National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Mesa Verde National Park

Paleontological Resource Inventory (Non-Sensitive Version)

Natural Resource Report NPS/MEVE/NRR—2017/1550

ON THE COVER

An undescribed chimaera (ratfish) egg capsule of the ichnogenus *Chimaerotheca* found in the Cliff House Sandstone of Mesa Verde National Park during the work that led to the production of this report.

Photograph by: G. William M. Harrison/NPS Photo (Geoscientists-in-the-Parks Intern)

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November 2017

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

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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, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

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Please cite this publication as:

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.

NPS 307/140595, November 2017

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Executive Summary

Although there is a long history of geological study in and around Mesa Verde National Park (MEVE), and outcrops at and around the cuesta have been used to provide names and definitions for several formations, the fossils of the park have attracted limited attention. MEVE's rocks contain a detailed record of about 10 to 15 million years of shifting coastal and marine environments in the Late Cretaceous, approximately 90 to 75 Ma (million years ago). The surficial deposits of the park have been explored to a limited extent and have produced some paleoecological materials, including pollen of Holocene age.

Fossils found in MEVE's Cretaceous rocks represent organisms from a variety of settings, from calm offshore marine waters to coastal swamps and rivers. There are four geologic formations, in ascending order (oldest to youngest): the Mancos Shale, Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone. The marine Mancos Shale has yielded diverse fossils, including terrestrial pollen and spores, plant fragments, bivalves, ammonites, gastropods, worm tubes, crinoids, fish teeth, invertebrate burrows, fecal pellets, foraminifera, coccoliths, other calcareous nannofossils, and dinoflagellates. The nearshore Point Lookout Sandstone has the least diverse fossil record of the four formations, but invertebrate trace fossils, bits of wood, and bivalve and ammonite shells are occasionally found. The terrestrial Menefee Formation has abundant but little-studied plant fossils, including conifer trunks and foliage and other organs of ferns, cycads, conifers, and angiosperms. Finally, the nearshore Cliff House Sandstone includes both mollusks and the most significant vertebrate remains from the park. Among the vertebrates are sharks, rays, bony fishes, turtles, plesiosaurs, mosasaurs, and dinosaurs. Some of the Cretaceous fossils appear to represent undescribed species, such as a *Palaeoaster*-like fruit from the Menefee Formation, a leaf in the genus *Platanites* from the Menefee Formation, a sea star from the Cliff House Sandstone, and chimaera egg cases from the Cliff House Sandstone. In addition, MEVE collections include some fossils from outside of the park, notably Mancos Shale fossils from a project to define a principal reference section of the formation and Naturita Formation ammonites from the vicinity.

The Upper Cretaceous fossils from MEVE are among the best in the National Park Service, and many of them can be placed in a detailed geologic section, further increasing their scientific value. Although the fossils of the park have long been overshadowed by the world-class archeological resources, it is hoped that this inventory and other ongoing efforts will attract more research. In addition, the Quaternary fossils found to date suggest that further exploration is merited and will provide information useful for understanding the conditions that attracted the Ancestral Puebloans and later caused them to leave the area. The fossils of MEVE present a rich resource for education, interpretation, and scientific research.

Acknowledgments

We thank George San Miguel, Natural Resource Program Manager, Mesa Verde National Park and Dr. Tara Travis, Supervisory Museum Curator, Mesa Verde National Park for organizing the internship. George San Miguel brought the Geoscientists-in-the-Parks (GIP) program to Mesa Verde National Park and ensured its continuation. He has been instrumental in arranging and overseeing the project. Dr. Tara Travis's assistance has been invaluable to this project; not only has she allowed access to the archives, repository, and accession records, she guided the intern through the required procedures to use images from other institutions and conduct tests on the specimens. Superintendent Cliff Spencer's support was essential for this project.

This inventory would not have been possible without the help of the Geoscientists-in-the Parks program, which in 2015 was run by Matt Dawson, GSA GeoCorps Program Officer for Education and Outreach and Lisa Norby, NPS Program Manager for the Geoscientists-in-the-Parks and Mosaics-in-Science programs. We thank Limaris Soto and Allison Kerns, who helped administer the Geoscientists-in-the-Parks program for the NPS, and Ben Baldwin who administers youth internships for the NPS. Don Weeks, Physical Resources Program Manager for the Intermountain Regional offices, provided critical support for this internship. In 2017 the intern was also funded by the Environmental Stewards program, which is run by Conservation Legacy. Mandy Eskelson assisted the intern with paperwork and procedures while Krista Rogers coordinated with George San Miguel.

Special thanks goes to the many staff members at Mesa Verde National Park who assisted in this project, furnishing critical locality information and helping extract valuable specimens, and the park's ruins stabilization crew, who loaned us tools to extract paleontological specimens.

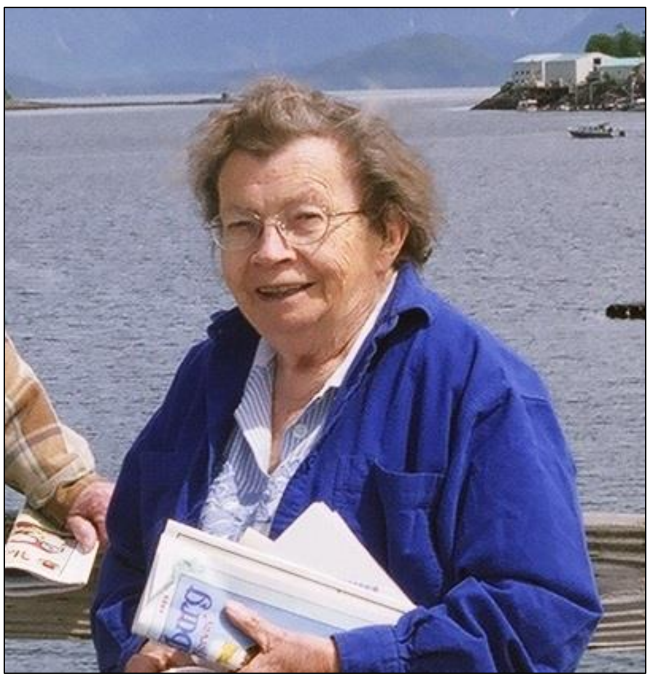
Mesa Verde National Park thanks Dr. Jim Kirkland, Utah State Paleontologist from the Utah Geological Survey for reviewing our collections, correcting the taxonomy of many specimens, and providing recommendations for future collections management. We also thank Jan Fischer (Urweltmuseum GEOSKOP) for his help identifying the chimaerid egg case which is housed in our collections. Ian Miller from the Denver Museum of Nature and Science has helped us identify recent leaf fossil collections and provided other assistance.

The continued valuable support and information provided by additional NPS Geologic Resources Division staff, including Dave Steensen, Hal Pranger, Tim Connors, and Jason Kenworthy, is greatly appreciated. Finally, this report would not have been possible without the funding from the NPS Geologic Resources Division (GRD) and the opportunities available through the partnership with the Geological Society of America's Geoscientists-in-the-Parks program and the American Geosciences Institute.

Finally, we would like the thank Mark Leckie, James Kirkland, and Tim Connors for reviewing this work. Their insights helped us improve the final product.

Dedication

We dedicate this report to a one-of-a-kind paleontologist, Dr. Mary O. Griffitts, who studied the geology and paleontological resources of Mesa Verde National Park. In her retirement she came once or twice a year equipped with her scopes, her multitude of books and maps, her trusted and honored rock hammer, and especially a thorough and analytical mind. Perfection and thoroughness were a must for Mary and intensity was her middle name. She had to be very certain about fossil identification and geologic relationships. She worked very hard to find reputable sources that could identify plant fossils from the park. During her years here she added hundreds of fossils to the park collection, wrote a good number of reports, authored *Guide to the Geology of Mesa Verde National Park*, and developed the definitive bedrock geologic map for the park and some adjoining lands including various features such as dikes, slip joints, and high terraces.



Mary had a passionate interest in the natural world, especially fossils, beginning in her childhood in the Upper Peninsula of Michigan, where she was born in 1920. Her interests led her to a Bachelor of Science degree at the University of Michigan, Ann Arbor, and to earn the first-ever PhD in geology awarded to a woman at the University of Colorado. Her doctoral dissertation was from her fieldwork at Mesa Verde during the 1940s. She taught at the University of Michigan, University of Illinois, Bryn Mawr College in Pennsylvania, and University of Colorado, where she was an Assistant Professor and taught historical geology and paleontology. She also worked as a ranger naturalist for Yellowstone National Park.

She married Wallace Griffitts in 1940 and raised four children, but never lost her passion for the natural sciences and geology, interests which she passed on to all of her children, each of whom became adept at identifying local rocks, fossils and plants. During this time she also started the Junior Natural Science School with the Thorne Institute and worked on other science programs for schoolchildren.

In 1981 she returned to Mesa Verde Natural Park as a V.I.P. (Volunteer in Park) to work on the collections she made in the 1940s. Mary was forced to retire a second time for health reasons at the age of 83. Among her many projects at Mesa Verde were training sessions in geology for park rangers, field collecting specimens for the museum, advising the ruins stabilization crews, designing displays for the museum, work on the museum collections, ceramic tempers, and stone and lithic collections, and various other duties. Mary immensely enjoyed her work at Mesa Verde and was sad when she had to retire. She passed away on June 20, 2010 at the age of 90.

Introduction

Mesa Verde National Park (MEVE) encompasses 21,240 hectares (52,485 acres) of the Mesa Verde cuesta, a geographic feature in Montezuma County, southwestern Colorado (Figure 1). The park was initially established to protect archeological sites of the Ancestral Puebloan people (previously known as the Anasazi), chief among them extensive cliff dwellings. MEVE was established June 29, 1906, making it one of the oldest national parks. Its boundaries have changed several times: June 30, 1913; May 27, 1932; December 23, 1963; and December 26, 2007. In 1928 the purpose of the park was expanded through an act of Congress to include the preservation of natural features such as forests and wildlife. Wilderness was designated for 8,500 acres within MEVE on October 20, 1976, and the park was designated a World Heritage Site on September 6, 1978.

Mesa Verde (technically a cuesta because it dips, up to 7° to the south, unlike a true mesa which is flat) is an erosional remnant of a plain that once stretched between the La Plata and San Juan Mountains (Griffitts 1990; Harris and Tuttle 1990). Although it looks like a single flat unit from afar, it is actually heavily dissected by steep canyons carved by south-flowing drainage, cutting it into numerous narrow mesas and impeding east-west movement across the park. The erosion that isolated Mesa Verde began only about 3 to 2 million years ago, but has left the mesa top as much as 610 m (2,000 ft) above the surrounding country. Maximum elevation is 2,613 m (8,572 ft) at Park Point. Beneath recent deposits and gravel left by the Mancos River system before downcutting are rocks of four formations deposited during the Late Cretaceous (see Appendix H for a geologic time scale). In ascending order, from oldest to youngest, they are the Mancos Shale, the Point Lookout Sandstone, the Menefee Formation, and the Cliff House Sandstone (Figures 2 and 3). These rocks record fluctuations of a vast epicontinental sea, the Western Interior Seaway, which covered much of the interior of North America during the Late Cretaceous (Griffitts 1990).

A detailed record of between 10 and 15 million years of coastal and terrestrial deposition is represented in the rocks exposed at MEVE, beginning around 90 Ma (million years ago) with the Juana Lopez Member of the Mancos Shale (Leckie et al. 1997) and ending around 77.5 Ma in the Cliff House Sandstone (M. Griffitts, pers. comm. to MEVE, 2006). Each of the four formations preserves records of the organisms that existed during their deposition, from marine mollusks and other marine life in the Mancos Shale, to trace fossils in the coastal marine sandstone of the Point Lookout Sandstone, to plant fossils of the swampy coastal Menefee Formation, to shark teeth and marine invertebrates of the shallow seas and barrier beaches of the Cliff House Sandstone (Griffitts 1990). Any younger formations that were deposited here have been eroded away, with the exception of the most recent surficial deposits. Surficial Quaternary deposits of the past few thousand years have been studied for paleoecological and fire history data (Herring 2009; Herring et al. 2014). Carrara (2012) created a map of MEVE’s surficial geology which details Pleistocene and Holocene soils and mass movements. Although fossils are abundant within MEVE, and Mesa Verde has a place in the history of geology, the paleontology of MEVE has attracted little attention to date.

Purpose and Need

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

Project Objectives

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

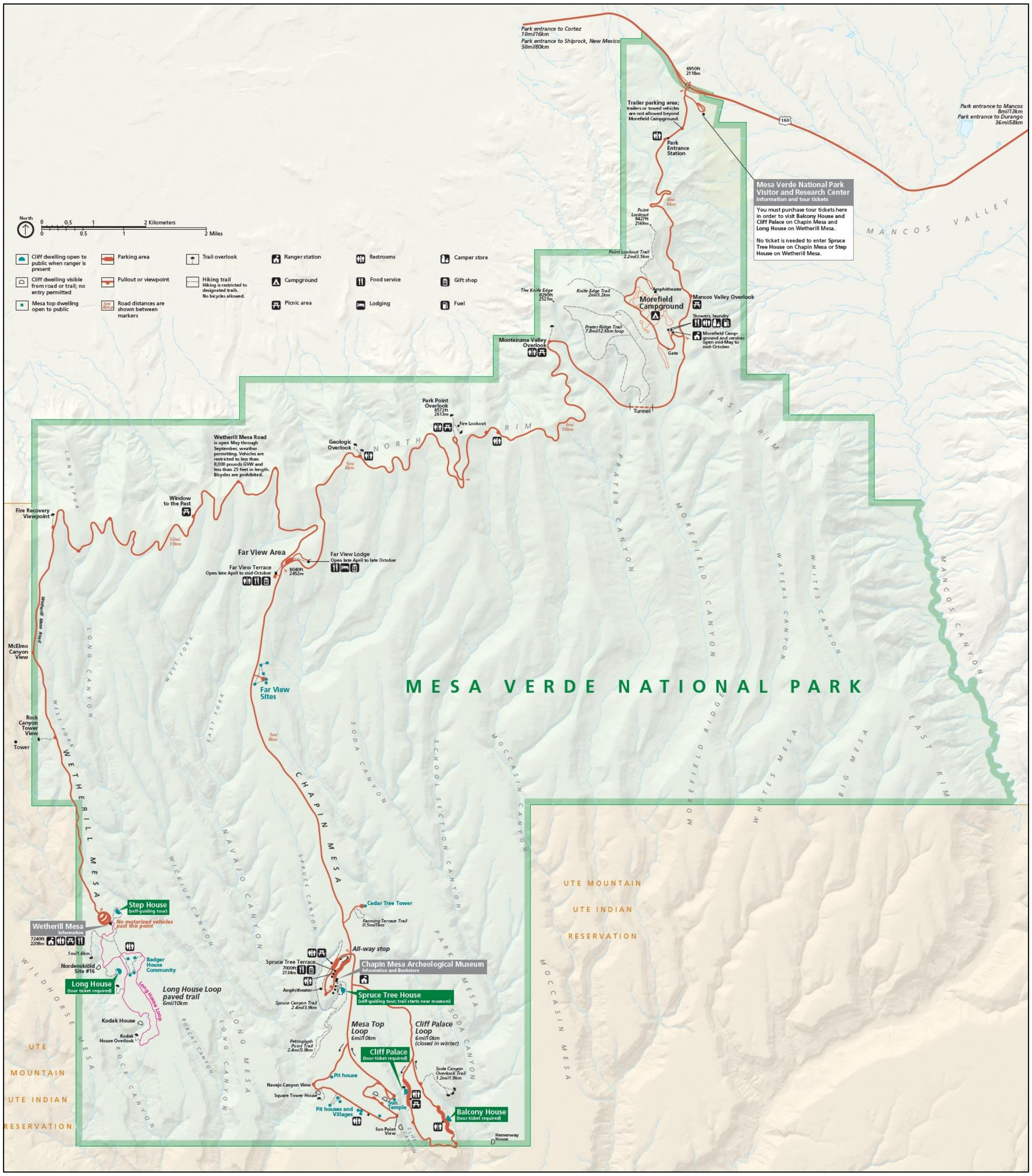


Figure 1. Geography of MEVE (NPS).

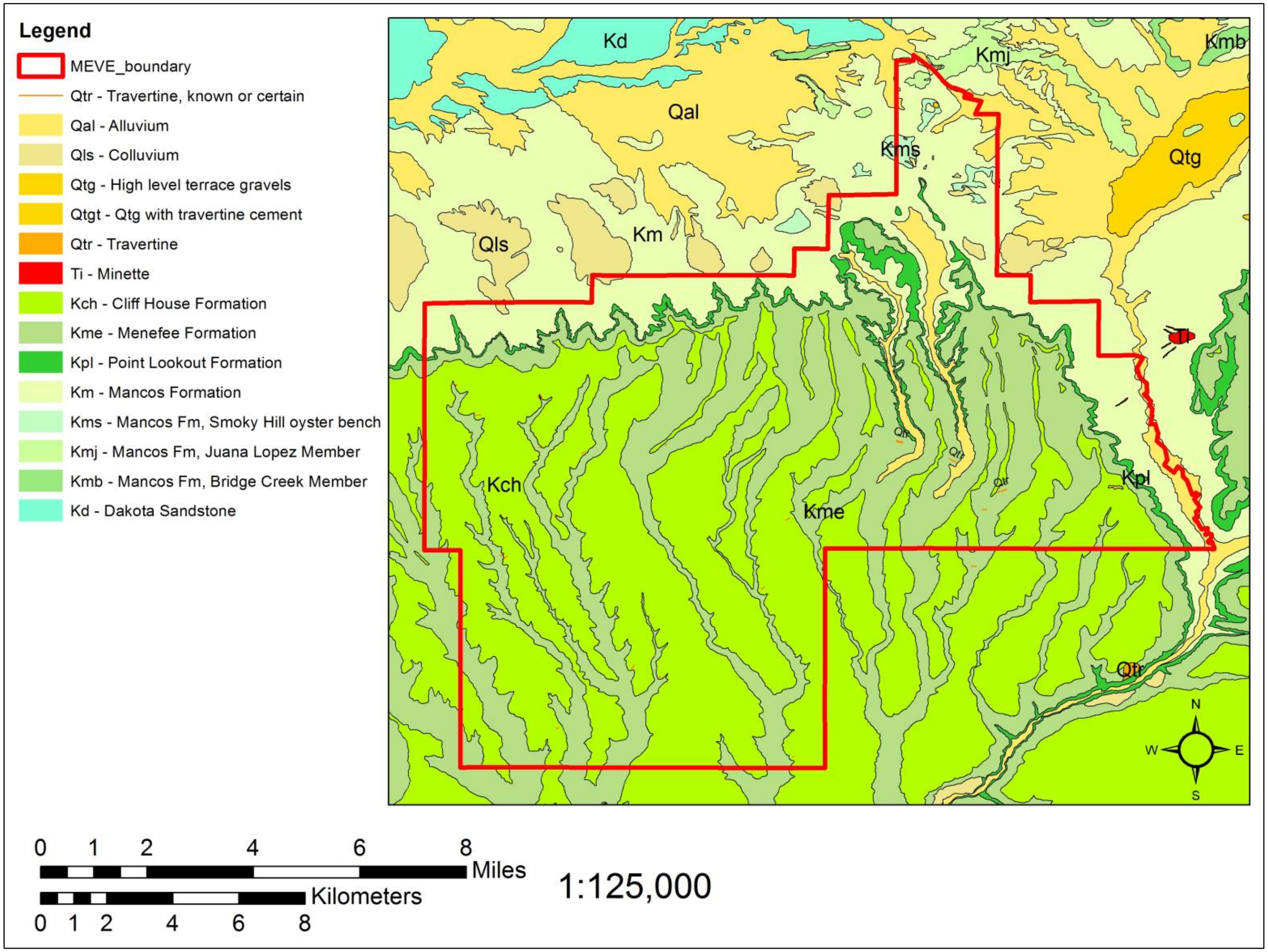


Figure 2. Schematic geological map of MEVE (NPS/JUSTIN TWEET), adapted from digital geologic map data available at the following URL: https://irma.nps.gov/DataStore/Reference/Profile/1049016. All of the Cretaceous bedrock units have produced fossils within MEVE and the various Quaternary units are either fossiliferous or potentially fossiliferous.

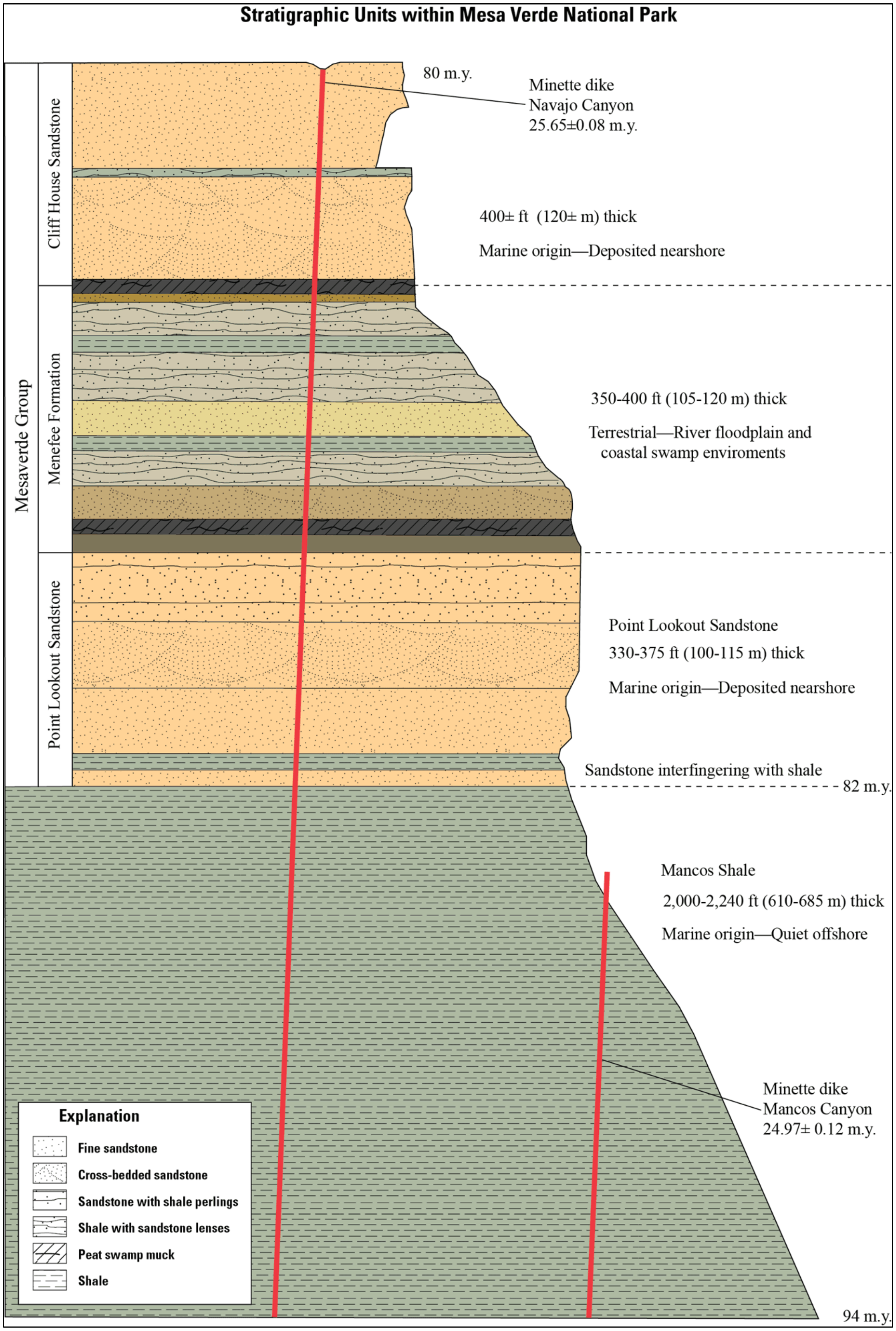


Figure 3. MEVE stratigraphic section, from Carrara (2012) after Wanek (1959) and Griffitts (1990) (entire Mancos Shale not exposed in park) (USGS/CARRARA).

History of Paleontological Work at MEVE

Mesa Verde has a footnote place in the history of geology as the source of several formation names and typical outcrops/type sections. Although its geology has been described in some detail, the paleontological resources of MEVE have not received the scientific attention they merit, perhaps because the fossils are not of charismatic vertebrates and the outstanding archeology overshadows other resources. Significant references for the park's geology and paleontology include Pike (1947), Wanek (1959), Thompson (1972), Griffitts (1990), Kirkland et al. (1995), Leckie et al. (1997), Scott et al. (2001), and Carrara (2012).

The earliest description of the geology of Mesa Verde appears to be a report by William H. Holmes (1877). Holmes briefly set out the basic geology of the cuesta as it is still recognized today, albeit under somewhat different terminology. He recognized the presence of a sequence of shales and limestones (then described as the "Colorado Group") under a set of three units he named the Mesaverde Formation. This formation was composed of a lower escarpment, a middle coal group, and an upper escarpment. Four decades later, Collier (1919) redesignated the Mesaverde Formation as the Mesa Verde Group, and gave formal names to Holmes's three subunits. The "lower escarpment" became the Point Lookout Sandstone, the "middle coal group" became the Menefee Formation, and the "upper escarpment" became the Cliff House Sandstone. The names and typical sections were chosen from locations in and around the cuesta (Collier 1919). The underlying "Colorado" section was named the Mancos Shale from outcrops around the nearby Mancos Valley (Cross and Purington 1899). It is in part because the Mancos Shale was named from the area that exposures of the formation in and around MEVE were used by Kirkland et al. (1995) and Leckie et al. (1997) to describe a principal reference section.

Holmes (1877) may also be the source of the earliest reference to fossils at Mesa Verde. In his report he mentioned a locality with abundant fossil leaves at Mesa Verde, which is presumably a reference to the copious fossil plants of the Menefee Formation. Stanton (1893) briefly described several faunal zones in the Mancos Shale from an area "along the Mancos river north of Mesa Verde and in the valley of Animas river." By comparison with the descriptions in Leckie et al. (1997), and with some allowance for inaccurate measurements, Stanton's Zone 1 can be correlated to the Graneros Member, Zone 2 to the Bridge Creek Limestone Member, Zone 3 to the combined Fairport and Blue Hill members, and Zone 4 to the Juana Lopez Member.

Aside from the curious case of the "palm fossil" at Sun Temple (Fewkes 1916a, 1916b) (see "Cultural Resource Contexts" below), the next significant account of fossils at MEVE may be that of Deric Nusbaum, stepson of MEVE superintendent Jesse L. Nusbaum. His book (Nusbaum 1926), written at the age of twelve, includes the two following passages:

> "*When we first came to the Mesa, I used to love to split open the sandstone slabs and find shark's teeth in them. I got big ones and little ones, and some that were wide and had saw-tooth edges. Then later, I collected fossils of shell fish and one very rare star-fish. These seemed such strange things to get up here because this is considered an awfully dry country.*" (Nusbaum 1926:39)

> "*Last summer when they were making the big cuts for the new road right through this [Mesaverde] formation, we found portions of tree trunks, branches and even the leaves and fruit. The fruit looks like little dried-up figs. The leaves are often beautiful. Some of the fossils are of large palm leaves, others, smaller and more like those of the elm; there are also some that resemble ferns.*" (Nusbaum 1926:41–42)

The teeth of the first passage can be attributed to the Cliff House Sandstone, which has produced a small assemblage of vertebrate teeth. The "star-fish" may be the same as the sea star fossil in the MEVE collections, which otherwise lacks provenance data. The fossils of the second passage are readily recognized as from the Menefee Formation and serve as an example of the adventitious discovery of plant fossils in this formation down to the present day. They also serve as a reminder of the importance of construction, maintenance, and other infrastructure work within the park for the discovery of fossils. Although not described in the literature at the time, the construction of an addition to the MEVE museum in 1934 led to the collection of numerous fossils from the upper Cliff House Sandstone (Griffitts 1990; Scott et al. 2001). Nusbaum also paraphrased a campfire talk by U.S. Geological Survey geologist Willis T. Lee describing the thinking about the geologic history of the park. This talk may date to the fall of 1925 because Franke (1934) reported that Lee visited MEVE at this time and insisted that the interpretation of the Sun Temple feature as a fossil leaf was incorrect.

The next significant discussion of MEVE paleontology is found in Pike (1947), a description of Upper Cretaceous rocks in the Four Corners region. Of the 46 sections discussed in that report, Section 1 is partially in MEVE and Section 2 is nearby on the Southern Ute Indian Reservation. The top of Section 1 is at Point Lookout, but at some point the section leaves MEVE. Judging by topography and comparison with the similar section of Leckie et al. (1997), at minimum, several hundred feet of the upper part of the section should be within the park. Fossil collections 137 through 146, from the upper 248 m (815 ft), are here regarded as from within MEVE. They are all biostratigraphically consistent with the Cortez Member of the Mancos Formation as described by Leckie et al. (1997) and include specimens of the large bivalve *Inoceramus* (or inoceramids; taxonomy of this group of flat clams has been perpetually unstable), the encrusting oyster *Pseudoperna* (=*Ostrea* of Pike), the coiled ammonites *Acanthoceras*, *Desmoscaphites*, and *Placenticeras*, the gently curved or straight ammonite *Baculites*, the partially coiled ammonite *Scaphites* (resembling a 6 or 9), the free-floating crinoid (sea lily) *Uintacrinus*, and fragmentary remains of plants and fishes. Inoceramids, encrusting oysters, and coiled, linear, and open ammonites are typical of the Mancos Shale in and around MEVE. Pike also included data from a usually invisible source: the subsurface of the park, sampled during NPS well drilling. Fossils were found at several horizons, but because of the general inaccessibility of the source rocks (two of the fossiliferous layers were more than 1,000 m [3,300 ft] below the surface), the occurrences are only included for completeness and will only be discussed in passing.

The 1950s are noted for Alexander Wanek's geologic maps of the park (Wanek 1954, 1959). Wanek produced a preliminary map (Wanek 1954), followed by a detailed description of the geology of the area (Wanek 1959). Although he did not dwell at length on the paleontology, this document is particularly useful for its coverage of the Mesa Verde Group. Unlike the Mancos Shale, the formations of the Mesa Verde Group have never been the subject of a dedicated publication based on outcrops at the cuesta, which is somewhat surprising given that two of the formations were named for Mesa Verde features (the Point Lookout Sandstone and Cliff House Sandstone). The 1960s include a description of the geology of the nearby Ute Mountains (Ekren and Houser 1965), which is of interest with respect to Yucca House National Monument (YUHO), an analysis of insect remains and traces found in the archeological resources of MEVE (Graham 1965), and a description of lower Mancos Shale stratigraphy that incorporated an area near and around the park entrance (Lamb 1968). In early October of 1964, U.S. Geological Survey scientists William Cobban and J. R. Gill collected a handful of mollusk fossils from five sites within MEVE. A few of the fossils were later included in a publication by Cobban (1973; see below), but the entire collection was only documented in an E&R file prepared by Cobban (1965/02/03). E&R reports (from "Examination and Report on Referred Fossils") are unpublished internal USGS documents. For over a century, USGS paleontologists would identify and make 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. Extensive access to the original files was granted to the NPS by the USGS beginning in 2014 (Santucci et al. 2014). Research in the E&R archives has thus far turned up only this report for sites within the park, but several other reports document fossils found just outside of it, within about 3 km/2 mi (J. B. Reeside, Jr., USGS, written comm. to A. J. Collier, 1916/05/24; J. B. Reeside, Jr., USGS, written comm. to H. Bernes, 1952/12/18; W. A. Cobban, USGS, written comm. to E. B. Ekren, 1956/01/27; W. A. Cobban, USGS, written comm. to E. G. Kauffman, 1964/05/25; W. A. Cobban, USGS, written comm. to E. R. Landis, 1969/02/20; W. A. Cobban, USGS, written comm. to E. A. Merewether, 1982/09/18).

Two publications from the early 1970s mention MEVE fossils. Thompson (1972) described palynomorphs (organic microfossils such as pollen, spores, and cysts) from the Mancos Shale of southwestern Colorado, including from a section with one end at Point Lookout, as in Pike (1947) and Leckie et al. (1997). Thompson recovered a variety of pollen, spores, dinoflagellates (single-celled organic walled protists that use two whip-like flagella to move), acritarchs (unclassifiable organic microfossils), and algae from this section, which were used to track environmental changes in the fluctuating Mancos Sea. Cobban (1973) briefly discussed ammonites from two localities in the park (USGS locality D4788, uppermost Mancos Shale, and D4789, Point Lookout Sandstone float). Cobban had previously (Cobban 1951) included a few specimens found near MEVE in a description of scaphitid ammonites from the Mancos Shale and equivalent formations.

The study of paleontology in MEVE became more systematic starting in the 1980s. In the summer of 1981, geologist Mary O. Griffitts began a long association with Mesa Verde National Park, collecting fossils and documenting geology for the park. The most visible product of these years of work is her volume on MEVE geology (Griffitts 1990), but a significant portion of MEVE's fossil collections come from her efforts. Griffitts (1990) includes a great deal of information on the fossils of the cuesta, along with photographs. In the late 1980s, a team of researchers based out of the University of Massachusetts (Amherst) selected outcrops of the Mancos Shale in and around MEVE as a principal reference section for the formation based on its extensive exposures, proximity to the originally described area around the Mancos River, and National Park Service protection (Kirkland et al. 1995; Leckie et al. 1997). It should be noted that of the stratigraphy described by Leckie et al. (1997), only two of the 23 sampling areas are definitely within MEVE (areas 22 and 23), although they make up more than half of the complete reference section. The section from area 22 encompasses MV380 to MV430, 297.5 to 383.2 m (976 to 1,257 ft) above the base of the formation. The section from area 23 encompasses MV430 to MV686, 382.9 to 677.7 m (1,256 to 2,223 ft), to the top of the formation at Point Lookout. Together they document essentially the entire Cortez Member. A third area of interest, area 12, has an ambiguous location; it is described as “across from MVNP entrance.” Subsequent formal publications that refer to Leckie et al.’s Mesa Verde section and samples have to date been based on material from the other areas and thus outside of the park (Leckie et al. 1998; West et al. 1998; Corbett and Watkins 2013, 2014a, 2014b), but some unpublished documents incorporate the Cortez Member (Sterzinar 2005; Mizintseva 2013; Lowery 2015). For reference, descriptions of any of the Leckie et al. material below MV380 or 297.5 m (976 ft), or areas other than 22 and 23, or from a member other than the Cortez Member, should be regarded as documenting material outside of MEVE.

On the heels of the work done by Griffitts and the Mancos reference section team, Scott et al. (2001) summarized the paleontology of MEVE, along with the other NPS units of Colorado. This was one of several publications produced for the National Park Service on the geology and paleontology of the park. Others include the geologic summary by Graham (2006) and the MEVE chapter of Tweet et al. (2009). Recently, investigators have begun to study the Quaternary deposits and fossils of MEVE, although to date nothing older than the Holocene has been reported (Carrara 2012; Herring et al. 2014).

In 2015, Geoscientists in the Parks (GIP) intern G. William M. Harrison data-mined accession files for maps and used them to relocate many sites found before the advent of GPS technology (Figure 4). During these surveys he discovered a chimaerid egg capsule of a previously unknown ichnospecies (Harrison et al. 2016). He also photographed most of the pre-existing collections, recovered provenience data for many of those fossils, and created both spreadsheets and an ArcGIS map that link all of the above information. Finally, he began surveying archeological sites for fossils to promote their interpretation. Later that year, Dr. Jim Kirkland reviewed the collections and updated taxonomic identifications as well as giving recommendations for future curation (Figure 5). Mesa Verde is currently endeavoring to implement his suggestions, including reorganizing the collection based on taxonomy and stratigraphic location. This work was summarized in a report he wrote for Mesa Verde National Park (Kirkland 2015).

Figure 4. 2015 Geoscientists-in-the-Parks participant G. William M. Harrison recording a fossil found in Spruce Tree House (NPS/GEORGE SAN MIGUEL).

Figure 5. Dr. Jim Kirkland reviews Mesa Verde National Park's collection, updating taxonomy and giving recommendations for future work (NPS).

George San Miguel continued surveying archeological sites in 2016 after Neil Morris provided maps that marked suspected fossils (Figure 6). George San Miguel also relocated several old sites and recorded an important leaf locality with potentially unknown plant species (Figure 7). A team from the Imperial College of London surveyed material in the Mancos Formation as part of their study of aragonite bias in the Western Interior Seaway. They examined several specimens but did not collect.

Figure 6. Natural Resources Manager George San Miguel stands atop a Juana Lopez Member calcarenite layer surveying the surrounding Mancos Shale (NPS GIP/G. WILLIAM M. HARRISON).

Figure 7. Archeologists helping collect leaves at a Menefee outcrop (NPS). A) (left to right) Neal Morris and Cristy Brown. B) (left to right) Carrie Billy, George San Miguel, and Cristy Brown. C) (left to right) Cristy Brown and Kay Barnett. Archeologists and volunteers are crucial to paleontology in Mesa Verde National Park.

MEVE's Cretaceous fossils place it in a group of parks that contain evidence of the Western Interior Seaway (Figure 8). Among these are Badlands National Park, Big Bend National Park, Bryce Canyon National Park, Chaco Culture National Historical Park, Dinosaur National Monument, Glen Canyon National Recreation Area, Missouri National Recreational River, Yellowstone National Park, and Yucca House National Monument. Together they tell the story of a long-vanished seaway, its fluctuating shorelines, and its lifeforms. While the basic story is the same, each park was located in a different part of the Western Interior Seaway and thus each park has a unique perspective. When the Western Interior Seaway was at its deepest, Mesa Verde exhibits a muddy but open ocean pelagic community; fluctuating sea level also resulted in near-shore marine environments for the Mancos Shale (Leckie et al. 1998; M. Leckie, pers. comm., September 2017). This unique community contrasts with the fauna found at other parks and provides unique opportunities for scientific studies. The Quaternary fossils of the park, although incompletely known at present, are a significant resource for understanding the processes of climate change and biological responses in the area, such as the climate shifts that led to humans populating and then leaving the area.

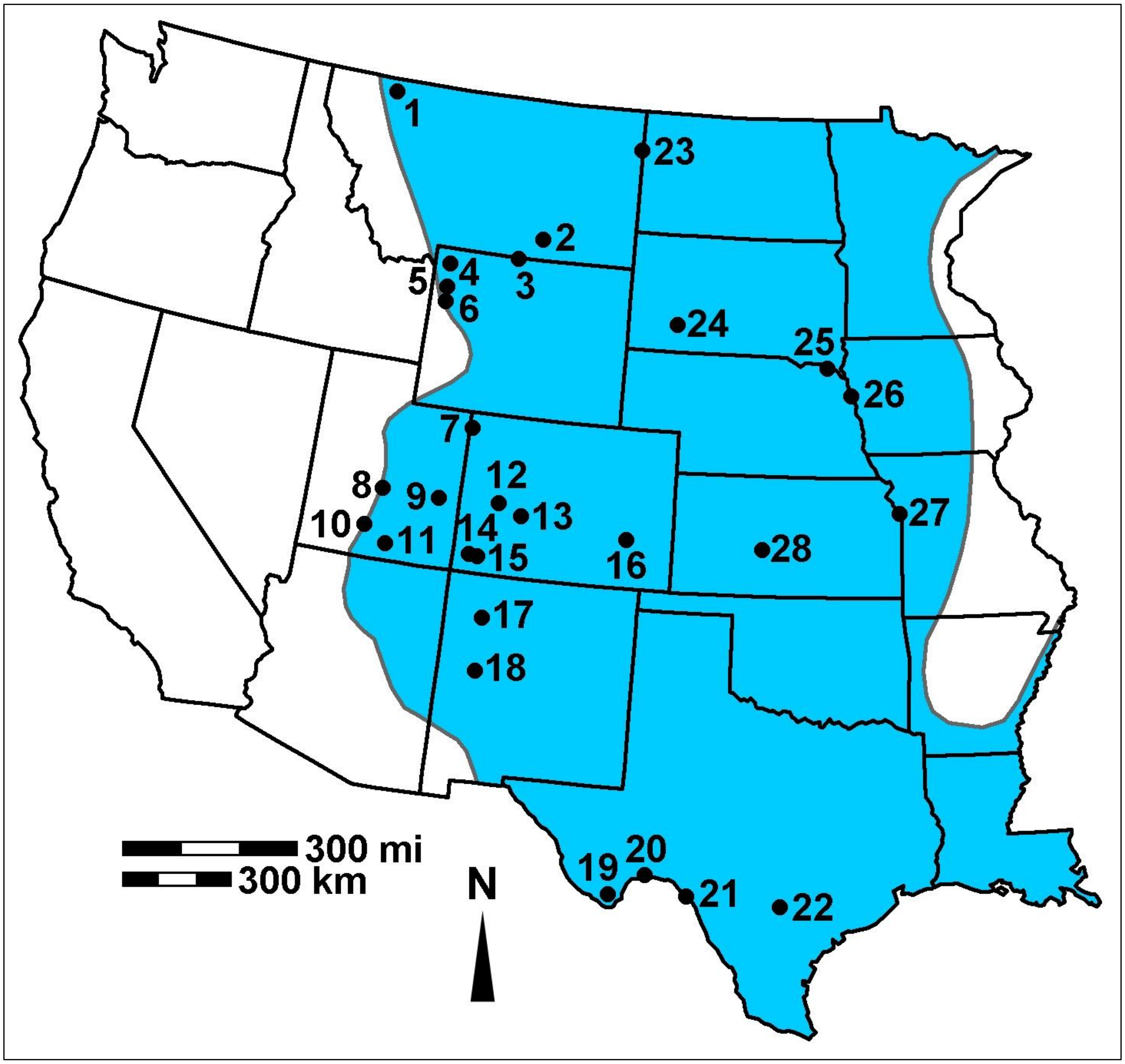


Figure 8. National Park Service units with Western Interior Seaway fossils (NPS/JUSTIN TWEET). 1. Glacier NP (National Park); 2. Little Bighorn Battlefield NM (National Monument); 3. Bighorn Canyon NRA (National Recreation Area); 4; Yellowstone NP; 5. John D. Rockefeller Memorial Parkway; 6. Grand Teton NP; 7. Dinosaur NM; 8. Capitol Reef NP; 9. Arches NP; 10. Bryce Canyon NP; 11. Glen Canyon NRA; 12. Black Canyon of the Gunnison NP; 13. Curecanti NRA; 14. Yucca House NM; 15. Mesa Verde NP; 16. Bent's Old Fort NHS (National Historic Site); 17. Chaco Culture NHP (National Historical Park); 18. El Malpais NM; 19. Big Bend NP; 20. Rio Grande Wild and Scenic River; 21. Amistad NRA; 22. San Antonio Missions NHP (building stone); 23. Fort Union Trading Post NHS (cultural); 24. Badlands NP; 25. Missouri National Recreational River; 26. Lewis & Clark NHT (National Historic Trail); 27. Santa Fe NHT; 28. Fort Larned NHS (building stone). Blue overlay approximates an idealized near-maximum extent of the Seaway, modified after Robinson Roberts and Kirschbaum (1995) with alterations to take into account Utah records and the Mississippi Embayment. The eastern shore is more conjectural than the western.

Geology

Geologic History

Several formations are exposed at MEVE, as well as igneous intrusions and surficial deposits (Figures 2 and 3; Table 1). The exposed geology of MEVE is limited in scope to primarily the Late Cretaceous, between roughly 90 and 75 Ma, but it makes up for this in the amount of detail the rocks provide. At about the Early Cretaceous–Late Cretaceous boundary (approximately 100 Ma), the MEVE area, which had been flat-lying and terrestrial for tens of millions of years going back into the Jurassic, began to be influenced by a shallow epicontinental sea (Griffitts 1990). This epicontinental sea is commonly known as the Western Interior Seaway or Cretaceous Interior Seaway, and it covered much of central North America from approximately 100 to 70 Ma. At its greatest extent, it bisected the continent from the Arctic to the Gulf of Mexico (Elder and Kirkland 1993, 1994). Many units of the National Park Service have rocks deposited beneath this sea (Figure 8). The first expression of the sea in the MEVE area is the Naturita Formation (historically known as the Dakota Sandstone or Dakota Formation in this area; see Carpenter 2014). Although it is not exposed within MEVE, park collections include Naturita Formation ammonites collected from near the county fairgrounds south of US Highway 160 and at a nearby mesa north of the highway (Leckie et al. 1997; J. Kirkland, collections report to MEVE). It can also be encountered within park boundaries via deep drilling, as described in Pike (1947).

The Naturita Formation represents the onset of several cycles when the sea advanced over the land (a marine transgression) and then retreated (a marine regression) in the Four Corners area. Five large-scale transgression-regression cycles are documented, with most of southern Colorado submerged until near the end of the Cretaceous except for relatively brief periods of terrestrial exposure (Aubrey 1991). It is because of such a history that the neighboring San Juan Basin to the southeast is referred to as a SCI-SWO zone: “sea came in, sea went out” (Molenaar 1977). The Naturita Formation is composed of fine-grained terrestrial sandstones, siltstones, and coal interbedded with offshore sandstones as the level of the advancing sea fluctuated. The overlying Mancos Shale represents fully marine deposition with the shoreline by that time as far away as western Utah, 320 km (200 mi) west of MEVE (Griffitts 1990; Leckie et al. 1998). Several members have been distinguished in the Mancos Shale in and around the park (Griffitts 1990; Leckie et al. 1997) representing changes in depositional conditions. Seafloor-dwelling bivalves, free-swimming ammonites, and other organisms flourished and declined repeatedly. Some beds are essentially accumulations of fossil fragments (the tiny components of inoceramid bivalve shells) or whole fossils (oyster beds) (Griffitts 1990). The fossils of the Mancos Shale in and around MEVE include a number of species that are important for biostratigraphy (relative dating of rock units by fossils) as detailed in Leckie et al. (1997). The fossil zonation of the Mancos Shale can be tied to absolute dates because of the presence of bentonites (beds of altered volcanic ash, which often include minerals that can be radiometrically dated), making this formation exceptionally well-dated (Leckie et al. 1997).

Table 1. Summary of MEVE 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 MEVE	Depositional Environment
Quaternary sediments	Pleistocene–Holocene	Holocene charcoal and pollen of conifers, *Ephedra*, and angiosperms; packrat middens of modern and indeterminate age are also known	Alluvial, cave, glacial, lacustrine, landslide, and talus deposits
Travertine	Pleistocene?	None to date	Springs
High level terrace gravels	Quaternary?	None to date	Fluvial
Minette	Late Oligocene	Unfossiliferous (intrusive igneous)	Not applicable (igneous rocks that solidified at depth)
Cliff House Sandstone	Late Cretaceous	Wood, debris of undetermined plants, bivalves, ammonites, undetermined shells, ray teeth, shark teeth and vertebrae, bones and other fossils of bony fishes, bones and scales of undetermined fish, turtle bones, plesiosaur bones, dinosaur bones, dinosaur or plesiosaur bones, bones of undetermined reptiles, bones of undetermined vertebrates, invertebrate trace fossils (borings, tracks, and burrows), mosasaur teeth, and chimaera egg capsules	Coastal marine
Menefee Formation	Late Cretaceous	Ferns, cycads, conifer wood and foliage, angiosperm foliage and seeds, debris of undetermined plants (including coal and jet), undetermined bivalves, and invertebrate burrows	Coastal terrestrial
Point Lookout Sandstone	Late Cretaceous	Wood, bivalves, ammonites, and invertebrate burrows and trails	Coastal marine
Mancos Shale	Late Cretaceous	Wood, debris of undetermined plants, conifer and angiosperm pollen, bivalves, ammonites, gastropods, annelid tubes; crinoids, teeth of bony fishes, scales of undetermined fish, invertebrate burrows and tracks, invertebrate fecal pellets, acritarchs, coccoliths, dinoflagellates, and foraminifera	Epicontinental sea
Naturita Formation (subsurface)	Late Cretaceous	Unspecified shells recovered during well drilling	Coastal terrestrial and marginal marine
Undetermined Jurassic rocks (subsurface)	Jurassic	Unspecified shells recovered during well drilling	Undetermined

Deposition transitioned from the fine-grained marine Mancos Shale to the coarser nearshore Point Lookout Sandstone of the Mesa Verde Group around 81 Ma (Leckie et al. 1997). At this time, the Seaway was in regression with the shoreline moving toward the northeast and sediments arriving by rivers flowing from the southwest (Griffitts 1990). Taken together, the Mesa Verde Group makes up a large deltaic wedge pointing to the northeast. The base of the Mesa Verde Group (Point Lookout Sandstone) traces marine retreat and the top (Cliff House Sandstone) corresponds to a marine transgression (Fassett 1974; Aubrey 1991). The nearshore marine sand bodies of the Point Lookout Sandstone were replaced by the fully terrestrial rocks of the Menefee Formation as the marine regression reached its maximum. The Menefee Formation represents a broad, flat coastal plain dotted with swamps and streams. It includes upper and lower coal-rich portions sandwiching a zone of sandstones and shaly sandstones deposited by rivers. Plant life flourished in this subtropical setting. The presence of *Teredolites* trace fossils, created by bivalves boring into dead wood, implies that the Menefee swamps were brackish (estuarine), at least for a portion of their existence. During deposition, the sea began transgressing again and the upper part of the Menefee Formation includes increasing quantities of marine sandstone, grading into the overlying sandstone-dominated Cliff House Sandstone. The Cliff House Sandstone is similar to the Point Lookout Sandstone and was also deposited in nearshore marine settings, except under a transgression instead of a regression. Another marine shale, the Lewis Shale, is known to succeed the Cliff House Sandstone elsewhere in the region, followed by another regressive sandstone (the Pictured Cliffs Sandstone), but any evidence of their presence at MEVE has been erased by erosion (Griffitts 1990). These two units can be seen at Chaco Culture National Historical Park to the south in northern New Mexico, which closely complements the geologic record at MEVE. Aerial surveys by Kim Gerhardt suggest that the Lewis Shale may overlie the Cliff House Sandstone in some portions of Mesa Verde on Ute land, but this has never been confirmed.

The final withdrawal of the Western Interior Seaway near the end of the Cretaceous took place at the same time as the beginning of a major mountain-building event known as the Laramide Orogeny. This event began around 70 to 66 Ma in the MEVE area and persisted off-and-on for another 25 million years (Griffitts 1990). It was the first step in the sculpting of the present form of the Rocky Mountains (Aubrey 1991). Closer to MEVE, the Laramide Orogeny led to the emplacement of laccoliths (mushroom-shaped subsurface igneous bodies), including the laccoliths that form the cores of the Ute Mountains to the west and the La Plata Mountains to the northeast (Griffitts 1990). La Plata igneous samples have been dated to 67 Ma (Semken and McIntosh 1997). Erosion levelled out the Mesa Verde area by the middle Cenozoic, but volcanic activity created new geographic features. The San Juan Mountains to the northeast of MEVE formed about 35 to 26 Ma as the result of volcanic activity (Griffitts 1990), producing 15 calderas (collapsed magma chambers) in the process (Marcus and Marcus 1983). The central San Juan volcanic field was most active from 28 to 26 Ma (Lanphere 1988). Igneous intrusions of a rock known as minette were emplaced in MEVE at this time and some are now exposed; two dikes in MEVE have been dated to 25.65 ± 0.08 Ma and 24.97 ± 0.12 Ma (Peters 2011a, 2011b) and could be related to the Shiprock intrusion in nearby northwestern New Mexico.

Following millions of years of erosion, Mesa Verde was part of a broad plain adjoining to the La Plata and San Juan mountains. Gravel beds occasionally encountered on the top of the mesa were left by streams that flowed across this plain. Approximately 3 to 2 Ma, renewed uplift led to streams downcutting and carving out the cuesta and its many canyons. Episodes of uplift and stability contributed to the creation of terraces in the canyons (Griffitts 1990). Glaciation occurred in the high elevations of nearby mountain ranges. The San Juan Mountain ice cap northeast of MEVE was the nearest ice cap to the park during the last glacial maximum. The Animas Valley lobe moved as far south as present day Durango, but began retreating approximately 19.4 ka (thousand years ago) and was completely gone by about 12.3 ka (Guido et al. 2007). Climate was cool and wet immediately following the last glacial period (Marcus and Marcus 1983), becoming warmer and drier overall with periodic fluctuations in moisture and temperature (Hall 1977; Hewett 1977). The Ancestral Puebloan culture arrived at Mesa Verde approximately 1,400 years ago (450 AD) and lived on the mesa until about 1200 AD, when some of them also moved down into the cliffs (Graham 2006). They left the Four Corners area approximately 1285 AD as conditions deteriorated (Varien 2006).

Geologic Formations

Mancos Shale (Upper Cretaceous)

Lithology: Predominantly gray to black fissile shale with interbedded thin beds (<25 cm/1 ft thick) of tan siltstone, fine-grained sandstone, and limestone (Carrara 2012). The upper contact with the Point Lookout Sandstone is transitional (Leckie et al. 1997) with alternating beds of siltstone and sandstone, making the division between the two a matter of choice. Because of this, the quoted thickness of the Mancos Shale in and around MEVE varies by author, from 608.84 m (1,997.5 ft) in Wanek (1959) to 682 m (2,237 ft) in Leckie et al. (1997). The Mancos Shale is often divisible into a number of members, and in the MEVE area eight such members have been recognized. In ascending order, from oldest to youngest, they are the Graneros Member, the Bridge Creek Limestone Member, the Fairport Member, the Blue Hill Member, the Juana Lopez Member, the Montezuma Valley Member, the Smoky Hill Member, and the Cortez Member (Leckie et al. 1997). Some of them have different names in older references; for example, the Bridge Creek Limestone Member has also been called the Greenhorn Limestone Member and the Smoky Hill Member has also been called the Niobrara Member, by way of correlation to other geologic units deposited in the Western Interior Seaway (see Leckie et al. 1997: figure 6 for a nomenclature chart). The Bridge Creek and Juana Lopez members are the most readily recognized of the members because of their distinct lithologies. Of the eight members, the lowest unit known to crop out within MEVE is the Juana Lopez Member (Scott et al. 2001), although the other members may be encountered via well-drilling. The lower four members are summarized briefly here for completeness. The Graneros Member is about 24 m (79 ft) thick and is composed of dark gray sandy mudstone, silty shale, and calcareous (lime-rich) silty shale, with some bentonite beds and concretion-rich intervals. The Bridge Creek Limestone Member is composed of light olive gray to dark olive gray limestone, shaly limestone, calcareous shale, calcarenite (limestone composed of sand-sized grains), and marlstone, about 14 m (46 ft) thick. The Fairport Member is composed primarily of medium gray to olive gray fossiliferous calcareous shale, with bentonite and is about 28 m (91 ft) thick. Finally, the Blue Hill Member is composed of dark-olive-gray to olive-black shale and silty shale with thin siltstone beds and scattered concretions, about 75 m (250 ft) thick. These four units represent a few million years between the late Cenomanian and middle Turonian stages of the Cretaceous, approximately 94 to 90.5 Ma (Leckie et al. 1997).

The four overlying members are exposed within MEVE. The Juana Lopez Member (Figure 9) is composed of dark slightly silty to silty shale with numerous beds of orange-weathering calcarenite, about 43 m (140 ft) thick. It occupies the interval 141.6 to 184.2 m (464.6 to 604.3 ft) in the stratigraphic section of Leckie et al. (1997), represented by units MV224 to MV304. This member was deposited about 90 Ma. The upper contact with the Montezuma Valley Member is sharp. The calcarenite beds of the Juana Lopez Member are made up primarily of bioclastic debris including "shells of foraminifers, inoceramid shell debris (calcite 'prisms' from the prismatic layer of the shell), broken and abraded shells of ammonites and oysters, and phosphatic debris including fish bones and teeth" (Leckie et al. 1997). It is not as easily eroded as most of the Mancos Shale and its resistant beds form ridges (Graham 2006).

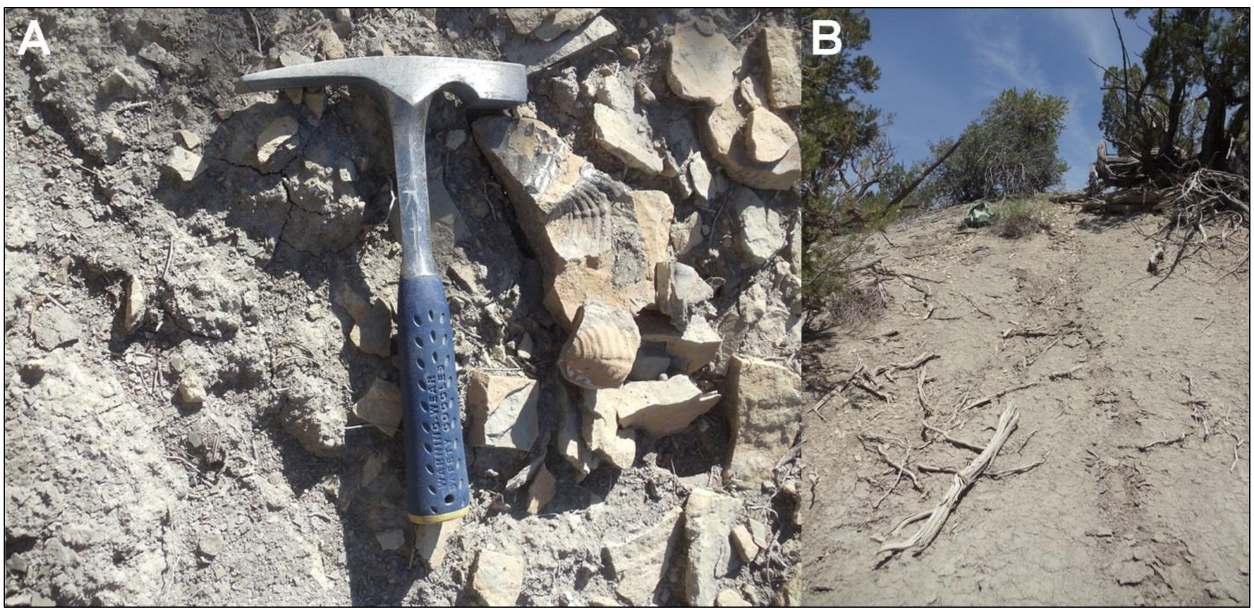


Figure 9. Juana Lopez Member of the Mancos Shale (NPS GIP/G. WILLIAM M. HARRISON). A) Calcarenite beds commonly found within the Juana Lopez Member with inoceramids. B) Calcarenite bench in the Juana Lopez Member capping a small hill.

The overlying Montezuma Valley Member is composed of gray to dark olive gray, slightly silty or sandy calcareous shale, about 16 m (52 ft) thick, with abundant concretions. It occupies the interval 184.2 to 200.4 m (604.3 to 657.5 ft) in the stratigraphic section of Leckie et al. (1997), represented by units MV305 to MV329. The upper contact with the Smoky Hill Member is sharp and disconformable with a hiatus that removes part of the early Coniacian, around 89 Ma. The Montezuma Valley Member is fossiliferous with bivalves and ammonites common in concretions and as compressions in the shale (Leckie et al. 1997). One locality in MEVE, UCM (University of

Colorado Museum of Natural History) 95061, has yielded various inoceramids and ammonites (UCM records).

The Smoky Hill Member (Figure 10) is composed of dark gray calcareous shale, mudstone, and marlstone, about 90 m thick (300 ft). It occupies the interval 200.4 to 289.0 m (657.5 to 948.2 ft) in the stratigraphic section of Leckie et al. (1997), represented by units MV330 to MV376. The upper contact with the Cortez Member is gradational. Deposition occurred from the Coniacian into the Santonian, about 88 to 85 Ma (Leckie et al. 1997). Some of the beds in the Smoky Hill Member are more resistant and form benches (Leckie et al. 1997) including a resistant "oyster bench" mapped within MEVE (Graham 2006).

Figure 10. Smoky Hill Member of the Mancos Shale (NPS GIP/G. WILLIAM M. HARRISON). A) Surface scatter typical of the Smoky Hill Member. B) Oyster beds are commonly found within the Smoky Hill Member.

Finally, the Cortez Member (Figure 11) is composed of two coarsening-upward sequences: a lower sequence of calcareous shale with an increasing abundance of thin sandstone beds higher in the sequence, and an upper sequence of silty to sandy shale and sandy mudstone transitioning to the sandstone of the overlying Point Lookout Sandstone. It is by far the thickest of the members at around 390 m (1,280 ft) thick. It occupies the interval 289.0 to 682.0 m (948.2 to 2,237.5 ft) in the stratigraphic section of Leckie et al. (1997), represented by units MV377 to MV686. It is sparsely fossiliferous, but there are enough fossils to establish that it was deposited from the Santonian into the Campanian, about 85 to 81 Ma (Leckie et al. 1997).

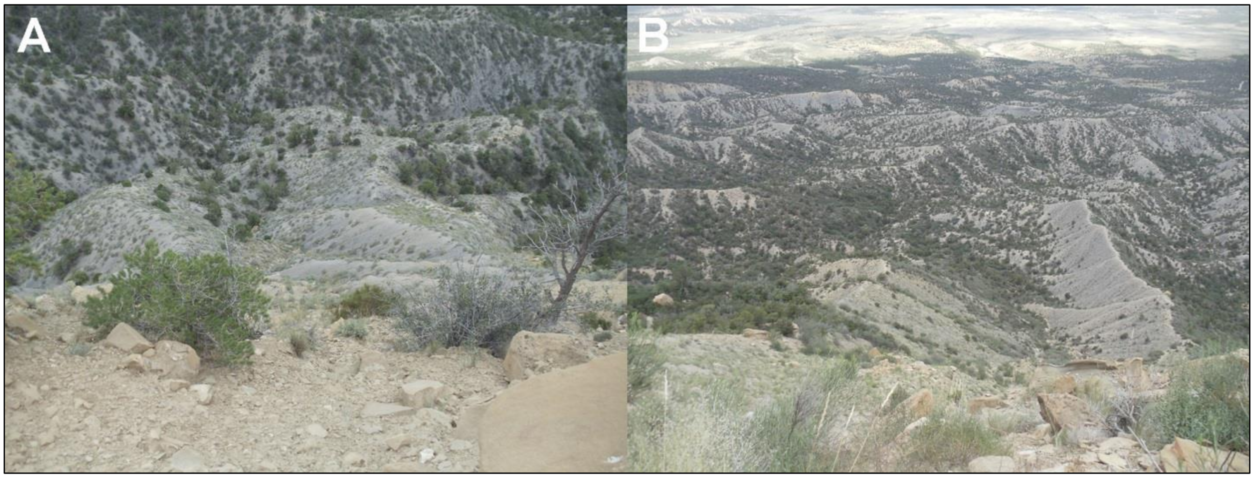


Figure 11. Cortez Member of the Mancos Shale (NPS GIP/G. WILLIAM M. HARRISON). A) The Cortez Member as seen from the base of the Point Lookout Sandstone. B) A photo from one of the ridges of the Cortez Member. Note how ridges and hills are topped by a thin layer of Point Lookout Sandstone debris, which provides an erosion-resistant cap.

Fossils found within MEVE: Wood (internal MEVE records), debris of undetermined plants (Pike 1947; Leckie et al. 1997), conifer and angiosperm pollen (Thompson 1972), bivalves (internal MEVE records; Pike 1947; Leckie et al. 1997), ammonites (internal MEVE records; Pike 1947; Leckie et al. 1997), gastropods (internal MEVE records), annelid tubes (internal MEVE records; Leckie et al. 1997); crinoids (internal MEVE records; Pike 1947; Leckie et al. 1997), teeth of bony fishes (Pike 1974), scales of undetermined fishes (internal MEVE records), invertebrate burrows and tracks (internal MEVE records; Leckie et al. 1997), invertebrate fecal pellets (Leckie et al. 1997), acritarchs (Thompson 1972), coccoliths (Thompson 1972), dinoflagellates (Thompson 1972), and foraminifera (Leckie et al. 1997, 1998; West et al. 1998; Tibert et al. 2003; Sterzinar 2005; Tibert and Leckie 2013).

Fossils found elsewhere: Corals (Kirkland 1996), bryozoans (Hill 1982), brachiopods (Leckie et al. 1997), nautiloids (Reeside 1927), scaphopods, mantis shrimps, lobsters (Kirkland 1996), crabs (Kues 1980), barnacles (Griffitts 1990), ostracodes (Bagshaw 1977; Tibert et al. 2003, 2009), echinoids (Hill 1982; Kirkland 1996), sharks and rays (Ekren and Houser 1965), chimaeras (Kirkland 1996), turtles (Elliott et al. 1997), plesiosaurs, mosasaurs (Spielmann and Lucas 2006), and radiolarians (Olesen 1991).

Mesa Verde Group: Point Lookout Sandstone (Upper Cretaceous)

Lithology: Beds of pale to yellow-orange sandstone (Figure 12), divided into a lower portion of alternating sandstone and shale approximately 24 to 38 m (80 to 125 ft) thick and an upper portion of massive sandstone 70 to 105 m (230 to 340 ft) thick. The contact with the overlying Menefee Formation is intertonguing (Wanek 1959). Sandstone sheets on the order of 9 to 12 m (30 to 40 ft) thick form the caprock on the north face of the cuesta and there is a 20-cm (8-in)-thick bentonite layer at the base of the massive sandstone (Griffitts 1990). Fossils are uncommon (Wanek 1959).

Fossils found within MEVE: Wood, bivalves, ammonites, and invertebrate burrows and trails (internal MEVE records).

Fossils found elsewhere: Gastropods, shark teeth, and root traces (Wright 1986).

Figure 12. The Point Lookout Sandstone as viewed from the upper Cortez Member of the Mancos Shale. Boulders of Point Lookout Sandstone material crowd the ravine (NPS GIP/G. WILLIAM M. HARRISON).

Mesa Verde Group: Menefee Formation (Upper Cretaceous)

Lithology: Heterogeneous with gray to grayish-orange lenticular pods of cross-bedded sandstone and gray to black carbonaceous shale and coal beds (Figure 13). Upper and lower coal members sandwiching a barren middle member can be distinguished locally. The contact with the overlying Cliff House Sandstone is intertonguing. The Menefee Formation is 100 to 240 m (340 to 800 ft) thick in the MEVE area (Wanek 1959).

Fossils found within MEVE: Ferns, cycads, conifer wood and foliage, angiosperm foliage and seeds, debris of undetermined plants (including coal and jet), undetermined bivalves, and invertebrate burrows (internal MEVE records and correspondence).

Fossils found elsewhere: Palynomorphs of algae, mosses, liverworts, lycophytes, ferns, seed ferns, cycads, ginkgoes, conifers, gnetophytes, and angiosperms (Jameossanaie 1987), generally fragmentary vertebrate body fossils pertaining to sharks, rays, gars, bowfins, amphibians, turtles, squamates, crocodile relatives, dinosaurs, and mammals (Williamson 1996; Lewis et al. 2004, 2006a, 2006b; Heckert et al. 2007), dinosaur tracks (Lucas and Hunt 2006), and dinoflagellates (Hall 1977).

Figure 13. An outcrop displaying typical Menefee stratigraphy, alternating between coal and shale layers (NPS GIP/G. WILLIAM M. HARRISON).

Mesa Verde Group: Cliff House Sandstone (Upper Cretaceous)

Lithology: Pale to dark yellow-orange cliff-forming cross-bedded sandstone (Figure 14). Locally several tongues can be distinguished near the base. The formation is approximately 120 m (400 ft) thick in the area, but the top is not present in the park (Wanek 1959). In the southern part of MEVE, the formation is usually composed of two sandstone units separated by softer sandy shale. The cliff dwellings were mostly developed in the upper sandstone unit. Farther north in the park, the upper unit transitions into alternating thinner bedded sandstone and sandy shale from slightly deeper water. Cliff dwellings could not be developed in the northern facies (Griffitts 1990). Deposition ended in the MEVE area around 77.5 Ma (M. Griffitts, pers. comm. to MEVE, 2006). MEVE collections from this formation include specimens of the bivalve *Inoceramus* (or *Cataceramus*) *subcompressus* and the ammonite *Baculites maclearni*, which fit the biostratigraphy of this time frame as defined in Cobban et al. (2006).

Fossils found within MEVE: Wood, debris of undetermined plants, bivalves, ammonites, undetermined shells, ray teeth, shark teeth and vertebrae, *Enchodus* teeth, bones and other fossils of bony fishes, bones and scales of undetermined fishes, turtle bones, plesiosaur bones, dinosaur bones, dinosaur or plesiosaur bones, mosasaur teeth, bones of undetermined reptiles, bones of undetermined vertebrates, invertebrate trace fossils (borings, tracks, and burrows) (internal MEVE records), and chimaera egg capsules (Harrison et al. 2016)

Fossils found elsewhere: Bryozoans (Miller et al. 1991) and body fossils of amphibians and mosasaurs (Scott et al. 2001).

Figure 14. An outcrop of the Cliff House Sandstone in the foreground, with more Cliff House outcrops across the canyon (NPS GIP/G. WILLIAM M. HARRISON).

Minette (Upper Oligocene)

Lithology: Greenish-gray to black igneous rocks. Less than 10% to more than 50% of a given sample is composed of phenocrysts (crystals visible to the naked eye) 1 mm to 1 cm (0.03 to 0.3 in) across, of pyroxene, mica, and olivine minerals. Minette is found in and around MEVE as intrusive igneous dikes, meter-scale in thickness, which are more resistant than the Mancos Shale and Menefee Formation but less resistant than the Point Lookout and Cliff House sandstones (Carrara 2012). The dikes intruded during the Late Oligocene; two dikes in MEVE have been dated to 25.65 ± 0.08 Ma and 24.97 ± 0.12 Ma (Peters 2011a, 2011b).

Fossils: Unfossiliferous, included for completeness.

High level terrace gravels (Pliocene to middle Pleistocene?)

Lithology: Areas of scattered, subrounded to rounded clasts of mostly pebble to cobble size on the bedrock surface with no appreciable thickness in the park. Most clasts are fine- to coarse-grained quartzite with some volcanic clasts originating in the La Plata Mountains. These gravel deposits were deposited by an earlier stage of the Mancos River before it eroded the modern valley system (Carrara 2012). In some references these gravels are identified as the Bridgetimber gravel (Atwood and Mather 1932; Wanek 1959).

Fossils: Unfossiliferous, included for completeness. There is some chance that the gravels include fossils transported from outside of the park; for example, fossiliferous quartzite clasts or petrified wood, both of which are durable enough to survive long transport in a river.

Quaternary rocks and sediments (Pleistocene–Holocene)

Lithology: Quaternary deposits on the cuesta tops mostly consist of loess deposited during the Pleistocene and Holocene. In the canyons, alluvium and colluvium from the Menefee Formation often cover Menefee outcrops; these deposits are dotted by rockfalls from the Cliff House Sandstone. Rocks fallen from the Point Lookout Sandstone often cap ridges in the Mancos Shale.

Fossils found within MEVE: Holocene: Charcoal (Carrara 2012; Herring et al. 2014), conifer pollen (Herring et al. 2014), *Ephedra* pollen (Herring et al. 2014), angiosperm pollen (Herring et al. 2014).

Fossils found elsewhere: The most likely types of fossils that may be present in MEVE's Quaternary deposits include ancient packrat middens in rock shelters (middens of perhaps a few hundred years' antiquity have been reported) and isolated durable remains of large extinct mammals, such as limb bones, skull bones, and teeth of mammoths, horses, camels, and bison. Partial remains of an extinct muskox have been found at Grass Mesa, roughly 30 km (20 mi) north of MEVE (McDonald et al. 1987) and extensive mammal remains have been recovered in the course of work on the Navajo Indian Irrigation Project of San Juan County, New Mexico, about 48 km (30 mi) south of MEVE (Lyman 1983).

Taxonomy

See also Appendix B for full lists of taxa by formations.

Fossil Plants

MEVE has significant but little-studied Upper Cretaceous plant fossils (Figure 15) and some Holocene plant material, again little-studied. All four of the Cretaceous formations exposed in MEVE have yielded at least some plant material, although for the Point Lookout and Cliff House sandstones the only records are of wood and other plant debris documented in park records. Unspecified Mancos Shale plant material found within MEVE has been mentioned in passing in Pike (1947) and Leckie et al. (1997); in both cases, the plants can be attributed to the Cortez Member of the Mancos Shale. Thompson (1972) described palynomorphs from a stratigraphic section of the Mancos Shale beginning at Point Lookout and ending outside of MEVE. Thompson reported a variety of acritarch, dinoflagellate, and terrestrial pollen taxa from the uppermost part of the section, the part that can be reliably attributed to MEVE. Again, this represents the Cortez Member. The pollen included a conifer (*Classopollis* sp. 1) and angiosperms (*Quadripollis krempii*, *Triporopollenites* cf. *T. scabroporus*, and *Trudipollis* cf. *T. hemiparvus*) (Thompson 1972). The acritarchs and dinoflagellates are discussed under “Microfossils” below.

The best paleobotanical record in MEVE comes from the Menefee Formation. At this time, the Menefee flora of Mesa Verde has not been described in the literature. According to park museum records and informal internal communications, the park’s Menefee flora includes ferns, cycads, several conifers (araucariacean and pinacean wood and generic “*Brachyphyllum*” foliage), and several flowering plants (foliage of *Ficus*, grass, hamamelidaceans, lauraceans, *Magnolia*, monocots, the palm *Sabalites*, *Sassafras*, and thecaceans, and a fruit). The fruit is reportedly similar to *Palaeoaster inquirenda* but different enough to indicate a distinct, perhaps ancestral species. Because of the propensity of the Menefee Formation to form landslides, new fossil sites are liable to be found after slumps and slides. Mary Griffitts frequently collected fallen material from one such site as it contains the best exposure of the middle sandstone member of the Menefee, which is rich in plant fossils. Griffitts collected fern, cycad, laurel, *Ficus*, sassafras, and magnolia leaves at this locality along with needles and tree bark. Most notably, the *Palaeoaster*-like seed originated from this locality. Immediately after the rock slides, many specimens of *Teredolites* were collected as well as a sizable piece of amber. G. William Harrison continued to resurvey this site in 2015 and 2017; he discovered several leaves affiliated with *Platanites* as well as redwood needles. Wet-sieving for micro-vertebrate fossils is planned for this site. In 2016 George San Miguel recorded a new Menefee site, which yielded an unknown species of *Platanites* among other specimens.

Figure 15. Cretaceous plant fossils (NPS GIP/G. WILLIAM M. HARRISON). Black bar is 1 cm. A) *Sequoia* relative. B) *Platanites* leaf from the Menefee Formation inside Mesa Verde.

Herring (2009) and Herring et al. (2014) have documented the mid to late Holocene vegetation of MEVE from sediment cores taken mainly from Prater and Morefield canyons. Pollen of conifers, the gnetophyte *Ephedra*, and angiosperms were found in these cores along with charcoal and peat (Herring et al. 2014). The fossils in these cores are of interest for paleoecological and fire history studies of the park. They show a transition from xeric-adapted flora in open settings to more mesic pinyon–juniper woodlands over the past 1,500 years, with fluctuating fire frequency. Fires were more frequent in the lowest part of the described core, from about 4,800 to 4,000 years ago. Frequency then decreased, only to rise again with a peak about 740 years ago, close to the peak of the Ancestral Puebloan civilization on the mesa of about 1250 AD (Herring et al. 2014). Herring et al. (2014) also noted some anomalously old dates, which they attributed to older sediment being mobilized following fires. These dates indicate the possibility of finding older material. Carrara (2012) reported a few other Holocene radiocarbon dates from the park. Packrat middens of essentially modern age are in MEVE collections, indicating that more ancient middens may be present in MEVE. If any are found, the plant fossils in them could be used to complement the known Holocene pollen record of the park.

In addition to the plant fossils from localities demonstrably in MEVE, park collections include specimens from localities outside of MEVE or with uncertain provenance. The specimens from outside of the park include examples of the Cretaceous tree fern *Tempskya*, a cycadeoid, and dicot leaves, and probable seed impressions from the Mancos Shale. Specimens with uncertain provenance include additional angiosperm leaves from the Menefee Formation, conifer wood, and foliage of ferns or fern-like plants.

Fossil Invertebrates

MEVE's invertebrates have been documented in much more detail in the literature than its plant fossils, but still only in a limited fashion. Pike (1947) and Leckie et al. (1997) give the most information and Wanek (1959), Lamb (1968), and Cobban (1973) touch on them. Leckie et al. (1997) place the mollusk fossils of the Mancos Shale into a biostratigraphic scheme that allows the rocks of MEVE and the vicinity to be correlated to the wider Western Interior Seaway. Most of the invertebrate fossils come from the Mancos Shale with a few found in the Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone (more in the two sandstone formations, which have more marine influence than the Menefee Formation). The vast majority of invertebrate fossils from MEVE and in MEVE collections are ammonites and bivalves. Both groups are abundant in the local Upper Cretaceous rocks and are useful for biostratigraphy in the Western Interior Seaway.

In addition to the following fossils, Pike (1947) reported that invertebrate fossils were recovered from a well drilled in MEVE. These possibly were shells from the Menefee Formation at 151 m (495 ft) down, the Naturita Formation at 1,022 m (3,352 ft) down, and an undesignated formation at 1,186 m (3,896 ft) down. The last formation is presumably of Jurassic age because the underlying rocks were attributed to the Navajo Sandstone, a Lower Jurassic formation.

Phylum Cnidaria: Class Anthozoa (corals)

There is a single coral reported from MEVE: a horn coral in park collections designated cf. *Streptelasma*, a widely distributed coral of the Ordovician, Silurian, and Devonian, much older than the rocks exposed at and around MEVE. Fossils have been encountered at many archeological sites in the Southwest, sometimes having been altered by people; numerous examples have been found at Pecos National Historical Park and Salinas Pueblo Missions National Monument (J. Tweet, pers. obs.). It would not be at all unusual for this to be something that someone brought to Mesa Verde for personal or cultural reasons. However, the coral identification is under scrutiny as it may be a weathered conical pebble.

Phylum Brachiopoda (lamp shells)

Examples of the brachiopods *Discinisca* and possibly *Lingula* from the Mancos Shale outside of MEVE are in the park collections (Figure 16). Brachiopods are a minor component of Mancos Shale faunas, with *Discinisca* reported from the Smoky Hill Member just outside of MEVE (Leckie et al. 1997), so brachiopods are probably present in the park as well. Additionally, the park museum houses a shell necklace made from a brachiopod.

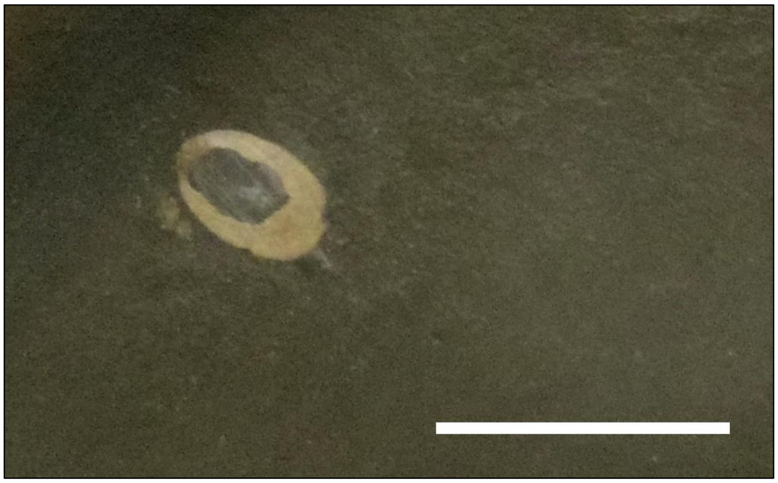


Figure 16. *Lingula* collected from the Mancos Shale outside of Mesa Verde (MEVE 51909). White bar is 1 cm (NPS GIP/G. WILLIAM M. HARRISON).

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

More than two dozen species of bivalves have been found in the Cretaceous rocks of MEVE (Figure 17), although only the bivalves of the Mancos Shale have been discussed in detail in the literature (Pike 1947; Leckie et al. 1997). Other identifications come from museum records. Many of the bivalves from MEVE are inoceramids, a type of marine epifaunal bivalve common in Upper Cretaceous rocks. Inoceramids are noted for their size, with a few species reaching 1 m (3 ft) or more across. These large bivalves were often colonized by smaller bivalves such as *Pseudoperna*, as seen on MEVE specimens. Inoceramids are also noted for their complex taxonomy. Since the initial descriptions of inoceramids, species have frequently been synonymized, divided, and transferred between various genera and subgenera. Therefore, the taxonomy presented here should be regarded as subject to change. Bivalves collected from the Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone in MEVE are also in the park collections, but have not been discussed in the literature aside from a mention of *Inoceramus* sp. in the Point Lookout Sandstone in Wanek (1959). Park collections also house a number of bivalves from outside of MEVE or with unclear locality information. Many of those from outside of MEVE are part of Leckie et al.'s (1997) collections from the Mancos Shale along the north side of the park.

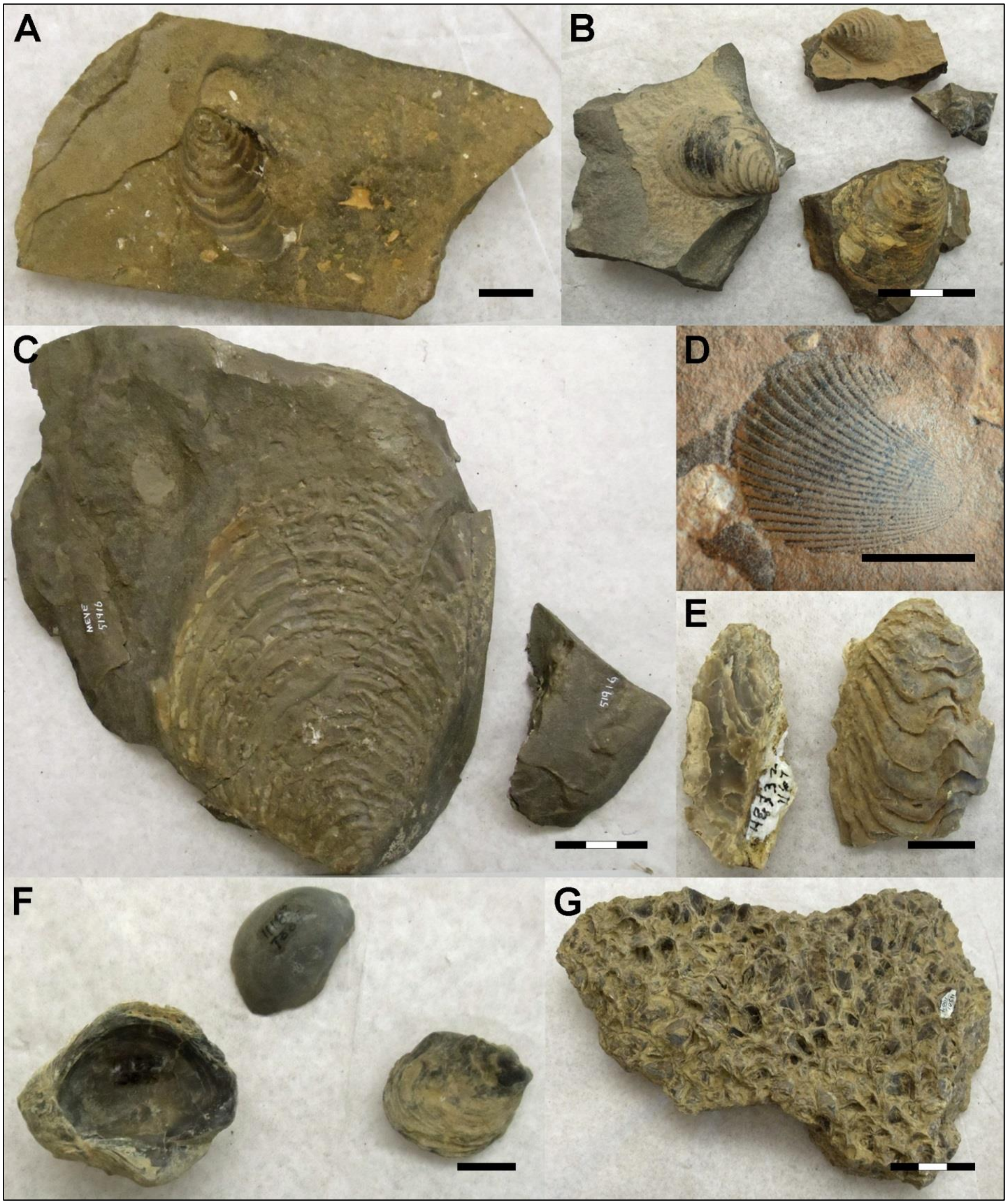


Figure 17. Bivalves (NPS GIP/G. WILLIAM M. HARRISON). Black bars are 1 cm; black and white bars are 3 cm. A) *Inoceramus perplexus* (Whitfield) external mold from the Juana Lopez Member (MEVE 11242). B) *Inoceramus dimidius* (White) cast from the Mancos Shale outside of Mesa Verde National Park (MEVE 78541). C) *Inoceramus subquadratus crenelatus* impression from the Mancos Shale (MEVE 51916). D) An *Ethmocardium* cast in the Cliff House Sandstone Spruce Tree House. E) Nearly complete *Ostrea russelli* (Landes) from the Cliff House Sandstone of Mesa Verde National Park (MEVE 48332). F) Loose *Pycnodonte newberryi* (Stanton) likely from the Mancos Shale (MEVE 11183). G) A bed of *Pseudoperna bentonensis* (Logan) from the Mancos Shale (MEVE 11301).

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

Cephalopods have been collected from the Mancos Shale, Point Lookout Sandstone, and Cliff House Sandstone in MEVE, with at least nine genera represented in the park collections (Figure 18). The great majority of the finds are from the Mancos Shale. Several other forms collected from outside of the park or from equivocal locations are also in the park collections. The specimens from MEVE are all ammonites, an extinct group of shelled cephalopods that generally resembled the modern coiled nautilus but which were more closely related to octopuses and squids. Like the inoceramids, the ammonites of MEVE are useful for biostratigraphy and have been divided into a number of species. The most detailed reference on MEVE ammonites is Leckie et al. (1997). Pike (1947) and Lamb (1968) also cited several species and Cobban (1973) identified occurrences of *Baculites aquilaensis* and *Scaphites hippocrepis* from the park. Not all of the specimens are of shells or shell parts; the museum also has specimens of scaphitid aptychi, which are interpreted as mouthparts or head coverings.

The cephalopods in MEVE collections from outside of the park are generally ammonites from the lower Mancos Shale, collected during the work of Leckie et al. (1997), but there are also several ammonites from the Naturita Formation (historical Dakota Formation or Sandstone) from the vicinity of the county fairground south of Highway 160. These Naturita forms are undescribed and worthy of study (J. Kirkland, 2016 collections report to MEVE). The Upper Cretaceous nautiloid *Eutrephoceras* is also represented from the Mancos Shale in what is now Canyon of the Ancients National Monument. The cephalopods with equivocal or no locality information are generally consistent with an origin either within or just outside of the park.

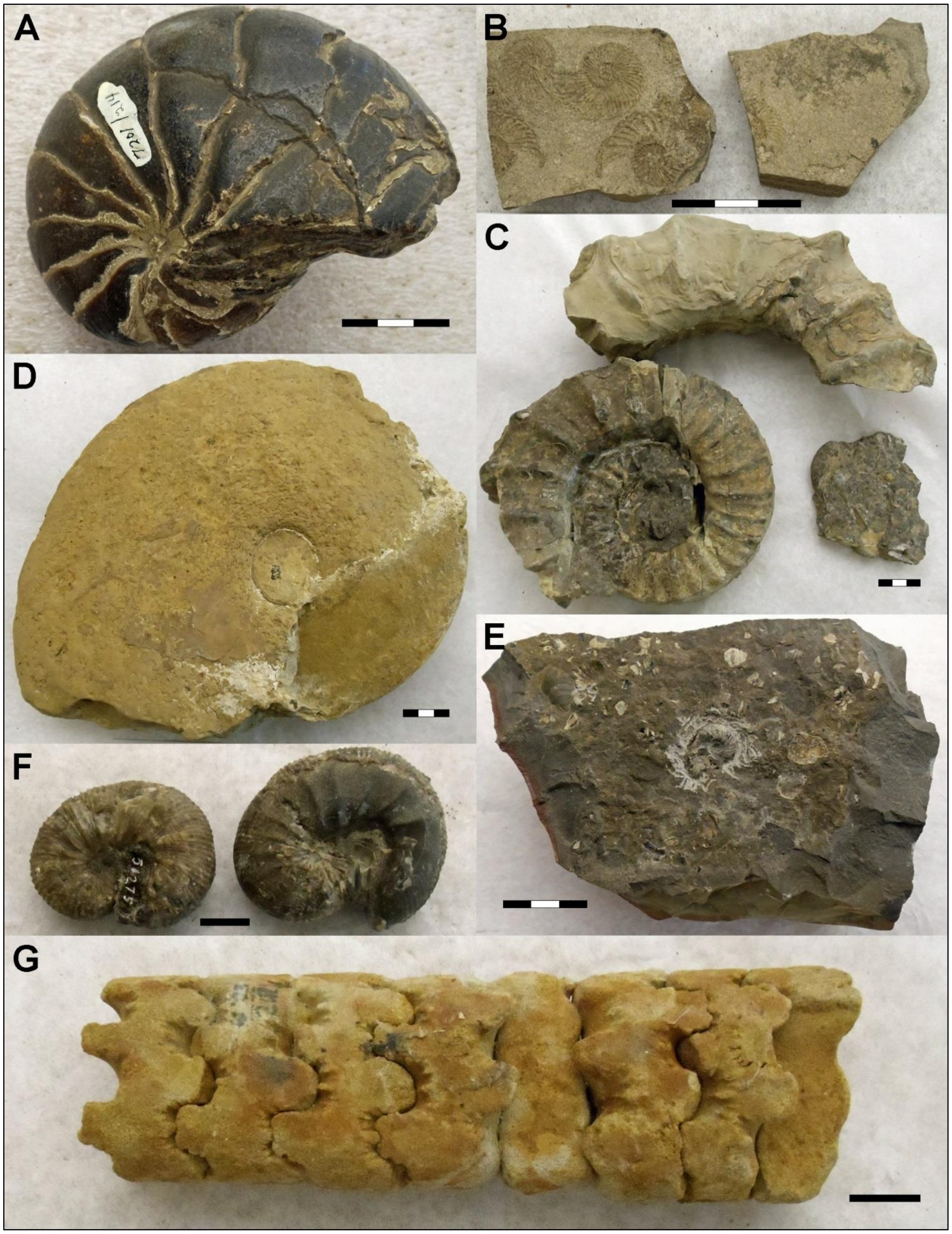


Figure 18. Cephalopods (NPS GIP/G. WILLIAM M. HARRISON). Black bars are 1 cm; black and white bars are 3 cm. A) Nautiloid *Eutrephoceras dekayi* from the Mancos Shale in Canyon of the Ancients (MEVE 7201). B) *Collignoniceras woollgari* (Mantell) impressions from the Totten Reservoir (MEVE 11210). C) Large *Prionocyclus macombi* (Meek) cast from the Mancos outside Mesa Verde National Park (MEVE 51230). D) *Placenticeras planum* (Hyatt) internal mold from the Mancos (MEVE 51835). E) *Prionocyclus macombi* (Meek) with exquisitely preserved ornamentation from the Mancos outside of Mesa Verde (MEVE 78546). F) *Scaphites whitfieldi* (Cobban) from the Mancos outside Mesa Verde National Park (MEVE 51275). G) *Baculites* from the Cliff House Sandstone of Mesa Verde National Park (MEVE 7257).

Phylum Mollusca: Class Gastropoda (snails)

A handful of gastropods are in the MEVE collections (Figure 19). Some of them were recovered from the Mancos Shale within MEVE and have been assigned to the high-spired marine genus *Turritella*. A few other gastropods in the park collections come from the Mancos Shale outside of MEVE. The collections also include several Holocene terrestrial gastropods from unspecified locations; without additional information, it is not possible to know if they are fossil or modern.

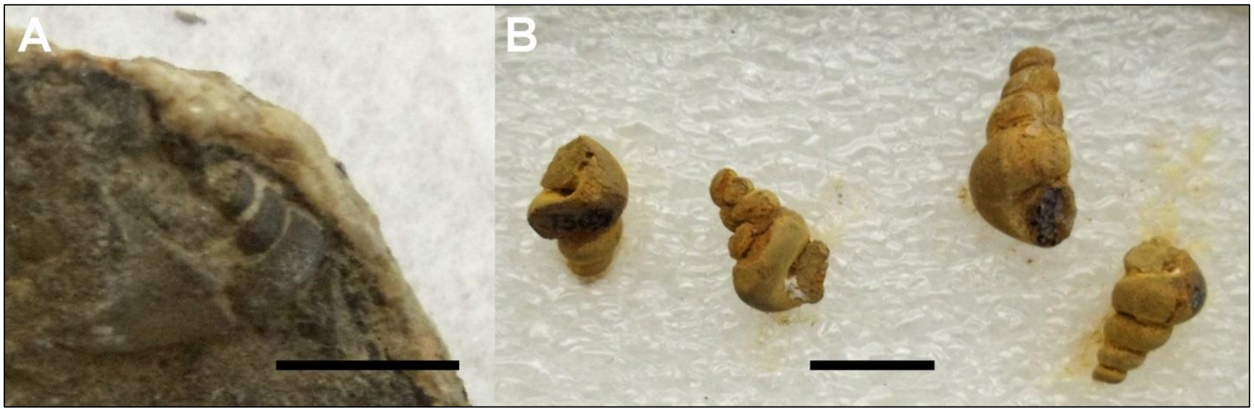


Figure 19. Gastropods (NPS GIP/G. WILLIAM M. HARRISON). Black bars are 1 cm. A) *Turritella* cf. *whitei* collected by Mary Griffitts in the Juana Lopez Member (MEVE 71612). B) Gastropods from the Cliff House Sandstone of MEVE (MEVE 7301).

Phylum Annelida (segmented worms)

Although the bodies of worms rarely fossilize, some annelids are known in the fossil record from their hard chitinous jaw parts (scolecodont elements) or from mineralized tubes. Tubes assigned to *Serpula* have been reported from the Mancos Shale of MEVE (Leckie et al. 1997). MEVE collections also include scolecodont elements from the Mancos Shale found outside of the park.

Phylum Arthropoda

Although trace fossils produced by arthropods are known from MEVE, such as burrow tubes and trackways, arthropod body fossils have not been reported from the park (unless insect remains found in the ruins are included; e.g. Graham 1965). However, barnacles (*Stramentum* sp.) found in the Mancos Shale from outside of MEVE are in park collections (Figure 20).

Figure 20. Barnacle scutal plate from Totten Reservoir (MEVE 11197). Black bar is 1 cm (NPS GIP/G. WILLIAM M. HARRISON).

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

Several kinds of echinoderms have been found in MEVE or are in the MEVE collections (Figure 21). The free-floating crinoid *Uintacrinus* is known from the Mancos Shale of the park (Pike 1947; Leckie et al. 1997) (Figure 21A). A natural mold of a sea star is in the MEVE collections (MEVE 7103). Daniel Blake (University of Illinois) proposed describing it in 2004, but it has not been published. The discovery locality of this specimen is not certain, but it is from the Cliff House Sandstone and it may have been mentioned in Nusbaum (1926), so it probably came from Mesa Verde and likely from the portion of the Mesa inside Mesa Verde National Park. Finally, there is an echinoid from an unspecified location in MEVE collections (MEVE 78591) (Figure 21B).

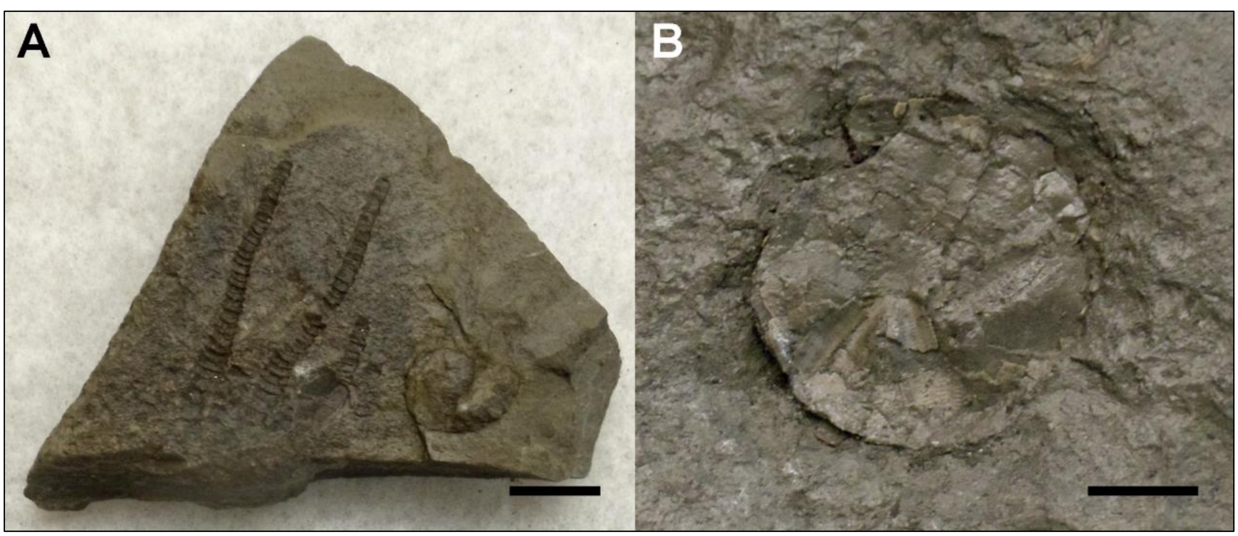


Figure 21. Echinoderms (NPS GIP/G. WILLIAM M. HARRISON). Black bars are 1 cm. A) Free-floating crinoid *Uintacrinus* sp. from the Mancos Shale in Mesa Verde (MEVE 53028). B) Echinoid from the Mancos Shale outside Mesa Verde (MEVE 78591).

Fossil Vertebrates

Vertebrate fossils, primarily from cartilaginous and bony fishes, have been reported from the Mancos Shale and Cliff House Sandstone in MEVE. The park's collections include vertebrate fossils from the Mancos Shale, Menefee Formation, and Cliff House Sandstone found outside of the park and from equivocal locations. Most of the vertebrate fossils from MEVE originate from the Cliff House Sandstone.

Class Chondrichthyes (sharks and rays)

A partial tooth of the ray *Ischyrhiza* and shark teeth (including teeth of the goblin-shark-like *Scapanorhynchus*) have been found in the Cliff House Sandstone of MEVE. A variety of shark teeth were recovered from the Mancos Shale outside of MEVE during the work conducted by Leckie et al. (1997) and are in the MEVE collections. Another group of shark and ray teeth in MEVE collections come from unspecified locations, but are taxonomically consistent with both the Mancos Shale and Cliff House Sandstone (Figure 22).

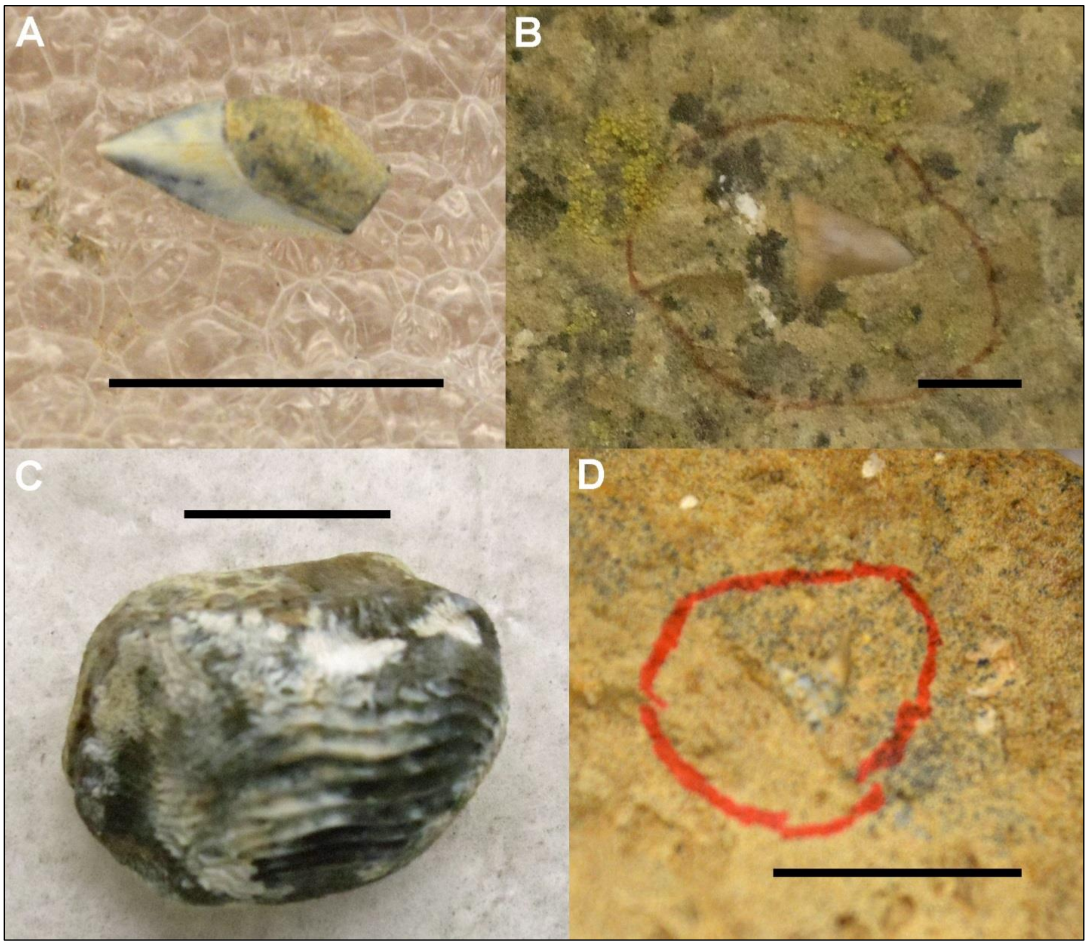


Figure 22. Chondrichthyan teeth (NPS GIP/G. WILLIAM M. HARRISON). Black bars are 1 cm. A) *Squalicorax* tooth from the Mancos Shale outside of Mesa Verde (MEVE 51220). B) Lamnid shark tooth likely from the Cliff House Sandstone (MEVE 73667). C) *Ptychodus decurrens* tooth from the Mancos Shale outside of Mesa Verde (MEVE 51222). D) *Ischyrhiza* tooth likely from the Cliff House Sandstone (MEVE 73670).

Class Osteichthyes

Fossils of undetermined bony fishes and teeth of the bony fish *Enchodus* have been found in the Cliff House Sandstone at MEVE and the Mancos Shale in the park has yielded fossils of another bony fish ("*Hypsodon* sp." of Pike 1947) (Figure 23). *Ichthyodectes* scales collected from the Mancos Shale outside of MEVE are in the park collections, along with additional *Enchodus* fossils from unknown locations.

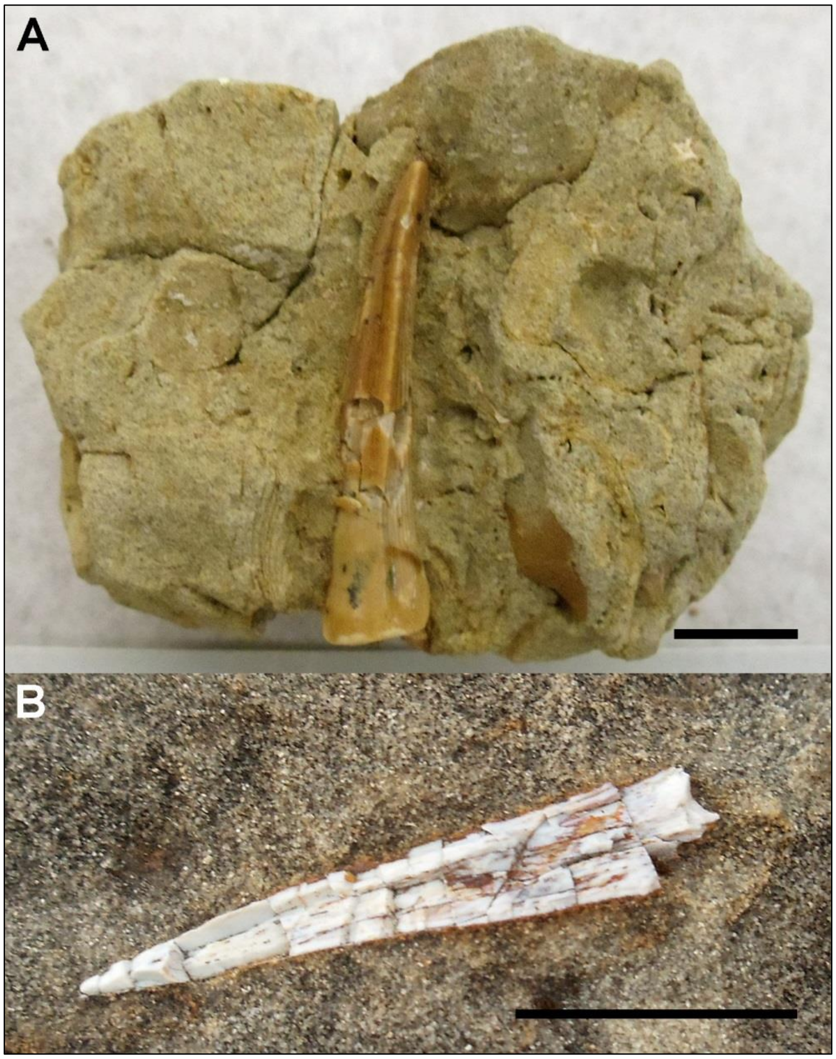


Figure 23. Osteichthyan teeth. A) *Enchodus* tooth collected during the construction of the Chapin Museum (MEVE 43908) (NPS GIP/G. WILLIAM M. HARRISON). B) *Enchodus* tooth as it appears in the field (NPS/GEORGE SAN MIGUEL). Both are from the Cliff House Sandstone in Mesa Verde National Park. Black bars are 1 cm.

Class Reptilia

Fossils of several kinds of marine reptiles have been found in the Cliff House Sandstone at MEVE (Figure 24). These include turtle shell fragments, a mosasaur tooth, plesiosaur bones, and dinosaur bones. Plesiosaurs were marine reptiles with flippers and broad bodies. The MEVE specimens appear to include a long-necked form ("*Plesiosaurus*," an anachronistic reference; an Upper Cretaceous long-necked plesiosaur from the Western Interior Seaway would have been more similar to *Elasmosaurus* and its relatives than to *Plesiosaurus*, from Lower Jurassic rocks of Europe) and a short-necked form (a polycotylid; more complete polycotylid fossils of similar age have been described from Glen Canyon National Recreation Area to the west).

Reptile fossils in MEVE collections from uncertain locations include undetermined reptile fossils from the Menefee Formation and turtle, pterosaur, dinosaur, and undetermined reptile fossils from unspecified rocks.

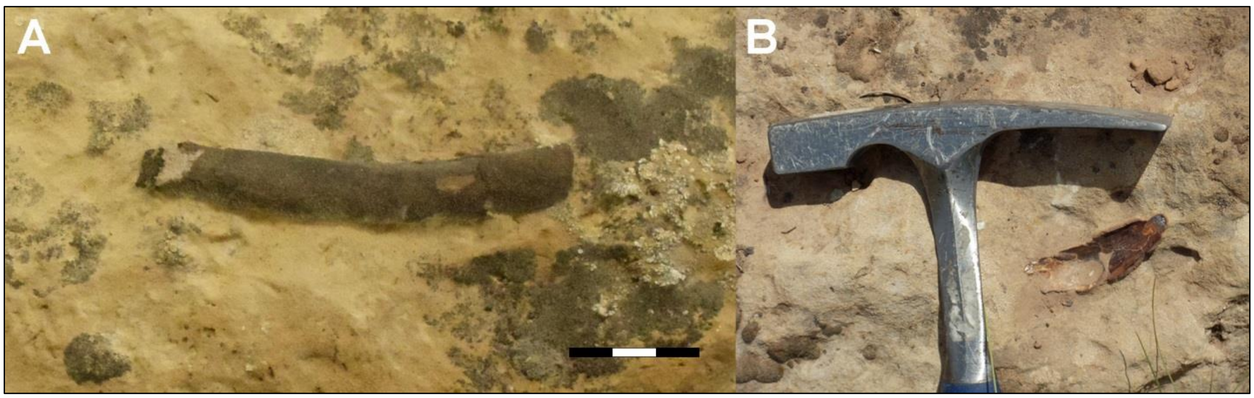


Figure 24. Reptile bones (NPS GIP/G. WILLIAM M. HARRISON). A) Reptile bone collected from the Cliff House Sandstone (MEVE 10358). Black and white bar is 3 cm. B) Mosasaur tooth found in the Cliff House Sandstone above an alcove.

Ichnofossils

A variety of trace fossils from invertebrates and vertebrates have been found in MEVE (Figure 25). All four Cretaceous formations exposed in the park have produced invertebrate trace fossils. Leckie et al. (1997) reported burrows, general bioturbation, and fecal pellets from the Mancos Shale, and the park museum has possible crustacean tracks from this formation. For the Point Lookout Sandstone, park collections include examples of *Ophiomorpha* (burrows attributed to ghost shrimp, with a "corn cob"-like surface), *Planolites*-like trails, and unnamed burrows and trails. The Menefee Formation has yielded *Ophiomorpha* (Wanek 1959, identified under the outdated name "*Halymenites*") and *Teredolites*, borings made by a shipworm-like creature on wood. For the Cliff House Sandstone, park collections include borings, invertebrate tracks, *Ophiomorpha*, *Teredolites*, and *Thalassinoides* burrows. Invertebrate trace fossils collected from unspecified Upper Cretaceous rocks in MEVE include borings, possible arthropod tracks, and a "tubeworm-marked surface."

A small number of invertebrate trace fossils from outside of MEVE are in the park collections including Mancos Shale burrows and tracks, *Gyrochorte* and *Thalassinoides* from the Cliff House

Sandstone, and thin sections of *Ophiomorpha* from the Upper Cretaceous Pierre Shale brought in for comparative purposes. Invertebrate trace fossils in MEVE collections from unspecified locations include an ammonite touch mark, probably from the Mancos Shale, and borings, trails, and burrows from unspecified rocks.

Vertebrate trace fossils from MEVE include a new form of chimaera (ratfish) egg capsules of the ichnogenus *Chimaerotheca* found in the Cliff House Sandstone (Harrison et al. 2016). MEVE museum collections include packrat (*Neotoma* spp.) middens dated to the modern era from the park, but older middens are reportedly present as well. Cary (1911) noted large packrat middens in the ruins blackened with smoke, suggesting they date to the time of the Ancestral Puebloans. Nusbaum (1926) mentioned being permitted to tear apart a packrat nest in a ruin in Soda Canyon and noted that "You always find pack-rats' nests in ruins."

In addition to these vertebrate trace fossils, MEVE collections also include Jurassic dinosaur tracks from outside of the park and Pleistocene horse tracks from what is now Death Valley National Park. The horse tracks were collected before Death Valley National Park was established as such, although why they were reposited in MEVE remains a mystery.

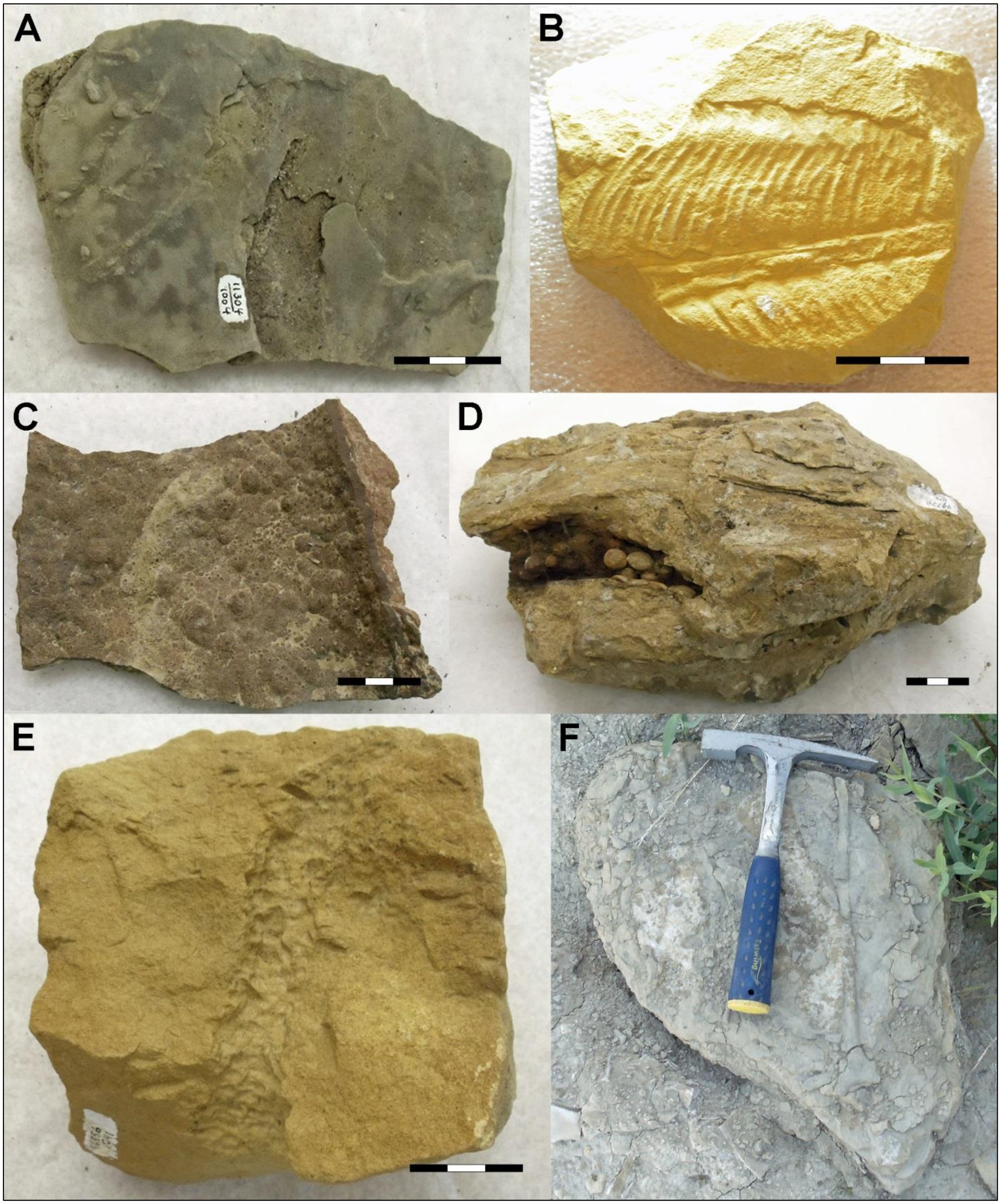


Figure 25. Ichnofossils (NPS GIP/G. WILLIAM M. HARRISON). Black and white bars are 3 cm. A) Crustacean tracks found in Mesa Verde National Park (MEVE 11304). B) A chimaerid egg capsule discovered in the Cliff House Sandstone in 2015. C) *Teredolites* discovered in the Cliff House Sandstone (MEVE 10342) and D) Menefee Formation (MEVE 99778). E) *Ophiomorpha* burrow external molds in the Cliff House Sandstone (MEVE 46956) and F) casts in the Point Lookout Sandstone.

Microfossils (exclusive of paleobotany)

Examples of several groups of microfossils have been reported from the Mancos Shale in MEVE. In addition to pollen, Thompson (1972) reported a number of taxa of single-celled acritarchs and dinoflagellates from the upper Mancos Shale. Acritarchs are organic microfossils that cannot be assigned to any other group, while dinoflagellates are a kind of plankton that propel themselves with whip-like flagella. Leckie et al. (1997) mentioned in passing the presence of foraminifera in the Smoky Hill and Cortez members, which Sterzinar (2005) later documented in greater detail. Leckie et al. (1998) and West et al. (1998) documented the distribution of planktic and benthic foraminifera through the lower members of the Mancos Shale, just outside the north end of the park. Lamb (1968) referred to several species of forams from the basal "Niobrara" (=Smoky Hill Member) as exposed along the north side of Mesa Verde, but it is not clear if the material came from within or outside of MEVE. Foraminifera are free-floating and bottom-dwelling single-celled protists that can be briefly described as amoebas with shells. Finally, Mizintseva (2013) reported a handful of coccolith taxa from the Cortez Member. Coccoliths are tiny mineralized plates from certain "algae," and are among the smallest fossils that have been studied. They are one of the main kinds of "nannofossils." Each of these groups is useful for biostratigraphy and paleoenvironmental interpretation.

Pseudofossils and Misidentified Fossils

Mesa Verde National Park has rarely had a professional paleontologist on its staff. Therefore, much of the paleontological collection has been done by archeologists, volunteers, and rangers from other divisions. This is especially true in the early days of MEVE when Deric Nusbaum, stepson of former Superintendent Jesse Nusbaum, was allowed to collect any surface finds and when CCC workers excavated the roads and built the park headquarters, which are still in use. Therefore, it is inevitable that many objects have been incorrectly collected and accessioned as fossils (Figure 26). These range in authenticity from a piece of modern wood that was labelled as petrified wood to a calculus from a deer stomach (Figure 26A) which appeared so convincingly like a reptile egg that two casts were made for further study. Recently, a bryozoan/cycad fossil has been re-identified as a fabric impression on ceramic as a part of continuing work on the collections (Figures 26B and 26C). Additionally, a fossil identified as a horn coral is under scrutiny as a conical pebble (Figure 26E).

Figure 26. Pseudofossils and misidentified fossils (NPS GIP/G. WILLIAM M. HARRISON). Black bars are 1 cm; black and white bars are 3 cm. A) MEVE 10470, a calculus (naturally occurring internal organic concretion) from a deer's stomach, misidentified as a reptile egg. B) and C) Two views of MEVE 10493, once identified as a bryozoan, now known to be textile impressions. D) MEVE 9361, initially identified as a scaphopod but later identified as a burrow cast. E) Supposed horn coral MEVE 68105.

Cultural Resource Connections

Befitting a park established to protect archeological sites, there are multiple records of paleontological resources or potential paleontological resources found in cultural resource contexts at MEVE. The Ancestral Puebloans and other prehistoric groups in the Mesa Verde area had multiple uses for paleontological resources. Stone tools from southwest Colorado were made from fossiliferous rocks in some cases. Chert from algal limestones of the Lower Cretaceous Burro Canyon Formation and fossiliferous sedimentary cobbles (including fossiliferous Paleozoic cherts and Cretaceous petrified wood) are among the types of rock used for stone tools in the area (Gerhardt 2003). Wood (1938) presented a brief study of types of stone used for tools and other artifacts at MEVE. 139 MEVE catalog numbers have been assigned to petrified wood in the archeological collections. Those that have been at least tentatively identified to specific artifact types or human modifications include awls (1), choppers (1), cylinders (1), disks (1), drills (4), flakes (11), gravers (1), grooved weights (1), hammerstones (3), knives (4), lithic cores (7), manos (1), medicine stones (4), polished stones (2), polishing stones (1), projectile points (3), scrapers (7), shaped or worked stones (2), spatulate objects (2), and tablets (4) (G. Cox, pers. comm. to Justin Tweet, February 2009). Worked jet from the Menefee Formation is also in the MEVE collections (M. Griffitts, pers. comm. to George San Miguel/MEVE, 2001).

Holocene insects are known from a number of MEVE archeological sites (Graham 1965; Evans and Baldwin 1977; Elias 1997). The insect assemblages appear to have persisted almost unchanged from the Basketmaker culture to the Pueblo culture (Elias 1997). Insects have been found associated with human remains, coprolites, and in food storage containers (Scott et al. 2001). Olsen (1971) mentioned natural mummies of the lizards *Sceloporus* and *Cnemidophorus* found in diggings at Mug House Ruin. Remains of plants, insects, and animals (represented by thousands of bones) that lived at the same time as the cliff dwellers have been found in refuse (Cattanach 1980). Pollen from reservoirs built by the Ancestral Puebloans between 750 and 1180 AD has been analyzed. Reservoir sites studied include Box Elder Reservoir, Morefield Canyon, Far View, and Sagebrush, with the first two from canyon bottom sites and the latter two from mesa tops. These reservoirs were probably used for domestic water (Holloway and Wright 2006). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

There is an interesting case of a pseudofossil from MEVE with a cultural context. J. Walter Fewkes, in an abstract describing Sun Temple, reported an object he described as a “fossil leaf of a palm in relief on the upper surface of the cornerstone at the western edge of the building” (Fewkes 1916a) (Figure 27). He interpreted it as a sun symbol (Fewkes 1916a, 1916b). Paleobotanist Frank H. Knowlton identified the object as a leaf of a Cretaceous palm (Fewkes 1916b). This interpretation was discredited by Lang (1937), and it is now regarded as a solution rill (Mesa Verde National Park 2005). A history of the shifting early identifications can be found in Franke (1934). Although this object proved to be a pseudofossil, there are many actual fossils incorporated into the ruins. In 2015 Geoscientists-in-the-Parks intern G. William Harrison documented many fossils within archeological contexts and created a document for Interpretive Rangers that lists where fossils in cliff dwellings are located and gives information about the specimens. In 2016 George San Miguel, Director of Natural Resources at Mesa Verde National Park, created a more complete list and used architectural maps to get better locational data. G. William Harrison is currently working on a more detailed document for Interpretive Ranger training purposes. Fossiliferous stone is known from nearby Yucca House National Monument (YUHO) (Tweet et al. 2009), and has been reported since the late 19th century (Holmes 1878, as "Aztec Springs"). A site in Johnson Canyon just south of MEVE also has fossiliferous stone (Chapin 1892, as "Acowitz Canyon").

Figure 27. An overhead view of the solution rill of Sun Shrine, Sun Temple (Figure 10 in Fewkes 1916b).

Paleontological Resource Management and Protection

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

In 2009, the Paleontological Resources Preservation Act (PRPA) was signed into law as part of the Omnibus Public Land Management Act of 2009. The new paleontology-focused legislation includes provisions related to inventory, monitoring, public education, research and collecting permits, curation, and criminal/civil prosecution associated with fossils from designated DOI lands. Paleontological resource protection training is available for NPS staff through the NPS Geologic Resources Division (GRD). GRD is also available to provide support in paleontological resource theft or vandalism investigations.

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

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

In the course of this inventory, paleontological localities have been evaluated for factors that could cause potential loss of paleontological resources (see the separate locality document for full details). Their overall conditions are reported as good, fair, or poor based on the situations found at each individual locality. Risks and conditions that influence the degree of potential loss are identified in each Paleontological Condition Evaluation Form. These 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, such as inherently soft rapidly eroding sediment or mass wasting on steep hillsides. “Abundance” judges both the natural condition and number of specimens actually preserved in the deposits as well as the risk of being easily recognized as a fossil-rich area which could lead to the possibility of unpermitted collecting. “Site Access” assesses the risk of a locality being visited by large numbers of visitors or the potential for easy removal of large quantities of fossils or fossil-bearing sediments as a result of convenient transportation corridors.

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

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

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

Interpretation and Education

Fossils and paleontology are popular topics with large segments of the public; this is especially true with children. The increased understanding of the paleontological resources at Mesa Verde National Park presents many opportunities for public interpretation and education. Fossils possess interesting scientific and educational information about the ancient organisms themselves and often reveal important information about geologic history and paleoenvironments.

A brief guide to fossils within cliff dwellings was created and is used by some Interpretive Rangers on their tours, although it is not presented to new hires during training. A more complete guide is under development. Furthermore, some fossils are displayed in the museum in glass cases.

Some basic paleontological resource interpretive/educational information could be developed to post on the park website or include in informational brochures/site bulletins or wayside exhibits and other types of interpretive media. A few slabs of representative stone could be bolted to a table in the Visitor and Research Center for a visual-tactile display. Fossil replicas can be obtained by the park for use in educational outreach, school field trips or public interpretation.

The National Park Service coordinates the National Fossil Day partnership (second Wednesday in October) (https://www.nps.gov/subjects/fossilday/index.htm) and hosts fossil-focused events across the country, in conjunction with Earth Science Week. The NPS Geologic Resources Division can assist parks with planning for National Fossil Day activities in the park and provide supplies of Junior Paleontologist (https://www.nps.gov/subjects/fossils/junior-paleontologist.htm) paraphernalia, including activity booklets, badges, posters and other fossil-related educational resources.

Paleontological Research and Collections

Paleontological Research Permits

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

MEVE Paleontological Specimens in Museum Collections

The MEVE Research Center has an extensive and growing collection with a total of 2,428 paleontological specimens (G. Cox, pers. comm. to Justin Tweet, February 2009). 989 MEVE catalog numbers have been assigned to paleontological specimens not associated with cultural resources, including 44 from Yucca House National Monument (YUHO). The following counts have the YUHO specimens removed. Specimens include trace fossils (40 catalog numbers, including a coprolite, two dinosaur footprints, and horse tracks), brachiopods (5), cephalopods (193 specimens with a single identified cephalopod taxon), bivalves (344 specimens with a single bivalve taxon), mixed ammonites and bivalves (43), gastropods (13), annelid worms (2), barnacles (2), sea star (1), crinoids (2), echinoids (1), unknown vertebrates (25), cartilaginous fishes (32), bony fishes (19), turtles (2), plesiosaurs (1), pterosaurs (1), dinosaurs (1), petrified wood (19), other plants (130), plants and bones from packrat middens (29), specimens mixing material from multiple categories (30), and unknown fossils (10) (G. Cox, pers. comm. to Justin Tweet, February 2009).

Several thousand fossils representing 110 species were collected from both the Mancos Shale and the overlying Point Lookout Formation during the project to define the principal reference section for the Mancos Shale (Kirkland et al. 1995; Leckie et al. 1997); this collection of fossils is also stored at the MEVE Research Center. Bulk samples (mostly shale and mudrock) from the Mancos Shale collected for this project are reposited at the University of Massachusetts (Amherst) Department of Geosciences, where they have been used for microfossil studies including fossils from MEVE (Leckie et al. 1998; West et al. 1998; Sterzinar 2005; Mizintseva 2013; Corbett and Watkins 2014a; Lowery 2015).

It is likely that some of the specimens lacking provenance data in MEVE collections were collected by Deric Nusbaum. In his book, he mentioned "I am not allowed to dig in the Park, but if I find anything lying around I bring it to the Museum" (Nusbaum 1926:76). The most obvious candidate is the sea star because he mentioned finding one and these are rare fossils. Additionally, many fossils were collected by CCC workers in the 1930s.

The MEVE collections have a long and complex history. In the 1930s, they were housed in the Chapin Mesa Museum's basement. Later they were moved to the CCC camp, where they were reposited in a building known first as the Wetherill Lab and currently as the Tin Shed. However, this building was located in a fire danger zone. Therefore the collections had to be evacuated to an outside facility twice, once in 2000 and again in 2002.

At least six outside institutions may curate fossils from MEVE (see also Appendix F): the National Museum of Natural History (USNM; Washington, D.C.); the University of Colorado Museum of Natural History (UCM; Boulder); the University of Massachusetts (Amherst); Michigan State University (East Lansing, Michigan); the Chicago Field Museum (FMNH; Chicago); and the University of California Museum of Paleontology (UCMP; Berkeley, California). Also, USGS-Denver has information concerning MEVE fossils, but apparently no specimens. Finally, William S. Pike collected specimens in MEVE but left no indication of where or if they are reposited.

Potential USNM specimens are entwined with USGS-Denver in the history of the specimens collected by Cobban and Gill in 1964 and cited in Cobban (1973). It is unclear where these specimens are located. William Cobban was long affiliated with USGS-Denver and the specimens have USGS locality numbers. Most USGS specimens went to the USNM, but some fossils are still reposited at USGS-Denver. However, no specimens from the USGS localities D4787 through D4790, all confirmed as within MEVE, are in USGS-Denver collections (K. McKinney, pers. comm., November 2016), and the USNM database does not list any appropriate specimens either, although it is certainly possible that the fossils are in USNM collections but haven't been added to the database.

The University of Massachusetts specimens were mentioned above in connection with the Mancos Shale principal reference section. Because the relevant fossils are microfossils obtained from bulk sediments, there are no doubt uncountable additional microfossils in unprocessed samples. The Michigan State University specimens are also microfossils, stored on slides analyzed in Thompson (1972) with the Department of Geology. Michigan State University's specimens are now housed at the Field Museum in Chicago.

Steve Wallace's fossils were supposed to be at the University of Colorado (UCM locality 95061). Wallace reported that most of the inoceramids from the locality were in the possession of Christopher Collom of Alberta, Canada who had the specimens in anticipation of funding for study. Most of the ammonites were identified by William Cobban. Both the inoceramids and ammonites have not been accessioned into UCM collections (S. Wallace, pers. comm., November 2016). UCM invertebrate paleontology collections manager Talia Karim (pers. comm., November 2016) confirmed that there were no catalogued specimens from UCM 95061 in collections.

William P. Elder analyzed mollusks for Kirkland and Leckie and helped with the images for their paper (Leckie et al. 1997). All fossils used in images ended up with Chuck Powell at Menlo Park and are curated by the University of California Museum of Paleontology. These specimens are to be returned in the near future.

Paleontological Resource Management Recommendations

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

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

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

- Several new species have been discovered in MEVE. The park should attempt to describe these specimens for publication.

- MEVE contains significant undescribed fossil resources. Paleobotanical resources are abundant, easily accessible, and understudied. The Cliff House Sandstone contains multitudes of invertebrate impressions and vertebrate bones, none of which have been studied in Mesa Verde. Furthermore, the rocks contain significant mollusk resources that demonstrate over 10 million years of evolution if the surrounding Naturita Formation is included.

- MEVE should contact people who would be interested in documenting the Menefee flora.

- MEVE's and YUHO's abundant Western Interior Seaway fossils link it to several other NPS units, such as Badlands National Park, Big Bend National Park, Bryce Canyon National Park, Chaco Culture National Historical Park, Dinosaur National Monument, Glen Canyon National Recreation Area, Missouri National Recreational River, and Yellowstone National Park, which also have significant fossil resources from the Seaway (Figure 8). Coordination and communication with these other parks in regard to management issues, public outreach and interpretation, research, and other topics related to the Western Interior Seaway may be desirable.

- The Quaternary paleontological resources of MEVE contain important paleoecological and paleoclimatological data, with implications for resource management during times of past climate change. The park staff may want to seek opportunities for scientific study and collaboration.

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

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

- Any occurrence of paleontological resource theft or vandalism should be investigated by a park law enforcement ranger. When possible, the incident should be fully documented and the information submitted for inclusion in the annual law enforcement statistics.

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

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

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Appendix A. MEVE locality information

The field inventory documented 131 localities in and around MEVE. They represent all of the fossiliferous units in the park. Further information, including locality forms and condition evaluations, must be requested from the park.

Appendix B. Paleontological species list

Uncited taxa are derived from unpublished MEVE museum records. For space, no citation is included for taxa included in both museum records and a publication. Formation names are abbreviated for space (Fm = Formation, Sh = Shale, Ss=Sandstone). Taxonomy is generally after the source, with the exception of mollusks, which follow Leckie et al. (1997). The taxa found in the Mancos Shale can often be further restricted to specific members, but this has not been done here. Consult Leckie et al. (1997) for detailed biostratigraphy of the Mancos Shale.

In addition to these fossils which were collected at or near the surface, Pike (1947) mentioned the presence of fossils in a deep water well drilled in MEVE. The fossils included shells from what is possibly the Menefee Formation, the Naturita ("Dakota") Formation, and an undesignated unit below them and above the Navajo Sandstone.

Paleobotany

Plantae

Charcoal (Carrara 2012, Herring et al. 2014) ....Holocene
Coal and lignite (including jet) ....Menefee Fm, unspecified Upper Cretaceous
Leaves ....Menefee Fm
Plant material/debris .... Mancos Sh (Pike 1947, Leckie et al. 1997), Cliff House Ss
Wood...Mancos Sh, Point Lookout Ss, Menefee Fm, Cliff House Ss, unspecified Upper Cretaceous

The Menefee Formation at MEVE contains a diverse flora that has only been studied to a limited extent (M. Griffitts, pers. comm. to G. San Miguel, July 2001).

<u>Plantae: Sphenopsida</u>

"*Calamites*" sp.[1] ....unspecified Upper Cretaceous

<u>Plantae: Polypodiopsida</u>

Undetermined ferns (M. Griffitts, pers. comm. to G. San Miguel, July 2001)....................Menefee Fm

<u>Plantae: Cycadophyta</u>

Undetermined cycads (M. Griffitts, pers. comm. to G. San Miguel, July 2001) ....Menefee Fm

<u>Plantae: Pinales</u>

Araucariacean trunk and stem fossils..Menefee Fm
Brachyphyllum sp. (a form genus for conifer leaves) ....Menefee Fm
Classopollis sp. 1 pollen (Thompson 1972)... Mancos Sh

[1] *Calamites* is a Paleozoic horsetail-like genus; a similar Cretaceous fossil is more likely *Equisetum*.

Juniperus pollen (Herring et al. 2014) ....mid–late Holocene
Pinacean wood ....Menefee Fm
Pinus pollen (Herring et al. 2014)..mid–late Holocene
Pinus subgenus *Strobus* pollen (Herring et al. 2014)..mid–late Holocene
Sequoia sp. ....Menefee Fm
Undetermined conifer material, including wood ....Menefee Fm

Plantae: Gnetophyta
Ephedra sp. pollen (Herring et al. 2014) .... mid-late Holocene

Plantae: Magnoliophyta
Ambrosia-type pollen (Herring et al. 2014)..mid–late Holocene
Artemisia pollen (Herring et al. 2014) ....mid–late Holocene
Atriplex pollen (Herring et al. 2014)...mid–late Holocene
Ficus sp. ....Menefee Fm (M. Griffitts, pers. comm. to G. San Miguel, July 2001), unspecified Upper Cretaceous
Grass ....Menefee Fm
Hamamelidacean leaves...Menefee Fm
Lauracean leaves...Menefee Fm
Liguliflorae-type pollen (Herring et al. 2014) ....mid–late Holocene
Magnolia sp. (M. Griffitts, pers. comm. to G. San Miguel, July 2001)...............................Menefee Fm
Monocotyledon fossils ....Menefee Fm
Onagracean pollen (Herring et al. 2014)..mid–late Holocene
Palaeoaster inquirenda[2] ....Menefee Fm
Sabalites sp. ....Menefee Fm, unspecified Upper Cretaceous
Sassafras sp. (M. Griffitts, pers. comm. to G. San Miguel, July 2001)...............................Menefee Fm
Poacean pollen (Herring et al. 2014) ....mid–late Holocene
Quadripollis krempii pollen (Thompson 1972) .... Mancos Sh
Thecacean leaves ....Menefee Fm
Triporopollenites cf. *T. scabroporus* (with annulus) pollen (Thompson 1972) .... Mancos Sh
Trudopollis cf. *T. hemiparvus* pollen (Thompson 1972) .... Mancos Sh
Tubuliflorae-type pollen (Herring et al. 2014)..mid–late Holocene

Invertebrata
Unspecified shells ....Cliff House Ss

[2] Griffitts (pers. comm. to G. San Miguel, July 2001) reported that this may instead be ancestral to *Palaeoaster*; some park records misspell this as *Paleoaster iniqueriende*.

Anthozoa

<u>Anthozoa: Rugosa</u>
cf. *Streptelasma*?[3] .... unknown (transported by people)

Brachiopoda

Articulata[4] .... unknown (transported by people)

Mollusca

<u>Mollusca: Bivalvia</u>
Crassatella (or *Crassatellites*) sp. .... unspecified Upper Cretaceous
Cymbophora alta .... unspecified Upper Cretaceous
Cymbophora cf. *C. alta* .... Cliff House Ss
Ethmocardium ursaniense .... Cliff House Ss
Ethmocardium whitei .... Cliff House Ss, unspecified Upper Cretaceous
Ethmocardium cf. *E. whitei* .... Cliff House Ss
Ethmocardium sp. .... Cliff House Ss, unspecified Upper Cretaceous
Ethmocardium sp. aff. *whitei* .... Cliff House Ss
Idonearca sp. (Cobban E&R 1965/02/03) .... Point Lookout Ss
Inoceramus (*Cordiceramus*) *muelleri* .... Mancos Sh
Inoceramus (*Cordiceramus*) *muelleri*? .... Mancos Sh
Inoceramus (*Cordiceramus*) aff. *brancioformis* (Leckie et al. 1997) .... Mancos Sh
Inoceramus (*Cremnoceramus*) *inconstans* .... Mancos Sh
Inoceramus cf. *I.* (*Cremnoceramus*) *waltersdorfensis* .... Mancos Sh
Inoceramus (*Endocostea*) *balticus* .... Mancos Sh, Point Lookout Ss
Inoceramus (*Endocostea*) *simpsoni* .... Mancos Sh
Inoceramus (*Magadiceramus*) *subquadratus* .... Mancos Sh
Inoceramus (*Platyceramus*) *cycloides* .... Mancos Sh
Inoceramus (*Platyceramus*) *platinus* .... Mancos Sh
Inoceramus (*Sphenoceramus*) *lundbreckensis* .... Mancos Sh
Inoceramus (*Volviceramus*) *grandis* .... unspecified Upper Cretaceous
Inoceramus dimidius .... Mancos Sh
Inoceramus perplexus .... Mancos Sh
Inoceramus sagensis (Pike 1947) .... Mancos Sh
Inoceramus sagensis? (Pike 1947) .... Mancos Sh

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[3] *Streptelasma* is a widespread horn coral (solitary rugose coral) of Ordovician to Devonian (Paleozoic) age. Rugose corals as a group went extinct at the end of the Paleozoic, approximately 252 Ma, long before the deposition of the Cretaceous rocks at MEVE, so this specimen would have been transported by humans or natural agencies. However, its identity as a fossil is questionable (Figure 26E); it may simply be a rounded conical stone.

[4] This brachiopod has been polished, complicating identification.

Inoceramus subcompressus ....Cliff House Ss
Inoceramus sp. ....Mancos Sh, Point Lookout Ss (Wanek 1959), Cliff House Ss, unspecified Upper Cretaceous
Inoceramus sp. aff. *deformis*..Mancos Sh
Modiolus sp. (Cobban E&R 1965/02/03) ....Cliff House Ss
Nucula sp.?..Cliff House Ss
Ostrea russelli .... Cliff House Ss, unspecified Upper Cretaceous
Ostrea sp. (Pike 1947) ....Mancos Sh
Ostrea sp.? ....Cliff House Ss
Phelopteria sp. ....Mancos Sh
Pinna sp. ....Cliff House Ss
Pseudoperna bentonensis...Mancos Sh
Pseudoperna congesta .... Mancos Sh, unspecified Upper Cretaceous
Pseudoperna congesta? (Pike 1947)..Mancos Sh
Pseudoperna sp. ....Mancos Sh
Tellina cf. *T. equilateralis* (Cobban E&R 1965/02/03) ....Cliff House Ss
cf. *Tancredia* ....Cliff House Ss
Volsella sp. aff. *anomala* ....Cliff House Ss
Inoceramidae undetermined..Mancos Sh, Cliff House Ss
Bivalve impressions .... Point Lookout Ss
Bivalvia undetermined ....Menefee Fm

Mollusca: Cephalopoda: Ammonoidea

Acanthoceras sp. (Pike 1947) ....Mancos Sh
Baculites aquilaensis ....Mancos Sh (Cobban E&R 1965/02/03), Point Lookout Ss (Pike 1947, Cobban 1973)
Baculites asper.. Mancos Sh, Point Lookout Ss
Baculites cf. *B. asper* ....Mancos Sh
Baculites asperiformis (Cobban E&R 1965/02/03)...Cliff House Ss
Baculites codyensis ....Mancos Sh
Baculites haresi...Mancos Sh
Baculites haresi?..Mancos Sh
Baculites maclearni ....Cliff House Ss, unspecified Upper Cretaceous
Baculites ovatus ....unspecified Upper Cretaceous
Baculites ovatus? (Pike 1947)..Mancos Sh
Baculites cf. *B. ovatus* (Wanek 1959).. Point Lookout Ss
Baculites thorni? ....Mancos Sh
Baculites undulatus...Mancos Sh
Baculites yokoyamai ....Mancos Sh, unspecified Upper Cretaceous
Baculites sp. ....Mancos Sh, unspecified Upper Cretaceous
Baculites sp. rapid taper...Mancos Sh
Baculites sp. smooth (Leckie et al. 1997) ....Mancos Sh

Baculites sp. smooth tapered (Leckie et al. 1997) .... Mancos Sh
Baculites sp. wide *boulei* (Leckie et al. 1997) .... Mancos Sh
Clioscaphites choteauensis .... Mancos Sh
Desmoscaphites bassleri .... Mancos Sh
Desmoscaphites erdmanni .... Mancos Sh
Glyptoxoceras sp. (Leckie et al. 1997) .... Mancos Sh
Haresiceras montanaense .... Mancos Sh
Placenticeras bidorsatum (illustrated in Leckie et al. 1997 as *P*. aff. *sancarlosense*) .... Mancos Sh
Placenticeras guadalupae (Pike 1947) .... Mancos Sh
Placenticeras intercalare .... Cliff House Ss
Placenticeras cf. *P. intercalare* .... Cliff House Ss
Placenticeras planum .... Mancos Sh
Placenticeras cf. *P. syrtale* (Cobban E&R 1965/02/03) .... Cliff House Ss
Placenticeras sp. .... Mancos Sh, Point Lookout Ss (Cobban E&R 1965/02/03), Cliff House Ss
Prionocyclus wyomingensis .... Mancos Sh
Prionocyclus sp. .... Mancos Sh
Scaphites aquisgranensis (Cobban E&R 1965/02/03) .... Mancos Sh
Scaphites hippocrepis (Pike 1947, Cobban 1973, Leckie et al. 1997) .... Mancos Sh
Scaphites leei .... Mancos Sh
Scaphites warreni .... Mancos Sh
Scaphites whitfieldi .... Mancos Sh, unspecified Upper Cretaceous
Scaphites sp. .... Mancos Sh, Point Lookout Ss
Scaphitid aptychi (mouthparts or head coverings) .... Mancos Sh

Mollusca: Gastropoda
Turritella cf. *T. whitei* .... Mancos Sh
Turritella sp. .... Mancos Sh
Gastropoda undetermined .... Mancos Sh?

Annelida
Serpula sp. (Leckie et al. 1997) .... Mancos Sh
Serpula sp.? .... Mancos Sh

Echinodermata
Echinodermata: Crinoidea
Uintacrinus socialis (Pike 1947) .... Mancos Sh
Uintacrinus socialis? (Pike 1947) .... Mancos Sh
Uintacrinus sp. .... Mancos Sh

Vertebrata
Vertebrata undetermined .... Cliff House Ss, unspecified Upper Cretaceous

"Pisces" (Cartilaginous and Ray-Finned Fish)

Unidentified fish bones .... Cliff House Ss
Miscellaneous fish scales .... Mancos Sh, Cliff House Ss, unspecified Upper Cretaceous

Chondrichthyes

Chondrichthyes: Batoidea (Rays And Skates)
Ischyrhiza sp. .... Cliff House Ss

Chondrichthyes: Selachii (Sharks)
Scapanorhynchus sp. .... Cliff House Ss, unspecified Upper Cretaceous
cf. *Scapanorhynchus* .... Cliff House Ss
Possible shark vertebra .... Cliff House Ss
Selachii undetermined, including teeth .... Cliff House Ss

Osteichthyes

Enchodus sp. .... Cliff House Ss, unspecified Upper Cretaceous
Enchodus sp.? .... unspecified Upper Cretaceous
Hypsodon sp. (Pike 1947) .... Mancos Sh
Teleostei undetermined n. sp.? .... Cliff House Ss
Teleostei undetermined .... Cliff House Ss
Osteichthyes undetermined .... Cliff House Ss

Reptilia

Dinosaur or plesiosaur bones .... Cliff House Ss
Reptilia undetermined .... Cliff House Ss

Reptilia: Testudines
Testudines undetermined .... Cliff House Ss

Reptilia: Squamata
Mosasauroidea undetermined .... Cliff House Ss

Reptilia: Sauropterygia
cf. *Plesiosaurus*[5] .... Cliff House Ss
Polycotylidae undetermined .... Cliff House Ss

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[5] *Plesiosaurus* is a Lower Jurassic genus from Europe, so it is unlikely that this is actually *Plesiosaurus* or closely related.

Reptilia: Dinosauria

Dinosauria undetermined .... Cliff House Ss

Microfossils (Exclusive of Paleobotany)

Acritarchs

Form B sp. 1 (Thompson 1972) .... Mancos Sh
Form B sp. 2 (Thompson 1972) .... Mancos Sh
Form B sp. 3 (Thompson 1972) .... Mancos Sh
Form C sp. 1 (Thompson 1972) .... Mancos Sh
Form C sp. 2 (Thompson 1972) .... Mancos Sh
Form S sp. 1 (Thompson 1972) .... Mancos Sh
Michrystridium sp. (Thompson 1972) .... Mancos Sh

Coccoliths

Arkhangelskiella (Mizintseva 2013) .... Mancos Sh
Cretarhabdus/Retecapsa (Mizintseva 2013) .... Mancos Sh
Eiffellithus (Mizintseva 2013) .... Mancos Sh
Micula (Mizintseva 2013) .... Mancos Sh
Micula murus (Mizintseva 2013) .... Mancos Sh
Micula staurophora (Mizintseva 2013) .... Mancos Sh
Prediscosphaera (Mizintseva 2013) .... Mancos Sh
Prediscosphaera grandis (Mizintseva 2013) .... Mancos Sh

Dinoflagellata

Cordosphaeridium phragmites (Thompson 1972) .... Mancos Sh
Diconodinium arcticum (Thompson 1972) .... Mancos Sh
Dinogymnium sp. 1 (Thompson 1972) .... Mancos Sh
Dinogymnium sp. 2 (Thompson 1972) .... Mancos Sh
Exochosphaeridium phragmites (Thompson 1972) .... Mancos Sh
Hexagonifera suspecta (Thompson 1972) .... Mancos Sh
Hexagonifera suspecta var. 1 (Thompson 1972) .... Mancos Sh
Hystrichosphaera ramosa var. 2 (Thompson 1972) .... Mancos Sh
Hystrichosphaera ramosa var. 3 (Thompson 1972) .... Mancos Sh
Oligosphaeridium pulcherrimum (Thompson 1972) .... Mancos Sh
Palaeohystrichophora infusoroides (Thompson 1972) .... Mancos Sh
Palaeohystrichophora infusoroides var. 1 (Thompson 1972) .... Mancos Sh
Palaeohystrichophora infusoroides var. 2 (Thompson 1972) .... Mancos Sh
Pseudoceratium ceratioides (Thompson 1972) .... Mancos Sh
Surculosphaeridium cf. *S. vestitum* (Thompson 1972) .... Mancos Sh

Foraminifera

Unspecified foraminifera (Leckie et al. 1997, Sterzinar 2005)..Mancos Sh

Trace Fossils

Invertebrate Trace Fossils

Borings.. Cliff House Ss, unspecified Upper Cretaceous
Burrows and bioturbation (Leckie et al. 1997) ....Mancos Sh
Fecal pellets (Leckie et al. 1997) ....Mancos Sh
Invertebrate tracks..Cliff House Ss
Ophiomorpha .... Point Lookout Ss, Menefee Fm (Wanek 1959)[6], Cliff House Ss, unspecified Upper Cretaceous
Planolites-like trail..Point Lookout Ss
Possible arthropod tracks ....unspecified Upper Cretaceous
Probable crustacean tracks...Mancos Sh
Thalassinoides..Cliff House Ss
Teredolites .... Menefee, Cliff House Ss
Trails and burrows ....Point Lookout Ss
Tubeworm-marked surface (attributed to "*Nereis*") ....unspecified Upper Cretaceous
Unspecified .... Mancos Sh, Point Lookout Ss, unspecified Upper Cretaceous

Vertebrate Trace Fossils

Chimaerotheca n. sp. (Harrison et al. 2016)...Cliff House Ss
Packrat middens..late Holocene

Other Fossils

Unspecified fossils..Mancos Sh

[6] Wanek identifies this taxon as *Halymenites major*, an obsolete name.

Appendix C. Taxonomy of specimens in MEVE collections from localities that may or may not be in MEVE

The following taxa have ambiguous locality information, for example within a quarter of a section that is partially within and partially outside of MEVE. Because of this, they are separated from fossils with little or no locality information (see Appendix E). Formation names are abbreviated for space (Fm = Formation, Sh = Shale, Ss=Sandstone). Taxonomy is generally after the source, with the exception of mollusks, which follow Leckie et al. (1997). The taxa found in the Mancos Shale can often be further restricted to specific members, but this has not been done here. Consult Leckie et al. (1997) for detailed biostratigraphy of the Mancos Shale.

Paleobotany

Plantae

Jet .... Menefee Fm, unspecified Upper Cretaceous
Wood .... Menefee Fm, unspecified Upper Cretaceous

<u>Plantae: Magnoliophyta</u>
Lauracean leaves .... Menefee Fm
Palm frond .... Menefee Fm

Invertebrata

Mollusca

<u>Mollusca: Bivalvia</u>
Inoceramus (*Endocostea*) *balticus* .... Mancos Sh, unspecified Upper Cretaceous
Inoceramus (*Endocostea*) *simpsoni* .... Mancos Sh
Inoceramus (*Platyceramus*) *platinus* .... Mancos Sh
Inoceramus cf. *I. stantoni* .... Mancos Sh
Mytiloides aviculoides .... Mancos Sh
Mytiloides aff. *labiatoidiformis* .... Mancos Sh
Ostrea russelli .... unspecified Upper Cretaceous

<u>Mollusca: Cephalopoda: Ammonoidea</u>
Baculites sp. .... Mancos Sh
Prionocyclus wyomingensis .... Mancos Sh
Scaphites warreni .... Mancos Sh

Echinodermata

<u>Echinodermata: Asteroidea</u>
Astropecten? sp. (after identification in internal permit, D. Blake, 2003) .... Cliff House Ss

Vertebrata

"Pisces" (Cartilaginous and Ray-Finned Fish)

Unidentified fish bones.. Mancos Sh

Chondrichthyes

Chondrichthyes: Selachii (Sharks)

Scapanorhynchus sp.?.. Mancos Sh

Reptilia

Reptilia undetermined..Menefee Fm

Appendix D. Taxonomy of specimens in MEVE collections from outside of the park

Formation names are abbreviated for space (Fm = Formation, Sh = Shale, Ss=Sandstone). Taxonomy is generally after the source, with the exception of mollusks, which follow Leckie et al. (1997). The taxa found in the Mancos Shale can often be further restricted to specific members, but this has not been done here. Consult Leckie et al. (1997) for detailed biostratigraphy of the Mancos Shale.

Paleobotany

Plantae

Unidentified leaves associated with *Tempskya* sp. ....unspecified Upper Cretaceous

Plantae: Polypodiopsida

Tempskya sp. ....unspecified Upper Cretaceous
Tempskya sp., possible new sp. ....unspecified Upper Cretaceous

Plantae: Spermatophyta

Probable seed impressions ....Mancos Sh

Plantae: Bennettitales

Probable cycadeoid ....unspecified Upper Cretaceous

Plantae: Magnoliophyta

Dicotyledonous leaves ....unspecified Upper Cretaceous

Invertebrata

Unspecified shells ....Cliff House Ss

Brachiopoda

Brachiopoda: Inarticulata

Discinisca sp. ....Mancos Sh
Lingula? sp. ....Mancos Sh

Mollusca

Mollusca: Bivalvia

Corbula kanabensis ....Mancos Sh
Ethmocardium cf. *E. whitei* ....unspecified Upper Cretaceous
Inoceramus (*Cladoceramus*) *undulatoplicatus* ....unspecified Upper Cretaceous
Inoceramus (*Cladoceramus*)? sp. ....Mancos Sh

Inoceramus (*Magadiceramus*) *subquadratus complicatus* .... Mancos Sh
Inoceramus (*Magadiceramus*) *subquadratus crenelatus* .... Mancos Sh
Inoceramus (*Magadiceramus*) *subquadratus subquadratus* .... Mancos Sh
Inoceramus (*Platyceramus*) *platinus* .... unspecified Upper Cretaceous
Inoceramus (*Platyceramus*) *platinus*? .... Mancos Sh
Inoceramus (*Platyceramus*) *stantoni* .... Mancos Sh
Inoceramus (*Volviceramus*) *grandis* .... Mancos Sh
Inoceramus (*Volviceramus*) *grandis*? .... Mancos Sh
Inoceramus dimidius .... Mancos Sh
Inoceramus perplexus .... Mancos Sh
Inoceramus pictus .... Mancos Sh
Inoceramus sp. .... Mancos Sh, unspecified Upper Cretaceous
Lima sp.? .... Mancos Sh
Lopha lugubris .... Mancos Sh
Lucina sp. .... Mancos Sh
Lucina subundata .... Mancos Sh
Mytiloides incertus .... Mancos Sh
Mytiloides mytiloides .... Mancos Sh
Mytiloides cf. *M. opalensis* .... Mancos Sh
Mytiloides sp. .... Mancos Sh
Phelopteria sp. .... Mancos Sh
Pseudoperna congesta .... Mancos Sh
Pycnodonte kansasensis .... Mancos Sh
Pycnodonte newberryi .... Mancos Sh
Rhynchostreon acroumbonata .... Mancos Sh
Unspecified oysters .... Mancos Sh

Mollusca: Cephalopoda: Ammonoidea
Acanthoceratidae unspecified .... Naturita Fm
Allocrioceras annulatum .... Mancos Sh
Baculites codyensis .... Mancos Sh
Baculites maclearni .... unspecified Upper Cretaceous
Baculites undulatus .... Mancos Sh
Baculites cf. *B. undulatus* .... Mancos Sh
Baculites yokoyamai .... Mancos Sh
Baculites sp. .... Mancos Sh
Calycoceras canitaurinum .... Naturita Fm
Coilopoceras sp. .... Mancos Sh
Collignoniceras woollgari .... Mancos Sh
Dunveganoceras? sp. .... Naturita Fm
Mammitinae undetermined .... Mancos Sh
Metoicoceras geslinianum .... Mancos Sh

Phlycticrioceras oregonense .... Mancos Sh
Prionocyclus novimexicanus .... Mancos Sh
Prionocyclus quadratus .... Mancos Sh
Prionocyclus sp. .... Mancos Sh
Prionocyclus wyomingensis .... Mancos Sh
Protexanites shoshonensis .... Mancos Sh
Scaphites ventricosus? .... Mancos Sh
Scaphites warreni .... Mancos Sh
Scaphites sp. aff. *warreni* .... Mancos Sh
Scaphites cf. *S. warreni* .... Mancos Sh
Scaphites whitfieldi .... Mancos Sh
Scaphites sp. .... Mancos Sh
Sciponoceras gracile .... Mancos Sh
Ammonoidea undetermined .... Naturita Fm

Mollusca: Cephalopoda: Nautiloidea
Eutrephoceras sp. .... Mancos Sh

Mollusca: Gastropoda
Anisomyon sp. .... Mancos Sh
Arrhoges cf. *A. modesta* .... Mancos Sh
Cerithiopsis sohli .... Mancos Sh
Drepanochilus n. sp. .... Mancos Sh
Turritella whitei .... Mancos Sh

Annelida
Scolecodont elements (polychaete worm jaw elements) .... Mancos Sh

Arthropoda
Arthropoda: Crustacea: Cirripedia
Stramentum sp. .... Mancos Sh

Vertebrata
Vertebrata undetermined .... unspecified Upper Cretaceous

"Pisces" (Cartilaginous and Ray-Finned Fish)
Fish bones .... Mancos Sh
Fish scales .... Mancos Sh

Chondrichthyes

<u>Chondrichthyes: Selachii (Sharks)</u>

Cretoxyrhina sp. .... Mancos Sh
Lamna sp. .... Mancos Sh
Lamna? sp. .... Mancos Sh
Plicatolamna semiplicata .... Mancos Sh
Ptychodus anonymus .... Mancos Sh
Ptychodus decurrens .... Mancos Sh
Ptychodus whipplei .... Mancos Sh
Squalicorax falcatus .... Mancos Sh

Osteichthyes

Ichthyodectes sp. .... Mancos Sh
cf. *Ichthyodectes* .... Mancos Sh

Trace Fossils

Invertebrate Trace Fossils

Burrows and trails .... Mancos Sh
Gyrochorte .... Cliff House Ss
Ophiomorpha .... Pierre Sh
Probable crustacean tracks .... Mancos Sh
Thalassinoides .... Cliff House Ss

Vertebrate Trace Fossils

Dinosaur tracks .... Jurassic
Mammal tracks (horse) .... Pleistocene of Death Valley National Park

Appendix E. Taxonomy of specimens in MEVE collections with uncertain provenance

These taxa have limited provenance data and cannot be safely ascribed to either the park or to areas outside of the park, although doubtless this group includes examples of both. Formation names are abbreviated for space (Fm = Formation, Sh = Shale, Ss=Sandstone). Taxonomy is generally after the source, with the exception of mollusks, which follow Leckie et al. (1997). The taxa found in the Mancos Shale can often be further restricted to specific members, but this has not been done here. Consult Leckie et al. (1997) for detailed biostratigraphy of the Mancos Shale.

Paleobotany

Plantae

Fern or *Widdringtonia* leaf....................unspecified
Leaves....................unspecified
Plant material/debris....................unspecified
Wood....................unspecified

Plantae: Polypodiopsida

Fossils of undetermined ferns and fern-like plants....................unspecified

Plantae: Pinales

Araucariacean fossils....................unspecified
Conifer fossils, possibly araucariacean....................unspecified
Pinacean? wood....................unspecified

Plantae: Magnoliophyta

Betulacean leaves?....................unspecified
Dicotyledonous leaves....................unspecified
Grass....................unspecified
Hamamelidacean leaves.................... Menefee Fm, unspecified
Lauracean? leaves....................unspecified
Magnolia? leaves....................unspecified
Palm fossils.................... Menefee Fm, unspecified
Populus sp.....................unspecified
Reed-like leaves....................unspecified
Sabalites sp..................... Menefee Fm, unspecified
Salicacean leaves....................unspecified
Salix sp.....................unspecified
Sycamore-like leaves....................unspecified
Thecacean leaves.................... Menefee Fm, unspecified
Thecacean? leaves....................unspecified

Invertebrata

Brachiopoda

Brachiopoda: Inarticulata

Discinisca sp. .... unspecified

Mollusca

Mollusca: Bivalvia

Breviarca sp. .... unspecified Upper Cretaceous
Cardium sp. .... unspecified Upper Cretaceous
Crassatella (or *Crassatellites*) sp. .... unspecified Upper Cretaceous
Cyclorisma orbiculata .... unspecified Upper Cretaceous
Cymbophora sp. .... unspecified Upper Cretaceous
Ethmocardium whitei .... unspecified Upper Cretaceous
Ethmocardium sp. .... unspecified Upper Cretaceous
Gryphaea sp. .... unspecified Upper Cretaceous
Inoceramus (*Cladoceramus*) *undulatoplicatus* .... unspecified Upper Cretaceous
Inoceramus (*Cordiceramus*) *cordiformis* .... Mancos Sh, unspecified Upper Cretaceous
Inoceramus (*Cordiceramus*) *muelleri*? .... unspecified Upper Cretaceous
Inoceramus (*Cremnoceramus*) *inconstans* .... Mancos Sh, unspecified Upper Cretaceous
Inoceramus (*Cremnoceramus*) *waltersdorfensis* .... unspecified Upper Cretaceous
Inoceramus (*Endocostea*) *balticus* .... Mancos Sh, unspecified Upper Cretaceous
Inoceramus (*Endocostea*) *invelleri* .... unspecified Upper Cretaceous
Inoceramus (*Endocostea*) *simpsoni* .... Mancos Sh
Inoceramus (*Magadiceramus*) *subquadratus* .... Mancos Sh
Inoceramus (*Magadiceramus*) *subquadratus complicatus* .. Mancos Sh, unspecified Upper Cretaceous
Inoceramus (*Magadiceramus*) *subquadratus crenelatus* .... unspecified Upper Cretaceous
Inoceramus (*Magadiceramus*) *subquadratus* cf. *crenelatus* .... Mancos Sh
Inoceramus (*Magadiceramus*) *subquadratus subquadratus* .... unspecified Upper Cretaceous
Inoceramus (*Platyceramus*) *cycloides* .... Mancos Sh
Inoceramus (*Platyceramus*) *platinus* .... Mancos Sh, unspecified Upper Cretaceous
Inoceramus (*Platyceramus*) *platinus*? .... unspecified Upper Cretaceous
Inoceramus cf. *I.* (*Platyceramus*) *platinus* .... unspecified Upper Cretaceous
Inoceramus (*Platyceramus*) *stantoni* .... unspecified Upper Cretaceous
Inoceramus (*Platyceramus*) *stantoni*? .... unspecified Upper Cretaceous
Inoceramus (*Sphenoceramus*) *lundbreckensis* .... unspecified Upper Cretaceous
Inoceramus (*Volviceramus*) *grandis* .... unspecified Upper Cretaceous
Inoceramus (*Volviceramus*) *involutus* .... unspecified Upper Cretaceous
Inoceramus (*Volviceramus*) sp. .... unspecified Upper Cretaceous
Inoceramus cf. *I. barabini* .... unspecified Upper Cretaceous
Inoceramus cf. *I. costellatus* .... unspecified Upper Cretaceous

Inoceramus cuvieri....................unspecified Upper Cretaceous
Inoceramus dimidius....................Mancos Sh, unspecified Upper Cretaceous
Inoceramus longealatus....................unspecified Upper Cretaceous
Inoceramus longealatus? ....unspecified Upper Cretaceous
Inoceramus cf. *I. longealatus*....................unspecified Upper Cretaceous
Inoceramus perplexus ....unspecified Upper Cretaceous
Inoceramus cf. *I. perplexus*....................Mancos Sh
Inoceramus sagensis ....unspecified Upper Cretaceous
Inoceramus subhercynicus....................unspecified Upper Cretaceous
Inoceramus sp. aff. *howelli* ....unspecified Upper Cretaceous
Inoceramus sp. aff. *vanuxemi* ....unspecified Upper Cretaceous
Inoceramus sp. ....Mancos Sh, unspecified Upper Cretaceous
Inoceramus sp.? ....unspecified Upper Cretaceous
Lopha lugubris....................Mancos Sh, unspecified Upper Cretaceous
Modiolus n. sp.....................unspecified Upper Cretaceous
Modiolus sp.....................unspecified Upper Cretaceous
Mytiloides carpathicus....................unspecified Upper Cretaceous
Mytiloides cf. *I. columbianus*....................unspecified Upper Cretaceous
Mytiloides columbianus ....unspecified Upper Cretaceous
Mytiloides hercynicus ....Mancos Sh
Mytiloides incertus....................unspecified Upper Cretaceous
Mytiloides labiatoidiformis....................unspecified Upper Cretaceous
Mytiloides labiatus....................Mancos Sh, unspecified Upper Cretaceous
Mytiloides mytiloides ....Mancos Sh, unspecified Upper Cretaceous
Mytiloides mytiloides arcuata....................unspecified Upper Cretaceous
Mytiloides striatoconcentricus....................unspecified Upper Cretaceous
Mytiloides subhercynicus....................Mancos Sh, unspecified Upper Cretaceous
Mytiloides subhercynicus transiens ....Mancos Sh, unspecified Upper Cretaceous
Mytiloides sp. aff. *carpathicus*....................unspecified Upper Cretaceous
Mytiloides sp. ....unspecified Upper Cretaceous
Ostrea russelli....................unspecified Upper Cretaceous
Ostrea sp. ....unspecified Upper Cretaceous
Phelopteria sp. ....unspecified Upper Cretaceous
Plicatula sp. ....unspecified Upper Cretaceous
Pseudoperna bentonense ....unspecified Upper Cretaceous
Pseudoperna congesta ....Mancos Sh, unspecified Upper Cretaceous
Pycnodonte demissa....................unspecified Upper Cretaceous
Pycnodonte newberryi ....unspecified Upper Cretaceous
Pycnodonte sp. ....unspecified Upper Cretaceous
Inoceramidae undetermined....................Mancos Sh, unspecified Upper Cretaceous
Bivalvia undetermined....................unspecified Upper Cretaceous

Mollusca: Cephalopoda: Ammonoidea

Acanthoceras sp. .... Mancos Sh
Baculites asper .... unspecified Upper Cretaceous
Baculites codyensis .... Mancos Sh
Baculites haresi .... unspecified Upper Cretaceous
Baculites cf. *B. haresi* .... unspecified Upper Cretaceous
Baculites maclearni .... unspecified Upper Cretaceous
Baculites cf. *B. maclearni* .... unspecified Upper Cretaceous
Baculites ovatus .... unspecified Upper Cretaceous
Baculites sp. .... unspecified Upper Cretaceous
Baculites thorni? .... unspecified Upper Cretaceous
Baculites yokoyamai .... unspecified Upper Cretaceous
Clioscaphites choteauensis .... Mancos Sh, unspecified Upper Cretaceous
Collignoniceras woollgari .... unspecified Upper Cretaceous
Desmoscaphites bassleri .... unspecified Upper Cretaceous
Didymoceras? sp. .... unspecified Upper Cretaceous
Mammites sp. .... unspecified Upper Cretaceous
Phlycticrioceras oregonense .... unspecified Upper Cretaceous
Placenticeras cf. *P. meeki* .... unspecified Upper Cretaceous
Placenticeras planum .... unspecified Upper Cretaceous
Placenticeras sp. .... unspecified Upper Cretaceous
Prionocyclus cf. *P. macombi* .... unspecified Upper Cretaceous
Prionocyclus cf. *P. novimexicanus* .... unspecified Upper Cretaceous
Prionocyclus macombi .... unspecified Upper Cretaceous
Prionocyclus novimexicanus .... unspecified Upper Cretaceous
Prionocyclus quadratus .... Mancos Sh, unspecified Upper Cretaceous
Prionocyclus sp. .... unspecified Upper Cretaceous
Reesidites minimus .... unspecified Upper Cretaceous
Scaphites hippocrepis .... unspecified Upper Cretaceous
Scaphites impendicostatus .... Mancos Sh
Scaphites leei .... unspecified Upper Cretaceous
Scaphites preventricosus .... unspecified Upper Cretaceous
Scaphites ventricosus? .... unspecified Upper Cretaceous
Scaphites warreni .... unspecified Upper Cretaceous
Scaphites whitfieldi .... unspecified Upper Cretaceous
Scaphites sp. .... unspecified Upper Cretaceous
Subprionocyclus normalis .... unspecified Upper Cretaceous
Watinoceras cf. *W. praecursor* .... unspecified Upper Cretaceous
Scaphitidae undetermined .... unspecified Upper Cretaceous

Mollusca: Cephalopoda: Nautiloidea

"Nautaloid" [sic][7] .... unspecified

Mollusca: Gastropoda

Cochlicopa lubrica .... unspecified
Euconulus fulvus .... unspecified
Vallonia cyclophorella .... unspecified
Vitrina pellucida alaskana .... unspecified
Zonitoides arboreus .... unspecified
Unidentified "Triton-family" (Ranellidae) gastropod .... unspecified
Gastropoda undetermined .... unspecified

Echinodermata

Echinodermata: Echinoidea

Unidentified irregular echinoid .... unspecified

Vertebrata

Vertebrata undetermined .... unspecified

"Pisces" (Cartilaginous and Ray-Finned Fish)

Unidentified fish bones and teeth .... Cliff House Ss, unspecified
Miscellaneous fish scales .... unspecified

Chondrichthyes

Chondrichthyes: Batoidea (Rays and Skates)

cf. *Ischyrhiza* .... unspecified

CHONDRICHTHYES: SELACHII (Sharks)

Cretoxyrhina sp. .... unspecified
Ptychodus polygyrus .... unspecified
Ptychodus cf. *P. whipplei* .... unspecified
Ptychodus sp. .... unspecified
cf. *Scapanorhynchus* .... unspecified
Squalicorax falcatus .... unspecified
Squalicorax sp. .... unspecified
Selachii undetermined, including teeth .... unspecified

[7] With such limited information, this could also be an ammonite, if the identifier was just going off of shape.

Osteichthyes

Enchodus sp. ....unspecified
Enchodus sp.? ....unspecified
Osteichthyes undetermined ....unspecified

Reptilia

Reptilia undetermined ....unspecified

Reptilia: Testudines

Trionychidae undetermined ....unspecified

Reptilia: Pterosauria

Pterosauria undetermined ....unspecified

Reptilia: Dinosauria

Dinosauria undetermined ....unspecified

Trace Fossils

Invertebrate Trace Fossils

Ammonite touch mark ....probably Mancos Sh
Borings ....unspecified
Ophiomorpha ....unspecified
Thalassinoides ....unspecified
Trail with markings of appendages ....unspecified
Trails and burrows ....unspecified
Unspecified ....unspecified

Vertebrate Trace Fossils

Burrowed coprolite, large ....unspecified

Other Fossils

Unspecified fossils ....unspecified

Appendix F: Outside repositories of MEVE fossils

MICHIGAN STATE UNIVERSITY
Department of Earth and Environmental Sciences
Natural Science Building
288 Farm Lane, Room 207
East Lansing, MI 48824
517-355-4626
https://ees.natsci.msu.edu/
geosci@msu.edu

SMITHSONIAN INSTITUTION, NATIONAL MUSEUM OF NATURAL HISTORY
Department of Paleobiology
P.O. Box 37012
NHB MRC 121
Washington, D.C. 20013
http://paleobiology.si.edu/
paleodept@si.edu

UNIVERSITY OF COLORADO MUSEUM OF NATURAL HISTORY
Henderson Building
15th and Broadway
Boulder, CO 80309
303-492-6892
http://www.colorado.edu/cumuseum/
cumuseum@colorado.edu

UNIVERSITY OF MASSACHUSETTS
Department of Geosciences
627 North Pleasant Street
233 Morrill Science Center
Amherst, MA 01003
413-545-2286
https://www.geo.umass.edu/
webmaster@geo.umass.edu

UNITED STATES GEOLOGICAL SURVEY–DENVER
Denver Federal Center
Denver, CO 80225-0046

FIELD MUSEUM OF NATURAL HISTORY
Earth Sciences
1400 S. Lake Shore Drive
Chicago, IL 60605-2496
(312) 922-9410
collections@fieldmuseum.org

UNIVERSITY OF CALIFORNIA MUSEUM OF PALEONTOLOGY
Museum of Paleontology
University of California
1101 Valley Life Sciences Building
Berkeley, CA 94720-4780
(510) 642-1822
http://www.ucmp.berkeley.edu/about/contact.php

Appendix G: Paleontological resource law and policy

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Related Laws, Legislation, and Management Guidelines

National Park Service Organic Act

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

NPS Management Policies 2006

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

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

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

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 traces fossils. It describes the need for managers to identify potential paleontological resources using literature and collection surveys, the identification of areas with potential for significant paleontological resources, and conducting paleontological surveys (inventory). It also describes appropriate actions for managing paleontological resources including: no action, monitoring, cyclic prospecting, stabilization and reburial, construction of protective structures, excavation, area closures, patrols, and the need to maintain confidentiality of sensitive location information.

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

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.

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.

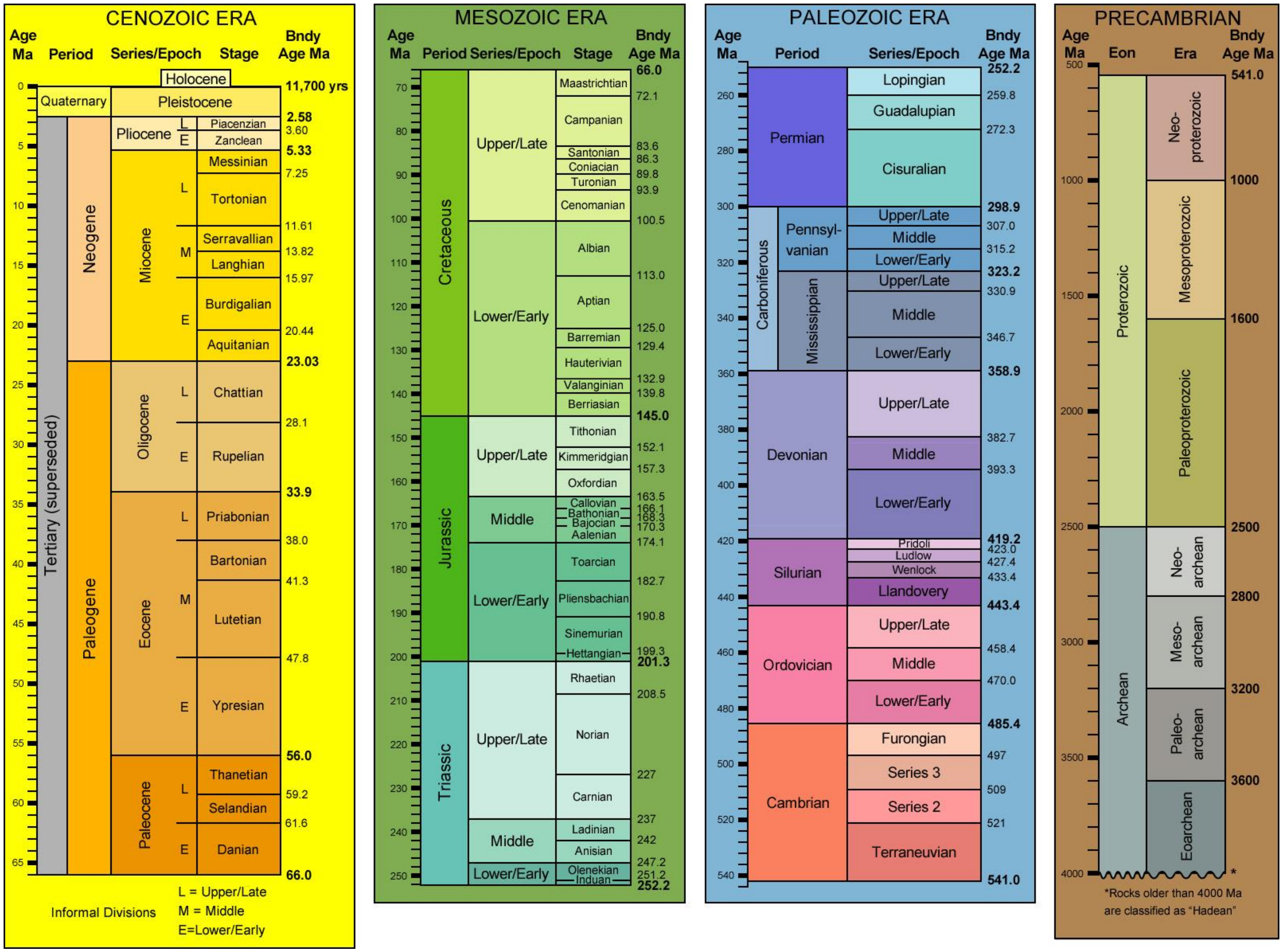
Periodic Photographic Monitoring

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 H: Localities of high significance

Some localities discovered and documented during the inventory are considered to be more significant than most. As a result they should receive substantially more management attention in the form of protection, monitoring, research concentration, and possibly salvage collecting under certain circumstances. Further information may be distributed as appropriate.

Appendix I: Geologic time scale.



Ma=Millions of year old. **Bndy Age**=Boundary Age. Colors are standard USGS colors for geologic maps. Modified from 1999 Geological Society of America Timescale (https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf). Dates and additional information from International Commission on Stratigraphy update 2014/02 (http://www.stratigraphy.org/index.php/ics-chart-timescale) and USGS Fact Sheet 2007-3015 (https://pubs.usgs.gov/fs/2007/3015/).

NPS 307/140595, November 2017

National Park Service
U.S. Department of the Interior

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