stated below.

Climatological Data Assessments

These assessments include measurements of factors such as annual and storm precipitation, freeze/thaw index (number of 24-hour periods per year where temperature fluctuates above and below 32 degrees Fahrenheit), relative humidity, and peak hourly wind speeds.

Rates of Erosion Studies

These studies require evaluation of lithology, slope degree, percent vegetation cover, and rates of denudation around established benchmarks.

Assessment of Human Activities, Behaviors, and Other Variables

These assessments involve determining access/proximity of paleontological resources to visitor use areas, annual visitor use, documented cases of theft/ vandalism, commercial market value of the fossils, and amount of published material on the fossils.

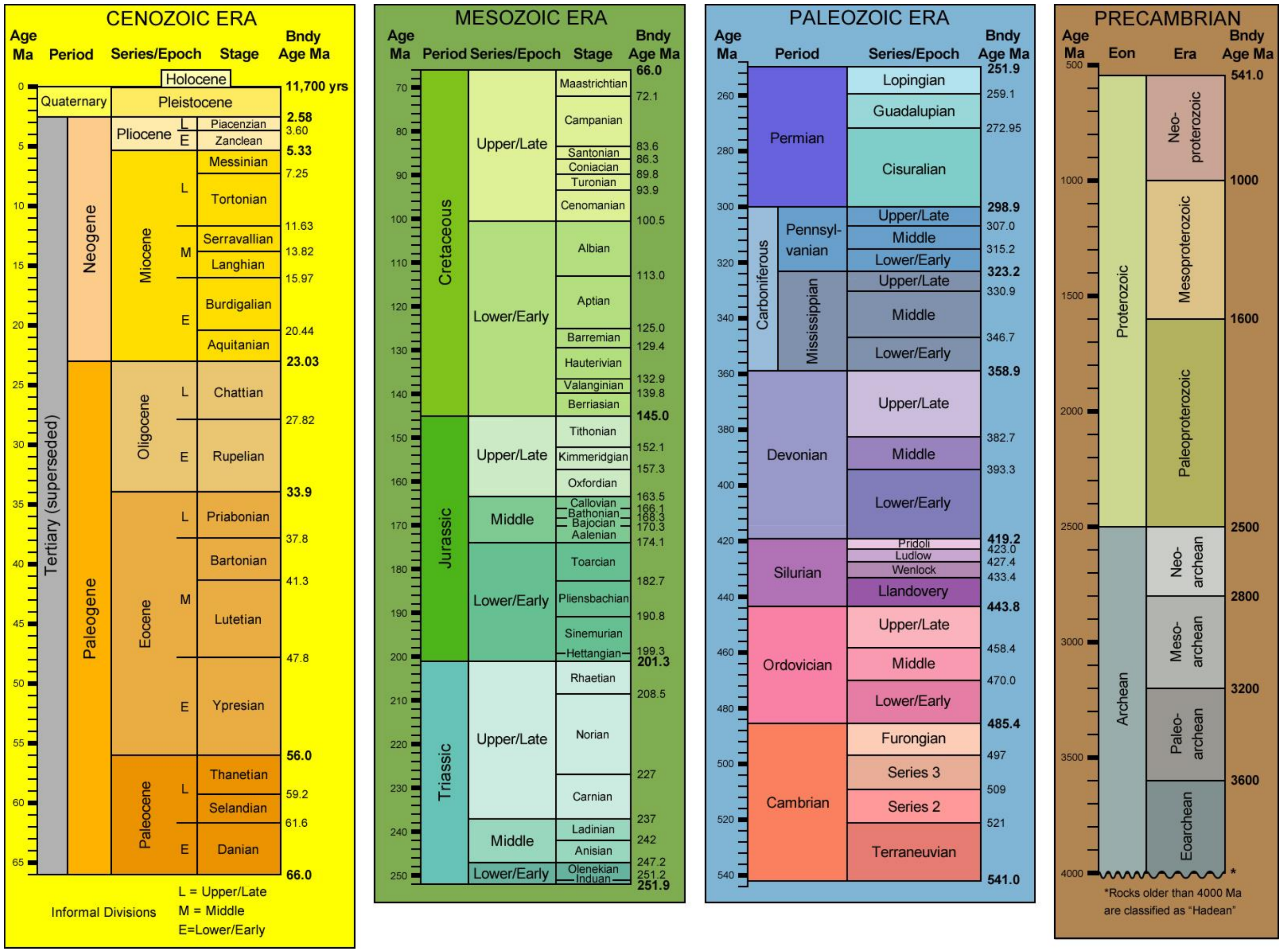
Condition Assessment and Cyclic Prospecting

These monitoring methods entail visits to the locality to observe physical changes in the rocks and fossils, including the number of specimens lost and gained at the surface exposure. Paleontological prospecting would be especially beneficial during construction projects or road repair.

Periodic Photographic Monitoring

Maintaining photographic archives and continuing to photo-document fossil localities from established photo-points enables visual comparison of long-term changes in site variables.

Appendix E: Geologic Time Scale



Ma=Millions of year old. **Bndy Age**=Boundary Age. Colors are standard USGS colors for geologic maps. Modified from 1999 Geological Society of America Timescale (https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf). Dates and additional information from International Commission on Stratigraphy update 2017/02 (http://www.stratigraphy.org/index.php/ics-chart-timescale) and USGS Fact Sheet 2007-3015 (https://pubs.usgs.gov/fs/2007/3015/).

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National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525