National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Chaco Culture National Historical Park

Paleontological Resources Inventory (Non-Sensitive Version)

Natural Resource Report NPS/CHCU/NRR—2019/1915

ON THE COVER

Volutomorpha sp., a marine gastropod in the Upper Cretaceous Cliff House Sandstone of Chaco Culture National Historical Park. Photo by Tom Lyttle (NPS).

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Executive Summary

Scientific interest in Chaco Canyon began in the mid-19th century when United States military expeditions reported on the vast archeological resources in and around the current boundaries of the national historical park. Since then, Chaco Canyon has become one of the most important centers for archeological research in the world, and is also a World Heritage Site location. Perhaps partly due to the intense archeological focus, paleontological studies were largely ignored in the canyon, despite the obvious presence of fossils. Sporadic paleontological studies occurred throughout the 20th century, and recent paleontological surveys have begun to reveal the fossil resources of the canyon, which are much more abundant, diverse, and scientifically significant than previously realized.

Cretaceous fossils at Chaco Culture National Historical Park (CHCU) represent approximately 10–15 million years of the history of life on Earth (about 90 to 75 million years ago), and document the biologically diverse populations of the ancient ecosystems. The rock units within CHCU represent repeated transgressive (marine advance) and regressive (marine retreat) depositional cycles of the Western Interior Seaway, providing a unique opportunity to study the ancient and dynamic relationships between the terrestrial on-shore and marine off-shore environments, including numerous fossil specimens that have not yet been scientifically described.

From oldest to youngest, the geologic formations at CHCU include the Crevasse Canyon Formation, the Menefee Formation, the Cliff House Sandstone, the Lewis Shale, and the Pictured Cliffs Sandstone. The Crevasse Canyon, Cliff House, and Pictured Cliffs Formations primarily represent nearshore marine environments, the Lewis Shale represents an offshore marine environment, and the Menefee Formation represents a terrestrial environment. Overlying Pleistocene and Holocene alluvial deposits make up the canyon floor upon which much of the Chacoan world was built.

Marine rock units contain the remains of abundant marine life, including bivalves, gastropods, cephalopods, echinoderms, sharks, bony fish, and marine reptiles. Invertebrate trace fossils and plant material, including impressions of woody debris and logs, are preserved in the marine rocks. Terrestrial rock units contain the remains of abundant petrified trees and logs, several types of turtles and dinosaurs, and crocodiles. More than 120 species of fossils have been reported from Cretaceous rocks at CHCU, the majority being fossil invertebrates from the Cliff House Sandstone. The abundance of undescribed fossils at CHCU offers an opportunity to discover and describe additional and new fossil taxa, aiding in the understanding of the evolution of life on Earth.

Quaternary fossils were found from extensive archeological excavations, especially during the Chaco Project (1960s–1980s). More than 270 Quaternary species have been identified from pollen analyses, packrat midden studies, and site excavations. A notable fossil is an extinct species of rabbit brush (*Chrysothamnus pulchelloides*), which is thought to have gone extinct due to human practices that contributed to desertification of the environment. Understanding the differences between modern and ancient ecosystems may shed light on the human impact on the environment, the conditions that may have attracted the Ancestral Puebloans to the canyon, and what may have contributed to their eventual departure from the canyon.

Acknowledgments

We thank the Geoscientist-in-the-Parks program (GIP, formerly GeoCorps) for their support of this inventory over many years. We especially thank Matt Dawson, GIP Program Officer; Lisa Norby, retired former NPS GIP Program Manager; and Limaris Soto, NPS GIP Program Manager. Most of the primary field investigations were initiated thanks to internships sponsored by GIP. Without them, this project would not have been possible. We also thank the NPS Geologic Resources Division, Conservation Legacy, the Stewards Program, and AmeriCorps for supporting the writing of this report. Stewards program coordinators Emma Savely, Katie Nemmer, and Krista Rogers provided logistical support to ensure that the project got underway smoothly. Much gratitude goes to Don Weeks, Physical Resources Program Manager for the NPS Intermountain Region, and Aron Adams, Chief of Resources at CHCU, both of whom provided critical support to ensure this project could be funded. We also thank CHCU Superintendent Denise Robertson for her support of this project.

The results presented in this inventory report come from the culmination of work from a great number of people from many agencies and institutions. We would like to thank the staff and volunteers at CHCU for their support and contributions to field work, collection and curation, interpretation, and protection of fossil resources. Much credit goes to Thomas Lyttle, Donna Smith, and Brad Shattuck, who formally initiated the Paleontological Resources Inventory in 2005. We also thank Jim Von Haden who ensured that paleontology remained a priority for CHCU Natural Resources Division. Without his dedication, this inventory would not have been possible. We extend our gratitude to former park management who supported paleontological work, including Barbara West, Larry Turk, Dabney Ford, Christine Czazasty, and Don Whyte. Many thanks go to the wonderful staff at the NPS Chaco Museum Collection, who were always willing to help locate documents and provide support for specimen curation, including Wendy Bustard, Brenna Lissoway, Tyler Love, Joan Mathien, Rita Shukla, and Errin Edlin.

We thank Douglas Wolfe, Hazel Wolfe, Christopher Wolfe, and Andrew Radich from the Zuni Dinosaur Institute for Geosciences, Andrew McDonald and Joe Reavis from the Western Science Center, and Sherman Mohler, Ben Mohler, Kara Kelley, and Jennifer Borst from the Southwest Paleontological Society who completed field work and data collection on Chacra Mesa. Other work was aided by many archeologists, biologists, and volunteers including Roger Moore, Katie Earp, Laura Johnston, Cindy Winkler, Alex Black, Paul Scholtz, Rechanda Lee, and Brittany Bankston.

We also thank Bill Parker (PEFO) for providing intern training and professional guidance, and George San Miguel (MEVE), Alison Harvey (WHSA), Phil Gensler (BLM paleontologist), Gregory McDonald (BLM paleontologist) and Lisa Boucher (University of Texas at Austin) for providing additional guidance during consultation workshops. Dr. Kenshu Shimada (DePaul University) and Dr. Chris Fielitz (Emory & Henry College) provided shark tooth and fish identifications for the museum collection. Barry Kues (University of New Mexico) provided additional identification for marine invertebrates.

Finally, we would like to thank Andrew McDonald, Douglas Wolfe, Spencer Lucas, and Tim Connors for reviewing this report.

Dedication

We dedicate this report to Thomas (Tom) Lyttle and Dr. Donna Smith who helped initiate the first comprehensive baseline paleontological resources inventory at CHCU in 2005. Tom first worked at CHCU in 1996 as a volunteer geologist with the GeoCorps program (now Geoscientist-in-the-Parks). During his first season at CHCU, Tom began documenting fossils in the Cly's Canyon, Wijiji Mesa, South Mesa, and Gallo areas of the park. He collected and curated several specimens to add to the Chaco Museum's paleontology collection. Tom also presented geology and paleontology themed interpretive presentations to visitors during evening programs and offered guided walks for groups, students, and the general public.

Tom and Donna both worked at Los Alamos National Laboratory (Los Alamos, New Mexico) until 2005 when they returned to the NPS as volunteers. In addition to their volunteer work at CHCU, they volunteered at Valles Caldera National Preserve locating and documenting drill core sites.

From 2005–2010, Tom and Donna systematically documented 167 paleontological sites at CHCU, including a number of significant localities and fossil specimens. Their dedication to paleontology at CHCU led them to coordinate with area paleontologists with expertise in vertebrate paleontology and paleobotany to facilitate research in the park.

Among the most significant specimens discovered by Tom and Donna is a nearly complete specimen of a bothremydid (side-necked) turtle. The specimen was later identified as *Elochelys* cf. *E. perfecta*, and is considered the oldest specimen of bothremydid turtle from New Mexico, and only one of two specimens currently known from the state. This discovery, among others that are referenced in this report, reiterated the need for continued fossil surveys at CHCU. Tom and Donna also initiated the park's first program for monitoring paleontological localities. Thanks to their many years of work locating and assessing the condition of fossils at CHCU, the park now has baseline condition evaluation reports for hundreds of paleontological sites in all areas of the park.

We offer our sincere thanks to Tom Lyttle and Donna Smith for their long-lasting dedication, hard work, and meaningful contributions to CHCU paleontology.

Introduction

Originally proclaimed as Chaco Canyon National Monument in 1907 to preserve sites of the prehistoric Chaco culture, the monument was expanded and re-designated as Chaco Culture National Historical Park (CHCU) in 1980 to recognize the interconnections between the park and its 130,000 km^2 (50,000 mi^2) area of influence. CHCU encompasses more than 13,700 hectares (34,000 acres) and contains more than 4,000 recorded archeological sites within four park units (Figure 1), including the main Chaco Canyon unit (Figure 2) and three smaller detached units: Kin Bineola, Pueblo Pintado, and Kin Ya'a. The park is nationally and internationally significant and is listed in the National Register of Historic Places (1966) and as a United Nations Educational, Scientific, and Cultural Organization (UNESCO) World Heritage Site (1987) that includes Aztec Ruins National Monument (National Park Service) and five smaller Chacoan sites managed by the Bureau of Land Management.

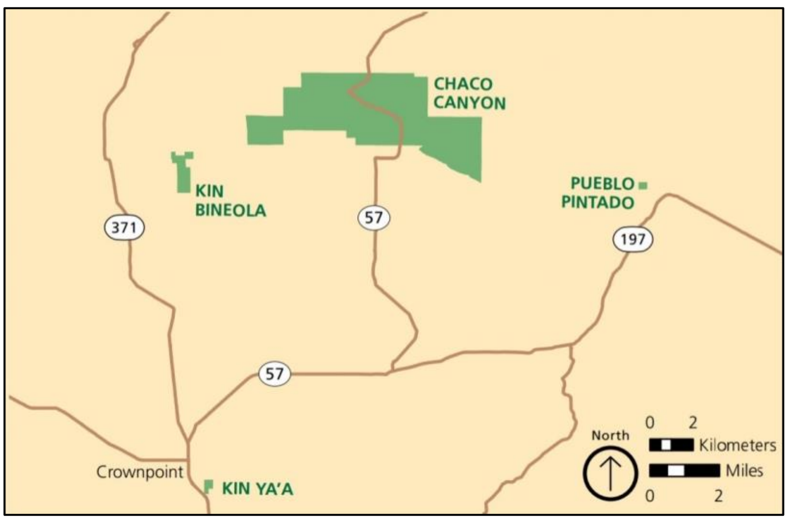

Figure 1. Map of CHCU, including the main unit (Chaco Canyon unit) and three detached units (Kin Bineola, Pueblo Pintado, and Kin Ya'a units). Map extracted from KellerLynn (2015).

Chaco Canyon is located in the San Juan Basin of northwestern New Mexico (San Juan and McKinley counties). The canyon was a major center of trade, political activity, and spiritual ceremonies in a vast cultural complex that dominated the region from the middle 9th to early 13th centuries C.E. It is remarkable for its monumental buildings and distinctive great houses (large multi-storied stone structures). Many of the great houses were built near the base or on top of the vertical sandstone cliffs of the Cliff House Sandstone, or on top of the Menefee Formation (Mesaverde Group), which are part of a suite of rocks deposited during the Late Cretaceous.

The permanent retreat of the Cretaceous Western Interior Seaway left behind an abundance and wide variety of marine and terrestrial fossils throughout the park. CHCU's location along the seaway's former migrating shoreline provides a rare opportunity to study remnants of its ancient and dynamic near-shore environment, including numerous fossil specimens that have not yet been scientifically described. Preliminary analysis indicates a high potential to discover and identify scientifically significant specimens, particularly in the Cliff House and Menefee formations that contain high concentrations of well-preserved fossils.

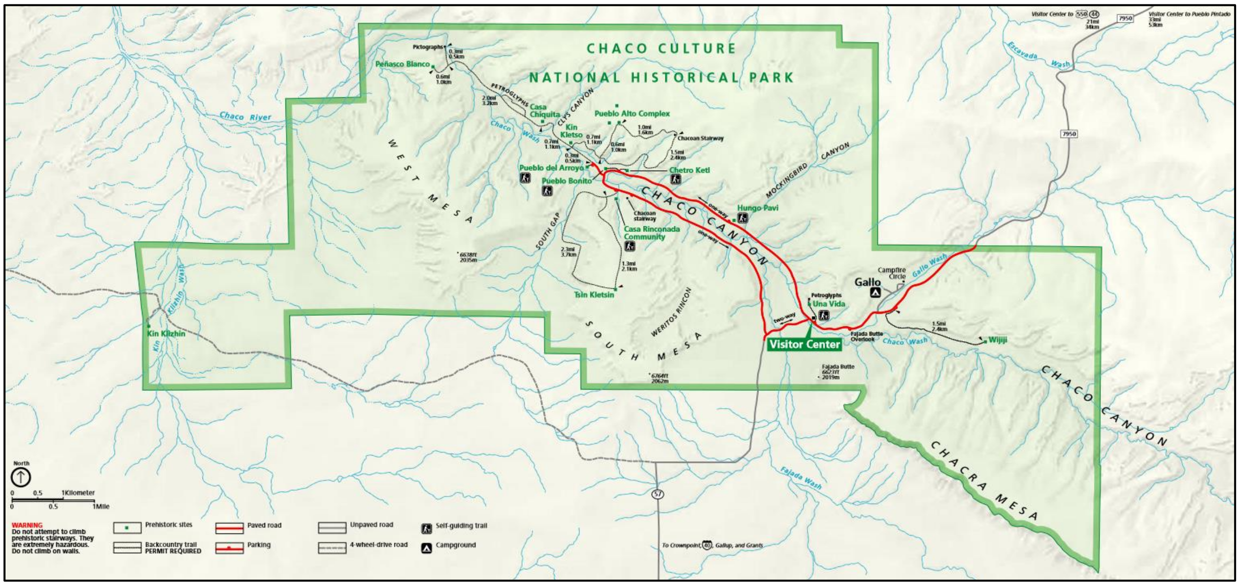

Figure 2. Detailed map of Chaco Canyon unit of CHCU (NPS Map).

Significance of Paleontological Resources at CHCU

Paleontological resources at CHCU represent approximately 10–15 million years of the history of life on Earth, and represent the populations of diverse and complex extinct ecospheres. Paleontological resources are widespread geographically and stratigraphically, and may occur in every geologic formation present in the park. CHCU is situated on a series of Upper Cretaceous terrestrial and marine rock units that represent repeated transgressive (marine advance) and regressive (marine retreat) depositional cycles of the Western Interior Seaway. All rock formations at CHCU are sedimentary and therefore have potential for paleontological resources. Many of these fossils occur *in situ* in their geologic context, and some occur in a cultural resource context.

Initial assessments of vertebrate skeletal remains indicate that any diagnostic elements may represent previously unknown species, especially within the Menefee Formation. Invertebrate species provide important biostratigraphic context for regional geologic correlation and the understanding of paleoenvironments of the Late Cretaceous. Fossil plants, especially the abundance of fossil trees at CHCU, may provide important information on the early evolution of angiosperm trees, which marks a significant shift of plant diversity on Earth.

The formations in which these fossils occur have been largely understudied in the Four Corners area, a region that is world-renowned for its paleontological resources. Given the documented density and geographical distribution of fossils and the relatively understudied strata in which they occur, as well as the preserved interface between terrestrial and marine paleoenvironments, preliminary evaluations of the significance of paleontological resources at Chaco indicate that there is high potential for these fossils to be much more scientifically significant than previously recognized.

Purpose and Need

The NPS is required to manage its lands and resources in accordance with federal laws, regulations, management policies, guidelines, and scientific principles. Paleontological resources are non-renewable remains of past life preserved in a geologic context. At present, there are 419 official units of the National Park System, plus national rivers, national trails, and various other affiliated units. Of these, at least 271 are known to have some form of paleontological resources, and paleontological resources are mentioned in the enabling legislation of 17 units. Fossils possess scientific and educational values and are of great interest to the public; therefore, it is exceedingly important that appropriate management attention be placed on protecting, monitoring, collecting, and curating paleontological specimens from federal lands.

The completion of a baseline paleontological inventory for CHCU was identified as a need in the park's foundation document (National Park Service 2015). This paleontological resource inventory has been developed in order to compile information regarding the scope, significance, distribution, and management issues associated with fossil resources present within CHCU. The information presented within this report is intended to increase awareness of park fossils and paleontological issues in order to facilitate future research and to inform management decisions and actions that comply with all relevant laws, directives, and policies.

Project Objectives

The primary objective of this report is to present results from all known past and current paleontology work at CHCU. Methods and tasks addressed in this inventory report include: locating, identifying, and documenting paleontological resource localities through field reconnaissance using photography, GPS data, and standardized forms; relocating and assessing historical and other known localities; and assessing collections of CHCU fossils maintained within the park collections and in outside repositories. A thorough search was conducted for relevant publications, unpublished geologic notes, and outside fossil collections from CHCU. Historical data are presented alongside newly discovered data.

Baseline Paleontology Resource Data Inventories

A baseline inventory of paleontological resources is critical for implementing effective management strategies, as it provides information for decision-making. This inventory report has compiled information on previous paleontological research done in and near CHCU, taxonomic groups that have been reported within CHCU boundaries, and localities that were previously reported. This report can serve as a baseline source of information for future research, inventory reports, monitoring, and paleontological decisions. The Paleontological Resource Inventory and Monitoring report for the Southern Colorado Plateau Network (Tweet et al. 2009) and the references cited within were important baseline paleontological resource data sources for this CHCU Paleontological Resources Inventory Report. Paleontological site data is managed by the Resources Division at CHCU. This data consists of individual site files, photographs, databases, and condition assessments that contain sensitive information and are not available to the public.

History of Paleontological Work at CHCU

Early geologic surveys by Holmes (1877) provide the basis for understanding the geology of Chaco Canyon. The geologic formations in Chaco Canyon exhibit the same characteristics as the rocks described as the Mesaverde Group by Holmes from exposures in the Mesa Verde area of southwestern Colorado. Holmes described three divisions of the Mesaverde Group: the "lower escarpment sandstone", the "middle coal group", and the "upper escarpment sandstone". These divisions were named by Collier (1919) as the Point Lookout Sandstone (not present in CHCU), Menefee Formation, and Cliff House Sandstone, respectively (Reeside and Knowlton 1924). Overlying the Mesaverde Group are the Lewis Shale, named by Cross (1899) from exposures near Fort Lewis, Colorado, and the Pictured Cliffs Sandstone, named by Holmes (1877) for exposures north of the San Juan River near Fruitland, New Mexico.

Paleontological interest in areas of the San Juan Basin north of CHCU dates back as far as the early 1880s when Edward Drinker Cope described fossils from collections made by David Baldwin (Gilmore 1916). The type specimen for *Aspideretes* (*Trionyx*) *singularis* was collected from a locality at "Chaco Canyon" by Baldwin in 1883 from the "Torrejon beds". The type specimen for *Naiadochelys ingravata* was collected at "Chaco Canyon" by Professor F. W. Putnam in 1900 from the "Laramie beds" (Hay 1908). In 1906, George Pepper reported dinosaur remains near Ojo Alamo Trading Post at "Chaco Cañon" during the Hyde Expedition (Brown 1910). It should be noted that the nomenclature used by late 19^{th} and early 20^{th} century researchers is not necessarily used today, and place names or geologic formations may be more broadly used. For example, Brown (1910) described the Ojo Alamo Trading Post as at "Chaco Cañon", but it is not located within the boundaries of CHCU. Likewise, the Torrejon and Laramie beds refer to terrestrial Paleogene and Upper Cretaceous geologic formations that are not present at CHCU, placing these localities outside of Chaco Canyon proper. CHCU was not established until 1906, so early references to "Chaco Canyon" may refer to areas outside of the present day park boundaries.

The first significant scientific investigations at CHCU were part of the Hyde Exploring Expedition (1896–1901), which primarily focused on archeological investigations. In 1900, Professor Richard E. Dodge completed a small geologic study of the arroyo at the ruins of Pueblo Bonito, and his results were published in the outline of the expedition report (Pepper and Nelson 1920). In his report, Dodge indicated that he gave up on studying the arroyo in favor of studying the ruin to aid in future work in the arroyo. He did map the cliff profile and surface streams, however.

One of the earliest documented fossil collections in Chaco Canyon comes from Charles Sternberg in 1921. Sternberg was drawn to the San Juan Basin of New Mexico thanks in part to the work of Gilmore (1916) in the Ojo Alamo, Kirtland, and Fruitland Formations. Sternberg was also encouraged by Edgar Lee Hewett, an archeologist who would later direct University of New Mexico Field School excavations at Chetro Ketl (Chaco Canyon). Sternberg arrived in Thoreau, New Mexico and drove to Chaco Canyon on June 14, 1921. There, he and his assistant John Bender found *Inoceramus* fossils at a site in "Pueblo Bonita" that he later tried to sell to Dr. Carl Wiman (University of Uppsala, Sweden), who had hired Sternberg to collect Cretaceous vertebrate fossils in the San Juan Basin (Hunt et al. 1992). The fossils were never sold, and Sternberg would later work in the more fossiliferous areas north of Chaco Canyon. The whereabouts of any fossils collected by Sternberg from Chaco Canyon are currently unknown.

Over the next century to the present day, Upper Cretaceous formations like the Fruitland, Kirkland, and Ojo Alamo formations north of Chaco Canyon would be the subjects of intense paleontological research. These formations, not found in CHCU, were deposited immediately after the geologic units exposed in the park. Given the immense archeological focus within Chaco Canyon and the intensive paleontological focus north of Chaco Canyon, few paleontological investigations were conducted within the geologic formations present in CHCU.

Additional paleontological investigations at Chaco Canyon were conducted by Reeside and Knowlton (1924) as part of a larger study of the Upper Cretaceous and Tertiary strata in the San Juan Basin of Colorado and New Mexico. Reeside and Knowlton report approximately 25 fossil taxa (mostly gastropods and bivalves) at a locality (USGS 9743) described as being located "*3 miles east of Pueblo Bonito, N. Mex. Horizon 40 feet above base of the Cliff House sandstone*." This locality description is characteristic of many areas within Chaco Canyon, but without more specific information, the exact location may never be known. See Appendix Table A-1 for the taxa observed.

In 1924 and 1925, Kirk Bryan studied the geologic history of Chaco Canyon, based in part on some of Dodge's previous work. Bryan's work was proposed on the initiative of Neil M. Judd of the National Geographic Society's Pueblo Bonito Expeditions and recommended by John C. Merriam, then president of the Carnegie Institution of Washington. The survey was intended to relate the recent geology to the life of prehistoric people who inhabited Chaco Canyon (Bryan 1954). Due to the intense interest in cultural resources at Chaco Canyon, most of this geologic work was conducted within the context of archeological investigations and primarily focused on the Quaternary history.

The University of New Mexico Field School had a lasting impact on archeological research of the ruins at Chaco Canyon. Not much is known about many paleontological finds during the course of the excavations aside from two reports by students. Richard Pickard Vann was a student at the field school from 1929–1931. His Master's thesis "Paleontology of the Upper Cretaceous of Chaco Canyon, NM" (Vann 1931) is the earliest known work that focused specifically on fossils at Chaco Canyon. Vann based much of his work on Reeside and Knowlton's (1924) work a decade prior. In 1940, Lucile Wood completed a short report (unpublished student work, Wood 1940) documenting fossils in the vicinity of Pueblo Bonito and Chetro Ketl. Both Vann and Wood report that fossils were collected, but the physical locations of these fossil collections are unknown.

Several decades passed before additional paleontological research was conducted in Chaco Canyon, when Charles T. Siemers (University of New Mexico) and Norman R. King (University of Tennessee) documented the stratigraphy and fauna of the Cliff House Sandstone in Chaco Canyon National Monument. The purpose of this research was to establish a datum for the comparison of Cliff House fossil accumulations being investigated throughout the San Juan Basin at the time (Siemers and King 1974). Siemers's and King's work built off of the work of Reeside and Knowlton (1924) and Vann (1931), to the extent that many of Vann's fossil localities were revisited. Today, much of the basis for understanding the fossil accumulations at Chaco Canyon is largely understood thanks to the work of Siemers and King.

Since the 1970s, vertebrate fossils were known anecdotally by various scientists visiting the area. No research permits were granted by the park to study the vertebrate fossil assemblages despite submitted proposals by area paleontologists. The most recent paleontological research that has been conducted at CHCU is a paleobotanical study of fossil wood by Dr. Lisa Boucher (University of Texas Austin) from 2007–2018. Complete results from this study are still under development.

Summary of Paleontological Surveys 1996–2018

The CHCU Paleontological Resources Inventory was formally initiated in 2005 when NPS volunteers and staff began to systematically document fossil sites at CHCU. Prior to 2005, Thomas Lyttle (former CHCU Physical Science Technician) documented fossil sites within the Cliff House Sandstone at CHCU in 1996 and 1998 as a volunteer with the GeoCorps program. Lyttle's first two sites would later be formally included in a broader Paleontological Resources Inventory of the park. This inventory was piloted by Brad Shattuck (former CHCU Natural Resources Manager), Lyttle, and Donna Smith (former CHCU volunteer) and was initiated as part of the NPS Paleontological Locality Condition Survey. The purpose of the inventory was to locate, identify, map, and assess the condition of paleontological resources in the park. Formal paleontological resource surveys at CHCU were concluded in 2018. Nearly all areas of the park have been inventoried for paleontological resources which is an uncommon accomplishment for paleontological resource surveys in National Park Service units.

In order to facilitate survey work, the park was divided into inventory project areas, later called Paleontological Management Areas (PMAs) (Figure 3). Twelve areas were set up within the park: 1) Kin Bineola; 2) Kin Ya'a; 3) Pueblo Pintado; 4) Kin Klizhin; 5) Wijiji Mesa; 6) Gallo; 7) Chacra Mesa; 8) Mockingbird Canyon; 9) Cly's Canyon; 10) South Mesa; 11) West Mesa South; and 12) West Mesa North. Navajo Allotments are not included in the survey area.

Between 2005 and 2010, Lyttle and Smith documented 167 paleontology sites and implemented paleontological condition assessments at sites with significant fossils. In 2010, Lyttle invited Douglas Wolfe (Zuni Dinosaur Institute for Geosciences, formerly Zuni Basin Paleontological Project) and Andrew McDonald (Western Science Center, formerly at the University of Pennsylvania) to assess newly discovered dinosaur bones in the Menefee Formation. During their visit, McDonald and Wolfe visited vertebrate fossil sites and identified dinosaur skeletal elements. Potentially diagnostic elements were observed at two localities and were determined to be "at risk". After consulting one of the park archeologists (Roger Moore), a small surface collection was made. Shortly after this collection, Lyttle and Smith left CHCU, and the specimens were never fully described.

Between 2011 and 2017, Phillip Varela (CHCU Physical Science Technician) continued the work of Lyttle and Smith. During this time, 177 more paleontological sites were documented, primarily on West Mesa, South Mesa, and Chacra Mesa. Paleontological locality condition assessments continued and were expanded. A comprehensive paleontological site database and GIS database were created to better manage paleontological site data.

In 2018, McDonald and Wolfe were contacted by NPS Senior Paleontologist Vincent Santucci to help complete paleontological resource field surveys on Chacra Mesa. The survey was conducted with the help of students and volunteers from the Southwest Paleontological Society and Western Science Center. After the completion of field surveys on Chacra Mesa, the CHCU baseline paleontological resources inventory was considered complete, with nearly 100% of the park acreage having been inventoried for paleontological resources. However, it should be noted that surveys are never truly finished, as new specimens can become uncovered through natural erosion. The park now manages paleontological sites through locality condition assessments (see “Paleontological Resource Management and Protection”).

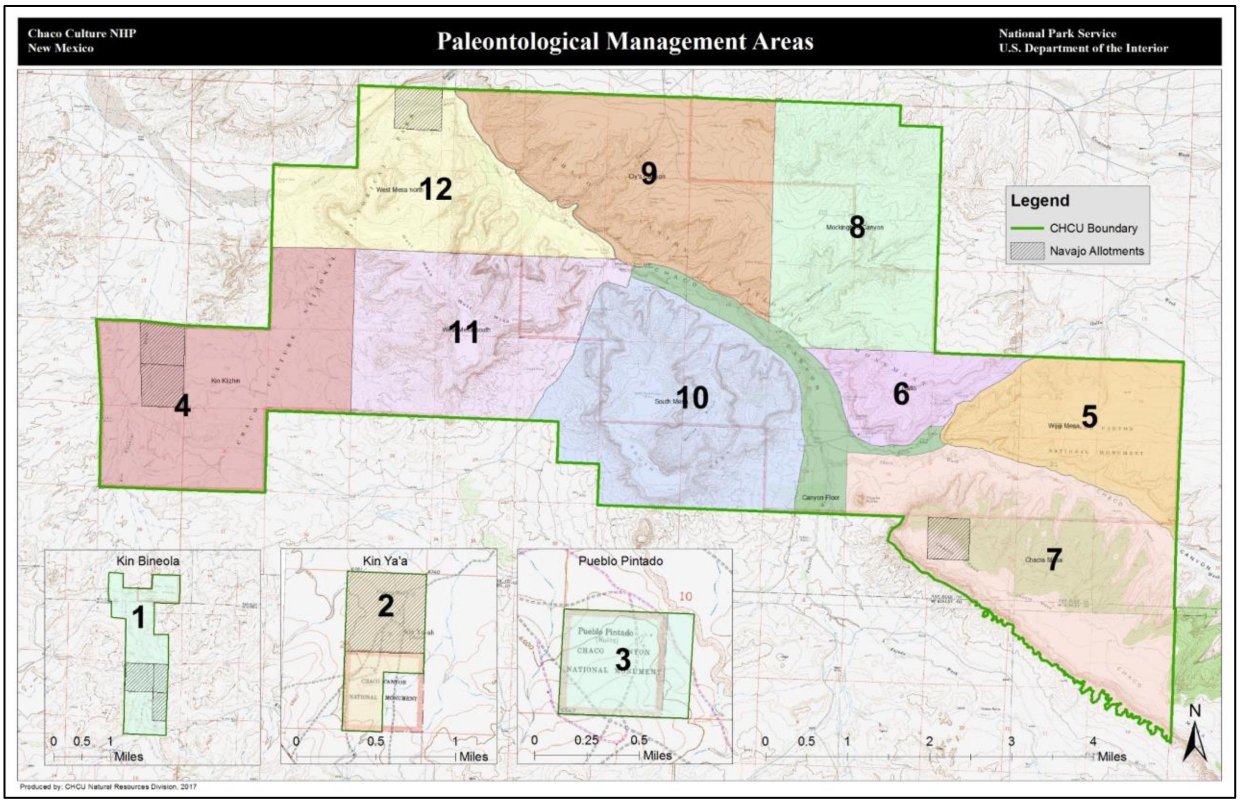

Figure 3. Map of CHCU Paleontological Management Areas: 1) Kin Bineola; 2) Kin Ya’a; 3) Pueblo Pintado; 4) Kin Klizhin; 5) Wijiji; 6) Gallo; 7) Chacra Mesa; 8) Mockingbird Canyon; 9) Cly’s Canyon; 10) South Mesa; 11) West Mesa South; 12) West Mesa North.

The area in the immediate vicinity of Chaco Wash (called “Canyon Floor”) has not been formally introduced as a Paleontological Management Area, due to the fact that the inventory primarily focused on documenting fossils from Cretaceous-aged geologic formations, and the sediments in and around Chaco Wash are much younger (Quaternary) and contain abundant sensitive cultural resources. Quaternary fossils have been extensively documented in the context of archeological surveys and excavations of the Chacoan great houses and packrat midden sites. These Quaternary fossils are summarized in Appendix Table A-2.

Geology

Geologic History

Chaco Canyon is situated in the modern San Juan Basin, a structural and physical feature encompassing more than 67,000 km^2 (26,000 mi^2) in northwestern New Mexico and extending into southwestern Colorado. It is a bowl-shaped depression containing a thick succession of sedimentary rocks ranging in age from Pennsylvanian to Pliocene (300 million to 2 million years ago) (Figure 4). These sedimentary rocks are underlain by Precambrian (1.7 to 1.4 billion years ago) crystalline rocks (Price 2010) (see Appendix E for a geologic time scale). Older sediments are exposed near the margins of the basin where Precambrian rocks were uplifted and exposed as mountain ranges (e.g. the Nacimiento and Zuni mountains in New Mexico and the San Juan mountains in Colorado). CHCU is approximately 72 km (45 mi) southwest of the center of the basin (KellerLynn 2015).

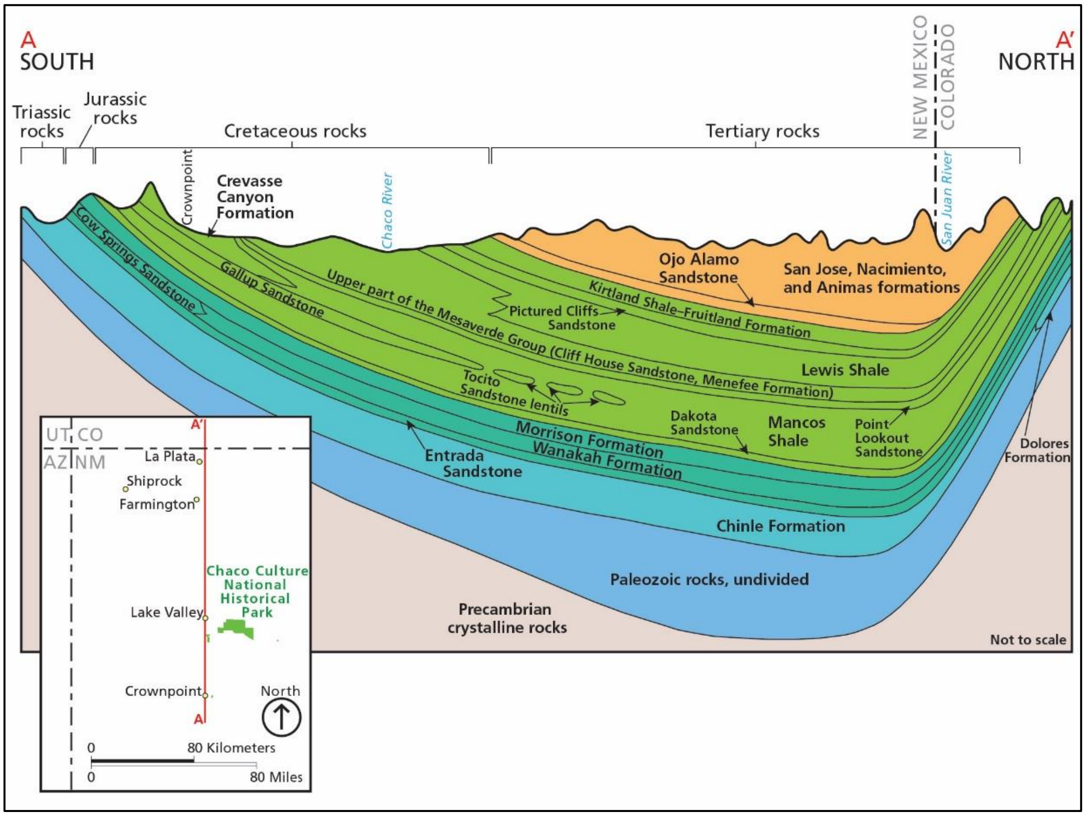

Figure 4. Cross-section of the San Juan Basin. Graphic modified by Trista Thornberry-Ehrlich (Colorado State University) from KellerLynn, (2015, figure 4) after Brister and Hoffman (2002, figure 3) and Martin (2005, figure 9).

The rocks exposed in and around CHCU are Late Cretaceous in age (approximately 89 to 75 million years old) and were deposited following inundation by the Western Interior Seaway, which extended northwest-southeast across western North America from the Arctic to the Gulf of Mexico. Approximately 96 million years ago, seawater began to cover land in what is now New Mexico. As sea level advanced and retreated, sediments were deposited in marine and coastal environments such as barrier islands, lagoons, tidal inlets, stream deltas, estuaries, and swamps. Changes in sea level, sediment supply, and subsidence caused multiple northeast-southwest shifts in shoreline position (Love 2010). As many as five major transgression-regression episodes and many smaller episodes took place over a period of 30 million years (Molenaar 1977).

The transgression-regression cycles of the Western Interior Seaway are recorded in the rocks within the San Juan Basin, including at CHCU, which primarily belong to the Mesaverde Group, named for outcrops in Mesa Verde National Park (MEVE) (Harrison et al. 2017) (Figure 5). The Mesaverde Group consists of the Point Lookout Sandstone (not exposed at CHCU), the Menefee Formation, and the Cliff House Sandstone. The Menefee Formation is the primary bedrock unit in the Kin Bineola unit of the park and in the south, west, and southwestern areas of the Chaco Canyon unit. It is also exposed as gentle slopes below the massive cliffs of the Cliff House Sandstone which makes up the walls on the northern and southern sides of Chaco Canyon. The Cliff House Sandstone also caps West Mesa, South Mesa, and Chacra Mesa on the southern side of the canyon. The contact between the Menefee Formation and Cliff House Sandstone is visible on Fajada Butte, a significant landmark in Chaco Canyon.

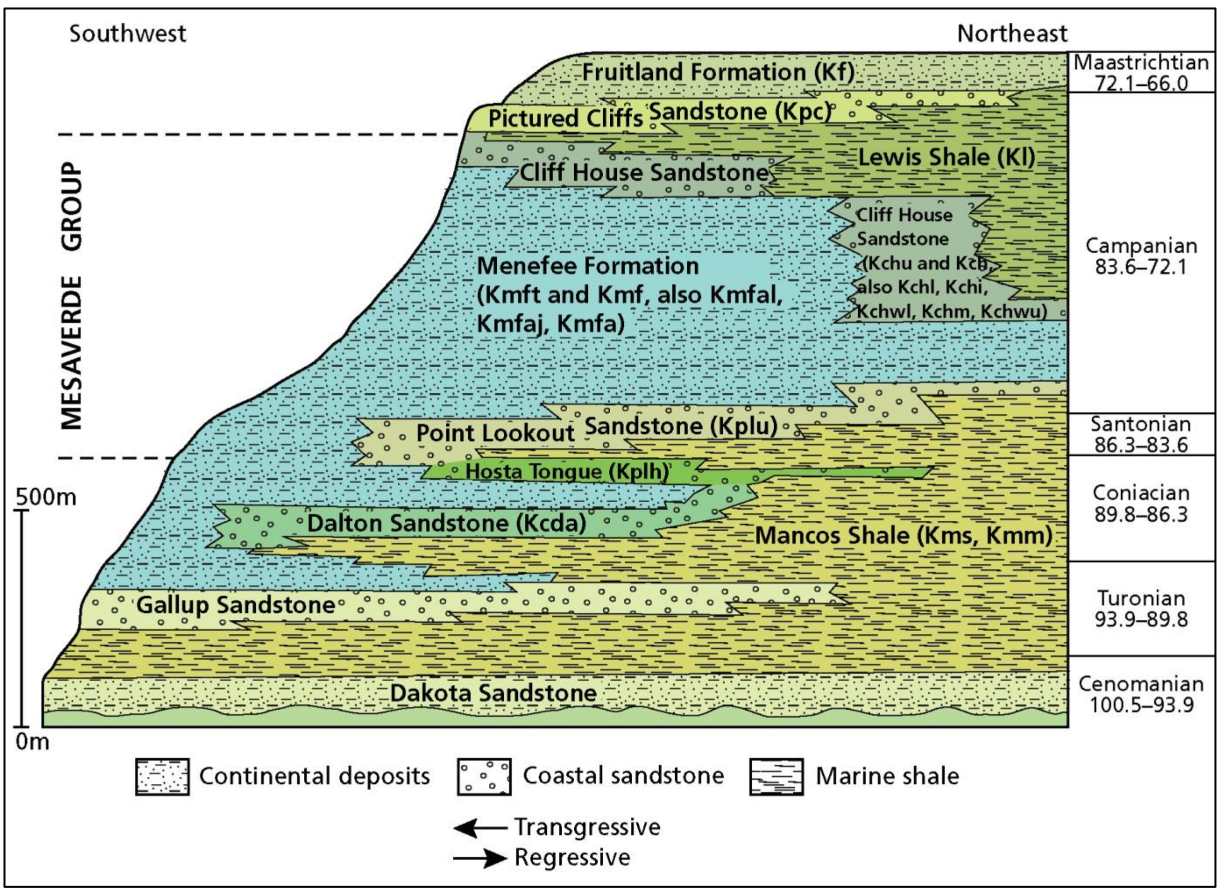

Figure 5. Cretaceous stratigraphy of the San Juan Basin including units exposed at CHCU: Crevasse Canyon Formation, Menefee Formation, Cliff House Sandstone, Lewis Shale, and Pictured Cliffs Sandstone. Graphic by Trista Thornberry-Erlich from KellerLynn (2015, figure 6) after Donselaar (1989, figure 2). The time scale at right contains Late Cretaceous stages in millions of years.

Overlying the Mesaverde Group are the Lewis Shale and Pictured Cliffs Sandstone. The Lewis Shale is exposed in the northeastern parts of the Chaco Canyon and Pueblo Pintado units of CHCU. The Pictured Cliffs Sandstone is exposed in the far northeastern part of the Chaco Canyon unit of the park. These formations represent the final advance and retreat of the Western Interior Seaway northeast from the San Juan Basin area about 75 million years ago.

As the Western Interior Seaway made its final retreat to the northeast, deformation associated with the Laramide Orogeny (a massive mountain building event that created the Rocky Mountains between 75 million and 40 million years ago) uplifted the Colorado Plateau, caused episodes of volcanism in parts of New Mexico, and created many structural features including the San Juan Basin. Erosion from the ancestral Rocky Mountains shed terrestrial sediments into the San Juan Basin which contributed to the downwarped Upper Cretaceous rocks that can be seen today. More than 3,000 feet of sediment deposited during the Paleocene through the Oligocene (66 million to 25 million years ago) covered the area before being eroded away (KellerLynn 2015).

Following the erosion of Paleocene–Oligocene sediment, the ancestral Chaco River drainage began incising through the rocks of the Cretaceous-aged Fruitland and Kirtland formations (now exposed north of CHCU), then into the Pictured Cliffs Sandstone, Lewis Shale, Cliff House Sandstone, and Menefee Formation, eventually exposing what can be seen today. The canyon probably incised to its present depth during the middle Pleistocene Epoch (780,000 to 126,000 years ago), and deposits of Pleistocene gravels can still be seen on top of the mesas. Chaco Canyon remains a dynamic system, as “cut and fill” cycles of sedimentation and erosion continue to the present day. For a detailed summary of the Pleistocene and Holocene geologic history of Chaco Canyon, see “Chaco Culture National Historical Park: Geologic Resources Inventory Report” (KellerLynn 2015). A brief summary of the stratigraphic units of CHCU and their paleontological resources is included below in Table 1. Geologic maps of CHCU can be found in Appendix C.

By at least 13,000 years ago, humans were occupying the San Juan Basin, with the earliest evidence of human activity at Chaco being dated from about 7,000 to 1,500 years ago. The Chacoans flourished in the canyon and surrounding areas between 850–1250 C.E. until eventually leaving the Four Corners area. Since then, the canyon has been sporadically occupied by Pueblo people and later by Navajos until the time of American westward expansion in the mid-1800s (KellerLynn 2015).

Table 1. Summary of CHCU 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 CHCU	Depositional Environment
Quaternary rocks and sediments (Qj, Qes, Qsw, Qn, Qnt, Qal)	Pleistocene–Holocene	Primarily Holocene: charcoal, wood, plant fragments from packrat middens, pollen, gastropods, fishes, salamanders, frogs, lizards, snakes, birds, shrews, rodents, rabbits, bats, canids, felids, ursids, bison, deer, elk, pronghorns, sheep, bone fragments, and latest Pleistocene–Holocene packrat middens	Alluvial, fluvial, eolian, landslide, and talus deposits
Pictured Cliffs Sandstone (Kpc)	Late Cretaceous (Campanian)	Bivalves, bone fragments, and invertebrate burrows	Coastal delta front, beach, and stream channel
Lewis Shale (Kl)	Late Cretaceous (Campanian)	Petrified wood/plant fragments including a tree stump (possibly eroded from the Pictured Cliffs Sandstone), bivalves, gastropods, a tooth, a mosasaur bone fragment, bone and shell fragments, and invertebrate trace fossils	Offshore marine (deep water)
Cliff House Sandstone (Kch, Kchu, Kchwu, Kchwl, Kchm, Kchi, and Kchl)	Late Cretaceous (Campanian)	Gymnosperm and angiosperm wood including logs, woody debris impressions, reed molds, bivalves, ammonites, gastropods, echinoids, shark teeth, fish, mosasaurs, plesiosaurs, turtle bones, undetermined vertebrate bones, and invertebrate burrows (some in rock used as building stone) such as *Ophiomorpha nodosa*	Barrier island, beach, nearshore marine (shallow water)
Menefee Formation (Kmf, Kmft, Kmfa, Kmfaj, and Kmfal)	Late Cretaceous (Campanian)	Gymnosperm and angiosperm wood and leaves, tree stumps, possible reed molds, coal (some worked into beads) and carbonaceous debris, amber pellets, bivalves, turtles, crocodilians, dinosaurs (theropods, hadrosaurids, and possibly ceratopsids), and termite burrows with fecal pellets	Lowland swamp, lagoon, deltaic plain, river floodplain, and stream channel
Crevasse Canyon Formation (Kcg and Kcda)	Late Cretaceous (Coniacian–Santonian)	Trace fossils	Lagoon, estuary, and beach

Geologic Formations

Crevasse Canyon Formation (Upper Cretaceous: Coniacian to Santonian)

Lithology: The Crevasse Canyon Formation is exposed in and around the Kin Ya'a unit of the park, where Robertson (1986, 1992) mapped the Gibson Coal (Kcg) and Dalton Sandstone (Kcda) members. Only the Gibson Coal Member is found within the park boundaries, but the Dalton Sandstone is found just outside the park. Overall, the Crevasse Canyon Formation marks a marine regression after deposition of the Mancos Shale. The Gibson Coal Member overlies the Dalton Sandstone and is composed of carbonaceous shale, siltstone, claystone, and sandstone. It was deposited in estuarine, fluvial channel, and floodplain environments. The unit also has intertonguing tidal channel and marine-beach and bar deposits (Robertson 1986, 1992). The Dalton Sandstone Member was deposited during a marine transgression (Kirk and Zech 1977). As the shoreline migrated seaward, lagoon, tidal, estuarine channel, and beach settings developed (Robertson 1986, 1992).

Fossils found within CHCU: Only a few trace fossils have been found in the Kin Ya'a unit (Tweet et al. 2009)

Fossils found elsewhere: Some of the beds are bioturbated, indicating animal activity (Robertson 1986). The Gibson Coal Member has yielded pollen, spores, coal (Tschudy 1976), plant debris, petrified wood, leaf impressions (Kirk and Zech 1977), and some fragmentary dinosaur material (Lucas et al. 2000), including a partial lower jaw from a hadrosaur dinosaur (Williamson 2000). The Dalton Sandstone also contains bioturbated beds and trace fossils in tidal or estuarine sediments which include *Ophiomorpha* (burrows from shrimp-like crustaceans), *Thalassinoides* (cylindrical, horizontal branching burrows), and *Skolithos* (tube-like vertical burrows). Foreshore sediments contain fish teeth, broken shell fragments, and a few fossil burrows (Robertson 1992). The Dalton Sandstone has also yielded internal casts of ammonites, coprolites of cartilaginous fish, and body fossils of adocid and trionychid turtles, mosasaurs, crocodilians, dinosaurs, and cartilaginous and bony fish (Johnson and Lucas 2003; Lichtig and Lucas 2015, 2016).

Menefee Formation (Upper Cretaceous: Campanian)

Lithology: The Menefee Formation (Kmf) consists of mudstone and siltstone interbedded with cross-stratified lenticular sandstone and contains carbonaceous shale and thin coal beds. It is exposed in the Kin Bineola unit and Chaco Canyon unit of the park. The Menefee Formation is divided into two members: the Allison Member (Kmfa) and the Cleary Coal Member (Kmfc). The Cleary Coal Member is not found at CHCU. The Allison Member is further divided into several beds (Miller et al. 1991). In descending order (youngest to oldest) they are the La Vida Beds (Kmfav), the Juans Lake Beds (Kmfaj), and the lower beds of the Allison Member (Kmfal). The presence of calcareous concretions distinguishes the Juans Lake Beds from the lower beds of the Allison Member. The Juans Lake Beds also contain abundant small siderite concretions that are scattered across mudstone horizons. In the Chaco Canyon unit, the uppermost La Vida Beds are exposed at the base of the steep walls on the northern side of the canyon as slopes of dark carbonaceous shale. On the southern side of the canyon, it forms gentler slopes sometimes as irregular ledges due to the regional dip of the rocks to the north and east (Bryan 1954). The Menefee Formation is often capped by the Cliff House

Sandstone, but in the southern and western areas of the Chaco Canyon unit (west of West Mesa, for example), it forms badlands where the Juans Lake Beds are prevalent. As much as 48 m (160 ft) of the uppermost part of the Menefee Formation is exposed in the park (Siemers and King 1974) (Figure 6). The Menefee Formation also intertongues with the Cliff House Sandstone and can be as thick as 30 m (100 ft) between the lower (Kchl) and middle (Kchm) sandstone units, and as thick as 15 m (50 ft) between the middle (Kchm) and upper (Kchu) sandstones. The Menefee Formation represents an overall terrestrial environment with lowland swamps, streams, lagoons, and coastal deltaic plains that later became coal seams, sandstone ledges, carbonaceous shale, and mudstones.

Figure 6. Expansive Menefee Formation exposures in the western part of CHCU (NPS/PHIL VARELA).

<u>Fossils found within CHCU</u>: 158 paleontological sites have been documented from the Menefee Formation at CHCU. They include abundant petrified wood and vertebrate fossil remains. Fossilized wood includes gymnosperm and angiosperm species in the form of stumps (some upright), logs, and palm leaf and bark impressions. Rare fossilized termite burrows (infilled with fecal pellets) have been found in fossil conifer logs in the Kin Bineola unit and western Chaco Canyon unit. Fossil vertebrates from the Menefee Formation include dinosaur bones (hadrosaurid, theropod, and possible ceratopsid dinosaurs), and crocodilian bone and scute fragments. Turtle fragments are also found, including trionychid turtle fragments and a ~70% complete specimen of a bothremydid turtle (*Elochelys* cf. *E. perfecta*) known to be the oldest bothremydid turtle from New Mexico and one of only two specimens found in New Mexico (Lichtig and Lucas 2015). Unspecified invertebrates

(bivalves, invertebrate trace fossils) are found sporadically among minor sandstone beds. Amber pellets have also been documented within coal seams in the Menefee Formation.

Fossils found elsewhere: Palynomorphs of algae, mosses, liverworts, lycophytes, ferns, seed ferns, cycads, ginkgoes, conifers, gnetophytes, angiosperms, and dinoflagellates (Hall 1977; Jameossanaie 1984, 1986, 1987), herbaceous dicotyledonous angiosperms (Cross et al. 1988), fragmentary remains of sharks, rays, gars, bowfins, amphibians, lizards, turtles (adocids, trionychids, baenids, bothremydids, and solemydids), squamates, crocodile relatives, dinosaurs (hadrosaurs, theropods, and nodosaurs), and mammals, and dinosaur tracks (Hunt 1993; Williamson 1996; Lucas and Hunt 2006; Lewis 2006; McDonald and Wolfe 2018; McDonald et al. 2018; Dalman and Lucas 2018). Paleontological resource inventories of MEVE reported the presence of ferns, cycads, angiosperm and gymnosperm wood, leaves, twigs, seeds, bark, undetermined bivalves, and invertebrate burrows in the Menefee Formation (Scott et al. 2001; Harrison et al. 2017).

Cliff House Sandstone (Upper Cretaceous: Campanian)

Lithology: The Cliff House Sandstone can be divided into several distinct units in the park: the lower sandstone (Kchl), the intermediate unit (Kci), the middle sandstone (Kchm), the upper and lower white to light-gray sandstone (Kcwu and Kcwl), and the upper sandstone (Kchu). Overall, the Cliff House Sandstone is a succession of medium to thick-bedded, cross-stratified, massive marine sandstones with each unit ranging in thickness between 3 to 30 m (10 to 100 ft). The lower, middle, and upper sandstone units form prominent cliffs and ledges (Figure 7). The white to gray sandstones form ledges and benches and transition southwestward into mudstone and carbonaceous shale of the Menefee Formation. The intermediate unit is a thin- to thick-bedded, lenticular and cross-stratified marine sandstone locally interbedded with marine shale that is lithologically similar to the Lewis Shale. The Cliff House Sandstone is exposed across the majority of the Chaco Canyon unit of the park and is the most recognizable cliff-forming unit.

Fossils found within CHCU: 175 paleontological sites have been documented from the Cliff House Sandstone. *Ophiomorpha nodosa* burrows are extremely abundant and can be found in every unit but are most commonly found in the massive units of the lower, middle, and upper sandstones (Vann 1931; Reeside and Knowlton 1924; Siemers and King 1974; Mytton and Schneider 1987). Wood is present but not as abundant as in the Menefee Formation. Invertebrate fossils are abundant in all units of the Cliff House Sandstone and include nearly 100 documented species of bivalves, gastropods, and ammonites. Marine vertebrates are less abundant, but still common. Shark teeth are easily recognized poking out of the sandstone or lying at the base of cliffs. Fossil taxa include *Scapanorhynchus texanus*, *Archaeolamna kopingensis*, *Squalicorax kaupi*, *Squalicorax pristodontus*, cf. *Serratolamna* sp., and undetermined lamniform species. Bony fish vertebrae can co-occur with shark teeth in fossiliferous lenses, particularly in the upper unit. Taxa include *Enchodus* sp. and an undetermined clupeiform (cf. Paraclupeidae) species. Turtle fragments, undetermined dinosaur bones and teeth, and large marine reptile (mosasaur and plesiosaur) bones are also present.

Figure 7. Sandstone ledges of the upper unit, Cliff House Sandstone (NPS/PHIL VARELA).

Fossils found elsewhere: Ammonites, bivalves, echinoids, shark and fish teeth, and amphibians (Scott et al. 2001). As part of a paleontological resources inventory of MEVE, Harrison et al. (2017) reported that wood, plant debris, bivalves, ammonites, teeth of rays and sharks, fish scales and bones, turtle bones, plesiosaur bones, dinosaur bones, mosasaur teeth, chimaera egg capsules, and invertebrate trace fossils (borings, tracks, and burrows) occur in the Cliff House Sandstone.

Lewis Shale (Upper Cretaceous: upper Campanian)

Lithology: The Lewis Shale (Kcl) is an olive-gray marine shale with thin interbeds of claystone, siltstone, and sandstone and scattered beds of limestone, as well as some thin bentonite layers from volcanic ash (Scott et al. 1984; Mytton and Schneider 1987). A widely distributed bentonite bed within the formation, the Huerfanito Bentonite Bed, has been dated to 75.76 ± 0.34 million years old (Cather 2003). The Lewis Shale represents marine deposition in deeper water, farther offshore during an advance of the Western Interior Seaway to the southwest (Carey 1990). The Lewis Shale reaches its maximum thickness of 730 m (2,400 ft) on the northeastern side of the San Juan Basin (Molenaar 1983), but it is only about 30 m (100 ft) thick in the Chaco area and is exposed only in the northeast part of the Chaco Canyon unit. The Lewis Shale interfingers with the underlying Cliff House Sandstone and transitions into the overlying Pictured Cliffs Sandstone through a series of interbedded sandstones, siltstones, and shales (Mytton and Schneider 1987).

Fossils found within CHCU: Five paleontological sites have been documented from the Lewis Shale at CHCU and include bivalves, gastropods, a mosasaur bone fragment, and petrified wood. The petrified wood may have eroded from overlying strata, but presently rest atop exposures of the Lewis Shale.

Fossils found elsewhere: Worm burrows and other trace fossils (Lucas and Reser 1981), dinoflagellates, acritarchs (Manfrino 1984a, 1984b), foraminifera, sponges (Hutchinson and Kues 1985), ammonites, bivalves, gastropods (Bauer 1916; Stanton 1916; Lucas and Reser 1981), ostracodes (Carey 1990), shark teeth, bony fish scales, and mosasaurs (Lucas and Reser 1981). Shallower deposits from delta front shoals have produced seeds, pollen, foraminifera, bivalves, and fish scales (Hutchinson and Kues 1985). Marine mollusk shells are abundant (Scott et al. 1984).

Pictured Cliffs Sandstone (Upper Cretaceous: upper Campanian)

Lithology: The Pictured Cliffs Sandstone is a cross-stratified marine sandstone up to 18 m (60 ft) thick interbedded with a few thin beds of shale. Sandstones form cliffs and ledges in the northeastern parts of the Chaco Canyon unit in the park.

Fossils found within CHCU: One paleontological site has been documented from the Pictured Cliffs Formation at CHCU and includes sporadic indeterminate bivalves and bone fragments.

Fossils found elsewhere: Fossils are not common in the Pictured Cliffs Sandstone, but trace fossils, plant debris, and some invertebrates are relatively common, particularly *Ophiomorpha* (Dane 1936; Erpenbeck and Flores 1979; Flores and Erpenbeck 1981; Hutchinson and Kues 1985; Wolberg et al. 1985). Other microfossils and invertebrates include dinoflagellates, acritarchs (Manfrino 1984a, 1984b), ammonites (Lucas et al. 2006), bivalves, and gastropods (Bauer 1916; Stanton 1916; Dane 1936). Vertebrate fossils are rarer, and include sharks, rays, bony fish, turtles, plesiosaurs, crocodilians, dinosaurs, and rare mammals (Rigby and Clement 1983; Williamson and Lucas 1992; Johnson and Lucas 2003; Spielmann and Lucas 2006). Additionally, Edward Drinker Cope named four plesiosaurs from the San Juan Basin, but it is not certain if they came from the Pictured Cliffs Sandstone or Lewis Shale (Spielmann and Lucas 2006).

Quaternary Rocks and Sediments (Pleistocene–Holocene)

Lithology: Quaternary sediments at CHCU are found in all areas of the park, in canyons, valleys, across mesa tops, and on benches and ledges. Sediments include alluvium (Qal), gravel terraces (Qg), eolian sand (Qes), sheetwash alluvium (Qsw), and soils. Terminology for Quaternary alluvium varies, but Hewett (1977) differentiated the alluvium into three units: Jeddito alluvium (Qj, 11,000 to 7,500 years ago), Tsegi alluvium (Qt, 4,900 to 1,900 years ago), and Naha alluvium (Qn, 1200 to 1800 C.E.) A five-unit scheme for describing alluvial units was used by Hall (1977, 1980) and consists of Fajada alluvium (late Pleistocene), Gallo alluvium (7,000 to 2,400 years ago), Chaco alluvium (2,200 to 850 years ago), Post-Bonito alluvium (600 years ago to 1860 C.E.), and Historic alluvium (1935 to present). Hall (1977) correlated the Gallo alluvium to the lower Tsegi alluvium, the Chaco alluvium to the upper Tsegi alluvium, and the Post-Bonito alluvium to the Naha alluvium.

Fossils found within CHCU: Quaternary micropaleontology is well known in the Four Corners area due to the use of pollen and packrat middens to study climate change. CHCU has been an important site for this research. At CHCU, pollen (Hall 1977; Fredlund and Johnson 1984), carbon isotopes from wood (Mazany et al. 1978, 1980; Lerman and Long 1980), and packrat middens (Anderson 1980; Betancourt and Van Devender 1980a, 1980b, 1981; Gillespie 1982, 1984a, 1984b; Betancourt et al. 1983; Spaulding 1984; Cinnamon 1988; Hall 1988; Betancourt 1990; Long et al. 1990; and Smith and Betancourt 1998) have been the subjects of extensive research that has revealed the remains of many taxa of flora and fauna from the Pleistocene and Holocene. Anderson (1980) named an extinct species of rabbit brush (*Chrysothamnus pulchelloides*) from a CHCU midden that likely went extinct as a direct result of prehistoric and historic human impacts on the land. Gillespie (1982) summarized vertebrate remains from packrat middens and excavations in Atlatl Cave (a shallow alcove), which date from the early to late Holocene period. Akins (1985) summarized prehistoric faunal remains from archeological excavations at CHCU since 1896, which included 43 species of mammals, 47 species of birds, five species of amphibians, eight species of reptiles, and five species of fish. These species are mostly late Holocene fauna and include modern species as well as exotic species that were likely transported to Chaco Canyon for utilization by prehistoric humans. Prehistoric fauna discovered within archeological excavations of Ancestral Puebloan structures are summarized in Appendix Table A-2.

Fossils found elsewhere: A large assemblage of late Pleistocene to Holocene vertebrates was recovered from the Sheep Camp Shelter in Chaco Canyon (Gillespie 1984a, 1984b). Sheep Camp Shelter is just outside park boundaries, but the site is characteristic of other archeological sites found within the park. The faunal assemblage includes several taxa no longer found within the San Juan Basin, including an extinct horse (*Equus* sp.) and peccary (cf. *Platygonus compressus*) (O'Neill 1992). Most taxa are now prevalent in the sagebrush communities of the Great Basin (Gillespie 1985). The Sheep Camp Shelter has yielded fossils of frogs, salamanders, lizards, grouse, weasels, rodents (including cricetids, geomyids, heteromyids, porcupines, and sciurids), insectivores, rabbits, peccaries, deer, and equids (Harris 1993).

Taxonomy

See Appendix A for full lists of fossil taxa. Locality data for fossil sites can be found in Appendix B.

Fossil Plants

Fossilized wood is abundant at CHCU. Out of 344 documented paleontological sites, 151 sites contain fossilized wood. Most of the fossil wood has not been identified beyond gymnosperm or angiosperm, but the majority of wood seems to be conifer wood similar to that of Cupressaceae (the cypress family). Fossil wood can be found within most stratigraphic units of the park *in situ* or as float.

By far, fossil wood is the most commonly preserved type of fossil in the Menefee Formation (115 sites) and can be preserved as upright stumps, fallen logs, branches, bark impressions, and debris scatters (Figure 8). In the Cliff House Sandstone fossil wood is less common, but is not uncommonly preserved (32 sites), and it is most likely to be preserved in the Intermediate unit (Kchi) as debris scatters, fragmented logs, bark impressions, and more rarely, as *in situ* logs protruding from cliff faces (Figure 9).

Few studies have been conducted on the fossil plants from the park (Hall 1977; Anderson 1980; Jameossanaie 1984, 1986, 1987; Cross et al. 1988), and most of these studies focused on palynomorphs from Quaternary sediments, often in an archeological context. Anderson (1980) described a new species of rabbit brush, *Chrysothamnus pulchelloides*, from a rock shelter in Mockingbird Canyon. This species went extinct after human occupation of the region, possibly from desertification of the environment due to human collection of wood for fuel.

Since 2007, Dr. Lisa Boucher (University of Texas, Austin) has been conducting paleobotanical research on wood specimens from CHCU and nearby areas to further understand the relationship between ecological radiation and plant evolution. The fossil wood at CHCU is significant from a paleobotanical perspective because during the Cretaceous, flowering plants (angiosperms) substantially increased in taxonomic diversity which contributed to their rise to global dominance in modern vegetation. Gymnosperms dominate the wood assemblage, with specimens consisting of a few xylotypes including *Cupressinoxylon* and *Araucarioxylon*. Angiospermous woods include examples with possible Lauraceae, Saptoaceae, and Anacardiaceae affinities, and some new xylotypes (Boucher, pers. comm.). CHCU collections contains 488 paleobotanical specimens. See “Park Collections” under “Museum Collections and Curation” for more information about the cataloged plant specimens, including those cataloged for archeology.

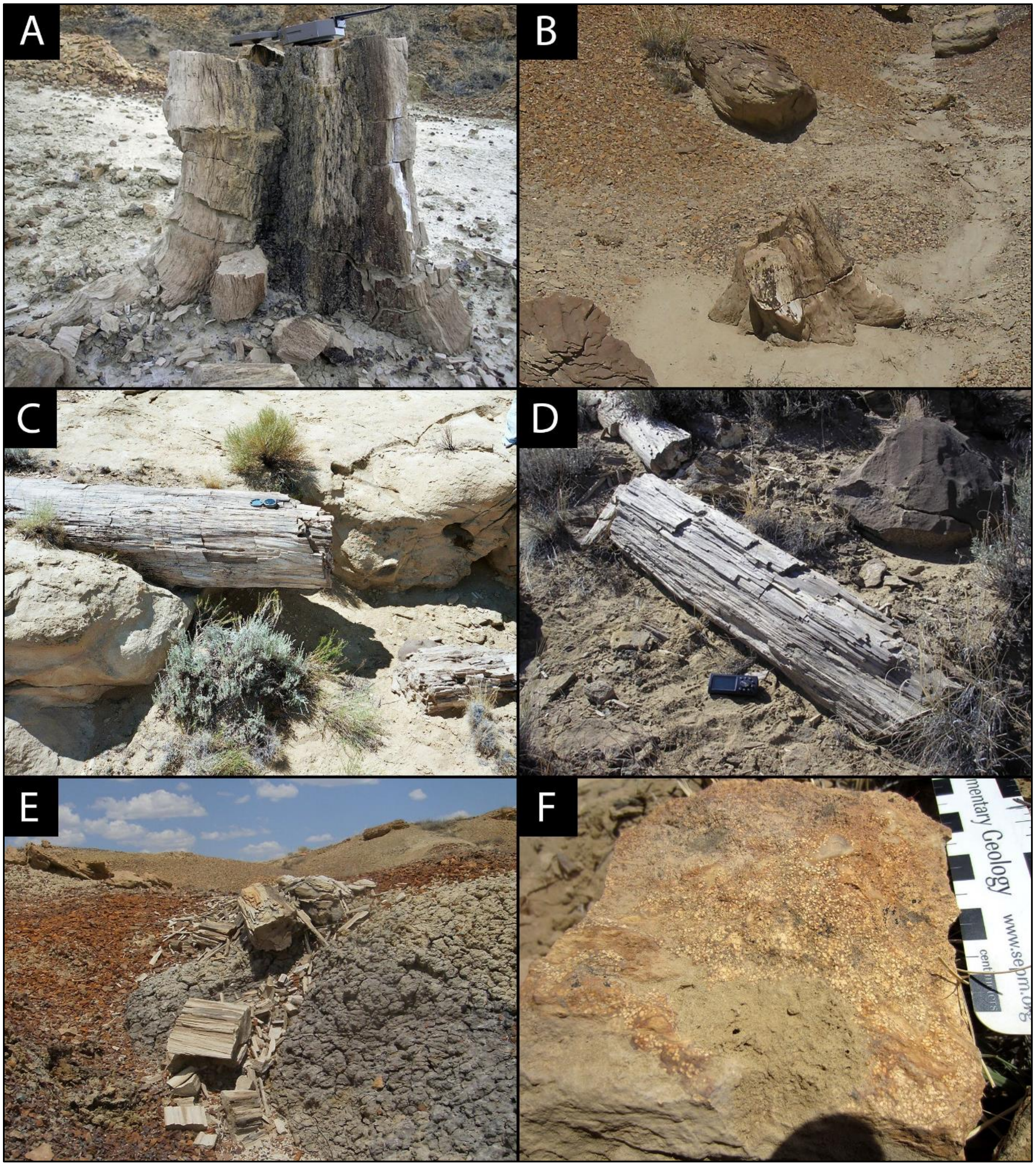

Figure 8. Fossil wood from the Juans Lake Beds, Menefee Fm (Kmfaj). A) Fossil tree stump of Cupressaceae or Podocarpaceae (CHCU 107452) (NPS/TOM LYTTLE); B) Fossil tree stump (NPS/PHIL VARELA); C) Fossil Cupressaceae log (NPS/TOM LYTTLE); D) Fossil conifer log (NPS/Lyttle); E) Fossil Cupressaceae logs (NPS/PHIL VARELA); F) Fossil conifer wood with coprolite-infilled termite galleries (CHCU 131402) (NPS/PHIL VARELA).

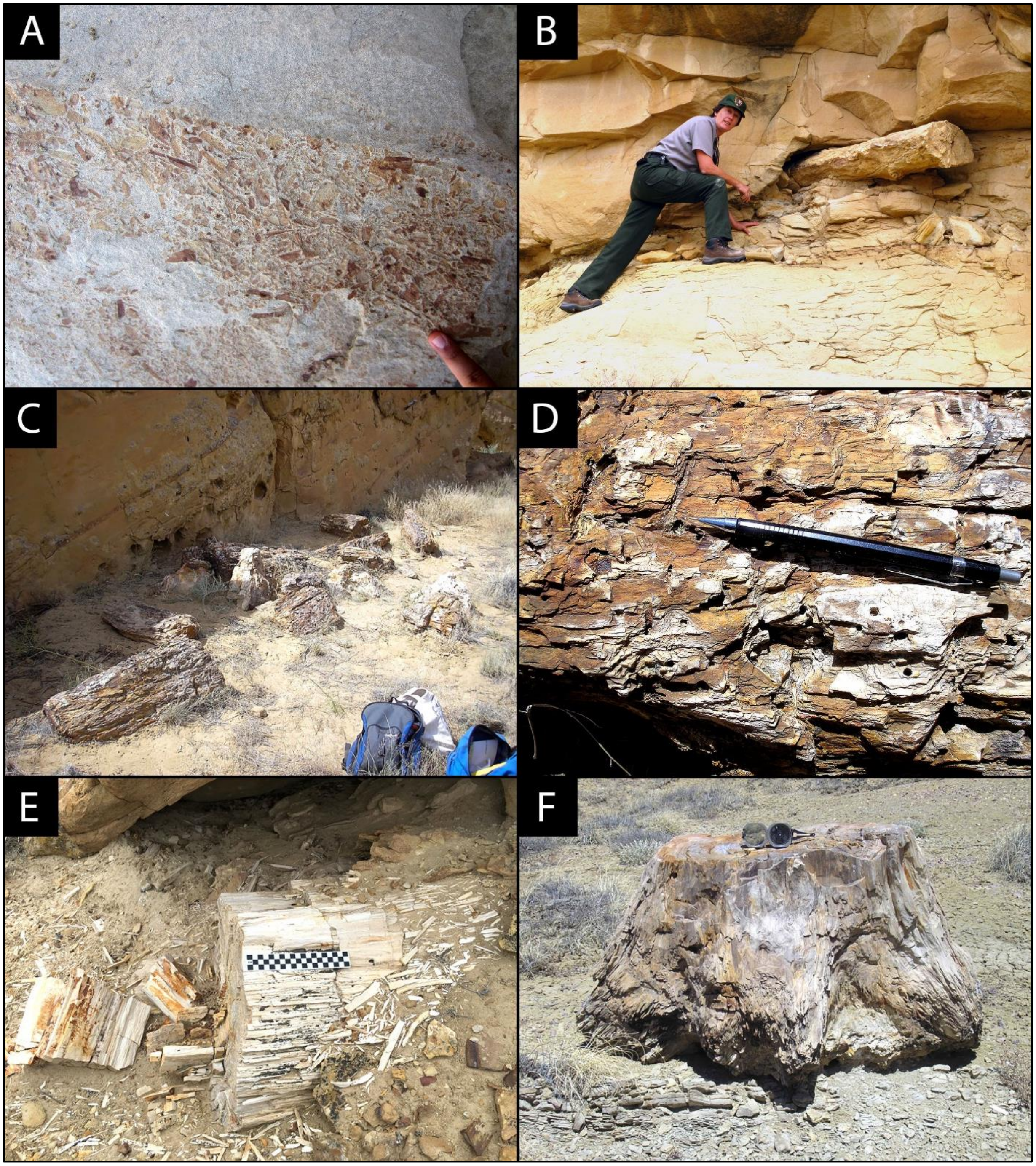

Figure 9. Fossil wood from the upper Mesaverde Group. A) Fossil plant impressions (Kchm) (NPS/PHIL VARELA); B) Fossil conifer log (Kch) (NPS/TOM LYTTLE); C) Fossil logs (Kch) (NPS/TOM LYTTLE); D) Fossil log with boreholes (Kchl) (NPS/TOM LYTTLE); E) Fossil log (Kchu) (NPS/PHIL VARELA); F) Fossil tree stump (Kl) (NPS/TOM LYTTLE).

Fossil Invertebrates

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

54 species of bivalve mollusks have been identified at CHCU, and most of these identifications come from the work of Reeside and Knowlton (1924), Vann (1931), Wood (1940), and Siemers and King (1974). Bivalves are extremely common throughout the Cliff House Sandstone with the most abundant genus being *Inoceramus* (at least six species) (Figure 10). Some fossiliferous horizons in the lower and upper sandstone of the Cliff House Sandstone are made up of almost exclusively bivalve fragments. Siemers and King (1974) summarized typical fossil assemblages made up of invertebrate fossils (mostly bivalves and gastropods). Assemblages 2 and 4 (Siemers and King 1974) contain mostly *Inoceramus* shell casts and molds, sometimes preserved un-fragmented or articulated in current-oriented densely packed accumulations (Assemblage 4). Oysters are also common in the lower and upper Cliff House Sandstone and are often associated with stratigraphic horizons containing abundant shark teeth. CHCU collections contains 12 bivalve specimens. See “Park Collections” under “Museum Collections and Curation” for more information about the cataloged bivalve specimens.

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

Three species of ammonites have been identified at CHCU: *Placenticeras intercalare*, *Baculites anceps*, and *Baculites perplexus*. Few ammonites have been collected from CHCU, so it is hoped that many more species could be collected and described. Ammonites are important index fossils for biostratigraphic correlation of geologic formations, so there is likely great potential for scientifically significant specimens to be described. At least 11 paleontological sites contain ammonites either in the lower or upper sandstones of the Cliff House Sandstone (Figure 11). Some ammonites are casts without much visible structure, while some have very prominent suture lines. Some cephalopods are simple impressions in highly fossiliferous sandstone beds. The CHCU collections contain five cephalopod specimens. See “Park Collections” under “Museum Collections and Curation” for more information about the cataloged cephalopod specimens.

Phylum Mollusca: Class Gastropoda (snails)

Gastropods are the second most common invertebrate fossil at CHCU, both in terms of abundance and species diversity (Figure 12). About 40 species of Cretaceous gastropods and 17 species of Quaternary gastropods have been identified, and at least 31 paleontological sites have been documented to contain gastropod specimens. Most of the Cretaceous gastropod species were identified from the work of Reeside and Knowlton (1924), Vann (1931), Wood (1940), and Siemers and King (1974), and Quaternary gastropods were identified from archeological investigations by Drake (1948) and Hall (1980). Many gastropod specimens were collected from Cretaceous rocks, but the current whereabouts of these collections are unknown. There is one fossil gastropod specimen cataloged in the CHCU collections.

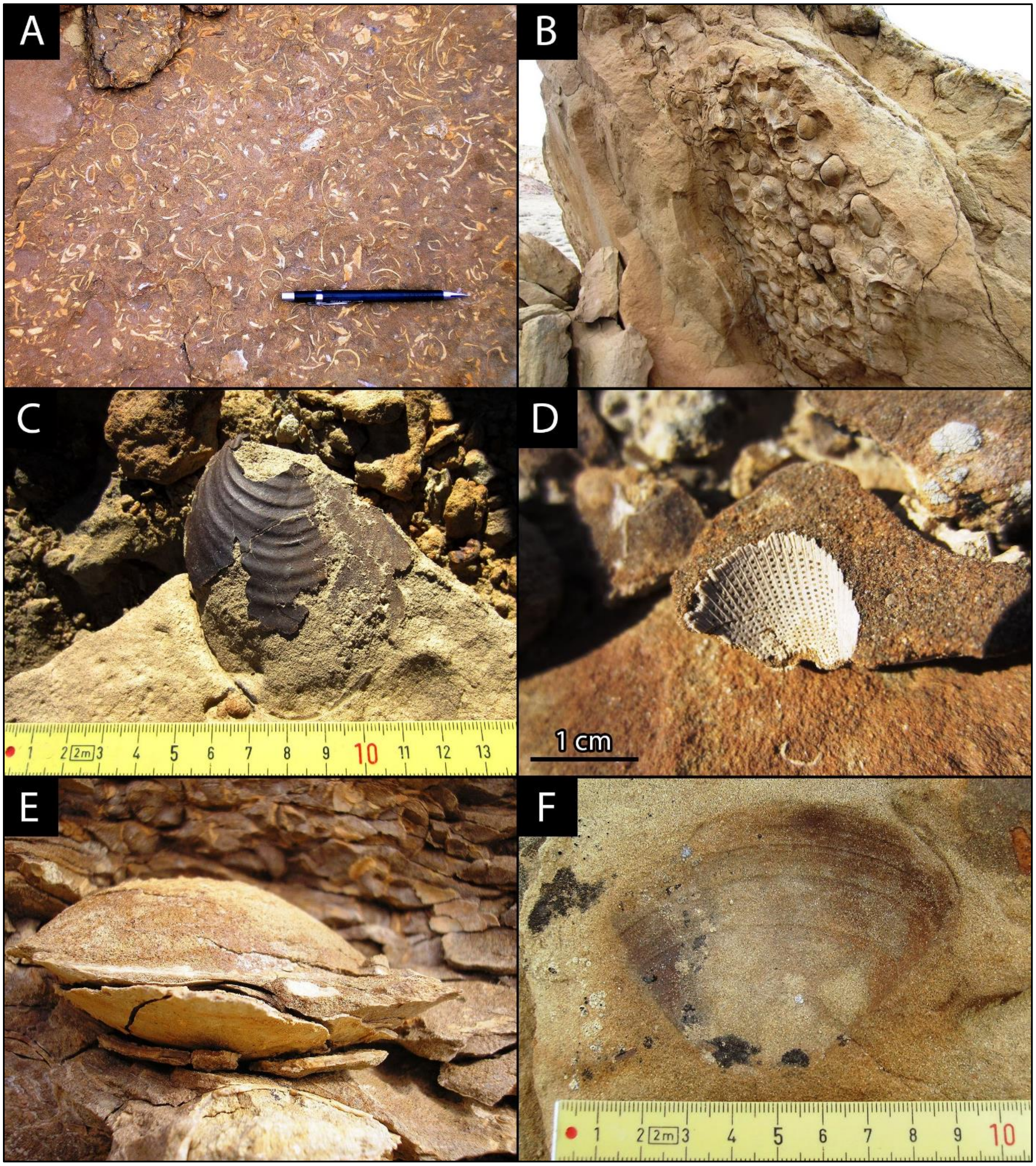

Figure 10. Fossil bivalves in the Cliff House Sandstone. A) Fossiliferous sandstone containing abundant invertebrate (bivalve and gastropod) fragments, typical of many lower and upper Cliff House Sandstone exposures and characteristic of fossil assemblages described in Siemers and King (1974) (NPS/TOM LYTTLE); B) Molds and casts of *Inoceramus* accumulation in a fallen sandstone boulder (NPS/PHIL VARELA); C) Fossilized shell material of an *Inoceramus* clam (NPS/PHIL VARELA); D) Fossil shell material of cf. *Granocardium* bivalve (NPS/PHIL VARELA); E) Steinkern of fossil bivalve (NPS/TOM LYTTLE); F) Mold (impression) of fossil bivalve (NPS/PHIL VARELA).

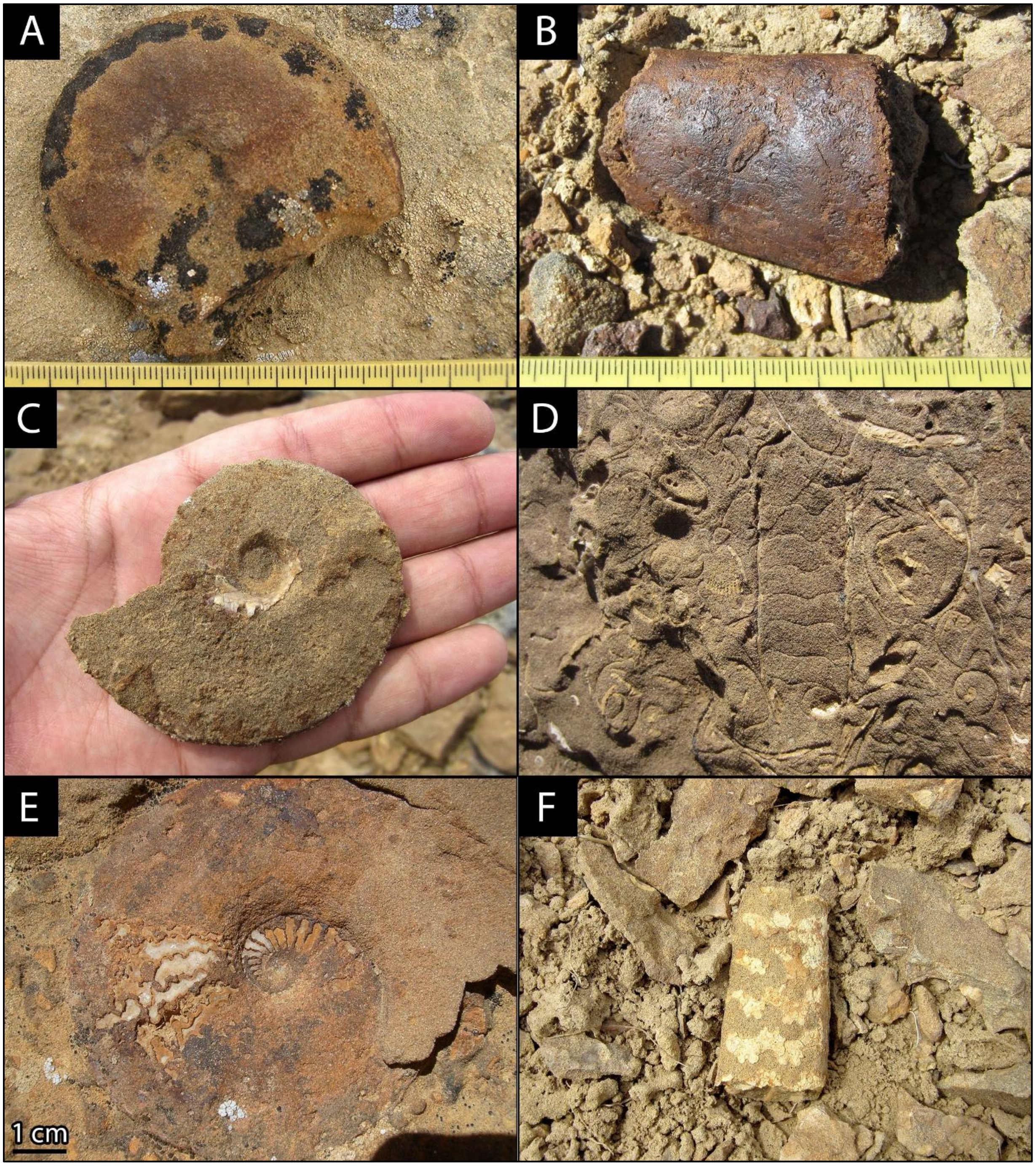

Figure 11. Fossil cephalopods from the lower (Kchl) and upper (Kchu) units of the Cliff House Sandstone (NPS/PHIL VARELA): A) Undetermined ammonite cast (CHCU 121701) (Kchu); B) *Baculites* sp. cast (CHCU 131419) (Kchu); C) Undetermined ammonite cast (Kchl); D) *Baculites* sp. impression (Kchu); E) Undetermined ammonite cast; F) *Baculites* sp. cast.

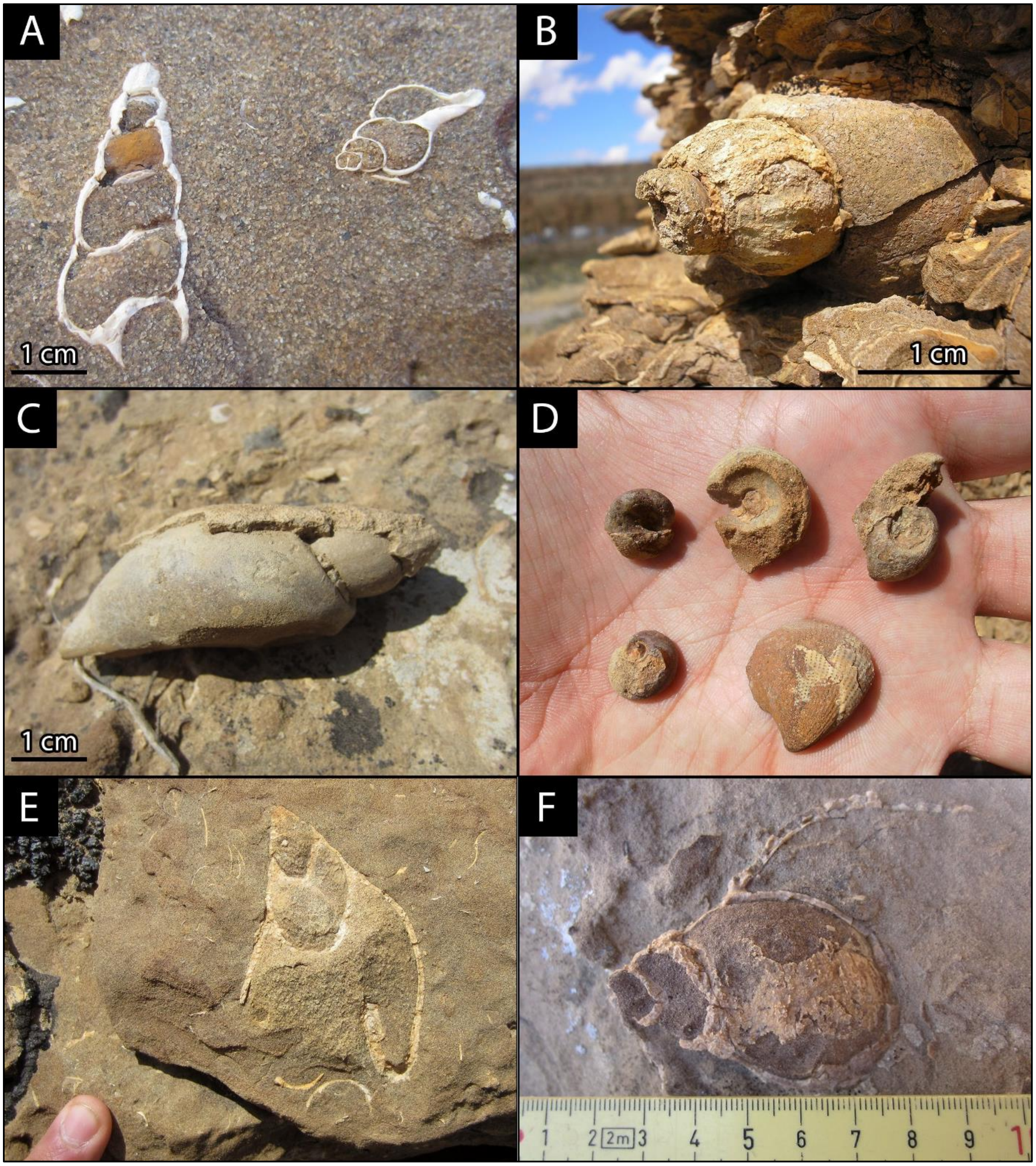

Figure 12. Fossil gastropods from the Cliff House Sandstone. A) Fossil gastropods *in situ* (NPS/PHIL VARELA); B) *Volutomorpha* sp. gastropod cast *in situ* (NPS/TOM LYTTLE); C) Fossil gastropod cast (NPS/PHIL VARELA); D) cf. *Gyrodes* sp. gastropod casts and cf. *Granocardium* sp. bivalve cast (NPS/PHIL VARELA); E) Fossil gastropod *in situ* (NPS/PHIL VARELA); F) Fossil gastropod *in situ* (NPS/PHIL VARELA).

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

Echinoderms very rarely occur at CHCU. Siemers and King (1974) identified the echinoid (sea urchin) *Hardouinia taylori* in the Cliff House Sandstone at CHCU. The species was listed in a table of taxa present but the specimen was not described in the text or collected. Furthermore, no locality information was given for this specimen, but it is likely that it was found in one of the several "fossil assemblages" described in the study. One site possibly containing crinoids (sea lilies) was documented during the paleontological resources inventory. Several crinoid specimens are cataloged in the CHCU collections, but these specimens have uncertain provenance or are associated with cultural sites. See "Park Collections" under "Museum Collections and Curation" for more information about the cataloged echinoderm specimens.

Fossil Vertebrates

Class Chondrichthyes (cartilaginous fishes, sharks, and rays, etc.)

Shark teeth are commonly found in the Cliff House Sandstone and can be found *in situ* or as float (Figure 13). At least 42 documented paleontological sites contain shark teeth, but they are likely present at many more sites. Some sites contain dozens of shark teeth representing multiple species. At least four genera are represented from CHCU, but only an extremely limited taxonomic analysis has been conducted to determine which species are present. Dr. Kenshu Shimada (DePaul University) identified several shark species from photographs of a small collection of shark teeth that is used for interpretive programs at CHCU. The following taxa have been identified: *Squalicorax kaupi*, *Squalicorax pristodontus*, *Scapanorhynchus texanus*, cf. *Serratolamna* sp., *Archaeolamna kopingensis*, and many specimens of indeterminate lamniforms. See "Park Collections" under "Museum Collections and Curation" for more information about the cataloged chondrichthyan specimens.

Class Osteichthyes (bony fishes)

Fossils of bony fish are commonly found in association with shark teeth and reptile fossils in the Cliff House Sandstone at CHCU (Figure 14). At least 13 documented paleontological sites contain osteichthyan fossils, but it is likely that bony fish are much more abundant than currently known. Fish vertebrae can be found among mixed fossiliferous horizons which contain abundant invertebrate and vertebrate fragments. Fish fossils are most commonly found in the upper sandstone of the Cliff House Sandstone (Kchu), but cranial elements from *Enchodus* were identified in the lower sandstone during field investigations in 2018. Body fossils of fish are cataloged in the Chaco Museum Collections. One specimen, CHCU 79452 (Figure 14-A), consists of two sandstone fragments containing several body fossils of an unidentified fish. The provenance of the fish fossils is unknown, but the specimens were reportedly turned in by unidentified park visitors in 2003. The fossils were identified as belonging to the order Clupeiformes (a group containing herring, sardine, and anchovy families) by Dr. Chris Fielitz (Emory and Henry College). They may possibly be of the family Paraclupeidae (Ellimmichthyidae), but since the fossils were identified through only photos, more specific identification was not determined. One other similar fossil (CHCU 125938, no provenance) was returned by mail from an anonymous park visitor in 2017. See "Park Collections" under "Museum Collections and Curation" for more information about the cataloged osteichthyan specimens.

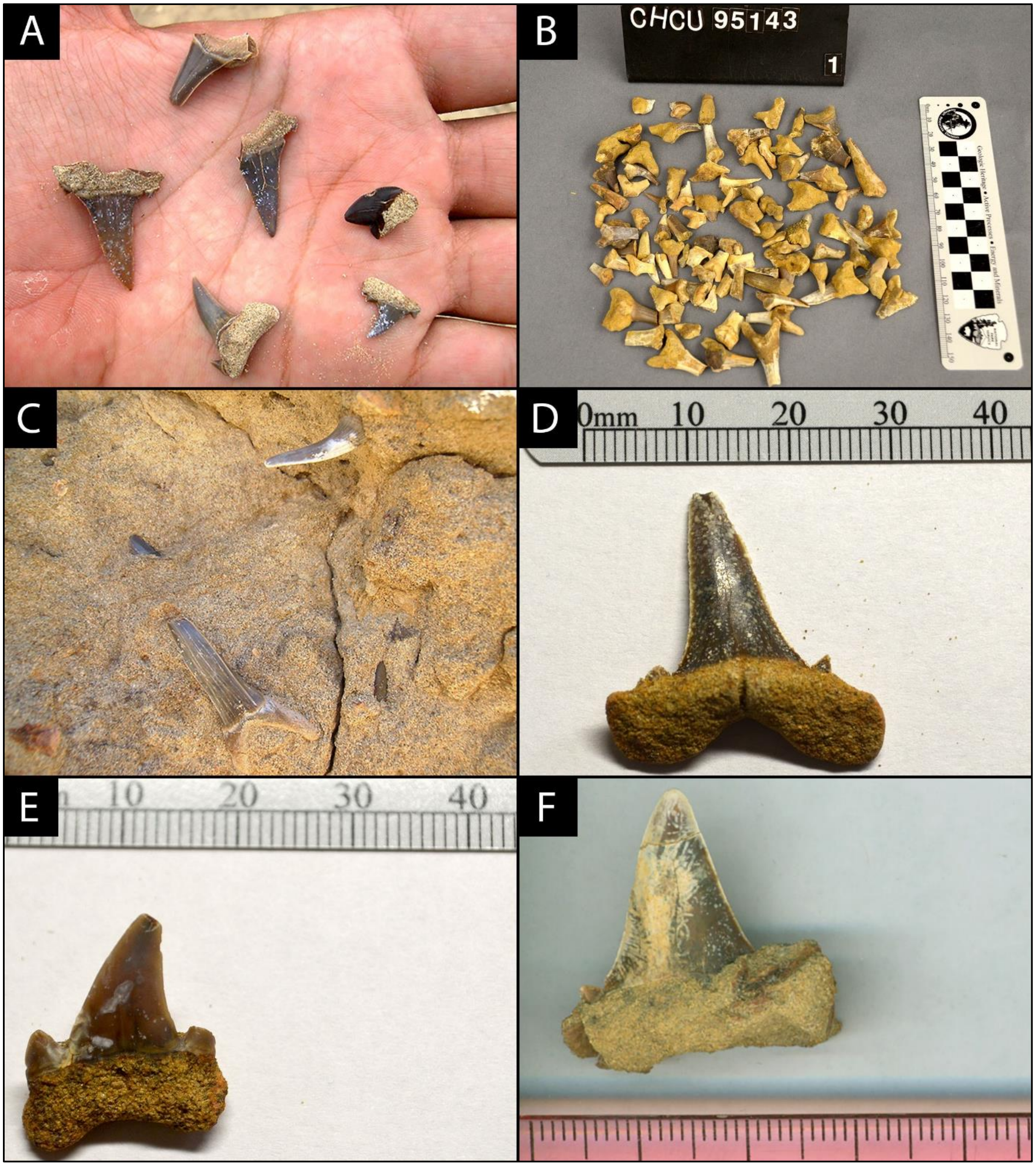

Figure 13. Fossil shark teeth from the Cliff House Sandstone (NPS/PHIL VARELA). A) Assorted shark teeth found in float including *Squalicorax* sp. and other unidentified lamniform shark teeth; B) Bulk collection of unidentified shark teeth (CHCU 95143); C) Undetermined lamniform shark teeth *in situ* eroding out of sandstone; D). cf. *Serratolamna* sp. shark tooth; E) *Archaeolamna kopingensis* shark tooth (CHCU 131416); F) *Scapanorhynchus texanus* shark tooth.

Figure 14. Fossil fish from the Cliff House Sandstone (NPS/PHIL VARELA). A) Clupeiform fish (cf. Paraclupeidae) (CHCU 79452); B) Unidentified fish vertebra; C) Unidentified fish vertebra *in situ*; D) Unidentified fish vertebrae *in situ* in a fossiliferous horizon.

Class Reptilia (turtles, dinosaurs, mosasaurs, plesiosaurs, crocodiles, etc.)

Fossil bones at CHCU have been known anecdotally for decades from the Cliff House Sandstone and to a lesser extent the Menefee Formation. Reeside and Knowlton (1924), Vann (1931), Wood (1940) and Siemers and King (1974) all make reference to fragmentary vertebrate material in the fossil assemblages of CHCU. However, each of these previous studies had a large focus on invertebrate material. Even as late as the 2003, following a recommendation by the BLM Regional Paleontologist at the time who expressed doubt that there were any unique fossils at CHCU, a paleontological resource inventory was not a high priority (National Park Service 2003). It was not until more recent years that the abundance and significance of vertebrate fossils at CHCU was realized. Several new dinosaurs from the Menefee Formation near CHCU were described in 2018 alone (Dalman and Lucas 2018; McDonald et al. 2018; McDonald and Wolfe 2018).

Since 1996, at least 95 paleontological sites containing reptile bones or possible reptile bones have been documented at CHCU (Figure 15 and 16). These sites are found in almost all of the formations at CHCU and represent diverse animal groups: marine reptiles such as mosasaurs (*Prognathodon overtoni*) and plesiosaurs, dinosaurs (including theropod and hadrosaurid dinosaurs), turtles (bothremydid and trionychid turtles), and a possible crocodilian. Very few specimens have been the subject of thorough scientific investigations. One notable example is a fossil turtle (CHCU 81269) which turned out to be a nearly complete specimen of a bothremydid turtle (*Elochelys* cf. *E. perfecta*) known to be the oldest bothremydid turtle from New Mexico and one of only two specimens found in New Mexico (Lichtig and Lucas 2015). There are 13 catalog numbers for reptile specimens in the CHCU collections. The amount of unidentified material in CHCU illustrates the potential for scientific research related to Cretaceous reptiles of Chaco Canyon. See "Park Collections" under "Museum Collections and Curation" for more information on cataloged reptile specimens.

Class Aves (birds)

Fossil birds are rare in Cretaceous rocks. No fossil birds have been definitely documented in CHCU or in the stratigraphic units present in the park. *Ichthyornis* (and similar pelagic bird species) has been found in the Mancos Shale (not present in CHCU) near Cuba, New Mexico (Lucas and Sullivan 1982). One paleontological site from the upper unit of the Cliff House Sandstone may contain the remains of a cervical vertebra from a bird-like species (Figure 16C). The vertebra is broken and not completely exposed from the matrix, so identification is difficult. Alternatively, the vertebra may be from a baenid turtle, but no other identifiable turtle remains were found at the site. Fish vertebrae are also present at the site. The fossil has not been excavated or studied to confirm identification.

Modern bird specimens have been recovered during archeological investigations of the great houses and rock shelters in alcoves at CHCU. In addition to common species of birds for the San Juan Basin in Chacoan and present times, species also include those not native to the San Juan Basin, such as *Ara macao* (scarlet macaw), and species that are now extinct, such as *Ectopistes migratorius* (passenger pigeon). The presence of the remains of the scarlet macaw and passenger pigeon illustrate the great long-distance transport of live animals to Chaco during prehistoric times (Akins 1985). For information on modern bird specimens recovered from archeological investigations at CHCU, see "Park Collections" under "Museum Collections and Curation" and Appendix Table A-2.

Figure 15. Fossil Reptilia from the Menefee Formation. A) *Elochelys* cf. *E. perfecta* (side-necked turtle) before excavation (CHCU 81269) (NPS/TOM LYTTLE); B) Vertebra of ornithischian dinosaur (NPS/PHIL VARELA); C) Left distal humerus fragments of ornithischian dinosaur (NPS/PHIL VARELA); D). Bone fragments of unidentified dinosaur (NPS/TOM LYTTLE); E) Trionychid turtle carapace fragments (CHCU 110196) (NPS/PHIL VARELA); F) Crocodilian scute fragment (CHCU 131420) (NPS/PHIL VARELA).

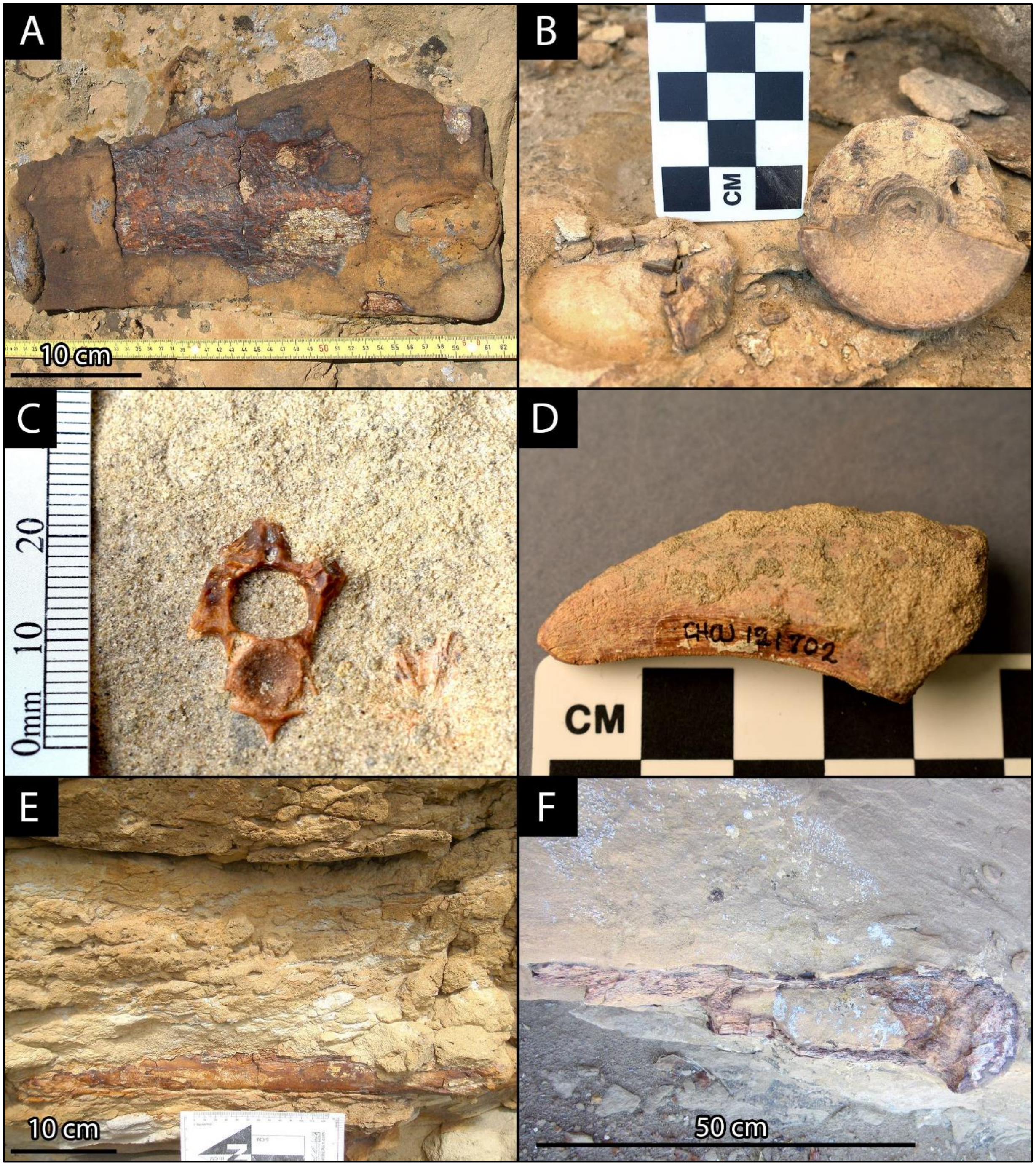

Figure 16. Fossil Reptilia from the Cliff House Sandstone. A) Possible plesiosaur humerus (NPS/PHIL VARELA); B) Vertebrae of undetermined marine reptile (NPS/PHIL VARELA); C) Vertebra of Testudines or Aves undetermined (NPS/PHIL VARELA); D) Possible theropod tooth (CHCU 121702) (NPS/PHIL VARELA); E) Long bone from undetermined marine reptile? (NPS/PHIL VARELA); F) Limb bone from undetermined reptile (NPS/PHIL VARELA).

Class Mammalia (mammals)

No fossil mammals were documented from the paleontological resources inventory. Since most of the rocks at CHCU are of Late Cretaceous age, mammals would be rare. Mammal remains have been recovered as a result of archeological investigations in packrat middens and excavations of great house sites. Mammals recovered from archeological investigations are mostly Holocene in age, with a few extinct Pleistocene species having been identified in the area. A few mammal specimens are also attributed to "Chaco Canyon" as a general locality, but these specimens were likely recovered from the Nacimiento Formation (Paleocene) outside of the park. See "Collections in Other Repositories" under "Museum Collections and Curation" and Appendix Table A-2 for further information about mammal fossils found in and around CHCU.

Ichnofossils (trace fossils)

Invertebrate trace fossils are extremely common in the Cliff House Sandstone at CHCU, and are typical of the shallow marine and marginal-marine sedimentary units of the Western Interior Seaway. *Ophiomorpha nodosa* is the most common and abundant trace fossil of the Cliff House Sandstone. The structures are cylindrical, vertical, and hollow (or infilled), with a smooth interior and knobby iron-cemented external wall that commonly branches as a horizontal Y-shaped burrow system. Previous studies (Reeside and Knowlton 1924; Vann 1931; Wood 1940) identified these fossils as *Halymenites major*, a marine alga. Paleontologists now know that the fossils were created by a burrowing crustacean similar to the modern genus *Callianassa* (Weimer and Hoyt 1964). Some burrow systems don't have the distinct knobby outer texture and are usually classified more generally as *Thalassinoides*. *Ophiomorpha nodosa* and *Thalassinoides* are so common in the park that it is not practical to attempt to map every occurrence. During the paleontological resources inventory, the presence of trace fossils was noted in site files, but trace fossils were not typically documented as standalone paleontological sites. Trace fossils from the ichnogenera *Chondrites* and *Planolites* have been documented in the paleontological resource inventory. Siemers and King (1974) identified the occurrence of the genus *Gyrochorte* as a sinuous, bilobate trail probably made by browsing gastropods.

*Teredolithus (*or *Teredolites)* is a structure resulting from teredinid bivalve boring into fossil wood. These traces are uncommon but present in some fossilized wood. Notably, the fossil wood of unknown origin at paleontological site CHCU-0131 contains abundant boreholes. Other trace fossils can be found within fossil wood. Rare fossilized termite burrows (infilled with fecal pellets) have been found in fossil conifer logs at paleontological sites in the Kin Bineola unit and western Chaco Canyon unit. Preliminary analysis of the fecal pellets indicates they belong to a species of "damp wood" termite (Lisa Boucher, pers. comm. 2019). Determining the species may have paleoclimatic implications and provide information for paleoenvironmental reconstructions of the Cretaceous Western Interior Seaway in New Mexico.

Packrat middens, as discussed in greater length at "Quaternary Rocks and Sediments" under "Geology", are considered to be a type of vertebrate trace fossil, although they are primarily of interest for the structural fossils they contain (plant fragments, pollen, invertebrate and vertebrate body fossils, and vertebrate fecal material), rather than as unified trace fossils.

Fossil Localities

A brief description of fossils found within the Paleontological Management Areas documented during the CHCU Paleontological Resources Inventory is described below. Specific locality information must be requested from the CHCU Resources Division. See Appendix B for individual locality descriptions.

Kin Bineola (PMA01)

Three fossil localities composed of 16 sites are monitored in the Kin Bineola area. Large logs of conifer wood are eroding from mudstone mounds of the Menefee Formation (Juans Lake Beds). This locality contains some of the largest specimens of fossilized wood (tree trunks, logs, and log fragments). Fossil conifer wood was also found that preserves damp wood termite fecal pellets infilling the galleries.

Pueblo Pintado (PMA02)

No fossil localities.
No fossil collection.

Kin Ya'a (PMA03)

No fossil localities.
No fossil collection.

Kin Klizhin (PMA04)

Five fossil localities composed of 39 sites are monitored in the Kin Klizhin area. Fossil assemblages contain mostly conifer and angiosperm wood eroding from mudstones of the Menefee Formation (Juans Lake Beds). Conifer wood is more common. A specimen with preserved termite galleries in fossil wood (similar to that in PMA01-LOC03) is a rare and potentially significant discovery. Fossilized bone fragments are fragmentary and mostly unidentified. A nearly complete carapace of a side-necked turtle (*Elochelys* cf. *E. perfecta*) was excavated in 2007.

Wijiji Mesa (PMA05)

Four fossil localities composed of 13 sites are monitored in the Wijiji Mesa area. Fossils found in the lower unit of the Cliff House Sandstone (Kcl) are primarily invertebrate specimens such as bivalves (*Inoceramus* clams, oysters) and gastropods, and more rarely cephalopods (*Placenticeras*). Several coquina-like exposures are visible at the top of the lower unit and are made up of bivalves, gastropods, and less commonly include shark teeth and small bone fragments. Fossilized wood and vertebrate bones are also found in the intermediate unit of the Cliff House Sandstone (Kci).

Gallo Mesa (PMA06)

Two fossil localities composed of five sites are monitored in the Gallo Mesa area. Fossil assemblages in the Gallo unit are primarily concentrated near a stratigraphic contact or a physical boundary such as ledges or near the base of a cliff. Fossilized wood and vertebrate bone assemblages are commonly found in the intermediate unit of the Cliff House Sandstone (Kchi). Fossils found in the lower unit of the Cliff House Sandstone (Kchl) are primarily invertebrate specimens such as bivalves (*Inoceramus* sp., oysters) and gastropods. Several coquina-like exposures consistent with Assemblage 1 of Siemers and King (1974) are visible at the top of the lower unit and contain abundant bivalve and gastropod shells.

Chacra Mesa (PMA07)

Three fossil localities composed of 13 sites are monitored in the Chacra Mesa area. Fossil assemblages on Chacra Mesa are typical for the Cliff House Sandstone, and include fossiliferous horizons containing bivalves, gastropods, and cephalopods which are consistent with those of Siemers and King (1974). Fossil horizons in the upper unit of the Cliff House Sandstone contain shark teeth, fish vertebrae, and other vertebrate bones (possibly marine reptile at some sites). Fossilized wood is also present in the intermediate unit of the Cliff House Sandstone and Menefee Formation. At the base of Chacra Mesa, large exposures of the Menefee Formation have the potential for containing fossil vertebrates and wood; however, very little vertebrate material has been documented in the Menefee Formation north of Chacra Mesa. Fossil wood from the Menefee Formation has been collected from several sites in the Chacra Mesa area as part of an ongoing paleobotanical study by Dr. Lisa Boucher.

Mockingbird Canyon (PMA08)

Three fossil localities composed of eight sites are monitored in the Mockingbird Canyon area. The Mockingbird Canyon unit contains the largest exposures of the Lewis Shale (Kl) and Pictured Cliffs Sandstone (Kpc). Mockingbird Canyon itself is formed within the Cliff House Sandstone, and the fossil assemblages there are typical of other Cliff House exposures, mostly consistent with the assemblages described by Siemers and King (1974). The fossils within the Lewis Shale are mostly fossil wood logs, stumps, and debris scatters. Considering the marine origin of the Lewis Shale, the amount of fossilized wood found in this unit presents a challenge in determining whether or not the wood eroded from stratigraphically higher rock units. It is likely these specimens are float from non-marine rock units. Very few fossils other than sporadic invertebrate fragments have been documented in the Pictured Cliffs Formation.

Large fossilized wood logs at locality PMA08-LOC03 are situated on the valley floor of Mockingbird Canyon at the base of the lower unit of the Cliff House Sandstone. The source of these logs remains unknown, but given the random orientation, large size, and no known *in situ* source, it is possible that the logs were moved by people. Mockingbird Canyon contains areas with large amounts of garbage from historical projects. A well-known Civilian Conservation Corps era stone wall was built near Hungo Pavi ruins at the mouth of the canyon. No historical records are known to have referenced the large fossil wood specimens. This site contains some of the largest angiosperm logs documented during the inventory. Typically, the larger logs are conifer trees. Evidence of boreholes in these logs contributes to the potential significance of these specimens. Fossil wood has been collected from several sites in the Mockingbird Canyon area as part of an ongoing paleobotanical study by Dr. Lisa Boucher.

Cly's Canyon (PMA09)

Five fossil localities composed of five sites are monitored in the Cly's Canyon area. Cly's Canyon is geographically and stratigraphically similar to Mockingbird Canyon, and the fossil assemblages there are typical of other Cliff House exposures, mostly consistent with the assemblages described by Siemers and King (1974). Fossiliferous horizons commonly consist of mixed invertebrate–vertebrate horizons containing abundant *Inoceramus* sp. shells, casts, and molds, other bivalves and gastropods, and some fragmentary vertebrate material including shark teeth, unidentified reptile fragments, and a possible partial mosasaur dentary.

South Mesa (PMA10)

Five fossil localities composed of 18 sites are monitored in the South Mesa area. South Mesa contains excellent exposures of the Menefee Formation and all units of the Cliff House Sandstone. Fossilized wood and bone was found in the Menefee Formation including possible partial hadrosaur skeletons. Dinosaur specimens were collected in 2010 by Douglas Wolfe and Andrew McDonald, who also provided the tentative taxonomic identifications. Exposures in the lower Cliff House Sandstone are characteristic of fossiliferous assemblages described by Siemers and King (1974). Fossil wood has been collected from one locality in the South Mesa area as part of an ongoing paleobotanical study by Dr. Lisa Boucher.

West Mesa South (PMA11)

Nine fossil localities composed of 29 sites are monitored in the West Mesa South area. Fossil assemblages were widespread and abundant, especially in the badlands terrain of the Juans Lake Beds (Allison Member) of the Menefee Formation (Kmaj) in the southwestern portion of this project area. Several petrified wood assemblages and vertebrate bone assemblages were discovered, with a possible ceratopsian vertebra. Shark teeth and bone fragments are common occurrences in the upper sandstone unit of the Cliff House Sandstone.

West Mesa North (PMA12)

Eight fossil localities composed of 16 sites are monitored in the West Mesa North area. Fossil assemblages are widespread and abundant, especially in the upper sandstone unit of the Cliff House Sandstone where shark teeth and bone fragments are common. Bone assemblages consist of small float fragments, to large *in situ* specimens. Fossiliferous horizons commonly consist of a mixed invertebrate–vertebrate matrix containing abundant bivalves and gastropods often found within an ironstone concretionary horizon. The Menefee Formation contains numerous vertebrate bone assemblages including trionychid (soft shell turtle) carapace fragments and a possible crocodile bone assemblage.

Museum Collections and Curation

Natural History Collections

The NPS Chaco Collection is located at the Hibben Center at the University of New Mexico in Albuquerque, New Mexico. There are thousands of fossil specimens in the Chaco Collections, but most of them are cataloged under the Cultural History collection. The CHCU Natural History collection consists of 117 catalog numbers containing 831 fossil specimens. Of these, 488 objects are plants (mostly fossil wood), 162 objects are Reptilia, 153 objects are Chondrichthyes (shark teeth), 12 objects are Bivalvia, five objects are Cephalopoda, three objects are Osteichthyes, two objects are Echinodermata (crinoids), one object is Gastropoda, and five objects are unknown.

Table 2. Cataloged specimens in the CHCU Natural History Collections.

Taxon	Catalog Numbers in CHCU Natural History Collections. n = 117
Plantae	CHCU 32973, 107451, 107452, 107453, 107454, 107455, 107456, 107457, 107458, 107459, 107460, 107461, 107462, 107463, 107464, 107465, 107466 , 107467, 107468, 107469, 107470, 107471, 107472, 107473, 107474, 107475, 107476, 107477, 107478, 107479, 107480, 107481, 107482, 107483, 107484, 107485, 107486, 107487, 107488, 107489, 107490, 107491, 107492, 107493, 107494, 107495, 107496, 107497, 107498, 107499, 107500, 107501, 107502, 107503, 107504, 107505, 107506, 107507, 131402, 131403, 131404, 131405, 131406, 131407, 131408
Bivalvia	CHCU 32697, 95895, 95897, 95901, 95902, 95903, 95906
Cephalopoda	CHCU 95896, 95898, 95899, 121701, 131419
Gastropoda	CHCU 131415
Echinodermata	CHCU 125933, 125939
Chondrichthyes	CHCU 32734, 95143, 95433, 95900, 121704, 131409, 131410, 131411, 131412, 13143, 131414, 131416, 131471, 131418
Osteichthyes	CHCU 79452, 125938
Reptilia	CHCU 48885, 81269, 109794, 109795, 109796, 109797, 110196, 121702, 121703, 121705, 121706, 131420, 131421
Unknown	CHCU 32700, 95904, 95905

Cultural History Collections

There are at least 38,886 objects under 4,763 catalog numbers with paleontological connections in the CHCU Cultural History Collections. Although some of these objects are not fossils, such as sandstone artifacts in lots with petrified wood artifacts, this is still a substantial collection. 4,643 catalog numbers include human-modified pieces of petrified wood including: chipped petrified wood specimens (2,049 catalog numbers), flakes (1,256), hammer stones (529), cores (217), lithic specimens (102), projectile points (100), stone artifact fragments (75), scrapers (59), manuports or human-transported but unmodified objects (58), knives (46), drills (43), choppers (19), bifaces (17), abraders (2), blades (2), burins (1), bracelet fragments (1), gravers (4), ground stones (4), hoes (1), mauls (1), mineral specimens (2), paint palettes (1), pecking stones (3), polishing stones (1), shaft smoothers (1), tchamahias (2), and wedges (2). Other paleontological specimens in the cultural resources collection include: shark teeth (55 catalog numbers), shell (32), bones (4), bryozoans (a type of colonial invertebrates) (1), crinoids (6), gastropods (5), gizzard stones (1), plants (2), reptile teeth (1), trace fossils (4), mixed lots (4), and unknown (9). Additional collections come from confiscated items and visitor turn-ins. Most of these are petrified wood flakes.

Some of the objects in the cultural history collections were brought in from great distances, such as the remains of gar scales from the Rio Grande, marine shells from the Gulf of Mexico and the west coast of North America, and exotic birds from Mexico (Gillespie 1984a).

Photographic Archives

Photographic archives are managed by the Chaco Collections at the Hibben Center, University of New Mexico. The Chaco Archive manages over 3,170 photographs related to the paleontological resources inventory, mostly consisting of photographs from paleontological sites.

Collections in Outside Repositories

MUSEUM OF NORTHERN ARIZONA
3101 Valley Fort Road
Flagstaff, Arizona 86001
https://musnaz.org/

The Museum of Northern Arizona has fossil collections from three Chaco localities. No geographic data is specified for any of the localities. The geologic formations represented are the Mesaverde Group (Kmv), an unknown formation, and the "?Puerco Formation." The Puerco Formation is now considered a lower zone of the Nacimiento Formation (Tn), and the fauna found within the zone became the basis of the Puercan Land Mammal Age (Paleocene, 66 million to 63.3 million years ago). The Nacimiento Formation is not exposed at CHCU, so it is almost certain that the fossils were not found within park boundaries. Some historic descriptions of "Chaco Canyon" include areas north of the park in the vicinity of the greater Chaco River valley.

Locality MNA LOC 881-0 (Mesaverde Group, Kmv) contains specimens that could have come from within the boundaries of CHCU. Fossils from this locality include *Ophiomorpha nodosa* burrows (MNA.N.3779), *Baculites perplexus* (MNA.N.7130), *Cymbophora* sp. (MNA.N.7210), *Inoceramus* sp. (MNA.N.7211), *Cardium* sp. (MNA.N.7212), conifer wood (MNA.P.639, MNA.P.688), and unidentified dinosaur bone fragments (MNA.V.95). Locality MNA LOC 957-0 contains unidentified dinosaur vertebrae, limb, and bone fragments (MNA.V.1112) from an unknown geologic formation.

Locality MNA LOC 957-0 (Nacimiento Formation, Tn) contains specimens that are unlikely to have come from within the boundaries of CHCU, since there are no Paleocene exposures in the park. Fossils from this locality include a mandible fragment and teeth of the mammal *Periptychus* sp. (MNA.V.1107), premolar, incisors, and canine teeth of an unidentified mammal (MNA.V.3147), a mandible fragment and phalanx of the crocodilian *Leidyosuchus* sp. (MNA.V.3148), and unidentified crocodilian teeth (MNA.V.3149).

GRAND CANYON NATIONAL PARK
Museum Collections
2 Albright Ave
Grand Canyon Village, AZ 86203
https://www.nps.gov/grca/learn/historyculture/muscol.htm

Grand Canyon National Park has Chaco fossil collections under two catalog numbers: GRCA 2969 and GRCA 2943. Both specimens are *Inoceramus* sp., but lack locality data. Specimens were collected by Louis Schellbach in 1934, assistant park naturalist at Grand Canyon at the time. Both specimens were collected in Chaco Canyon, and GRCA 2969 was apparently collected in "a Pueblo Ruin". *Inoceramus* is common at Chaco, but without specific locality or stratigraphic data, the specimens have little scientific value. GRCA 2943 went missing from the Grand Canyon Museum Collection sometime before 1968 and is now deaccessioned (Colleen Hyde, GRCA Museum Curator, pers. comm.).

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http://epswww.unm.edu/

The fossils collected by Siemers and King (1974) had been housed by the University of New Mexico, Albuquerque. Siemers and King report that they collected fossils from 22 localities in Chaco Canyon, including the same locality near Pueblo Bonito (USGS 9743) collected by Reeside and Knowlton (1924). Detailed information about how many specimens were collected at which specific sites was not provided in Siemers's and King's published work. More than 50 molluscan taxa are represented in the combined collections of Vann (1931), Wood (1940), and Siemers and King (1974), but the current whereabouts of any of these collections are unknown. Barry Kues (Department of Earth and Planetary Studies, UNM) could not locate the Siemers and King specimens in the UNM Collections in February 2009, and suggested that the specimens were either discarded or removed by Siemers when he left the University in the late 1970s (Tweet et al. 2009).

Cultural Resource Connections

The southwestern United States, including the area in and around Chaco Canyon, is one of the most fossiliferous areas in the world. Paleontologists have been studying fossils in the area almost as long as archeologists have been studying the human prehistory in the area. Despite this, traditional interpretations of fossils are not widely known, especially compared to the modern scientific understanding of fossils. This is also true of the fossils found in Chaco Canyon. The results of this inventory have illustrated the abundance and diversity of fossils in Chaco Canyon. However, most of the fossils collected from archeological excavations are pieces of petrified wood thought to be more utilitarian in nature (see "Cultural Resource Collections" under "Museum Collections and Curation").

Given the abundance of cultural objects such as beads, jewelry, pendants, ornamentation, animal effigies, copper bells, etc., it is obvious that prehistoric people in Chaco made and traded items that held more artistic or ceremonial value in addition to utilitarian goods. Curiously, archeologists did not recover fossil artifacts that demonstrated such uses; or, perhaps these items were not accurately or completely recorded.

Furthermore, there is still limited dialogue between paleontologists and Native Americans today about the meaning and significance of fossils. Chaco Canyon's affiliated tribes are culturally diverse, so there can probably never be one way to traditionally understand fossils. In 2014, the NPS discussed paleontological resources at CHCU during consultation meetings with affiliated Tribal representatives. During tribal consultation, it was universally agreed that fossils represent the past and its continued presence today and that fossils are important in native oral histories. Conversations between native communities and paleontologists should continue as more information is learned.

Fossils may be considered sacred because they play a role in many native oral traditions relating to origin or emergence stories. The exact meaning or interpretation of the fossils may differ between tribes, but there may also be some universal themes. In certain Zuni traditions, it is known that beasts from the past died and turned to stone. Present day stone artifacts may still carry the spirit of the dead animal. The Zuni would collect stones, fossils, or other natural objects that resembled animals and would create animal fetishes that could be worn or carried and were valued for their protective, healing, or other beneficial powers. In Navajo tradition, a widely known story about a slain monster that was beaten into the earth and whose spirit still remains with its bones offers a different perspective. Based on the belief that the remains of the dead should not be disturbed, traditional Navajos avoid corpses, death, and places where the spirits of the dead may be, including fossil bone beds (Mayor 2005).

These two perspectives are only small examples and in no way represent all traditional beliefs, but having a better understanding of present cultural attitudes towards fossils may help in determining possible prehistoric connections. The presence or absence of fossil artifacts in a cultural context may be as equally significant. There is still much to be learned from the thousands of artifacts that were collected. A more thorough review of natural objects in the cultural history collection such as shells, shark teeth, and bones should be examined to determine how fossils were or were not represented in the Chacoan sites. Such a review was beyond the scope of this current inventory. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Interpretation and Education

Paleontology-focused interpretive programs have been developed at CHCU since 1996. Since that time, programs have been given sporadically depending on the availability of interpretive staff or geology and paleontology focused physical science staff. Programs focusing on geology and paleontology have consisted of guided walks through Pueblo Bonito, campfire talks, evening programs in the amphitheater, and PowerPoint presentations in the Visitor Center theatre. The Resources Division has also hosted guest lectures by paleontology researchers to inform visitors of ongoing research conducted in the park. Additionally, rangers and volunteers have traveled to local schools in Farmington, Aztec, and Laguna Pueblo, New Mexico to give programs related to the geologic and paleontological history of Chaco Canyon.

Current Long Range Interpretive Plan

The CHCU Foundation Document identifies paleontological resources as "Other Important Resources and Values". These resources have been selected because they are important enough in the operation and management of the park and warrant special consideration in park planning. Paleontological Resources, however, are not explicitly identified as a Fundamental Resource to be incorporated as a permanent interpretive theme for CHCU. Interpretive themes help explain why a park story is relevant to people who may otherwise be unaware of connections they have to an event, time, or place associated with the park. Of the park's four identified interpretive themes, paleontological resources may fall into one category as part of the "complex natural environment and cultural landscape that can evoke a sense of wonder and curiosity, inviting personal discovery." The foundation document has also identified that the park has increased its interpretation of fossils to the public over time, and that there are still opportunities to continue to study how ancient and modern people understand fossils (National Park Service 2015).

Recommended Interpretive Themes

Geology and paleontology oriented programs help raise awareness to visitors of the significance and importance of fossil resources in the park. Many visitors come to CHCU without the realization that fossils are present, especially in such abundance and diversity. Generally, visitors are positively receptive of learning about the geologic and paleontological history of the park, especially as it relates to the ancient cultural sites and the environment. Chaco Canyon is such a striking geologic feature that further interpretation of the geology and paleontology may enhance the visitor experience. Furthermore, educational programs serve as reminders to be aware that fossils should be respected within park boundaries, just as historic and cultural artifacts are.

A new museum exhibit in the lobby of the Chaco Canyon Visitor Center focuses on paleontology and other natural processes that helped shape Chaco Canyon. This exhibit has been well received by visitors since its installation, and it serves as a foundational introduction to the natural history of Chaco. Interpretive rangers should become familiar with paleontological resources in order to better help address visitors' questions or to formulate discussion of natural history. The Resources Division also has a small fossil collection for use in interpretive programs. See "Interpretative Fossil Collection" under "Museum Collections and Curation" for more information.

Visitors should be reminded that fossils are non-renewable resources that possess scientific and educational information and provide insight into what Earth was like thousands to millions of years ago. If fossils are found in the park by a visitor, the visitor should photograph it and notify a ranger of where it was found. Most importantly, they should leave the fossil where they found it. It is extremely important for scientific and resource management purposes for locational information to be preserved. Visitors should be informed that like cultural artifacts, park fossils are protected by law (see "Paleontological Resource Management and Protection").

National Fossil Day is celebrated annually on Wednesday of the second full week in October, which is also National Earth Science Week. Conducting paleontology focused talks on this day would be a perfect opportunity to not only increase public awareness about paleontological resources at CHCU, but also connect with other parks and museums who are also participating in this national event. The first National Fossil Day at CHCU was hosted in 2012, and in subsequent years has been hosted in coordination with International Archaeology Day which usually coincides closely with National Fossil Day (Figure 17).

Figure 17. Phil Varela, NPS Physical Science Technician, meets with second graders from Farmington Area Schools on National Fossil Day 2012 at CHCU (NPS/JIM VON HADEN).

Resources for Interpreting Geology and Paleontology

The National Park Service, Natural Resources Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest to a broad audience including the public. In addition to this report on paleontological resources, the NPS Geologic Resources Division (GRD) has completed a Geologic Resources Inventory (GRI) for CHCU (KellerLynn 2015). This report in part is intended to be used by the Interpretation Division to aid in the development of geology related programs. The report is available from the GRI website (https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm) and the Natural Resources Publications Management Website (https://www.nps.gov/im/publication-series.htm).

The NPS GRD can also assist with planning for National Fossil Day activities in the park and provide supplies for the Junior Paleontologist Program (including activity booklets, badges, posters and other fossil-related educational resources). For more information on National Fossil Day and how to register your event, visit: https://www.nps.gov/subjects/fossilday/index.htm. For more information on the Junior Paleontologist program and to request materials, visit: https://www.nps.gov/subjects/fossils/junior-paleontologist.htm.

Interpretive Fossil Collection

A small collection of fossils was discovered in the Interpretation Division offices by former Chief of Interpretation Russ Bodnar when offices were cleaned and relocated to the new Chaco Canyon Visitor Center in January 2012. Most of the fossils have no provenance and no documentation to indicate when or why the specimens were collected. Although it cannot be confirmed that the specimens were collected from within the park, most are presumed to have been collected from the Cliff House Sandstone. Taxa represented in the collection include *Inoceramus* spp., *Granocardium* sp., cf. ?*Plesiopinna* sp., unidentified venerid bivalves, cf. *Gyrodes* sp. gastropods, other unidentified gastropods, unidentified lamniform shark teeth, *Ophiomorpha nodosa* burrows, a palm leaf impression, and unidentified petrified wood. Barry Kues (Professor Emeritus, University of New Mexico) assisted with providing tentative identifications for the invertebrate specimens. Since most of the invertebrate specimens don't have preserved shell material, it is difficult to get definitive identifications. This fossil collection is housed within the Resources Division and has been used for National Fossil Day celebrations and other fossil-related interpretive programs.

CHCU 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. Because 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 for a more complete interpretation of the physical and biological history of Earth. Therefore, paleontological resource management must serve to protect not only the fossils themselves, but to collect and maintain the ancillary data as well.

In general, losses of paleontological resources result from naturally occurring physical processes, by direct or indirect human activities, or by a combination of both. The greatest loss of ancillary data occurs when fossils are removed from their original geological context. Thus, when a fossil weathers and erodes from its surrounding sediments and geologic context, it begins to lose significant ancillary data until at some point it becomes more of a scientific curiosity than a useful piece of scientific data.

A piece of loose fossil ("float") can still be of scientific value; however, when a fossil has been completely removed from its original context, such as an unlabeled personal souvenir or a specimen with no provenance information in a collection, it is of very limited scientific utility. It is not necessary to list all of the natural and anthropogenic factors that can lead to the loss of paleontological resources; rather, it is sufficient to acknowledge that anything which disturbs native sediment or original bedrock has potential to result in the loss of the paleontological resources or data that occur there.

In the course of this inventory, paleontological localities have been evaluated for factors that could cause potential loss of paleontological resources. Their overall conditions are reported as good, fair, or poor based on the situations found at each individual locality. Risks and conditions that influence the degree of potential loss are categorized as Disturbance, Fragility, Abundance, and Site Access.

"Disturbance" evaluates conditions that promote accelerated erosion or mass wasting resulting from human activities.

"Fragility" evaluates natural conditions that may influence the degree to which fossil transportation is occurring, such as inherently soft rapidly eroding sediment or mass wasting on steep hillsides.

"Abundance" judges both the natural condition and number of specimens actually preserved in the deposits as well as the risk of being easily recognized as a fossil-rich area which could lead to the possibility of unpermitted collecting.

"Site Access" assesses the risk of a locality being visited by large numbers of visitors or the potential for easy removal of large quantities of fossils or fossil-bearing sediments as a result of proximity to public use areas or other access (along trails, near campgrounds, etc.).

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 with abundant or rare fossils, or with high rates of erosion, may be considered for periodic monitoring in order to assess the stability and condition of the locality and resources, in regard to both natural processes and human-related activities. Localities may also benefit from more frequent law enforcement patrols.

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

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

Paleontological Resource Management Recommendations

The paleontological resource inventory at CHCU has documented rich and previously unrecognized paleontological resources from within park boundaries. This report captures the scope, significance, and distribution of fossils at CHCU as well as provides recommendations to support the management and protection of the park's non-renewable fossil resources. The following recommendations should be taken into consideration by park management, resource staff, interpreters, and law enforcement personnel:

- CHCU 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.
- Fossil theft is one of the greatest threats to the preservation of paleontological resources and any methods to minimize these activities should be utilized by staff. Any occurrence of paleontological resource theft or vandalism should be investigated by a law enforcement ranger. When possible, the incident should be fully documented and the information submitted for inclusion in the annual law enforcement statistics. At CHCU, fossils are often collected with cultural artifacts (pottery shards, lithics, etc.). These fossils should be treated in much the same way as cultural artifacts.
- 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 found in a cultural context may be culturally sensitive as well (i.e., 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 park may fund and recruit paleontology interns as a cost-effective means of enabling some level of paleontological resource support. The Geoscientists-in-the-Parks Program is an established program for recruitment of geology and paleontology interns.
- CHCU Management should encourage Interpretation Division staff to incorporate paleontology related themes into the public programs, guided walks, and educational outreach efforts. See the "Interpretation and Education" section of this report for more information.
- Contact the NPS Geologic Resources Division for technical assistance with paleontological resource management issues.

If fossil specimens are found by CHCU staff, it is recommended they follow the steps outlined below:

- Do not remove the fossil before consulting with the Chief of Resources or the person responsible for managing paleontological resources in the park. The fossil may be part of one of the 344+ documented paleontological sites at CHCU. If provided adequate data, Resource Division staff can check the paleontological and archeological site databases to determine if the fossils have been previously documented and if the fossil was found within an archeological site.
- Take notes about the fossil specimen that was found including the person who found it and the date of discovery. Write down associated data, such as rock type, general description of the fossil, type of fossil if identifiable, general location within the park, position within the rock wall or if it is loose on the ground, any associated fossils, and any other additional information that would aid in the relocation or identification of the specimen.
- Photo-document the specimen without moving it from its location. Include a scale in the photograph. A common item such as a coin, pen, or pencil will work for scale if a ruler or scale bar is not available. Label the photograph with the date and subject, and keep notes about the photographs so they can be properly identified later.
- Record the location of the specimen with GPS coordinates if possible. If GPS is not available, record the general location within CHCU and height within the rock wall. If possible, revisit the site when a GPS unit is available.
- If it is determined that the fossil should be collected, it should be done within established NPS standards. The specimen should be properly curated within the Chaco Museum Collection preserving all taxonomic and geographic data.
- Refer to Paleontological Resource Law and Policy, NPS Management Policies 2006, and NPS Director's Order-77 for guidance on best practices for paleontological resource management. A Geologic Resource Monitoring Manual published by the Geological Society of America and NPS Geologic Resources Division (GRD) includes a chapter on paleontological resource monitoring (Santucci et al. 2009). Santucci and Koch (2003) also present information on paleontological resource monitoring.

NPS Paleontological Resource Laws and Policy

The following material is reproduced in large part from Henkel et al. (2015):

National Park Service Policy

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

National Park Service 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.*"

Paleontological Resources Protection Act (PRPA)

(Public Law 111-011, Omnibus Public Land Management Act of 2009, Subtitle D)

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.

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

NPS Management Policies 2006

NPS Management Policies 2006 include direction for preserving and protecting cultural resources, natural resources, processes, systems, and values. 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. 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. National Park Service management policies state that "*management actions will be taken to prevent illegal collecting [of fossil resources] and may be taken to prevent damage from natural processes such as erosion. Protection may include construction of shelters over specimens for interpretation* in situ, *stabilization in the field [which can include reburial] or collection, preparation, and placement of specimens in museum collections. The locality and geologic data associated with a specimen will be adequately documented at the time of specimen collection. Protection may also include, where necessary, the salvage collection of threatened specimens that are scientifically significant*."

NPS Director's Order-77, Paleontological Resources Management

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

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

No action: If no action is taken, the fossils will be left to erode naturally over time or may be exposed to intentional or unintentional vandalism or theft.

Inventory: All potential fossil sites will be documented using a Paleontological Site Form and will be entered into the park GIS database. Associated stratigraphic and depositional environment information will be collected for each site. A preliminary taxa 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.

Periodic Monitoring: Paleontological sites will be examined periodically to determine if conditions have changed to such an extent that additional management actions are warranted. The site monitoring frequency will depend on locality-specific characteristics such as rates of sediment erosion, abundance or rarity of fossils, and proximity to visitor use areas. Areas of high erosion which also have a high potential for producing significant specimens will be examined for new sites. Periodic resurvey may be coordinated in conjunction with the monitoring of established sites. Photographic records should be kept so that changes can be more easily ascertained.

Stabilization and reburial: Significant specimens which cannot be immediately collected may be stabilized using appropriate consolidants (e.g. Paraloid B-72) and reburied. Reburial slows but does not stop the destruction of a fossil by erosion. Therefore, this mitigation measure is only temporary.

Surface Collection or Excavation: Partial or complete removal of any or all fossils present on the surface or within the substrate may be necessary to mitigate a threat. Many fossils cannot be fully identified without being removed from the ground and properly prepared. All collected fossils must be curated within an NPS approved repository. The Chaco Museum Collection has been identified as the approved repository.

Closure: An area containing fossils may be temporarily or permanently closed to the public to protect the fossil resources. Closures may also include visible but roped-off areas. Most fossil rich areas at CHCU are already closed to the public. Access to closed areas may be approved through the development of ranger-guided hikes.

Patrols: The scientific community and the public expect the NPS to protect its paleontological resources from vandalism and theft. Increased patrols can prevent and/or reduce theft and vandalism of all park resources. Patrols can include additional law enforcement patrols, roving rangers, or a volunteer site steward program.

National Park Service paleontological resource monitoring strategies were developed by Santucci et al. (2009). Clites and Santucci (2012) outline additional recommendations for effective monitoring of paleontological resources incorporating the measurement and evaluation of the factors stated below:

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

Rates of Erosion Studies: These studies require evaluation of lithology, slope degree, percent vegetation cover, and rates of denudation around established benchmarks. If a park does not have this information, there may opportunities to set up joint projects, because erosion affects more than just paleontological resources.

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

Paleontological Research Permits

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/).

Foundation Documents and Resource Stewardship Strategies

Foundation documents and Resource Stewardship Strategies are two types of park planning documents that may contain and reference paleontological resource information.

A Foundation Document is intended to provide basic guidance about a park for planning and management. It briefly describes a given park and its purpose, significance, fundamental resources and values, other importance resources and values, and interpretive themes. Mandates and commitments are also identified, and the state of planning is assessed. The CHCU Foundation Document (National Park Service 2015) identifies paleontological resources as "Other Important Resources and Values". These resources are important in the operation and management of the park and may not be fundamental to the purpose of the park but warrant special consideration in park planning.

A Resource Stewardship Strategy (RSS) is a strategic plan intended to help park managers achieve and maintain desired resource conditions over time. It offers specific information on the current state of resources and planning, management priorities, and management goals over various time frames. A RSS for CHCU is under development as of March 2019, and scoping is planned for calendar year 2019.

NPS Paleontology Archives

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

Geologic Maps

Geologic maps are one of the foundational elements of a paleontological resource management program. Knowing which sedimentary rocks and deposits underlie a park and where they are exposed are essential for understanding the park's paleontological resources. Ideally, geologic bedrock maps at a scale of 1:24,000 or finer will exist for parks located in the 48 contiguous states (maps for areas in Alaska tend to be coarser). The GRD has been working to compile geologic maps for parks with significant natural resources, and is making them available in GIS formats. Whenever possible, page-sized geologic maps derived from the GRD's files are included in paleontological resource inventory reports for reference, but park staff is encouraged to download the GRD's source files from IRMA. The source files can be explored in much greater detail and incorporated into the park GIS database.

Geologic Maps for CHCU are available at https://www.nps.gov/articles/nps-geodiversity-atlas-chaco-culture-national-historical-park-new-mexico.htm#gri.

Paleontological Resource Potential Maps

Paleontological resource potential maps are also included in this inventory report (Appendix D). These maps show the distribution of geologic units within a park based on whether they are known to have yielded fossils within the park, have not yielded fossils within the park but are fossiliferous elsewhere, or have not yielded fossils and are practically unfossiliferous (most igneous and metamorphic units). These maps give a quick indication of areas with elevated potential for fossil discovery, which in turn can provide suggestions for areas to survey or monitor, or areas where the discovery of fossils may be of concern during work that disturbs the ground (road work, building construction, etc.). Most of the geologic formations in the park have a high potential for containing paleontological resources. Of course, this does not mean that less fossiliferous units contain fewer sensitive resources, as these units (Quaternary deposits) have a high potential for containing archeological resources.

E&R Files

E&R ("Examination and Report on Referred Fossils") files are unpublished internal USGS documents. For more than a century, USGS paleontologists identified and prepared informal reports on fossils sent to the survey by other geologists, for example to establish the relative age of a formation or to help correlate beds. The system was eventually formalized as a two-part process including a form sent by the transmitting geologist and a reply by the survey geologist. Sometimes the fossil identifications were incorporated into publications, but in many cases this information is unpublished. These E&R files include documentation of numerous fossil localities within current NPS areas, usually predating the establishment of the NPS unit in question and frequently unpublished or previously unrecognized. Extensive access to the original files was granted to the NPS by the USGS beginning in 2014 (Santucci et al. 2014).

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Appendix A: Paleontological Species Lists

Paleontological species lists are presented in the following tables:

Appendix Table A-1: Cretaceous fossil taxa from CHCU

Table A-1 documents the Cretaceous fossil taxa reported from CHCU in stratigraphic context as reported in the literature, in museum collections, and through personal observations. The rows are organized systematically, placing taxa of the same broad groups together, with gray rows providing summaries of each group. The columns are organized by formation, which are presented in ascending order (oldest to youngest) left to right. The columns also include the taxon (first column) and references (last column; included in "Literature Cited" above). If a taxon is present in a given formation at a locality that can be placed within CHCU, that cell is marked "Y"; if there is some question about the formation or whether the locality is within CHCU, the cell is marked "?". A null record is marked "–".

It is likely that some of the genera and species cited here are actually the result of different authors identifying the same forms using different names. Some of the taxa identified to the species level are now classified under different genera. Faced with a choice between changing the handful of species-level entries while leaving the identified genera alone (and presumably at least some of them are also outdated), or using the original terminology for all taxa, it was decided to use the original terminology in this table.

The data is derived from paleontological studies summarized by Reeside and Knowlton (1924), Vann (1931), Wood (1940), Siemers and King (1974), Mytton and Schneider (1987), and Varela (2013a, 2013b). Taxa with "[new]" in the reference column were documented during the NPS Paleontological Surveys from 2005–2018, are previously unpublished, and may be tentative identifications. Cretaceous flora and fauna are represented by more than 140 different species.

Kpc = Pictured Cliffs Sandstone
Kl = Lewis Shale
Kch = Cliff House Sandstone
Kmf = Menefee Formation
Kc = Crevasse Canyon Sandstone

Appendix Table A-1. Cretaceous fossil taxa reported from CHCU in stratigraphic context. References are provided where appropriate. If a taxon is present in a given formation at a locality that can be placed within CHCU, that cell is marked "Y" (in blue); if there is some question about the formation or whether the locality is within CHCU, the cell is marked "?" (in yellow). A null record is marked "–".

Taxon	Kc	Kmf	Kch	Kl	Kpc	References
FOSSIL PLANTS	**–**	**Y**	**Y**	**Y**	**Y**	**–**
Araucarioxylon sp.	–	Y	–	–	–	L. Boucher (pers. comm.)
Cupressinoxylon sp.	–	Y	–	–	–	L. Boucher (pers. comm.)
Laurinoxylon sp.	–	Y	–	–	–	L. Boucher (pers. comm.)
Paraphyllanthoxylon sp.	–	Y	–	–	–	L. Boucher (pers. comm.)

Taxon	Kc	Kmf	Kch	Kl	Kpc	References
Anacardiaceae? undetermined	–	Y	–	–	–	L. Boucher (pers. comm.)
Saptoaceae undetermined	–	Y	–	–	–	L. Boucher (pers. comm.)
Podocarpaceae? undetermined	–	Y	–	–	–	L. Boucher (pers. comm.)
Pinopsida undetermined	–	Y	Y	?	?	L. Boucher (pers. comm.)
Magnoliopsida undetermined	–	Y	Y	?	?	L. Boucher (pers. comm.)
Unclassified wood	–	Y	Y	Y	Y	Siemers and King 1974, Wood 1940
Carbonaceous debris and coal	–	Y	–	–	–	Siemers and King 1974, Mytton and Schneider 1987
FOSSIL INVERTEBRATES	**–**	**Y**	**Y**	**Y**	**Y**	**–**
Phylum Mollusca	**–**	**Y**	**Y**	**Y**	**Y**	**–**
Mollusca: Class Bivalvia (clams, oysters, etc.)	**–**	**Y**	**Y**	**Y**	**Y**	**–**
Anadara? sp.	–	–	Y	–	–	Siemers and King 1974
Anomia sp.	–	–	Y	–	–	Reeside and Knowlton 1924
Arcopagella n. sp.	–	–	Y	–	–	Siemers and King 1974
Astarte? sp.	–	–	Y	–	–	Reeside and Knowlton 1924
Cardium n. sp. I	–	–	Y	–	–	Vann 1931
Cardium (*Ethmocardium*) sp. undescribed	–	–	Y	–	–	Reeside and Knowlton 1924, Wood 1940
Corbula sp. undescribed	–	–	Y	–	–	Reeside and Knowlton 1924
Crassostrea subtrigonalis	–	–	Y	–	–	Siemers and King 1974
Cymbophora aff. C. *alta*	–	–	Y	–	–	Siemers and King 1974
?*Cymbophora simpsonensis*	–	–	Y	–	–	Siemers and King 1974
Cyprina n. sp. I	–	–	Y	–	–	Vann 1931
Cyrena securis	–	–	Y	–	–	Vann 1931
Cyprimeria? sp.	–	–	Y	–	–	Wood 1940
Donax n. sp. I	–	–	Y	–	–	Vann 1931
Donax? sp. undescribed	–	–	Y	–	–	Reeside and Knowlton 1924
Exogyra aff. *E. ponderosa*	–	–	Y	–	–	Siemers and King 1974
Granocardium (*Ethmocardium*) *whitei*	–	–	Y	–	–	Siemers and King 1974
cf. *Granocardium* sp.	–	–	Y	–	–	[new]
Gouldia subelliptica	–	–	Y	–	–	Vann 1931
Hercodon n. sp.	–	–	Y	–	–	Siemers and King 1974
Idonearca n. sp.	–	–	Y	–	–	Siemers and King 1974
Inoceramus barabini	–	–	Y	–	–	Reeside and Knowlton 1924, Vann 1931, Siemers and King 1974, Wood 1940
Inoceramus pertenuis	–	–	Y	–	–	Siemers and King 1974
Inoceramus sagensis	–	–	Y	–	–	Siemers and King 1974
Inoceramus tenuilineatus	–	–	Y	–	–	Siemers and King 1974
Inoceramus vanuxemi	–	–	Y	–	–	Siemers and King 1974
Inoceramus cf. *I. simpsoni*	–	–	Y	–	–	Siemers and King 1974
Inoceramus spp. undetermined	–	–	Y	–	–	Vann 1931, Wood 1940
Mactra formosa	–	–	Y	–	–	Reeside and Knowlton 1924
Mactra warrenana	–	–	Y	–	–	Reeside and Knowlton 1924

Taxon	Kc	Kmf	Kch	Kl	Kpc	References
Mactra sp. undetermined	–	–	Y	–	–	Wood 1940
Nucula? sp.	–	–	Y	–	–	Siemers and King 1974
Ostrea plumosa	–	–	Y	–	–	Siemers and King 1974
Ostrea translucida	–	–	Y	–	–	Vann 1931
Ostrea sp.	–	–	Y	–	–	Reeside and Knowlton 1924, Wood 1940
Oxytoma sp.	–	–	Y	–	–	Siemers and King 1974
Pteria nebrascana	–	–	Y	–	–	Reeside and Knowlton 1924
Parmicorbula? sp.	–	–	Y	–	–	Siemers and King 1974
Parvilucina? aff. ?*P. linearia*	–	–	Y	–	–	Siemers and King 1974
Protodonax chloropagus	–	–	Y	–	–	Siemers and King 1974
Protodonax exaquilius	–	–	Y	–	–	Siemers and King 1974
Protodonax n. sp. A	–	–	Y	–	–	Siemers and King 1974
Protodonax n. sp. B	–	–	Y	–	–	Siemers and King 1974
Pteria n. sp. I	–	–	Y	–	–	Vann 1931
Pycnodonte (*Phygraea*) ex. Gr. *P.* (*P.*) *vesicularis*	–	–	Y	–	–	Siemers and King 1974
Tancredia? sp. undescribed	–	–	Y	–	–	Wood 1940
Tellina equilateralis	–	–	Y	–	–	Vann 1931
Tellina sp. undescribed	–	–	Y	–	–	Reeside and Knowlton 1924
Tellinimera n. sp.	–	–	Y	–	–	Siemers and King 1974
Yoldia evansi	–	–	Y	–	–	Reeside and Knowlton 1924, Vann 1931
Yoldia? sp. undescribed	–	–	Y	–	–	Wood 1940
Veneridae undetermined	–	–	Y	–	–	Siemers and King 1974
Bivalvia n. genus undescribed	–	–	Y	–	–	Vann 1931
Bivalvia undetermined	–	Y	–	Y	Y	[new]
Mollusca: Class Cephalopoda (squids, octopuses,* Nautilus*, etc.)	**–**	**–**	**Y**	**–**	**–**	**–**
Class Cephalopoda: Subclass Ammonidea (ammonites)	**–**	**–**	**Y**	**–**	**–**	**–**
Baculites anceps	–	–	Y	–	–	Vann 1931
Baculites perplexus	–	–	Y	–	–	Siemers and King 1974
Baculites sp. undescribed	–	–	Y	–	–	Wood 1940, Varela 2013a, 2013b
Placenticeras intercalare	–	–	Y	–	–	Reeside and Knowlton 1924, Vann 1931, Siemers and King 1974
Placenticeras sp.	–	–	Y	–	–	Varela 2013a, 2013b
Mollusca: Class Gastropoda (snails)	**–**	**–**	**Y**	**Y**	**–**	**–**
Acteon sp.	–	–	Y	–	–	Reeside and Knowlton 1924
Anchura sp.	–	–	Y	–	–	Reeside and Knowlton 1924
Anisomyon borealis	–	–	Y	–	–	Vann 1931, Siemers and King 1974
Anisomyon centrale	–	–	Y	–	–	Vann 1931
Anisomyon shumardi	–	–	Y	–	–	Vann 1931
Anisomyon cf. *A. sexsulcatus*	–	–	Y	–	–	Siemers and King 1974

Taxon	Kc	Kmf	Kch	Kl	Kpc	References
Anisomyon cf. *A. shumardi*	–	–	Y	–	–	Reeside and Knowlton 1924, Wood 1940
Anisomyon n. sp. I	–	–	Y	–	–	Vann 1931
Banis cf. *B. siniformis*	–	–	Y	–	–	Siemers and King 1974
Cerithiopsis n. sp. I	–	–	Y	–	–	Vann 1931
Chemnitzia cerithiformis?	–	–	Y	–	–	Reeside and Knowlton 1924
Chemnitzia? sp.	–	–	Y	–	–	Wood 1940
Euspira obliquata	–	–	Y	–	–	Siemers and King 1974
Fusus or *Pyrifusus* or *Fasciolaria* sp	–	–	Y	–	–	Wood, 1940
Gyrodes aff. *G. petrosal*	–	–	Y	–	–	Reeside and Knowlton 1924
Gyrodes n. sp. I	–	–	Y	–	–	Vann 1931
Gyrodes n. sp. II	–	–	Y	–	–	Vann 1931, Wood 1940
Haminea subcylindrica	–	–	Y	–	–	Reeside and Knowlton 1924
Holospira sp.	–	–	Y	–	–	Siemers and King 1974
Lunatia concinna	–	–	Y	–	–	Vann 1931
Lunatia concinna?	–	–	Y	–	–	Reeside and Knowlton 1924
Lunatia occidentalis	–	–	Y	–	–	Vann 1931
Lunatia subcrassa	–	–	Y	–	–	Vann 1931
Lunatia subcrassa?	–	–	Y	–	–	Reeside and Knowlton 1924
Lunatia sp. undetermined	–	–	Y	–	–	Wood 1940
Mesalia kansasensis	–	–	Y	–	–	Vann 1931
Morea? sp.	–	–	Y	–	–	Reeside and Knowlton 1924
Oreohelix? sp.	–	–	Y	–	–	Siemers and King 1974
Pachymelania? sp.	–	–	Y	–	–	Siemers and King 1974
Parafusus sp.	–	–	Y	–	–	Siemers and King 1974
Pseudomelania? sp.	–	–	Y	–	–	Wood 1940
Solarium n. sp. I	–	–	Y	–	–	Vann 1931
Solarium n. sp. II	–	–	Y	–	–	Vann 1931, Wood 1940
Spironema cf. *S. perryi*	–	–	Y	–	–	Siemers and King 1974
Trachytriton? sp.	–	–	Y	–	–	Siemers and King 1974
Velatella? sp.	–	–	Y	–	–	Siemers and King 1974
Volutoderma spp.	–	–	Y	–	–	Reeside and Knowlton 1924, Wood 1940
Volutomorpha novamexicana	–	–	Y	–	–	Vann 1931
Volutomorpha retifera	–	–	Y	–	–	Siemers and King 1974
Volutomorpha n. sp. I	–	–	Y	–	–	Vann 1931
Cymatiidae undetermined	–	–	Y	–	–	Siemers and King 1974
Gastropoda undetermined	–	–	–	Y	–	[new]
Phylum Echinodermata (sea stars, sea urchins, sea lilies, etc.)	**–**	**–**	**Y**	**–**	**–**	**–**
Echinodermata: Class Echinoidea (sea urchins)	**–**	**–**	**Y**	**–**	**–**	**–**
Hardouinia taylori	–	–	Y	–	–	Siemers and King 1974
FOSSIL VERTEBRATES	**–**	**Y**	**Y**	**Y**	**Y**	**–**
Class Chondrichthyes	**–**	**–**	**Y**	**–**	**–**	**–**

Taxon	**Kc**	**Kmf**	**Kch**	**Kl**	**Kpc**	**References**
Archaeolamna kopingensis	–	–	Y	–	–	Varela 2013a, 2013b
Scapanorhynchus texanus	–	–	Y	–	–	Varela 2013a, 2013b
cf. Serratolamna, sp.	–	–	Y	–	–	Varela 2013a, 2013b
Squalicorax kaupi	–	–	Y	–	–	Varela 2013a, 2013b
Squalicorax pristodontus	–	–	Y	–	–	[new]
Lamniformes undetermined	–	–	Y	–	–	Vann 1931, Wood 1940, Siemers and King 1974, Varela 2013a, 2013b
Class Osteichthyes	**–**	**–**	**Y**	**–**	**–**	**–**
Paraclupeidae?	–	–	Y	–	–	CHCU 79452 (Chaco Museum Coll.)
Osteichthyes undetermined	–	–	Y	–	–	Varela 2013a, 2013b
Class Reptilia	**–**	**Y**	**Y**	**Y**	**Y**	**–**
Elochelys cf. *E. perfecta*	–	Y	–	–	–	CHCU 81269 (Chaco Museum Coll.), Lichtig and Lucas 2015
Trionychidae undetermined	–	Y	–	–	–	Varela 2013a, 2013b
Testudines undetermined	–	Y	Y	–	Y	Varela 2013a, 2013b
Mosasauridae undetermined	–	–	Y	Y	?	Varela 2013a, 2013b
Prognathodon overtoni	–	–	Y	–	–	CHCU 48885 (Chaco Museum Coll.)
Saurischia undetermined	–	Y	–	–	–	Varela 2013a, 2013b
Ornithischia undetermined	–	Y	–	–	–	Varela 2013a, 2013b
?Crocodilia undetermined	–	Y	–	–	–	Varela 2013a, 2013b
?Plesiosauria undetermined	–	–	Y	–	–	Varela 2013a, 2013b
Other vertebrates	**–**	**–**	**Y**	**–**	**–**	**–**
Testudines or Aves undetermined	–	–	Y	–	–	[new]
Vertebrata undetermined	–	–	Y	–	–	Siemers and King 1974
ICHNOFOSSILS	**Y**	**Y**	**Y**	**Y**	**Y**	**–**
Plant trace fossils	**–**	**Y**	**Y**	**–**	**–**	**–**
Reed? molds	–	Y	Y	–	–	Siemers and King 1974
Invertebrate trace fossils	**Y**	**Y**	**Y**	**Y**	**Y**	**–**
Chondrites	–	–	Y	–	–	Siemers and King 1974
Gyrochorte	–	–	Y	–	–	Siemers and King 1974
Ophiomorpha (including “*Halymenites major*”)	–	–	Y	–	Y	Vann 1931, Wood 1940, Siemers and King 1974, Mytton and Schneider 1987
Teredolithus	–	–	Y	–	–	Siemers and King 1974
Thalassinoides	–	–	Y	–	–	Siemers and King 1974
Damp wood termite burrows in wood	–	Y	–	–	–	Varela 2013a, 2013b
Clionid sponge borings	–	–	Y	–	–	Siemers and King 1974
Polydorid worm borings	–	–	Y	–	–	Siemers and King 1974
General bioturbation	–	–	Y	–	–	Mytton and Schneider 1987
Unspecified trace fossils, presumed invertebrate	Y	–	–	Y	–	Tweet et al. 2009

Appendix Table A-2: Quaternary fossil taxa from CHCU

Table A-2 documents taxonomic information on Pleistocene and Holocene fossils identified within CHCU boundaries. These taxa were identified over many years of packrat midden excavations and include palynological, macrobotanical, and faunal analyses from archeological investigations. Vertebrate species may include exotic or now extinct species related to human transport. Therefore, it should not be assumed that every species listed is a native resident of Chaco Canyon. The data is derived from many studies of packrat midden and other archeological excavations summarized by Drake (1948), Hall (1977, 1980, 1988), Anderson (1980), Betancourt and Devender (1981), Gillespie (1982), Akins (1985), Betancourt (1990), Harris (1993), and Smith and Betancourt (1998). Many species listed are current (modern) residents of Chaco Canyon. Most of the vertebrate species identifications come from analyses of prehistoric faunal utilization in Chaco Canyon Basketmaker III through Pueblo III sites (late Holocene, Akins 1985) and vertebrate faunal analyses of Atlatl Cave (early to late Holocene, Gillespie 1982). Additional data comes from the USGS/NOAA (2007) packrat midden database. Midden sites come from Atlatl Cave, Chacra Mesa, Casa Chiquita, Cly's Canyon, Gallo Wash, Indian Ruins, Mockingbird Canyon, Sheep Camp Canyon (outside CHCU), and Werito's Rincon (Tweet et al. 2009).

Quaternary flora and fauna within CHCU are represented by over 250 different species.

Pl = Pleistocene
EHo = early Holocene (11650 – 8200 YBP)
MHo = middle Holocene (8200 – 4200 YBP)
LHo = late Holocene (4200 – 1050 YBP)
GQ = general Quaternary
YBP = Years Before Present

Appendix Table A-2. Quaternary fossil taxa reported from CHCU in stratigraphic context. References are provided where appropriate. If a taxon is present the cell is marked "Y" (in blue); A null record is marked "–".

Taxon	PI	EHo	MHo	LHo	GQ	References
FOSSIL PLANTS	**Y**	**Y**	**Y**	**Y**	**Y**	**–**
Phylum Gnetophyta	**–**	**–**	**Y**	**Y**	**–**	**–**
Ephedra torreyana	–	–	Y	Y	–	USGS/NOAA Midden DB
Ephedra viridis	–	–	–	Y	–	USGS/NOAA Midden DB
Ephedra sp.	–	–	–	Y	–	USGS/NOAA Midden DB
Phylum Pinophyta (conifers)	**–**	**Y**	**Y**	**Y**	**–**	**–**
Juniperus monosperma	–	Y	Y	Y	–	Gillespie 1982
Juniperus cf. *monosperma*	–	–	Y	Y	–	USGS/NOAA Midden DB
Juniperus scopulorum	–	Y	Y	–	–	Gillespie 1982
Picea pungens	–	Y	–	–	–	USGS/NOAA Midden DB
Picea sp.	–	Y	–	–	–	Gillespie 1982
Pinus edulis	–	Y	Y	Y	–	Gillespie 1982
Pinus flexilis	–	Y	–	–	–	Gillespie 1982
Pinus ponderosa	–	Y	Y	Y	–	Gillespie 1982
Pseudotsuga menziesii	–	Y	Y	Y	–	Gillespie 1982
Phylum Angiospermae (flowering plants)	**–**	**Y**	**Y**	**Y**	**–**	**–**
Allionia incarnata	–	–	?	Y	–	USGS/NOAA Midden DB
Ambrosia acanthicarpa	–	–	Y	Y	–	USGS/NOAA Midden DB
Artemisia frigida	–	Y	–	Y	–	USGS/NOAA Midden DB
Artemisia ludoviciana	–	Y	Y	Y	–	USGS/NOAA Midden DB
Artemisia tridentata-type	–	Y	Y	Y	–	USGS/NOAA Midden DB
Astragalus sp.	–	Y	–	Y	–	USGS/NOAA Midden DB
Atriplex canescens	–	Y	Y	Y	–	USGS/NOAA Midden DB
Atriplex confertifolia	–	–	–	Y	–	USGS/NOAA Midden DB
Berberis fendleri	–	Y	Y	–	–	USGS/NOAA Midden DB
Boerhavia sp.	–	–	?	Y	–	USGS/NOAA Midden DB
Brickellia brachyphylla	–	–	–	Y	–	USGS/NOAA Midden DB
Brickellia scabra	–	–	–	Y	–	USGS/NOAA Midden DB
Brickellia sp.	–	–	–	Y	–	USGS/NOAA Midden DB
Celtis reticulata	–	–	–	Y	–	USGS/NOAA Midden DB
Ceratoides lanata	–	–	Y	Y	–	USGS/NOAA Midden DB
Chenopodium berlandieri	–	–	Y	Y	–	USGS/NOAA Midden DB
Chenopodium sp. A	–	Y	–	Y	–	USGS/NOAA Midden DB
Chenopodium sp. B	–	Y	–	–	–	USGS/NOAA Midden DB
Chrysanthemum-type	–	–	–	Y	–	USGS/NOAA Midden DB
Chrysothamnus greenei	–	–	–	Y	–	USGS/NOAA Midden DB
Chrysothamnus nauseosus ssp. *bigelovii*	–	Y	Y	Y	–	USGS/NOAA Midden DB
Chrysothamnus nauseosus cf. ssp. *leiospermus*	–	–	–	Y	–	USGS/NOAA Midden DB
† *Chrysothamnus pulchelloides*	–	–	–	Y	–	Anderson 1980
Chrysothamnus sp.	–	–	–	Y	–	USGS/NOAA Midden DB
Cirsium sp.	–	–	–	Y	–	USGS/NOAA Midden DB

Taxon	Pl	EHo	MHo	LHo	GQ	References
Cleome serrulata	–	–	–	Y	–	USGS/NOAA Midden DB
Corispermum sp.	–	Y	Y	Y	–	USGS/NOAA Midden DB
Cowania mexicana	–	–	–	Y	–	USGS/NOAA Midden DB
Cryptantha flava-type	–	–	–	Y	–	USGS/NOAA Midden DB
Cryptantha sp.	–	Y	–	Y	–	USGS/NOAA Midden DB
cf. *Dalea* sp.	–	–	–	Y	–	USGS/NOAA Midden DB
Dithyrea wislizeni	–	–	Y	Y	–	USGS/NOAA Midden DB
Echinocereus sp.	–	Y	–	Y	–	USGS/NOAA Midden DB
Eriogonum alatum	–	–	–	Y	–	USGS/NOAA Midden DB
Euphorbia sp.	–	–	–	Y	–	USGS/NOAA Midden DB
Forestiera neomexicana	–	–	Y	Y	–	USGS/NOAA Midden DB
Grindelia sp.	–	–	–	Y	–	USGS/NOAA Midden DB
Gutierrezia sp.	–	Y	Y	Y	–	USGS/NOAA Midden DB
Hedeoma sp.	–	–	–	Y	–	USGS/NOAA Midden DB
Helianthus sp.	–	Y	Y	Y	–	USGS/NOAA Midden DB
Heterotheca sp.	–	Y	–	Y	–	USGS/NOAA Midden DB
Ipomopsis sp.	–	Y	–	–	–	USGS/NOAA Midden DB
Kallstroemia sp.	–	–	Y	Y	–	USGS/NOAA Midden DB
Lappula redowskii	–	Y	Y	Y	–	USGS/NOAA Midden DB
Lesquerella sp.	–	Y	–	Y	–	USGS/NOAA Midden DB
Lithospermum sp.	–	Y	–	Y	–	USGS/NOAA Midden DB
Lycium pallidum	–	–	–	Y	–	USGS/NOAA Midden DB
Mentzelia sp.	–	–	Y	Y	–	USGS/NOAA Midden DB
Mirabilis multiflora	–	–	Y	Y	–	USGS/NOAA Midden DB
Mirabilis oxybaphoides	–	–	–	Y	–	USGS/NOAA Midden DB
cf. *Oenothera* sp.	–	–	–	Y	–	USGS/NOAA Midden DB
Opuntia polyacantha	–	Y	Y	Y	–	USGS/NOAA Midden DB
Opuntia whipplei	–	Y	Y	Y	–	USGS/NOAA Midden DB
Opuntia sp.	–	Y	–	Y	–	USGS/NOAA Midden DB
Oryzopsis hymenoides	–	–	Y	Y	–	USGS/NOAA Midden DB
Parthenocissus/*Vitis*	–	Y	–	–	–	USGS/NOAA Midden DB
Penstemon sp.	–	Y	Y	Y	–	USGS/NOAA Midden DB
cf. *Phlox* sp.	–	Y	Y	Y	–	USGS/NOAA Midden DB
Physalis sp.	–	–	–	Y	–	USGS/NOAA Midden DB
Polygonum sp.	–	–	Y	Y	–	USGS/NOAA Midden DB
Prunus virginiana	–	–	–	Y	–	USGS/NOAA Midden DB
Rhus aromatica	–	Y	Y	Y	–	USGS/NOAA Midden DB
Rhus trilobata	–	Y	–	Y	–	USGS/NOAA Midden DB
Rosa sp.	–	Y	–	–	–	USGS/NOAA Midden DB
Sarcobatus vermiculatus	–	–	–	Y	–	USGS/NOAA Midden DB
Sclerocactus mesae-verdae	–	Y	–	–	–	Betancourt 1990
cf. *Sclerocactus mesae-verdae*	–	Y	–	–	–	USGS/NOAA Midden DB
Sphaeralcea sp.	–	–	–	Y	–	USGS/NOAA Midden DB
Stipa neomexicana	–	–	–	Y	–	USGS/NOAA Midden DB

Taxon	**Pl**	**EHo**	**MHo**	**LHo**	**GQ**	**References**
Thuidium abietinum	–	Y	–	–	–	USGS/NOAA Midden DB
Xanthium strumarium	–	–	–	Y	–	USGS/NOAA Midden DB
Yucca angustifolia	–	Y	Y	Y	–	USGS/NOAA Midden DB
Yucca angustissima	–	Y	–	–	–	Betancourt 1990
Yucca sp.	–	Y	–	–	–	USGS/NOAA Midden DB
Palynomorphs	**–**	**Y**	**Y**	**Y**	**–**	**–**
Alnus	–	–	Y	Y	–	Hall 1977
Ambrosia-type	–	Y	Y	Y	–	Hall 1977, 1988
Artemisia	–	Y	Y	Y	–	Hall 1977, 1988
Aster-type	–	Y	Y	Y	–	Hall 1988
Cactaceae	–	–	Y	Y	–	Hall 1977
Chenopod-*Amaranthus* (including *Chenopodium*-type of Hall 1988)	–	Y	Y	Y	–	Hall 1977, 1988
Other Compositae	–	–	Y	Y	–	Hall 1977
Cruciferae	–	–	Y	Y	–	Hall 1977
Cyperaceae	–	Y	Y	Y	–	Hall 1977, 1988
Ephedra	–	Y	Y	Y	–	Hall 1977, 1988
Eriogonum	–	–	Y	Y	–	Hall 1977
Gramineae	–	Y	Y	Y	–	Hall 1977, 1988
Juniperus	–	Y	Y	Y	–	Hall 1977, 1988
Liguliflorae	–	–	Y	Y	–	Hall 1977
Malvaceae	–	–	Y	Y	–	Hall 1977
Onograceae	–	–	Y	Y	–	Hall 1977
Picea	–	Y	Y	Y	–	Hall 1977, 1988
Pinus	–	Y	Y	Y	–	Hall 1977, 1988
Polygonaceae	–	–	Y	Y	–	Hall 1977
cf. *Populus*	–	–	Y	Y	–	Hall 1977
Pseudotsuga	–	Y	Y	Y	–	Hall 1977, 1988
Quercus	–	Y	Y	Y	–	Hall 1977, 1988
Salix	–	–	Y	Y	–	Hall 1977
Sarcobatus	–	Y	Y	Y	–	Hall 1977, 1988
Zea	–	–	Y	Y	–	Hall 1977
Other plants	**Y**	**–**	**Y**	**Y**	**Y**	**–**
Charcoal	–	–	Y	Y	–	Hall 1977
Miscellaneous plant fragments	–	–	–	–	Y	Betancourt and Van Devender 1981
Petrified wood (reworked?)	Y	–	–	–	–	Hall 1977
Reworked Upper Cretaceous to potentially Paleocene palynomorphs (megaspores, spores, pollen, and dinoflagellates; not all are plants, but are included here for convenience)	–	–	–	–	Y	Hall 1977
FOSSIL INVERTEBRATES	**Y**	**–**	**Y**	**Y**	**Y**	**–**
Phylum Mollusca	**Y**	**–**	**Y**	**Y**	**Y**	**–**
Mollusca: Class Gastropoda (snails)	**Y**	**–**	**Y**	**Y**	**Y**	**–**
Fossaria parva	–	–	–	–	Y	Drake 1948, Hall 1980

Taxon	PI	EHo	MHo	LHo	GQ	References
Gastrocopta pellucida hordeacella	–	–	Y	Y	Y	Drake 1948, Hall 1980
Gyraulus circumstriatus	–	–	–	–	Y	Drake 1948, Hall 1980
Gyraulus sp.	–	–	Y	Y	–	Hall 1980
Hawaiia miniscula	–	–	Y	Y	–	Hall 1980
Hawaiia miniscula form *alachuana*	–	–	Y	–	Y	Drake 1948, Hall 1980
Helisoma tenue cf. *sinuosum*	–	–	–	–	Y	Drake 1948, Hall 1980
Pupilla cf. *blandii*	–	–	–	–	Y	Drake 1948, Hall 1980
Pupilla hebes	–	–	–	–	Y	Drake 1948, Hall 1980
Pupoides albilabris	–	–	–	–	Y	Drake 1948, Hall 1980
Pupoides hordaceus	–	–	Y	Y	Y	Drake 1948, Hall 1980
Stagnicola cockerelli	–	–	Y	Y	Y	Drake 1948, Hall 1980
Succinea grosvenorii	–	–	–	–	Y	Drake 1948, Hall 1980
Succinea sp.	Y	–	Y	Y	–	Hall 1980
Vallonia cyclophorella	–	–	Y	Y	Y	Drake 1948, Hall 1980
Vallonia gracilicosta	–	–	Y	–	Y	Drake 1948, Hall 1980
Vertigo ovata	–	–	–	–	Y	Drake 1948, Hall 1980
FOSSIL VERTEBRATES	**Y**	**Y**	**Y**	**Y**	**Y**	**–**
Class Chondrichthyes	**–**	**–**	**–**	**Y**	**–**	**–**
Lamnidae sp. (mackerel shark, non-fossil)	–	–	–	Y	–	Akins 1985
Class Osteichthyes	**–**	**–**	**–**	**Y**	**–**	**–**
Gila sp. (unidentified bonytail)	–	–	–	Y	–	Akins 1985
Lepisosteus osseus (long nosed gar)	–	–	–	Y	–	Akins 1985
Lepisosteus sp.(unidentified gar)	–	–	–	Y	–	Akins 1985
Class Amphibia	**–**	**Y**	**Y**	**Y**	**–**	**–**
Ambystoma tigrinum (tiger salamander)	–	Y	–	Y	–	Gillespie 1982
Bufo sp.(unidentified toad)	–	–	–	Y	–	Akins 1985
Bufo punctatus (red-spotted toad)	–	–	Y	Y	–	Gillespie 1982
Bufo woodhousii (Woodhouse's toad)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Scaphiopus couchii (Couch's spadefoot toad)	–	–	Y	Y	–	Gillespie 1982
*Spea bombifons (*plain spadefoot toad)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Spea multiplicata (western spadefoot toad)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Spea sp. (unidentified spadefoot toad)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Class Reptilia	**–**	**–**	**Y**	**Y**	**Y**	**–**
Arizona elegans (glossy snake)	–	–	–	–	Y	Gillespie 1982
Cnemidophorus velox (plateau whiptail lizard)	–	–	–	Y	–	Akins 1985
Cnemidophorus sp. (unidentified whiptail lizard)	–	–	Y	–	–	Gillespie 1982
Crotalus cf. *viridis* (prairie rattlesnake)	–	–	–	Y	–	Gillespie 1982
Crotaphytus collaris (collared lizard)	–	–	–	Y	–	Gillespie 1982
Colubridae sp. (unidentified snake)	–	–	–	Y	–	Akins 1985
Heterodon nasicus (western hognose snake)	–	–	Y	Y	–	Gillespie 1982
Hypsiglena torquata (night snake)	–	–	–	–	Y	Gillespie 1982
cf. Masticophus sp. or *Coluber constrictor* (coachwhip or racer)	–	–	Y	Y	–	Gillespie 1982

Taxon	PI	EHo	MHo	LHo	GQ	References
Phrynosoma douglasii (mountain short-horned lizard)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Pituophus melanoleucus (gopher snake)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Sceloporus graciosus (sagebrush lizard)	–	–	–	Y	–	Akins 1985
Sceloporus undulatus (north plateau lizard)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Testudines sp. (unidentified turtle)	–	–	–	Y	–	Akins 1985
Thamnophis sp. (garter snake)	–	–	Y	–	–	Gillespie 1982
Class Aves	**–**	**–**	**Y**	**Y**	**Y**	**–**
Accipiter cooperii (Cooper's hawk)	–	–	–	Y	–	Akins 1985
Accipiter gentilis (goshawk)	–	–	–	Y	–	Akins 1985
Anas acuta (pintail)	–	–	–	Y	–	Akins 1985
Anas americana (American wigeon)	–	–	–	Y	–	Gillespie 1982, Akins 1985
Anas platyrhynchos (mallard)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Anas sp. (unidentified duck)	–	–	–	Y	–	Gillespie 1982, Akins 1985
Anas small sp. (small unidentified duck)	–	–	Y	–	–	Gillespie 1982
Anas large sp. (large unidentified duck)	–	–	–	–	Y	Gillespie 1982
Aquila or Haliaeetus (eagle)	–	–	–	Y	–	Akins 1985
Ara macao (scarlet macaw)	–	–	–	Y	–	Akins 1985
Ara sp. (unidentified macaw)	–	–	–	Y	–	Akins 1985
Asio flammeus (short eared owl)	–	–	–	Y	Y	Gillespie 1982
Asio otus (long eared owl)	–	–	–	Y	Y	Gillespie 1982, Akins 1985
Asio cf. *otus* (long eared owl?)	–	–	Y	Y	–	Gillespie 1982
Asio sp. (unidentified owl)	–	–	Y	Y	–	Gillespie 1982
Aythya americana (redhead)	–	–	–	Y	–	Akins 1985
Branta canadensis (Canada goose)	–	–	–	Y	–	Akins 1985
Bubo virginianus (great horned owl)	–	–	–	Y	–	Akins 1985
Buteo jamaicensis (red-tailed hawk)	–	–	–	Y	–	Akins 1985
Buteo lagopus (rough legged hawk)	–	–	–	Y	–	Akins 1985
Buteo regalis (ferruginous hawk)	–	–	–	Y	–	Akins 1985
Buteo sp. (unidentified hawk*)*	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Buteo swainsoni (Swainson's hawk)	–	–	–	Y	–	Akins 1985
Callipepla squamata (scaled quail)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Cathartes aura (turkey vulture)	–	–	Y	Y	–	Gillespie 1982
Charadrius vociferous (killdeer)	–	–	–	Y	Y	Gillespie 1982
Circus cyaneus (marsh hawk)	–	–	–	Y	–	Akins 1985
Colaptes auratus (common flicker)	–	–	–	Y	–	Akins 1985
Corvus corax (common raven)	–	–	–	Y	–	Akins 1985
† *Ectopistes migratorius* (passenger pigeon)	–	–	–	Y	–	Akins 1985
Eremophila alpestris (horned lark)	–	–	–	Y	Y	Gillespie 1982, Akins 1985
Falco mexicanus (prairie falcon)	–	–	–	Y	–	Akins 1985
Falco sp. (unidentified falcon)	–	–	–	Y	–	Akins 1985
Falco sparverius (American kestrel)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Grus canadensis (sandhill crane)	–	–	–	Y	–	Akins 1985
Gymnorhinus cyanocephalus (pinyon jay)	–	–	–	Y	Y	Gillespie 1982, Akins 1985

Taxon	PI	EHo	MHo	LHo	GQ	References
Haliaeetus leucocephalus (bald eagle)	–	–	–	Y	–	Akins 1985
Hirundinidae sp. (unidentified swallow)	–	–	–	Y	–	Akins 1985
Icteridae sp. (unidentified blackbird)	–	–	–	Y	–	Akins 1985
Junco hyemalis (dark-eyed junco)	–	–	–	Y	–	Akins 1985
Lanius ludovicianus (loggerhead shrike)	–	–	–	Y	–	Akins 1985
Meleagris gallopavo (wild turkey)	–	–	–	Y	–	Akins 1985
Otus asio (screech owl)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Oxyura jamaicensis (ruddy duck)	–	–	Y	Y	–	Gillespie 1982
Pica pica (Eurasian magpie)	–	–	–	Y	–	Akins 1985
Pipilo chlorurus (green-tailed towhee)	–	–	–	Y	–	Akins 1985
Pipilo erythrophthalmus (eastern towhee)	–	–	–	Y	–	Akins 1985
cf. Podilymbus podiceps (pie-billed grebe)	–	–	–	Y	Y	Gillespie 1982
Rhynchopsitta pachyrhyncha (thick billed parrot)	–	–	–	Y	–	Akins 1985
Sialia currucoides (mountain bluebird)	–	–	–	Y	–	Akins 1985
Sialia mexicana (western bluebird)	–	–	–	Y	–	Akins 1985
Sialia sp. (unidentified bluebird)	–	–	–	Y	–	Akins 1985
Trochilidae sp. (unidentified hummingbird)	–	–	–	Y	–	Akins 1985
Turdus migratorius (American robin)	–	–	–	Y	–	Akins 1985
Tyto alba (barn owl)	–	–	–	Y	–	Akins 1985
Zenaida macroura (mourning dove)	–	–	–	Y	Y	Gillespie 1982, Akins 1985
Class Mammalia	**Y**	**Y**	**Y**	**Y**	**Y**	**–**
Mammalia undetermined, large	Y	–	–	–	–	Hall 1977
Mammalia: Order Artiodactyla	**–**	**–**	**Y**	**Y**	**–**	**–**
Antilocapra americana (pronghorn)	–	–	Y	–	–	Gillespie 1982
Bison bison (American bison)	–	–	–	Y	–	Gillespie 1982, Akins 1985
† *Bison antiquus* (extinct bison)	–	–	Y	–	–	Gillespie 1982
Bos taurus (domestic cow)	–	–	–	Y	–	Akins 1985
Cervus elaphus (elk)	–	–	–	Y	–	Akins 1985
Odocoileus hemionus (mule deer)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Ovis canadensis (bighorn sheep)	–	–	–	Y	–	Akins 1985
Ovis sp. or *Capra* sp. (unidentified sheep or goat)	–	–	–	Y	–	Akins 1985
Mammalia: Order Carnivora	**–**	**–**	**–**	**Y**	**Y**	**–**
Canis familiaris (domestic dog)	–	–	–	Y	–	Akins 1985
Canis latrans (coyote)	–	–	–	Y	–	Gillespie 1982, Akins 1985
Canidae sp. (unidentified dog)	–	–	–	Y	–	Gillespie 1982, Akins 1985
Felis concolor (mountain lion)	–	–	–	Y	–	Akins 1985
Felis rufus (bobcat)	–	–	–	Y	–	Akins 1985
Mustela nigripes (black footed ferret)	–	–	–	–	Y	Gillespie 1982
Taxidea taxus (badger)	–	–	–	–	Y	Gillespie 1982, Akins 1985
Urocyon cinereoargenteus (gray fox)	–	–	–	Y	–	Akins 1985
Ursus americanus (black bear)	–	–	–	Y	–	Akins 1985
Ursus arctos (grizzly bear)	–	–	–	Y	–	Akins 1985
Ursus sp. (unidentified bear)	–	–	–	Y	–	Akins 1985
Vulpes vulpes (red fox)	–	–	–	Y	–	Akins 1985

Taxon	PI	EHo	MHo	LHo	GQ	References
Mammalia: Order Chiroptera	**–**	**–**	**Y**	**Y**	**–**	**–**
Antrozous pallidas (pallid bat)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Myotis californicus (California myotis)	–	–	–	Y	–	Akins 1985
Myotis sp. (undetermined bat)	–	–	–	Y	–	Gillespie 1982
Lasionycteris noctivagans (silver haired bat)	–	–	–	Y	–	Gillespie 1982
Mammalia: Order Lagomorpha	**–**	**Y**	**Y**	**Y**	**Y**	**–**
Lepus americanus (snowshoe hare)	–	–	–	Y	–	Akins 1985
Lepus californicus (black-tailed jackrabbit)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Lepus sp.	–	–	Y	Y	–	Gillespie 1982
Sylvilagus audubonii (desert cottontail)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Sylvilagus nuttallii (Nuttall's cottontail)	–	Y	Y	–	–	Gillespie 1982, Akins 1985
Sylvilagus sp.	–	–	–	–	Y	Gillespie 1982
Mammalia: Order Rodentia	**–**	**Y**	**Y**	**Y**	**Y**	**–**
Ammospermophilus leucurus (white-tailed antelope ground squirrel)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Castor canadensis (beaver)	–	–	–	Y	–	Akins 1985
Cynomys gunnisoni (Gunnison's prairie dog)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Dipodomys ordii (Ord's kangaroo rat)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Dipodomys spectabilis (banner-tailed kangaroo rat)	–	–	–	Y	–	Gillespie 1982, Akins 1985
Erethizon dorsatum (North American porcupine)	–	–	–	Y	–	Akins 1985
Eutamias cf. *quadrivitattus* (Colorado chipmunk)	–	–	–	–	Y	Gillespie 1982
Lemniscus curtatus (sagebrush vole)	–	Y?	Y	–	–	Gillespie 1982, Harris 1993
Microtus mexicanus (Mexican vole)	–	–	–	Y	–	Akins 1985
Microtus ochrogaster (prairie vole)	–	–	Y	–	–	Gillespie 1982, Harris 1993
Microtus sp.(unidentified vole)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Neotoma albigula (white-throated woodrat)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Neotoma cinerea (bushy-tailed woodrat)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Neotoma mexicana (Colorado woodrat)	–	–	–	Y	–	Akins 1985
Neotoma sp. (unidentified woodrat)	–	Y	Y	Y	–	Gillespie 1982, Akins 1985
Neotoma stephensi (Stephen's woodrat)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Onychomys leucogaster (northern grasshopper mouse)	–	Y	Y	Y	–	Gillespie 1982, Akins 1985
Perognathus flavescens (plains pocket mouse)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Perognathus flavus (silky pocket mouse)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Perognathus sp. (unidentified pocket mice)	–	Y	Y	Y	–	Gillespie 1982, Akins 1985
Peromyscus boylii (brush mouse)	–	–	–	Y	Y	Gillespie 1982, Akins 1985
Peromyscus crinitus (canyon mouse)	–	–	Y	Y	–	Gillespie 1982
Peromyscus maniculatus (North American deer mouse)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Peromyscus sp. (unidentified deer mouse)	–	Y	Y	Y	–	Gillespie 1982, Akins 1985
Reithrodontomys megalotis (western harvest mouse)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Sciuridae, gen. et sp., indet.	–	–	–	–	Y	Gillespie 1982
Sciurus aberti (Abert's squirrel)	–	–	–	Y	–	Akins 1985

Taxon	PI	EHo	MHo	LHo	GQ	References
Sigmodon hispidus (hispid cotton rat)	–	–	Y	–	–	Gillespie 1982, Harris 1993
Spermophilus variegatus (rock squirrel)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Thomomys bottae (Botta's pocket gopher)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
cf. *Thomomys* sp. (unidentified pocket gopher)	–	–	Y	Y	–	Gillespie 1982, Akins 1985
Mammalia: Order Soricomorpha	**–**	**–**	**Y**	**–**	**–**	**–**
Notiosorex crawfordi (Crawford's gray shrew)	–	–	Y	–	–	Gillespie 1982
ICHNOFOSSILS	**–**	**Y**	**Y**	**Y**	**Y**	**–**
Vertebrate trace fossils	**–**	**Y**	**Y**	**Y**	**Y**	**–**
Erethizon dorsatum (porcupine) fecal pellets	–	–	–	–	Y	Gillespie 1982
Lepus sp. (hare) fecal pellets	–	–	–	Y	–	USGS/NOAA Midden DB
Neotoma sp. (woodrat) fecal pellets	–	Y	Y	Y	–	Smith and Betancourt 1998, USGS/NOAA Midden DB
Neotoma sp. (woodrat) middens	–	Y	Y	Y	–	See text for a detailed discussion

Appendix B: CHCU Paleontological Site Data

More than 344 paleontological sites have been documented at CHCU between 2005 and 2018. A *paleontological site* is an area where fossils occur in geological context, preferably *in situ*. Some fossils are found in float (not in original geologic context), and may be documented if the fossils are found in large numbers or are of a large size. Defining a paleontological site can be somewhat subjective, but generally a site contains several fossils or several taxa occurring in a limited geographic area or constrained to a limited stratigraphic horizon. Not every fossil ever found is documented as a site, but the discovery of an isolated fossil could lead to the discovery of a site.

Each site is documented using a Paleontological Site Form which contains geographic, stratigraphic, and taxonomic data related to the site and fossils found at the site. Paleontological site files may also contain copies of field notes, site sketches, and any collection data if necessary (specimen numbers, taxon, element, and additional photographs).

A cluster of related sites (geographically or stratigraphically) may be grouped together to form a *paleontological locality*. A locality is a group of sites that the park has determined should be included in the cyclic monitoring program (regularly scheduled condition assessments). This may be because the sites within the locality contain scientifically significant or "at risk" fossils. Grouping related paleontological sites into localities for inclusion into the monitoring program is intended to simplify the monitoring and reporting process. As of 2019, there are 49 localities which represent approximately 150 individual sites, or approximately 43% of known sites. This does not mean that the other sites should be ignored, but merely that they have not been incorporated into the monitoring schedule; all sites should be revisited periodically, but some sites are given priority.

The CHCU Resources Division manages all of the site data including electronic databases, a geodatabase (ArcGIS), electronic and paper site files, photographs, and condition assessments. Paleontological site files contain sensitive data. Therefore, detailed information about specific paleontological sites must be requested from the CHCU Resources Division.

The tables below summarize the paleontological site data organized by geologic formation: Menefee Formation (Appendix Table B-1), Cliff House Sandstone (Appendix Table B-2), and Lewis Shale and Pictured Cliffs Formation (Appendix Table B-3) (the Crevasse Canyon Formation is omitted due to lack of sites), broken down by the occurrence of fossil Plantae, Bivalvia, Cephalopoda, Gastropoda, Chondrichthyes, Osteichthyes, and Reptilia, and unspecified taxa. The four-digit numbers in the tables correspond to the Paleontological Site Numbers (CHCU-XXXX). Some paleontological sites contain more than one type of fossil and are therefore listed where appropriate. Some fossil types contain unspecified taxa, usually unidentified bone.

Appendix Table B-1. Paleontological sites in the Menefee Formation of CHCU.

Fossil Type	Paleontological Sites in the Menefee Formation
Plantae	CHCU-0001, 0002, 0003, 0004, 0005, 0006, 0007, 0008, 0009, 0010, 0011, 0012, 0013, 0014, 0015, 0016, 0017, 0018, 0019, 0020, 0021, 0022, 0023, 0024, 0025, 0026, 0027, 0028, 0029, 0030, 0031, 0032, 0033, 0034, 0035, 0036, 0037, 0038, 0039, 0040, 0041, 0042, 0043, 0044, 0045, 0046, 0048, 0049, 0052, 0053, 0055, 0057, 0058, 0059, 0060, 0061, 0062, 0063, 0064, 0065, 0066, 0067, 0068, 0069, 0070, 0071, 0072, 0095, 0153, 0154, 0155, 0169, 0170, 0173, 0174, 0176, 0190, 0194, 0195, 0196, 0200, 0205, 0206, 0211, 0212, 0213, 0214, 0215, 0216, 0218, 0219, 0224, 0225, 0226, 0227, 0229, 0252, 0254, 0255, 0275, 0278, 0281, 0282, 0298, 0299, 0300, 0301, 0302, 0303, 0308, 0311, 0312, 0313, 0316, 0317
Reptilia	CHCU-0047, 0050, 0051, 0054, 0056, 0156, 0157, 0158, 0159, 0160, 0165, 0166, 0172, 0191, 0192, 0193, 0198, 0199, 0200, 0201, 0202, 0203, 0204, 0208, 0209, 0210, 0217, 0221, 0223, 0230, 0231, 0232, 0244, 0253, 0309, 0310, 0327, 0342

Appendix Table B-2. Paleontological sites in the Cliff House Sandstone of CHCU.

Fossil Type	Paleontological Sites in the Cliff House Sandstone
Plantae	CHCU-0077, 0080, 0081, 0086, 0087, 0088, 0089, 0093, 0094, 0102, 0111, 0112, 0113, 0114, 0115, 0117, 0119, 0120, 0121, 0131, 0132, 0167, 0180, 0228, 0268, 0271, 0272, 0273, 0274, 0283, 0318, 0322, 0333.
Bivalvia	CHCU-0073, 0074, 0082, 0084, 0087, 0098, 0100, 0101, 0105, 0106, 0107, 0108, 0109, 0116, 0117, 0123, 0127, 0130, 0136, 0140, 0142, 0143, 0145, 0147, 0148, 0149, 0150, 0151, 0152, 0163, 0177, 0178, 0183, 0184, 0185, 0187, 0236, 0237, 0239, 0241, 0242, 0243, 0248, 0250, 0258, 0263, 0264, 0266, 0267, 0269, 0270, 0273, 0277, 0285, 0286, 0287, 0288, 0289, 0290, 0291, 0292, 0293, 0294, 0295, 0296, 0297, 0304, 0305, 0306, 0314, 0321, 0323, 0324, 0334, 0335, 0338, 0341.
Cephalopoda	CHCU-0082, 0085, 0103, 0104, 0187, 0243, 0264, 0290, 0291, 0295, 0304.
Gastropoda	CHCU-0073, 0074, 0098, 0100, 0105, 0108, 0130, 0142, 0149, 0150, 0151, 0241, 0243, 0264, 0285, 0286, 0287, 0288, 0290, 0291, 0292, 0293, 0294, 0295, 0296, 0297, 0304, 0305, 0306, 0314, 0335.
Chondrichthyes	CHCU-0082, 0086, 0087, 0089, 0099, 0122, 0128, 0133, 0134, 0161, 0162, 0163, 0177, 0178, 0179, 0180, 0182, 0183, 0185, 0186, 0188, 0234, 0236, 0243, 0247, 0250, 0251, 0261, 0269, 0270, 0276, 0277, 0280, 0285, 0295, 0314, 0326, 0330, 0331, 0332, 0335, 0339
Osteichthyes	CHCU-0162, 0180, 0186, 0234, 0250, 0261, 0270, 0277, 0295, 0331, 0332, 0339, 0341
Reptilia	CHCU-0076, 0079, 0083, 0087, 0089, 0091, 0092, 0097, 0099, 0110, 0118, 0122, 0123, 0127, 0128, 0129, 0133, 0134, 0135, 0137, 0138, 0139, 0141, 0146, 0161, 0162, 0164, 0175, 0177, 0179, 0180, 0183, 0185, 0186, 0188, 0189, 0233, 0235, 0236, 0238, 0240, 0246, 0247, 0249, 0250, 0251, 0259, 0261, 0262, 0265, 0277, 0329, 0337, 0339, 0341

Appendix Table B-3. Paleontological sites in the Lewis Shale and Pictured Cliffs Sandstone of CHCU.

Fossil Type	Paleontological Sites in the Lewis Shale / Pictured Cliffs Sandstone
Plantae	CHCU-0124, 0125, 0126
Reptilia	CHCU-0144, 0279

Brief descriptions of fossils documented at localities from the CHCU Paleontological Resources Inventory between 2005 and 2018 are included below. Paleontological site numbers are listed as hyphenated four-digit numbers. Catalog numbers of curated CHCU fossil specimens (listed as unhyphenated five- or six-digit numbers) are listed if fossils were collected. Detailed site descriptions are found within individual site files.

Kin Bineola (PMA01) – 3 Localities
PMA01-LOC01 **–** *Juans Lake Beds, Menefee Formation (Kmfaj)*
Fossils: large fossilized conifer wood logs.
Collected specimens: conifer wood (CHCU 107484, 107485, 107486)
Sites: CHCU-0001, -0002, -0003, -0004, -0005

PMA01-LOC02 – *Juans Lake Beds, Menefee Formation (Kmfaj)*
Fossils: conifer logs and numerous large wood fragments
Collection: conifer wood (CHCU 107488, 107489)
Sites: CHCU-0006, -0007, -0008, -0009, -0010, -0011, -0012

PMA01-LOC03 – *Juans Lake Beds, Menefee Formation (Kmfaj)*
Fossils: conifer wood logs and fossil wood debris.
Collected specimens: conifer wood (CHCU 107490)
Sites: CHCU-0013, -0014, -0015, -0016

Pueblo Pintado (PMA02) – 0 Localities
No fossil localities.
No fossil collection.

Kin Ya'a (PMA03) – 0 Localities
No fossil localities.
No fossil collection.

Kin Klizhin (PMA04) – 5 Localities
PMA04-LOC01 – *Juans Lake Beds, Allison Member, Menefee Formation (Kmfaj)*
Fossils: abundant conifer wood.
Collected specimens: conifer wood (CHCU 107461, 107462)
Sites: CHCU-0022, -0023

PMA04-LOC02 – *Juans Lake Beds, Allison Member, Menefee Formation (Kmfaj)*
Fossils: abundant conifer wood.
Collected specimens: conifer wood (CHCU 107451, 107452, 107453, 107454, 107455)
Sites: CHCU-0024, -0025, -0026, -0027, -0028, -0029, -0030, -0031, -0032, -0033, -0034

PMA04-LOC03 – *Juans Lake Beds, Allison Member, Menefee Formation (Kmfaj)*
Fossils: abundant conifer wood, sparse fossil angiosperm wood and indeterminate bone.
Collected specimens: angiosperm wood (CHCU 107456), conifer (CHCU 107457, 107495, 107496).
Sites: CHCU-0035, -0036, -0037, -0038, -0039, -0040, -0041, -0042, -0043, -0044, -0045, -0046, -0047, -0048, -0049, -0050, -0051, -0052, -0053, -0054

PMA04-LOC04 – *Juans Lake Beds, Allison Member, Menefee Formation (Kmfaj)*
Fossils: partial carapace of a bothremydid turtle (*Elochelys* cf. *E. perfecta*), conifer wood.
Collected specimens: *Elochelys* cf. *E. perfecta* (CHCU 81269).
Sites: CHCU-0055, -0056

PMA04-LOC05 – *Juans Lake Beds, Allison Member, Menefee Formation (Kmfaj)*
Fossils: conifer tree trunk and several other fossil conifer wood fragments.
Collected specimens: conifer wood (CHCU 107458, 107459, 107460)
Sites: CHCU-0057, -0058, -0059, -0060

Wijiji Mesa (PMA05) – 4 Localities
PMA05-LOC01 – *Lower unit, Cliff House Sandstone (Kchl*)
Fossils: fossiliferous sandstone with abundant bivalves, gastropods, and *Ophiomorpha nodosa* traces. The assemblage is consistent with the description of Assemblage 1 of Siemers and King (1974).
Collected specimens: none
Sites: CHCU-0073, -0074, -0075

PMA05-LOC02 – *Intermediate and middle units, Cliff House Sandstone (Kchi, Kchm)*
Fossils: unidentified *in situ* fossil bone fragments in massive sandstone blocks, burrow traces.
Collection: none
Sites: CHCU-0076, -0077, -0078, -0079

PMA05-LOC03 – *Middle unit, Cliff House Sandstone (Kchm)*
Fossils: conifer wood log fragments in float at base of cliff, *in situ* conifer wood logs in sandstone.
Collected specimens: conifer wood (CHCU 107504, 107505)
Sites: CHCU-0080, -0081

PMA05-LOC04 – *Middle unit, Cliff House Sandstone (Kchm)*
Fossils: fossiliferous sandstone with abundant bivalves, large *Inoceramus* sp. shells and molds, gastropods, unidentified bones and teeth, an ammonite, and *Ophiomorpha nodosa* traces. The assemblage is consistent with the description of Assemblages 2 and 3 of Siemers and King (1974).
Collected specimens: none.
Sites: CHCU-0082, -0083, -0084, -0085

Other collected specimens from the Wijiji Mesa (site CHCU-0103) include *Placenticeras* sp. (CHCU 95986), *Baculites* sp. (CHCU 95898), and bivalves (CHCU 95895).

Gallo (PMA06) – 2 Localities
PMA06-LOC01 - *Lower unit, Cliff House Sandstone (Kchl)*
Fossils: *in situ* invertebrate trace and body fossil sites including bivalves, gastropods, and cephalopods. *Inoceramus* sp. shells, casts, and molds are abundant and large, up to 15 cm (5.9 in) long.
Collection: none
Sites: CHCU-0106, -0107, -0108, -0109

PMA06-LOC02 – *Intermediate unit, Cliff House Sandstone (Kchi)*
Fossils: A well-preserved, unidentified *in situ* bone is eroding from a silty sandstone ledge.
Collected specimens: none
Sites: CHCU-0110

Chacra Mesa (PMA07) – 3 Localities
PMA07-LOC01 - *La Vida Beds, Allison Member, Menefee Formation (Kmfav)*
Fossils: conifer wood logs, fragments, and debris scatters.
Collected specimens: conifer wood (CHCU 107500, 1075001, 107502)
Sites: CHCU-0298, -0299, -0300, -0301, -0302, -0303

PMA07-LOC02 **-** *Lower unit, Cliff House Sandstone (Kchl)*
Fossils: *Inoceramus* sp. bivalves, gastropods, *Placenticeras* and *Baculites* sp. ammonites.
Collected specimens: none
Sites: CHCU-0334, -0335, -0336

PMA07-LOC03 - *Upper unit, Cliff House Sandstone (Kchu)*
Fossils: fossiliferous lenses with abundant shark teeth, fish vertebrae, vertebrae of large unidentified reptiles, and large unidentified *in situ* bones in fallen boulders.
Collected specimens: none
Sites: CHCU-0329, -0330, -0331, -0332,-0338, -0339

PMA07-LOC04 - *Upper unit, Cliff House Sandstone (Kchu)*
Fossils: large unidentified *in situ* bones in fallen boulders.
Collected specimens: none
Sites: CHCU-0325

PMA07-LOC05 - *Upper unit, Cliff House Sandstone (Kchu)*
Fossils: fossiliferous lenses with abundant shark teeth, fish vertebrae, vertebrae of large reptiles
Collected specimens: none
Sites: CHU-0341

Mockingbird Canyon (PMA08) – 3 Localities
PMA08-LOC01 – *Lewis Shale (Kl)*
Fossils: conifer wood stumps, conifer and possible angiosperm wood log fragments.
Collected specimens: conifer wood (CHCU 107498, 107499)
Sites: CHCU-0124, -0125, -0126

PMA08-LOC02 – *Lower unit, Cliff House Sandstone (Kchl)*
Fossils: fossiliferous lenses of *in situ* bivalves and gastropods, loose casts of cf. *Gyrodes* sp., shark tooth fragments, unidentified bone fragments, and *Ophiomorpha nodosa* traces.
Collected specimens: none
Sites: CHCU-0127, -0128, -0129, -0130

PMA08-LOC03 – *Lower unit, Cliff House Sandstone (Kchl)*
Fossils: abundant, large conifer and angiosperm logs. Some logs contain borehole traces.
Collected specimens: conifer wood (CHCU 107464, 107468, 107471, 107477), angiosperm wood (CHCU 107463, 107465-107467, 107469-107470, 107472-107476, 107478-107483). This is the largest collection of angiosperm wood in the park.
Sites: CHCU-0130

Cly's Canyon (PMA09) – 5 Localities
PMA09-LOC01 – *Intermediate unit, Cliff House Sandstone (Kchi)*
Fossils: *Inoceramus* sp. shells, casts, and molds, *Ophiomorpha nodosa* traces.
Collected specimens: none
Sites: CHCU-0136

PMA09-LOC02 – *Intermediate unit, Cliff House Sandstone (Kchi)*
Fossils: shell fragments of an unidentified turtle were discovered in 1998. Efforts to preserve the specimen through stabilization with burlap were unsuccessful, and by 2007 the specimen had deteriorated.
Collected specimens: none
Sites: CHCU-0137

PMA09-LOC03 – *Lower unit, Cliff House Sandstone (Kchl)*
Fossils: possible dentary of a mosasaur *in situ* on a fallen boulder.
Collected specimens: none
Sites: CHCU-0138

PMA09-LOC04 – *Intermediate unit, Cliff House Sandstone (Kchi)*
Fossils: unidentified Reptilia bone fragments *in situ* and in float.
Collected specimens: none
Sites: CHCU-0139

PMA09-LOC05 – Lower unit, Cliff House Sandstone (Kchl)
Fossils: *Inoceramus* sp. shells, casts, and molds up to 12 cm (4.7 in) long and 6 cm (2.4 in) wide, *Ophiomorpha nodosa* traces and possibly oyster shells.
Collected specimens: none
Sites: CHCU-0140

South Mesa (PMA10) – 5 Localities

PMA10-LOC01 – *Lower unit, Cliff House Sandstone (Kchl)*
Fossils: fossiliferous sandstone with abundant bivalves and gastropods.
Collected specimens: none
Sites: CHCU-0149, -0150, -0151, -0152

PMA10-LOC02 – *Juans Lake Beds, Allison Member, Menefee Formation (Kmfaj)*
Fossils: conifer logs, log fragments, wood debris, and unidentified bone.
Collected specimens: conifer wood (CHCU 107506, 107507)
Sites: CHCU-0153, -0154, -0155, -0156, -0157, -0158, -0159, -0160

PMA10-LOC03 – *Upper unit, Cliff House Sandstone (Kchu)*
Fossils: fossiliferous lenses with oysters, shark teeth (*Archaeolamna kopingensis*, cf. *Serratolamna* sp., *Scapanorhynchus texanus*, *Squalicorax kaupi*), and large and small bone fragments including a well-preserved unidentified *in situ* vertebra that resembles a bird or baenid turtle.
Collected specimens: possible theropod tooth fragments (CHCU 121703, 121706) and a mosasaur tooth fragment (CHCU 121705).
Sites: CHCU-0161, -0162, -0163, -0164

PMA10-LOC04 – *Juans Lake Beds, Allison Member, Menefee Formation (Kmfaj)*
Fossils: fragmented dinosaur humerus tentatively identified as large ornithischian (hadrosaur).
Collected specimens: 89 fragments of dinosaur bone (CHCU 109796).
Sites: CHCU-0165

PMA10-LOC05 – *Juans Lake Beds, Allison Member, Menefee Formation (Kmfaj)*
Fossils: A scatter of fossil bone fragments was found eroding out of a mudstone capped by sandstone. Specimens included vertebrae (centra) and a possible jaw fragment tentatively identified as an ornithischian dinosaur similar to the one found in PMA10-LOC04.
Collected specimens: 11 bone fragments (CHCU 109794) were collected in 2010. 35 additional small, loose bone fragments (CHCU 109795) were collected in 2012 as part of site monitoring.
Sites: CHCU-0166

West Mesa South (PMA11) – 9 Localities

PMA11-LOC01 – *Upper unit, Cliff House Sandstone (Kchu)*
Fossils: Fish vertebrae, bone fragments, oysters, and unidentified bivalves, and abundant shark teeth including *Squalicorax kaupi*, *Scapanorhynchus texanus*, and unidentified lamniform sharks. Fossil wood is also found in nearby gravel horizons (Pleistocene?)
Collected specimens: Reptile (theropod?) tooth fragment (CHCU 109797)
Sites: CHCU-0177, -0178, -0179

PMA11-LOC02 – *Upper unit, Cliff House Sandstone (Kchu)*
Fossils: Shark teeth, bone fragments, and fish vertebrae. Fossil wood is also present in nearby gravel deposits (Pleistocene?)
Collected specimens: Reptile (theropod?) tooth (CHCU 121702, Figure 16-D)
Sites: CHCU-0180, -0181

PMA11-LOC03 – *Upper unit, Cliff House Sandstone (Kchu)*
Fossils: Abundant shark teeth, bone fragments, oysters, unidentified bivalves, and gastropods.
Collected specimens: none
Sites: CHCU-0182, -0183, -0184

PMA11-LOC04 – *Upper unit, Cliff House Sandstone (Kchu)*
Fossils: Fossiliferous sandstone containing shark teeth, fish vertebrae, undetermined bones, shells, *Ophiomorpha nodosa* burrows.
Collected specimens: none
Sites: CHCU-0185, -0186

PMA11-LOC05 – *Upper unit, Cliff House Sandstone (Kchu)*
Fossils: Ammonite casts, *Inoceramus* molds, shark teeth, unidentified vertebrate bones, possible plesiosaur vertebra.
Collected specimens: Ammonite cast (CHCU-121701, Figure 11-A)
Sites: CHCU-0187, -0188

PMA11-LOC06 - *Upper unit, Cliff House Sandstone (Kchu)*
Fossils: Possible *in situ* plesiosaur humerus (Figure 16-A).
Collected specimens: none
Sites: CHCU-0189

PMA11-LOC07 – *Juans Lake Beds, Allison Member, Menefee Formation (Kmfaj)*
Fossils: Abundant wood logs, abundant unidentified bone, partial dinosaur humerus (Figure 15-C), unidentified dinosaur vertebrae (Figure 15-B), bone bed.
Collected specimens:
Sites: CHCU-0190, -0191, -0192, -0193, -0342

PMA11-LOC08 – *Juans Lake Beds, Allison Member, Menefee Formation (Kmfaj)*
Fossils: Abundant conifer wood (upright stump, logs, scattered wood fragments, possible *in situ* stump), unidentified vertebrate bones.
Collected specimens: none
Sites: CHCU-0194, -0195, -0196, -0197

PMA11-LOC09 – *Juans Lake Beds, Allison Member, Menefee Formation (Kmfaj)*
Fossils: Abundant unidentified bone fragments, conifer wood fragments.
Collected specimens: none
Sites: CHCU-0198, -0199, -0200, -0201, -0202, -0203, -0204

West Mesa South (PMA11) – 9 Localities
PMA12-LOC01 – *Juans Lake Beds, Allison Member, Menefee Formation (Kmfaj)*
Fossils: Trionychidae carapace fragments, unidentified bone fragments.
Collected specimens: Trionychidae carapace fragments (CHCU 110196, Figure 15-E)
Sites: CHCU-0230, -0231, -0232

PMA12-LOC02 – Upper unit, Cliff House Sandstone (Kchu)
Fossils: Abundant shark teeth, fish vertebrae, bone fragments, invertebrate shells. One significant specimen is a nearly 50 cm (20 in) long *in situ* bone (Figure 16-E).
Collected specimens:
Sites: CHCU-0233, -0234, -0235

PMA12-LOC03 – *Upper unit, Cliff House Sandstone (Kchu)*
Fossils: abundant invertebrate shells (bivalves, gastropods), *Ophiomorpha nodosa* traces, unidentified bone fragments.
Collected specimens: none
Sites: CHCU-0236, -0237, -0238

PMA12-LOC04 – *Lower unit, Cliff House Sandstone (Kchl)*
Fossils: Abundant *Inoceramus* shells, casts, and molds.
Collected specimens: none
Sites: CHCU-0239

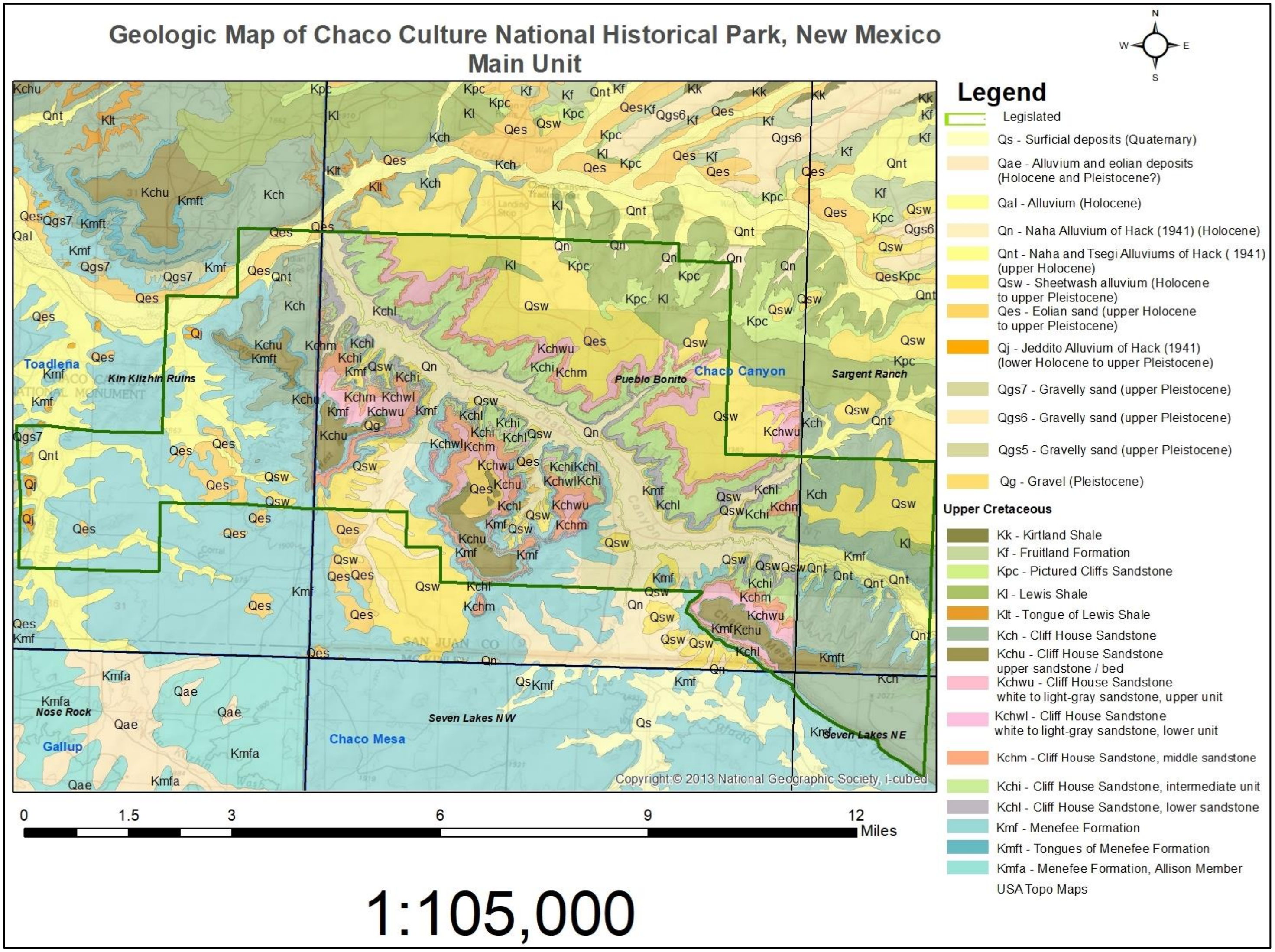
PMA12-LOC05 – *Lower unit, Cliff House Sandstone (Kchl)*
Fossils: Large unidentified *in situ* limb bone (Figure 16-F).
Collected specimens: none
Sites: CHCU-0240

PMA12-LOC06 – *Lower unit, Cliff House Sandstone (Kchl)*
Fossils: *Inoceramus* clams, oysters, shark teeth, unidentified bivalves, gastropods, cephalopods.
Collected specimens: none
Sites: CHCU-0241, -0242

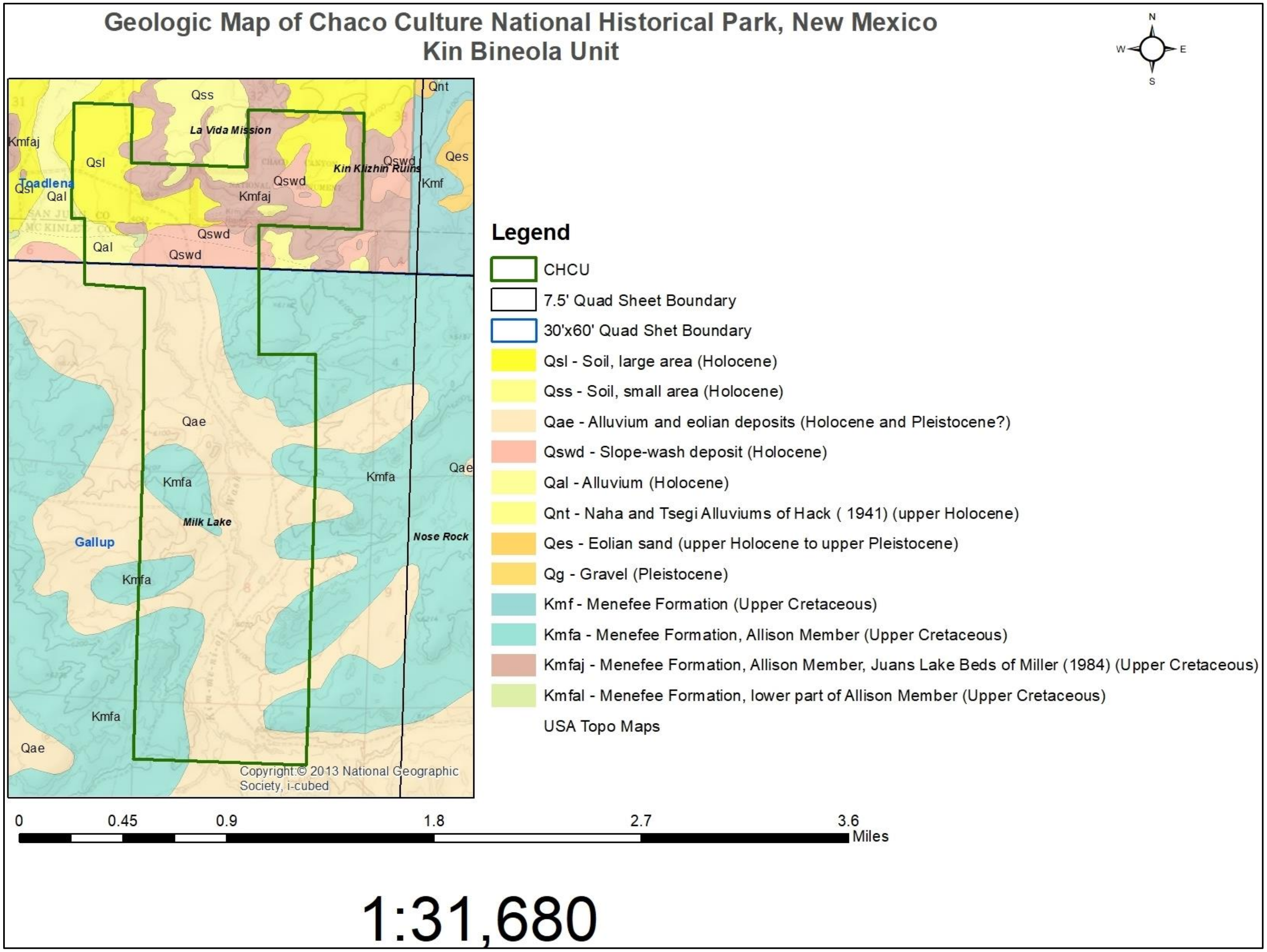
PMA12-LOC07 – *Upper unit, Cliff House Sandstone (Kchu)*
Fossils: *Baculites* ammonite in float, abundant invertebrates including bivalves and gastropods.
Collected specimens: none
Sites: CHCU-0243

PMA12-LOC08 – *Juans Lake Beds, Allison Member, Menefee Formation (Kmfaj)*
Fossils: Possible crocodilian bones and scutes (Figure 15-F).
Collected specimens: none
Sites: CHCU-0244

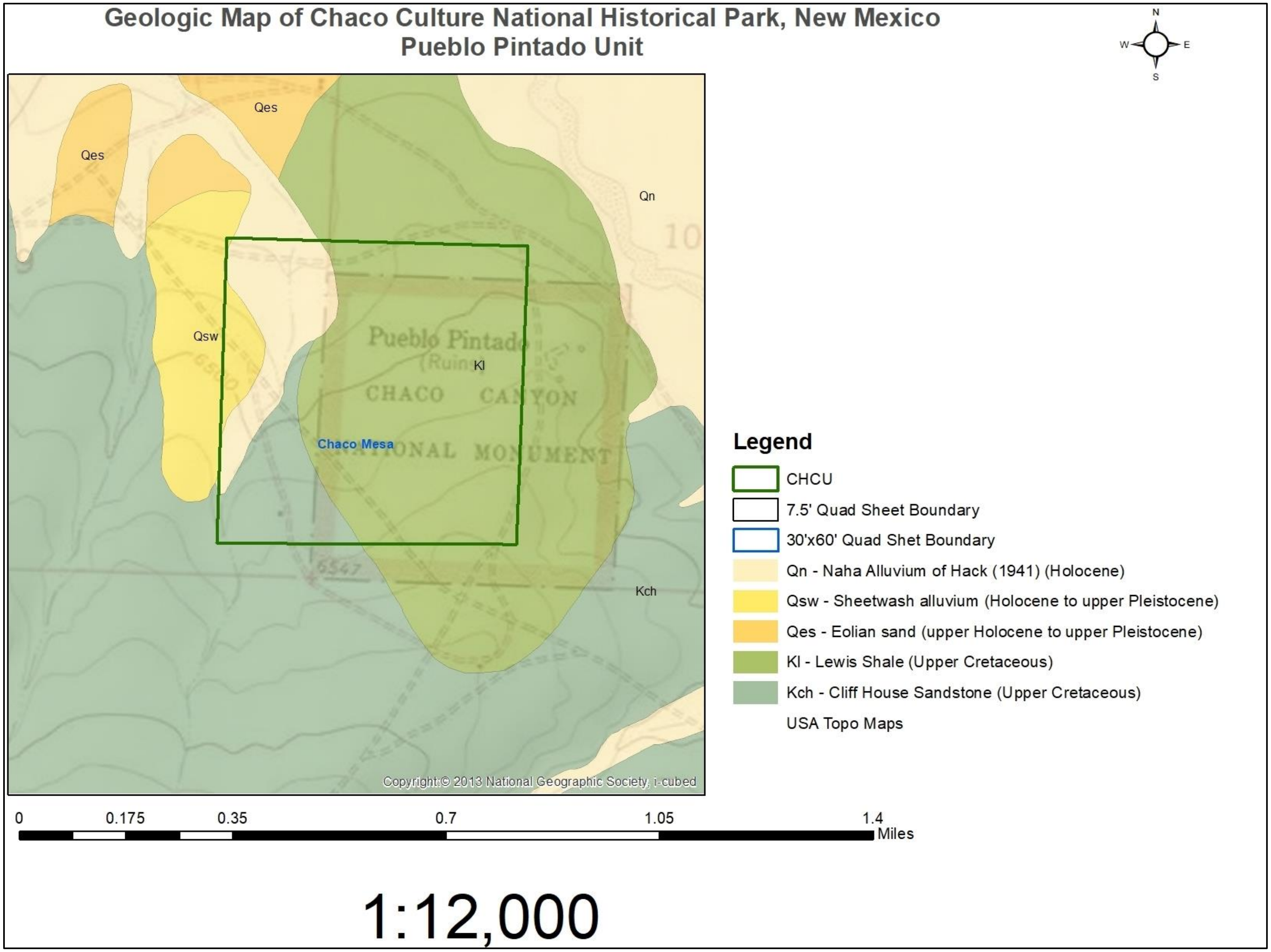
Appendix C: CHCU Geologic Maps



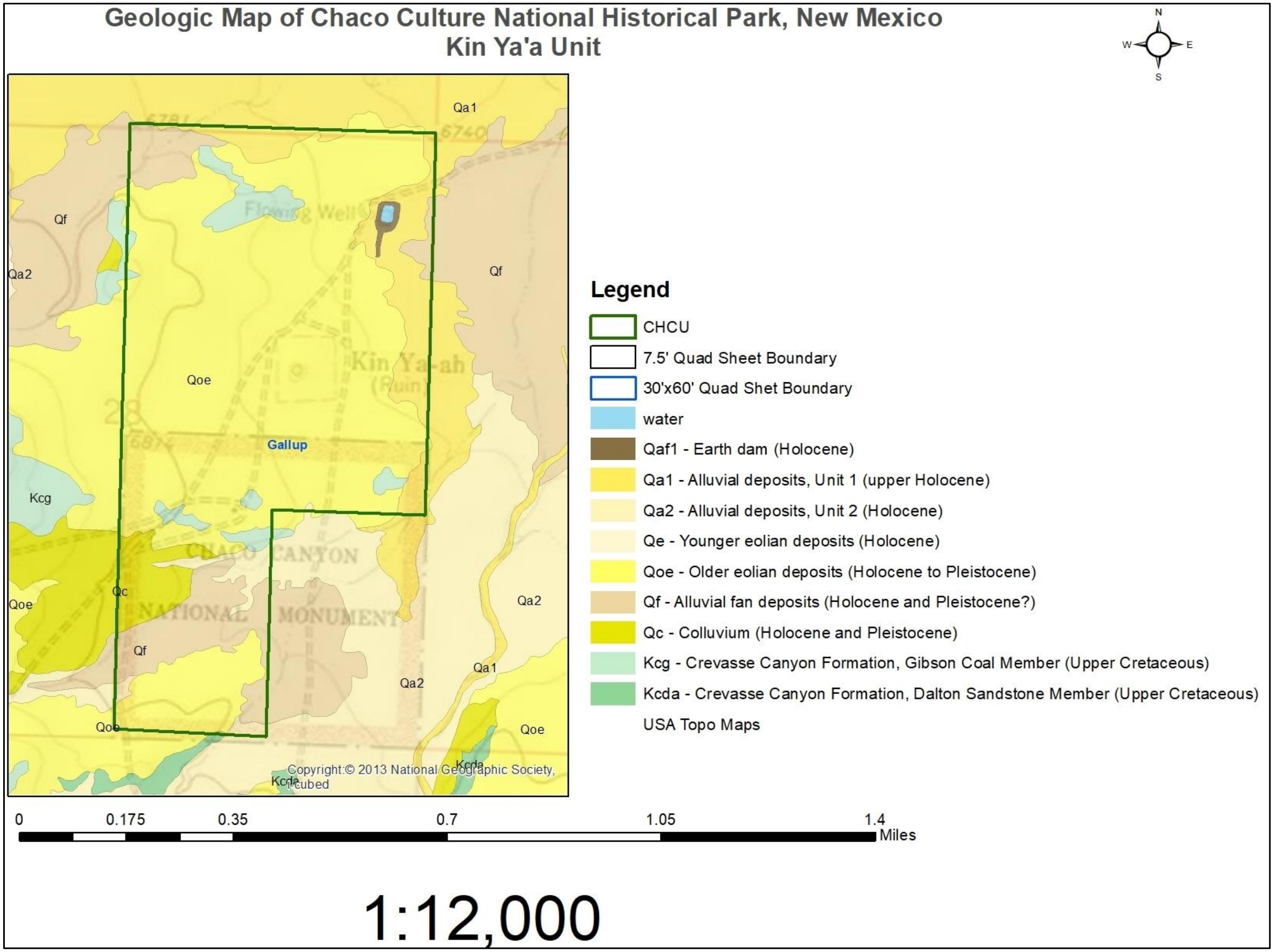
Appendix Figure C-1. Geologic map of the main unit of CHCU (NPS/TIM CONNORS, Geologic Resources Division data).



Appendix Figure C-2. Geologic map of the Kin Bineola unit of CHCU (NPS/TIM CONNORS, Geologic Resources Division data).



Appendix Figure C-3. Geologic map of the Pueblo Pintado unit of CHCU (NPS/TIM CONNORS, Geologic Resources Division data).



Appendix Figure C-4. Geologic map of the Kin Ya’a unit of CHCU (NPS/TIM CONNORS, Geologic Resources Division data).

Appendix D: Paleontological Resource Potential Maps

These maps are based on the geologic maps in Appendix C, and the unit abbreviations are the same as in the geologic maps. For reference, and to save space on the maps, the geologic units referenced in the paleontological resource potential maps are given below. Units that are known to be fossiliferous within CHCU are colored green. Units that are potentially fossiliferous but have not yielded fossils in CHCU are colored yellow. Units that are unfossiliferous are colored red.

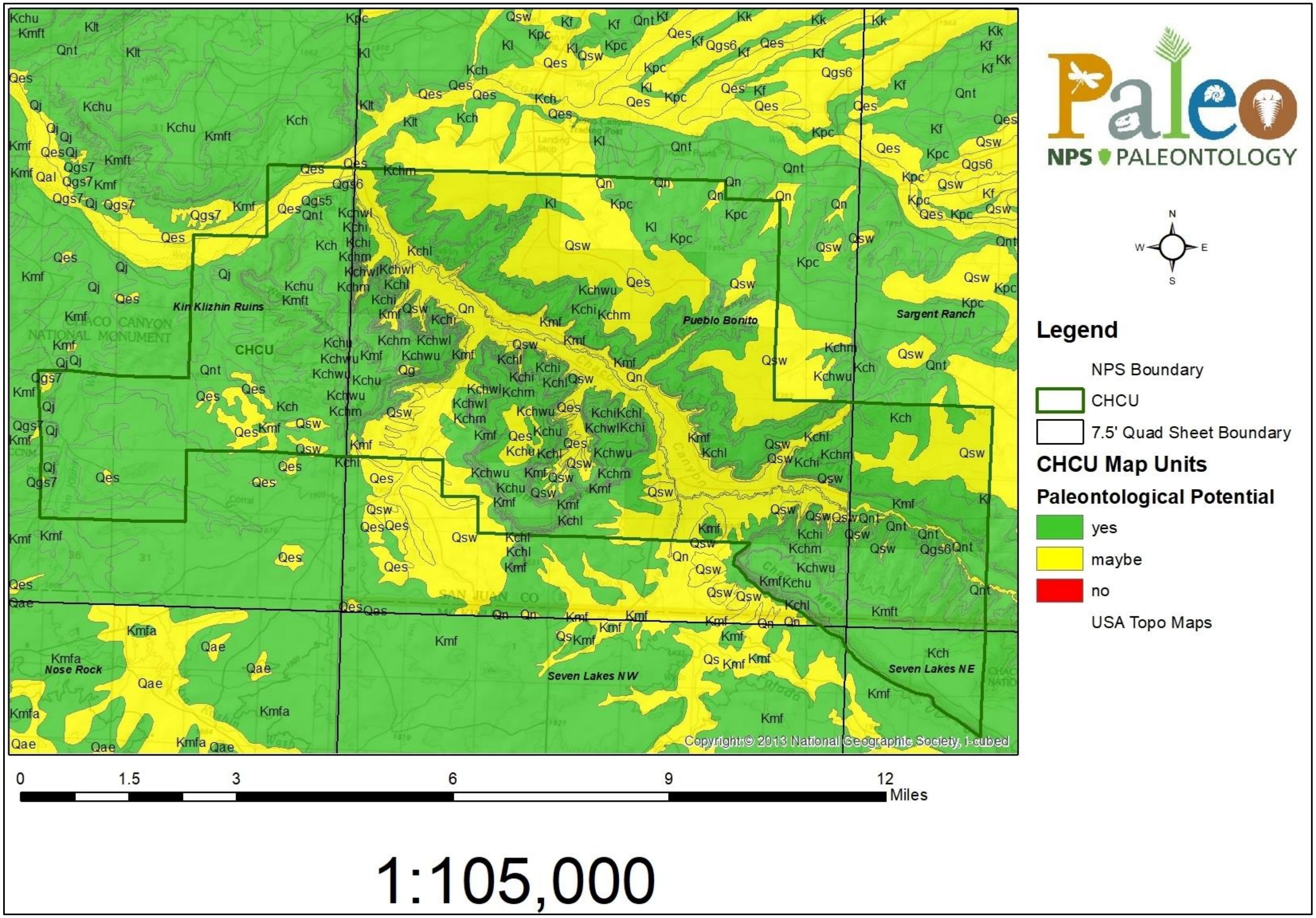
Quaternary Units
Qal = Alluvium (Holocene)
Qn = Naha alluvium (Holocene)
Qnt = Naha and Tsegi alluvium, undifferentiated (upper Holocene)
Qj = Jeddito alluvium (upper Pleistocene to lower Holocene)
Qae = Alluvium and eolian (Pleistocene? to Holocene)
Qsw = Sheetwash alluvium (upper Pleistocene to Holocene)
Qes = Eolian sand (upper Pleistocene to Holocene)
Qg = Gravel (Pleistocene)

Upper Cretaceous Units
Kk = Kirtland Shale (not present in CHCU)
Kf = Fruitland Formation (not present in CHCU)
Kpc = Pictured Cliffs Sandstone
Kl = Lewis Shale

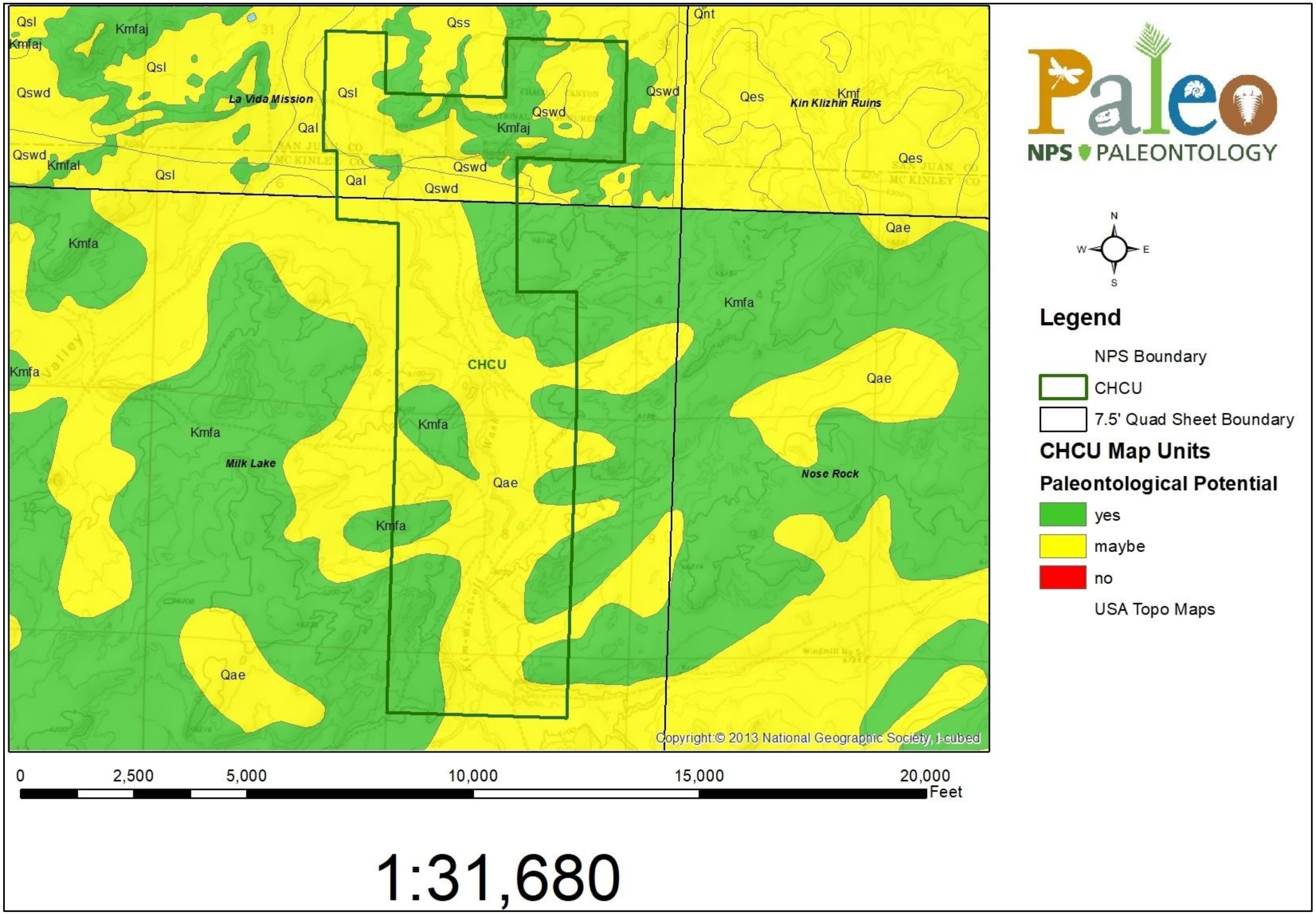
Cliff House Sandstone – Upper Cretaceous
Kch = Cliff House Sandstone
Kchu = upper sandstone unit
Kchw = white to light gray sandstone, upper unit
Kchwl = white to light gray sandstone, lower unit
Kchm = middle sandstone unit
Kchl = lower sandstone unit

Menefee Formation – Upper Cretaceous
Kmf = Menefee Formation
Kmft = Tongues of the Menefee Formation
Kmfa = Allison Member
Kmfav = Allison Member, La Vida Beds
Kmfaj = Allison Member, Juans Lake Beds
Kmfal = lower part of Allison Member

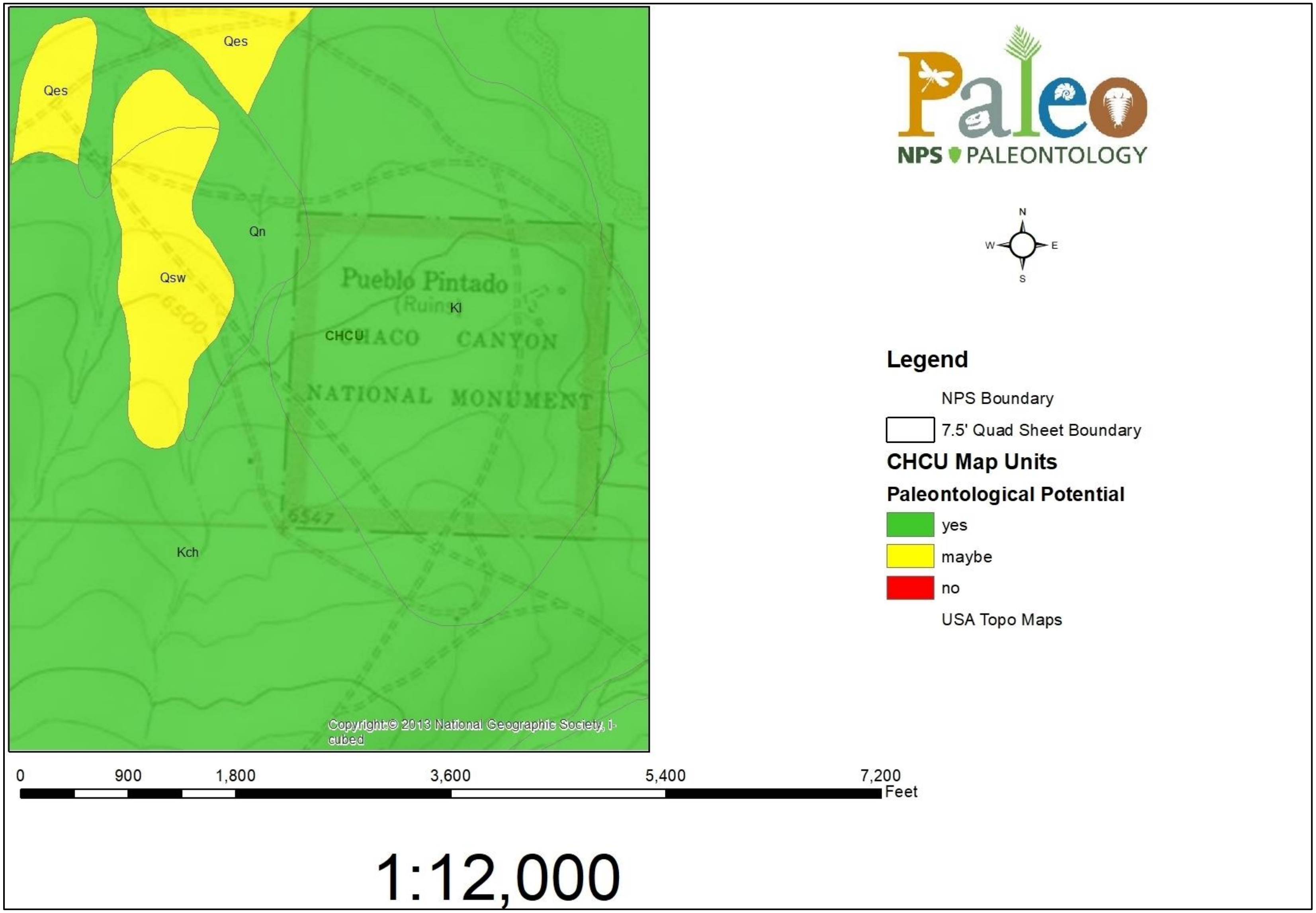
Crevasse Canyon – Upper Cretaceous
Kcg = Gibson Coal Member
Kcda = Dalton Sandstone Member



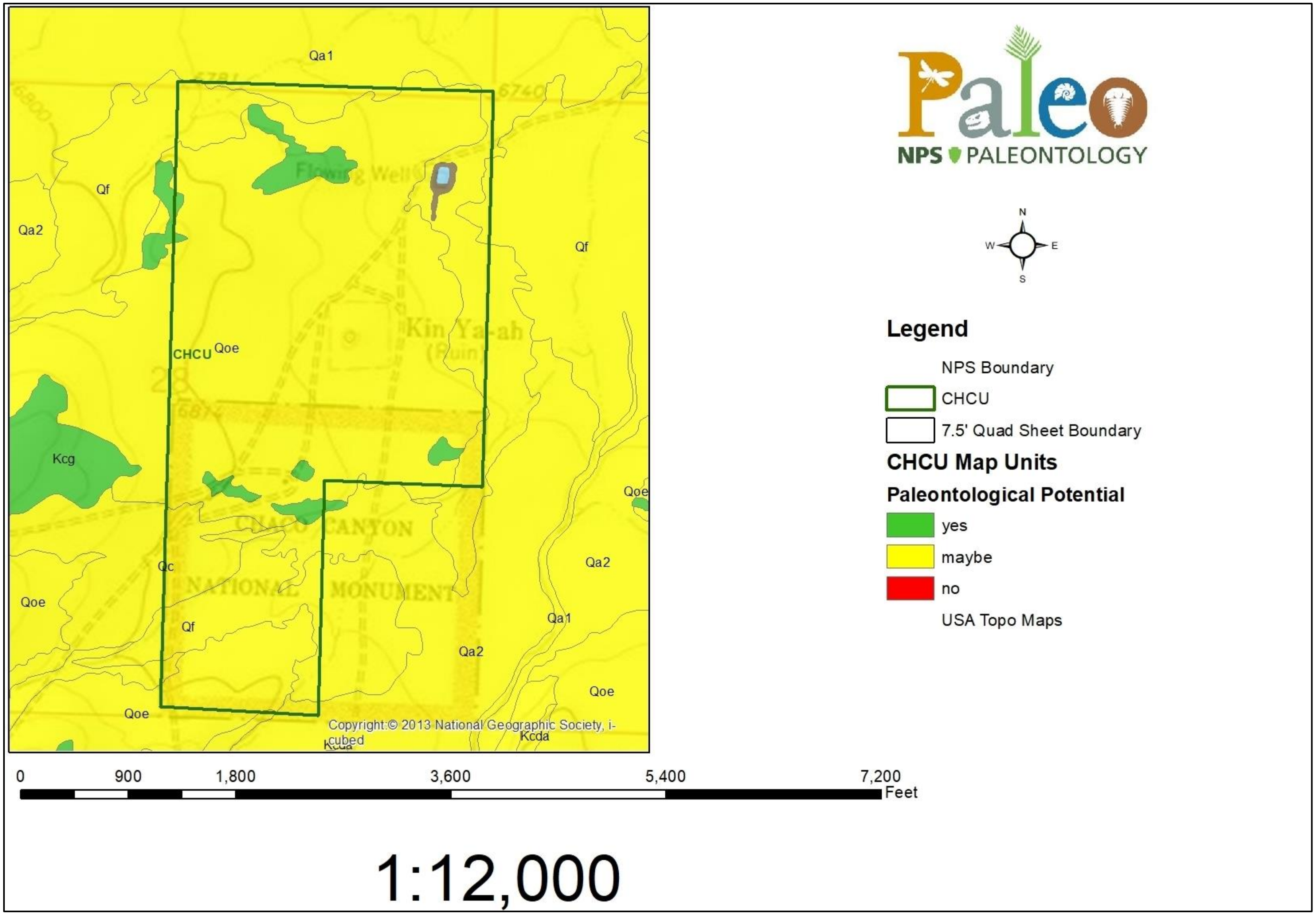
Appendix Figure D-1. Paleontological potential map of the main unit of CHCU (NPS/TIM CONNORS, Geologic Resources Division data).



Appendix Figure D-2. Paleontological potential map of the Kin Bineola unit of CHCU (NPS/TIM CONNORS, Geologic Resources Division data).

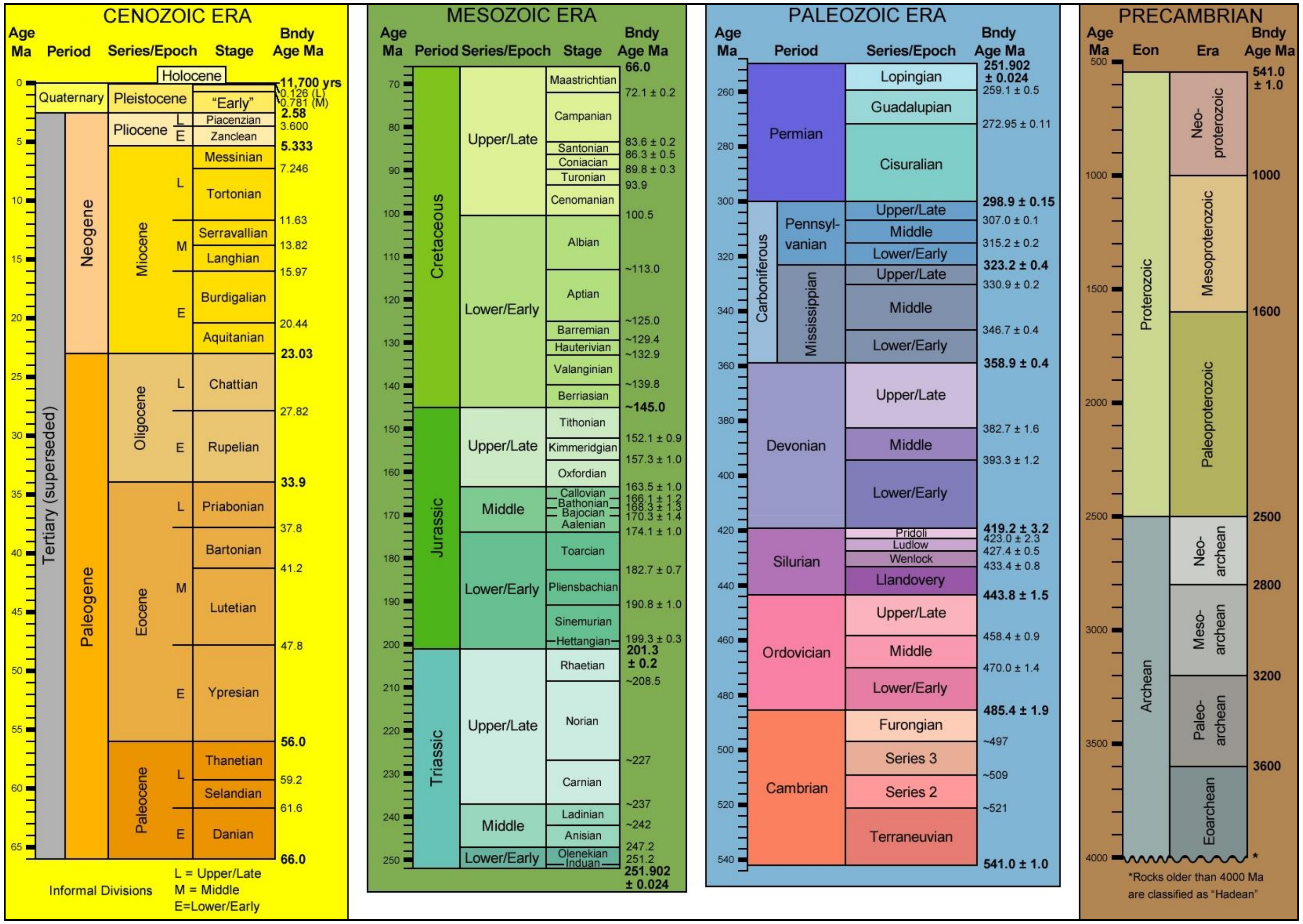


Appendix Figure D-3. Paleontological potential map of the Pueblo Pintado unit of CHCU (NPS/TIM CONNORS, Geologic Resources Division data).



Appendix Figure D-4. Paleontological potential map of the Kin Ya'a unit of CHCU (NPS/TIM CONNORS, Geologic Resources Division data).

Appendix E: Geologic Time Scale



Ma=Millions of years 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 2018/08 (http://www.stratigraphy.org/index.php/ics-chart-timescale) and USGS Fact Sheet 2007-3015 (https://pubs.usgs.gov/fs/2007/3015/).

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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National Park Service
U.S. Department of the Interior

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