National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Yucca House National Monument

Paleontological Resource Inventory (Public Version)

Natural Resource Report NPS/YUHO/NRR—2022/2392

ON THE COVER

Prionocyclus wyomingensis, an ammonite in the Cretaceous Juana Lopez Member of the Mancos Shale in Yucca House National Monument. Specimen YUHO 97 in the paleontology collections at Mesa Verde National Park Visitor and Research Center. NPS / VICTORIA CRYSTAL

Yucca House National Monument

Paleontological Resource Inventory (Public Version)

Natural Resource Report NPS/YUHO/NRR—2022/2392

Victoria F. Crystal,[1] Justin S. Tweet,[2] and Vincent L. Santucci[3]

[1]National Park Service
Geologic Resources Division
Post Office Box 25287
Denver, CO 80225

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

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

May 2022

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible and technically accurate.

This report is available in digital format from the Southern Colorado Plateau Inventory and Monitoring Network website and the Natural Resource Publications Management website. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Crystal, V. F., J. S. Tweet, and V. L. Santucci. 2022. Yucca House National Monument: Paleontological resource inventory (public version). Natural Resource Report NPS/YUHO/NRR—2022/2392. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/nrr-2293617.

NPS 318/180509, May 2022

Contents

Contents (continued)

Contents (continued)

Figures

Page

Figures (continued)

Page

Tables

Page

Appendices

Page

Executive Summary

Yucca House National Monument (YUHO) in southwestern Colorado protects unexcavated archeological structures that were constructed by the Ancestral Puebloan people between 1050 and 1300 CE. It was established by Woodrow Wilson by presidential proclamation in 1919 and named "Yucca House" by archeologist Jesse Fewkes as a reference to the names used for this area by the local Ute, Tewa Pueblo, and other Native groups. It was originally only 3.9 ha (9.6 ac) of land, but in 1990, an additional 9.7 ha (24 ac) of land was donated by Hallie Ismay, allowing for the protection of additional archeological resources. Another acquisition of new land is currently underway, which will allow for the protection of even more archeological sites. The archeological resources at YUHO remain unexcavated to preserve the integrity of the structures and provide opportunities for future generations of scientists.

One of the factors that contributed to the Ancestral Puebloans settling in the area was the presence of natural springs. These springs likely provided enough water to sustain the population, and the Ancestral Puebloans built structures around one of the larger springs, Aztec Spring. Yet, geologic features and processes were shaping the area of southwest Colorado long before the Ancestral Puebloans constructed their dwellings.

The geologic history of YUHO spans millions of years. The oldest geologic unit exposed in the monument is the Late Cretaceous Juana Lopez Member of the Mancos Shale. During the deposition of the Mancos Shale, southwestern Colorado was at the bottom of an inland seaway. Beginning about 100 million years ago, sea level rose and flooded the interior of North America, creating the Western Interior Seaway, which hosted a thriving marine ecosystem. The fossiliferous Juana Lopez Member preserves this marine environment, including the organisms that inhabited it.

The Juana Lopez Member has yielded a variety of marine fossils, including clams, oysters, ammonites, and vertebrates from within YUHO and the surrounding area. There are four species of fossil bivalves (the group including clams and oysters) found within YUHO: *Cameleolopha lugubris*, *Inoceramus dimidius*, *Inoceramus perplexus*, and *Pycnodonte* sp. or *Rhynchostreon* sp. There are six species of ammonites in three genera found within YUHO: *Baculites undulatus*, *Baculites yokoyamai*, *Prionocyclus novimexicanus*, *Prionocyclus wyomingensis*, *Scaphites warreni*, and *Scaphites whitfieldi*. There is one unidentifiable vertebrate bone that has been found in YUHO.

Fossils within YUHO were first noticed in 1875–1876 by W. H. Holmes, who observed fossils within the building stones of the Ancestral Puebloans' structures. Nearly half of the building stones in the archeological structures at YUHO are fossiliferous slabs of the Juana Lopez Member. There are outcrops of the Juana Lopez 0.8 km (0.5 mi) to the west of the structures, and it is hypothesized that the Ancestral Puebloans collected the building stones from these or other nearby outcrops.

Following the initial observation of fossils, very little paleontology work has been done in the monument. There has only been one study focused on the paleontology and geology of YUHO, which was prepared by paleontologist Mary Griffitts in 2001. As such, this paleontological resource inventory report serves to provide information to YUHO staff for use in formulating management

activities and procedures associated with the paleontological resources. In 2021, a paleontological survey of YUHO was conducted to revisit previously known fossiliferous sites, document new fossil localities, and assess collections of YUHO fossils housed at the Mesa Verde National Park Visitor and Research Center. Notable discoveries made during this survey include: several fossils of *Cameleolopha lugubris*, which had not previously been found within YUHO; and a fossil of *Pycnodonte* sp. or *Rhynchostreon* sp. that was previously unknown from within YUHO.

Acknowledgments

We would like to thank the staff members at Yucca House National Monument and Mesa Verde National Park for their assistance with this project. Thanks to Samuel Denman, Museum Technician; Paul Morey, Program Manager; Andrew Spear, Air Quality and Physical Science Technician; Tova Spector, Chief of Natural Resources; and Dr. Tara Travis, Supervisory Museum Curator. This report would not have been possible without their guidance and support. A special thanks to Samuel Denman and Dr. Travis for access to the YUHO collection and records.

Additional thanks to Joseph Crystal for assistance in the field; Andrea Blaser (University of Michigan Museum of Anthropological Archaeology) for background information and discussions about the history of the Southwest; Will Elder (Golden Gate National Recreation Area) for discussions on Western Interior Seaway mollusks; Gay Ives (Mesa Verde National Park) for correspondence regarding tribal consultations; Talia Karim (University of Colorado Boulder) for information about the collections of the University of Colorado Museum of Natural History; Kristy Sholly (Mesa Verde National Park) for discussions on interpretation at YUHO; and Trista Thornberry-Ehrlich (Colorado State University, Geologic Resources Inventory) for assistance with graphics.

The continued valuable support and information provided by additional NPS Geologic Resources Division staff, including Jason Kenworthy, Tim Connors, and Hal Pranger, is greatly appreciated. This report would not have been possible without funding from the NPS Geologic Resources Division and the opportunities available through the Scientists in Parks (SIP) program and partnerships with Conservation Legacy and the Geologic Society of America.

Finally, we would like to thank Jim Kirkland (Utah Geological Survey) and Phil Varela (Petrified Forest National Park) for peer reviews, Don Weeks (Intermountain Region) for coordinating the peer review, Andrew Spear for internal park review, Rebecca Port (NPS Geologic Resources Division) for initial review and copy-edit, and Tim Connors (NPS Geologic Resources Division) for a final program review. Their insights helped improve the final publication.

Dedication

We dedicate this report to the Indigenous peoples of the American Southwest, past and present. The region has a long, rich human history, beginning long before Europeans or Americans of European descent arrived in the area.

It is important to acknowledge that long prior to the establishment of the National Park Service units in this area, the Ancestral Puebloans and their descendants inhabited the land. It is an honor to be able to conduct this paleontological resource inventory on this land.

The Ancestral Puebloan people were the first inhabitants of the land that is now Yucca House National Monument and the first people to form a connection to the monument's paleontological resources. They first settled in the southwest region of Colorado in 550 CE, and in the land that is now the monument in 1050 CE. Many generations of Ancestral Puebloans cared for and developed the land. They established thriving communities and built villages and dwellings. In the process of doing so, they were the first to discover the region's paleontological resources. At Yucca House National Monument, Ancestral Puebloans used fossiliferous building stones in the construction of their dwellings. The nearest outcrop of fossiliferous rock is approximately 0.8 km (0.5 mi) west of their buildings; presumably the Ancestral Puebloans deemed this rock important enough to collect and transport blocks of it to use as building materials. The majority of the building stones are these fossiliferous rocks. This is an example of paleontological resources in a cultural context, which is recognized in many National Park Service units.

Both National Park Service units in the area, Yucca House National Monument and Mesa Verde National Park, were established to protect the dwellings built by the Ancestral Puebloans. Both units also have a wealth of paleontological resources. Because of the Ancestral Puebloans' presence in these park units, we (the National Park Service) are able to protect and preserve fossils that might otherwise have been lost had they not settled here. They and their descendants were the first stewards of the land and resources.

Today, there are many native groups or tribes with traditional associations with Yucca House National Monument: Hopi Tribe of Arizona; Jicarilla Apache Nation, New Mexico; Kewa Pueblo, New Mexico (formerly the Pueblo of Santo Domingo); Navajo Nation, Arizona, New Mexico and Utah; Ohkay Owingeh, New Mexico (formerly the Pueblo of San Juan); Pueblo of Acoma, New Mexico; Pueblo of Cochiti, New Mexico; Pueblo of Isleta, New Mexico; Pueblo of Jemez, New Mexico; Pueblo of Laguna, New Mexico; Pueblo of Nambé, New Mexico; Pueblo of Picuris, New Mexico; Pueblo of Pojoaque, New Mexico; Pueblo of San Felipe, New Mexico; Pueblo of San Ildefonso, New Mexico; Pueblo of Sandia, New Mexico; Pueblo of Santa Ana, New Mexico; Pueblo of Santa Clara, New Mexico; Pueblo of Taos, New Mexico; Pueblo of Tesuque, New Mexico; Pueblo of Zia, New Mexico; Southern Ute Indian Tribe of the Southern Ute Reservation, Colorado; Ute Indian Tribe of the Uintah and Ouray Reservation, Utah; Ute Mountain Tribe of the Ute Mountain Reservation, Colorado, New Mexico and Utah; Ysleta Del Sur Pueblo of Texas; and Zuni Tribe of the Zuni Reservation, New Mexico.

Introduction

Yucca House National Monument (YUHO) is located in the southwestern corner of Colorado on the eastern slope of Sleeping Ute Mountain in Montezuma County. It is approximately 16 km (10 mi) west of Mesa Verde National Park (MEVE) and is under the management of the MEVE staff. Located within the Colorado Plateau region, YUHO sits at approximately 1,800 m (5,800 ft) above sea level, with an arid climate and plant communities dominated by big sage and piñon–juniper (Rink and Cully 2007). The monument was established in 1919 by a presidential proclamation from Woodrow Wilson to protect the unexcavated archeological structures constructed by the Ancestral Puebloan people dating from the 13th century (National Park Service 2015). It originally encompassed only 3.9 ha (9.6 acres) of land deeded to the federal government on July 2, 1919 by Henry Van Kleeck at the behest of archeologist Jesse Fewkes (National Park Service undated). Fewkes gave the monument the name "Yucca House" as a reference to the names used for this area by the local Ute, Tewa Pueblo, and other Native groups. In May 1990, 9.7 ha (24 acres) of the surrounding land was donated by Hallie Ismay, thus enabling protection of additional archeological sites, and bringing the total area of YUHO to 13.6 ha (33.6 acres; Glowacki and Blackburn 2019).

Another boundary expansion that is currently underway (Figure 1) will add approximately 65 ha (160 acres) of land to YUHO. The parcel will be acquired from Bernard and Nancy Karwick sometime in late 2021 or 2022 (A. Spear, MEVE air quality and physical science technician, pers. comm., 25 May 2021). The addition of this land, here referred to as the Karwick parcel, will protect and preserve at least ten additional archeological sites (McBride and McBride 2014).

Ancestral Puebloans occupied the land within YUHO from 1050–1150 CE and 1225–1300 CE (National Park Service 2015). The archeological sites at YUHO are remnants of their occupation of the area and consist of a multistory stone masonry pueblo that includes a well-preserved Great House (a large, multistory Ancestral Puebloan structure; see Appendix F for a glossary), multiple towers in small plazas, a bi-wall structure, many kivas, and a well-delineated ceremonial plaza containing a great kiva, partially enclosed by an imposing wall just to the north (National Park Service 2015). There are two major complexes of archeological sites—the Western Complex, which has more than 600 rooms and 100 kivas, and the Lower House, which has at least eight rooms and a great kiva (National Park Service undated). These sites remain largely unexcavated, preserving the integrity of the structures and providing research opportunities for future generations of archeologists.

The long human history of the area has been shaped and influenced by the dynamic geologic features and processes present in the region. The Ancestral Puebloans likely settled at YUHO because of the presence of natural springs, particularly the larger Aztec Spring, situated in the center of the Western Complex (National Park Service undated). Though the springs currently have very low flows, indicated by the presence of a small wetland, at the time the Ancestral Puebloans occupied the area, the springs must have been prolific enough to sustain the population and were most likely a contributing reason to the Ancestral Puebloans' decision to settle in the area (National Park Service undated; Thornberry-Ehrlich 2013).

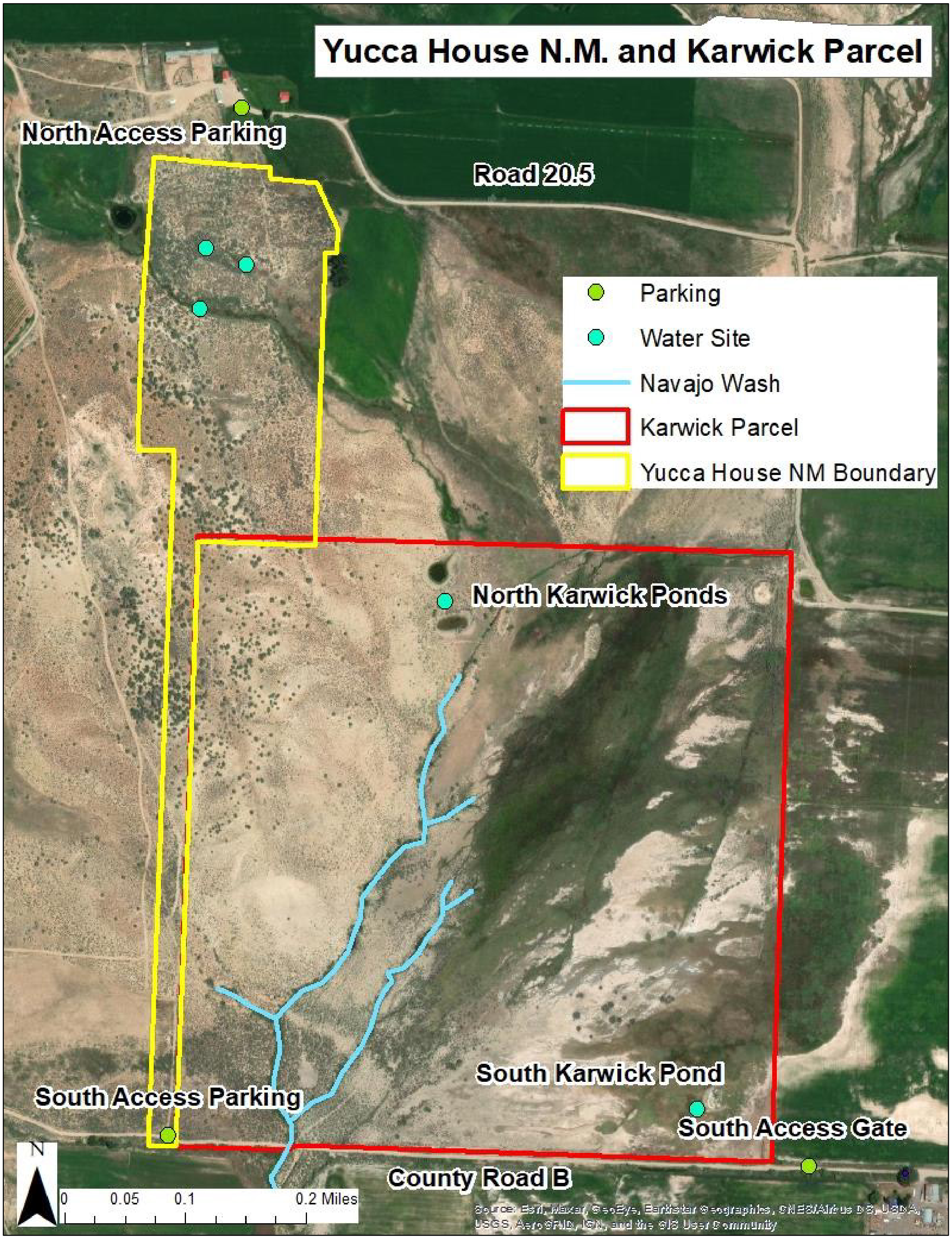


Figure 1. Map of Yucca House National Monument with notable features marked (NPS/ANDREW SPEAR). Original NPS boundary and Karwick parcel boundary expansion are indicated by yellow and red lines, respectively.

Yet, the geologic features and processes in the region influenced life long before human habitation. Millions of years ago—well before humans occupied the area—communities of ancient organisms thrived. This multimillion-year history of geology and life is recorded in the rock units, including fossils, that underlie the national monument; thus, although the monument is known for is archeological resources, it has rich paleontological resources as well.

This report provides detailed information on the paleontological resources of YUHO, including the history of paleontological work on the lands now within the park, geologic units, taxonomic groups, localities, museum collections, research, interpretation, and management and protection. In addition to the main body of text, there are seven appendices: Appendix A, a table of paleontological species; Appendix B, museum collections data; Appendix C, repository contact information; Appendix D, paleontological resource law and policy; Appendix E, paleontological locality data; Appendix F, a glossary; and Appendix G, a geologic time scale.

Significance of Paleontological Resources at YUHO

The main bedrock unit (see Appendix F for a glossary) at YUHO is the fossiliferous Mancos Shale, which was deposited during a time when the region looked much different than it does today (Elder and Kirkland 1993, 1994; Leckie et al. 1997). Today, YUHO sits at approximately 1,800 m (5,800 ft) above sea level in the Colorado Plateau, but 90 million years ago, during the Cretaceous Period, the area was submerged by the Western Interior Seaway which hosted a variety of marine invertebrates (Elder and Kirkland 1993, 1994; West et al. 1998). The three members of the Mancos Shale present at YUHO and in its vicinity record fluctuations of the Western Interior Seaway and preserve some of the organisms that existed during deposition (Leckie et al. 1997; West et al. 1998; Corbett and Watkins 2014). Very little paleontological work has been done at YUHO, but there is a small collection of fossils from YUHO and the surrounding area that is housed at the MEVE Visitor and Research Center.

The Juana Lopez Member of the Mancos Shale is the only rock unit within YUHO that has currently yielded fossils (Griffitts 2001), and the majority of the fossils in the YUHO collection at the MEVE Visitor and Research Center are from the Juana Lopez Member (MEVE unpublished records). The Montezuma Valley and Smoky Hill Members, which are the bedrock units present in the Karwick parcel, have yielded fossils in other locations outside of the monument, but fossils from these units have not yet been documented within YUHO (MEVE unpublished records; Leckie et al. 1997; Mereweather et al. 2006; Walaszczyk and Cobban 2006; Harrison et al. 2017). However, there are several fossils that were collected from the Smoky Hill Member within the vicinity of YUHO that are reposited in the YUHO fossil collection.

Natural molds and casts, recrystallized original shells, and bioclastic debris of invertebrate shells from the Juana Lopez Member are common, including those of bivalves such as inoceramid clams and oysters and ammonite cephalopods. These fossils generally occur in well-cemented calcarenite layers and are commonly found in the monument within fossiliferous slabs that range in size from a few cm across to ~30 cm across (approximately 1 to 12 in) (Leckie et al. 1997; Figure 2). Many of these fossiliferous slabs were used as building materials by the Ancestral Puebloans, who likely collected the slabs from nearby outcrops, the closest of which are 0.8 km (0.5 mi) west of the structures they built (Glowacki 2001; Griffitts 2001). This is an example of fossils in a cultural resource context, illustrating the interconnectedness of geologic history and human history.

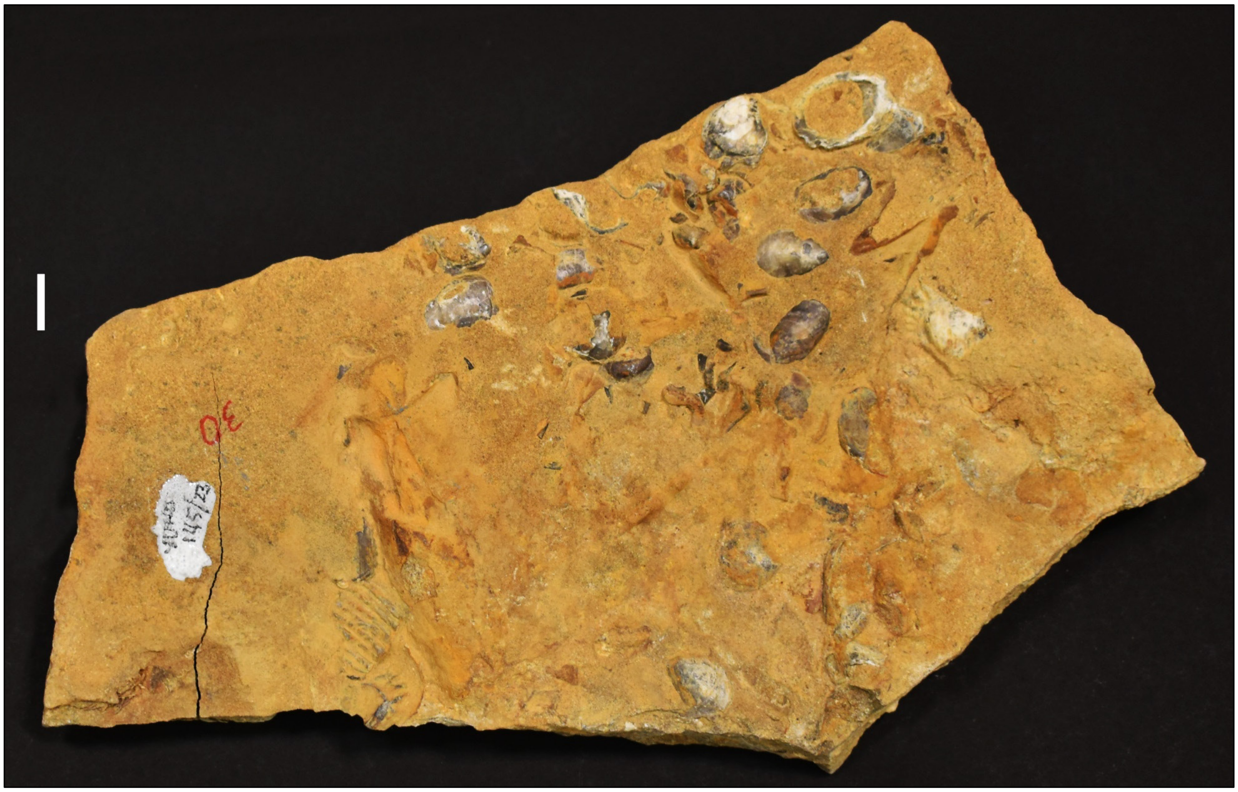


Figure 2. YUHO 145 (specimen catalog number in the collection at the MEVE Visitor and Research Center), an example of the densely fossiliferous slabs of the Juana Lopez calcarenite (NPS/VICTORIA CRYSTAL). Scale bar is 1 cm (0.4 in).

The fossiliferous slabs are primarily found as piles of building blocks that have eroded out of the prehistoric structures and are thus not in situ geologically. Because the structures are all buried, it is rare to find building blocks still in situ archeologically, but Figure 3 shows a rare example of visible fossiliferous slabs in situ. Some fossiliferous slabs found on the surface may also have naturally eroded out of the outcrops to the west of the monument and been transported via intermittent flows of water on the surface.

Following the deposition of the Mancos Shale during the Late Cretaceous, the Western Interior Seaway receded (Elder and Kirkland 1994). Because the Mancos Shale is overlain by Quaternary surficial deposits of the last 2.5 million years, any rocks or sediments that may have been deposited between these units must have since been eroded away (Thornberry-Ehrlich 2013). The recent surficial deposits indicate that the active erosional processes occurring in YUHO today are intermittent sheet flows and stream channels that are eroding and transporting sediment from Sleeping Ute Mountain to the west and depositing it within YUHO (Thornberry-Ehrlich 2013). The active erosional processes contribute to the exhumation and transportation of fossils.

Figure 3. Fossiliferous slabs in situ archeologically (NPS/VICTORIA CRYSTAL). The image shows the top of a wall (looking down at it) with fossiliferous slabs of Juana Lopez calcarenite as building stones. The arrow annotation is pointing to an ammonite fossil in one of the slabs. Scale bar is 15 cm (6 in).

Purpose and Need

The National Park Service (NPS) is required to manage its lands and resources in accordance with federal laws, regulations, management policies, guidelines, and scientific principles. Those authorities and guidance directly applicable to paleontological resources are cited below in "Paleontological Resource Management and Protection" and Appendix D. Paleontological resource inventories have been developed by the NPS in order to compile information regarding the scope, significance, distribution, and management issues associated with fossil resources present within parks. This information is intended to increase awareness of park fossils and paleontological issues in order to inform management decisions and actions that comply with these laws, directives, and policies. Options for paleontological resource management are locality-specific, and may include no action, surveys, site monitoring, cyclic prospecting, stabilization and reburial, shelter construction, excavation, closure, patrols, and alarm systems or electronic surveillance. See Appendix D for additional information on applicable laws and legislation.

Project Objectives

This park-focused paleontological resource inventory project was initiated to provide information to YUHO staff for use in formulating management activities and procedures that would enable compliance with related laws, regulations, policy, and management guidelines. Additionally, this project will facilitate future research, proper curation of specimens, and resource management practices associated with the paleontological resources at YUHO. The objectives of the paleontological resource inventory project include:

- Determining the scope, significance, distribution, and management issues associated with fossil resources present within YUHO.
- Locating, identifying, and documenting paleontological resource localities through field reconnaissance and perusal of archives using photography, GPS data, and standardized forms.
- Relocating and assessing previously documented paleontological localities.
- Assessing collections of YUHO fossils maintained within park collections and in outside repositories.
- Documenting current information on faunal assemblages and paleoecological reconstructions.
- Consulting park staff to gather information on the current status of paleontological resources, to aid in formulating plans for management, ideas for interpretation, and recommendations for future planning and actions.
- Conducting a thorough search for relevant publications, unpublished geologic notes, and outside repositories of fossil collections from YUHO.
- Develop recommendations for future paleontology-focused projects or activities supporting science and stewardship of YUHO fossils.

History of Paleontological Work at YUHO

The primary resources at YUHO and neighboring MEVE are cultural resources—mainly the prehistoric structures built by the Ancestral Puebloans. As such, most of the previous work in the area has been focused on the archeology, and the fossils have received limited attention. The handful of geological and paleontological studies undertaken in the area have focused on MEVE, which is larger, better known, and receives more visitors than YUHO. As a result, there have been very few studies focused on YUHO geology and paleontology. The significant references for YUHO's paleontology include Gould (1939), Ekren and Houser (1965), Griffitts (2001), Scott et al. (2001), and Tweet et al. (2009).

The earliest geological work at YUHO was conducted by W. H. Jackson and W.H. Holmes of the Hayden Survey in the 1870s (Holmes 1878; Gould 1939). The first mention of fossils at YUHO was by W.H. Holmes in 1878, in which he reported on his time in the area for the United States Geological Survey (USGS). He described the prehistoric mounds at YUHO, which was then called "Aztec Spring," in detail and included sketches (Holmes 1878). His mention of the paleontology focused on briefly describing the fossiliferous nature of the building stones used to construct the prehistoric structures. Noting the fossils present in them, he remarked on the distance—approximately 0.8 km (0.5 mi)—the builders must have transported the stones from the nearest outcrops in the area (Griffitts 2001). Holmes was also the first to describe the geology at neighboring MEVE, which he recognized as the shales/mudstones and limestones of the Mancos Shale (also present at YUHO), though he referred to it as the "Colorado Group," as it was referred to then (Harrison et al. 2017). It was later renamed the Mancos Shale, and the principal reference section was described at MEVE (Leckie et al. 1997).

Following Holmes, the next mention of YUHO geology or paleontology in the published literature was by J. Walter Fewkes in 1919. However, this report, in Bulletin 70 of the Bureau of American Ethnology, only focused on describing the prehistoric structures (Fewkes 1919).

The next mention of the geology and paleontology of the area was not until 1939, when Chas. N. Gould, regional geologist for then-Region 3 of the NPS, published a brief geological report of YUHO (Gould 1939). He conducted a detailed geological and paleontological survey of the area, accompanied by then-Assistant Director Bryant, Dr. W.B. McDougall of the NPS regional office in Santa Fe, New Mexico, and MEVE Naturalist Watson (Gould 1939). The report described the regional geology, recognizing the major rock units present in the area including the Mancos Shale and fossiliferous building blocks. Gould also described the major fossil groups present in the monument, though the terminology he used is now outdated and identified genera other than those present in the monument. Nonetheless, he correctly identified that the fossils at YUHO are various bivalves and cephalopods.

In 1965, Ekren and Houser published a comprehensive report focused on the igneous laccoliths of the Ute Mountains area, about 6 km (10 mi) northwest of YUHO. Though the report focused on describing the igneous rock and did not conduct any work at YUHO, the authors did provide a detailed description of members of the Mancos Shale that are also present at YUHO. They measured a section about 6 km (10 mi) southwest of YUHO that included a detailed lithological description of the Juana Lopez Member, the main bedrock unit underlying YUHO. They noted the presence of fossils but did not conduct a comprehensive paleontological analysis. They did identify *Inoceramus perplexus* and *Inoceramus dimidius*, both bivalves, and the ammonite *Prionocyclus wyomingensis*, as well as one taxon not yet documented at YUHO—a tooth from *Ptychodus whipplei*, a large mollusk-eating shark (Hamm 2020).

The most comprehensive work on the geology and paleontology of YUHO was conducted by paleontologist Mary Griffitts. She spent the majority of her career focused on the paleontology of the greater MEVE area. She was the first woman to receive a PhD in geology from the University of Colorado in 1944. Her dissertation research focused on the geology and paleontology of the MEVE area (Harrison et al. 2017). She returned to work in the area again in the 1980s. Throughout her time in the area, she collected hundreds of fossils from both MEVE and YUHO that are now housed in the collections at the MEVE Visitor and Research Center. Additionally, she wrote many reports and books about the geology and paleontology of the region, one of which (Griffitts 2001) focuses entirely on YUHO.

Griffitts (2001) is the only publication devoted entirely to geology and paleontology at YUHO, and the only publication to formally describe the fossils present at YUHO. In the 1980s and 1990s, Griffitts conducted extensive fieldwork in YUHO and the surrounding area within the Mud Creek and Towaoc 7.5′ Quadrangles and collected more than 100 fossils now curated in the collections at the MEVE Visitor and Research Center (MEVE unpublished records). She described the members of the Mancos Shale present in the monument, gave an overview of other geologic formations in the region, and wrote a geologic history of the area.

Griffitts (2001) recognized the fossiliferous nature of the calcarenite beds within the Juana Lopez Member and the presence of distinct faunal zones (intervals of strata characterized by the occurrence/ranges of one or more fossil taxa), and outlined the taxa present in each. She provided a formal paleontological description and annotated figures of each of the species that define the faunal zones as well as other species found in the area. The species she reported include: ammonites *Baculites yokoyamai*, *Prionocyclus novimexicanus*, and *Scaphites whitfieldi* of the uppermost zone (zone 4); bivalve *Inoceramus perplexus* and ammonites *Baculites undulatus*, *Prionocyclus wyomingensis*, and *Scaphites warreni* of zone 3; and bivalves *Cameleolopha lugubris* and *Inoceramus dimidius* of zone 2. All subsequent paleontological work at YUHO has largely summarized Griffitts' work. Scott et al. (2001) and Tweet et al. (2009) provide an overview of the fossils within and around YUHO based almost entirely on Griffitts' work.

Summary of 2021 Paleontological Survey

In September 2021, a three-day survey for paleontological resources within YUHO was conducted by the lead author with assistance from Joseph Crystal and staff members Samuel Denman, Andrew Spear, Tova Spector, and Tara Travis, with activities conducted under permit YUHO-2021-SCI-0002. The survey work consisted of two phases: assessment of the YUHO collection housed at the MEVE Visitor and Research Center and field reconnaissance within YUHO to revisit known localities and record new ones.

During the first phase of the survey, the fossil collection and archives at the MEVE Visitor and Research Center were visited (Figure 4). The collection has 101 specimens that were collected from within YUHO and from the surrounding area within 4 km (2.5 mi) of the monument; this does not include the fossils collected during this survey, which have yet to be cataloged at time of publication (see "Fossil Localities"). For many of the specimens in the collection, the specific collection location is unknown. All 101 specimens were examined, and classifications were confirmed. General classifications include: eight species of ammonites, seven species of bivalves, two trace fossils (one possible crustacean track and one possible ammonite bounce mark), and one vertebrate bone. The vertebrate bone was discovered during this part of the survey on a slab (YUHO 55) of the Juana Lopez Member that also contained specimens of the ammonites *Baculites undulatus*, *Prionocyclus wyomingensis*, and *Scaphites* sp. YUHO 55 had been cataloged as "*Prionocyclus wyomingensis*, *Baculites undulatus* and *Scaphites* sp.," which did not acknowledge the presence of the bone. The bone does not have any visible features that can identify it to a level other than "vertebrate," but this discovery is notable because there hadn't been any vertebrate fossils confirmed from YUHO or the surrounding area prior to this survey.

Figure 4. All 101 YUHO fossil specimens in the collection at the MEVE Visitor and Research Center (NPS/VICTORIA CRYSTAL).

One of the main objectives of this survey was to revisit previously collected fossil localities within YUHO, so the first portion of the survey also included surveying the archives at MEVE for information regarding the fossil collection localities. For many of the specimens in the collection, there wasn't any locality information included in the Interior Collection Management System (ICMS). When present, it was very general and lacked any geospatial data (i.e., no latitude/longitude coordinates, GPS coordinates, or PLSS information). The locality descriptions that were given for some specimens were very general (e.g., many just said "Yucca House"), and therefore it was not possible to revisit these collection localities. A thorough survey of the archives, looking for anything pertaining to fossils at YUHO, was conducted. Unfortunately, no further information was located. Estimations of the locations of previously collected localities were made based on the information available in the ICMS (see "Fossil Localities").

The second phase of the survey consisted of a site visit to YUHO to revisit previously collected localities and to document new ones. There are no outcrops of the Juana Lopez Member within YUHO, so all fossil collection localities are from surficial deposits, and most often are archeological building blocks eroded out of the archeological structures; ten previously collected localities were visited. Five of these localities (localities from which specimens YUHO 85, 86, 141, 149, and 153 were collected) still contained fossiliferous Juana Lopez Member blocks, which were in piles of eroded building blocks on the surface near the archeological sites. Five other localities in the southern portion of the monument (from which YUHO 140, 157, 159, 160, and 1034 were collected) did not contain fossiliferous blocks. They only contained float of other rock types, mainly igneous rocks, eroded from the surrounding area. At the time when the fossils were collected, there likely were some blocks of Juana Lopez on the surface eroded either from outcrops or from the archeological sites and transported and deposited by water flows on the surface.

The second phase of the survey also involved collection of fossils from new collection localities (Figure 5). Fossils were collected if they held scientific, educational, or research value, and were exposed and at risk of potentially being eroded or transported away. A total of 11 fossils were collected from nine new localities. These fossils were all found within or eroded from archeological building blocks. The fossils were photo-documented, and GPS coordinates and other associated data were recorded. The fossils were brought to the MEVE Visitor and Research Center where they will be accessioned into the collection and cataloged.

There were several notable discoveries made in this phase of the survey. First, a fragment of a *Prionocyclus* sp. was found with a small hole in it. The hole is very round in shape, and initially it was thought that the hole may have been made by humans. Fossils have been incorporated into jewelry or spiritual objects by ancient peoples, and there are many examples of this in NPS areas (Kenworthy and Santucci 2006). Archaeologists at YUHO examined the fossil and determined that the hole was not made by humans (T. Travis, MEVE museum curator, pers. comm., 16 November 2021).

Figure 5. Victoria Crystal (left) and Andrew Spear (right) in the field during the 2021 paleontology survey (NPS/TOVA SPECTOR).

In addition, several fossils of the oyster *Cameleolopha lugubris* were discovered within YUHO during the second phase of the survey. This is notable because it had previously only been found outside of the monument and this was the first discovery of it within the monument itself.

Finally, a bivalve that was previously unknown from the area was discovered. It was discovered in an eroded building block of Juana Lopez calcarenite. It was tentatively identified in the field as a *Pycnodonte* species on the basis of its slightly enrolled morphology, texture of the remaining shell material, and similarity to *Pycnodonte newberryi* specimens in the collection (see “Taxonomy”). These *Pycnodonte newberryi* specimens, however, were collected from the Graneros Shale Member of the Mancos Shale approximately 4.0 km (2.5 mi) west of the monument. The Juana Lopez Member is stratigraphically outside the range of *Pycnodonte newberryi* and no other species of *Pycnodonte* have been found in the Juana Lopez Member (J. Kirkland and W. Elder, Utah Geological Survey and Golden Gate National Recreation Area [respectively], pers. comm., 29 September 2021) Thus, there are two possible scenarios if it is *Pycnodonte*: 1) if it is *P. newberryi*, this indicates an extension of the temporal range of this species; or 2) it could be a new *Pycnodonte* species. It may also be a species of *Rhynchostreon* (J. Kirkland, pers. comm., 20 October 2021). However, new species determinations for oysters require a population of fossils to examine and interpret. Given that there is only one specimen of this type, further analysis to determine if it is a new species is not possible (J. Kirkland and W. Elder, pers. comm., 14 October 2021). In addition, the Juana Lopez Member slabs in YUHO are not geologically in situ, and without geologic context, the scientific value of these specimens is limited. Thus, further investigation will not be conducted at this time, but future discoveries at YUHO or exploration of the surrounding area may open possibilities for further study.

Access to the Karwick parcel was granted for the second phase of this survey. The western side of the Karwick parcel is a small ridge covered in surficial deposits, likely pediment deposits and slope wash, similar to the area of the monument to the west and northwest of the parcel. This side of the Karwick parcel was surveyed for fossils, but, like the revisited localities in the southern portion of the monument, the surficial deposits did not contain any fossiliferous blocks of the Juana Lopez Member. The majority of the cobbles on the surface are igneous rocks that originated west of the monument. The eastern side of the parcel is ranched land, with very little rock or soil exposure, no outcrops, and, therefore, low potential for fossils on the surface (Figure 6). No fossils were collected from the Karwick parcel.

Figure 6. Photo taken on the ridge on the western side of the Karwick parcel looking east. The top of the ridge is in the foreground, Mesa Verde is in the background, and the ranched land of the Karwick parcel is between the two (NPS/VICTORIA CRYSTAL).

Geology

Geologic History

The rocks at YUHO and the surrounding area record a dynamic geologic history, including five episodes of sea level change, several uplift events, and many instances of volcanic activity (Elder and Kirkland 1993, 1994; West et al. 1998; Thornberry-Ehrlich 2013; Harrison et al. 2017). Since there are not many geologic units present within YUHO, the rocks from neighboring MEVE, as well as rocks within the greater Colorado Plateau region, provide insight into the rich geologic history of the area (Harrison et al. 2017). Much of the bedrock in the area is from the Cretaceous Period (143–66 million years ago), a time in which southern Colorado looked much different than it does today (Elder and Kirkland 1993, 1994; West et al. 1998; Thornberry-Ehrlich 2013; Harrison et al. 2017). In contrast to the high plateau and dry climate of today, the region was low-lying and wet with fluvial systems and coastal plains rapidly being inundated by a rising inland sea (Elder and Kirkland 1993, 1994; West et al. 1998; Thornberry-Ehrlich 2013). This epicontinental sea, commonly known as the Western Interior Seaway, covered much of the western North American continent and, at its greatest extent, stretched from the Arctic to the Gulf of Mexico (Figure 7; Elder and Kirkland 1994). Although sea level advanced and retreated during its existence, the Colorado Plateau region remained submerged for most of the Late Cretaceous, creating the thick Cretaceous deposits in the area (Elder and Kirkland 1993, 1994).

Movement of Earth's tectonic plates during the Triassic and Jurassic Periods (252–143 million years ago; see Appendix G for a geologic time scale) set the stage for the dynamic events of the Cretaceous Period. During the Triassic Period, and preceding Paleozoic Era (542–252 million years ago), Earth's continents had come together to form the supercontinent Pangea. By the Jurassic, tectonic rifting had initiated, and Pangea split apart (Frizon de Lamotte et al. 2015). Plate collisions on the western margin of North America during the Cretaceous Period resulted in mountain building along the margin, known as the Sevier Orogeny, and the development of a north–south trending basin in the interior of the continent (DeCelles and Giles 1996; Taylor et al. 2000; Thornberry-Ehrlich 2013). Merging water bodies from the ancestral Gulf of Mexico and Arctic Ocean flooded the North American continent, forming the Western Interior Seaway (Elder and Kirkland 1993, 1994).

The onset of this flooding, approximately 100 million years ago, is recorded in the Naturita Formation (previously known as the Dakota Sandstone in areas on the western side of the Western Interior Seaway; Young 1960, 1965; Carpenter 2014). The Naturita Formation is not present at YUHO, but it is found in the greater Colorado Plateau region (Young 1960, 1965; Carpenter 2014; Harrison et al. 2017). It represents a marginal marine environment, with terrestrial sandstones, siltstones, and coal interbedded with offshore sandstones (Harrison et al. 2017). Fossils from the Naturita Formation, mainly ammonites, are in the collections at MEVE (Harrison et al. 2017).

The Mancos Shale conformably overlies the Naturita Formation, and records a deeper inundation by the Western Interior Seaway (Leckie et al. 1997, 1998). It represents a fully marine environment, with the shoreline in western Utah, an estimated 310 km (190 mi) west of YUHO (Leckie et al. 1998; Harrison et al. 2017). The Mancos Shale, deposited over approximately 13 million years, records four episodes of sea level rise (transgression) and fall (regression; Griffitts 2001). The thick Mancos Shale deposits are comprised of shale/mudstone, siltstone, and limestone beds, and are subdivided into eight members (Leckie et al. 1997; Thornberry-Ehrlich 2013). There are also numerous bentonite layers throughout the Mancos Shale, produced as a result of far-field volcanic activity (Leckie et al. 1997; Harrison et al. 2017).

Figure 7. Paleogeographic map of the Western Interior Seaway, approximately 75 million years ago. The red star indicates the location of YUHO. Base map published as Figure 1 in Sampson et al. (2010) and licensed under Creative Commons Attribution 4.0 International (https://creativecommons.org/licenses/by/4.0). Graphic annotated by Victoria Crystal (NPS).

The Juana Lopez Member of the Mancos Shale makes up the majority of the bedrock within the original boundary of YUHO (Figure 8) and is the most fossiliferous unit in the monument (Table 1). It represents a quiet offshore environment with little input from land (Leckie et al. 1997; Griffitts 2001; Thornberry-Ehrlich 2013). The Montezuma Valley Member overlies the Juana Lopez Member (Leckie et al. 1997). It is only present at the southernmost tip of the original monument boundary, but it underlies much of the new area of the Karwick parcel (Figure 8). While fossils have been found in the Montezuma Valley Member at other locations, including at least one locality at MEVE (Leckie et al. 1997; Harrison et al. 2017), none have been found at YUHO. The expanded boundary area also includes the Smoky Hill Member of the Mancos Shale, which was not present within the original boundary. There is an "oyster bench" layer of this member mapped within MEVE (Harrison et al. 2017). Like the Montezuma Valley Member, no fossils from the Smoky Hill Member have been found at YUHO. See also Figure 9 for a stratigraphic diagram of YUHO geologic units.

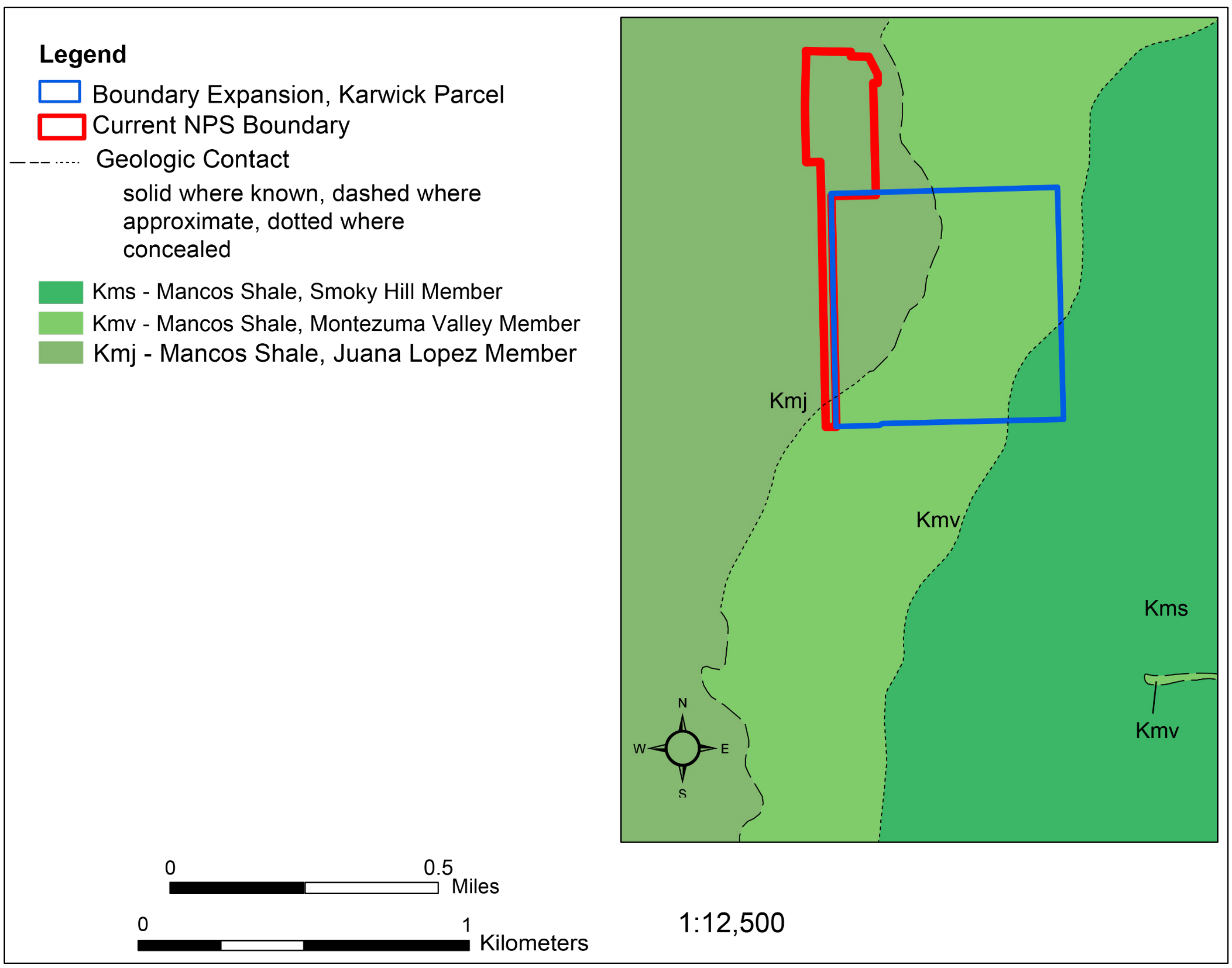


Figure 8. Geological map of YUHO adapted from Geologic Resources Inventory (GRI) digital geologic map data available at the following URL: https://irma.nps.gov/DataStore/Reference/Profile/2187477. Original NPS boundary and Karwick parcel boundary expansion are indicated by red and blue lines, respectively.

Table 1. Summary of YUHO 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 YUHO	Depositional Environment
Quaternary rocks and sediments	Pleistocene–Holocene	None to date	Alluvial, fluvial, slope movement deposits
Mancos Shale, Smoky Hill Member	Late Cretaceous	None to date	Epicontinental sea
Mancos Shale, Montezuma Member	Late Cretaceous	None to date	Epicontinental sea
Mancos Shale, Juana Lopez Member	Late Cretaceous	Bivalves, ammonites, ammonite bounce mark, possibly vertebrates; primarily in locally sourced building stone	Epicontinental sea

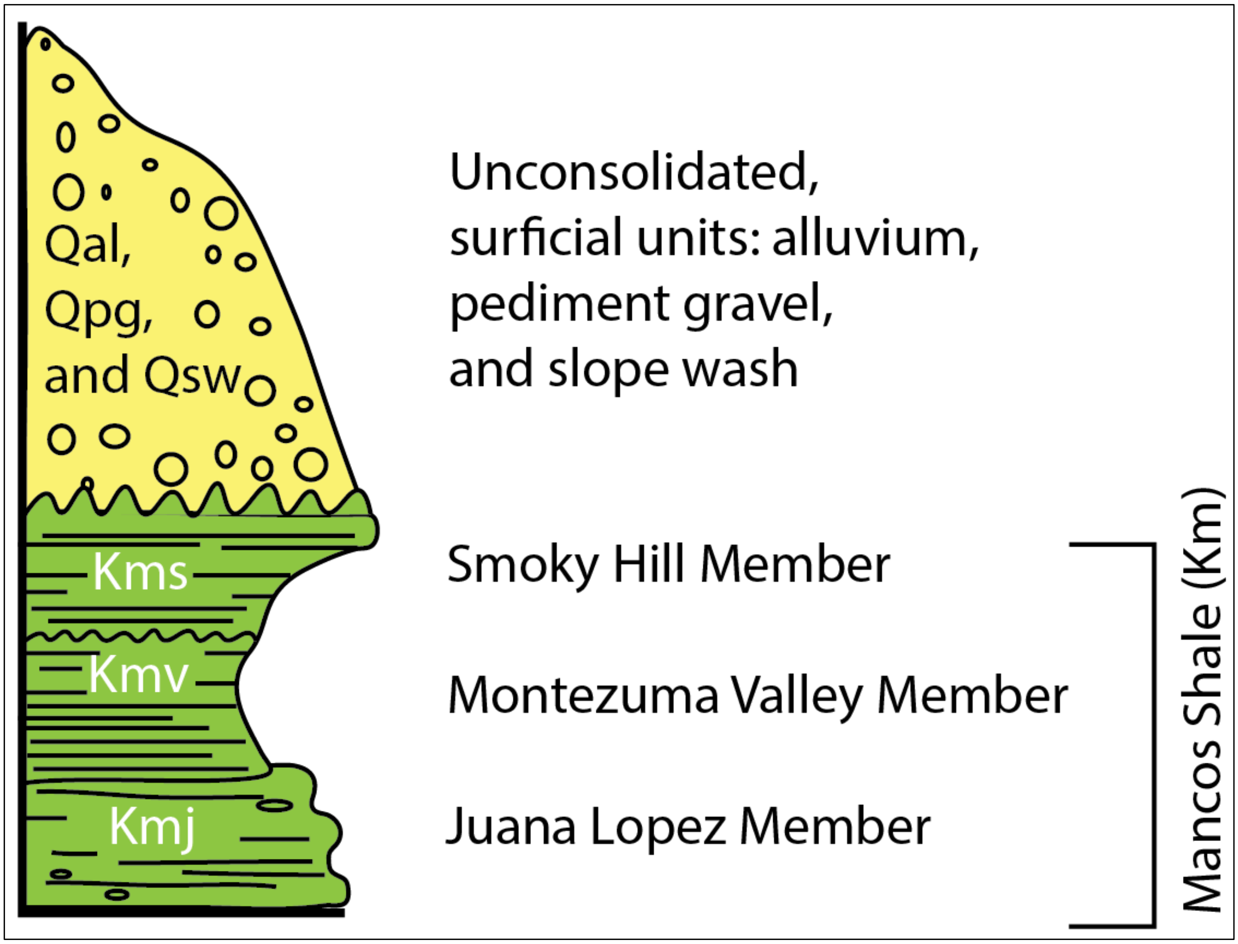


Figure 9. Stratigraphic column of the geologic units within YUHO. Oldest rock units are on the bottom, and youngest rock units are on the top. Unit thicknesses are not to scale. Relative weathering profiles are indicated by indentations on the right side of each rock unit. Adapted from Geologic Resources Inventory graphic by Trista Thornberry-Ehrlich (Colorado State University, 2013).

Overall, fossil and lithologic evidence from the eight members of the Mancos Shale suggest ocean currents changed drastically as sea level rose and fell (West et al. 1998; Corbett and Watkins 2014). The presence of fossiliferous deposits suggests that, at times, ocean currents circulated oxygenated water throughout the water column, including at and near the seabed (Leckie et al. 1998; West et al. 1998). This allowed for marine fauna to thrive at all depths. Other times, however, circulation became restricted to the upper portion of the water column, resulting in oxygen-depleted bottom water and little to no seabed fauna (West et al. 1998). The lack of oxygen restricted decomposition of organic material, so organic-rich mud accumulated during these times (Leckie et al. 1997). Deep burial resulted in higher temperatures and pressures transforming the organic material to hydrocarbons, which have been the subject of oil and gas exploration in the greater western interior region (Hettinger and Kirschbaum 2002; Thornberry-Ehrlich 2013).

Following the marine depositional environments of the Mancos Shale, around 81 million years ago, fluvial systems that drained the highlands to the west brought sediment into the area as sea level regressed toward the northeast and the depositional environment shifted to a near-shore deltaic environment (Elder and Kirkland 1994; Thornberry-Ehrlich 2013, Harrison et al. 2017). The Mesa Verde Group records this final transgression and regression of the Western Interior Seaway near the end of the Cretaceous (Leckie et al. 1997; Harrison et al. 2017).

During this time period, a mountain-building event known as the Laramide Orogeny began, initiating the formation of the modern Rocky Mountains (between approximately 70 to 66 million years ago; Elder and Kirkland 1994). While the Rocky Mountains folded and faulted, the Colorado Plateau region remained relatively intact, uplifted as a block and folded into step-like monoclines (Graham 2006). Locally, the mountain-building event manifested as igneous activity (Ekren and Houser 1965; Thornberry-Ehrlich 2013; Harrison et al. 2017). Laccoliths were emplaced within the region, including those that compose the Ute Mountains to the west of YUHO and the La Plata Mountains to the northeast (Ekren and Houser 1965). These laccoliths have been dated to approximately 67 million years ago (Semken and McIntosh 1997; Harrison et al. 2017).

Volcanic activity renewed around the Eocene to Oligocene (35 to 26 million years ago) as a result of melting within the mantle (Lake and Farmer 2015). This emplaced more igneous intrusive bodies in the area, including dikes exposed at MEVE (Harrison et al. 2017), though none are present at YUHO. This volcanic activity also produced the San Juan volcanic field to the northeast (Lipman et al. 1978).

In the latter part of the Cenozoic Era (66 million years ago–present), the compressional tectonic regime that had influenced the geologic processes for most of the Mesozoic and early Cenozoic Eras shifted into an extensional regime (Keller and Baldridge 1999). This new tectonic regime formed the modern block-faulted topography of the southwestern U.S. and the Rio Grande Rift in New Mexico (Keller and Baldridge 1999; Thornberry-Ehrlich 2013). It also contributed to the uplift of the Colorado Plateau and caused further volcanic activity in the region in the form of basaltic lava flows. Erosion and weathering occurred contemporaneously to the uplift, downcutting and carving deep river valleys, including the famous Grand Canyon in Arizona (Graham 2020).

During the Pleistocene Epoch (2.5 million–11,700 years ago), repeated alpine glaciations brought ice to the mountain ranges surrounding YUHO. During the last glacial maximum, the San Juan Mountains to the northeast of YUHO were covered by an ice cap (Guido et al. 2007). Retreating of the ice began approximately 19,400 years ago, and by 12,300 years ago, the ice was completely melted (Guido et al. 2007). Meltwater from the mountains surrounding YUHO brought sediment into the area, and thick soils developed following the glaciations. Ancestral Puebloans utilized this soil following their arrival into the region approximately 950 years ago (National Park Service 2015).

Geomorphological processes that have been active since the rise of the Colorado Plateau have eroded sediment from Sleeping Ute Mountain and deposited it atop the Juana Lopez Member of the Mancos Shale, forming the Quaternary rocks and sediments present in YUHO today (Figure 10). Intermittent streams and sheet flows continue to erode and transport sediment in the area. This erosional regime naturally excavates fossils from within the bedrock and brings them to rest on the surface where they can be discovered by paleontologists, monument staff, or others. Erosion, however, can also result in the destruction or loss of paleontological resources.

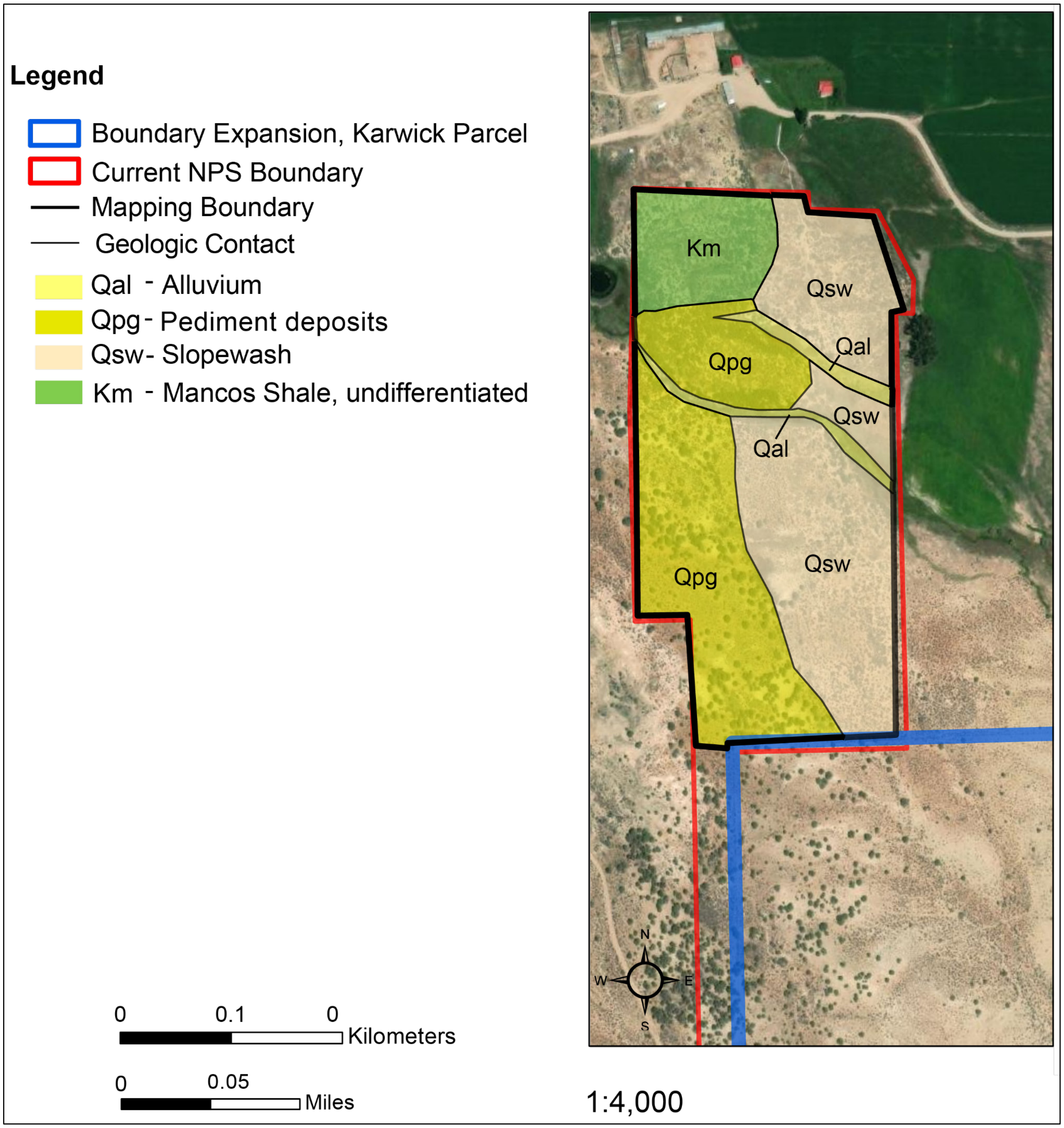


Figure 10. Surficial geological map of YUHO adapted from GRI digital map data available at the following URL: https://irma.nps.gov/DataStore/Reference/Profile/2187478. Original NPS boundary and Karwick parcel boundary expansion are indicated by red and blue lines, respectively. Basemap imagery from Esri, Maxar, GeoEye, Earthstar.

Geologic Formations

Mancos Shale: Juana Lopez Member (Upper Cretaceous)

Description: The Juana Lopez Member of the Mancos Shale dates to the Turonian Stage of the Late Cretaceous, 93.9–89.4 million years ago (Leckie et al. 1997; Tweet et al. 2009). It is a dark silty shale/mudstone with intervals of calcarenite (Leckie et al. 1997). This unit has a sharp contact with the underlying Lower Mancos Member and the overlying Montezuma Valley Member. The base of the Juana Lopez Member is marked by the first occurrence of a calcarenite interval (Leckie et al. 1997). At the principal reference section of the Mancos Shale in MEVE, the Juana Lopez Member is 42.6 m (140 ft) thick (Leckie et al. 1997). Due to poor exposures at YUHO, the thickness has not been measured within the monument, though it likely does not differ much from the thickness at MEVE (Griffitts 2001). The silty shale/mudstone is generally olive black in color, but can be brown, yellow-brown, or gray when silt content is relatively higher. The calcarenite layers are generally darker in color but weather to orange or brown (Leckie et al. 1997; Griffitts 2001). The calcarenite layers are the fossiliferous layers of the Juana Lopez Member, and consist of well-cemented bioclastic debris, and often have basal scour surfaces, sole marks, low-angle cross-stratification, and ripples on the upper surfaces (Leckie et al. 1997). The Juana Lopez Member also contains many concretion horizons and six bentonite layers. The bentonite layers range in thickness from 5 to >10 cm (2 to >4 in) (Leckie et al. 1997).

Four prominent calcarenite intervals are recognized in the Juana Lopez Member (Leckie et al. 1997). Within these intervals, layers of calcarenite are interbedded with shale/mudstone. The calcarenite layers range in thickness from <1 to approximately 80 cm (<0.4 to 31 in). Each calcarenite interval contains a distinct fauna (Griffitts 2001). The prominent calcarenite layers form low terraces and irregular hills within the area (Griffitts 2001). The calcarenite breaks into blocks or slabs, from which many of the prehistoric buildings are made (Griffitts 2001). There are no calcarenite outcrops within YUHO. The nearest outcrop is approximately 0.8 km (0.5 mi) west of the prehistoric buildings, from which the Ancestral Puebloans presumably collected building materials (Griffitts 2001; unpublished MEVE records). The blocks are almost solidly composed of fragmented or entire fossils (Figure 2), and almost every block contains fossils (Scott et al. 2001). The two upper calcarenite intervals are visible over a wide area within the vicinity of YUHO, recognizable as low ridges that trend northeast/southwest (Griffitts 2001). Although there are no outcrops of the Juana Lopez Member within YUHO, it is recognizable on the surface as float and can be found in situ in gullies to the west/southwest of the monument.

Fossils found within YUHO: Bivalves (Griffitts 2001; Scott et al. 2001; unpublished MEVE records), ammonites (Griffitts 2001; Scott et al. 2001; unpublished MEVE records), ammonite trace fossil (unpublished MEVE records), and vertebrates (2021 paleontology survey).

Fossils found elsewhere: Bivalves (Dane et al. 1966; Leckie et al. 1997; Mereweather et al. 2006), ammonites (Dane et al. 1966; Leckie et al. 1997; Mereweather et al. 2006), gastropods (Lucas and Johnson 2003), possible crustacean trace fossils (Scott et al. 2001; Tweet et al. 2009; unpublished MEVE record), fish (Leckie et al. 1997), skates (Ekren and Houser 1965), sharks (Leckie et al. 1997;

Lucas and Johnson 2003; Lucas 2006), plesiosaurs (Tweet et al. 2009), an upper arm bone of the toothed bird *Ichthyornis* (Lucas and Sullivan 1982), and foraminifers (Leckie et al. 1997).

Mancos Shale: Montezuma Valley Member (Upper Cretaceous)

Description: The Montezuma Valley Member of the Mancos Shale overlies the Juana Lopez Member. It is a silty to sandy calcareous shale/mudstone (Leckie et al. 1997). It has a sharp contact with the underlying Juana Lopez Member and overlying Smoky Hill Member. At the principal reference section of the Mancos Shale in MEVE, it is 16.2 m (53.2 ft) thick (Leckie et al. 1997). It varies in color from gray to medium dark gray, to olive gray, to dark olive gray. Leckie et al. (1997) recognized three informal units within the Montezuma Valley Member: 1) a slightly silty, weakly calcareous shale unit containing thin layers and lenses of calcarenite; 2) a more calcareous shale/mudstone with septarian concretions ranging in size from 5–20 cm (2–8 in) that preserve ammonites; and 3) slightly very fine- to fine-grained sandy calcareous shale/mudstone. Fossils are found within all three informal units preserved as compressions in the shale/mudstone and within the concretions (Leckie et al. 1997). Fossils are not as abundant as in the overlying Juana Lopez Member (Scott et al. 2001; Tweet et al. 2009).

Fossils found within YUHO: None to date

Fossils found elsewhere: Plant material (Leckie et al. 1997), bivalves (Leckie et al. 1997; Mereweather et al. 2006), and ammonites (Leckie et al. 1997; Mereweather et al. 2006).

Mancos Shale: Smoky Hill Member (Upper Cretaceous)

Description: The Smoky Hill Member of the Mancos Shale is predominately a dark gray, well-laminated calcareous shale/mudstone, with lesser components of dark gray mudstone and medium gray marlstone (Leckie et al. 1997). It has a sharp lower contact with the Montezuma Valley Member and a gradational upper contact with the overlying Cortez Member. The lower contact with the Montezuma Valley Member corresponds with a widespread hiatus in deposition known as the Carlile–Niobrara disconformity (Leckie et al. 1997). At the principal reference section of the Mancos Shale in MEVE, the Smoky Hill Member is 88.6 m (291 ft) thick. Fossils are found throughout the member, as are fecal pellet laminae; fecal pellets are particularly abundant on bedding surfaces (Leckie et al. 1997). The marlstone layers are more resistant to weathering and form prominent benches and outcrops throughout. Bentonite layers are rare in the Smoky Hill Member. When present, most are < 5 cm (2 in) in thickness, but there is one bentonite layer that is notably thicker (23 cm [9 in]) which caps a thick (13 m [43 ft]), prominent bench unit of the marlstone.

Fossils found within YUHO: None to date

Fossils found elsewhere: Brachiopods (Leckie et al. 1997), bivalves (Leckie et al. 1997; Walaszczyk and Cobban 2006; unpublished MEVE records), ammonites, invertebrate fecal pellets (Leckie et al. 1997), and foraminifers (Leckie et al. 1997).

Quaternary rocks and sediments (Pleistocene–Holocene)

Description: Much of the bedrock in YUHO is overlain by Quaternary surficial units, mainly slope wash deposits, pediment deposits, and alluvium. In places, these deposits extend to at least 12 m (40 ft) in thickness (Griffitts 2001). The slope wash deposits formed as a result of broad sheets of water flowing along sloped surfaces, eroding and depositing material (Thornberry-Ehrlich 2013). These deposits occur primarily on the eastern side of YUHO. The alluvium deposits form where the surface water flow becomes channelized. There are two incised alluvial channels that flow southwest across YUHO (Figure 10; Thornberry-Ehrlich 2013), and others in the area outside of the monument. The third Quaternary unit, pediment deposits, is found on the western side of the monument. Similar to the slope wash deposits, the pediment deposits were formed by an unconfined overland flow, though there may also be some debris from gravity-driven slope movements (Thornberry-Ehrlich 2013).

Fossils found within YUHO: None to date

Fossils found elsewhere: In the region, fossils found in Quaternary rocks and sediments include charcoal (Harrison et al. 2017), conifer, *Ephedra*, and angiosperm pollen (Tweet et al. 2009; Thornberry-Ehrlich 2013; Harrison et al. 2017), packrat middens (Tweet et al. 2009; Thornberry-Ehrlich 2013; Harrison et al. 2017), mammoths (Harrison et al. 2017), horses (Harrison et al. 2017), camels (Harrison et al. 2017), bison (Harrison et al. 2017), muskox (Tweet et al. 2009; Thornberry-Ehrlich 2013; Harrison et al. 2017), and other vertebrates found in association with archeological sites including canids, weasels, rodents, rabbits, cervids (deer and elk), bovids (antelope, sheep, cattle), and equids (Tweet et al. 2009; Thornberry-Ehrlich 2013).

Taxonomy

See Appendix A for a full list of taxa.

Fossil Plants

No plant fossils have been found at YUHO to date.

Fossil Invertebrates

The vast majority of the fossils found within the monument are invertebrates from the Juana Lopez Member of the Mancos Shale. The fossils are found in the calcarenite intervals of well-cemented, densely packed bioclastic debris in blocks or slabs that have weathered out of archeological structures or outcrops. Leckie et al. (1997) recognized four distinct intervals of calcarenite throughout the Juana Lopez Member. Each interval contains a distinct and recognizable faunal assemblage, and, as such, are hereafter referred to as faunal zones or simply zones. Fossils from the three uppermost zones (in ascending order: zones 2, 3, and 4) are present at YUHO (Griffitts 2001). The calcarenites of zones 3 and 4 are thicker than the lower two, and they form low northeast/southwest-trending ridges that are recognizable across the landscape in the vicinity of YUHO. Zone 4, the uppermost zone, is recognized by *Prionocyclus novimexicanus* and *Scaphites whitfieldi* (Griffitts 2001). Zone 3 is about 9–11 m (30–35 ft) below zone 4 and is recognized by *Prionocyclus wyomingensis* and *Scaphites warreni*, and also contains *Inoceramus perplexus*. Zone 2 is about 9 m (30 ft) below that and is recognized by large accumulations of *Cameleolopha lugubris* and *Inoceramus dimidius*. Zone 1, the lowest zone, is not exposed at YUHO or the surrounding area. Though there are many other fossils found throughout the Juana Lopez Member, these are the most recognizable and the most diagnostic (as assemblages) of the different zones. Some of these species have much longer ranges individually, so the faunal assemblage is most useful for distinguishing the different zones (Griffitts 2001).

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

Few publications have described bivalves at YUHO. The earliest discussion of bivalves at YUHO is a brief mention by Gould (1939). Earlier authors noted the fossiliferous nature of the rock, but Gould was the first to specifically mention bivalves. A more elaborate discussion of bivalves at YUHO was done by Griffitts (2001). However, bivalves of the Mancos Shale from locations other than YUHO have been described in greater detail in the literature. In particular, Leckie et al. (1997) describes the biostratigraphy of the Mancos Shale principal reference section at MEVE.

There are eight species of bivalves found within YUHO and its vicinity: four are found in the Juana Lopez Member; three in the Smoky Hill; and one in the Graneros Shale, the stratigraphically lowest member of the Mancos Shale (Figure 11 illustrates the most common of these species). They are all preserved as whole and fragmentary casts, external molds, internal molds, and recrystallized original shells. The four species of bivalves of the Juana Lopez Member have been found within YUHO, including two inoceramid clams and two oysters, and the other species have only been found in the area surrounding YHUO. The four species found within YUHO are: *Inoceramus dimidius*, *Inoceramus perplexus*, *Cameleolopha lugubris*, and *Pycnodonte* sp. or *Rhynchostreon* sp.

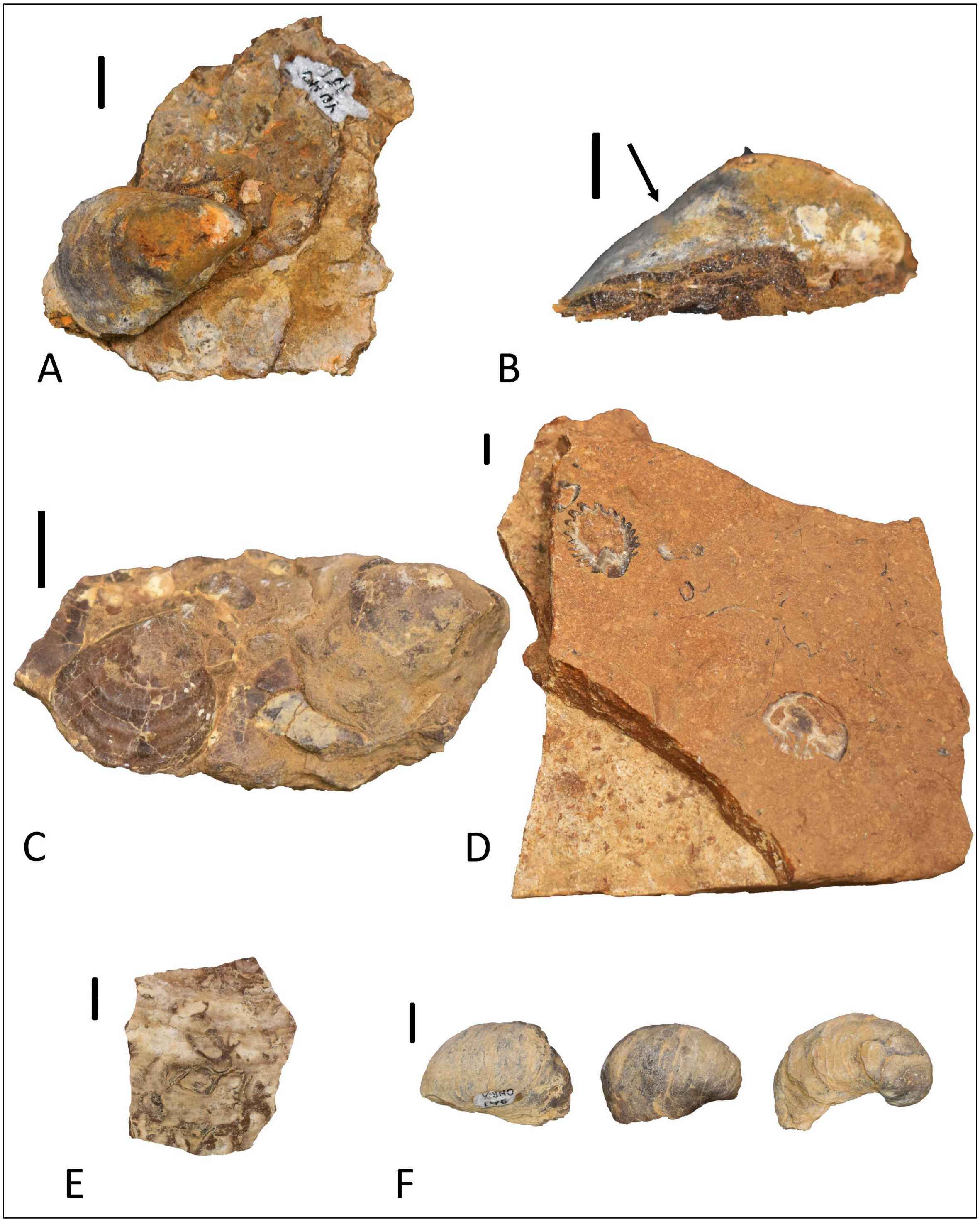


Figure 11. Bivalve taxa found at and within the vicinity of YUHO (NPS/VICTORIA CRYSTAL). Scale bars are all 1 cm (0.4 in). **A.** *Inoceramus dimidius* (YUHO 151). **B.** Lateral view of *Inoceramus dimidius* (YUHO 151). The sharp change in slope of the shell noted by the arrow indicates the change in morphology between the juvenile and adult portions of the shell and is diagnostic of this species. **C.** *Inoceramus perplexus* (YUHO 159). **D.** *Cameleolopha lugubris* (Conrad; YUHO 1031). **E.** *Pseudoperna congesta* encrusted on an inoceramid shell from the Smoky Hill Member (YUHO 1033). **F.** *Pycnodonte newberryi* from the Graneros Shale (YUHO 146).

The inoceramid clams found in the Juana Lopez Member at YUHO are *Inoceramus dimidius* and *Inoceramus perplexus*. Inoceramids are epifaunal bivalves that were common during the Late Cretaceous and are known for their large size; a few species could grow greater than 1 m (3 ft) across. They also have a complex taxonomy, and have frequently been synonymized, divided, and transferred between various genera and subgenera. Therefore, the taxonomy discussed here is subject to change; the most recent literature should be consulted for up-to-date taxonomy. The YUHO collections housed at the MEVE Visitor and Research Center include approximately 25 specimens of *Inoceramus dimidius* and eight of *Inoceramus perplexus* collected from YUHO and the land surrounding it (Appendix B). There are also several specimens in the collection that have been identified as inoceramids or belonging to the genus *Inoceramus*, without attribution to either species. *Inoceramus dimidius* is recognized by the difference in morphology between the juvenile and adult parts of the shell (Figure 11A and 11B; Walaszczyk and Cobban 2000; Griffitts 2001). The juvenile part of the shell is often ornamented, while the adult part is not. There is also a notable bend in the shape of the shell at the intersection between the two parts (Figure 11B; Walaszczyk and Cobban 2000; Griffitts 2001). *Inoceramus perplexus* is recognized by regular, concentric growth lines on the shell (Griffitts 2001). The majority of the inoceramids in the YUHO collection at MEVE were found in slabs of the Juana Lopez calcarenite that were not geologically in situ. These slabs were found in gullies within and around YUHO, or on the surface as building blocks that had eroded out of the prehistoric structures at YUHO. See the "Paleontological Research and Collections" section for more details about the collection at the MEVE Visitor and Research Center.

In addition to the inoceramid taxa present in the Juana Lopez Member at YUHO, two other inoceramids, *Volviceramus involutus* and *Platyceramus cycloides*, have been found in the Smoky Hill Member in the vicinity of YUHO (Griffitts 2001; Scott et al. 2001). With the boundary expansion, a small portion of the Smoky Hill Member is now present in the monument, but it is covered by surficial deposits and has not yielded any fossils to date. There is one specimen of *Volviceramus involutus* in the YUHO collection at MEVE. It was collected southeast of the monument by Mary Griffitts in 2000.

The oysters found at YUHO are *Cameleolopha lugubris* (Griffitts 2001) and a species of either *Pycnodonte* or *Rhynchostreon. Cameleolopha lugubris* is found throughout the Juana Lopez Member, but it is most abundant in, and diagnostic of, zone 2 (Griffitts 2001). This fossil oyster species is recognized by its flat, ribbed valves that are round to subovate in shape with crenulated margins (Griffitts 2001; Hook and Cobban 2012). It is sometimes found encrusting the shells of larger bivalves such as *Inoceramus* (Griffitts 2001). There are approximately 10 instances of *Cameleolopha lugubris* in the YUHO collection, three of which were collected during the 2021 paleontology survey (Figure 12). Prior to this survey, *Cameleolopha lugubris* had only been found from the vicinity of YUHO, not within the monument itself.

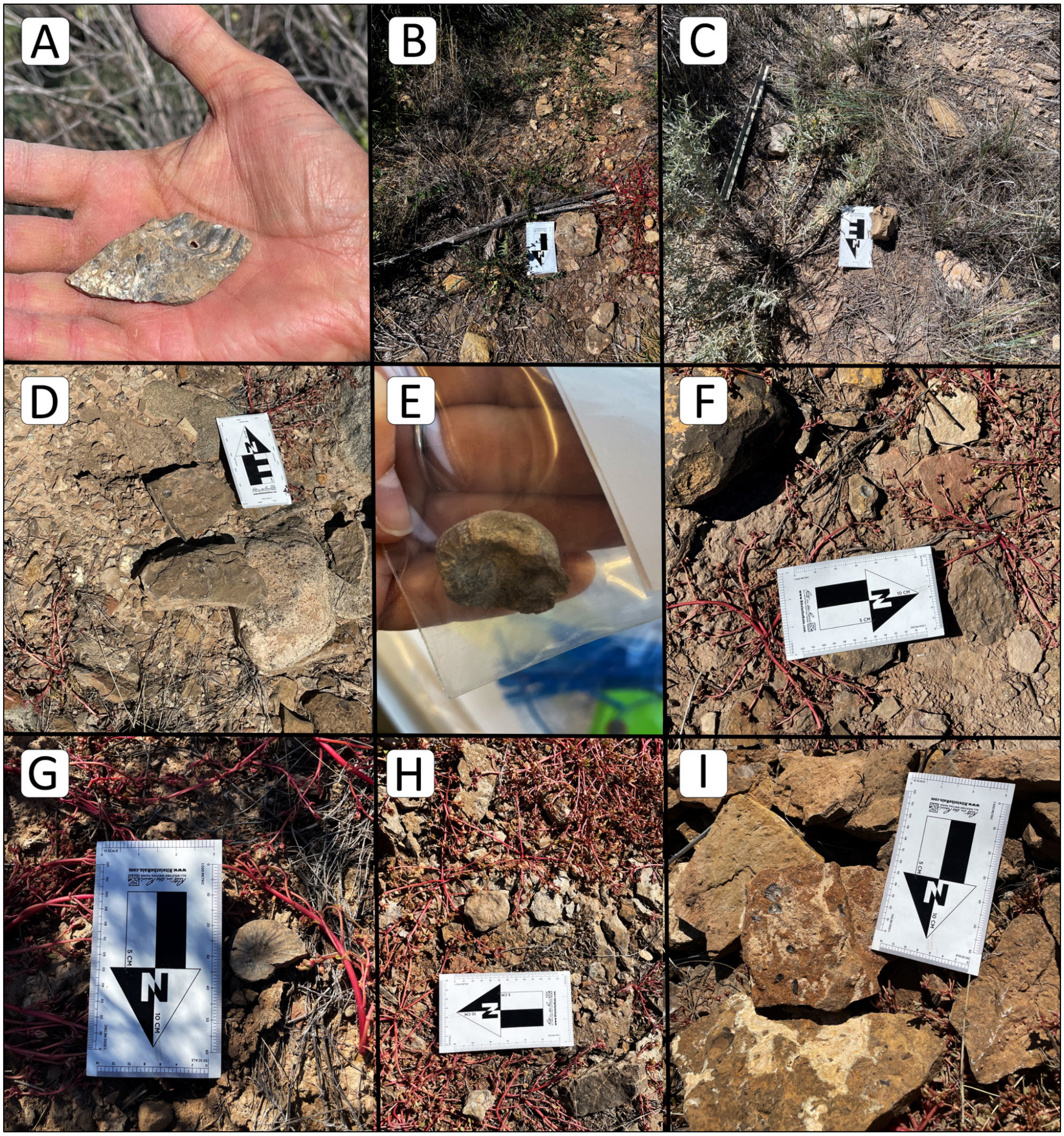


Figure 12. Fossils collected during the 2021 paleontology field survey (NPS/VICTORIA CRYSTAL). Scale bars are 15 cm (6 in). **A.** Shell fragment of *Prionocyclus* sp. with a hole. Hand for scale. **B.** *Pycnodonte* sp. or *Rhynchostreon* sp. and *Prionocyclus* sp. **C.** *Scaphites whitfieldi* and *Prionocyclus wyomingensis*. **D.** *Cameleolopha lugubris*. **E.** *Scaphites whitfieldi*. **F.** *Cameleolopha lugubris*. **G.** *Prionocyclus wyomingensis*. **H.** *Scaphites warreni*. **I.** *Cameleolopha lugubris*.

During the 2021 paleontology survey, a fossil tentatively identified as a *Pycnodonte* species was found (Figure 13), identified by its slightly enrolled morphology, texture of the remaining shell material, and similarity to other *Pycnodonte* specimens. Prior to this survey, no fossils resembling *Pycnodonte* had been found within the monument itself. It may instead be a species of

Rhynchostreon; it is difficult to identify from only one specimen (J. Kirkland, pers. comm., 20 October 2021).

Figure 13. Unknown bivalve, likely *Pycnodonte* sp. or *Rhynchostreon* sp., that was discovered during the 2021 paleontology field survey (NPS/SAMUEL DENMAN). Specimen is indicated by black arrow. Scale bar is 1 cm (0.4 in).

The oyster *Pseudoperna congesta* from the Smoky Hill Member has also been found within the vicinity of YUHO, but not within the monument, (Griffitts 2001; Scott et al. 2001). It is commonly found encrusted on large bivalves such as inoceramids. It is irregular to ovate in shape and is often found encrusted in masses (Griffitts 2001). There are two specimens featuring *Pseudoperna congesta* encrusting inoceramids in the YUHO collection at the MEVE Visitor and Research Center. They were collected southeast of YUHO.

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

Like bivalves, few publications have described cephalopods at YUHO. The earliest discussion of cephalopods at YUHO is a brief mention in Gould (1939), with more elaborate discussions by Griffitts (2001). Cretaceous cephalopods have been widely studied at locations other than YUHO, and the body of literature about cephalopods found at other locations is vast.

There are eight species of ammonites (subclass Ammonoidea) in three genera that have been found in the Juana Lopez Member of the Mancos Shale at or within the vicinity of YUHO. They are preserved as whole and fragmentary casts, external molds, and recrystallized shells. Six of these species have been found within YUHO, as reported by Griffitts (2001): *Baculites undulatus*, *Baculites yokoyamai*, *Prionocyclus novimexicanus*, *Prionocyclus wyomingensis*, *Scaphites warreni*, and *Scaphites whitfieldi.*

The three genera at YUHO have distinct morphologies that allow them to be easily identified to the genus level. Specimens of the genus *Baculites* have straight or slightly bent shells. Specimens of the genus *Prionocyclus* have the tightly coiled or spiraled shells that even non-paleontologists often recognize as belonging to an ammonite. Specimens of the genus *Scaphites* have loosely coiled shells shaped like the number nine (Figure 14).

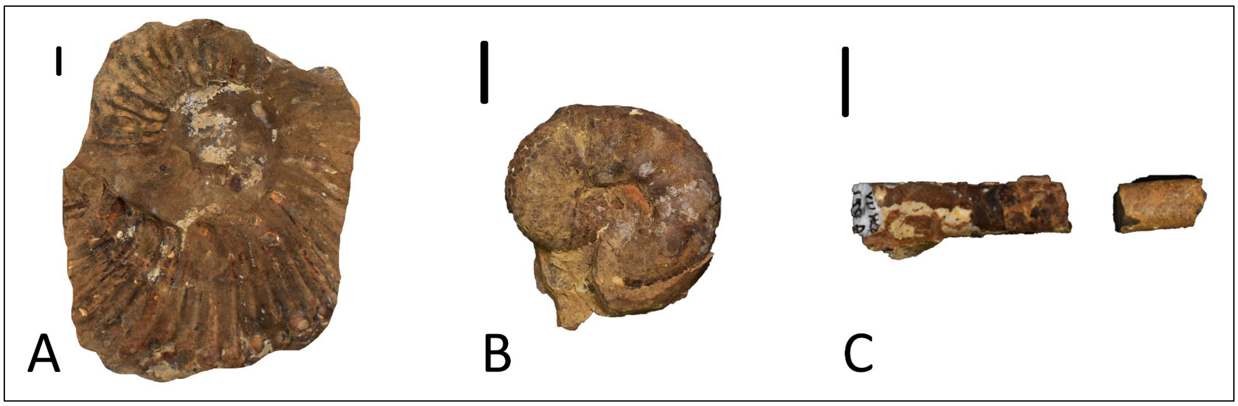


Figure 14. Ammonite genera found at YUHO (NPS/VICTORIA CRYSTAL). Scale bars are all 1 cm (0.4 in). **A.** YUHO 97. Fossils of the genus *Prionocyclus* are recognized by the characteristic tightly coiled or spiraled shells that even non-paleontologists often recognize as belonging to an ammonite. **B.** YUHO 142. Fossils of the genus *Scaphites* are loosely coiled and vaguely resemble the number nine. **C.** YUHO 159. Fossils of the genus *Baculites* have straight or slightly bent shells.

YUHO has two species of the genus *Baculites*. These are distinguished from the other two ammonite genera by their straight or slightly bent shells. *Baculites* only have a small coil with one or two whorls, and the rest of the shell is not coiled (Griffitts 2001). Most of the *Baculites* specimens in the YUHO collection are fragmentary. *Baculites undulatus* is associated with *Prionocyclus wyomingensis* and *Scaphites warreni* in zone 3 of the Juana Lopez Member, and is rounded and oval in cross section with swellings along the outside of the shell (Griffitts 2001). *Baculites yokoyamai* is associated with *Prionocyclus novimexicanus* and *Scaphites whitfieldi* in zone 4 and is oval in cross section with closely spaced ribs on the venter. There are approximately 30 fossils of *Baculites undulatus* and three fossils of *Baculites yokoyamai* in the YUHO collection, as well as some specimens only identified to the genus level.

There are two species of the genus *Prionocyclus* found within YUHO. *Prionocyclus wyomingensis* has a continuous serrated keel (serrated adornments on the outer edge of the shell), nodes on the depression in the center of the shell (umbilical bullae), and double rows of protrusions on the sides of the bottom of the shell (ventrolateral tubercles) (Griffitts 2001; Kennedy et al. 2001). *Prionocyclus novimexicanus* is similar, though it is more compressed in cross section, has only one row of ventrolateral tubercles, and usually lacks the umbilical nodes (Griffitts 2001; Kennedy et al. 2001). There are approximately 40 fossils of *Prionocyclus wyomingensis* and seven fossils of *Prionocyclus novimexicanus* in the collection, as well as some specimens only identified to the genus level.

There is another species of the genus *Prionocyclus* found in the vicinity of the monument. It is *Prionocyclus* cf. *P. macombi;* there is one specimen present in the YUHO collections at MEVE that was collected southwest of the monument. It is characteristic of the lowermost calcarenite zone, which is the only zone not exposed at or near YUHO (Leckie et al. 1997; Griffitts 2001).

The ammonites of the genus *Scaphites* have initial involute coils proceeded by a section that is more loosely coiled or nearly straight (Griffitts 2001). *Scaphites warreni* is subovate in cross section and has primary ribs on the coiled portion of the shell, but the body chamber is relatively smooth (Griffitts 2001). *Scaphites whitfieldi* is more rectangular in cross section and has more dense ribs throughout (Griffitts 2001). There are approximately 25 fossils of *Scaphites warreni* and just a few of *Scaphites whitfieldi* in the collections at YUHO. Many specimens in the YUHO collection are also only identified to the *Scaphites* genus level. Several specimens of the species *Scaphites ferronensis* were collected by Mary Griffitts within the vicinity of YUHO, but none have been found within the monument itself.

Like the bivalve specimens, the majority of these fossils were found in slabs of the Juana Lopez calcarenite found in gullies or the weathered building blocks of the prehistoric structures at YUHO. See the "Paleontological Research and Collections" section for more details about the collection at the MEVE Visitor and Research Center.

Fossil Vertebrates

No vertebrate fossils had been found at YUHO prior to the 2021 paleontology survey. During the first phase of the 2021 paleontology survey, each specimen in the YUHO collection at the MEVE Visitor and Research Center was examined. A small vertebrate bone approximately 2.75 cm (1.08 in) in length was discovered on a slab (catalog number YUHO 55) of the Juana Lopez Member that also contained specimens of *Baculites undulatus*, *Prionocyclus wyomingensis*, and *Scaphites* sp. (Figure 15). The bone does not have any visible features that can identify it to a level other than "vertebrate."

Figure 15. YUHO 55. Slab of the Juana Lopez Member with a vertebrate bone (lighter-colored linear feature on the left side of the slab) as well as specimens of *Baculites undulatus*, *Prionocyclus wyomingensis*, and *Scaphites* sp. (NPS/VICTORIA CRYSTAL). Scale bar is 1 cm (0.4 in).

Ichnofossils

There is one ichnofossil (MEVE collection specimen YUHO 147) that was found within YUHO by Mary Griffitts in 2000. It is a bounce mark of a *Prionocyclus* sp., with the tubercles present in the trace (Figure 16). The ammonite likely bounced off the sea floor with a glancing blow (MEVE unpublished records).

There is also an ichnofossil specimen in the YUHO collections at MEVE that was found in the vicinity of YUHO, but not within the monument itself (YUHO 64). It is from the Juana Lopez Member and was found in situ west of the monument (Figure 16). It preserves tracks most likely from a crustacean (MEVE unpublished records).

Other Fossils

Fossils that are not plants, invertebrates, vertebrates, or trace fossils are mostly the hard parts of various types of microorganisms. To date, none have been reported from YUHO, although it would certainly not be surprising if rocks at YUHO contain foraminifers, plates from phytoplankton, pollen, or other microfossils.

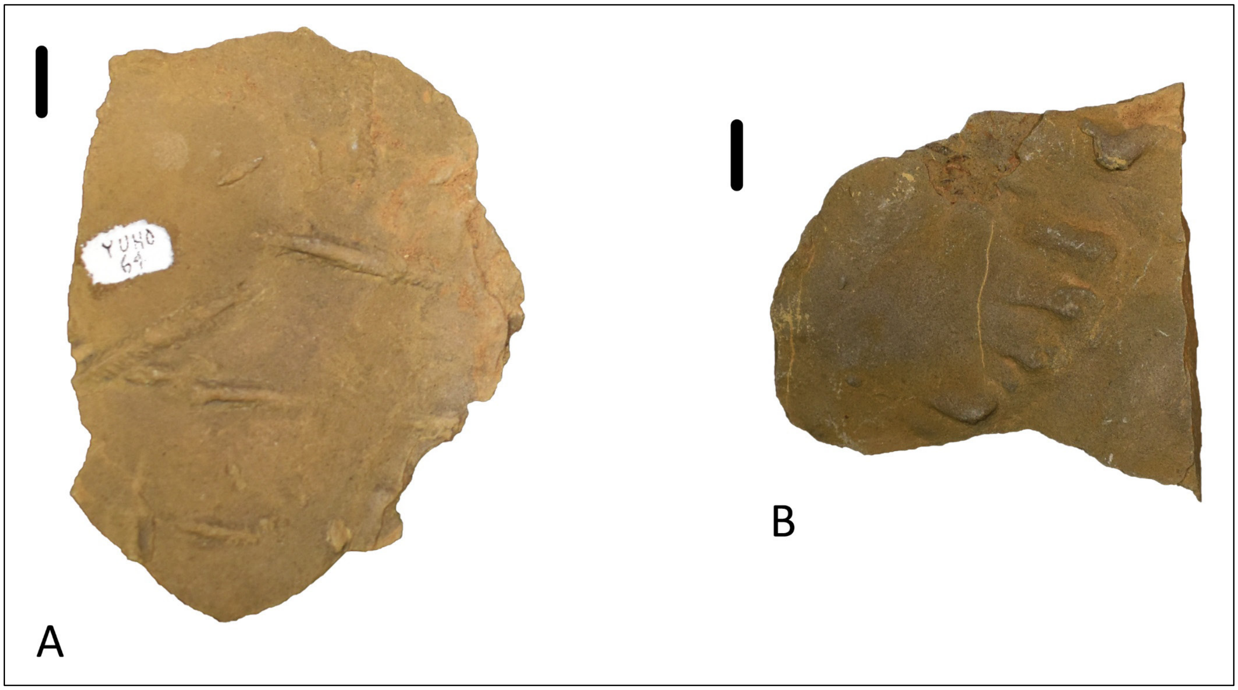


Figure 16. Ichnofossils found at and within the vicinity of YUHO (NPS/VICTORIA CRYSTAL). Scale bars are 1 cm (0.4 in). **A.** YUHO 64. Likely traces of crustaceans. **B.** YUHO 147. Bounce mark of a *Prionocyclus* sp.

Fossil Localities

There are no outcrops within the monument, so all YUHO fossil localities are surficial. They are either: 1) fossiliferous slabs that were used by the Ancient Puebloans as building blocks and are now found as piles of building blocks that have eroded out of the structures; or 2) fossiliferous slabs found on the surface that have naturally been transported via intermittent flows of water and deposited on the surface. Thus, most fossil localities co-occur with archeological sites or within areas of active or recent deposition.

Since very little paleontological work has been done at YUHO, fossil localities identified prior to the 2021 paleontological survey were limited to the work done by Mary Griffitts in the 1980s and 1990s. During this time, she conducted extensive fieldwork in YUHO and the surrounding area (within a radius of approximately 4 km (2.5 mi) of the monument within the Mud Creek and Towaoc 7.5′ Quadrangles and collected nearly 90% of the 101 fossils in the collection. Her study area extended from Aztec Divide north of the monument to the border of Ute Mountain Reservation south of the monument, and from the western boundary of MEVE east of the monument to the boundary of Ute Mountain Reservation west of the monument (Griffitts 2001). However, as described in the "2021 Paleontology Survey" section, the ICMS lacks specific locality information for the fossils that she collected, including latitude/longitude coordinates, GPS coordinates, or PLSS information. As such, only estimates of previously collected fossil localities can be made. Since fossil localities in YUHO occur as piles of building rubble, many of the previously collected localities within the monument are concentrated around the archeological sites.

Paleontological Localities near YUHO

Many of Mary Griffitts' fossil localities were outside the monument, but within 4 km (2.5 mi) of it. These include the nearest outcrops of the Juana Lopez Member of the Mancos Shale, approximately 0.8 km (0.5 mi) west of the monument, as well as other outcrops of Juana Lopez along low ridges that trend northeast–southwest in the area (Griffitts 2001). She also visited outcrops of other formations not present within the current YUHO boundaries including the Smoky Hill Member of the Mancos Shale and the Point Lookout Formation southeast of YUHO.

In addition, the rocks of nearby MEVE, 16 km (10 mi) east of YUHO, host a number of fossil localities. See Harrison et al. (2017) for details.

The University of Colorado Museum of Natural History has 21 fossil localities in Montezuma County, though none within YUHO or its immediate vicinity. The localities are primarily near the town of Mancos, Colorado, and the closest locality to YUHO is approximately 7.2 km (4.5 mi) southwest (T. Karim, UCM collections manager, written comm., May 2021).

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) and Santucci et al. (2021) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

The fossiliferous building stones in the structures built by the Ancestral Puebloans at YUHO are an example of fossils in a cultural context (Figure 3). Approximately 42% of the building stones are slabs of fossiliferous calcarenite from the Juana Lopez Member that contain fossils of the many bivalves and ammonites found at YUHO (Glowacki 2001; Thornberry-Ehrlich 2013). Sandstone blocks of the Naturita Formation or the Point Lookout Formation, which overlies the Mancos Shale and is exposed more than 5 km (3 mi) away from the structures, account for 39% of the building stones (Glowacki 2001; Thornberry-Ehrlich 2013), and igneous rocks eroded from the nearby Sleeping Ute Mountain are the remaining 19% (Ekren and Houser 1965; Glowacki 2001; Thornberry-Ehrlich 2013). These percentages are based upon assessment of building stone within the original monument boundary, not the buildings in the Karwick parcel expansion. Further studies of archeological sites in the Karwick parcel might change these overall percentages. The nearest outcrops of the Juana Lopez Member are 0.8 km (0.5 mi) to the west of the structures, which are most likely the source for the building stones (Griffitts 2001; MEVE unpublished records). While the buildings remain unexcavated, 38 of the fossil specimens in the YUHO collection at the MEVE Visitor and Research Center were specifically mentioned to have been found on the surface as building stones that eroded out of the structures (though many other specimens in the collection are likely eroded building stones as well). Many of these specimens are blocks bearing multiple fossils. Together the blocks specifically described as building stones contain approximately 15 *Baculites undulatus*, 12 *Inoceramus dimidius*, three *Inoceramus perplexus*, one *Prionocyclus novimexicanus*, approximately 15 *Prionocyclus wyomingensis*, and 11 *Scaphites warreni*.

During the 2021 paleontology survey, a *Prionocyclus* sp. fossil was found with a small (several mm [about 1/8 in] in diameter) hole in it (Figure 12A). It was initially thought that this hole was made by the Ancestral Puebloans to use as a jewelry pendant or other use. Archeologists from YUHO recently examined the hole and determined that it was not made by humans (T. Travis, pers. comm., 16 November 2021). Although this fossil turned out not to be in a cultural context, future paleontological surveys and discoveries may yield fossils in a cultural context.

A discussion of fossils has never been included during a tribal consultation for YUHO (G. Ives, MEVE supervisory compliance archaeologist, pers. comm., 8 November 2021). However, given the interconnected nature of the archeological and paleontological resources at YUHO, there may be value in doing so. As such, paleontological resources should be taken into consideration during discussions at any future tribal consultations (see “Paleontological Resource Management Recommendations”).

Museum Collections and Paleontological Archives

Museum Collections and Curation

Monument Collections

Fossils from YUHO and the surrounding area are currently held at the MEVE Visitor and Research Center. This new facility has state-of-the art climate-controlled storage and research facilities for the monument's archives and the three million objects in the collections. It has a LEED (Leadership in Energy and Environmental Design) Platinum certification (T. Travis, pers. comm., 21 September 2021).

In total, there are currently 101 fossil specimens housed at the MEVE Visitor and Research Center that were collected from YUHO and have been cataloged and assigned YUHO catalog numbers (Appendix B; the 11 specimens collected during the 2021 paleontology survey are still awaiting YUHO catalog numbers). Many of these specimens are slabs of calcarenite that contain multiple individual fossils. Specimens include bivalves (35 catalog numbers), ammonites (82 catalog numbers), trace fossils (two catalog numbers), and vertebrates (one catalog number). Many of the slabs contain fossils from multiple groups (e.g., some slabs contain both bivalves and ammonites). There are no fossils from YUHO currently cataloged as cultural objects.

The majority (~90%) of the fossils were collected by Mary Griffitts in the 1980s, 1990s, and early 2000s. Four fossils were collected by Marilyn Colyer (former MEVE Natural Resource Ranger), who assisted Mary Griffitts in the field. Descriptions and discussions of these fossils are included in Griffitts' 2001 report. Her work at YUHO focused on the monument itself, but also encompassed much of the surrounding area. As such, the specimens in the collection at the MEVE Visitor and Research Center were collected from within the monument, as well as within 4 km (2.5 mi) of the monument in all directions. See "Fossil Localities" for more information.

There are also two specimens in the collection that were collected by Dr. Jack Smith, who was a historian and chief of resources at MEVE in the 1950s and 1960s, and four specimens collected by M. W. H. Wirt, who was a graduate student (T. Travis, pers. comm., 21 September 2021).

Collections in Other Repositories

As of the date of publication, there are no other repositories known to have specimens collected at YUHO. The University of Colorado Museum of Natural History (UCM) has fossil collections from elsewhere within Montezuma County, Colorado, but none from YUHO or the immediate vicinity (T. Karim, written comm., May 2021).

Type Specimens

No fossil species have been described from YUHO specimens to date.

Archives

NPS Paleontology Archives

All data, references, images, maps and other information used in the development of this report are maintained in the NPS Paleontology Archives and Library. These records consist of both park-specific and servicewide information pertaining to paleontological resources documented throughout the NPS. If any resources are needed by YUHO staff, or additional questions arise regarding paleontological resources, contact the NPS Senior Paleontologist & Paleontology Program Coordinator Vincent Santucci, vincent_santucci@nps.gov. Staff are also encouraged to communicate new discoveries to the NPS Paleontology Program, not only when support is desired, but in general, so that this information can be incorporated into the archives. A description of the Archives and Library can be found in Santucci et al. (2018).

E&R Files

E&R files (from "Examination and Report on Referred Fossils") are unpublished internal USGS documents. For more than a century, USGS paleontologists identified and prepared informal reports on fossils sent to the survey by other geologists, for example to establish the relative age of a formation or to help correlate beds. The system was eventually formalized as a two-part process including a form sent by the transmitting geologist and a reply by the survey geologist. Sometimes the fossil identifications were incorporated into publications, but in many cases this information is unpublished. These E&R files include documentation of numerous fossil localities within current NPS areas, usually predating the establishment of the NPS unit in question and frequently unpublished or previously unrecognized. Extensive access to the original files was granted to the NPS by the USGS beginning in 2014 (Santucci et al. 2014). There are no E&R files known for YUHO as of the preparation of this report.

Photographic Archives

There are no photos of YUHO fossils currently in the photographic archives. However, photos taken during the 2021 paleontology survey, including photos of 17 specimens in the collection and nine fossils collected during the 2021 survey, have been provided to museum staff to add to the archives.

Park Paleontological Research

Current and Past Research

As of the time of publication, there are no current research permits at YUHO. The 2021 paleontology survey was conducted under permit number YUHO-2021-SCI-0002. Mary Griffitts' research on the bedrock geology of YUHO was conducted under permit YUHO-2000-Griffitts. Surficial geology at the monument was studied by Mary Gillam under permits YUHO-2002-SCI-0001 and YUHO-2003-SCI-0002.

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://irma.nps.gov/DataStore/Reference/Profile/572379). 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.*

Any collection of paleontological resources from an NPS area must be made under an approved research and collecting permit. The NPS maintains an online Research Permit and Reporting System (RPRS) database 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.

Interpretation

Current Long-Range Interpretive Plan

There is currently no long-range interpretive plan for YUHO (Kristy Sholly, chief of interpretation and visitor services at MEVE, 29 September 2021). There is, however, interpretive information available on the YUHO website (https://www.nps.gov/yuho/index.htm) and interpretive tours are available when MEVE and YUHO are at full staff and operating their full range of tours.

The acquisition of the Karwick parcel will allow for increased interpretation opportunities. Currently, access to the monument is through private property and there is very little signage directing visitors to the monument and no interpretive signs within the monument. The acquisition of the Karwick parcel will change the visitor access to the monument and provide a new approach to the site so visitors will no longer be accessing it through private property. The acquisition of the Karwick parcel also provides opportunities to develop infrastructure at YUHO (perhaps a visitor center with interpretive exhibits). A long-range interpretive plan will be developed following the acquisition as planning begins for infrastructure development. In addition to interpretive exhibits, this plan may also include a guided audio tour through the monument (Kristy Sholly, MEVE chief of interpretation and visitor services, pers. comm., 29 September 2021).

Prior to publication, excerpts from this report were used to make a short interpretive write-up about paleontology for the YUHO website. It includes information about past ecosystems and what fossils are present in the monument, with clear instructions for what visitors should do if they find fossils (https://www.nps.gov/yuho/paleontology-at-yucca-house.htm).

In contrast to YUHO, there is a detailed interpretive plan for MEVE, as well as a museum within the park. The museum focuses on archeological resources but has one small exhibit of paleontological resources. One of the fossil specimens on display comes from the YUHO collection (Figure 17). The specimen is a fossiliferous slab of Juana Lopez calcarenite that contains fossils of *Prionocyclus wyomingensis, Scaphites warreni,* and *Baculites undulatus*. Thus, while interpretation at YUHO is limited, fossils from YUHO still play a role in interpretation at MEVE. (Note: at time of publication, the museum is currently closed for renovations and due to the COVID-19 pandemic).

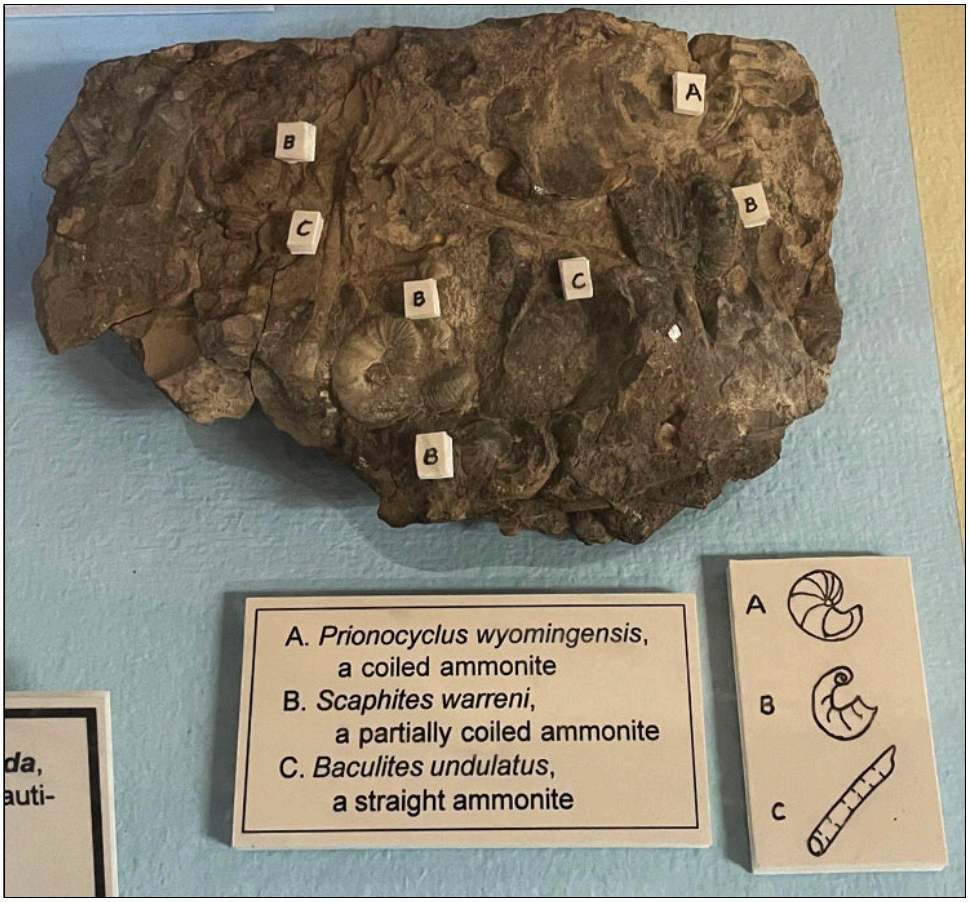


Figure 17. YUHO 16 on display in the MEVE museum (NPS/VICTORIA CRYSTAL).

Recommended Interpretive Themes

I. General Paleontological Information

All of the following interpretation topics include a section instructing visitors how to be paleontologically aware while in the monument. The ranger will provide the visitor with advice on 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 park boundaries.

- Fossils are non-renewable resources that possess scientific and educational 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 for planning 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 takes into the field include a field notebook for recording data and observations, small picks and brushes, consolidants to stabilize fossils, GPS, camera, topographic maps, and appropriate First Aid and safety equipment. These tools insure not only that fossils are collected safely, but also that associated information about the surrounding rocks is recorded. While a fossil itself is important, the information associated with it is at least

as important and is easily lost during collection. It might be helpful to provide examples of these items for visitors when giving an interpretive talk.

- 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. It is extremely important for scientific and resource management purposes for locational information to be preserved. Visitors should be informed that NPS fossils are protected by law.

II. Fossils of YUHO

- A program could be developed to educate the public on what types of fossils are present in YUHO and what they tell scientists about Earth's dynamic history. The goal of this program would be to increase visitors' understanding of local geology and paleontology. Any interpretation of paleontological resources should consider including a resource stewardship message. Information regarding fossils from the vicinity of YUHO can be included.

III. Further Interpretation Themes

Staff at YUHO should be sure to promote their paleontological resources and provide additional opportunities or programs for visitors to learn about fossils on National Fossil Day, celebrated annually on Wednesday of the second full week in October (National Earth Science Week). For more information on this event visit: https://www.nps.gov/subjects/fossilday/index.htm. The NPS coordinates the National Fossil Day partnership and hosts fossil-focused events across the country. Conducting one or more paleontology-focused activities on this day would be a perfect opportunity to not only increase public awareness about paleontological resources in YUHO, but also connect with other parks and museums who are also participating in this national event. The NPS Geologic Resources Division (GRD) can assist with planning for National Fossil Day activities and provide Junior Paleontologist Program supplies including activity booklets, badges, posters and other fossil-related educational resources (https://www.nps.gov/subjects/fossils/junior-paleontologist.htm).

Paleontological Resource Management and Protection

National Park Service Policy

Paleontological resources are non-renewable remains of past life preserved in a geologic context. At present, there are 423 official units of the National Park System, plus national rivers, national trails, and affiliated units that are not included in the official number. Of these units, 283 are known to have some form of paleontological resources. Paleontological resources are mentioned in the enabling legislation of 18 units. 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 protecting, monitoring, collecting, and curating these paleontological specimens from 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. More information on laws, policies, and authorities governing NPS management of paleontological resources is detailed in Appendix D. Paleontological resource protection training is available for NPS staff through the NPS GRD. GRD is also available to provide support in investigations of paleontological resource theft or vandalism.

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) is in the process 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 has reviewed public comments provided for the draft regulation and have drafted the final regulation. The final regulation has completed surnaming by the DOI Solicitor's Office and each of the four bureau directors. The final regulation has been forwarded for final review by DOI Assistant Secretaries. For more information regarding this act, visit https://www.nps.gov/subjects/fossils/fossil-protection.htm.

2006 National Park Service Management Policies (section 4.8.2.1) state

> *… 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. The Service will study and manage paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment).*
>
> *Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. 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. Fossil localities and associated geologic data will be adequately documented when specimens are collected. Paleontological resources found in an archeological context are also subject to the policies for archeological resources. Paleontological specimens that are to be retained permanently are subject to the policies for museum objects.

The Service will take appropriate action to prevent damage to and unauthorized collection of fossils. To protect paleontological resources from harm, theft, or destruction, the Service will ensure, where necessary, that information about the nature and specific location of these resources remains confidential, in accordance with the National Parks Omnibus Management Act of 1998.

All NPS construction projects in areas with potential paleontological resources must be preceded by a preconstruction surface assessment prior to disturbance. For any occurrences noted, or when the site may yield paleontological resources, the site will be avoided or the resources will, if necessary, be collected and properly cared for before construction begins. Areas with potential paleontological resources must also be monitored during construction projects.

Fossils have scientific, aesthetic, cultural, educational, and tourism value, and impacts to any of these values impairs their usefulness. Effective paleontological resource management protects fossil resources by implementing strategies that mitigate, reduce, or eliminate loss of fossilized materials and their relevant data. Because fossils are representatives of adaptation, evolution, and diversity of life through deep time, they have intrinsic scientific values beyond just the physical objects themselves. Their geological and geospatial contexts provide additional critical data concerning paleoenvironmental, paleogeographic, paleoecologic, and other conditions that together allow for 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 other contextual 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. These processes or activities influence the stability and condition of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). The greatest loss of associated contextual data occurs when fossils are removed from their original geological context without appropriate documentation. Thus, when a fossil weathers and erodes from its surrounding sediments and geologic context, it begins to lose significant ancillary data until, at some point, it becomes more a scientific curiosity than a useful piece of scientific data. A piece of loose fossil “float” can still be of scientific value. However, when a fossil has been completely removed from its original context, such as an unlabeled personal souvenir or a specimen with no provenance information in a collection, it is of very limited scientific utility. Similarly, fossils inadvertently exhumed during roadway construction or a building excavation may result in the loss or impairment of the scientific and educational values associated with those fossils. It is not necessary to list here all of the natural and anthropogenic factors 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, or the loss of the associated paleontological resource data.

Cave 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 this task at YUHO. 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 implementing effective management strategies, as it provides information for decision-making. This inventory report has compiled information on previous paleontological research done in and near YUHO, taxonomic groups that have been reported within YUHO 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 completed by Tweet et al. (2009) and the references cited within were important baseline paleontological resource data sources for this YUHO-specific report.

Paleontological Resource Monitoring

Paleontological resource monitoring is a significant part of paleontological resource management, and one which usually requires little to implement beyond time and equipment already on hand, such as cameras and GPS units. Monitoring enables the evaluation of the condition and stability of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). A monitoring program revolves around periodic site visits to assess conditions compared to a baseline for that site, with the periodicity depending on factors such as site productivity, accessibility, and significance of management issues. For example, a highly productive site which is strongly affected by erosion or unauthorized collection, and which can be easily visited by park staff, would be scheduled for more frequent visits than a less productive or less threatened site.

A monitoring program is generally implemented after an inventory has been prepared for a park and sites of concern have been identified, with additional sites added as necessary. Because each park is different, with different geology and paleontology among other factors, ideally each park that has in situ fossils or significant accumulations of reworked fossils would have its own monitoring protocol to define its monitoring program. Data accumulated via monitoring is used to inform further management decisions, such as the following questions: Is the site suitable for interpretation and education? Does the site require stabilization from the elements? Is collection warranted? Is there a need for some form of law enforcement presence?

Collection is recommended to be reserved for fossils possessing exceptional value (e.g., rare or high scientific significance) or at immediate risk of major degradation or destruction by human activity and natural processes. Therefore, paleontological resource monitoring is a more feasible potential management tool. The first step in establishment of a monitoring program is identification of localities to be monitored, as discussed previously. Locality condition forms are then used to evaluate factors that could cause loss of paleontological resources, with various conditions at each locality rated as good, fair, or poor. Risks and conditions 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. Sites with elevated fragility exhibit inherently soft rapidly eroding sediment or mass wasting on steep hillsides. A bedrock outcrop that is strongly lithified has low fragility. "Abundance" judges both the natural condition and number of specimens preserved in the deposits as well as the risk of being easily recognized as a fossil-rich area by non-paleontologists, which could lead to 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. A locality with high access would be in close proximity to public use areas or other access (along trails, at roadcuts, at beach or river access points, and so on).

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 document and/or collect exposed fossils in order to prevent or reduce losses. Localities with abundant or rare fossils, or high rates of erosion, may be considered for periodic monitoring in order to assess the stability and condition of the locality and resources, in regard to both natural processes and human-related activities. Localities that are easily accessible by road or trail would benefit from the same management strategies as those with abundant fossils and by occasional visits by park staff, documentation of in situ specimens, and/or frequent law enforcement patrols. Further information on paleontological resource monitoring can be found in Santucci and Koch (2003) and Santucci et al. (2009).

Foundation Documents and Resource Stewardship Strategies

Foundation documents and Resource Stewardship Strategies are two types of park planning documents that may contain and reference paleontological resource information. A foundation document is intended to provide basic guidance about a park for planning and management. It briefly describes a given park and its purpose, significance, fundamental resources and values, other importance resources and values, and interpretative themes. Mandates and commitments are also identified, and the state of planning is assessed. Foundation documents may include paleontological information and are also useful as a preliminary assessment of what park staff know about their paleontological resources, the importance they place on these resources, and the present state of these non-renewable resources. A foundation document for YUHO has been published (National Park Service 2015).

A Resource Stewardship Strategy (RSS) is a strategic plan intended to help park managers achieve and maintain desired resource conditions over time. It offers specific information on the current state of resources and planning, management priorities, and management goals over various time frames. An RSS for YUHO has not yet been published.

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at or beneath the land surface (Evans 2016). Colors and symbols on geologic maps correspond to geologic map units. The unit symbols consist of an uppercase letter indicating the age and lowercase letters indicating the formation's name. The American Geosciences Institute website (https://www.americangeosciences.org/environment/publications/mapping) provides more information about geologic maps and their uses. The NPS Geologic Resources Inventory (GRI) has been digitizing existing maps of NPS units and making them available to parks for resource management.

Geologic maps are one of the foundational elements of a paleontological resource management program. Knowing which sedimentary rocks and deposits underlie a park and where they are exposed are essential for understanding the distribution of known or potential paleontological resources. The ideal scale for resource management in the 48 contiguous states is 1:24,000 (maps for areas in Alaska tend to be coarser). Whenever possible, page-sized geologic maps derived from GRI files are included in paleontological resource inventory reports for reference, but park staff are encouraged to download GRI source files from IRMA. The source files can be explored in much greater detail and incorporated into the monument GIS database. Links to the maps digitized by the GRI for YUHO can be found in IRMA at https://irma.nps.gov/DataStore/Reference/Profile/2187477. In addition to a digital GIS geologic map, the GRI program also produces a park-specific report discussing the geologic setting, distinctive geologic features and processes within the monument, highlighting geologic issues facing resource managers, and describing the geologic history leading to the present-day landscape of the monument. A report for YUHO was produced by Thornberry-Ehrlich (2013); see https://irma.nps.gov/DataStore/Reference/Profile/2202881. The entire YUHO GRI project can be found in IRMA at https://irma.nps.gov/DataStore/Reference/Profile/2171449.

Paleontological Resource Potential Maps

A paleontological resource potential map is included in this report (Figure 18). The map shows the distribution of geologic units within a park that are known to have yielded fossils within the monument (green on Figure 18), have not yielded fossils within the monument but are fossiliferous elsewhere (yellow), or have not yielded fossils (red; no such units at YUHO). This map gives a quick indication of areas where fossils may be discovered, which in turn can provide suggestions for areas to survey or monitor, or areas where the discovery of fossils may be of concern during work that disturbs the ground (road work, building construction, etc.).

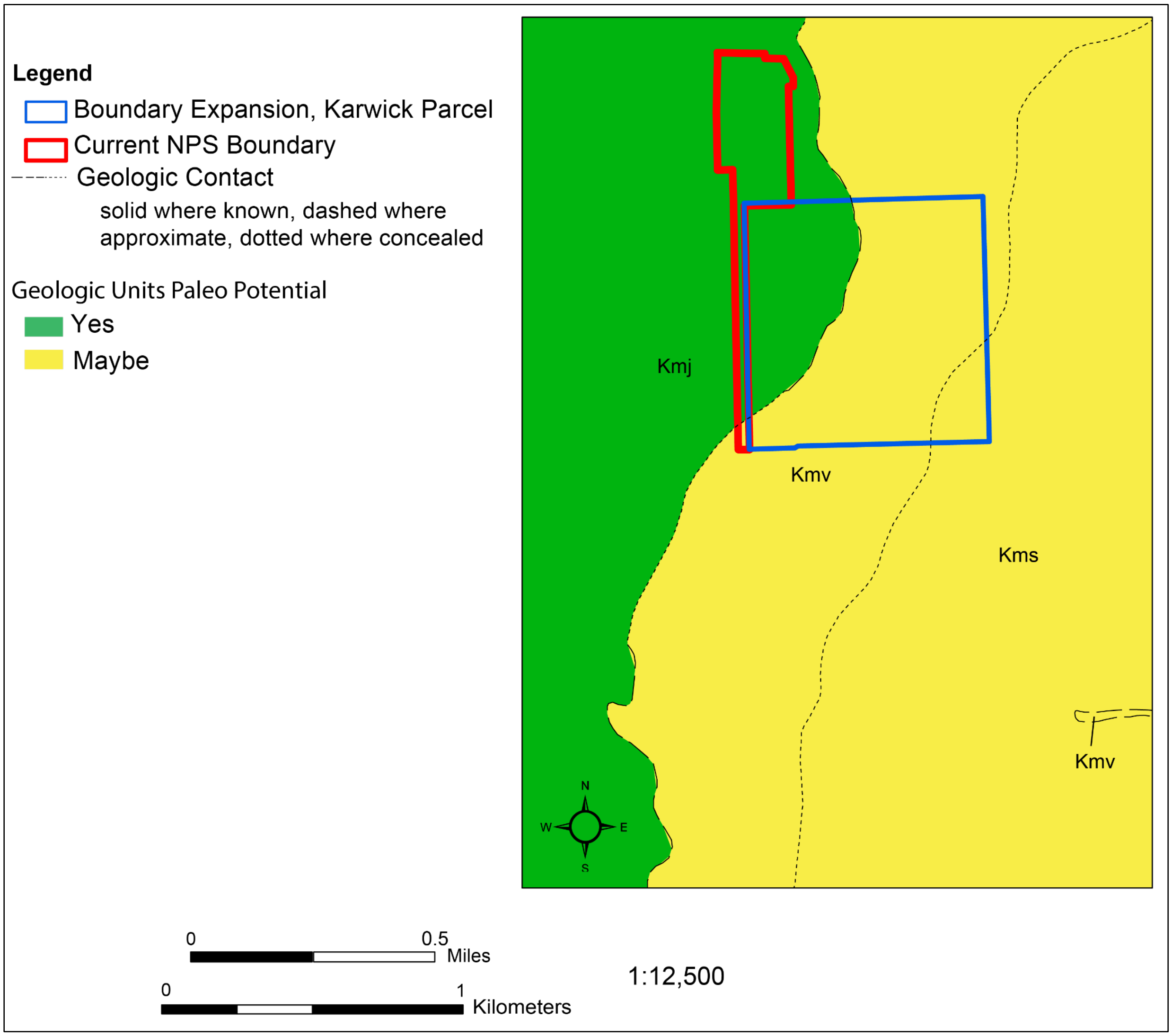


Figure 18. Map indicating paleontological potential of geologic map units (GRI). The Juana Lopez Member of the Mancos Shale has yielded fossils within YUHO and the Montezuma Valley and Smoky Hill Members are potentially fossiliferous. Geologic data from GRI digital geologic map data available at the following URL: https://irma.nps.gov/DataStore/Reference/Profile/2187477.

Paleontological Resource Management Recommendations

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

- YUHO 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 on recognizing common local fossils and basic documentation of fossils and localities. 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.
- YUHO 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 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. 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.
- Presently, there are no signs in the monument to indicate that fossil collection is prohibited. The addition of such signage could mitigate fossil theft.
- 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. A discussion of paleontological resources may need to be incorporated into tribal consultations. The GRD can coordinate additional documentation/research of such material.
- The active erosional processes occurring within YUHO contribute to naturally excavating and exposing paleontological resources, but they can also contribute to the destruction or removal of fossils. To address this, YUHO staff are encouraged to observe and document changes in the surface morphology and surficial deposits following large precipitation events or flooding.
- The monument staff may fund and recruit paleontology interns as a cost-effective means of enabling some level of paleontological resource support. The Scientists in Parks Program is an established program for recruitment of geology and paleontology interns (https://www.nps.gov/subjects/science/scientists-in-parks.htm).

- Contact the NPS Paleontology Program for technical assistance with paleontological resource management issues.

If fossil specimens are found by YUHO 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 YUHO. If possible, revisit the site when a GPS unit is available. Most smartphones can also record coordinates; if no GPS unit is available, attempt to record the coordinates with a phone.
- Record associated data, such as rock type, general description of the fossil, type of fossil if identifiable, general location in YUHO, sketch of the fossil, surroundings (in or associated with an archeological site, or loose on the ground), any associated fossils, and any other additional information.
- Do not remove the fossil unless it is loose in a heavily visited 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 tissue paper, and place in a labeled plastic bag with associated notes. Because YUHO 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.

Literature Cited

Carpenter, K. 2014. Where the sea meets the land—the unresolved Dakota problem in Utah. Pages 357–372 *in* J. S. MacLean, R. F. Biek, and J. E. Huntoon, editors. Geology of Utah's far south. Utah Geological Association, Salt Lake City, Utah. Publication 43.

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. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2191254 (accessed 9 December 2021).

Cobban, W. A. 1951. Scaphitoid cephalopods of the Colorado Group. U.S. Geological Survey, Washington, D.C. Professional Paper 239. Available at: https://pubs.er.usgs.gov/publication/pp239 (accessed 9 December 2021).

Conrad, T. A. 1857. Descriptions of Cretaceous and Tertiary fossils. Pages 141–174 *in* W. H. Emory. Report on the United States and Mexican boundary survey, made under the direction of the Secretary of the Interior. Volume I, Part II. A. O. P. Nicholson, printer, Washington, D.C. Available at: https://www.biodiversitylibrary.org/item/44522 (accessed 9 December 2021).

Corbett, M. J., and D. K. Watkins. 2014. Cenomanian through basal Coniacian calcareous nannofossil biostratigraphy of the Mancos Shale reference section, Mesa Verde National Park, CO. Stratigraphy 11(1):97–108.

d'Orbigny, A. 1850. Prodrome de Paléontologie stratigraphique universelle des animaux mollusques et rayonnés, vol. 2. V. Masson, Paris, France.

Dane, C. H., W. A. Cobban, and E. G. Kauffman. 1966. Stratigraphy and regional relationships of a reference section for the Juana Lopez Member, Mancos Shale, in the San Juan Basin, New Mexico. U.S. Geological Survey, Washington D.C. Bulletin 1224-H Available at https://pubs.er.usgs.gov/publication/b1224H (accessed 9 December 2021).

DeCelles, P. G., and K. A. Giles. 1996. Foreland basin systems. Basin Research 8(2):105–123.

Ekren, E. B. and F. N. Houser. 1965. Geology and petrology of the Ute Mountains area, Colorado. U.S. Geological Survey, Washington D.C. Profession Paper 481. Available at https://pubs.er.usgs.gov/publication/pp481 (accessed 9 December 2021).

Elder, W. P., and J. I. Kirkland. 1993. Cretaceous paleogeography of the Colorado Plateau and adjacent areas. Museum of Northern Arizona Bulletin 59:129–151.

Elder, W. P., and J. I. Kirkland. 1994. Cretaceous paleogeography of the southern Western Interior region. Pages 415–440 *in* M. V. Caputo, J. A. Peterson, and K. J. Franczyk, editors. Mesozoic System of the Rocky Mountain region, USA. Rocky Mountain Section, Society for Sedimentary Geology, Denver, Colorado.

Evans, T. J. 2016. General standards for geologic maps. Section 3.1 *in* M. B. Carpenter and C. M. Keane, compilers. The geoscience handbook 2016. AGI Data Sheets, 5th Edition. American Geosciences Institute, Alexandria, Virginia.

Fewkes, J. W. 1919. Prehistoric villages, castles, and towers of southwestern Colorado. Bureau of American Ethnology, Washington D.C. Bulletin 70. Available at https://repository.si.edu/handle/10088/15537 (accessed 9 December 2021).

Frizon de Lamotte, D., B. Fourdan, S. Leleu, F. Leparmentier, and P. de Clarens. 2015. Style of rifting and the stages of Pangea breakup. Tectonics 34(5):1009–1029.

Glowacki, D. M. 2001. Yucca House (5MT5006) mapping project. Mesa Verde National Park, Cortez, Colorado.

Glowacki, D. M., and F. M. Blackburn. 19 December 2019 (most recent edit). Yucca House National Monument. Colorado Encyclopedia. Available at: https://coloradoencyclopedia.org/article/yucca-house-national-monument (accessed 9 December 2021).

Gould, C. N. 1939. Geological Report on Yucca House National Monument. Southwestern National Monuments Supplement for November 1939. National Park Service, Santa Fe, New Mexico. Available at: http://npshistory.com/publications/yuho/geological-rpt.pdf (accessed 9 December 2021).

Gradstein, F. M., J. G. Ogg, M. D. Schmitz, and G. M. Ogg, editors. 2020. Geologic time scale 2020. Elsevier, Amsterdam, Netherlands.

Graham, J. 2006. Mesa Verde National Park Geologic Resource Evaluation Report. Natural Resource Report NPS/NRPC/GRD/NRR—2006/015. National Park Service, Denver, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/644395 (accessed 9 December 2021).

Graham, J. P. 2020. Grand Canyon National Park: Geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2020/2195. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2279886 (accessed 9 December 2021).

Griffitts, M. O. 2001. Bedrock geology and paleontology of Yucca House National Monument area. Internal report, National Park Service, Mesa Verde National Park, Cortez, Colorado.

Guido, Z. S., D. J. Ward, and R. S. Anderson. 2007. Pacing the post-last glacial maximum demise of the Animas Valley Glacier and the San Juan Mountain ice cap, Colorado. Geology 35(8):739–742.

Hamm, S. A. 2020. Stratigraphic, geographic and paleoecological distribution of the Late Cretaceous shark genus *Ptychodus* within the Western Interior Seaway, North America. New Mexico Museum of Natural History and Science Bulletin 81.

Harrison, G. W. M., J. S. Tweet, V. L. Santucci, and G. L. San Miguel. 2017. Mesa Verde National Park: Paleontological resource inventory (non-sensitive version). Natural Resource Report NPS/MEVE/NRR—2017/1550. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2246088 (accessed 9 December 2021).

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.

Hettinger, R. D., and M. A. Kirschbaum. 2002. Stratigraphy of the Upper Cretaceous Mancos Shale (upper part) and Mesaverde Group in the southern part of the Uinta and Piceance Basins, Utah and Colorado. U.S. Geological Survey, Reston, Virginia. Geologic Investigations Series 2764. Available at: https://pubs.er.usgs.gov/publication/i2764 (accessed 9 December 2021).

Holmes, W. H. 1878. Report on the ancient ruins of southwestern Colorado, examined during the summers of 1875 and 1876. United States Geological and Geographical Survey of the Territories Annual Report 10:383–408. Available at: https://www.biodiversitylibrary.org/item/104082 (accessed 9 December 2021).

Hook, S. C., and W. A. Cobban. 2012. Evolution of the Late Cretaceous oyster genus *Cameleolopha* Vyalov 1936 in central New Mexico. New Mexico Geology 34:76–95.

Keller, G. R., and W. S. Baldridge. 1999. The Rio Grande rift: A geological and geophysical overview. Rocky Mountain Geology 34(1):121–130.

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://irma.nps.gov/DataStore/Reference/Profile/2195223 (accessed 9 December 2021).

Kennedy, W. J., W. A. Cobban, and N. H. Landman. 2001. A revision of the Turonian members of the ammonite subfamily Collignoniceratinae from the United States Western Interior and Gulf Coast. Bulletin of the American Museum of Natural History 267.

Kottkamp, S., V. L. Santucci, J. S. Tweet, J. De Smet, and E. Starck. 2020. Agate Fossil Beds National Monument: paleontological resources management plan (public version). Natural Resource Report NPS/AGFO/NRR—2020/2172. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2278685 (accessed 9 December 2021).

Lake, E. T., and L. G. Farmer. 2015. Oligo-Miocene mafic intrusions of the San Juan Volcanic Field, southwestern Colorado, and their relationship to voluminous, caldera-forming magmas. Geochimica et Cosmochimica Acta 157:86–108.

Leckie, R. M., J. I. Kirkland, and W. P. Elder. 1997. Stratigraphic framework and correlation of a principal reference section of the Mancos Shale (Upper Cretaceous), Mesa Verde, Colorado.

Pages 163–216 *in* O. J. Anderson, B. Kues, and S. G. Lucas, editors. Mesozoic geology and paleontology of the Four Corners Region. New Mexico Geological Society, Socorro, New Mexico. Guidebook, 48th Field Conference.

Leckie, R. M., R. F. Yuretich, O. L. O. West, D. Finkelstein, and M. Schmidt. 1998. Paleoceanography of the southwestern Western Interior Sea during the time of the Cenomanian–Turonian boundary (Late Cretaceous). Pages 101–126 *in* W. E. Dean and M. A. Arthur, editors. Stratigraphy and paleoenvironments of the Cretaceous Western Interior Seaway, USA. Society for Sedimentary Geology (SEPM), Tulsa, Oklahoma. Concepts in Sedimentology and Paleontology 6.

Lipman, P. W., B. R. Doe, C. E. Hedge, and T. A. Steven. 1978. Petrologic evolution of the San Juan volcanic field, southwestern Colorado: Pb and Sr isotope evidence. Geological Society of America Bulletin 89(1):59–82.

Lucas, S. G. 2006. Type locality of the Late Cretaceous shark *Ptychodus whipplei* Marcou, northern New Mexico. New Mexico Museum of Natural History and Science Bulletin 35:157–159.

Lucas, S. G., and S. C. Johnson. 2003. Cretaceous invertebrate and selachian fossil assemblage from the Juana Lopez Member of the Mancos Shale near Herrera, west-central New Mexico. Pages 347–351 *in* S. G. Lucas, S. C. Semken, W. Berglof, and D. Ulmer-Scholle, editors. Geology of the Zuni Plateau. New Mexico Geological Society, Socorro, New Mexico. Guidebook, 54th Field Conference.

Lucas, S. G., and R. M. Sullivan. 1982. *Ichthyornis* in the Late Cretaceous Mancos Sale (Juana Lopez Member), northwestern New Mexico. Journal of Paleontology 56(2):545–547.

Marcou, J. 1858. Geology of North America. Zurcher and Furrer, Zurich, Switzerland. Available at: https://www.biodiversitylibrary.org/bibliography/129806 (accessed 9 December 2021).

McBride, R. C., and D. E. McBride. 2014. Cultural resource survey of the Bernard and Nancy Karwick property, Montezuma County, Colorado. Unpublished report submitted to History Colorado, Office of Archaeology and Historic Preservation, Denver, Colorado.

Meek, F. B. 1876a. Descriptions of Cretaceous fossils collected on the San Juan exploring expedition under Capt. J. N. Macomb, U.S. Engineers. Pages 119–133 *in* J. N. Macomb. Report of the exploring expedition from Santa Fe, New Mexico, to the junction of the Grand and Green Rivers of the great Colorado of the West in 1859. U.S. Army Engineer Department, Government Printing Office, Washington, D.C. Available at: https://www.biodiversitylibrary.org/bibliography/31763 (accessed 9 December 2021).

Meek, F. B. 1876b. A report on the invertebrate Cretaceous and Tertiary fossils of the Upper Missouri country. F.V. Hayden survey, U.S. Geological Survey of the Territories. Government Printing Office, Washington, D.C. Monograph 9. Available at: https://books.google.com/books?id=fdc8jR-RbRYC (accessed 9 December 2021).

Meek, F. B., and F. V. Hayden. 1860. Descriptions of new organic remains from the Tertiary, Cretaceous, and Jurassic rocks of Nebraska. Proceedings of the Academy of Natural Sciences of Philadelphia 12:175–185. Available at: https://www.biodiversitylibrary.org/page/1801632 (accessed 9 December 2021).

Merewether, E. A., D. A. Sawyer, and W. A. Cobban. 2006. Molluscan fossils and stratigraphic descriptions from the Upper Cretaceous Mancos Shale, west-central Colorado. U.S. Geological Survey, Reston, Virginia. Open-File Report 2006–1326. Available at: https://pubs.usgs.gov/of/2006/1326/ (accessed 9 December 2021).

National Park Service. Undated. Visitor Guide. Yucca House National Monument, Mesa Verde, Colorado. Available at: https://www.nps.gov/yuho/learn/historyculture/upload/yuhositebulletin_508.pdf (accessed 9 December 2021).

National Park Service. 2006. NPS Management Policies 2006. National Park Service, Washington, D.C. Available at: https://www.nps.gov/orgs/1548/upload/ManagementPolicies2006.pdf (accessed 9 December 2021).

National Park Service. 2015. Foundation document, Yucca House National Monument, Colorado (October 2015). YUHO 318/125647. Denver Service Center, Denver, Colorado. Available at: http://npshistory.com/publications/foundation-documents/yuho-fd-overview.pdf (accessed 9 December 2021).

Neuendorf, K. K. 2005. Glossary of geology. Springer Science & Business Media.

Nicollet, J. N. 1843. Report intended to illustrate a map of the hydrographical basin of the upper Mississippi river. Blair and Rives, Washington, D.C. Available at: https://www.biodiversitylibrary.org/item/74535 (accessed 9 December 2021).

Rink, G. R., and A. C. Cully. 2007. A checklist of the vascular flora of Yucca House National Monument and surrounding lands, Montezuma County, Colorado. The Journal of the Torrey Botanical Society 134(2):289–300.

Sampson, S. D., M. A. Loewen, A. A. Farke, E. M. Roberts, C. A. Forster, J. A. Smith, and A. L. Titus. 2010. New horned dinosaurs from Utah provide evidence for intracontinental dinosaur endemism. PLoS ONE 5(9):e12292. doi:10.1371/journal.pone.0012292. Available at: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0012292 (accessed 9 December 2021).

Santucci, B. A., C. A. Moneymaker, J. F. Lisco, and V. L. Santucci. 2021. An overview of paleontological resources preserved within prehistoric and historic structures. New Mexico Museum of Natural History and Science Bulletin 82:347–356. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2283741 (accessed 9 December 2021).

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://irma.nps.gov/DataStore/Reference/Profile/2201293 (accessed 9 December 2021).

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. Available at: https://irma.nps.gov/DataStore/Reference/Profile/573879 (accessed 9 December 2021).

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://irma.nps.gov/DataStore/Reference/Profile/2203105 (accessed 9 December 2021).

Santucci, V. L., J. M. Ghist, and R. B. Blodgett. 2014. Inventory of U.S. Geological Survey paleontology collections to identify fossil localities in National Park Service areas. Proceedings of the 10th Conference on Fossil Resources. Dakoterra 6:215–218. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2256493 (accessed 9 December 2021).

Santucci, V. L., J. S. Tweet, and T. B. Connors. 2018. The Paleontology Synthesis Project and establishing a framework for managing National Park Service paleontological resource archives and data. New Mexico Museum of Natural History and Science Bulletin 79:589–601. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2257152 (accessed 9 December 2021).

Scott, R., V. L. Santucci, and T. Connors. 2001. An inventory of paleontological resources from the national parks and monuments in Colorado. Pages 178–202 *in* V. L. Santucci and L. McClelland, editors. Proceedings of the 6th Fossil Resource Conference. NPS Paleontological Research Volume 6. Available at: http://npshistory.com/series/symposia/fossil-resources/6/proceedings.pdf (accessed 9 December 2021).

Semken, S. C., and W. C. McIntosh. 1997. $^{40}Ar/^{39}Ar$ age determinations for the Carrizo Mountains laccolith, Navajo Nation, Arizona. Pages 75–80 *in* O. Anderson, B. S. Kues, and S. G. Lucas, editors. Mesozoic geology and paleontology of the Four Corners region. New Mexico Geological Society, Socorro, New Mexico. Guidebook, 48th Field Conference.

Sowerby, J. D. C. 1826–1829. The mineral conchology of Great Britain; or coloured figures and descriptions of those testaceous animals or shells which have been preserved at various times and depths in the earth, vol. 6. London, United Kingdom. Available at: https://www.biodiversitylibrary.org/bibliography/14408 (accessed 9 December 2021).

Stanton, T.W. 1893. The Colorado formation and its invertebrate fauna. U.S. Geological Survey, Washington, D.C. Bulletin 106. Available at: https://pubs.er.usgs.gov/publication/b106 (accessed 9 December 2021).

Taylor, W. J., J. M. Bartley, M. W. Martin, J. W. Geissman, J. D. Walker, P. A. Armstrong, and J. E. Fryxell. 2000. Relations between hinterland and foreland shortening: Sevier orogeny, central North American Cordillera. Tectonics 19(6):1124–1143.

Thornberry-Ehrlich, T. L. 2013. Yucca House National Monument: geologic resources inventory report. Natural Resource Report. NPS/NRSS/GRD/NRR—2013/705. National Park Service. Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2202881 (accessed 9 December 2021).

Tokunaga, S., and S. Shimizu. 1926. The Cretaceous Formation of Futaba, and its fossils. Proceedings of the Imperial Academy 2(1):25–26.

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.

Walaszczyk, I., and W. A. Cobban. 2000. Inoceramid faunas and biostratigraphy of the Upper Turonian-Lower Coniacian of the Western Interior of the United States. Palaeontological Association, London, United Kingdom. Special Papers in Palaeontology 64.

Walaszczyk, I., and W. A. Cobban. 2006. Palaeontology and biostratigraphy of the Middle–Upper Coniacian and Santonian inoceramids of the US Western Interior. Acta Geologica Polonica 56(3):241–348.

Wegner, T. 1905. Die Granulatenkreide des westlichen Münsterlandes. Zeitschrift der Deutschen Geologischen Gesellschaft 57:112–232.

West, O. L. O., R. M. Leckie, and M. Schmidt. 1998. Foraminiferal paleoecology and paleoceanography of the Greenhorn cycle along the southwestern margin of the Western Interior Sea. Pages 79–99 *in* W. E. Dean and M. A. Arthur, editors. Stratigraphy and paleoenvironments of the Cretaceous Western Interior Seaway, USA. Society for Sedimentary Geology (SEPM). Tulsa, Oklahoma. Concepts in Sedimentology and Paleontology 6.

White, C. A. 1874. Preliminary report upon invertebrate fossils collected by the expeditions of 1871, 1872, and 1873, with descriptions of new species. U.S. Government Printing Office, Washington, D.C. United States Army Engineer Department, Geographical and Geological Explorations and Surveys West of the One Hundredth Meridian. Available at: https://www.biodiversitylibrary.org/item/70266 (accessed 9 December 2021).

Whitfield, R. P. 1877. Preliminary report on the paleontology of the Black Hills, containing descriptions of new species of fossils from the Potsdam, Jurassic, and Cretaceous formations of the Black Hills of Dakota. U.S. Government Printing Office, Washington, D.C. United States Geographical and Geological Survey of the Rocky Mountain Region. Available at: https://www.biodiversitylibrary.org/item/115774 (accessed 9 December 2021).

Young, R. G. 1960. Dakota Group of Colorado Plateau. Bulletin of the American Association of Petroleum Geologists 44(2):156–194.

Young, R. G. 1965. Type section of the Naturita Formation. Bulletin of the American Association of Petroleum Geologists 49(9):1512–1531.

Appendix A: Paleontological Species List

The following table (Appendix Table A-1) documents the fossil species found at or near YUHO in stratigraphic context, as reported in the literature, in museum collections, and through personal observations. The rows are organized systematically, placing taxa of the same broad groups or categories together (first column). The columns also include the taxon (second column), geologic unit (third column), presence or absence within YUHO (fourth column), collection information (fifth column), and references (last column; included in "Literature Cited" above). For the fourth column, if a taxon has been found within YUHO, the cell is marked "Y". "Y" records were either observed in the field in 2021 or are museum specimens with enough locality information to place them within YUHO. If a taxon has been found near but not within YUHO, and therefore might eventually be found within the monument, the cell is marked "N". These records are based on specimens from the YUHO collection at MEVE with enough locality information to place them outside of YUHO. One taxon represented by a museum record has insufficient information to determine the status of the locality, so is marked "?". Dashes ("–") are used for null records.

The taxonomic histories of many Upper Cretaceous mollusks are convoluted. For reference, the original citation is included with the taxon name. Per standard convention, the citations for species that are no longer classified under their original genus are in parentheses, e.g. *Cameleolopha lugubris* (Conrad 1857; originally *Ostrea*) versus *Inoceramus dimidius* White 1874. Relevant species that have been synonymized with other species are listed below:

- *Inoceramus* (*Volviceramus*) *grandis* = *Volviceramus involutus*, Walaszczyk and Cobban 2006.
- *Inoceramus* (*Platyceramus*) *platinus* = *Platyceramus cycloides* (Wegner 1905), Walaszczyk and Cobban 2006.

Appendix Table A-1. Fossil taxa reported from or near YUHO in stratigraphic context. References are provided where appropriate.

Group	Taxon	Geologic Unit	Within YUHO?	Collection	Reference(s):
Invertebrata: Mollusca: Bivalvia (clams, oysters, etc.)	*Cameleolopha lugubris* (Conrad 1857)	Juana Lopez Member	Y	MEVE collection	Griffitts 2001; Scott et al. 2001
	Inoceramus dimidius White 1874	Juana Lopez Member	Y	MEVE collection	Griffitts 2001; Scott et al. 2001
	Inoceramus perplexus Whitfield 1877	Juana Lopez Member	Y	MEVE collection	Griffitts 2001; Scott et al. 2001
	Platyceramus cycloides (Wegner 1905)	Smoky Hill Member	N	–	Scott et al. 2001
	Pseudoperna congesta (Conrad *in* Nicollet 1843)	Smoky Hill Member	N	MEVE collection	Griffitts 2001; Scott et al. 2001
	Pycnodonte newberryi (Stanton 1893)	Graneros Shale and Bridge Creek Members	N	MEVE collection	Leckie et al. 1997; Griffitts 2001
	Pycnodonte sp. or *Rhynchostreon* sp.	Juana Lopez Member	Y	MEVE collection	–
	Volviceramus involutus (Sowerby 1826–1829)	Smoky Hill Member	N	MEVE collection	Griffitts 2001; Scott et al. 2001
Invertebrata: Mollusca: Ammonoidea (ammonites)	*Baculites undulatus* d'Orbigny 1850	Juana Lopez Member	Y	MEVE collection	Griffitts 2001; Scott et al. 2001
	Baculites yokoyamai Tokunaga and Shimizu 1926	Juana Lopez Member	Y	MEVE collection	Griffitts 2001; Scott et al. 2001
	Prionocyclus cf. *P. macombi* Meek 1876a	Juana Lopez Member	N	MEVE collection	Griffitts 2001
	Prionocyclus novimexicanus (Marcou 1858)	Juana Lopez Member	Y	MEVE collection	Griffitts 2001; Scott et al. 2001
	Prionocyclus wyomingensis Meek 1876b	Juana Lopez Member	Y	MEVE collection	Griffitts 2001; Scott et al. 2001
	Scaphites ferronensis Cobban 1951	Juana Lopez Member	N	MEVE collection	–
	Scaphites warreni Meek and Hayden 1860	Juana Lopez Member	Y	MEVE collection	Griffitts 2001; Scott et al. 2001
	Scaphites whitfieldi Cobban 1951	Juana Lopez Member	Y	MEVE collection	Griffitts 2001; Scott et al. 2001
Vertebrata	Vertebrata undetermined	Juana Lopez Member	?	MEVE collection	–
Ichnofossils	Crustacean (trace)	Juana Lopez Member	N	MEVE collection	–

Appendix B: YUHO Specimens in MEVE Collections

The following table presents the unpublished museum records of the 101 YUHO specimens in the collection at MEVE, representing a mix of specimens found within and near the monument. At the time of publication of this report, the 11 fossils collected during the 2021 paleontology survey have not yet been assigned catalog numbers.

Appendix Table B-1. Unpublished YUHO paleontological records from the collection at MEVE Visitor and Research Center; not all specimens were found within YUHO boundaries.

Specimen Catalog #	Taxa Present
YUHO 16	*Baculites undulatus*, *Prionocyclus wyomingensis*, *Scaphites warreni*
YUHO 17	*Baculites undulatus*, *Scaphites warreni*
YUHO 18	*Inoceramus dimidius*, *Baculites undulatus*, *Prionocyclus wyomingensis*
YUHO 19	*Prionocyclus wyomingensis*, *Scaphites warreni*
YUHO 42	*Scaphites warreni*
YUHO 43	*Inoceramus dimidius*, *Scaphites warreni*
YUHO 44	*Inoceramus dimidius*, *Baculites undulatus*, *Prionocyclus wyomingensis* (fragments), *Scaphites warreni*
YUHO 45	*Inoceramus dimidius*, *Baculites undulatus*
YUHO 46	*Scaphites* cf. *S. warreni*
YUHO 47	*Inoceramus perplexus*
YUHO 48	*Inoceramus* sp.
YUHO 49	*Baculites yokoyamai*, *Prionocyclus novimexicanus*
YUHO 50	*Inoceramus dimidius*, *Baculites undulatus*, *Scaphites warreni*
YUHO 51	*Inoceramus perplexus*, *Baculites undulatus*, fragment of *Prionocyclus* sp. and *Scaphites* sp.
YUHO 52	*Baculites undulatus*
YUHO 53	*Inoceramus dimidius*, *Baculites undulatus*
YUHO 54	*Scaphites warreni*
YUHO 55	*Baculites undulatus*, *Prionocyclus wyomingensis*, *Scaphites* sp., vertebrate
YUHO 56	*Baculites undulatus*, *Scaphites warreni*
YUHO 57	*Baculites* cf. *B. undulatus*
YUHO 58	*Baculites undulatus*, *Prionocyclus wyomingensis*, *Scaphites warreni*
YUHO 59	*Inoceramus dimidius*, *Baculites undulatus*, *Prionocyclus wyomingensis*
YUHO 60	*Inoceramus dimidius*, *Baculites undulatus*, *Prionocyclus wyomingensis*
YUHO 61	*Prionocyclus wyomingensis*
YUHO 62	*Inoceramus perplexus*
YUHO 63	*Inoceramus perplexus*
YUHO 64	Track, in situ; probably crustacean
YUHO 65	*Baculites undulatus*
YUHO 66	*Inoceramus dimidius*

Appendix Table B-1 (continued). Unpublished YUHO paleontological records from the collection at MEVE Visitor and Research Center; not all specimens were found within YUHO boundaries.

Specimen Catalog #	Taxa Present
YUHO 67	*Inoceramus dimidius*
YUHO 68	*Prionocyclus wyomingensis*
YUHO 69	*Inoceramus dimidius*
YUHO 70	*Inoceramus dimidius*
YUHO 71	*Baculites undulatus*, *Scaphites* cf. *S. warreni*
YUHO 72	*Baculites undulatus*, *Prionocyclus wyomingensis*
YUHO 73	*Inoceramus dimidius*
YUHO 74	*Inoceramus dimidius*
YUHO 75	*Scaphites warreni*
YUHO 76	*Baculites undulatus*
YUHO 77	*Prionocyclus novimexicanus*
YUHO 78	*Prionocyclus wyomingensis*
YUHO 79	*Baculites undulatus*, *Prionocyclus wyomingensis*, *Scaphites warreni*
YUHO 80	*Inoceramus dimidius*, *Baculites undulatus*, *Prionocyclus wyomingensis*, *Scaphites warreni*
YUHO 81	*Inoceramus dimidius*, *Baculites undulatus*, *Prionocyclus wyomingensis*
YUHO 85	*Prionocyclus wyomingensis*, *Scaphites warreni*
YUHO 86	*Prionocyclus wyomingensis*
YUHO 87	*Prionocyclus wyomingensis*
YUHO 88	*Inoceramus perplexus*, *Baculites undulatus*
YUHO 89	*Prionocyclus wyomingensis*
YUHO 90	*Prionocyclus wyomingensis*
YUHO 91	*Prionocyclus novimexicanus*
YUHO 92	*Baculites undulatus*, *Prionocyclus wyomingensis*
YUHO 93	*Inoceramus dimidius*, *Inoceramus* sp., *Prionocyclus wyomingensis*
YUHO 94	*Baculites undulatus*
YUHO 95	*Scaphites warreni*
YUHO 96	*Prionocyclus wyomingensis*
YUHO 97	*Prionocyclus wyomingensis*
YUHO 98	*Scaphites* cf. *S. whitfieldi*
YUHO 99	*Prionocyclus* cf. *P. novimexicanus*
YUHO 100	*Prionocyclus* cf. *P. macombi*
YUHO 101	*Prionocyclus novimexicanus*
YUHO 109	*Baculites undulatus*, *Prionocyclus* cf. *P. wyomingensis*
YUHO 110	*Prionocyclus wyomingensis*
YUHO 111	*Inoceramus dimidius*
YUHO 112	*Inoceramus perplexus*, *Baculites undulatus*, *Scaphites warreni*
YUHO 113	*Inoceramus dimidius*, *Prionocyclus wyomingensis*

Appendix Table B-1 (continued). Unpublished YUHO paleontological records from the collection at MEVE Visitor and Research Center; not all specimens were found within YUHO boundaries.

Specimen Catalog #	Taxa Present
YUHO 114	*Prionocyclus wyomingensis*
YUHO 115	*Baculites undulatus*
YUHO 116	*Baculites undulatus*
YUHO 117	*Scaphites warreni*
YUHO 140	*Prionocyclus wyomingensis*
YUHO 141	*Prionocyclus novimexicanus*
YUHO 142	*Prionocyclus wyomingensis*, *Scaphites warreni*
YUHO 143	*Cameleolopha lugubris*, *Inoceramus dimidius*, *Prionocyclus* cf. *P. wyomingensis*
YUHO 144	*Prionocyclus wyomingensis*, *Scaphites warreni*
YUHO 145	*Cameleolopha lugubris*
YUHO 146	*Pycnodonte newberryi*
YUHO 147	Trace of *Prionocyclus* sp.
YUHO 148	*Cameleolopha lugubris*, *Scaphites warreni*
YUHO 149	*Prionocyclus wyomingensis*
YUHO 150	*Cameleolopha lugubris*, *Prionocyclus* sp., *Scaphites ferronensis*
YUHO 151	*Inoceramus dimidius*
YUHO 152	*Cameleolopha lugubris*, *Prionocyclus* sp., *Scaphites ferronensis*
YUHO 153	*Prionocyclus wyomingensis*
YUHO 154	*Scaphites* cf. *S. ferronensis*
YUHO 155	*Prionocyclus wyomingensis*
YUHO 156	*Prionocyclus wyomingensis*
YUHO 157	*Inoceramus perplexus*, *Baculites yokoyamai*, *Prionocyclus* sp., *Scaphites* cf. *S. whitfieldi*
YUHO 158	*Pseudoperna congesta* on *Volviceramus involutus*
YUHO 159	*Inoceramus perplexus*, *Baculites yokoyamai*, *Prionocyclus* sp.
YUHO 160	*Prionocyclus* cf. *P. wyomingensis*, *Scaphites* sp.
YUHO 1026	*Cameleolopha lugubris*
YUHO 1027	*Scaphites warreni*
YUHO 1028	*Inoceramus dimidius*, *Scaphites warreni*
YUHO 1029	*Prionocyclus wyomingensis*, *Scaphites* sp.
YUHO 1030	*Inoceramus dimidius*, *Scaphites warreni*
YUHO 1031	*Cameleolopha lugubris*
YUHO 1032	*Baculites undulatus*, *Prionocyclus wyomingensis*, *Scaphites warreni*
YUHO 1033	*Inoceramus* sp., *Pseudoperna congesta*
YUHO 1034	*Prionocyclus wyomingensis*
YUHO 1035	*Inoceramus dimidius*, *Prionocyclus wyomingensis*

Appendix C: YUHO Repository Contact Information

MESA VERDE NATIONAL PARK
Visitor and Research Center
35853 Rd H.5
Mancos, CO 81328
970-529-4465
https://www.nps.gov/meve/planyourvisit/meve_vc.htm

Appendix D: Paleontological Resource Law and Policy

The following material is reproduced in large part from Henkel et al. (2015); see also Kottkamp et al. (2020):

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 [E]arth's crust, that are of paleontological interest and that provide information about the history of life on [E]arth.*

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. The proper management and preservation of these non-renewable resources 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 and a park management program will probably incorporate multiple options depending on specific circumstances:

- **No action**—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 by visitors, either intentionally or unintentionally. This is the least preferable plan of action of those listed here.
- **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. A standard version of this form will be provided by the Paleontology Program of the Geologic Resources Division upon request and can be modified to account for local conditions and needs.

- **Monitoring**—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**—areas of high erosion which also have a high potential for producing significant specimens would be examined periodically for new sites. The periodicity of such cyclic prospecting will depend on locality-specific characteristics such as rates of sediment erosion, abundance or rarity of fossils, and proximity to visitor use areas.
- **Stabilization and reburial**—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. In some situations, stabilization of a locality may require the consideration of vegetation. For example, roots can destroy in situ fossils, but can also protect against slope erosion, while plant growth can effectively obscure localities, which can be positive or negative depending on how park staff want to manage a locality.
- **Shelter construction**—it may be appropriate to exhibit certain fossil sites or specimens in situ, which would require the construction of protective shelters to protect them from the natural forces of weathering and erosion. The use of shelters draws attention to the fossils and increases the risk of vandalism or theft, but also provides opportunities for interpretation and education.
- **Excavation**—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**—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. In some situations, a volunteer site stewardship program may be appropriate (for example the "Paleo Protectors" at Chesapeake & Ohio Canal National Historical Park).
- **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, the National Park Service established National Fossil Day as a celebration and partnership 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). National Fossil Day occurs annually on Wednesday of the second full week in each October in conjunction with Earth Science Week.

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).

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

Section 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.*

Federal Cave Resources Protection Act of 1988 (16 USC 4301)

This law provides a legal authority for the protection of all cave resources on NPS and other federal lands. The definition for "Cave Resource" in Section 4302 states

> *Cave resources include any material or substance occurring naturally in caves on Federal lands, such as animal life, plant life, paleontological deposits, sediments, minerals, speleogens, and speleothems.*

NPS Management Policies 2006

National Park Service Management Policies 2006 include direction for preserving and protecting cultural resources, natural resources, processes, systems, and values (National Park Service 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. The following is taken from section 4.8.2.1 of the NPS Management Policies 2006, "Paleontological Resources and their contexts":

> *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. The Service will study and manage paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment).*
>
> *Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. 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. Fossil localities and associated geologic data will be adequately documented when specimens are collected. Paleontological resources found in an archeological context are also subject to the policies for archeological resources. Paleontological specimens that are to be retained permanently are subject to the policies for museum objects.*
>
> *The Service will take appropriate action to prevent damage to and unauthorized collection of fossils. To protect paleontological resources from harm, theft, or destruction, the Service will ensure, where necessary, that information about the nature and specific location of these resources remains confidential, in accordance with the National Parks Omnibus Management Act of 1998.*
>
> *Parks will exchange fossil specimens only with other museums and public institutions that are dedicated to the preservation and interpretation of natural heritage and qualified to manage museum collections. Fossils to be deaccessioned in an exchange must fall outside the park's scope of collection statement. Systematically collected fossils in an NPS museum collection in compliance with 36 CFR 2.5 cannot be outside the scope of collection statement. Exchanges must follow deaccession procedures in the Museum Handbook, Part II, chapter 6.*
>
> *The sale of original paleontological specimens is prohibited in parks.*
>
> *The Service generally will avoid purchasing fossil specimens. Casts or replicas should be acquired instead. A park may purchase fossil specimens for the park museum collection only after making a written determination that*

- *The specimens are scientifically significant and accompanied by detailed locality data and pertinent contextual data;*
- *The specimens were legally removed from their site of origin, and all transfers of ownership have been legal;*
- *The preparation of the specimens meets professional standards;*
- *The alternatives for making these specimens available to science and the public are unlikely;*
- *Acquisition is consistent with the park's enabling legislation and scope of collection statement, and acquisition will ensure the specimens' availability in perpetuity for public education and scientific research.*

> *All NPS construction projects in areas with potential paleontological resources must be preceded by a preconstruction surface assessment prior to disturbance. For any occurrences noted, or when the site may yield paleontological resources, the site will be avoided or the resources will, if necessary, be collected and properly cared for before construction begins. Areas with potential paleontological resources must also be monitored during construction projects.*

(See Natural Resource Information 4.1.2; Studies and Collections 4.2; Independent Research 5.1.2; and Artifacts and Specimens 10.2.4.6 in National Park Service 2006, available here. Also see 36 CFR 2.5.)

NPS Director's Order-77, Paleontological Resources Management

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 and Santucci (2012):

Monitoring

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. If a park does not have this information, there may be opportunities to set up joint projects, because erosion affects more than just paleontological resources.

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: YUHO Paleontology Locality Data

Sensitive locality information has been removed from this version of the inventory report. Qualified researchers can contact YUHO staff for more information.

Appendix F: Glossary

This glossary contains definitions of selected terms used in this report. Most of the definitions are from the YUHO GRI report (Thornberry-Ehrlich 2013) and are based on those in the American Geosciences Institute Glossary of Geology (Neuendorf 2005).

Bedrock. A general term for the rock that underlies soil or other unconsolidated, surficial material.

Bentonite. A clay produced by weathering of the volcanic glass particles that make up volcanic ash.

Bioclastic. Describes rock or sediment made of fragments of biologic materials (e.g., shell fragments).

Brachiopod. A shelled invertebrate resembling a bivalve mollusk but with a much different internal anatomy.

Calcareous. Describes rock or sediment that contains the mineral calcium carbonate ($CaCO_3$), often as a cement.

Calcarenite. A limestone consisting predominantly of sand-size carbonate grains; a consolidated calcareous sand. Many of these beds in the Juana Lopez Member are informally referred to as inoceramites, as they are composted of prismatic calcite from inoceramid shells.

Carbonate. A mineral that has CO_3^{-2} as its essential component (e.g., calcite and aragonite).

(Natural) Cast. In paleontology, sediment-filled external molds of an organism.

Cementation. Chemical precipitation of material into pores between grains that bind the grains into rock.

Clast. An individual grain or rock fragment in a sedimentary rock, produced by the physical disintegration of a larger rock mass.

Clastic. Describes rock or sediment made of fragments of pre-existing rocks (clasts).

Clay. Can be used to refer to clay minerals or as a sedimentary fragment size classification (less than 1/256 mm [0.00015 in]).

Cross-bedding (cross-stratification). Uniform to highly varied sets of inclined sedimentary beds deposited by wind or water that indicate flow conditions such as water flow direction and depth.

Cross section. A graphical interpretation of geology, structure, and/or stratigraphy in the third (vertical) dimension based on mapped and measured geological extents and attitudes depicted in a vertically oriented plane.

Epifauna. Aquatic animals that live on the seafloor.

Faunal zone. An assemblage of specific fossils with a limited vertical extent in a formation or other geologic unit, representing a specific interval in time.

Fluvial. Pertaining to rivers.

Foraminifer. A generally microscopic single-celled organism usually with a protective external structure; an “amoeba with a shell”.

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

Great House. A large, multistory Ancestral Puebloan structure.

Gully. A small channel produced by running water in earth or unconsolidated material (e.g., soil or a bare slope).

Ichnofossil. Trace fossil; fossil evidence of the activities of past organisms, such as burrows, tracks, root traces, feeding marks, fossilized dung, and layers produced by microbial mats.

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

Involute. In descriptions of coiled shells, a coil that is tightly curled or spiraled.

Kiva. A ceremonial structure, generally subterranean and with a circular floorplan.

Laccolith. An igneous intrusion with a domed upper surface, caused by magma intrusion under enough pressure to fold overlying rocks.

Limestone. A sedimentary rock consisting mainly of calcium carbonate, primarily in the form of the mineral calcite.

Mass wasting. A general term for the downslope movement of soil and rock material under the direct influence of gravity.

Member. A lithostratigraphic unit with definable contacts; a member is a subdivision of a formation.

(Natural) Mold. In paleontology, internal or external impressions of organisms.

Orogeny. A mountain-building event.

Paleogeography. The study, description, and reconstruction of the physical landscape from past geologic periods.

Pediment. A gently sloping, erosional bedrock surface and associated sediment. As defined by Gregory, extending out from the foot of mountains or plateau escarpments; paleo-valley floors.

Plesiosaur. An extinct paddle-limbed marine reptile found in Triassic, Jurassic, and Cretaceous rocks; most had either a long neck with a small head, or a short neck with a large head.

PLSS. Public Land Survey System.

Recrystallization. Reorganization of a mineral's structure under the influence of temperature, pressure, and/or chemically active fluids.

Regression. A long-term seaward retreat of the shoreline or relative fall of sea level.

Sand. A clastic particle smaller than a granule and larger than a silt grain, having a diameter in the range of 1/16 mm (0.0025 in) to 2 mm (0.08 in).

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

Sediment. An eroded and deposited, unconsolidated accumulation of rock and mineral fragments.

Sedimentary rock. A consolidated and lithified rock consisting of clastic and/or chemical sediment(s). One of the three main classes of rocks—igneous, metamorphic, and sedimentary.

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

Sheet flow. An overland flow or downslope movement of water taking the form of a thin, continuous film over relatively smooth soil or rock surfaces and not concentrated into channels larger than rills.

Silt. Clastic sedimentary material intermediate in size between fine-grained sand and coarse clay (1/256 to 1/16 mm [0.00015 to 0.002 in]).

Siltstone. A clastic sedimentary rock composed of silt-sized grains.

Slope. The inclined surface of any geomorphic feature or measurement thereof. Synonymous with "gradient."

Soil. Surface accumulation of weathered rock and organic matter capable of supporting plant growth and often overlying the parent material from which it formed.

Sole mark. An inorganic feature found at the contact of two beds, generally a groove or other scour incised into the underlying bed.

Spring. A site where water issues from the surface due to the intersection of the water table with the ground surface.

Stratification. The accumulation or layering of sedimentary rocks in strata. Tabular, or planar, stratification refers to essentially parallel surfaces. Cross-stratification refers to strata inclined at an angle to the main stratification.

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

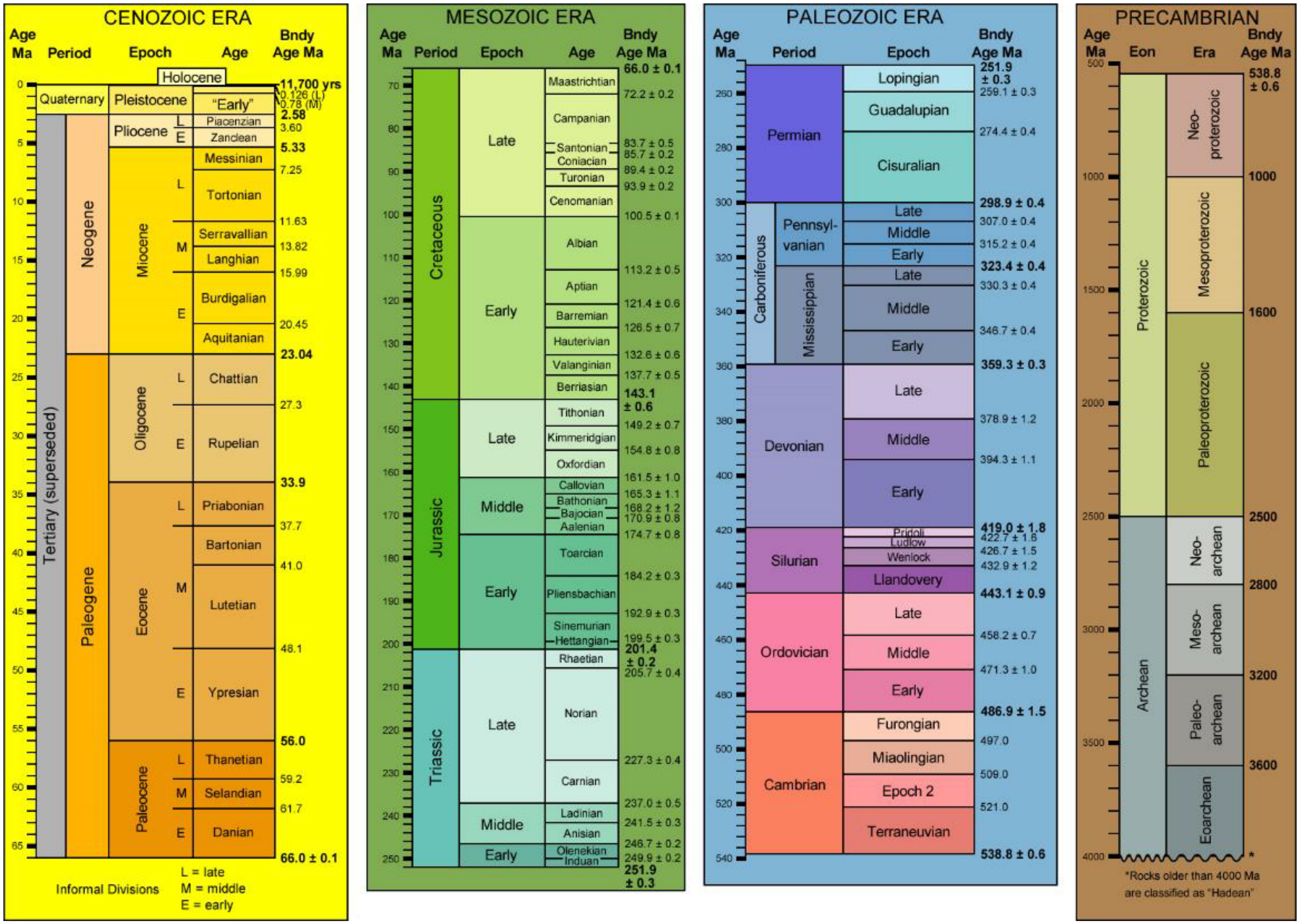
Transgression. Landward migration of the sea as a result of a relative rise in sea level.

Valve. A shell; a bivalve has two valves.

Wash. A term used especially in the southwestern united states for the broad, gravelly dry bed of an intermittent stream, generally in the bottom of a canyon; it is occasionally swept by a torrent of water.

Weathering. The physical, chemical, and biological processes by which rock is broken down.

Appendix G: Geologic Time Scale



Ma=Millions of years old. **Bndy Age**=Boundary Age. Layout after 1999 Geological Society of America Time Scale (https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf). Dates after Gradstein et al. (2020).

NPS 318/180509, May 2022

National Park Service
U.S. Department of the Interior

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