National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Wind Cave National Park

Paleontological Resource Inventory (Public Version)

Natural Resource Report NPS/WICA/NRR—2023/2536

ON THE COVER

A marine gastropod from the Madison Formation embedded within the iconic boxwork of Wind Cave.
NPS

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Natural Resource Report NPS/WICA/NRR—2023/2536

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Note: Paleontological resources in National Park Service lands are protected by law. Unauthorized collection of fossils from National Park Service lands is prohibited except under the terms of an approved research and collecting permit. See the text for more information on protecting and preserving these non-renewable resources for the benefit of all.

June 2023

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

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Please cite this publication as:

Herring, T., J. S. Tweet, and V. L. Santucci. 2023. Wind Cave National Park: Paleontological resource inventory (public version). Natural Resource Report NPS/WICA/NRR—2023/2536. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/2299620

NPS 108/189648, June 2023

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Executive Summary

Wind Cave National Park (WICA), the first cave in the world to become a national park, is famous for the park's namesake feature. Wind Cave, named for the noticeable wind-flow patterns observed as air moves in and out of the natural cave entrance, is currently the third longest cave system in the United States and seventh longest in the world. Wind Cave formed when groundwater dissolved buried layers of the fossiliferous Madison Limestone, which were deposited during the Mississippian subperiod approximately 359 to 347 million years ago. In addition to the Madison Limestone, several other formations are exposed within the park, dating from the early Proterozoic to the Holocene.

The presence of fossils within the park has been known since at least the late 19th century when early settlers explored the cave to turn the geologic feature into a tourist attraction. However, most of the geologic work conducted during the park's history has focused on the exploration and development of the cave itself, rather than its fossils. Paleontology became a bigger focus in the late 20th century when the park partnered with the South Dakota School of Mines and Technology to recover and research fossils found within the cave and on the park's surface. Other partnerships include those with the Mammoth Site of Hot Springs and Northern Arizona University, through which researchers have studied Quaternary cave deposits found across the park.

In ascending order (oldest to youngest), the geologic formations at WICA include undifferentiated lower Proterozoic rocks (Precambrian), Harney Peak Granite (Precambrian), Deadwood Formation (Cambrian–Ordovician), Englewood Limestone (Devonian–Mississippian), Madison Limestone (Mississippian), Minnelusa Formation (Pennsylvanian–Permian), Opeche Shale (Permian), Minnekahta Limestone (Permian), Spearfish Formation (Permian–Triassic), Sundance Formation (Middle–Upper Jurassic), Unkpapa Sandstone (Upper Jurassic), Lakota Formation (Lower Cretaceous), Fall River Formation (Lower Cretaceous), White River Group (Eocene–Oligocene), and Quaternary alluvium, conglomerate, and gravel deposits. The units that are confirmed to be fossiliferous within the park are the Deadwood Formation, Englewood Limestone, Madison Limestone, and Minnelusa Formation, which contain a variety of marine fossils from a shallow sea deposition environment; the Sundance Formation, which has much younger marine fossils; the Lakota Formation, which has yielded petrified wood; and the White River Group and Quaternary deposits, which contain vertebrate and invertebrate fossils deposited in and near freshwater streams, lakes, and ponds.

Many of the fossils of WICA are visible from or near public trails and roads, which puts them at risk of poaching or damage, and there is evidence that fossil poaching occurred at several of the Klukas sites soon after they were discovered. Furthermore, there are several fossil sites on the tour routes within Wind Cave, which are of value to interpretation and the park experience. WICA has implemented cyclic fossil surveys in the past to monitor site conditions, and it is recommended that this paleontological resource monitoring be continued in the future.

Acknowledgments

We would like to thank the staff of WICA, who have been beyond helpful in the development of this report by assisting with questions about interpretation, management, and park history and allowing us to conduct fieldwork within the park. We extend our thanks to Superintendent Leigh Welling, Science and Resource Manager Greg Schroeder, Biological and Physical Sciences Technician Hollie Lybarger-Pucket, Chief of Interpretation Tom Farrell, Assistant Chief of Interpretation Lennie Ramacher, Museum Technician Erika Cerveny, and Park Ranger Peelee Clark. Paleontologists Jim Mead, Sandra L. Swift, and Derek J. Jurestovsky (Mammoth Site of Hot Springs) were invaluable in helping manage WICA collections and giving insight into local paleontology. Paleontologists Darrin Pagnac, Nathaniel Fox, and Rachel Benton (South Dakota School of Mines & Technology) helped provide context into the history of paleontology conducted within WICA and gave information on museum collections containing WICA fossils. Kristen Long and Anine Rosse (Northern Great Plains Inventory and Monitoring Network) participated in the initial scoping for this paleontological resource inventory, and Anine served as peer review coordinator. Sarah Jacquet and Tara Selly (University of Missouri) provided information about trilobite collections that came from within the park. Tiffany Adrian (University of Iowa) provided information about conodont collections that came from within the park. Rod Horrocks (Carlsbad Caverns National Park) participated in an oral history review of his service in the park, lending important context to the history of paleontological resource site monitoring and fieldwork within the park. Cavers from Colorado and South Dakota assisted with fossil collection during the Persistence Cave dig. Outside review was provided by Jim Mead (Mammoth Site), Darrin Pagnac (South Dakota School of Mines & Technology), and Rod Horrocks (Carlsbad Caverns National Park). Additional review was provided by Georgia Schneider and Pat Seiser (National Cave and Karst Research Institute).

Dedication

We are pleased to dedicate this report to two physical scientists who have contributed greatly to our knowledge of the resources of Wind Cave National Park: Rod Horrocks and Marc Ohms. Rod Horrocks was a physical scientist at WICA from 1999–2015. During his time, he completed several cave reports and recorded more than 2,250 hours surveying Wind Cave, contributing to an improved understanding of the cave's paleontological and geological resources. Rod also assessed and collected hundreds of fossils from the White River Group, discovered and named more than two dozen sites, and contributed to the discovery of the famous Centennial Site and orchestrated two major excavations of that site.

Marc Ohms, WICA physical scientist from 1998 to present, has also largely contributed to the park's value as a geological and paleontological resource. Marc's discovery of Persistence Cave in 2003 was one of the greatest geological discoveries in park history, solving a long-standing mystery of a second potential opening to Wind Cave. Persistence Cave has also proven to be a phenomenal paleontological locality, as thousands of Pleistocene and Holocene fossil specimens have been excavated so far with potentially thousands more to be discovered. Marc also has greatly contributed to our knowledge of Wind Cave, with more than 3,000 hours spent guiding, exploring, and surveying the cave.

Rod Horrocks, former WICA Physical Scientist (left), and Marc Ohms, current WICA Physical Scientist (right) (NPS).

Introduction

Wind Cave National Park (WICA) encompasses 13,697 hectares (33,847 acres) of land in Custer County, southwestern South Dakota, all under federal administration. The park was proclaimed a national park on January 9, 1903, making Wind Cave the first cave to become a national park. WICA was established to protect Wind Cave, now known to be one of the longest cave systems in the world with over 260 km (160 mi) of surveyed passages, as well as diverse wildlife on the surface (including the significant Wind Cave bison herd; Figure 1). WICA has had several boundary changes: March 4, 1931; August 9, 1946; November 10, 1978; September 21, 2005, and September 2011. Wind Cave National Game Preserve was established on August 10, 1912 and was added to the park on June 15, 1935. Fossil Cycad National Monument, established October 21, 1922, was formerly administered through WICA but was deauthorized on September 1, 1957 (Tweet et al. 2011; Santucci and Ghist 2014).

Figure 1. A bison lying in the plains of Wind Cave National Park (NPS/THEODORE HERRING).

WICA is in the southeastern Black Hills, less than 10 km (6 mi) north of Hot Springs and 17 km (11 mi) south of Custer. Black Hills National Forest borders WICA on the west, and Custer State Park borders WICA on the north (Figure 2). Jewel Cave National Monument (JECA), which shares a similar geologic context to WICA, is located 28 km (17 mi) to the northwest. Other nearby National Park Service (NPS) units include Badlands National Park (BADL), Devils Tower National Monument (DETO), and Mount Rushmore National Memorial (MORU) (Tweet et al. 2011).

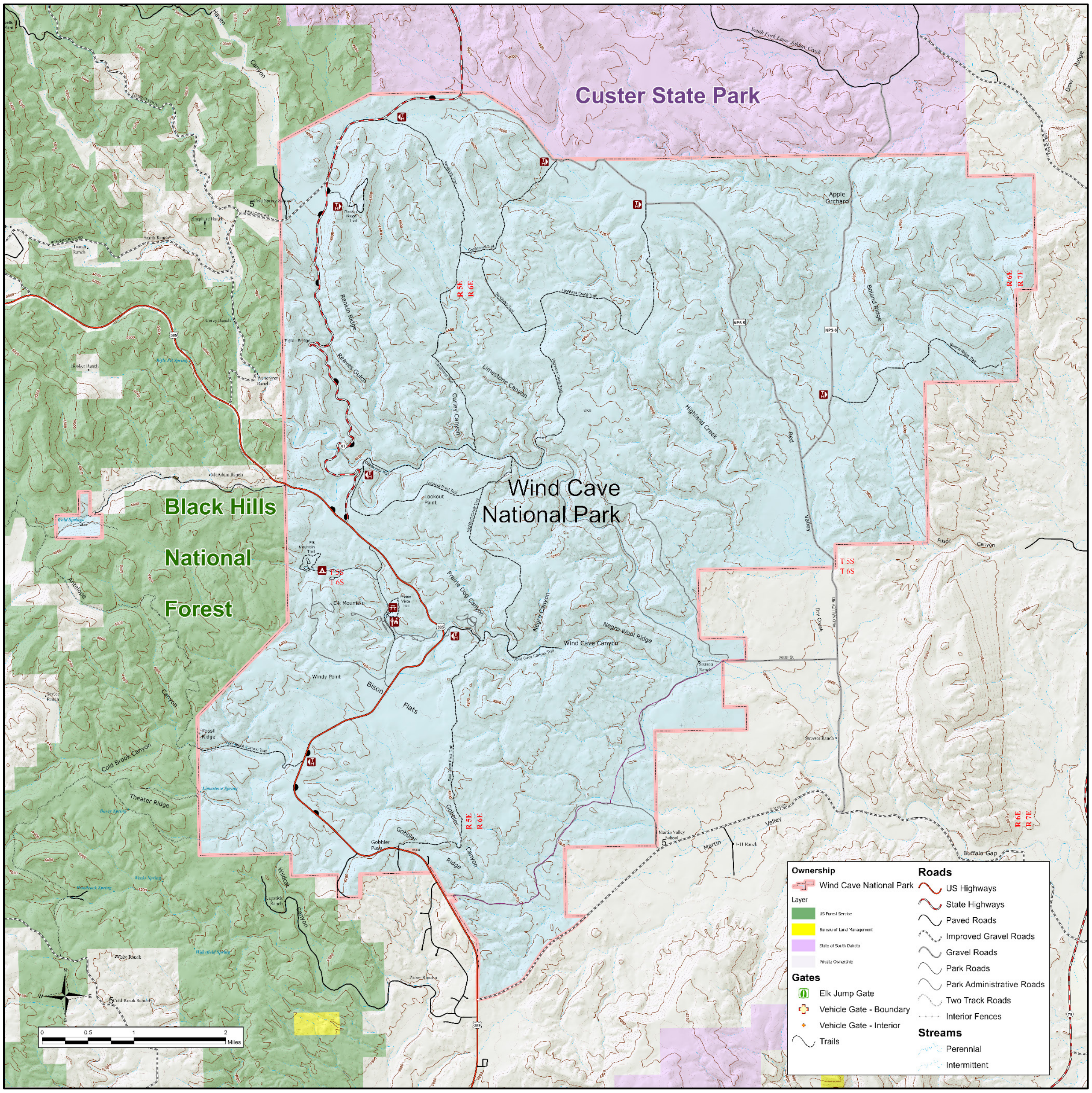

Figure 2. Park map of WICA (NPS map).

WICA is one of the most geologically diverse parks in the United States, with metamorphosed rocks dating to perhaps 2.6 Ga (billion years ago) to Holocene deposits from the last few thousand years. Some of the environmental features in WICA include caves and rock shelters, creeks, rock outcrops and ridges, sinkholes, and plains. WICA is also an important wildlife refuge: the Wind Cave bison herd has been protected since reintroduction in 1913 in an effort to stop the extinction of the species, and the park expends resources to protect the endangered black-footed ferret, reintroduced in 2007. Wind Cave is also an important cultural site, as the Lakota, an indigenous tribe resident to the Black Hills region, consider the natural entrance to Wind Cave to be sacred (Wind Cave National Park 2020).

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

Significance of Paleontological Resources at WICA

The fossils of WICA span a large swath of geologic history, with invertebrates that span the Paleozoic and vertebrates found in middle Cenozoic deposits and Quaternary surficial and cave deposits. Collectively, these fossils provide insight into the environmental changes that have occurred in the area over deep time. The marine invertebrate fossils within Wind Cave yield information on how and when the cave's bedrock was formed and help differentiate layers within the cave. Vertebrate surface fossils preserve information on how community structure might differ in higher elevation habitats compared to other geochronologically equivalent localities such as BADL. The excellent record of Holocene material also demonstrates how faunal and floral shifts occur over the scale of a few thousand years. The fossils of WICA are also a concern for resource management.

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. Those authorities and guidance directly applicable to paleontological resources are cited below in Appendix E. Paleontological resource inventories have been developed by the NPS Paleontology Program in order to compile baseline information regarding the scope, significance, distribution, and management issues associated with fossil resources present within parks. This information is intended to increase awareness of park fossils and paleontological issues in order to inform management decisions and actions that comply with these laws, directives, and policies. Options for paleontological resource management are locality-specific, and may include no action, surveys, site monitoring, cyclic surveys, stabilization and reburial, shelter construction, excavation, closure, patrols, and alarm systems or electronic surveillance. See Appendix E for additional information on applicable laws and policy.

Project Objectives

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

- Locating, identifying, and documenting paleontological resource localities through field reconnaissance and perusal of archives, using photography, GPS data, and standardized forms.
- Relocating and assessing historical fossil localities.

- Assessing collections of WICA fossils maintained within park collections and in outside repositories.
- Documenting current information on faunal assemblages and palaeoecological reconstructions.
- Interviewing current and previous park staff to gather information on the status of paleontological resources, to aid in formulating plans for management, ideas for interpretation, and recommendations.
- Conducting a thorough search for relevant publications, unpublished geologic notes, and outside fossil collections from WICA.

History of Paleontological Work at WICA

Paleontological observations in Wind Cave extend back to the late 19th century when the cave was explored by the McDonald family to market and prepare it for tourism. One member of this family, Alvin McDonald (Figure 3), developed a deep love and admiration for the cave and all its contents and kept a diary describing his exploration and discoveries. Despite being only sixteen years old when he started exploring the cave in 1891, Alvin was mature for his age and had a strong understanding of the importance of the fossils within the cave and recording their presence. His discovery of a "mountain rat" skeleton and a "giant coral" on January 2, 1891, are the first recorded fossil vertebrate and invertebrate discoveries within Wind Cave. He also found a calcite crystal with "coral studs" embedded in it and named different locations after fossil discoveries, such as "Giant Coral", "Coral Crevice", "Coral Pit", "Fossil Reef", and "Fossil Chamber", all recorded between 1891 and 1893 (McDonald 1893); the latter four names are still used today. Alvin died in December 1893 from typhoid fever, and exploration of the cave halted for decades.

Figure 3. Portrait of Alvin McDonald, one of the first explorers of Wind Cave, in the early 1890s (NPS/UNKNOWN PHOTOGRAPHER, WICA ARCHIVES).

Several other geologists and speleologists documented fossils in Wind Cave from 1891–1900. State Geologist James Edward Todd gave the first detailed description of invertebrate fossils discovered within the cave by 1894:

"In the boxwork of Wind Cave some very interesting fossils are beautifully preserved. That is, they are suspended in the open meshes of the boxwork and coated with crystals similar to those upon the boxwork. Some of these are long and slender like reeds or slender algae. They uniformly lie horizontal or parallel with the original embedding strata. Some attain a length of nearly a foot [30.5 cm] with a diameter of less than a quarter of an inch [6.4 mm]. Some of the shells resembling Euomphalus *and Pleurotomaria, with a diameter of from 2 to 3 inches [5.1 to 6.7 cm], were preserved in a similar way. Others preserved in this way were horn-shaped corals 5 or 6 inches [12.7 or 15.2 cm] in length, and shells resembling* Chonetes *about 2 inches [5.1 cm] in width."* (Todd 1894:51).

One Wind Cave visitor who documented their fossil finds was speleologist Luella Agnes Owen, known for her exploration of caves in Missouri. Owen writes about her caving exploits in "Cave Regions of the Ozarks and Black Hills", published in 1898, which also includes early photos of Wind Cave (Figure 4). This book includes the first mention of the brachiopod fossils in the low ceilings of the Fairgrounds Tour Route, a public tour still offered at WICA today: "A steep pathway and one flight of stairs now brings us to the Ticket Office, and another short stairway leads to the room above, which is the Fair Grounds [sic]. We enter the right wing, which measures two hundred and six links in length and forty-nine in width and no box work is seen, but the ceiling (which is low) shows many interesting fossils" (E. L. McDonald *in* Owen 1898:137–138).

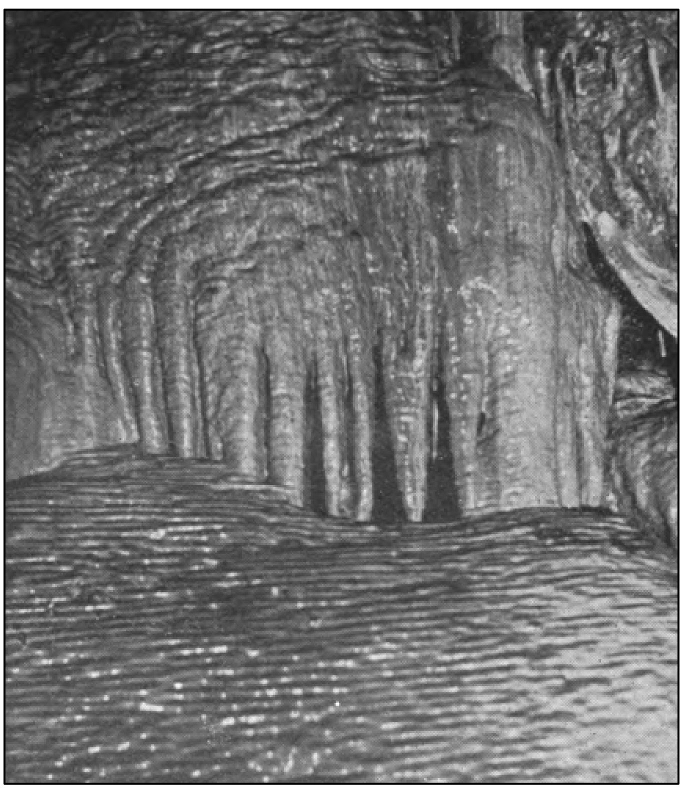

Figure 4. A flowstone calcite formation, called "Glacier" by Luella Agnes Owen, found within Wind Cave a short distance from the Fairgrounds Tour Route (Owen 1898: unnumbered between pages 150 and 151).

From 1899–1900, N.H. Darton studied the geology of the southern Black Hills. Darton mentioned that he had found fossils in the Deadwood Formation in an area now within WICA boundaries, but he did not mention the type of fossils or describe how they looked (Darton 1901).

Paleontological work in WICA from 1910 to 1984 was limited, but there were a few studies focused on fossils in the Deadwood Formation and Minnelusa Formation. In 1955, Robert L. Bates discovered fossils replaced by crystalline calcite in dolomite, fossiliferous limestone, and what he called "fossil cavities" when examining the Minnelusa Formation (Bates 1955). In 1956, Christina Lochman-Balk and her students studied the rocks of the Deadwood Formation, where they discovered and collected trilobites (Lochman-Balk 1956). In the late 1950s and early 1960s, paleontologists T. V. Jennings, George J. Verville, and Eric E. Thompson studied microfossils from Minnelusa Formation rocks in what is now the central part of WICA, in land not acquired by the park until recently (Jennings 1959; Verville and Thompson 1963).

Between 1922 and 1957, WICA was responsible for the administration of the nearby Fossil Cycad National Monument. The history of the monument includes the loss of the non-renewable fossil cycadeoids due to over-collecting at the locality. A few fossil cycadeoid specimens are currently maintained in the WICA museum collection, along with several other museums across the United States. Additional information about Fossil Cycad National Monument is included in a section of this report on fossil localities near WICA and in two publications dedicated to the history of the abolished national monument (Santucci and Hughes 1998; Santucci and Ghist 2014).

Knowledge of paleontological resources at WICA greatly expanded in the 1980s. In 1984, an NPS policy was established requiring that cave reports be prepared after all exploration, which led to better documentation of geologic and paleontological finds. Furthermore, WICA biologist Richard Klukas began to work closely with paleontologist James Martin from the South Dakota School of Mines & Technology (SDSMT), launching an era of paleontological work on a scale not previously seen within the park. One project they worked on was documenting the Chamber of Lost Souls, a Wind Cave room with a plethora of mammal bones. Together, they excavated the bones, which are currently held at the SDSMT (Martin 1984; Martin and Anderson 1997). A second project was the excavation of the Beaver Creek Rock Shelter (also known as just Beaver Creek Shelter), a Holocene paleontological and archaeological locality. Thousands of bones were eventually collected from this rock shelter and the collections were published by Martin and his students (Martin et al. 1988; Abbott 1989; Benton 1991). The third major collaboration between Martin and Klukas was the excavation of White River Group fossil sites. In 1985, Klukas discovered seven White River Group fossil sites in the park. Upon examination by Martin, these sites turned out to be some of the most productive fossil sites in the park, yielding hundreds of fossils from the Brule Formation, dating to the Oligocene epoch of the Paleogene Period (Martin 1988).

Other paleontological studies during this time include the excavations of Graveyard Cave (Manganaro 1994) and Salamander Cave (Mead et al. 1996), which revealed a phenomenal record of Pleistocene and Holocene flora and fauna. The trilobites discovered by Lochman-Balk in the 1950s were reexamined and identified for the first time in the late 1990s (Stitt 1998). In 2003, the park's centennial year, an excellent *Subhyracodon* (small hornless rhinoceros) fossil was discovered by

Greg McDonald at a new fossil site within the White River Group; it is likely the most famous individual fossil discovery from the park (Horrocks 2003a). The site was named the Centennial Site. The White River Group would continue to be explored through the 2000s and 2010s by park physical scientist Rod Horrocks, who discovered more than twenty additional fossil sites from this geologic layer. A remarkable Minnelusa Formation conodont locality was also discovered in 2003 by a USGS paleontologist conducting geological surveys in the Black Hills (Rod Horrocks, former WICA physical scientist, pers. comm., 2003).

One of the more important geologic discoveries in the park's history came in the early 2000s when park physical scientist Marc Ohms discovered Persistence Cave. This discovery generated significant media attention and was featured in national news. After preliminary excavation, it was hypothesized that Persistence Cave is likely another entrance to Wind Cave, as Persistence Cave has remarkably similar changes in air pressure to those observed within Wind Cave (Marc Ohms, WICA physical scientist, pers. obs., 2008). Persistence Cave has also proven to be an important Quaternary fossil reserve. This cave has yielded thousands of bones preserved at different intervals over the last forty thousand years. The excavated bones are currently being studied by paleontologists at the nearby Mammoth Site of Hot Springs (Theodore Herring, pers. obs., Nov. 2022). One of the most important discoveries associated with this dig was a fossil pine marten (*Martes americana*) dating between 40,000 to 12,000 years old. The pine marten is not presently found in the Black Hills and this record from Persistence Cave confirms the taxa's occurrence in the area during the late Pleistocene (Mead et al. 2021). Other discoveries of interest include several rodent and pika species that are not found in the area presently, and bison bones that indicate the bison were distinctly larger in the Pleistocene than they are today (Jim Mead, Mammoth Site of Hot Springs Director of Research, pers. comm. Feb. 2023). The Persistence Cave excavation is currently active and is one of the primary sources of interest for both park paleontology and geology (T. Herring, pers. obs., Nov. 2022).

There have been several cave trips over the past twenty years, documenting several notable fossil discoveries, but very little collection has taken place. WICA trip reports can be viewed at https://www.nps.gov/wica/learn/historyculture/wind-cave-trip-reports.htm (Wind Cave National Park 2019). Physical scientists Rod Horrocks and Marc Ohms have discovered mass brachiopod death assemblages (Wind Cave trip report: 2000, Horrocks and Ohms), remarkable coral preservation (Wind Cave trip report: 2007, Horrocks et al.), several types of burrows that reach up to 0.6 m (2 ft) in length (Wind Cave trip report: 2006, Horrocks and Marohn), filamental bacterial strands (Wind Cave trip report: 2003, Horrocks and Moreland), horn corals (Wind Cave trip report: 2011, Horrocks and Geu), and crinoid stems (Wind Cave trip report: 2012, Horrocks and Geu). Furthermore, there have been over 80 reported fossil bone localities within the cave, dating between 6,000 years to present (M. Ohms, pers. obs., Nov. 2022).

Summary of 2022 Paleontological Resource Inventory

The 2022 Wind Cave National Park Paleontological Resource Inventory compiles baseline fossil information from localities with the cave system and the terrestrial geologic exposures in the park. The inventory includes reexamination of previously reported fossil localities and documentation of new fossil localities. This inventory report presents information on the scope, significance, distribution (both temporal and geospatial), and management issues associated with WICA fossil resources. Further, fossil localities have been evaluated in terms of the stability and condition of the paleontological resources that are managed in situ at WICA. This project was performed under permit WICA-2022-SCI-0017.

One component of the paleontological inventory was the cyclic examination of the park's White River Group Sites, a collection of 30 fossil localities. These localities have all yielded fossils from the White River Group but have not been surveyed since 2014. Theodore Herring surveyed all thirty of these sites during October and November 2022. Herring concluded that little material had been exposed from these sites since they were last surveyed. He also updated the GPS coordinates for these sites if inaccurate and worked with park staff to curate an updated map of surface localities within the park. The few new fossils found at these White River Group sites included a gastropod and a partial *Leptomeryx* jaw, which were collected.

Herring also surveyed surface exposures of the Deadwood Formation, Englewood Limestone, Madison Limestone, Minnelusa Formation, Lakota Formation, and Quaternary deposits, confirming the existence of in situ fossil resources from many of these geologic layers. He documented several corals in the Englewood Limestone, collected brachiopods from the Madison Limestone, collected conodonts from the Minnelusa Formation, confirmed petrified wood specimens in the Lakota Formation, and documented and collected ungulate bones from Quaternary deposits.

Herring, Marc Ohms, and Hollie Lybarger-Pucket made several cave trips to document or collect fossils as well. Several brachiopod fossil sites were documented and photographed. There were also a few vertebrate sites with Holocene mammal remains, some of which were collected. Herring also participated in the Persistence Cave dig, helping to collect and document bones for study at the Mammoth Site of Hot Springs.

Geology

Geologic History

The oldest rocks in the Black Hills are metamorphosed rocks that formed from 2.6 to 2.56 Ga (giga-annum or billion years ago; see Appendix D for a glossary). They are overlain by rocks deposited during rifting events that occurred from 2.56 to 2.48 Ga and 2.1 to 1.88 Ga (Dahl et al. 2007). The depositional setting was likely a basin within a continent (Redden et al. 1990). Deposition occurred during the breakup of a large continental fragment between 2.6 and 2.1 Ga (Hark et al. 2008), followed by mantle plume events between 2.01 and 1.88 Ga (Van Boening and Nabelek 2008). These geologic events caused major metamorphic deformation in these rocks over time (Dahl et al. 2007).

The Black Hills are part of the Trans-Hudson Orogeny, rocks deformed by the junction of continental fragments such as the Wyoming Craton, the Yavapai Terrane, the Superior Craton, and the Hearne Craton (Dahl et al. 1999, 2007). Specifically, the Black Hills are on the outside of the Wyoming Craton. Rocks of the Trans-Hudson Orogeny were deformed during the collision of the Wyoming Craton and Superior Craton between 1.77 and 1.715 Ga; the Harney Peak Granite, one of the units found within WICA, formed at the end of this collision around 1.715 Ga ± 3 million years (Dahl et al. 1999).

The next youngest rocks in succession at WICA were deposited around 525 Ma (million years ago) during the Cambrian Period (Gries and Martin 1985). During this time, southwestern South Dakota was submerged beneath a shallow continental sea that underwent a series of transgressions and regressions (Kulik 1968; Stanley and Feldmann 1998). These transgression-regression cycles are recorded in the types of rocks that were deposited: one such long regression near the end of the Cambrian resulted in extensive exposure of marine sediments (Stitt and Perfetta 2000). There is a hundred-million-year gap in the rock record of WICA following these Cambrian deposits, resulting from either a period of either non-deposition or erosion (Tweet et al. 2011).

The next documented depositional period took place during the Devonian when a shallow sea once again covered the area (Fahrenbach 1990). This sea was present for the next three hundred million years, resulting in layers of deposition just above or just below sea level (Tweet et al. 2011). Shallow marine deposition during the Early Mississippian resulted in thick layers of Madison Limestone (also known as Pahasapa Limestone; WICA prefers "Madison Limestone"), the foundation for the park's caves. Additionally, when the continental sea retreated, the upper Madison Limestone was exposed to fresh groundwater, causing dissolution and the formation of voids in the rock. These early caves are considered by some to be precursors to the modern cave system (Palmer and Palmer 1989).

Following another marine transgression, the next deposited unit at WICA was the Minnelusa Formation (Cicimurri and Fahrenbach 2002). Depositional settings varied with sea level fluctuations caused by seafloor spreading and glacial sheets (Ward 1981). Eventually, the global icehouse phase would end early in the Permian, leading to warming and a rising sea level (Dopheide and Winniger 2008). The next three units, the Opeche Shale, Minnekahta Limestone, and Spearfish Formation, were deposited under settings highly adverse to diverse life. These settings included an arid saline coastal flat with strongly acidic waters (Benison and Goldstein 2000), a marine shelf beneath a hypersaline sea (Dopheide and Winniger 2008), and a hypersaline coastal to shallow marine setting similar to the modern Persian Gulf (Sabel 1984). These conditions existed until a Triassic marine regression that caused uplift and erosion, resulting in what is now the northwestern Black Hills (Robinson 1956).

Marine deposition returned during the Jurassic when a shallow seaway covered the area. There were several transgression-regression cycles from the Early Jurassic through the Late Jurassic, preserved in WICA as the Sundance Formation (Street et al. 2007). Once this sea waned, a dune field was left behind, eventually lithifying as the Unkpapa Sandstone before being covered by the Morrison Formation (Szigeti and Fox 1981). There is some potential for the Morrison Formation to be found in the park, but it has not yet been identified in park boundaries.

After a 20-to-30-million-year break in the rock record, the Lakota Formation, part of the Inyan Kara Group, is seen in the park, deposited from ancient floodplains, streams, and lakes (DeWitt et al. 1986). Deposition was then once again continuously interrupted by transgression-regression cycles of the Western Interior Seaway, which submerged the central United States for another 30 million years. These cycles are represented in the geologic record in part by the Fall River Formation (KellerLynn 2009).

The Black Hills, an asymmetric doubly plunging anticline (essentially a dome shape), formed partly by uplift during the Paleocene and partly by the Laramide Orogeny, a large mountain-building event that occurred during the Late Cretaceous and early Cenozoic (Karner 1989). By the late Oligocene, much of the present surface of the Black Hills had been produced by erosion, which contributed sediment to several Cenozoic formations of the Great Plains. Among these formations are the units of the White River Group, seen in WICA and BADL (Lester 2002).

The White River Group is a sequence of terrestrial deposits that filled basins during uplift events in the Laramide Orogeny. During the deposition of these sediments, there was a global climate shift, marking the Eocene–Oligocene boundary. This resulted in a “climate crash” that produced drier, more seasonal, cooler, and open forested grasslands in the place of forests (Sheldon 2009). The White River Group also incorporates significant volcanic elements; the origin of these elements is not known but may be attributed to volcanoes in the Great Basin (Loope et al. 2005) or the Rabbit Ears and Thirtynine Mile volcanics of Colorado (Rocky Mountain Association of Geologists 1972).

The Black Hills continued to rise through the Cenozoic, from the Oligocene up until the Pleistocene (Mears 1993). In the past 10 million years, there has been 100 to 500 m (330 to 1,600 ft) of uplift, resulting in the modern topography (Laury 1990). Since the White River Group, there have been no other layers recorded within the boundaries of WICA outside of Quaternary alluvium, conglomerate, and gravel deposits (Fagnan et al. 2013).

During the past 12,000 years, the climate has shifted from the Ice Age of the Pleistocene to a drier and warmer climatic regime. There were distinct dry periods throughout the Holocene, occurring 7,500, 5,400, and 2,800 years ago to the present (Lyford et al. 2003).

The caves at WICA developed throughout the Paleocene and Eocene, as the uplifted Black Hills eroded under a humid climate (KellerLynn 2009). Groundwater infiltrated the Madison Limestone, creating voids in the rock. These caves drained at the end of the Eocene as the climate dried, and they were buried by sediments eroding from the Black Hills. These buried caves were filled with stagnant geothermically heated water. More recently, the overlying sediments were eroded, the groundwater flow patterns were reactivated, and the caves were drained again, resulting in their modern state (Palmer et al. 2009). The full extent of Wind Cave is not known, but recent observations suggest the cave likely extends outside park boundaries (M. Ohms, pers. obs., 2006). See also Palmer (1981), Palmer and Palmer (1989), and Palmer et al. (2009) for summaries of cave geology.

More than a dozen bedrock formations are mapped in WICA (Fagnan et al. 2013) (Figure 5). In ascending order (oldest to youngest), they include several metamorphosed Proterozoic sedimentary units, the Harney Peak Granite (Proterozoic), Deadwood Formation (upper Cambrian–Lower Ordovician), Englewood Limestone (Upper Devonian–Lower Mississippian), Madison (Pahasapa) Limestone (Lower Mississippian), Minnelusa Formation (Upper Pennsylvanian–lower Permian), Opeche Shale (lower Permian), Minnekahta Limestone (Permian), Spearfish Formation (Permian–Triassic), Sundance Formation (Middle–Upper Jurassic), Unkpapa Sandstone (Upper Jurassic), Lakota Formation (Lower Cretaceous), Fall River Formation (Lower Cretaceous), White River Group (upper Eocene–lower Oligocene), and Quaternary sediments (Pleistocene–Holocene) (Table 1). (Note that "lower" and "upper" refer to stratigraphic position, whereas "early" and "late" refer to age. These terms are capitalized if formally defined, e.g., Lower or Early Ordovician versus upper or late Cambrian.)

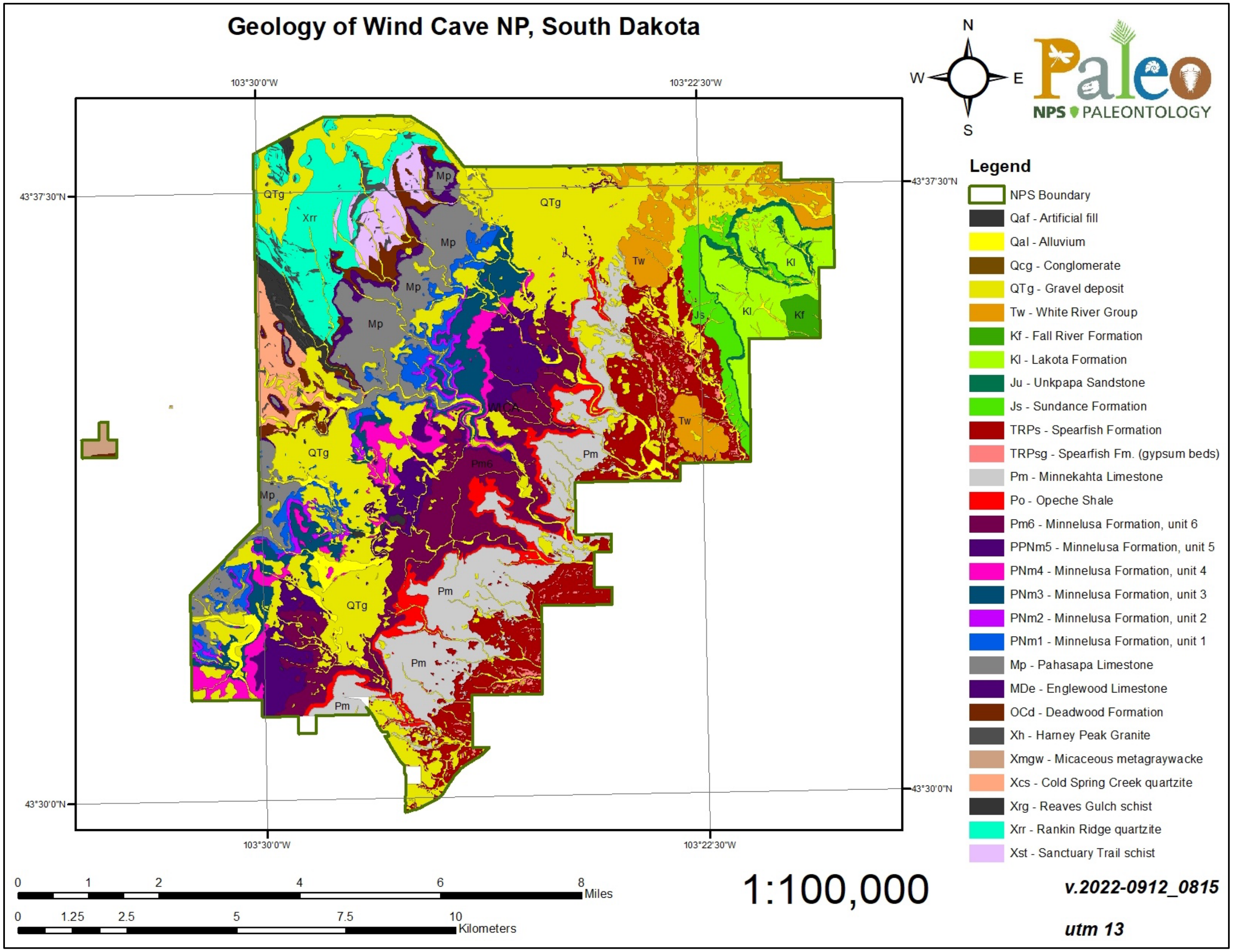

Figure 5. Geologic map of WICA, derived from digital geologic map data available at the following URL: https://irma.nps.gov/DataStore/Reference/Profile/2253881.

Table 1. Summary of WICA 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. (2011).

Formation	Age	Fossils Within WICA	Depositional Environment
Quaternary cave fossils	middle Pleistocene–Holocene	Pleistocene–Holocene cave fossils including charcoal, other plant fossils, bivalves, gastropods, insects, fish, frogs, toads, salamanders, lizards, snakes, falconiforms, owls, ducks, woodpeckers, galliforms, perching birds, other birds, insectivores, rodents, rabbits, pikas, bats, canids, mustelids, bears, horses (middle Pleistocene), peccaries, camels, deer, pronghorns, bison, and indeterminate artiodactyls	Cave resident mortality, carnivorous animals that would bring bones into the cave for feeding, or during flood events that washed organic material into the caves
Quaternary sediments	Pleistocene–Holocene	Late Pleistocene–Holocene phytoliths; charcoal, and bison and undetermined ungulate bones	Fluvial and floodplains
White River Group	late Eocene–early Oligocene	Hackberry seeds, unspecified plant fossils, rhizolith, bivalves, gastropods, tortoises and turtles, lizards, snakes, leptictids, rodents, rabbits, creodonts, canids, horses, rhinoceroses, oreodonts, and deer-like ruminants	Fluvial and floodplain with rare ponds and lakes in semiarid grasslands
Fall River Formation	Early Cretaceous	None found to date	Transgression-regression cycles of the Cretaceous Interior Seaway
Lakota Formation	Early Cretaceous	Petrified wood	Floodplains, streams, and lakes
Unkpapa Sandstone	Late Jurassic	None found to date	Lithified dune field left behind by the shallow continental sea
Sundance Formation	Middle–Late Jurassic	Belemnites	Transgression-regression cycles of a shallow seaway
Spearfish Formation	Permian–Triassic	None found to date	Hypersaline
Minnekahta Limestone	Permian	None found to date	Hypersaline
Opeche Shale	Permian	None found to date	Arid, saline, and acidic
Minnelusa Formation	Pennsylvanian–early Permian	Brachiopods, bivalves, gastropods, conodonts, and fusulinid foraminifera	Variety of coastal settings as sea level fluctuated
Fossil microbial filaments	Pennsylvanian?	Microbial filaments	Not a rock unit, but microbial filaments that grew during a period of ancient dissolution

Table 1 (continued). Summary of WICA 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. (2011).

Formation	Age	Fossils Within WICA	Depositional Environment
Madison (or Pahasapa) Limestone	Early Mississippian	Sponges, corals, bryozoans, brachiopods, gastropods, crinoids, invertebrate burrows, and "reed-like" fossils (likely burrows)	Shallow marine and coastal setting
Englewood Limestone	Late Devonian–Early Mississippian	Horn and tabulate corals, brachiopods, crinoids, unidentifiable bone and tooth fragments, and bioturbation	At or just below sea level in shallow continental seas
Deadwood Formation	late Cambrian–Early Ordovician	Brachiopods, trilobites, invertebrate burrows, and unspecified fossils	Intertidal and subtidal nearshore in a shallow continental sea
Harney Peak Granite	Paleoproterozoic (1715 Ma)	Unfossiliferous	Collision of the Wyoming and Superior cratons
Metamorphosed sedimentary units	Pre-Harney Peak Granite	None found to date; fossils are unlikely but not impossible	Basin within a continent, continental rifting, mantle plumes

Geologic Formations

Proterozoic metamorphic rocks (lower Proterozoic) (Xq, Xmgq, Xmgw, Xcs, Xrg, Xrr, Xst, Xu)

Description: The Proterozoic metamorphic rocks are subdivided into alternating quartzite and schist layers. Some of these layers contain various other minerals such as mica, biotite, muscovite, and manganese, or show other textures (plagioclase-quartz gneiss and granofels) (Fagnan et al. 2013). The rocks were formed between 2.6 and 1.88 Ga (Dahl et al. 2007), the depositional environment likely being a basin within a continent (Redden et al. 1990), and these beds underwent several events such as continental rifting (Hark et al. 2008) and mantle plumes (Van Boening and Nabelek 2008). Some more thick-bedded layers can result in cliffs and ridges ranging from 12–21 m (40–69 ft) tall. These rocks are located in the northwest corner of the park and are not fossiliferous (Fagnan et al. 2013). They are identified on the Fagnan et al. (2013) map as Xmgq (micaceous metagraywacke quartzite), Xmgw (micaceous metagraywacke schist), Xcs (Cold Spring Creek Quartzite), Xrg (Reaves Gulch Schist), Xrr (Rankin Ridge Quartzite), Xst (Sanctuary Trail Schist), Xu (undifferentiated lower Proterozoic Rocks).

Fossils found within WICA: Since these are ancient, high-grade metamorphic rocks, they are not fossiliferous.

Fossils found elsewhere: Since these are ancient, high-grade metamorphic rocks, they are not fossiliferous.

Harney Peak Granite (lower Proterozoic) (Xh)

Description: The Harney Peak Granite is comprised of dikes and sills of predominantly coarse-grained to pegmatitic S-type granite (Fagnan et al. 2013). The granite was formed around 1.715 Ga during the collision of the Wyoming and Superior cratons. The rocks are part of the Trans-Hudson Orogen (Dahl et al. 2007). They are found in the northwest corner of the park and are not fossiliferous.

Fossils found within WICA: Since these rocks are granitic, they are not fossiliferous.

Fossils found elsewhere: Since these rocks are granitic, they are not fossiliferous.

Deadwood Formation (upper Cambrian–Lower Ordovician) (OCd)

Description: The Deadwood Formation is a heterogeneous unit comprised of reddish-brown, basal conglomeratic sandstone, shale, siltstone, and local conglomerate. The upper sandstone exhibits nodular weathering and varies from laminated to thick-bedded. Thickness of the Deadwood Formation in WICA is approximately 9 m (30 ft) (Fagnan et al. 2013). Part of the upper Deadwood Formation has been redefined and transferred to the Whitewood Formation, so older publications might list the Deadwood Formation as being up to 20 m (66 ft) thick. The Deadwood Formation extends across a wide geographic area, from Alberta to Wyoming (Tweet et al. 2011). It was formed in an intertidal and subtidal nearshore and shelf unit and deposited under a shallow continental sea beginning around 525 Ma (Stanley and Feldmann 1998). The age of this formation ranges from the late Cambrian through Early Ordovician. Deadwood Formation rocks can be found in the northwestern part of the park (T. Herring, pers. obs., Nov. 2022).

Fossils found within WICA: Deadwood Formation fossils were discovered in what is now WICA in 1901, but the taxonomic identification of these fossils were not described (Darton 1901). Three trilobite sites have been reported within the park (Stitt 1998). Trilobite specimens were collected from these sites by Christina Lochman-Balk and her students and are presently in the collections of the Department of Geological Sciences at the University of Missouri at Columbia (Stitt 1998). Inarticulate brachiopods and invertebrate traces were also noted in the Deadwood Formation at WICA by Stitt (1998).

Fossils found elsewhere: The Deadwood Formation over its entire depositional area is known for the preservation of trace fossils, whereas body fossils are less common (Tweet et al. 2011). Fossils include sponges, hyoliths (Lochman 1964), brachiopods, cephalopods, gastropods (Lochman 1966), scolecodonts, trilobites, merostomates, barnacle-like fossils, crinoids (Lochman 1966), cystoids (Darton 1909), graptolites, invertebrate trace fossils (Stanley and Feldmann 1998), conodonts (Lochman 1966), and early jawless fish (Repetski 1978). These fossils are mostly found in the lower portion of the formation and in dolomitic limestone. The trilobites are abundant in the shale and limestone of the middle of the formation, while the upper part mostly contains trace fossils (Darton 1909). Beach facies may feature brachiopods, while tidal flat facies may have invertebrate trace fossils (Kulik 1968). Basal orthoquartzite beds commonly feature inarticulate brachiopods (Mark Fahrenbach, South Dakota Geological Survey senior geologist, pers. comm. in Tweet et al. 2011).

Englewood Limestone (Upper Devonian–Lower Mississippian) (MDe)

Description: The Englewood Limestone is comprised of gray to light-tan, interbedded limestone, dolomitic limestone, and shale, and varies from laminated to medium-bedded. The formation is fine to medium crystalline with occasional course-grained crinoidal beds. Thickness of the Englewood Limestone in WICA is approximately 10.7–15.2 m (35–50 ft) (Fagnan et al. 2013). Deposition occurred at or just below sea level in shallow continental seas (Tweet et al. 2011). Rock exposures can be found in the northwestern corner of the park (T. Herring, pers. obs., Nov. 2022).

Fossils found within WICA: Tabulate corals (T. Herring, pers. obs., Nov. 2022), horn corals (Figure 6), brachiopods, crinoids, and small unidentifiable vertebrate bone and tooth fragments have been observed. The corals and brachiopods are usually replaced by calcite and limonite (M. Fahrenbach, pers. comm. in Tweet et al. 2011).

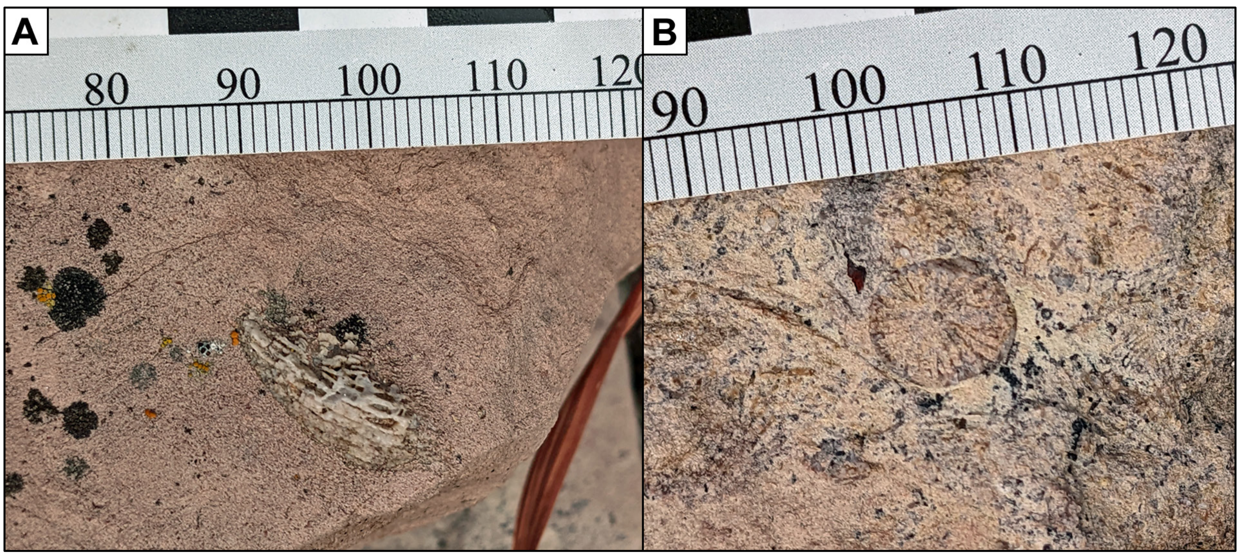

Figure 6. Two coral fossils from the Englewood Limestone (NPS/THEODORE HERRING). **A.** Side profile of a horn coral. **B.** Cross-section of a horn coral.

Fossils found elsewhere: Across its entire depositional area, the Englewood Limestone has fossils such as algal layers (Fahrenbach 1990), foraminifera (Klapper and Furnish 1962), rugose and tabulate corals (Klapper and Furnish 1962), conulariids, bryozoans (M. Fahrenbach, pers. comm. in Tweet et al. 2011), brachiopods (Darton 1909), bivalves (M. Fahrenbach, pers. comm., July 2010), gastropods (Darton 1909), nautiloid cephalopods (Miller and Unklesbay 1942), graptolites (Ruedemann and Lochman 1942), blastoids (M. Fahrenbach, pers. comm. in Tweet et al. 2011), crinoids, invertebrate trace fossils, conodonts, sharks (Fahrenbach 1990), and acanthodians (M. Fahrenbach, pers. comm. in Tweet et al. 2011). The uppermost 2.4 m (7.9 ft) is the most fossiliferous (KellerLynn 2009), and corals are abundant (Darton 1909).

Madison Limestone, also known as Pahasapa Limestone (Lower Mississippian) (Mp)
Description: The Madison Limestone is comprised of gray to light-tan, cavernous limestone and dolomitic limestone. Massive limestone contains chert nodules in the upper portion, while thin- to medium-bedded, dolomitic, sandy limestone comprises the lower portion. The limestone can form prominent cliffs. The disconformity with the overlying Minnelusa Formation is a paleokarst surface with terra rosa-filled sinkholes and breccia pipes. Thickness of the Madison Limestone in WICA is

approximately 83.8–114.3 m (275–375 ft) (Fagnan et al. 2013). The rocks formed in a shallow marine and coastal setting, laying the foundation for what would eventually become WICA's caves (Tweet et al. 2011). Madison Limestone is found in the northwestern and western sections of the park. Exposures can be seen within Wind Cave and in the western part of the park (T. Herring, pers. obs., Nov. 2022).

Fossils found within WICA: Several types of fossils may be encountered within the Madison Limestone of WICA, such as sponges (Santucci et al. 2001), corals, brachiopods (Figure 7), gastropods, crinoids, and invertebrate burrows, often found in relief (Horrocks 2008). Brachiopod molds and casts are abundant. Occasionally, fossils are replaced by calcite, giving them a sugary appearance (Tweet et al. 2011). In some cases, the boxwork intersects the fossils presenting an interesting association between the cave fossils and this cave feature (Santucci et al. 2001). Brachiopods tend to be found in the upper and middle levels of Wind Cave, while other fossils are mostly found in the middle level and are sparsely distributed in the lower and upper levels (KellerLynn 2009). Younger fossils, such as Quaternary vertebrate bones, are sometimes found in caves developed in the Madison Limestone (see the "Quaternary cave fossils" section below).

Figure 7. Several brachiopods in relief in the upper level of Wind Cave in the Madison Limestone (NPS/THEODORE HERRING).

The following is a communication from Rod Horrocks detailing the taphonomic processes that have affected Wind Cave bedrock fossils: "There are many processes that destroy or obscure fossils in Wind Cave (Horrocks 2008). In some places the fossils have been replaced by coarsely crystalline calcite and much of their intricate structure has been lost, making them difficult to identify, even to the generic level. These fossils were likely dissolved by sulfuric acid during the Mississippian Period when the first proto cave pockets were being dissolved and then later replaced by calcite (Palmer and Palmer, pers. comm., 2010). During the process of dolomitization of the Madison Limestone, many fossils in the cave were dissolved to obtain carbonate for the process of dolomitization, leaving only a mold or cast behind. Finally, calcite saturated water deposited thick layers of calcite over many of the exposed fossils, further obscuring them" (R. Horrocks, pers. comm., Feb. 2023).

Fossils found elsewhere: Nearby, JECA features sponge-like possible bryozoans, brachiopods, cephalopods, and burrows (Horrocks 2008). Over its entire depositional area, the Madison Limestone features microbial filaments (Palmer and Palmer 1989), algal structures (Petty 2003), foraminifera (Klapper and Furnish 1962), sponges (Santucci et al. 2001), rugose and tabulate corals (Darton 1909), bryozoans, brachiopods, bivalves (Petty 2003), cephalopods (Santucci et al. 2001), gastropods, blastoids (Darton 1909), crinoids, echinoids (Petty 2003), possible worm tubes (Santucci et al. 2001), burrows (Palmer and Palmer 1989), fecal pellets (Petty 2003), conodonts, and fish (Klapper and Furnish 1962). Fossils often take the form of natural molds (Petty 2003). Microbial filaments are associated with iron oxides that possibly postdate deposition (Palmer and Palmer 1989).

Minnelusa Formation (Upper Pennsylvanian–lower Permian) (PNm1–4, PPNm5, Pm6)

Description: The Minnelusa Formation is divided into six unnamed units, in ascending order 1 to 6. These units as they appear in WICA are described below. There are disconformities between unit 3 and unit 4, unit 4 and unit 5, and unit 5 and unit 6 (Fagnan et al. 2013). These units formed under a variety of coastal settings which varied as sea level fluctuated (Ward 1981). Rocks are found in the northwestern and western sections of the park (T. Herring, pers. obs., Nov. 2022).

Unit 1: Tan or red, medium- to coarse-grained, cross-bedded, basal sandstone overlain by fine-grained siltstone of similar thickness. This unit is poorly exposed and weathers into colluvial slopes. Thickness is approximately 7.6–27.4 m (25–90 ft) (Fagnan et al. 2013).

Unit 2: Yellowish-gray to light-gray, thin-bedded limestone with red and white chert nodules. Limestone beds are up to 0.6 m (2 ft) thick and are interbedded with sandstone and shale layers up to 0.2 m (0.5 ft) thick. Total thickness is approximately 12.2–18.3 m (40–60 ft) (Fagnan et al. 2013).

Unit 3: Brownish-yellow to tan, locally silicified sandstone interbedded with shale. Top of unit ma contain brownish yellow to light gray sandy limestone. Approximate thickness is 30.5–35.6 m (100–120 ft) (Fagnan et al. 2013).

Unit 4: Brownish-yellow to tan, dolomite interbedded with sandstone and laminated limestone, may contain manganese dendrites. Weathers into colluvial slopes. Thickness is approximately 18.3–24.4 m (60–80 ft) (Fagnan et al. 2013).

Unit 5: Bright-red, yellow, light-tan, to gray fine- to coarse-grained sandstone with light-blue-gray chert nodules near base. Upper portion is a red to light-red breccia with a carbonate matrix. The lower and upper portions are separated by a dark-red sandstone. Thickness is approximately 24.4–30.5 m (80–100 ft) (Fagnan et al. 2013).

Unit 6: Tan, gray, yellow, to red brecciated sandstone interbedded with brecciated limestone, thin layers of anhydrite, and unbrecciated sandstone. The top of the unit contains bright-red interbedded sandstone and shale. The sandstone beds from resistant benches. Thickness is approximately 33.5–39.6 m (110–130 ft) (Fagnan et al. 2013).

Fossils found within WICA: The Minnelusa Formation of WICA is fossiliferous. Conodonts are known from localities in the park, although they have only received minimal description (KellerLynn 2009). Conodonts (Figure 8) are useful for relative dating and could be used to establish relative ages in the Minnelusa Formation of WICA. Other fossils observed in this formation at WICA include fusulinid foraminifera (Verville and Thompson 1963), brachiopods (Fagnan et al. 2013), bivalves (Jennings 1959), and gastropods (Jennings 1959).

Figure 8. Two conodont elements in Minnelusa Formation Shale seen under a microscope (NPS/THEODORE HERRING).

Fossils found elsewhere: Over its entire depositional area, the Minnelusa Formation mostly features marine invertebrates with few vertebrates and terrestrial plants (Tweet et al. 2011). Plant fossils include coal (Darton 1901), charcoal, spores, wood fragments, resin (Tromp et al. 1981), and rhizoliths (Petty 2003). Marine non-vertebrates include stromatolites (Cicimurri and Fahrenbach 2002), acritarches, fusulinid foraminifera (Tromp et al. 1981), sponges, rugose corals, bryozoans, brachiopods, bivalves, cephalopods, gastropods, trilobites, crinoids, echinoids, worm tubes (Dillé

1930; Brady 1931, 1958), bioturbation (Schenk et al. 1988), and fecal material (Tromp et al. 1981). Marine vertebrates include conodonts, sharks and other cartilaginous fish (Cicimurri and Fahrenbach 2002), and bony fish teeth (Brady 1931, 1958). Fossils are often represented by natural molds (Petty 2003), similar to fossils in the Madison Limestone. Rugose corals, bryozoans, brachiopods, crinoids, and echinoids are present in the lower beds, while sponges, bivalves, gastropods, and trilobites are found higher in the formation (Dillé 1930). Fossils are most abundant lower in the formation in the southern Black Hills (Jennings 1959).

Opeche Shale (lower Permian) (Po)

Description: The Opeche Shale is comprised of unconsolidated red shale, mudstone, and siltstone with lavender coloring in the upper 1.5 m (5 ft). The shale erodes easily into a fine soil. Thickness of the Opeche Shale in WICA is approximately 24.4–30.5 m (80–100 ft) (Fagnan et al. 2013). Deposition conditions were not supportive for abundant and diverse life because of arid, saline, and acidic conditions (Benison and Goldstein 2000). Exposures are in the center and southwestern sections of the park.

Fossils found within WICA: No fossils have been found in the Opeche Shale within WICA.

Fossils found elsewhere: No definite fossils have been found in the Opeche Shale across its entire depositional area (Braddock 1963).

Minnekahta Limestone (Permian) (Pm)

Description: The Minnekahta Limestone is comprised of white, pink, and purple, finely crystalline, laminated to thin-bedded limestone interbedded with shale at the base and middle layers. The limestone forms prominent cliffs and dip slopes, and minor folds and box folds are common. Limestone may exude a locally petroliferous odor when broken. Thickness of the Minnekahta Limestone in WICA is approximately 12.2–15.2 m (40–50 ft) (Fagnan et al. 2013). The hypersaline depositional conditions were adverse to life (Dopheide and Winniger 2008). Exposures are in the central and southwestern sections of the park.

Fossils found within WICA: No fossils have been found in the Minnekahta Limestone within WICA.

Fossils found elsewhere: Bivalve and gastropod fossils are common; most remains are casts and are hard to identify. Indeterminate fossil fish fragments have also been discovered (Braddock 1963).

Spearfish Formation (Permian–Triassic) (TRPs, TRPsg)

Description: The Spearfish Formation is comprised of red shale and siltstone interbedded with brecciated limestone beds. Gypsum beds are abundant near the top, with small veins throughout the middle of the formation. Dissolution features are indicated by fragments of shale and siltstone silicified in the gypsum. Thickness of the Spearfish Formation in WICA is approximately 106.7–121.9 m (350–400 ft) (Fagnan et al. 2013). Deposition was not conducive for life because of hypersaline conditions, and the Spearfish Formation is sparsely fossiliferous for that reason (Sabel 1984). Rock exposures are in the eastern and southeastern sections of the park.

Fossils found within WICA: No fossils have been found in the Spearfish Formation within WICA.

Fossils found elsewhere: Stromatolites and other microbial structures, bivalve casts, and trace fossils are occasionally found in the Spearfish Formation outside of WICA, but the formation is generally sparsely fossiliferous (Sabel 1984).

Sundance Formation (Middle–Upper Jurassic) (Js)

Description: The Sundance Formation in WICA is comprised of several members, which are briefly described below from oldest to youngest. Total thickness of the Sundance Formation in WICA is 73.2–82.3 m (240–270 ft) (Fagnan et al. 2013). There is a disconformity between the Redwater Shale Member and the Lak Shale Member because of large-scale transgression-regression cycles in the shallow seaway that constituted the depositional environment (KellerLynn 2009). Exposures are in the northeastern part of the park.

Canyon Springs Sandstone Member: Tan, gray, and yellow, medium-grained, cross-bedded sandstone. Contains ripple marks (Fagnan et al. 2013).

Stockade Beaver Shale: Tan to light gray-green, calcareous, glauconitic, thin-bedded shale, sandstone, and siltstone (Fagnan et al. 2013).

Hulett Sandstone: Light-gray, fine-grained, calcareous, glauconitic sandstone interbedded with grayish-green claystone. Contains abundant ripple marks (Fagnan et al. 2013).

Lak Shale: Red fine-grained, calcareous, glauconitic siltstone and shale (Fagnan et al. 2013).

Redwater Shale: Light gray-green, calcareous, glauconitic siltstone and sandstone (Fagnan et al. 2013).

Fossils found within WICA: The only known fossil discovered within WICA from the Sundance Formation is the belemnite cephalopod *Pachyteuthis* sp. (Fagnan et al. 2013). For a description of belemnites (Figure 9) found in the Sundance Formation at DETO, see Tweet and Santucci (2019).

Fossils found elsewhere: At DETO, several fossils have been discovered, including bivalves, conifers, belemnites, burrows, unidentified vertebrates, and potential dinosaur tracks (Tweet and Santucci 2019). Other locations have also yielded foraminifera (Loeblich and Tappan 1950), bryozoans (Wright 1973), brachiopods, bivalves, cephalopods including belemnites (Imlay 1947), ostracodes (Wright 1974), decapods (Feldmann 1979), asteroids (Blake 1981), crinoids (Imlay 1947), echinoids (Specht and Brenner 1979), ophiuroids (Massare et al. 2014), burrows (Wright 1973), sharks, bony fish (Schaeffer and Patterson 1984), marine reptiles (including ichthyosaurs, plesiosaurs, and pliosaurs) (Massare et al. 2014), and unidentified reptiles (Specht and Brenner 1979).

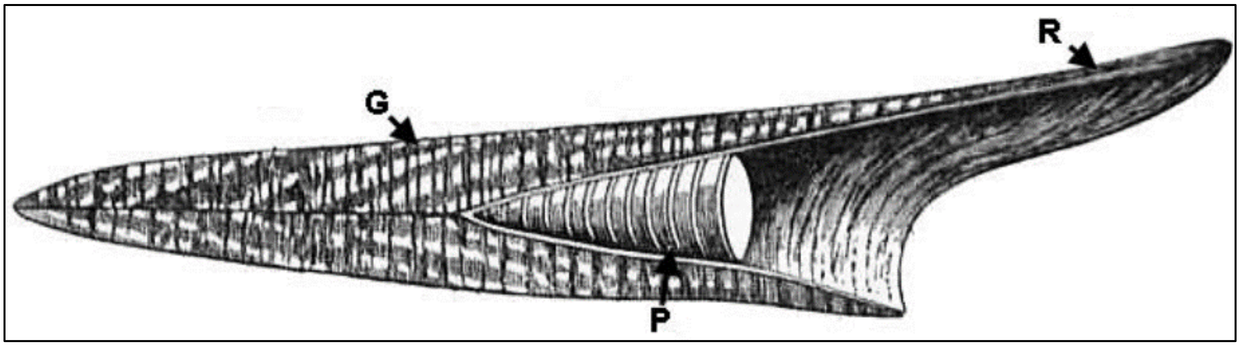

Figure 9. A line drawing of belemnite hard-part anatomy. G = guard; P = phragmocone; R = pro-ostracum. Reused from Tweet and Santucci (2019), modified from 1911 Encyclopædia Britannica diagram, downloaded from Wikimedia Commons (https://commons.wikimedia.org/wiki/File:EB1911_Cephalopoda_Fig._19.%E2%80%94Shell_Belemnite.jpg).

Unkpapa Sandstone (Upper Jurassic) (Ju)

Description: The Unkpapa Sandstone is comprised of buff to white, calcareous, well-sorted, friable, fine- to medium-grained, cross-bedded quartz sandstone and can be pink or purple at the top of the formation. Thickness of the Unkpapa Sandstone in WICA is approximately 3.0–15.2 m (10–50 ft) (Fagnan et al. 2013). The rocks are a lithified dune field left behind by a shallow continental sea (Szigeti and Fox 1981). Rocks are found in the northeastern corner of the park.

Some maps depict the Unkpapa Sandstone and Morrison Formation as undivided within WICA (e.g., DeWitt 2004). However, Fagnan et al. (2013) did not include the Morrison Formation in their geologic assessment of the park, and there are no other reports of the Morrison Formation in the park.

Fossils found within WICA: No fossils have been discovered in the Unkpapa Sandstone within WICA.

Fossils found elsewhere: Ichnofossils are abundant in the form of bioturbation (Szigeti and Fox 1981).

Lakota Formation (Lower Cretaceous) (Kl)

Description: The Lakota Formation is comprised of tan, brown, and light-gray, medium- to coarse-grained, cross-bedded sandstone interbedded with mudstone. The middle of the formation has lenses of sandy limestone. Prominent outcrops are common, and large boulders may occur as colluvium or talus. Thickness of the Lakota Formation in WICA is approximately 61–106.7 m (200–350 ft) (Fagnan et al. 2013). Deposition occurred in ancient floodplains, streams, and lakes (DeWitt et al. 1986). The Lakota Formation is at or near the surface in much of the northeastern corner of the park.

Fossils found within WICA: Fossils in the Lakota Formation at WICA are so far limited to petrified wood (Figure 10) (KellerLynn 2009).

Figure 10. Petrified wood found in the Lakota Formation (NPS/THEODORE HERRING).

Fossils found elsewhere: Outside of the park, the Lakota Formation is known for plant, invertebrate, and vertebrate fossils. Flora includes coal, fern spores (Gott et al. 1974), carbonized plants (Darton 1909), petrified wood, pine needles (Darton 1904), ferns, ginkgoes, cycads, cycadeoids, and conifers (Cahoon 1960). Invertebrates include freshwater bivalves, gastropods (Connor 1963), conchostracans, isopods, and ostracodes (Darton 1909). Vertebrates are represented by sharks (Cicimurri 1996), a fish comparable to *Lepidotes* (Gregory 1924), gars, turtles, crocodile relatives (Darton 1904), several kinds of dinosaurs (Foster et al. 1998), birds (Lockley et al. 2001), and early mammals (Cifelli and Gordon 2005). Reworked Paleozoic marine invertebrates (Graham 2008) and Sundance Formation belemnites (Waagé 1959) may be found in float. Cycadeoid fossils from the deauthorized Fossil Cycad National Monument were preserved in the Inyan Kara Group, which includes the Lakota Formation (Tweet et al. 2011).

Fall River Formation (Lower Cretaceous) (Kf)

Description: The Fall River Formation is comprised of gray to light-gray, fine- to very fine-grained, thin-bedded, carbonaceous sandstone interbedded with laminated carbonaceous siltstone. Thickness of the Fall River Formation in WICA is greater than 30.5 m (100 ft) (Fagnan et al. 2013). Deposition was interrupted by transgression-regression cycles of the Cretaceous Interior Seaway beginning about 100 Ma (KellerLynn 2009). Rocks are found in a small section of the northeastern corner of the park.

Fossils found within WICA: No fossils have been found in the Fall River Formation within WICA.

Fossils found elsewhere: Fossils in the Fall River Formation are rare. The only fossils confirmed from the formation are various plants (Crabtree 1987). Reports of other fossils, such as freshwater clams, sea snails, scaphopods, plesiosaurs, and crocodiles have been reported, but the rocks they were found in may no longer be classified as the Fall River Formation or may have been misinterpreted as the Fall River Formation (Dondanville 1963).

White River Group (upper Eocene–lower Oligocene) (Tw)

Description: White River Group exposures within WICA presumably belong to one or both of the Chadron Formation (upper Eocene) or the Brule Formation (lower Oligocene). However, the stratigraphy has not yet been differentiated within the park because of a lack of definitive taxonomic and stratigraphic evidence (Darrin Pagnac, Associate Professor and Curator of Fossil Vertebrates at the South Dakota School of Mines and Technology, pers. comm., Feb. 2023). Thickness of the White River Group in WICA is greater than 61 m (200 ft). Outcrops are common in eastern WICA (Fagnan et al. 2013).

The Chadron Formation is comprised of tan, brown, and light-gray siltstone, claystone, and white to light-gray, vuggy, finely crystalline, lacustrine limestone. Sparse conglomerate lenses may indicate stream channels. Volcanic tuff is also present. Deposition occurred from rivers flowing out of the Black Hills, which uplifted and eroded during the early Cenozoic as part of the Laramide Orogeny (Karner 1989). There was a climate shift during the formation of the White River Group, resulting in a shift in flora and fauna in the fossil record (Sheldon 2009). The top of the formation dates to about 33.9 ± 0.13 Ma (Prothero and Whittlesey 1995), with a disconformity with the overlying Brule Formation of about 1.2 million years (Evanoff 2006).

In South Dakota, the Brule Formation is divided into the lower Scenic Member and upper Poleslide Member; extensive erosion between the deposition of these two members resulted in paleotopography of up to 24.5 m (80 ft) (Evanoff 2004). The Scenic Member of South Dakota corresponds to the Orella Member of Nebraska and was deposited about 33 to 32 Ma (Prothero and Emry 2004). The depositional environment was a fluvial and floodplain setting with rare ponds and lakes. The climate ranged from subhumid to semiarid, indicating a dry warm grassland. It also features an increase in the amount of eolian volcanic sediments (Singler and Picard 1980). The Poleslide Member of South Dakota corresponds to the Whitney Member of Nebraska and was deposited from about 32 to 30 Ma (Prothero and Emry 2004). The depositional environment featured high amounts of eolian volcanic sediments with channel and floodplain deposition. Climate was semiarid to arid. Conditions varied between stable land surfaces, evidenced by paleosols with root traces and burrows, and periods of rapid eolian deposition evidenced by siltstone without bedding features (Benton et al. 2004).

Fossils found within WICA: Fossils from the White River Group are common within WICA and are found in several localities (note that previous discussions generally attribute the fossils to the Brule Formation of the White River Group). The best-known of these localities are the Centennial Site and the seven Klukas Sites. Plants are represented by hackberry seeds (Martin 1984, 1988; Brown 2014) and rhizoliths (R. Horrocks, pers. comm., 2014). Invertebrates are represented by bivalves, gastropods, dung beetle balls (R. Horrocks, pers. comm., 2014), and burrows (R. Horrocks, pers. obs.). Vertebrate fossils include tortoises, lizards, snakes, marsupials, shrew-like insectivores, rodents, lagomorphs, creodonts, canids, horses, rhinoceroses (Figure 11), oreodonts, and deerlike ruminants (Figure 12) (Martin 1988, 1994; Brown 2009, 2014). See Appendix Table A-2 for species-level identifications.

Figure 11. *Subhyracodon* palate discovered at the Centennial Site (NPS/ROD HORROCKS).

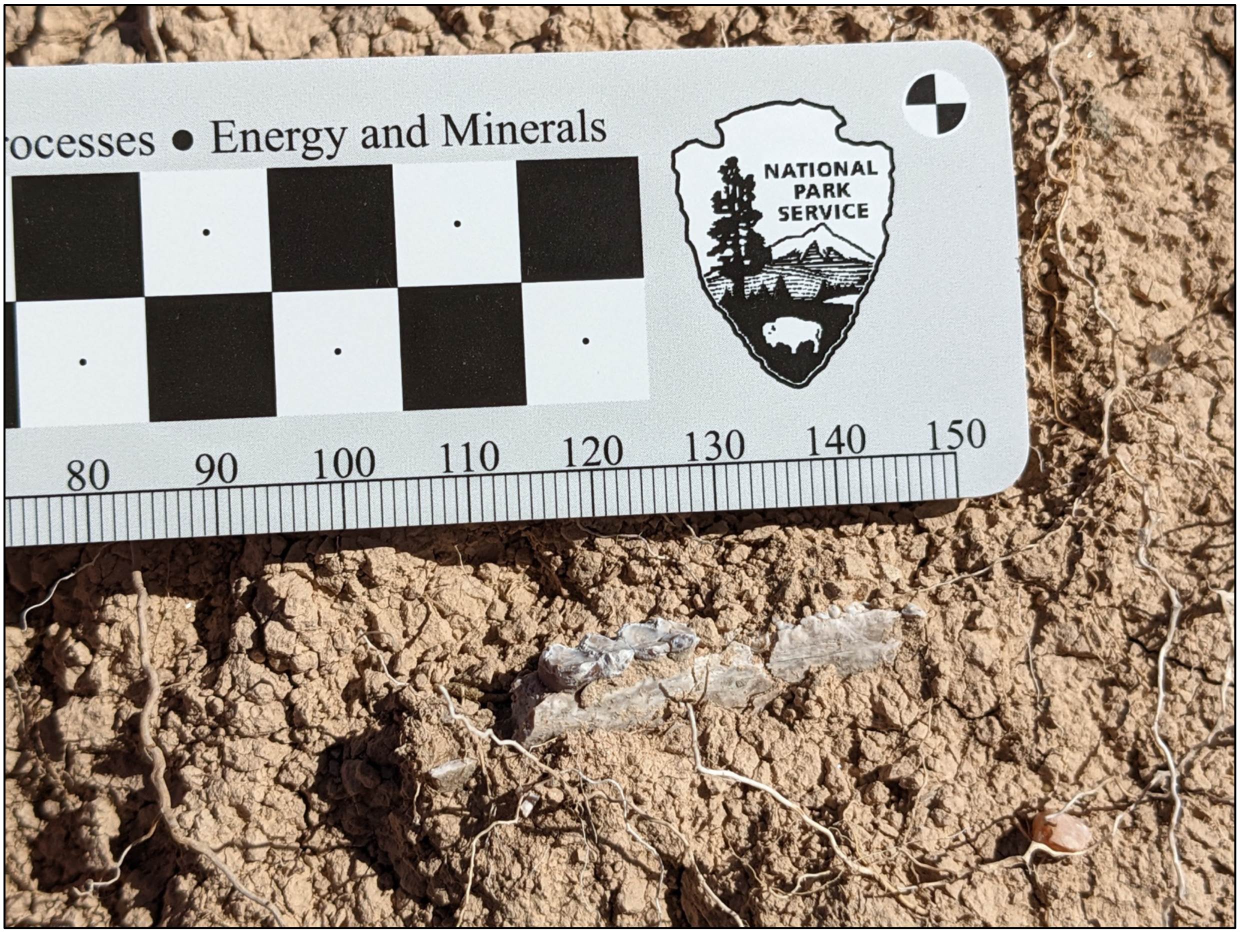

Figure 12. Portion of a *Leptomeryx* lower jaw found at Klukas Site #1 (NPS/THEODORE HERRING).

Fossils found elsewhere: A wide variety of fossils have been found in the Chadron Formation of the White River Group. Plant fossils include petrified wood and hackberry seeds. Invertebrate fossils include bivalves and gastropods. A rich vertebrate fauna, defining the Chadronian Land Mammal Age, are documented from the Chadron Formation and are best represented at Badlands National Park. Fossil vertebrates include, but are not limited to, the anuran *Eopelobates*; the turtles *Apalone, Chrysemys*, *Gopherus*, *Hesperotestudo*, *Pseudograptemys*, and *Stylemys*; the lizard *Helodermoides*; the boa *Calamagras*; the alligator *Alligator prenasalis*; the marsupial *Herpetotherium*; "insectivores" such as *Chadronia margaretae* and *Sinclairella*, the mole *Proscalops*, and the shrews *Apternodus*, *Centetodon*, *Clinopternodus*, and *Oligoryctes*; the rodents *Adjidaumo*, *Agnotocastor*, *Heliscomys*, *Ischyromys*, *Paradjidaumo*, and *Pelycomys*; the lagomorphs *Megalagus* and *Palaeolagus*; the creodont *Hyaenodon*; the nimravids *Dinictis* and *Hoplophoneus*; the amphicyonids *Brachyrhynchocyon/Daphoenocyon* and *Daphoenus*; the canid *Hesperocyon*; the ursid *Parictis*; the mustelid *Mustelavus*; the tapir *Colodon*; the horses *Mesohippus* and *Miohippus*; the rhinos *Amphicaenopus*, *Diceratherium*, *Hyracodon*, *Metamynodon*, *Penetrigonias*, *Subhyracodon*, and *Trigonias*; the brontothere *Megacerops*; the entelodont *Archaeotherium*; the leptochoerid *Leptochoerus*; the anthracothere *Aepinacodon*; the oreodonts *Agriochoerus*, *Merycoidodon*, and *Miniochoerus*; the camel *Poebrotherium*; the protoceratids *Heteromeryx* and *Leptotragulus*; and the leptomerycid *Leptomeryx*. Trace fossils include brontothere tracks, larval cells of bees, and both herbivore and carnivore coprolites (Benton et al. 2015).

A wide variety of fossils have been found in the Brule Formation as well. A rich vertebrate fauna, defining the Whitneyan Land Mammal Age, is documented from the Brule Formation and is best represented at Badlands National Park. Plant fossils include rhizoliths, hackberry seed pods, and petrified wood. Invertebrates include freshwater bivalves and gastropods. Vertebrates include the catfish *Ictalurus*; the tortoises *Gopherus*, *Hesperotestudo*, and *Stylemys*; the lizards *Helodermoides*, *Peltosaurus*, and *Rhineura*; the boas *Calamagras, Coprophis*, and *Geringophis*; the falconiform *Buteo*; the galliform *Palaeonossax*; the gruiforms *Badistornis*, *Bathornis*, and *Paracrax*; the ardeiform *Gnotornis*; "insectivore" mammals such as *Chadronia* and *Sinclairella*, the leptictid *Leptictis*, and *Domnina*, *Proscalops*, and *Proterix*; the rodents *Adjidaumo*, *Agnotocastor*, *Cedromus*, *Diplolophus*, *Eumys*, *Eutypomys*, *Heliscomys*, *Ischyromys*, *Paradjidaumo*, *Proheteromys*, *Protosciurus*, and *Scottimus*; the lagomorphs *Megalagus* and *Palaeolagus*; the creodont *Hyaenodon*; the nimravids *Dinictis*, *Eusmilus*, *Hoplophoneus*, *Nimravus*, and *Pogonodon*; the amphicyonids *Daphoenus* and *Paradaphoenus*; the canids *Archaeocyon*, *Cynarctoides*, *Ectopocynus*, *Hesperocyon*, *Osbornodon*, *Otarocyon*, *Oxetocyon*, and *Sunkahetanka*; the ursid *Parictis*; the mustelids *Mustelavus* and *Palaeogale*; the tapirs *Colodon* and *Protapirus*; the horses *Mesohippus* and *Miohippus*; the rhinos *Amphicaenopus*, *Diceratherium*, *Hyracodon*, *Metamynodon*, *Penetrigonias*, and *Subhyracodon*; the entelodont *Archaeotherium*; the leptochoerids *Leptochoerus* and *Stibarus*; the peccaries *Perchoerus* and *Thinohyus*; the anthracotheres *Bothriodon*, *Elomeryx*, and *Heptacodon*; the oreodonts *Agriochoerus*, *Eporeodon*, *Leptauchenia*, *Merycoidodon*, and *Miniochoerus*; the camels *Paralabis*, *Poebrotherium*, and *Pseudolabis*; the protoceratid *Protoceras*; the hypertragulids *Hypertragulus* and *Hypisodus*; and the leptomerycid *Leptomeryx*. Trace fossils include dung beetle balls, larval cells of bees, a multitude of animal tracks, and carnivoran coprolites (Benton et al. 2015).

Late Cenozoic rocks and deposits (upper Neogene–Holocene) (Qal, Qcg, QTg)

Description: Cenozoic deposits are composed of alluvial, conglomerate, and gravel deposits:

Qal, alluvium: Unconsolidated to loosely consolidated clay, silt, and angular to rounded sand and gravel. Found sparsely throughout the park (Fagnan et al. 2013).

Qcg, conglomerate: Well-cemented, angular to subangular, sand to pebble-sized clasts. Matrix is composed of calcium carbonate and calcium sulfate likely derived from hot springs. Approximate thickness is 0.6–4.6 m (2–15 ft). Located primarily in the eastern and southeastern sections of the park (Fagnan et al. 2013).

QTg, gravel deposits: Unconsolidated to loosely consolidated clay- to boulder-sized clasts comprised of Precambrian source rock and minor Paleozoic carbonate and sandstone. Gravels are sub-rounded to rounded. Found throughout the park, but mostly in the northern and western sections (Fagnan et al. 2013).

Fossils found within WICA: The Red Valley in eastern WICA yielded a limited number of Quaternary fossils, such as phytoliths, charcoal (Fredlund and Tieszen 1997), and bones of bison (Figure 13) and indeterminate ungulates (KellerLynn 2009).

Figure 13. Holocene bison vertebra discovered in the Red Valley (NPS/ROD HORROCKS).

Fossils found elsewhere: A nearby Quaternary fossil site is the Mammoth Site of Hot Springs, located 6 km (4 mi) south of WICA. This site has yielded pollen, bivalves, gastropods (Agenbroad 1997), ostracodes (Agenbroad 1984), fish, frogs, birds, moles, rodents, canids, ferrets, short-faced bears, Columbian and woolly mammoths (Agenbroad 1997), peccaries (Agenbroad 1984), camels, shrub oxen, carnivore dung (Agenbroad 1997), worm burrows (Laury 1980), bird tracks, and probable mammoth tracks (Falkingham et al. 2007).

Quaternary cave fossils (middle Pleistocene–Holocene)

Description: Cave entrances are often filled with alluvial and colluvial sediment that ranges from mud to gravel in grain size (KellerLynn 2009). Fossils likely result from several processes: animals that died while inhabiting the cave system or after becoming lost in it; carnivorous animals that brought bones into the cave for feeding; flood events that washed organic material into the caves;

snake dens; bat roosts; owl roosts; wood rats that added scavenged bones to their nests; and accidental falls (Benton 1999; R. Horrocks, pers. comm., Feb. 2023).

Relative ages of Quaternary fossils in cave systems in WICA:

Salamander Cave: minimum 252,000 years old (Mead et al. 1996).

Persistence Cave: ranges from 42,000 years ago to present (J. Mead, pers. comm., Nov. 2022).

Beaver Creek Shelter: 9,380–1,750 years old (Benton 1991)

Wind Cave (e.g., Chamber of Lost Souls): 11,000 years old (J. Mead, pers. comm., Feb. 2023); 6,000–4,000 years old, Chamber of Lost Souls (Martin 1992).

Graveyard Cave: 2,290–290 years old (Manganaro 1994)

Fossils found within WICA: Numerous fossils have been found within the several cave systems of WICA. Fossils include indeterminate plant matter, charcoal, mollusks, fish, salamanders, frogs, snakes, birds, shrews, rabbits, pikas, squirrels, gophers, mice, rats, voles, bats, foxes, coyotes, skunks, martens (Figure 14), horses, deer, and bison (Abbott 1989; Benton 1991; Martin 1992; Mead et al. 1996; Santucci et al. 2001). These fossils were likely deposited through a variety of methods, such as fluvial processes, mortality of shelter inhabitants, animals brought in by carnivores and scavengers, snake dens, bat roosts, owl roosts, and wood rats that add scavenged bones to their nests (Benton 1999; R. Horrocks, pers. comm., Feb. 2023).

Fossils found elsewhere: JECA has Quaternary fossils, but not to the extent of Wind Cave. The cave system contains cave debris yielding fossils such as gastropods, rattlesnakes, rodents, rabbits, an unidentified large mammal, coprolites, and several wood rat middens. Large mammal bones often have gnaw marks. The ages of these fossils are not certain but likely date to the late Pleistocene or Holocene (Santucci et al. 2001).

Figure 14. A pine marten discovered in Wind Cave, dated to 11,000 years old (NPS/HAZEL BARTON).

Taxonomy

See Appendix A for full lists of taxa. Summary locality data for fossil sites can be found in Appendix F.

Fossil Plants

There are two types of fossil plants found in WICA bedrock: petrified wood and hackberry seed pods. Petrified wood is found in the Lakota Formation of the park, dating to the Early Cretaceous, on top of Boland Ridge. The specimens are identified as cypress and palm (Figure 10) (M. Ohms, pers. obs., 2016). Fossilized hackberry seed pods (family Cannabaceae) occur when the seed pods are buried and later replaced by lithified minerals, preserving the original shape of the seed pods. They are commonly found in almost all the White River Group sites, dating to the early Oligocene (R. Horrocks, pers. comm., 2014).

Fossil Invertebrates

The majority of invertebrate fossils reported from WICA are marine invertebrates from the Paleozoic Era, found in the Deadwood Formation, Englewood Limestone, Madison Limestone, and Minnelusa Formation. These fossils were first reported at the end of the 19th century, when Alvin McDonald, Luella Owen, and N. H. Darton reported finding corals and other undescribed fossils in Wind Cave and in the Deadwood Formation (McDonald 1893; Owen 1898; Darton 1901). Invertebrate fossils from younger units include freshwater mollusks discovered in the White River Group sites (R. Horrocks, pers. comm., 2014) and Quaternary cave systems (Martin and Anderson 1997; Jass et al. 2002), and insects reported from Persistence Cave (Jass et al. 2017).

Phylum Cnidaria (jellyfish and corals)

There are two types of corals commonly found in Paleozoic rocks: rugose corals and tabulate corals. Rugose corals include both solitary forms, known as horn corals (Figure 6), and colonial forms. Rugose corals are commonly seen in the Englewood Limestone in WICA (T. Herring, pers. obs., Nov. 2022) and rarely within Wind Cave in the Madison Formation (R. Horrocks, pers. comm., Feb. 2023). Tabulate corals are almost exclusively colonial, sometimes with a chain-like form, a beehive-like form, or a pipe organ-like form. They can be confused with colonial rugose corals but can generally be distinguished by their smaller corallites (millimeter-scale) and lack of vertical structures in the corallites. Tabulate corals are commonly seen in the Madison Limestone in Wind Cave (Wind Cave trip report: 2009, Horrocks et al.). Not all corals have been formally identified, but the tabulate corals are thought to belong to the Syringoporidae (Horrocks 2008).

Phylum Brachiopoda (lamp shells)

Brachiopods are the most common invertebrate fossil in WICA and are documented in the Deadwood Formation, Englewood Limestone, Madison Limestone, and Minnelusa Formation. Brachiopods are known from both terrestrial sites and sites in Wind Cave. There are several brachiopod sites in Wind Cave, but the most accessible is on the Fairgrounds Tour Route. These are often mass mortality sites located on the underside of chert layers (R. Horrocks, pers. comm., Feb. 2023). Specimens include representatives of the orders Strophomenida (Todd 1894), Lingulida (Stitt 1998), and Spiriferida (Fagnan et al. 2013).

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

Bivalves are much less common in WICA than brachiopods. Freshwater bivalves can be found in the White River Group sites (R. Horrocks, pers. comm., 2014; T. Herring, pers. obs., Oct. 2022). Although not yet documented to the same extent, it is possible that bivalves may be found at Paleozoic brachiopod localities. Jennings (1959) reported bivalves in the Minnelusa Formation.

Phylum Mollusca: Class Gastropoda (snails)

Gastropods, commonly known as snails and slugs, are common in WICA. Both marine and freshwater gastropods have been discovered. The oldest gastropods have been found in the Madison Limestone in Wind Cave (Wind Cave trip report: 2011, Horrocks et al.). One remarkable specimen was even discovered embedded in boxwork, seen on the cover of this report. Freshwater gastropods of several varieties have been found in the White River Group fossil sites (R. Horrocks, pers. comm., 2014), and in more recent sites such as Graveyard Cave (Jass et al. 2002) and the Chamber of Lost Souls (Martin and Anderson 1997). The marine gastropods are tentatively identified as belonging to Euomphalidae and Pleurotomariidae (Todd 1894). Several freshwater gastropods from Graveyard Cave have been identified: *Gastrocopta armifera*, *Gastrocopta procera*, *Pupoides albilabris*, *Vallonia gracilicosta*, *Vallonia cyclophorella*, *Catinella* sp., *Discus whitneyi*, *Discus* sp., *Hawaiia minuscula*, and *Zonitoides arboreus* (Jass et al. 2002).

Phylum Arthropoda: Class Trilobita

Trilobites are one of the most abundant invertebrate fossils found in lower Paleozoic rocks, though they can be found throughout the Paleozoic. Two species of trilobites have been identified in the Deadwood Formation of WICA, *Cedarina dakotaensis* and *Modocia centralis*, while other specimens remain undetermined (Stitt 1998).

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

Crinoids, commonly called sea lilies, are echinoderms that have existed since the Ordovician Period and are still alive today. Crinoids are found in the Madison Limestone in WICA, namely within Wind Cave (Wind Cave trip report: 2012, Horrocks and Geu). Crinoid fossils have also been observed in the Englewood Limestone (Tweet et al. 2011) and in float in the Red Valley area (Vincent Santucci, pers. obs., Oct. 2022).

Fossil Vertebrates

Fossil vertebrates in WICA are documented from three defined stratigraphic units and Quaternary surficial and cave deposits. Scrap has been reported from the Devonian–Mississippian Englewood Limestone. The only vertebrates found in WICA from the Pennsylvanian Minnelusa Formation are conodonts, an extinct group of jawless vertebrates. There is an extensive record of terrestrial vertebrates from the Paleogene Period, particularly mammals, found in the White River Group fossil sites. A high diversity of vertebrate fossils represents the Pleistocene and Holocene Epochs of the Quaternary Period. These vertebrates have been recovered from caves and rock shelters within WICA, including Beaver Creek Shelter, Persistence Cave, Salamander Cave, Graveyard Cave, and Wind Cave.

Class Conodonta

Conodonts are an extinct group of agnathans, or jawless vertebrates, that lived from the Cambrian through the earliest Jurassic. Their jaw-like features, called elements, are commonly found as fossils (Figure 8). These elements are unique to each species, making conodonts valuable as index fossils. Conodonts are found in the Minnelusa Formation in WICA. Four species have been identified at WICA: *Streptognathodus eccentricus*, *S. elegantulus*, *S. oppletus*, and *S. simulator* (Jennings 1959).

Class Actinopterygii

Actinopterygii, also known as the ray-finned fishes, are the most diverse class of extant fish. The freshwater fish *Catostomus commersonii* (white sucker) and *Semotilus atromaculatus* (creek chub) were discovered in Beaver Creek Shelter, likely carried into the shelter by birds for feeding (Benton 1991).

Class Amphibia

Amphibia is a diverse group containing frogs, toads, salamanders, newts, and caecilians. In WICA, several species of frogs, toads, and salamanders from the Quaternary Period have been discovered in Beaver Creek Shelter, Persistence Cave, Graveyard Cave, and Salamander Cave (see Appendix Tables A-3–A-7 for species-level identification).

Class Reptilia

Reptilia is a paraphyletic group containing animals such as turtles, crocodilians, lizards, snakes, and tuatara. Reptiles have been discovered in the White River Group sites and in Quaternary deposits. The White River Group sites have yielded fossil snakes, lizards, and turtles, of which the land tortoise *Stylemys nebrascensis* and the anguid lizard *Peltosaurus* sp. indet. have been identified (Martin 1988). Quaternary deposits have yielded colubrid snakes, vipers, tortoises, and iguanids (see Appendix Tables A-3–A-7 for species-level identification). Persistence Cave was a snake den and contains countless bones from snakes.

Class Aves

Several avian fossils have been yielded from Quaternary deposits, but very few have been identified other than *Falco sparverius* (American kestrel) and *Dryobates pubescens* (downy woodpecker). Other indeterminate specimens come from the families Tetraonidae (grouses), Fringillidae (sparrows), Picidae (woodpeckers), Falconidae (falcons, kestrels, and caracaras), and Anatidae (ducks, geese, and swans) (Benton 1991).

Class Mammalia

Mammalia is the most well-represented class across all vertebrate fossils discovered in WICA. Several White River Group sites have yielded mammals such as the leptictid *Leptictis* sp.; the rodents *Ischyromys typus*, *Eumys elegans*, *Leidymys* sp. indet., *Paradjidaumo trilophus*, and an aplodontid comparable to *Prosciurus*; the lagomorphs *Palaeolagus* cf. *haydeni* and *Megalagus turgidus*; the creodont *Hyaenodon* sp. indet.; the canid *Hesperocyon* sp. indet.; the perissodactyls *Subhyracodon* cf. *occidentalis* (Figure 11), *Mesohippus bairdi*, and *Equus* sp.; and artiodactyls *Leptomeryx* (species uncertain) (Figure 12), *Merycoidodon* sp., and *Miniochoerus* sp. (Brown et al. 2008; Brown 2009, 2014; see Appendix Table A-2 for a full list).

Quaternary sites have also yielded a diverse assemblage of mammals, such as shrews, numerous rodents, lagomorphs, bats, canids, mustelids, perissodactyls, and artiodactyls (see Appendix Tables A-3–A-7 for species-level identifications).

Ichnofossils

Ichnofossils, also called trace fossils, are evidence of biological activity that do not include the physical remains of an organism but may provide information on the biology or behavior of prehistoric organisms. Examples of ichnofossils include burrows (Figure 15), tracks, feeding traces, dens, and dung. The oldest ichnofossils in WICA are invertebrate burrows discovered in the Deadwood Formation and are reported in the Yale Peabody Museum collection records and confirmed by more recent studies (Stitt 1998; Horrocks 2008; Fagnan et al. 2013). General bioturbation has also been discovered in Englewood Limestone rocks (Fagnan et al. 2013). Another example of trace fossils includes dung beetle balls discovered in the White River Group fossil sites (R. Horrocks field notes). Additionally, burrows have been discovered in White River Group sites (R. Horrocks, pers. comm., 2003). Other trace fossils in WICA include gnaw marks on Quaternary fossils and wood rat middens in Holocene caves (T. Herring, pers. obs., Nov. 2022).

Figure 15. A fossilized burrow found in Wind Cave (NPS/KEN GEU).

Other Fossils

Other types of fossils reported from WICA, including microfossils, have not been classified because of poor description or uncertain affinity. Some fossils were reported prior to park history and were poorly recorded, such as “coral studs” in Wind Cave (McDonald 1893), reed or algal-like fossils in Wind Cave (Todd 1894), and unspecified fossils in the Deadwood Formation (Darton 1901). Other fossils of uncertain affinity include “fossil cavities” in the Minnelusa Formation (Bates 1955), single-celled foraminifera found in the Minnelusa Formation (Verville and Thompson 1963), microbial filaments that formed on the Madison Limestone during early dissolution (Palmer and Palmer 1991), and potential fossil stromatolites (Wind Cave trip report: 1998, Davis and Allison).

Fossil Localities

Paleontological Localities Within WICA

Fossils at WICA have been found in several contexts: in bedrock or loose at the surface, outside of the cave system; in bedrock within the cave system; or as Quaternary material found within the cave system, having arrived via a variety of processes (washed in, lost animals, material brought in for consumption, etc.). Details on aboveground sites are omitted below; locality information is available to qualified researchers.

Cave Paleontological Resource Localities

<u>Bedrock Fossils</u>

Madison Limestone

All of the in situ fossils within Wind Cave are found in the Madison Limestone, dating back to the Mississippian. The most abundant fossils are brachiopods (T. Herring, pers. obs., Nov. 2022); however, corals (Wind Cave trip report: 2007, Horrocks et al.), gastropods (Wind Cave trip report: 2011, Horrocks et al.), crinoids (Wind Cave trip report: 2012, Horrocks and Geu), and burrows (Wind Cave trip report: 2006, Horrocks and Marohn) have also been reported. Brachiopod casts made of chert and shell molds are common (T. Herring, pers. obs., Nov. 2022).

One of the largest assemblages of brachiopods is in a room known by the station number BI32, which contains a death assemblage of hundreds of brachiopods in a distinct layer of the Madison Limestone. This room was originally discovered by Elmer McDonald, A.C. Platt, and GA Stoblem in 1894, who wrote their names and date of discovery on the wall over several brachiopods (Figure 16) (T. Herring, pers. obs., Dec. 2022).

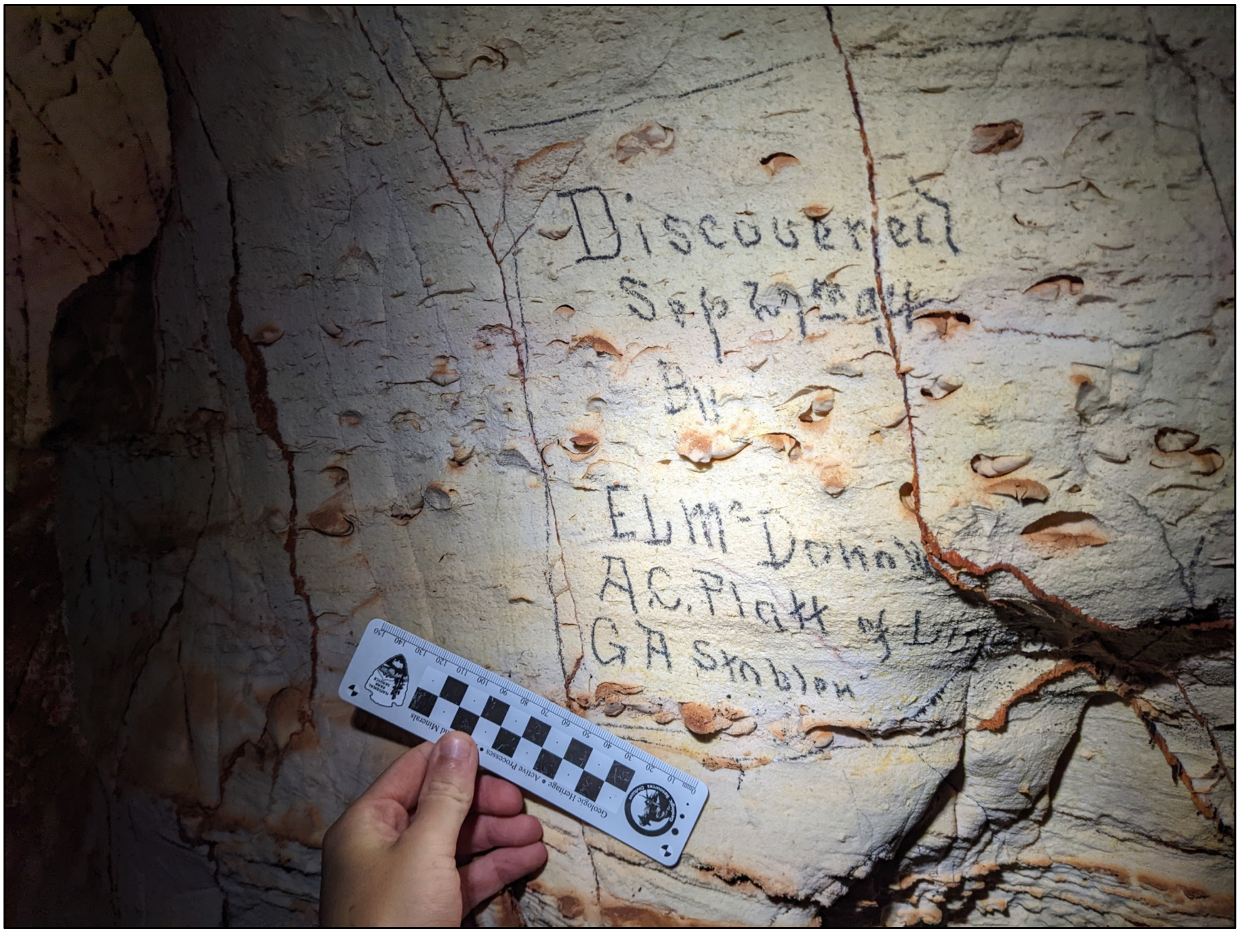

Figure 16. Graffiti from Wind Cave explorers who discovered an assemblage of brachiopods in 1894 (NPS/THEODORE HERRING).

Another brachiopod locality is along the Fairgrounds Tour Route. It features dozens of brachiopod molds and casts in the ceiling of the route (Figure 17). A second tour route locality is located just outside of the elevator room at the beginning of the Garden of Eden Tour Route, where brachiopods are embedded in a low ceiling. Both of these sites are accessible and within the reach of visitors, so they could be at risk of damage. However, park tour leaders routinely instruct visitors not to touch anything in the cave so not to damage the formations (T. Herring, pers. obs., Oct. 2022). Additionally, near but off-trail of the Garden of Eden Tour Route, there is a small death assemblage of brachiopods about 1.2 m (4 ft) long located in a low ceiling. Nearby, there is a tabulate coral surrounded by brachiopod casts located in the ceiling (T. Herring, pers. obs., Feb. 2023). Most of the brachiopods found within Wind Cave are thought to belong to the order Spiriferida, characterized by their long hinge-line and wing-shaped shells.

Figure 17. Brachiopods seen along the Fairgrounds Tour Route (NPS/THEODORE HERRING).

Two other notable brachiopod localities occur on the route to a section of the cave called the “Red and White Trail”, also known as the “Club Room Trail”. One of these locations, called “Silent Lake”, features a small slab of limestone with several chert casts of brachiopods (Figure 18). The second location, called the “Pyramid Room”, features brachiopods within the low ceiling of the cave (T. Herring, pers. obs., Nov. 2022).

Figure 18. Brachiopod casts located near Silent Lake (NPS/THEODORE HERRING).

Cave reports documenting newly discovered fossils within Wind Cave have been prepared starting in 1984 and have been required since 1986. Cave fossils discovered before 1984 were often not formally recorded. The fossils and their locations are listed below:

- 0.6 x 0.3 m (2 x 1 ft) disc-shaped coral fossil in the Silent Expressway (Wind Cave trip report: 1991, Burger et al.)
- Possible fossil stromatolites or bacterial filaments at Calcite Lake (Wind Cave trip report: 1998, Davis and Allison)
- Possible corals in the “White Coral Room” and “OK Coral” Rooms (Wind Cave trip report: 2004, Horrocks, Spoelman, Walz, and Pace-Graczyk)
- A 0.6 m (2 ft)-long fossil burrow in the Historic Section (Wind Cave trip report: 2006, Horrocks and Marohn)
- Unnamed fossils, presumably burrows, in “Filamental Fissure” (Wind Cave trip report: 2008, Horrocks et al.)
- Gastropods in “Fissure Kingdom” (Wind Cave trip report: 2008, Horrocks et al.)
- Horn coral fossils partially dissolved out of the walls near the TT survey (Wind Cave trip report: 2009, Horrocks et al.)

- Gastropods in “Gastro Flats”, a lower pancake-style room (Wind Cave trip report: 2011, Horrocks et al.)
- Crinoid stems in the Historic Section (Wind Cave trip report: 2012, Horrocks and Geu)
- Fossil corals near the “Museum” section (Wind Cave trip report: 1989, Nepstad and Ressler)
- Tiny gastropods underneath a ledge at UD9 (Wind Cave trip report: 2006, Horrocks, Spoelman, Niedringhaus, and Zindler)
- Juvenile corals completely dissolved out of the bedrock near the “Tin Can Room” (Wind Cave trip report: 2007, Horrocks et al.)
- A gastropod embedded within boxwork (seen on the report cover) near “Fissure Kingdom” and the WH survey (Wind Cave trip report: 2008, Horrocks et al.)
- A display of coral near LO55 (Wind Cave trip report: 2008, Bern et al.)
- Fossilized corals and worm burrows in “Hollow Earth” (Wind Cave trip report: 2008, Amidon et al.)
- Brachiopods, gastropods, crinoids, and worm tubes in “Dead Sea Stroll” (Wind Cave National Park undated, named 1993)
- A brachiopod assemblage in the “Brachdown room” (Wind Cave National Park undated, named 2006)
- A brachiopod assemblage in “Clam Bake” (Wind Cave National Park undated, named 1991)
- Two nearby brachiopod assemblages, named “Nokay Coral” and “The Oyster Coral” (Wind Cave National Park undated, named 2002)
- Several gastropods in “Gastropod Gallery” (Wind Cave National Park undated, named 1990)
- A coral that resembles Bryce Canyon National Park in the room “Bryce Canyon Causeway” (Wind Cave National Park undated, named 2005)

There is also a small limestone cave unrelated to Wind Cave called “Brachiopod Cave” (Figure 19), notable for numerous brachiopods in the cave ceiling (Wind Cave trip report: 2000, Horrocks and Ohms).

Figure 19. Rod Horrocks outside the entrance of Brachiopod Cave (NPS/MARC OHMS).

Quaternary Cave Fossils

Quaternary fossil sites have been recorded throughout the cave system, many of which are not yet published. There are 82 reported fossil vertebrate localities, some of which contain numerous different fossil species (for a full list of these localities, see Appendix F). The abundance of fossil localities, many of which are located far from the natural entrance, suggests that there have been several other paleo entrances to Wind Cave that have since closed. Most of these sites have alphanumeric codes, while the most productive sites have colloquial names, such as "Rainfall Hall", "Gollum's Room", and the "Chimera Room" (M. Ohms field notes 2004). Below are several Wind Cave localities and other cave localities in the park that have yielded a notable number of Quaternary fossils.

Chamber of Lost Souls

In one of the rooms near the natural entrance of Wind Cave, named the "Chamber of Lost Souls", bones were discovered and studied in 1984–1985. This room contained bones from numerous vertebrates; some bones have gnaw marks from wood rats, some were stream-worn, some appear to have come from raptor pellets, and others appear to be associated with animals that inhabited the cave and expired there. It was hypothesized that there was a paleo entrance to the room that no longer exists. This paleo entrance was discovered in 2002 by a survey team led by Rod Horrocks, who was looking for the source of the bones. Surveying a dome in the ceiling of the Chamber of Lost Souls, the survey team followed a passage up 18 vertical m (nearly 60 ft) to a dirt plug. A subsequent cave radio test revealed that the dirt plug was only 1.8 m (6 ft) below the bottom of Wind Cave Canyon. This canyon bottom entrance explained the stream-rounded bones, the charcoal, and the wood rat gnawed bones (R. Horrocks, pers. comm., Feb. 2023). All bones in the room were recovered and identified by Dr. James Martin and are currently held at the South Dakota School of Mines and Technology (Martin 1992; Martin and Anderson 1997; KellerLynn 2009). Recovered species include gastropods, salamanders, frogs, toads, birds, shrews, various rodents, rabbits, bats, canids, bison, and deer (see Appendix Table A-5 for species-level identifications).

FP3 and Waterfall Dome/Dripping Dome

Near the natural entrance of Wind Cave there are two other fossil localities. One locality, known only by its Wind Cave station number "FP3", has yielded a small number of vertebrate bones of various sizes, many of which have been collected but none of which have yet been identified. The second locality, "Waterfall Dome" or "Dripping Dome", contains vertebrate bones of several sizes, including some rodent crania. All specimens have been marked, but none have been collected or dated at the time this report was prepared (M. Ohms, pers. obs., Feb. 2021; T. Herring, pers. obs., Nov. 2022).

Rainfall Hall

Rainfall Hall is a room off the Wild Cave Tour Route where a bison femur and three interlocked bison vertebrae were discovered among flood debris and conglomerate. Charcoal among the flood debris was radiocarbon dated to about 6,000 years old (M. Ohms, pers. obs., Sept. 2019).

Beaver Creek Rock Shelter

"Beaver Creek Rock Shelter", or "Beaver Creek Shelter", is a collapsed rock shelter that is one of the most productive paleontological sites in the park and hosts one of the most complete Holocene sections within the Black Hills (Figure 20). Paleontological specimens from this shelter date back 9,380 to 1,750 years before present. Thousands of disarticulated fossils of more than 40 species have been identified, and this collection continues to be studied by the paleontologists at the South Dakota School of Mines and Technology (KellerLynn 2009). Fossil vertebrates identified from Beaver Creek Shelter include ray-finned fish, frogs, toads, salamanders, colubrid snakes, vipers, iguanids, grouses, sparrows, woodpeckers, kestrels, owls, waterfowl, landfowl, marsupials, shrews, rodents (squirrels, geomyids, heteromyids, mice, rats, voles, beavers, porcupines), lagomorphs, chiropterans, canids, and artiodactyls (Abbott 1989; Benton 1991; see Appendix Table A-4 for species-level identifications). Publications, mostly abstracts and theses or dissertations, on Beaver Creek Rock Shelter include Martin and Abbott (1986), Martin and Alex (1987), Martin et al. (1988, 1993a, 1993b), and Benton (1991, 1992, 1998, 1999).

Figure 20. The outside of Beaver Creek Shelter (NPS/UNKNOWN PHOTOGRAPHER, WICA ARCHIVES).

Salamander Cave

"Salamander Cave" is a pit discovered within the park unrelated to Wind Cave that has yielded mammalian fossils dating back about 250,000 years to the Pleistocene, around the boundary between the Irvingtonian and Rancholabrean land mammal ages. It is a solution cave, likely formed in the same way as many other caves in the region, such as Wind Cave. The present entrance is located on top of a limestone ridge and leads to several different rooms. Two rooms, the "Entrance Room" and "Porcupine Room", are being infilled via this entrance, and animals from many species, such as salamanders, deermice, and porcupines, are being trapped in these rooms today (Mead et al. 1996). Several other rooms, such as the "Horse Room", were likely filled by a paleo-entrance that has since sealed. The cave was investigated and assessed by a team from Northern Arizona University in the mid-1990s and all fossils are now held at the South Dakota School of Mines and Technology. Fossils excavated from the "Horse Room" were subsequently identified, described, and published (Mead et al. 1996). Specimens found include salamanders, several different rodents (the most common of which is prairie dog), lagomorphs, carnivores, horses, and artiodactyls (see Appendix Table A-3 for species-level identifications).

Graveyard Cave

"Graveyard Cave" is a pit near Salamander Cave that is also not physically connected to Wind Cave proper. This locality is a sinkhole within the Madison Limestone that has functioned as a natural trap for the past 2,000 years. There is only a single chamber, measuring 6.2 x 4.25 m (20 x 14 ft) at its greatest dimensions and around 1.5 m (4.9 ft) tall on average (Manganaro 1994). Mammalian remains are most common; however, mollusk, amphibian, and avian remains have been found here as well. A 1 x 1 x 0.8-m (3.3 x 3.3 x 2.6-ft) test pit was excavated from the cave (Manganaro 1994). All recovered remains are held at the South Dakota School of Mines and Technology. Species found include various frogs, salamanders, snakes, birds, shrews, squirrels, gophers, mice, rats, porcupines, lagomorphs, bats, foxes, coyotes, skunks, bison, and deer (see Appendix Table A-6 for species-level identifications). Mollusks were also discovered and described in a later publication (Jass et al. 2002).

Persistence Cave

"Persistence Cave" is a cave entrance hypothesized to be another entrance to Wind Cave. Persistence Cave is a small cave consisting of two diverging narrow passageways filled with sediment accumulated over tens of thousands of years. Both passages are undergoing excavation and have yielded numerous vertebrate fossils representing several different species. The northern passage, named the "Mammoth Passage" after the nearby Mammoth Site of Hot Springs whose paleontologists assisted with excavation, is now about 12 m (40 ft) long and is the primary dig face as of 2022. The southern passage, called the "NPS Passage", is approximately 150 m (500 ft) long and leads to a large room before dipping down into thus far unexplored passageways. Both passages are only about 0.5 m (1.6 ft) tall throughout and have thick deposits of sediment on their floors. The stratigraphic contexts of the fossils are not fully understood currently and so the ages of the fossils have been dated with radiocarbon dating. Fossil dating has revealed ages ranging from approximately 40,000 years ago to 2,000 years ago, suggesting that the cave had multiple temporary openings throughout the late Pleistocene and Holocene (J. Mead, pers. comm., Nov. 2022). All recovered fossils are temporarily held at the Mammoth Site, which also conducts all radiocarbon dating of the site. Fossils found include plant matter, various mollusks, salamanders, frogs, lizards, snakes, marmots, squirrels, voles, gophers, rats, mice, rabbits, pikas, bats, pine martens, horses, and bison (T. Herring, pers. obs., Nov. 2022). This site has not been widely documented in the literature yet; publications including specimens from the cave include Jass et al. (2017, 2020) and Mead et al. (2021).

Other Paleontological Resource Localities

There are several other small caves and shelters scattered throughout the park, where bones have been found but not yet classified by taxon or age. Site names and contents are briefly described below (M. Ohms field notes 2004):

- Ivy Cave: A large unidentified femur fragment was found within the cave.
- Boundary Cave: Several (unidentified) bones were found in the entrance chamber.
- Just Within Reach Cave: Several bones were found within the cave.
- Coyote Cave: A bison bone and a rodent tooth were found in the cave room.
- Rat Midden Cave: Numerous scattered (unidentified) bones were found inside the cave.

- Animal Shelter: Numerous scattered bones were found at the site.
- Campground Shelter: A few scattered (unidentified) bones were discovered here.
- Mall of America Shelter: A few small, scattered (unidentified) bones were found on site.
- Creature Feature: The floor of the shelter is littered with (unidentified) bones.
- Feature 141: A few (unidentified) bones were found on the floor of the room.

Paleontological Localities Near WICA

The Mammoth Site of Hot Springs (also a National Natural Landmark), a filled-in karst sinkhole located 6 km (4 mi) south of WICA, is one of the best-known Quaternary fossil sites in the Great Plains. Fossils yielded from the Mammoth Site include pollen, freshwater bivalves, gastropods, ostracodes, worm burrows, fish, frogs, birds, moles, rodents, wolves, coyotes, ferrets, short-faced bears, Columbian mammoths, woolly mammoths, peccaries, camels, llamas, shrub oxen, carnivore dung, bird tracks, and mammoth footprints. Columbian mammoths are the most commonly found with at least 58 individuals discovered thus far. The top of the sinkhole is approximately 100,000 years old while the bottom of what has been excavated is 200,000 years old (J. Mead, pers. comm., Nov. 2022). The sinkhole was filled by a pond surrounded by walls that the animals could not climb (Agenbroad 1984, 1997).

JECA has also yielded Pleistocene–Holocene fossils. Fossils found at JECA include gastropods, snakes, rodents, rabbits, bats, indeterminate mammals, wood rat middens, and non-rodent dung (Santucci et al. 2001).

An important Cretaceous (120 million years old) fossil plant locality was discovered in the southern Black Hills during the 1890s. Paleobotanists from the Smithsonian, Yale University, and other institutions recognized the exceptionally well-preserved remains of fossilized cycadeoids and obtained collections for study and exhibit. Advocacy for conservation of this fossil locality led to the proclamation of a national monument, similar to the history of what occurred with Petrified Forest National Monument (1906) and Dinosaur National Monument (1915). On October 21, 1922, President Warren G. Harding created Fossil Cycad National Monument in the Black Hills of South Dakota using the authority provided in the Antiquities Act (1906) using the following language, "…rich Mesozoic deposits of fossil cycads and other examples of paleobotany, which of great scientific interest and value…it appears that the public interest would be promoted by reserving these deposits as a national monument."

The monument originally consisted of 129 hectares (320 acres) of land located 18 km (11 mi) west-southwest of the town of Hot Springs, South Dakota, which were placed under the administration of WICA, which retains a small number of fossils from the monument (Figure 21). However, years of negligent management at the monument resulted in irreparable impacts on the finite and scientifically significant paleobotanical resources. Based on the complete loss of the non-renewable fossil cycadeoids on the surface at the monument, the basis for the monument's proclamation, Fossil Cycad National Monument was abolished by Congress in 1957 and the lands transferred to the Bureau of

Land Management. For more details on the history of Fossil Cycad National Monument, see publications by Santucci and Hughes (1998) and Santucci and Ghist (2014).

Figure 21. Fossil cycadeoid specimens from Fossil Cycad National Monument in the WICA Museum Collections (NPS/VINCE SANTUCCI).

Cultural Resource Connections

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

Fossils have been an important part of WICA history since Alvin McDonald explored the caves in 1891, and his descriptions of the fossils are a window into how local paleontology was practiced at the end of the 19th century. Additionally, at Beaver Creek Shelter, a worked antler tine was discovered (Martin et al. 1993a), the first example of a biological tool used by indigenous populations in the area.

The discovery of other fossil/cultural resource associations remains a possibility as further paleontological work occurs in WICA. Humans have been present in the area for over ten thousand years and commonly interacted with now-extinct animals (Hannus 1990). Examples of fossils that might be evidence of these interactions are mammoth butchering sites (Hannus 1990), biological tools, stone tools made with fossiliferous rocks, folk tales inspired by fossils (Mayor 2005), and the use of fossils in amulets (Mayor 2005).

Museum Collections and Paleontological Archives

Museum Collections and Curation

Park Collections

Wind Cave National Park has collections of specimens from within Wind Cave, surface fossil sites, and from the abolished Fossil Cycad National Monument. There are 40 fossil specimens total, including 20 brachiopod/bivalve specimens from the Madison Limestone, seven coral specimens from the Madison Limestone, two gastropods from the Madison Limestone, six specimens of petrified wood from the Lakota Formation, four cycadeoids from the Dakota Sandstone (a formation not found within WICA's present boundaries), and one specimen of unknown origin (T. Herring, pers. obs., Dec. 2022).

Collections in Other Repositories

The large majority of WICA fossil specimens are held at the Martin Paleontology Research Laboratory, South Dakota School of Mines & Technology (SDSMT), Rapid City, South Dakota. As of June 2022, there were 8,724 catalog numbers in the park database assigned to specimens held at the SDSMT, containing more than 24,000 individual specimens. 418 of these cataloged specimens are from the White River Group sites and 2 are from the Madison Limestone of Wind Cave. There are more than 8,000 Quaternary specimens from Beaver Creek Shelter, Graveyard Cave, Salamander Cave, the Chamber of Lost Souls, and Red Valley, with more than 7,000 coming from Beaver Creek Shelter alone (Rachel Benton, retired BADL park paleontologist and research scientist at the SDSMT, pers. comm., Oct 2022). The numbers corresponding to each site are not exact since many specimens are backlogged, but in 2011 there were 624 from Graveyard Cave, 502 from the Chamber of Lost Souls, and 210 from Salamander Cave (Tweet et al. 2011). The Salamander Cave fossils were formerly held at Northern Arizona University but were transferred in 2008 (Tweet et al. 2011).

All fossils collected from Persistence Cave are held at the Mammoth Site, Hot Springs, South Dakota. The Persistence Cave specimens have not yet been fully cataloged but number in the thousands. The trilobites collected by Christina Lochman-Balk in the 1950s are in the collections of the University of Missouri at Columbia's Department of Geological Sciences (Stitt 1998; Sarah Jacquet, assistant professor and Tara Selly, assistant professor, University of Missouri Department of Geological Sciences, pers. comm., Nov. 2022). The Yale Peabody Museum of Natural History in New Haven, Connecticut holds specimens of the ichnofossils cf. *Skolithos linearis* (YPM IP 160716), cf. *Macanopsis pagueyi* (YPM IP 160717), and cf. *Steinichnus carlsbergi* (YPM IP 160718) from the Deadwood Formation of WICA. Four specimens containing conodonts from the Minnelusa Formation described in Jennings (1959) are currently held at the University of Iowa, Iowa City, Iowa (Tiffany Adrian, Special Collections Manager, University of Iowa, pers. comm., Jan. 2023).

Archives

NPS Paleontology Archives

All data, references, images, maps, and other information used in the development of this report are maintained in the NPS Paleontology Archives and Library maintained by the NPS Paleontology

Program in Washington, D.C. These records consist of both park-specific and service-wide information pertaining to paleontological resources documented throughout the NPS. If any resources are needed by NPS staff at WICA, 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).

E&R Files

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

Photographic Archives

WICA maintains a Photographic Archive. However, there are very few photos relating to paleontology. The only photos pertaining to paleontology are those of the temporary Centennial Site exhibit featured in the WICA visitor center (see "Current Long Range Interpretive Plan" below).

Photos taken during cave and surface paleontological locality surveys are digitally stored within the resource management network drive. In Wind Cave, vertebrate sites are photographed if they contain abundant fossils, rare fossils, or fossils that appear to be much older than what is common. Invertebrate sites are photographed if specimens are rare or exceptionally preserved. A few photographs of corals, brachiopods, and gastropods are featured on the WICA website (https://www.nps.gov/media/photo/gallery.htm?pg=3024146&id=010C066B-155D-4519-3E5242C717C769DA).

Many photos of paleontological resources in the park resource drive lack a scale bar and sometimes lack any object that can provide scale. In the future, WICA staff are encouraged to photograph any cave or surface fossils with a scale bar or common object if a scale bar is not at hand.

As part of the 2022 WICA Paleontological Resource Survey, Theodore Herring took photos of all paleontological surface sites, several fossil sites within Wind Cave, and various museum collections. These are accessible in the resource management network drive.

Park Paleontological Research

Current and Recent Research

Since the 1990s, 25 permits have been issued for projects at WICA that were either paleontological in focus, or a geological project with paleontological significance. They are listed below in chronological order by project (note that some projects that spanned multiple years were issued multiple permits).

- WICA1992AFNW, principal investigator Jim Mead of Northern Arizona University, project "*Paleontological Investigations in Salamander and Graveyard Caves, WICA*", issued for 1992.
- WICA1993AIVA, principal investigator Jim Mead of Northern Arizona University, project "*Paleontology of Salamander Cave*", issued for 1993; this project was continued in 1994 under WICA1994AKGY.
- WICA1993AIUX, principal investigator Glen Fredlund of the University of Wisconsin, project "*The Use of Grass Phytolith Assemblages in Measuring Long-Term Vegetation and Climate Change in the Great Plains of North America*", issued for 1993.
- WICA1994AKGQ, principal investigator Glen Fredlund of the University of Wisconsin, project "*Investigation of Holocene Vegetation and Climate Change*", issued for 1994.
- WICA1999BENT, principal investigator Rachel Benton of Badlands National Park, project "*Comparison of osteological remains from recent raptor pellets and nest debris to fossil vertebrates collected from the Beaver Creek Shelter*", issued for 1999; this project was continued in 2000 under WICA2000BENT.
- WICA-2003-SCI-0050, principal investigator Arthur Palmer of the State University of New York at Oneonta, project "*Geology of Wind Cave*", issued for 2003–2013; this project was continued in 2014–2017 under WICA-2014-SCI-0004 and 2018–2025 under WICA-2018-SCI-0005.
- WICA-2008-SCI-0002, principal investigator Brian Fagnan of the South Dakota Department of Environment and Natural Resources, project "*Geologic Mapping of Wind Cave National Park*", issued for 2008–2011.
- WICA-2009-SCI-0008, principal investigator Rachel Brown of the South Dakota School of Mines & Technology, project "*Paleontological and Geological Study of White River Deposits in Wind Cave National Park, Including the Centennial, Klukas, and Future Fossil Localities*", issued for 2009–2010; this project was continued in 2011 under WICA-2010-SCI-0013.
- WICA-2010-SCI-0010, principal investigator Mike Wiles of Jewel Cave National Monument, project "*Evaluate paleoflood resources in Beaver Creek Drainage - Phase 1*", issued for 2010–2013.

- WICA-2011-SCI-0006, principal investigator Lauren Milideo of Penn State University, project "*Actualistic taphonomy of cold & temperate climates: applications for Pleistocene paleontology*", issued for 2011–2013.
- WICA-2014-SCI-0008, principal investigator Jim Mead of East Tennessee State University, project "*Quaternary fossil remains from Persistence Cave, WICA, South Dakota*", issued for 2015–2016.
- WICA-2015-SCI-0007, principal investigator Darrin Pagnac of the South Dakota School of Mines & Technology, project "*Survey and Salvage of Fossil Material from WICA-4 (Rattler Site), Wind Cave National Park*", issued for 2015.
- WICA-2016-SCI-0008, principal investigator Jeffrey Martin of the University of Maine (Orono), project "*Wind Cave National Park modern and fossil bison skeletal comparison: observing bison body size change through time in response to climate change*", issued for 2016.
- WICA-2017-SCI-0007, principal investigator Jeffrey Martin of Texas A&M University, project "*Drivers of morphological change in Bison: consequences of climate, heat load, and nutrition for managing a keystone species*", issued for 2017–2019.
- WICA-2017-SCI-0008, principal investigator Jim Mead of The Mammoth Site of Hot Springs, SD, Inc., project "*Persistence Cave, WICA: continued work on paleontological remains*", issued for 2017–2020.
- WICA-2018-SCI-0016, principal investigator Sarah Keenan of the South Dakota School of Mines & Technology, project "*Taphonomic study of Wind Cave vertebrate fossils*", issued for 2018–2019.
- WICA-2022-SCI-0002, principal investigator Sarah Keenan of the South Dakota School of Mines & Technology, project "*Assessing the paleoenvironmental and geobiological significance of carbonates from the Eocene-Oligocene boundary of the White River Group*", issued for 2022–2023.
- WICA-2022-SCI-0003, principal investigator Timothy Shanahan of the University of Texas at Austin, project "*Organic compounds as temperature indicators in cave sediments in Wind Cave*", issued for 2022.
- WICA-2022-SCI-0005, principal investigator Rebekah Stein of the University of California, Berkeley, project "*Temperature changes in the Early Holocene continental North America as recorded in carbonate fruits*", issued for 2022.
- WICA-2022-SCI-0017, principal investigator Justin Tweet of the National Park Service, project "*Wind Cave National Park Paleontological Resource Inventory*", issued for 2022–2023. This inventory report was supported by this permit.

Paleontological Research Permits

See the National Park Service Natural Resource Management Reference Manual DO-77 section on Paleontological Resource Management, subsection on Scientific Research and Collection (https://irma.nps.gov/DataStore/Reference/Profile/572379). NPS Management Policies 2006, section 4.8.2.1 on Paleontological Resources, states that

> *The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit.*

Any collection of paleontological resources from an NPS area must be made under an approved research and collecting permit. The NPS maintains an online Research Permit and Reporting System (RPRS) database for researchers to submit applications for research in NPS areas. Applications are reviewed at the park level and either approved or rejected. Current and past paleontological research and collecting permits and the associated Investigator's Annual Reports (IARs) are available on the RPRS website (https://irma.nps.gov/RPRS/). Additional information on NPS law and policy can be found in Appendix E.

Interpretation

Among the exhibits in the WICA Visitor Center, there is one fossil specimen currently on display: a tabulate coral embedded within boxwork (Figure 22). This fossil specimen is presumed to have been retrieved from the cave, though documentation on the fossil is minimal and it was listed as a "gift" to the park, shrouding its origins. WICA does not currently maintain an interpretive collection of fossils.

Figure 22. Tabulate coral embedded in the iconic boxwork of Wind Cave displayed in the WICA Visitor's Center (NPS/THEODORE HERRING).

Current Long Range Interpretive Plan

WICA has a current Long-Range Interpretive Plan, and paleontological resources are listed as one of the interpretive themes. However, minimal information is provided on how to support paleontological resources from an interpretation perspective. Information about the WICA interpretive plan was provided by Chief of Interpretation Tom Farrell during 2022.

The WICA website has an informative section about paleontology within the park (https://www.nps.gov/wica/learn/nature/paleontology.htm). The paleontology page opens with a description of the scope and aims of paleontology, before describing paleontology pertaining to the park. The first section describes Persistence Cave, including prominent fossils discovered from within the cave, the time period these fossils date to, and what they indicate about past environments. The second section describes the Centennial Site and how Oligocene fossils such as *Subhyracodon* and *Mesohippus* have provided information about the climate at the time. It also references Badlands National Park and Agate Fossil Beds National Monument as places to see Oligocene fossils on display. The last section discusses the Madison Limestone and its formation during the Mississippian when the local area was on the ocean floor, and corals, brachiopods, and crinoids thrived. It also notes that visitors can see these fossils on several Wind Cave tour routes.

There are currently no paleontological exhibits at the park, and none are planned at this time. There was a temporary exhibit for the Centennial Site in the past, which drew significant public interest, suggesting potential for a future paleontological exhibit (Figure 23). In 2017, South Dakota Public Broadcasting did a short segment on Persistence Cave as part of their *Dakota Life* series. The episode is titled "Persistence Paying Off" and features interviews with Marc Ohms (WICA) and Jim Mead (The Mammoth Site of Hot Springs). The segment could potentially be of interest to interpretation and can be found on YouTube: https://www.youtube.com/watch?v=rIB2kW29LP0be.

There are no outlined instructions to mention fossils during interpretive programming; however, park rangers may mention fossils if they find it relevant to do so. The hike programs do not visit fossil sites, so fossils are not mentioned. The cave tour routes tend to focus more on the geology and cultural history of the caves. The brachiopod fossils are mentioned on the Fairgrounds Tour Route, and the coral and brachiopod fossils located outside the elevator room are often mentioned on the Garden of Eden Tour Route. Only the fossils on the cave tour routes are addressed during the training of the seasonal staff. Seasonal staff are also trained to instruct all visitors not to touch any fossils or other formations within the cave.

WICA does not participate in National Fossil Day, other than making a Facebook post. WICA interpretation would be interested in participating in National Fossil Day in the future, but they are worried about giving away locations of fossil sites or resources, and so would not want to proceed without guidance from National Park Service paleontologists.

Figure 23. Temporary museum exhibit featuring *Subhyracodon* and *Mesohippus* fossils from the Centennial Site. The exhibit was displayed in the Wind Cave National Park visitor center (NPS/UNKNOWN PHOTOGRAPHER, WICA ARCHIVES).

WICA is also interested in assistance from NPS paleontologists in developing an exhibit on Persistence Cave in the visitor center. Additionally, WICA interpretive staff have expressed interest in developing a distance learning education program, for which the risk of revealing the location of fossils within the park might be lessened.

Recommended Interpretive Themes

I. General Paleontological Information

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

- Fossils are non-renewable resources that possess scientific and educational information and provide insight into what Earth was like thousands and even hundreds of millions of years ago.
- When paleontologists survey for paleontological resources, the most important tool for planning is a geologic map. Paleontological resources are more common in certain geologic units, so knowing where those units are exposed is important for a successful search. Another

crucially important tool for paleontological survey work is a field notebook for recording data and observations. The information we gain from fossils is incredibly valuable, and that information is lost without field notes. Other tools that a paleontologist takes into the field include small picks and brushes, a scale bar, consolidants to stabilize fossils, GPS, camera, topographic maps, and appropriate First Aid and safety equipment. It might be helpful to provide examples of these items for visitors when giving an interpretive talk.

- If fossils are found in the park by a visitor, the visitor should photograph it, take a GPS point if possible, and notify a ranger of where the resource was found, but most importantly, they should leave the fossil where they found it. It is extremely important for scientific and resource management purposes for locational information to be preserved. Visitors should be informed that park fossils are protected by law.

II. Fossils of WICA

- A program could be developed to educate the public on what types of fossils are present in WICA and what they tell scientists about Earth's dynamic history. The goal of this program is to increase visitors' understanding of local geology and paleontology. Therefore, information regarding fossils from the vicinity of WICA can be included.

III. Caves and Fossil Resources

- Resources for this Interpretation theme are listed in the references section.

IV. Further Interpretation Themes

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

Paleontological Resource Management and Protection

National Park Service Policy

Paleontological resources are non-renewable remains of past life preserved in a geologic context. At present, there are 424 official units of the National Park System, plus national rivers, national trails, and affiliated units that are not included in the official number. Of these, 286 are known to have some form of paleontological resources, and paleontological resources are mentioned in the enabling legislation of 18 units. Fossils possess scientific and educational values and are of great interest to the public; therefore, it is exceedingly important that appropriate management attention be placed on protecting, monitoring, collecting, and curating these non-renewable paleontological specimens from federal lands. In March 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 Department of Interior (DOI) lands. More information on laws, policies, and authorities governing NPS management of paleontological resources is detailed in Appendix E. Paleontological resource protection training is available for NPS staff through the NPS Paleontology Program. The Paleontology Program is also available to provide support in investigations involving paleontological resource theft or vandalism.

Between 2009 and 2022 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) developed the DOI final regulations for PRPA. The draft DOI regulations were published in the Federal Register in December 2016 and were available for 60 days to allow for public comment. The interagency team has reviewed public comments provided for the draft regulation and have incorporated these into the final regulation. The final regulation was surnamed by the DOI Solicitor's Office and each of the four bureau directors. On August 2, 2022, the DOI Paleontological Resources Preservation Act final regulation was published in the Federal Register. After 30 days the Office of Management and Budget approved the final DOI PRPA regulation on September 1, 2022, which is available at the following website: https://www.federalregister.gov/documents/2022/08/02/2022-16405/paleontological-resources-preservation. For more information regarding this act, visit https://www.nps.gov/subjects/fossils/fossil-protection.htm.

2006 National Park Service Management Policies (section 4.8.2.1) state

> *… Paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. The Service will study and manage paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment).*

Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit. Fossil localities and associated geologic data will be adequately documented when specimens are collected. Paleontological resources found in an archeological context are also subject to the policies for archeological resources. Paleontological specimens that are to be retained permanently are subject to the policies for museum objects.

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

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

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

In general, losses of paleontological resources result from naturally occurring physical processes, by direct or indirect human activities, or by a combination of both. These processes or activities influence the stability and condition of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). The greatest loss of associated contextual data occurs when fossils are removed from their original geological context without appropriate documentation. Thus, when a fossil weathers and erodes from its surrounding sediments and geologic context, it begins to lose significant ancillary data until, at some point, it becomes more a scientific curiosity than a useful piece of scientific data. A piece of loose fossil "float" can still be of scientific value. However, when a fossil has been completely removed from its original context, such as an unlabeled personal souvenir or a specimen with no provenance information in a collection, it is of very limited scientific utility. Similarly, inadvertent exhumation of fossils during roadway construction or a building excavation may result in the loss or impairment of the scientific and educational values associated with those fossils. It is not necessary to list here all the natural and anthropogenic factors that can lead to the loss of paleontological resources; rather it is sufficient to acknowledge that anything that disturbs native sediment or original bedrock has potential to result in the loss of the paleontological resources that occur there, or the loss of associated paleontological resource data.

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

WICA staff can seek assistance with the development of management strategies to address paleontological resource issues and questions that may arise in the future at the park. The NPS Paleontology Program is a primary office to provide support and technical assist on paleontological resource issues for parks. Visit the NPS Paleontology Program website dedicated to fossil stewardship (https://www.nps.gov/subjects/fossils/geoconservation.htm) for more information. Parks may seek partnerships and collaboration with paleontologists at local museums or universities. Paleontology students are often seeking opportunities for gain experience with fossil related activities and a variety of internship opportunities are available (e.g., Scientists in Parks Program and Student Conservation Association Internships).

Baseline Paleontology Resource Inventories

Baseline paleontological resource inventories are critical for implementing effective management strategies specifically designed for non-renewable fossils in parks. NPS park specific paleontological resource inventories compile information on the scope, significance, distribution (both geospatial and temporal), and management issues associated with park fossils. This inventory report for WICA has compiled information on previous paleontological research undertaken in and near WICA, lists of fossil taxa reported within WICA, and fossil localities documented in the park. This report can serve as a baseline source of information for future research, inventory reports, monitoring, and informing management decisions relative to paleontological resources. The Paleontological Resource Inventory and Monitoring report for the Northern Great Plains I&M Network completed by Tweet et al. (2011) and the references cited within were important baseline paleontological resource data sources for this WICA-specific report.

Paleontological Resource Monitoring

Paleontological resource monitoring is a significant part of paleontological resource management which involves the evaluation of the condition and stability of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). A monitoring program generally incorporates a prescription for periodic site visits to assess conditions of paleontological resources and localities. The frequency of field monitoring for fossil localities may be determined based on natural factors contributing to the rates of weathering and erosion, proximity of the fossil locality to visitor use areas, or whether a fossil locality has experienced past incidents of unauthorized fossil collecting, vandalism or other anthropogenic impacts.

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

Field collection of paleontological specimens may be recommended when fossils possess exceptional value (e.g., rare or high scientific significance) or at immediate risk of degradation or destruction by human activity and natural processes. Therefore, paleontological resource monitoring can be a valuable management tool to inform management decision-making. The first step in establishment of a monitoring program is identification of localities to be monitored, as discussed previously. Locality condition forms should be completed for each fossil locality of concern in order to evaluate factors that could cause loss or impairment of paleontological resources. Risks and conditions are categorized as Disturbance, Fragility, Abundance, and Site Access. “Disturbance” evaluates conditions that promote accelerated erosion or mass wasting resulting from human activities. “Fragility” evaluates natural conditions that may influence the degree to which fossil transportation is occurring. Sites with elevated fragility exhibit inherently soft rapidly eroding sediment or mass wasting on steep hillsides. A bedrock outcrop that is strongly lithified has low fragility. “Abundance” judges both the natural condition and number of specimens preserved in the deposits as well as the risk of being easily recognized as a fossil-rich area 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 fossils or fossil-bearing sediments. A locality with high access would be in close proximity to public use areas or other access (along trails, at roadcuts, at beach or river access points, and so on).

Each of the factors noted above may be mitigated through management actions. Localities exhibiting a significant degree of disturbance may require either active intervention to slow accelerated erosion, periodic collection and documentation of fossil materials, or both. Localities developed on sediments of high fragility naturally erode at a relatively rapid rate and would require frequent visits to document and/or collect exposed fossils in order to prevent or reduce losses. Localities with abundant or rare fossils, or high rates of erosion, may be considered for periodic monitoring in order to assess the stability and condition of the locality and resources, with regard to both natural processes and human-related activities. Localities that are easily accessible by road or trail would benefit from the same management strategies as those with abundant fossils and by occasional visits by park staff, documentation of in situ specimens, and/or frequent law enforcement patrols. Further information on paleontological resource monitoring can be found in Santucci and Koch (2003) and Santucci et al. (2009).

Foundation Documents and Resource Stewardship Strategies

Foundation documents and Resource Stewardship Strategies are two types of park planning documents that may contain and reference paleontological resource information. A foundation document is intended to provide basic guidance about a park for planning and management. It briefly describes a given park and its purpose, significance, fundamental resources and values, other importance resources and values, and interpretative themes. Mandates and commitments are also identified, and the state of planning is assessed. Foundation documents may include paleontological information and are also useful as a preliminary assessment of what park staff know about their paleontological resources, the importance they place on these resources, and the present state of these non-renewable resources. A foundation document for WICA has been published (National Park Service 2011).

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

Geologic Maps

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

Geologic maps are one of the foundational components of a paleontological resource inventory and fossil management program. Knowing which sedimentary rocks and deposits underlie a park and where they are exposed are essential for understanding the distribution of known or potential paleontological resources. The ideal scale for base geologic maps is 1:24,000 for maps in the 48 contiguous states, whereas maps for areas in Alaska tend to be coarser. Whenever possible, page-sized geologic maps derived from GRI files are included in paleontological resource inventory reports for reference, but park staff are encouraged to download GRI source files from IRMA. The source files can be explored in much greater detail and incorporated into the park GIS database. Links to the maps digitized by the GRI for WICA can be found in IRMA at https://irma.nps.gov/DataStore/Reference/Profile/2171444. In addition to a digital GIS geologic map, the GRI program also produces a park-specific geologic resource evaluation report discussing the geologic setting, distinctive geologic features, and processes within the park, highlighting geologic issues facing resource managers, and describing the geologic history leading to the present-day landscape of the park. A GRI report has been published for WICA (KellerLynn 2009).

Paleontological Resource Potential Maps

A paleontological resource potential map shows the distribution of geologic units that have high, low, or no potential for fossils (Figure 24). The map is color-coded to show the distribution of geologic units within a park that are 1) known to have yielded fossils in the park (green on Figure 24); 2) have not yielded fossils within the park but are fossiliferous elsewhere (yellow); or 3) are unfossiliferous (red; usually igneous or high-grade metamorphic rocks). This map gives a quick indication of areas where fossils may be discovered, which in turn can provide suggestions for areas to survey or monitor, or areas where the discovery of fossils may be of concern during work that disturbs the ground (road work, building construction, etc.).

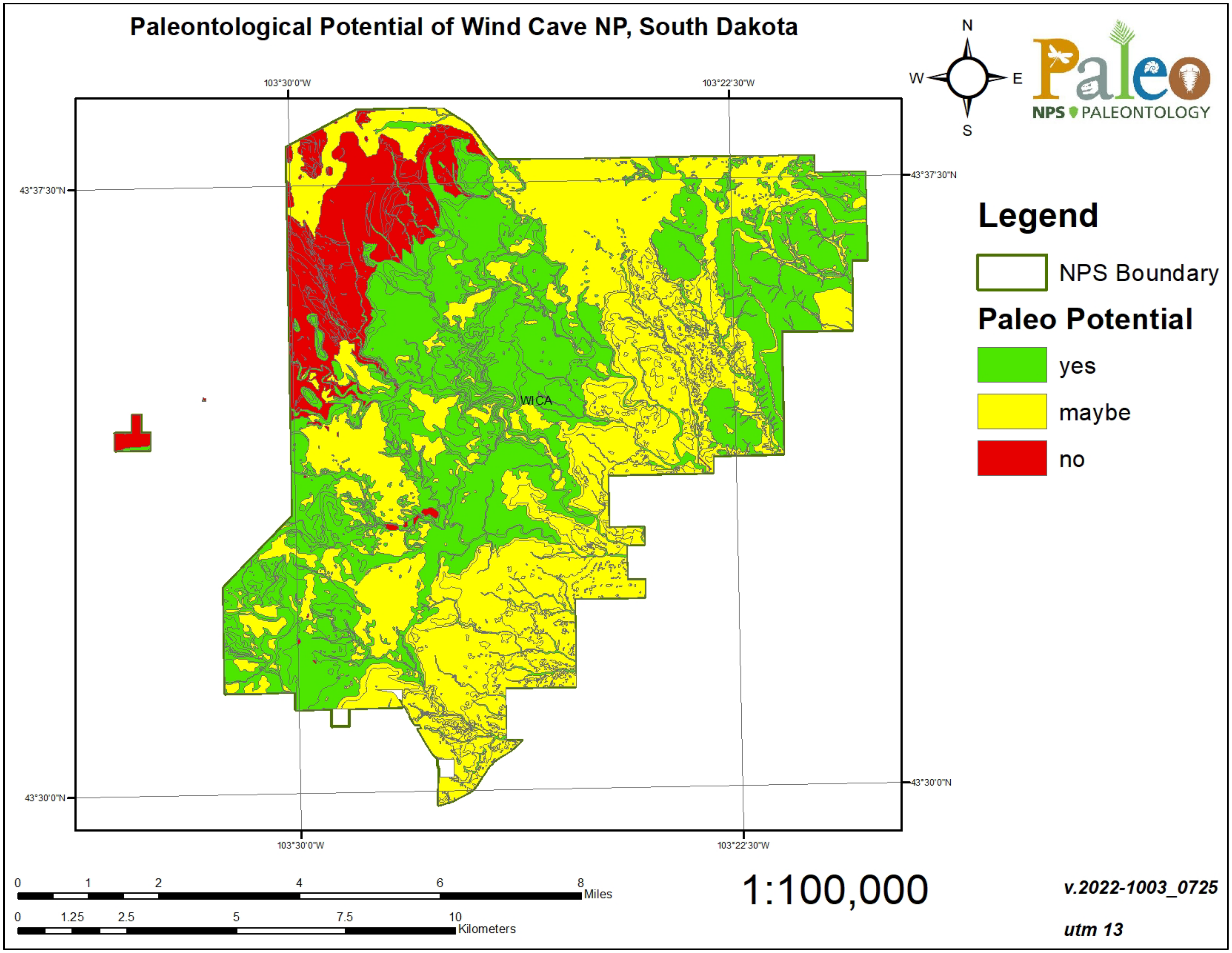

Figure 24. Map indicating paleontological potential of geologic map units in WICA (NPS/TIM CONNORS).

Paleontological Resource Management Recommendations

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

- WICA staff should be provided training on paleontological resources, including how to recognize and document these non-renewable resources.
- WICA staff should be encouraged to observe exposed rocks and sedimentary deposits for fossil material while conducting their usual duties. To promote this, staff need to receive guidance regarding how to recognize common local fossils. Park staff should seek opportunities to participate in paleontological field studies with trained paleontologists.
- WICA staff should photo document and monitor any occurrences of paleontological resources that may be observed in situ. Fossils and their associated geologic context (surrounding rock) should be documented but left in place unless they are subject to degradation or loss. A Geologic Resource Monitoring Manual published by the Geological Society of America and NPS Geologic Resources Division (GRD) includes a chapter on paleontological resource monitoring (Santucci et al. 2009). Santucci and Koch (2003) also present information on paleontological resource monitoring.
- Fossil theft and unauthorized fossil collecting represents threats to the preservation of non-renewable paleontological resources and any methods to minimize these activities should be utilized by staff. Any occurrence of paleontological resource theft or vandalism should be fully investigated by a law enforcement ranger. When possible, incidents should be fully documented and the information submitted for inclusion in the annual law enforcement statistics (i.e., IMARS).
- Fossils found in a cultural context should be documented like other fossils but will also require the input of an archeologist or a cultural resource specialist. Any fossil which has a cultural context may be culturally sensitive as well (i.e., subject to NAGPRA) and should be regarded as such until otherwise established. The Geologic Resources Division can assist with 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 Scientists in Parks program (SIP) is an established program for recruitment of geology and paleontology interns. The South Dakota School of Mines and Technology is another potential partner for student assistance.
- Contact the NPS Paleontology Program for technical assistance with paleontological resource management issues.

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

- Photo-document the specimen without moving it from its location if it is loose. Include a common item, such as a coin, pen, or pencil, for scale if a ruler or scale bar is not available.
- If a GPS unit is available, record the location of the specimen. If GPS is not available, record the general location within WICA and position within the outcrop. If possible, revisit the site when a GPS unit is available. Most smartphones also have the ability to record coordinates; if no GPS unit is available, attempt to record the coordinates with a phone. If the specimen is in a cave, use instead a system that does not require satellite reception, such as distance and direction from the nearest survey station. Hand drawn maps showing the fossil location relative to landmarks such as roads, structures, streams, or other natural features are encouraged when GPS units are not available or where they do not work underground.
- Write down associated data, such as rock type, general description of the fossil, type of fossil if identifiable, general location in WICA, sketch of the fossil, position within the outcrop or if it is loose on the ground, any associated fossils, and any other additional information.
- Do not remove the fossil unless it is loose in an area of heavy traffic, such as a public trail, and is at risk of being taken or destroyed. If the fossil is removed, be sure to wrap in soft material, such as tissue paper, and place in a labeled plastic bag with associated notes. If a fossil is moved but not collected, note its original position in a survey report and photograph the fossil in its original position with a scale bar if possible.

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Appendix A: Paleontological Species

Appendix Table A-1 and A-2 document the fossil species found at WICA in stratigraphic context (omitting cave sites; see Appendix Tables A-3–A-7 following), as reported in the literature, in museum collections, and through personal observations. For readability and convenience the records are split into Paleozoic (Appendix Table A-1) and younger (Appendix Table A-2) records. Rows are organized systematically, placing taxa of the same broad groups together (first column), with summary rows for particularly diverse groups. The columns are organized by formation, which are presented in ascending order (oldest to youngest) left to right. The columns also include the taxon (second 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 WICA, that cell is marked "Y"; if there is some question about the formation or whether the locality is within WICA, the cell is marked "?". A null record is marked "–".

It is likely that some of the genera and species cited here are actually cases in which different authors identified the same forms using different names. In addition, genera and species are frequently synonymized or transferred to other taxa. This publication is not intended to settle usage; the rule of thumb is that the usage in the most recent publication is preferred, and any older usages are listed in the notes section following the tables. Exceptions to this "hands-off" policy include corrections of typographical errors. In some cases, an author included a non-standard, obsolete, or otherwise unconventional usage that cannot be evaluated without further information; therefore, these records have been reproduced as originally presented. Similarly, some outdated names have been retained because it is not possible to determine a modern equivalent (for example, use of [*Genus*] sp. where [*Genus*] is historically species-rich and/or has a complex taxonomic history). Notes are included after Appendix Table A-2, as they apply to the taxa in that table.

Unit acronyms (after Fagnan et al. 2013; units not given acronyms in that publication have been given acronyms following the same style):

- Qal = Quaternary alluvium
- Tw = White River Group
- Kl = Lakota Formation
- Js = Sundance Formation
- PIPm = Minnelusa Formation
- Mp = Madison Limestone
- MDe = Englewood Limestone
- OCd = Deadwood Formation

Appendix Table A-1. Paleozoic fossil taxa reported from WICA in stratigraphic context. References are provided where appropriate.

Group	Taxon	OCd	MDe	Mp	PIPm	References
Invertebrates	**Invertebrates overall**	**Y**	**Y**	**Y**	**Y**	**–**
Porifera (sponges)	Porifera undetermined	–	–	Y	–	Santucci et al. 2001
Cnidaria: Anthozoa (corals)	Tabulata undetermined	–	Y	Y	–	Horrocks 2008, Fagnan et al. 2013; T. Herring, pers. obs.
	Unspecified horn corals	–	Y	Y	–	Todd 1894; Horrocks 2008; Tweet et al. 2011
	Rugosa undetermined	–	Y	Y	–	Fagnan et al. 2013
	Anthozoa undetermined	–	–	Y	–	Santucci et al. 2001; Horrocks 2007, 2008
Bryozoa (moss animals)	Bryozoan undetermined	–	–	Y	–	Santucci et al. 2001
Brachiopoda (lamp shells)	*Chonetes*-like shells	–	–	Y	–	Todd 1894
	Dicellomus sp.	Y	–	–	–	Stitt 1998
	Inarticulata undetermined	Y	–	–	–	Fagnan et al. 2013
	Spiriferida undetermined	–	Y	Y	–	Fagnan et al. 2013
	Brachiopoda undetermined	–	Y	Y	Y	Santucci et al. 2001; Horrocks 2008; Tweet et al. 2011; Fagnan et al. 2013
Mollusca: Class Bivalvia (clams, scallops, oysters, etc.)	Bivalvia undetermined	–	–	–	Y	Jennings 1959
Mollusca: Class Gastropoda (snails)	*Euomphalus*-like shells	–	–	Y	–	Todd 1894
	Pleurotomaria-like shells	–	–	Y	–	Todd 1894
	Gastropoda undetermined	–	–	Y	Y	Jennings 1959; Santucci et al. 2001; Horrocks 2008; Fagnan et al. 2013
Arthropoda: Class Trilobita	*Cedarina dakotaensis*	Y	–	–	–	Stitt 1998
	Modocia centralis	Y	–	–	–	Stitt 1998
	Trilobita undetermined	Y	–	–	–	Fagnan et al. 2013
Echinodermata: Class Crinoidea (sea lilies)	Crinoidea undetermined	–	Y	Y	–	Tweet et al. 2011; Fagnan et al. 2013; M. Ohms, pers. obs.
Other invertebrates	Shell-like fossils	–	–	Y	–	National Park Service 1979
Vertebrates	Undetermined bone and tooth fragments	–	Y	–	–	Tweet et al. 2011

Appendix Table A-1 (continued). Paleozoic fossil taxa reported from WICA in stratigraphic context. References are provided where appropriate.

Group	Taxon	OCd	MDe	Mp	PIPm	References
Conodonta	*Streptognathodus eccentricus*	–	–	–	Y	Jennings 1959
	Streptognathodus elegantulus	–	–	–	Y	Jennings 1959
	Streptognathodus oppletus	–	–	–	Y	Jennings 1959
	Streptognathodus simulator	–	–	–	Y	Jennings 1959
Trace Fossils	cf. *Macanopsis pagueyi*	Y	–	–	–	YPM collection records
	cf. *Skolithos linearis*	Y	–	–	–	YPM collection records
	cf. *Steinichnus carlsbergi*	Y	–	–	–	YPM collection records
	Possible worm tubes	–	–	Y	–	Santucci et al. 2001
	Invertebrate burrows	Y	–	Y	–	Palmer and Palmer 1989; Stitt 1998; Horrocks 2008; Fagnan et al. 2013
	General bioturbation	–	Y	–	–	Fagnan et al. 2013
Other Fossils	Foraminifera *Fusulina* sp.	–	–	–	Y	Verville and Thompson 1963
	“Fossil cavities”	–	–	–	Y	Bates 1955
	Long and slender reed or algae-like fossils	–	–	Y	–	Todd 1894
	Microbial filaments resembling *Leptothrix*	–	–	“Y”	–	Palmer and Palmer 1989, 1991; filaments appear to date to an early (pre-full paleokarst) stage of diagenesis
	Unspecified fossils	Y	–	–	–	Darton 1901

Appendix Table A-2. Mesozoic and Cenozoic fossil taxa (exclusive of caves) reported from WICA in stratigraphic context. References are provided where appropriate.

Group	Taxon	Js	Kl	Tw	Qal	References
Plants	Cypress wood	–	Y	–	–	Ohms 2017
	Ponderosa pine charcoal	–	–	–	Y	KellerLynn 2009
	Celtis hatcheri	–	–	Y	–	Martin 1984, 1988; Brown 2014
	Palm wood	–	Y	–	–	Ohms 2017
	Phytoliths, numerous morphologies	–	–	–	Y	Fredlund and Tieszen 1997
	Charcoal	–	–	–	Y	Fredlund and Tieszen 1997
	Petrified wood	–	Y	–	–	KellerLynn 2009; Fagnan et al. 2013
	Unspecified plants	–	–	Y	–	Horrocks 2003b
Invertebrates	*Pachyteuthis* sp.	Y	–	–	–	Fagnan et al. 2013
	Skinnerelix leidyi	–	–	Y	–	Martin 1988, 1994
	Bivalvia undetermined	–	–	Y	–	R. Horrocks, pers. comm., 2014
	Gastropoda undetermined	–	–	Y	–	Martin 1993; Horrocks 2003b
Vertebrates	**Vertebrates overall**	**–**	**–**	**Y**	**Y**	**–**
Testudines (turtles and tortoises)	*Stylemys nebrascensis*	–	–	Y	–	Martin 1988; Brown 2009, 2014
	Testudines undetermined	–	–	Y	–	Martin 1993; Horrocks 2003a, 2003b, McDonald and Horrocks 2004a, 2004b
Squamata (lizards and snakes)	*Peltosaurus* sp.	–	–	Y	–	Martin 1988; Brown 2009, 2014
	Lacertilia undetermined	–	–	Y	–	Martin 1993; Horrocks 2003b
	Serpentes undetermined	–	–	Y	–	Horrocks 2003b
Mammalia: Marsupialia	*Herpetotherium fugax*	–	–	Y	–	Brown 2014
Mammalia: “Insectivora”	*Leptictis* sp.	–	–	Y	–	Martin 1988; Brown 2009
	“Insectivora” undetermined	–	–	Y	–	Martin 1993; Horrocks 2003b
Mammalia: Rodentia	*Eumys elegans*	–	–	Y	–	Martin 1988; Brown 2009
	Ischyromys typus	–	–	Y	–	Martin 1988; Brown 2009, 2014

Appendix Table A-2 (continued). Mesozoic and Cenozoic fossil taxa (exclusive of caves) reported from WICA in stratigraphic context. References are provided where appropriate.

Group	Taxon	Js	Kl	Tw	Qal	References
Mammalia: Rodentia (continued)	*Leidymys* sp.	–	–	Y	–	Martin 1988; Brown 2009
	Paradjidaumo trilophus	–	–	Y	–	Brown 2009, 2014
	cf. *Prosciurus*	–	–	Y	–	Martin 1988
	Rodentia undetermined	–	–	Y	–	Martin 1993; Horrocks 2003b
Mammalia: Lagomorpha	*Megalagus turgidus*	–	–	Y	–	Martin 1988; Brown 2009
	Palaeolagus temnodon	–	–	Y	–	Brown 2014
	Palaeolagus cf. *P. haydeni*	–	–	Y	–	Martin 1988; Brown 2009, 2014
	Palaeolagus sp.	–	–	Y	–	Brown et al. 2008
	Palaeolagus?	–	–	Y	–	McDonald and Horrocks 2004b
	Lagomorpha undetermined	–	–	Y	–	Martin 1993; Horrocks 2003b
Mammalia: Creodonta	*Hyaenodon* sp.	–	–	Y	–	Brown 2009, 2014; Brown et al. 2008
	Creodonta undetermined?	–	–	Y	–	McDonald and Horrocks 2004b
Mammalia: Carnivora	*Hesperocyon* sp.	–	–	Y	–	Martin 1988; Brown 2009
	Canidae undetermined	–	–	Y	–	Horrocks 2003b
Mammalia: Perissodactyla	*Mesohippus bairdi*	–	–	Y	–	Brown 2009, 2014
	Mesohippus sp.	–	–	Y	–	Horrocks 2003a; McDonald and Horrocks 2004a, 2004b; Brown et al. 2008
	Subhyracodon cf. *S. occidentalis*	–	–	Y	–	Horrocks 2003a; McDonald and Horrocks 2004a, 2004b; Brown 2009, 2014; Brown et al. 2008
	Rhinocerotidae undetermined	–	–	Y	–	Martin 1988
	Perissodactyla undetermined	–	–	Y	–	Martin 1993
Mammalia: Artiodactyla	*Bison* sp.	–	–	–	Y	KellerLynn 2009
	Leptomeryx speciosus	–	–	Y	–	Brown 2014
	Leptomeryx cf. *L. evansi*	–	–	Y	–	Brown 2009, 2014
	Leptomeryx sp.	–	–	Y	–	Martin 1988; Horrocks 2003a; McDonald and Horrocks 2004b; Brown et al. 2008

Appendix Table A-2 (continued). Mesozoic and Cenozoic fossil taxa (exclusive of caves) reported from WICA in stratigraphic context. References are provided where appropriate.

Group	Taxon	Js	Kl	Tw	Qal	References
Mammalia: Artiodactyla (continued)	*Merycoidodon* sp.	–	–	Y	–	Martin 1988; Brown et al. 2008; Brown 2009
	Miniochoerus sp.	–	–	Y	–	Brown 2014
	Artiodactyla undetermined	–	–	Y	Y	Martin 1993
Ichnofossils	Dung beetle balls	–	–	Y	–	R. Horrocks, pers. comm., 2014
	Invertebrate burrows	–	–	Y	–	R. Horrocks, pers. obs.
	Rhizoliths	–	–	Y	–	R. Horrocks, pers. comm., 2014

Taxonomic Notes

- For simplicity, "[*Genus*] sp. indet." is rendered as "[*Genus*] sp."
- *Helix leidyi* = *Skinnerelix leidyi*
- Various identifications of the Centennial Site rhino are consolidated as *Subhyracodon* cf. *S. occidentalis*
- Various rabbit, horse, and *Leptomeryx* identifications may all refer to the same specimens

Appendix Tables A-3 through A-6 document the fossil species found in four major WICA cave sites as reported in the literature, in museum collections, and through personal observations. Rows are organized systematically, placing taxa of the same broad groups together, with summary rows for particularly diverse groups. The columns are organized by taxon group (first column), genus and species if available (second column), and references (last column; included in "Literature Cited" above). Appendix Table A-7 presents a combined table, with the four sites presented in approximate chronological order, oldest to youngest:

- Salamander Cave: minimum 252,000 years old (Appendix Table A-3)
- Beaver Creek Shelter: 9,380–1,750 years old (Appendix Table A-4)
- Chamber of Lost Souls: 6,000–4,000 years old (Appendix Table A-5)
- Graveyard Cave: 2,290–290 years old (Appendix Table A-6)

The fauna of Persistence Cave has not yet been fully documented, so has been omitted; deposits include late Pleistocene and Holocene components.

Appendix Table A-3. Salamander Cave fossil taxa; references provided where appropriate.

Group	Taxon	References
Amphibia: Urodela	*Ambystoma tigrinum*	Mead et al. 1996
Mammalia: Rodentia	*Cynomys* sp.	Mead et al. 1996
	Mictomys meltoni/kansasensis	Mead et al. 1996
	Microtus paroperarius	Mead et al. 1996
	Neotoma sp.	Mead et al. 1996
	Spermophilus sp.	Mead et al. 1996
	Terricola meadensis	Mead et al. 1996
Mammalia: Lagomorpha	*Lepus* sp.	Mead et al. 1996
	cf. *Lepus americanus*	Mead et al. 1996
Mammalia: Carnivora	cf. *Canis dirus*	Mead et al. 1996
	Mustela sp.	Mead et al. 1996
Mammalia: Perissodactyla	*Equus* spp.	Mead et al. 1996
Mammalia: Artiodactyla	*Camelops* sp.	Mead et al. 1996
	Antilocapra americana	Mead et al. 1996

Appendix Table A-4. Beaver Creek Shelter fossil taxa; references are provided where appropriate.

Group	Taxon	References
Plants	–	–
Plantae	Unspecified plant material	Martin et al. 1993a
Invertebrates	–	–
Bivalvia	Freshwater bivalves	Martin et al. 1993a
Gastropoda	Gastropoda, order indet.	Martin et al. 1993a
Vertebrates	–	–
Osteichthyes: Cypriniformes	*Catostomus commersoni*	Abbott 1989; Benton 1991

Appendix Table A-4 (continued). Beaver Creek Shelter fossil taxa; references are provided where appropriate.

Group	Taxon	References
Osteichthyes: Cypriniformes (continued)	*Semotilus atromaculatus*	Abbott 1989; Benton 1991
	Catostomidae, genus indet.	Abbott 1989; Benton 1991
	Cyprinidae, genus indet.	Abbott 1989; Benton 1991
Osteichthyes: Other	Osteichthyes, order indet.	Abbott 1989; Benton 1991
Amphibia: Anura	*Bufo cognatus*	Abbott 1989; Benton 1991
	Bufo woodhousii	Abbott 1989; Benton 1991
	Bufo sp.	Abbott 1989; Benton 1991
	Pseudacris triseriata	Benton 1991
	Rana catesbeiana	Abbott 1989; Benton 1991
	Rana pipiens	Abbott 1989; Benton 1991
	Scaphiopus bombifrons	Benton 1991
	Anura, family indet.	Abbott 1989; Benton 1991
Reptilia: Squamata	*Coluber constrictor*	Abbott 1989; Benton 1991
	Crotalus viridis	Abbott 1989; Benton 1991
	Heterodon nasicus	Abbott 1989; Benton 1991
	Heterodon sp.	Abbott 1989; Benton 1991
	Opheodrys vernalis	Abbott 1989; Benton 1991
	Thamnophis sirtalis	Abbott 1989; Benton 1991
	Thamnophis radix	Abbott 1989; Benton 1991
	Thamnophis sp.	Abbott 1989; Benton 1991
	Colubridae, genus indet.	Abbott 1989; Benton 1991
	Iguanidae, genus indet.	Benton 1991
	Serpentes, family indet.	Abbott 1989; Benton 1991
Aves: Falconiformes	*Falco sparverius*	Abbott 1989
	Falconiformes, genus indet.	Benton 1991

Appendix Table A-4 (continued). Beaver Creek Shelter fossil taxa; references are provided where appropriate.

Group	Taxon	References
Aves: Passeriformes	Passeriformes, family indet.	Abbott 1989; Benton 1991
Aves: Piciformes	*Dryobates pubescens*	Abbott 1989
	Picidae, genus indet.	Abbott 1989
Aves: Galliformes	Tetraonidae, genus indet.	Abbott 1989; Benton 1991
Aves: Strigiformes	Strigidae, genus indet.	Benton 1991
Aves: Anseriformes	Anatidae, genus indet.	Benton 1991
Aves: Other	Aves, order indet.	Abbott 1989
Mammalia: Insectivora	*Sorex cinereus*	Abbott 1989
	cf. *Sorex vagrans*	Benton 1991
Mammalia: Rodentia	*Cynomys ludovicianus*	Abbott 1989; Benton 1991
	Dipodomys sp.	Benton 1991
	Erethizon dorsatum	Abbott 1989
	Eutamias minimus	Abbott 1989
	cf. *Eutamias* sp.	Benton 1991
	Microtus ochrogaster	Abbott 1989; Benton 1991
	Microtus pennsylvanicus	Abbott 1989; Benton 1991
	Microtus sp.	Abbott 1989; Benton 1991
	Microtus sp. cf. *M. longicaudus*	Abbott 1989
	Neotoma cinerea	Benton 1991
	Neotoma floridana	Benton 1991
	Neotoma sp.	Abbott 1989; Benton 1991
	cf. *Neotoma* sp.	Abbott 1989
	Onychomys sp.	Benton 1991
	Perognathus hispidus	Benton 1991

Appendix Table A-4 (continued). Beaver Creek Shelter fossil taxa; references are provided where appropriate.

Group	Taxon	References
Mammalia: Rodentia (continued)	cf. *Perognathus hispidus*	Benton 1991
	cf. *Perognathus* sp.	Abbott 1989
	Peromyscus leucopus	Abbott 1989; Benton 1991
	Peromyscus maniculatus	Benton 1991
	Peromyscus sp.	Abbott 1989; Benton 1991
	cf. *Reithrodontomys megalotis*	Benton 1991
	Reithrodontomys sp.	Abbott 1989; Benton 1991
	cf. *Reithrodontomys* sp.	Abbott 1989
	Sciurus niger	Abbott 1989
	Spermophilus tridecemlineatus	Abbott 1989
	cf. *Spermophilus* sp.	Abbott 1989; Benton 1991
	Tamiasciurus hudsonicus	Abbott 1989; Benton 1991
	cf. *Tamiasciurus* sp.	Abbott 1989
	Thomomys talpoides	Abbott 1989; Benton 1991
	Zapus sp.	Abbott 1989
	cf. *Zapus* sp.	Abbott 1989
	Cricetidae, genus indet.	Abbott 1989; Benton 1991
	Geomyidae, genus indet.	Benton 1991
	Sciuridae, genus indet.	Abbott 1989; Benton 1991
	Rodentia, family indet.	Abbott 1989
Mammalia: Lagomorpha	cf. *Sylvilagus* sp.	Benton 1991
	Leporidae, genus indet.	Abbott 1989; Benton 1991
Mammalia: Chiroptera	*Eptesicus fuscus*	Abbott 1989; Benton 1991
	Myotis sp.	Abbott 1989; Benton 1991

Appendix Table A-4 (continued). Beaver Creek Shelter fossil taxa; references are provided where appropriate.

Group	Taxon	References
Mammalia: Carnivora	*Canis* sp.	Benton 1991
	Vulpes sp.	Benton 1991
	Canidae, genus indet.	Benton 1991
Mammalia: Artiodactyla	*Antilocapra americana*	Benton 1991
	Bison bison	Abbott 1989; Benton 1991
	Odocoileus sp.	Abbott 1989; Benton 1991
	Artiodactyla, family indet.	Abbott 1989
Mammalia: Other	Mammalia, order indet.	Abbott 1989; Benton 1991

Appendix Table A-5. Chamber of Lost Souls fossil taxa; references are provided where appropriate.

Group	Taxon	References
Invertebrates	–	–
Gastropoda	Gastropoda, order indet.	Martin and Anderson 1997
Vertebrates	–	–
Amphibia: Urodela	Urodela, family indet.	Martin and Anderson 1997
Amphibia: Anura	*Bufo* sp.	Martin and Anderson 1997
	Pseudacris sp.	Martin and Anderson 1997
Aves: Passeriformes	Passeriformes, family indet.	Martin and Anderson 1997
Aves: Falconiformes	Falconiformes, family indet.	Martin and Anderson 1997
Aves: Strigiformes	Strigiformes, family indet.	Martin and Anderson 1997
Mammalia: Insectivora	*Sorex* sp.	Martin and Anderson 1997
Mammalia: Rodentia	*Clethrionomys* sp.	Martin and Anderson 1997
	Marmota monax	Martin and Anderson 1997
	Neotoma cinerea	Martin 1984

Appendix Table A-5 (continued). Chamber of Lost Souls fossil taxa; references are provided where appropriate.

Group	Taxon	References
Mammalia: Rodentia (continued)	*Neotoma* sp.	Martin 1984; Martin and Anderson 1997
	cf. *Onychomys*	Martin and Anderson 1997
	cf. *Peromyscus leucopus*	Martin 1984; Martin and Anderson 1997
	cf. *Spermophilus*	Martin and Anderson 1997
	Sciuridae, genus indet.	Martin and Anderson 1997
Mammalia: Lagomorpha	Leporidae, genus indet.	Martin and Anderson 1997
Mammalia: Chiroptera	*Eptesicus* sp.	Martin and Anderson 1997
	Myotis sp.	Martin 1984; Martin and Anderson 1997
Mammalia: Carnivora	*Urocyon cinereoargenteus*	Martin and Anderson 1997
Mammalia: Artiodactyla	*Bison* sp.	Martin 1984
	Odocoileus sp.	Martin and Anderson 1997

Appendix Table A-6. Graveyard Cave fossil taxa; references are provided where appropriate.

Group	Taxon	Reference
Invertebrates	–	–
Gastropoda: Stylommatophora	*Catinella* sp.	Jass et al. 2002
	Deroceras laeve	Jass et al. 2002
	Discus whitneyi	Jass et al. 2002
	Discus sp.	Jass et al. 2002
	Gastrocopta armifera	Jass et al. 2002
	Gastrocopta procera	Jass et al. 2002
	Hawaiia minuscula	Jass et al. 2002
	Pupoides albilabris	Jass et al. 2002
	Vallonia cyclophorella	Jass et al. 2002

Appendix Table A-6 (continued). Graveyard Cave fossil taxa; references are provided where appropriate.

Group	Taxon	Reference
Gastropoda: Stylommatophora (continued)	*Vallonia gracilicosta*	Jass et al. 2002
	Zonitoides arboreus	Jass et al. 2002
Vertebrates	–	–
Amphibia: Urodela	*Ambystoma tigrinum*	Manganaro 1994
Amphibia: Anura	*Bufo* sp.	Manganaro 1994
	Pseudacris triseriata	Manganaro 1994
	Rana sp.	Manganaro 1994
Reptilia: Squamata	*Coluber constrictor*	Manganaro 1994
	Crotalus viridis	Manganaro 1994
	Lampropeltis sp.	Manganaro 1994
	Pituophis melanoleucus	Manganaro 1994
	Colubridae, genus indet.	Manganaro 1994
Aves: Galliformes	cf. *Tympanuchus*	Manganaro 1994
Aves: Passeriformes	Fringillidae, genus indet.	Manganaro 1994
	cf. Picidae, genus indet.	Manganaro 1994
	Passeriformes, family indet.	Manganaro 1994
Aves: Other	Aves, order indet.	Manganaro 1994
Mammalia: Insectivora	*Sorex merriami*	Manganaro 1994
Mammalia: Rodentia	*Cynomys ludovicianus*	Manganaro 1994
	Cynomys sp.	Manganaro 1994
	Erethizon dorsatum	Manganaro 1994
	Microtus ochrogaster	Manganaro 1994
	Microtus pennsylvanicus	Manganaro 1994
	Microtus sp.	Manganaro 1994
	Neotoma cinerea	Manganaro 1994

Appendix Table A-6 (continued). Graveyard Cave fossil taxa; references are provided where appropriate.

Group	Taxon	Reference
Mammalia: Rodentia (continued)	*Neotoma floridana*	Manganaro 1994
	Neotoma sp.	Manganaro 1994
	Ondatra zibethicus	Manganaro 1994
	Onychomys leucogaster	Manganaro 1994
	Perognathus hispidus	Manganaro 1994
	Perognathus sp.	Manganaro 1994
	Peromyscus maniculatus	Manganaro 1994
	Peromyscus leucopus	Manganaro 1994
	Peromyscus sp.	Manganaro 1994
	Reithrodontomys sp.	Manganaro 1994
	Sciurus sp.	Manganaro 1994
	Tamiasciurus sp.	Manganaro 1994
	Thomomys talpoides	Manganaro 1994
	Zapus hudsonicus	Manganaro 1994
Mammalia: Lagomorpha	*Lepus townsendii*	Manganaro 1994
	cf. *Lepus townsendii*	Manganaro 1994
	Lepus sp.	Manganaro 1994
	Sylvilagus sp.	Manganaro 1994
Mammalia: Chiroptera	*Myotis thysanodes*	Manganaro 1994
	Myotis sp.	Manganaro 1994
	Plecotus townsendii	Manganaro 1994
	Plecotus sp.	Manganaro 1994
Mammalia: Carnivora	*Canis familiaris*	Manganaro 1994
	Canis latrans	Manganaro 1994
	Mephitis mephitis	Manganaro 1994

Appendix Table A-6 (continued). Graveyard Cave fossil taxa; references are provided where appropriate.

Group	Taxon	Reference
Mammalia: Carnivora (continued)	*Vulpes velox*	Manganaro 1994
	Vulpes vulpes	Manganaro 1994
	Vulpes sp.	Manganaro 1994
Mammalia: Artiodactyla	*Bison bison*	Manganaro 1994
	Cervus elaphus	Manganaro 1994
	Odocoileus sp.	Manganaro 1994

Appendix Table A-7. Summary of cave site faunal assemblages.

Group	Taxon	Salamander	Beaver	Chamber	Graveyard
Invertebrates	**Invertebrates overall**	**–**	**Y**	**Y**	**Y**
Bivalvia	Freshwater bivalves	–	Y	–	–
Gastropoda: Stylommatophora	*Catinella* sp.	–	–	–	Y
	Deroceras laeve	–	–	–	Y
	Discus whitneyi	–	–	–	Y
	Discus sp.	–	–	–	Y
	Gastrocopta armifera	–	–	–	Y
	Gastrocopta procera	–	–	–	Y
	Hawaiia minuscula	–	–	–	Y
	Pupoides albilabris	–	–	–	Y
	Vallonia cyclophorella	–	–	–	Y
	Vallonia gracilicosta	–	–	–	Y
	Zonitoides arboreus	–	–	–	Y
Gastropoda	Gastropoda, order indet.	–	Y	Y	–
Vertebrates	**Vertebrates overall**	**Y**	**Y**	**Y**	**Y**

Appendix Table A-7 (continued). Summary of cave site faunal assemblages.

Group	Taxon	Salamander	Beaver	Chamber	Graveyard
Osteichthyes: Cypriniformes	*Catostomus commersoni*	–	Y	–	–
	Semotilus atromaculatus	–	Y	–	–
	Catostomidae, genus indet.	–	Y	–	–
	Cyprinidae, genus indet.	–	Y	–	–
Osteichthyes: Other	Osteichthyes, order indet.	–	Y	–	–
Amphibia: Urodela	*Ambystoma tigrinum*	Y	–	–	Y
	Urodela, family indet.	–	–	Y	–
Amphibia: Anura	*Bufo cognatus*	–	Y	–	–
	Bufo woodhousii	–	Y	–	–
	Bufo sp.	–	Y	Y	Y
	Pseudacris triseriata	–	Y	–	Y
	Pseudacris sp.	–	–	Y	–
	Rana catesbeiana	–	Y	–	–
	Rana pipiens	–	Y	–	–
	Rana sp.	–	–	–	Y
	Scaphiopus bombifrons	–	Y	–	–
	Anura, family indet.	–	Y	–	–
Reptilia: Squamata	*Coluber constrictor*	–	Y	Y	–
	Crotalus viridis	–	Y	Y	–
	Heterodon nasicus	–	Y	–	–
	Heterodon sp.	–	Y	–	–
	Lampropeltis sp.	–	–	Y	–
	Opheodrys vernalis	–	Y	–	–
	Pituophis melanoleucus	–	–	Y	–
	Thamnophis sirtalis	–	Y	–	–

Appendix Table A-7 (continued). Summary of cave site faunal assemblages.

Group	Taxon	Salamander	Beaver	Chamber	Graveyard
Reptilia: Squamata (continued)	*Thamnophis radix*	–	Y	–	–
	Thamnophis sp.	–	Y	–	–
	Colubridae, genus indet.	–	Y	Y	–
	Iguanidae, genus indet.	–	Y	–	–
	Serpentes, family indet.	–	Y	–	–
Aves: Anseriformes	Anatidae, genus indet.	–	Y	–	–
Aves: Falconiformes	*Falco sparverius*	–	Y	–	–
	Falconiformes, genus indet.	–	Y	–	–
	Falconiformes, family indet.	–	–	Y	–
Aves: Galliformes	cf. *Tympanuchus*	–	–	–	Y
	Tetraonidae, genus indet.	–	Y	–	–
Aves: Passeriformes	Fringillidae, genus indet.	–	–	–	Y
	cf. Picidae, genus indet.	–	–	–	Y
	Passeriformes, family indet.	–	Y	Y	Y
Aves: Piciformes	*Dryobates pubescens*	–	Y	–	–
	Picidae, genus indet.	–	Y	–	–
Aves: Strigiformes	Strigidae, genus indet.	–	Y	–	–
	Strigiformes, family indet.	–	–	Y	–
Aves: Other	Aves, order indet.	–	Y	–	Y
Mammalia: Insectivora	*Sorex cinereus*	–	Y	–	–
	Sorex merriami	–	–	–	Y
	cf. *Sorex vagrans*	–	Y	–	–
	Sorex sp.	–	–	Y	–
Mammalia: Rodentia	*Clethrionomys* sp.	–	–	Y	–
	Cynomys ludovicianus	–	Y	–	Y

Appendix Table A-7 (continued). Summary of cave site faunal assemblages.

Group	Taxon	Salamander	Beaver	Chamber	Graveyard
Mammalia: Rodentia (continued)	*Cynomys* sp.	Y	–	–	Y
	Dipodomys sp.	–	Y	–	–
	Erethizon dorsatum	–	Y	–	Y
	Eutamias minimus	–	Y	–	–
	cf. *Eutamias* sp.	–	Y	–	–
	Marmota monax	–	–	Y	–
	Microtus ochrogaster	–	Y	–	Y
	Microtus paroperarius	Y	–	–	–
	Microtus pennsylvanicus	–	Y	–	Y
	Microtus sp. cf. *M. longicaudus*	–	Y	–	–
	Microtus sp.	–	Y	–	Y
	Mictomys meltoni/kansasensis	Y	–	–	–
	Neotoma cinerea	–	Y	Y	Y
	Neotoma floridana	–	Y	–	Y
	Neotoma sp.	Y	Y	Y	Y
	cf. *Neotoma* sp.	–	Y	–	–
	Ondatra zibethicus	–	–	–	Y
	Onychomys leucogaster	–	–	–	Y
	Onychomys sp.	–	Y	–	–
	cf. *Onychomys*	–	–	Y	–
	Perognathus hispidus	–	Y	–	Y
	Perognathus sp.	–	–	–	Y
	cf. *Perognathus hispidus*	–	Y	–	–
	cf. *Perognathus* sp.	–	Y	–	–

Appendix Table A-7 (continued). Summary of cave site faunal assemblages.

Group	Taxon	Salamander	Beaver	Chamber	Graveyard
Mammalia: Rodentia (continued)	*Peromyscus leucopus*	–	Y	–	Y
	cf. *Peromyscus leucopus*	–	–	Y	–
	Peromyscus maniculatus	–	Y	–	Y
	Peromyscus sp.	–	Y	–	Y
	Reithrodontomys sp.	–	Y	–	Y
	cf. *Reithrodontomys megalotis*	–	Y	–	–
	cf. *Reithrodontomys* sp.	–	Y	–	–
	Sciurus niger	–	Y	–	–
	Sciurus sp.	–	–	–	Y
	Spermophilus sp.	Y	–	–	–
	Spermophilus tridecemlineatus	–	Y	–	–
	cf. *Spermophilus* sp.	–	Y	Y	–
	Tamiasciurus hudsonicus	–	Y	–	–
	Tamiasciurus sp.	–	–	–	Y
	cf. *Tamiasciurus* sp.	–	Y	–	–
	Terricola meadensis	Y	–	–	–
	Thomomys talpoides	–	Y	–	Y
	Zapus hudsonicus	–	–	–	Y
	Zapus sp.	–	Y	–	–
	cf. *Zapus* sp.	–	Y	–	–
	Cricetidae, genus indet.	–	Y	–	–
	Geomyidae, genus indet.	–	Y	–	–
	Sciuridae, genus indet.	–	Y	Y	–
	Rodentia, family indet.	–	Y	–	–

Appendix Table A-7 (continued). Summary of cave site faunal assemblages.

Group	Taxon	Salamander	Beaver	Chamber	Graveyard
Mammalia: Lagomorpha	*Lepus townsendii*	–	–	–	Y
	cf. *Lepus americanus*	Y	–	–	–
	cf. *Lepus townsendii*	–	–	–	Y
	Lepus sp.	Y	–	–	Y
	Sylvilagus sp.	–	–	–	Y
	cf. *Sylvilagus* sp.	–	Y	–	–
	Leporidae, genus indet.	–	Y	Y	–
Mammalia: Chiroptera	*Eptesicus fuscus*	–	Y	–	–
	Eptesicus sp.	–	–	Y	–
	Myotis thysanodes	–	–	–	Y
	Myotis sp.	–	Y	Y	Y
	Plecotus townsendii	–	–	–	Y
	Plecotus sp.	–	–	–	Y
Mammalia: Carnivora	*Canis familiaris*	–	–	–	Y
	Canis latrans	–	–	–	Y
	Canis sp.	–	Y	–	–
	cf. *Canis dirus*	Y	–	–	–
	Mephitis mephitis	–	–	–	Y
	Mustela sp.	Y	–	–	–
	Urocyon cinereoargenteus	–	–	Y	–
	Vulpes velox	–	–	–	Y
	Vulpes vulpes	–	–	–	Y
	Vulpes sp.	–	Y	–	Y
	Canidae, genus indet.	–	Y	–	–
Mammalia: Perissodactyla	*Equus* spp.	Y	–	–	–

Appendix Table A-7 (continued). Summary of cave site faunal assemblages.

Group	Taxon	Salamander	Beaver	Chamber	Graveyard
Mammalia: Artiodactyla	*Antilocapra americana*	Y	–	–	–
	Bison bison	–	Y	–	Y
	Bison sp.	–	–	Y	–
	Camelops sp.	Y	–	–	–
	Cervus elaphus	–	–	–	Y
	Odocoileus sp.	–	Y	Y	Y
	Artiodactyla, family indet.	–	Y	–	–
Mammalia: Other	Mammalia, order indet.	–	Y	–	–

Appendix B: Museum Collections Data

Appendix Table B-1. List of all repositories, number of catalogued specimens, localities of specimens, and specimen type. See Appendix C for repository contact information.

Repository	# of Catalogued Specimens	Locality or Formation	Specimen Type	Notes
Wind Cave National Park Visitor Center	40	Fossil Cycad National Monument Madison Limestone Lakota Formation	Invertebrates, cycadeoids, petrified wood	–
South Dakota School of Mines & Technology	8,724	Beaver Creek Shelter Graveyard Cave Salamander Cave Chamber of Lost Souls Red Valley White River Group Madison Limestone	Plants, invertebrates, vertebrates, ichnofossils	Salamander Cave specimens formerly held at Northern Arizona University
The Mammoth Site of Hot Springs	Unknown (in the thousands)	Persistence Cave	Plants, invertebrates, vertebrates, ichnofossils	–
University of Iowa	4	Minnelusa Formation	Conodonts	–
University of Missouri at Columbia	Unknown	Deadwood Formation	Trilobites	–
Yale Peabody Museum	Unknown, minimum 3	Deadwood Formation	Ichnofossils	–

Appendix Table B-2. Fall 2022 collections by Theodore Herring (transferred to SDSMT).

Specimen Type	Number of Specimens	Locality, Formation, Age	Notes
Vertebrate fragments	6	Room FP3, Wind Cave, Holocene	Various species
Gastropod	1	White River Group, Oligocene	–
Gastropod or rhizolith	1	White River Group, Oligocene	–
Leptomeryx	1	White River Group, Oligocene	Portion of lower jaw
Brachiopod	3	Fossil Ridge, Madison Limestone, Mississippian	Many of them are fused together
Conodonts	3	Lagoon Conodont Site, Minnelusa Formation, Pennsylvanian	There are three shale fragments containing 14 specimens

Appendix C: Repository Contact Information

Contact information for institutions known to have collections from WICA are included below. Addresses, links, and email addresses to departments are included as available. This information is subject to change, particularly hyperlinks.

SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY, MARTIN PALEONTOLOGY RESEARCH LABORATORY
Department of Geology and Geological Engineering
531 University Loop
Rapid City, SD 57701
https://www.sdsmt.edu/Academics/Museum-of-Geology/Paleontology-Research-Laboratory/ (Paleontology Research Laboratory)
https://www.sdsmt.edu/Academics/Departments/Geology-and-Geological-Engineering/Research/Paleontology/ (Paleontology)
South Dakota School of Mines & Technology WICA Holdings: Chamber of Lost Souls, White River Group, Beaver Creek Shelter, Salamander Cave, Graveyard Cave, and Red Valley fossils.

THE MAMMOTH SITE
1800 US-18 Bypass
Hot Springs, SD 57747
(605) 745-6017
https://mammothsite.org/
The Mammoth Site WICA Holdings: Persistence Cave fossils.

UNIVERSITY OF MISSOURI (COLUMBIA)
Department of Geological Sciences
101 Geological Sciences Bldg
Columbia, MO 65211
https://geology.missouri.edu/taxonomy/term/8
University of Missouri WICA Holdings: Trilobites from the Deadwood Formation.

YALE PEABODY MUSEUM
170 Whitney Ave
New Haven, CT 06520
(203) 432-8987
https://peabody.yale.edu/
Yale Peabody Museum WICA Holdings: Ichnofossils from the Deadwood Formation.

Appendix D: Glossary

Definitions are in part after Tweet et al. (2021).

Acanthodian: An extinct jawed fish with a shark-like body and fins supported by bony spines; also known as a "spiny shark".

Acritarch: An organic-walled microfossil of unknown classification.

Alluvial (adjective), alluvium (noun): A general term for unconsolidated terrestrial sediment moved by water and not attributed to a more specific process (i.e., not fluvial, glacial, or lacustrine).

Amphicyonid: An extinct carnivoran mammal also known as a "bear dog".

Anhydrite: A calcium sulfate mineral similar to gypsum but lacking water in its structure.

Anthracothere: An extinct hippo-like artiodactyl mammal.

Anticline: A stratigraphic feature where geologic layers slope downwards from a crest.

Ardeiform: A member of the group of birds including herons and relatives.

Arthropod: Any of a diverse group of invertebrates with exoskeletons, segmented bodies, and jointed appendages. Insects, arachnids, and crustaceans are modern examples.

Artiodactyl: An even-toed ungulate mammal (e.g., bison, camels, deer, pigs, sheep).

Asteroid: An echinoderm familiar for its five radiating arms; also known as a "sea star" or "starfish".

BADL: Badlands National Park.

Basin (geological): A geologic downwarp formed by folding and faulting; geologic basins can often be identified by rock strata dipping to a central point, a bull's-eye pattern of rocks in a geologic map with the youngest rocks at the center, or an anomalous area of young rocks at the same elevation as older rocks in the vicinity. An eroded geologic basin does not necessarily form a physical depression.

Belemnite: An extinct squid-like cephalopod, noted for its bullet-shaped mineralized internal guard.

Bioturbation: Disturbance of sediment by organisms to the extent that sedimentary features such as bedding and stratification are destroyed.

Bivalve: A mollusk with two shells; bivalves are also sometimes known as pelecypods, to reduce confusion (the term "bivalve" in a general sense also applies to other groups, such as brachiopods and some arthropods). Examples include clams, oysters, mussels, and scallops.

Black Hills: Mountain range on the border of eastern Wyoming and western South Dakota.

Blastoid: An extinct stalked echinoderm resembling a crinoid but with a nut-shaped body bearing numerous small filtering appendages, rather than a cup-shaped body with a smaller number of large appendages. Blastoids are sometimes identified informally as "sea buds".

Boxwork: A cave feature composed of calcite that forms a honeycomb pattern. Commonly found in Wind Cave.

Brachiopod: A marine filter-feeding animal with two shells, resembling bivalve mollusks but more closely related to bryozoans. Brachiopods are sometimes known as "lamp shells" because some of them resemble ancient oil lamps.

Breccia: A rock composed of large angular fragments in a fine-grained matrix.

Brontothere: An extinct horned perissodactyl that resembled a rhinoceros.

Bryozoan: A filter-feeding aquatic colonial animal. Bryozoans are sometimes known as "moss animals" because they often encrust objects.

Calcareous: Mostly or partly composed of calcium carbonate; lime-rich.

Calcite: A mineral made of calcium carbonate; found in limestone and some fossils.

Canid: A member of the group of mammals including dogs and relatives.

Carnivoran: A member of the group of mammals including most of the living flesh-eating forms (e.g., felines, canines, bears, raccoons, weasels, seals, etc.).

Cast: An impression of an organism that has been filled in by sediment.

Cenozoic: A geologic era, dated approximately 66 Ma to the present, noted for the diversification of mammals; the term means "new life".

Cephalopod: A mollusk with a prominent head fringed by tentacles. Examples include squids, octopuses, *Nautilus*, and many extinct forms, especially ammonoids.

Chert: A rock made of silica lacking obvious macroscopic crystals. Flint is a variety of chert found in chalk and marly limestone.

Chiropteran: A bat.

Colluvium: Sediment that has accumulated at the base of a slope.

Conchostracan: A bivalved crustacean, also known as "clam shrimp".

Conifer: A general term for non-flowering plants that produce seeds and pollen from cones.

Conodont: An extinct eel-like chordate, known primarily from jaw elements.

Conulariid: An extinct distant relative of corals that formed flat-sided conical structures from small mineralized rods.

Coprolite: Fossil feces.

Corallite: The dwelling cell of an individual coral animal.

Creodont: A member of an informal group of extinct carnivorous mammals.

Cretaceous: The third and last geologic period of the Mesozoic Era, noted for the rise of flowering plants and the extinction of many groups at the end of the period; approximately 143 to 66 Ma.

Crinoid: An echinoderm, also known as a sea lily, featuring a cup-like body with feathery tentacular arms, usually but not always attached to a surface with a stalk.

Cycad: A seed plant with a woody trunk and a crown of large stiff palm-like leaves.

Cycadeoid: An extinct seed plant similar to and often confused with cycads, but bearing flower-like reproductive structures.

Cystoid: An extinct echinoderm similar to a crinoid but with an ovoid body, instead of cup-like.

Death assemblage: A mass collection of fossil organisms that forms after a mass die-off, often caused by storm events.

Decapod: A member of the group of crustaceans including crabs, crayfish, shrimp, and lobsters.

DETO: Devils Tower National Monument.

Devonian: The fourth geologic period of the Paleozoic Era; approximately 419 to 359 Ma.

Dike: A sheet of rock emplaced in a fracture in older rocks; it can be igneous or sedimentary, and horizontal to vertical, depending on the orientation of the original fracture.

Disconformity: An erosional or non-depositional surface between parallel layers of sedimentary rock.

Dolomite: A mineral made of calcium-magnesium carbonate, and a rock (alternatively dolostone) composed primarily of this mineral. Most dolomite is formed by the replacement of some of the calcium ions in calcium carbonate by magnesium, a process called dolomitization.

Echinoderm: Any of a group of invertebrates noted for their five-fold symmetry. Sea stars and sea urchins are familiar echinoderms.

Echinoid: An echinoderm, also known as a sea urchin, commonly having a globose body covered in spines.

Entelodont: An extinct pig-like artiodactyl.

Eolian: Wind-blown transport or an environment where wind transport dominates.

Falconiform: A member of the group of birds including falcons and close relatives.

Float: In geology, eroded material resting on the surface, not attached to an outcrop.

Fluvial: A river as depositional environment or mode of transport.

Foraminifera: A "shelled amoeba"; "foraminifera" is often used for both singular and plural, although some authorities prefer "foraminiferan" for singular and "foraminiferans" or "foraminifers" for plural, and others use the more informal "foram" and "forams." Foraminifera, which still exist today, are well-known as microfossils from their tests, which are usually composed of calcium carbonate or tiny sediment grains (agglutinated).

Formation: A group of rocks that share some characteristics and can be depicted on a geological map; the basic unit of stratigraphy.

Fossiliferous: A rock or deposit that yields fossils.

Friable: Rocks and deposits that are easily crumbled.

Fusulinid: A variety of extinct foraminifera noted for their chambered, relatively enormous tests (as much as several cm/more than an inch long). In the field, they may resemble rice or other similar grains, and can be abundant in rocks of Pennsylvanian or Permian age.

Ga: An abbreviation for "giga-annum," but more easily understood as "million years ago".

Galliform: A member of a group of ground-feeding birds including chickens, grouse, quail, and turkeys.

Gneiss: A high-grade metamorphic rock characterized by banding of light-colored (quartz) and dark minerals.

Granite: An igneous rock formed at depth, composed primarily of light-colored quartz and feldspar minerals with small quantities of dark minerals.

Granofels: A metamorphic rock with large crystals (visible to the naked eye) and no distinct banding or foliation.

Graptolite: A colonial invertebrate that lived in bottom-attached or free-floating colonies; pterobranch "worms" may be modern graptolites.

Gruiform: A member of the group of birds including cranes and relatives.

Holocene: The second and most recent epoch of the Quaternary Period, following the Pleistocene and the last glacial maximum; approximately 11,700 years ago to the present.

Horn coral: A solitary rugose coral. The name refers to the animal-horn-like hard structure.

Hyolith: An extinct animal with an elongate triangular shell, apparently close to the ancestry of brachiopods, mollusks, or both..

Hypertragulid: A small extinct deer-like artiodactyl ungulate.

Ichnofossil: Fossilized remains of biological activity of an organism, including traces of footprints, tracks, burrows, trails, and other biogenically produced features.

Ichthyosaur: An extinct marine reptile resembling a dolphin in form.

IMARS: Incident Management, Analysis and Reporting System.

In situ: When describing fossils, this means found in place at an outcrop.

Inarticulate brachiopod: A brachiopod with a shell hinge lacking hard structures to keep it closed, instead relying on muscles.

Intrusive: In igneous rocks, "intrusive" refers to rocks that cooled from a molten state below the surface of the Earth.

Isopod: A member of the group of crustaceans including woodlice and relatives.

JECA: Jewel Cave National Monument.

Jurassic: The second geologic period of the Mesozoic Era; approximately 201 to 143 Ma.

Karst: Topography produced by the dissolution of bedrock, such as caves and sinkholes, usually associated with limestone.

Lacustrine: A lake as depositional environment or mode of transport.

Lagomorph: A member of the group of mammals including pikas, rabbits, and relatives.

Leptictid: An extinct small mammal with long hind legs and tail, traditionally classified as an insectivore.

Leptochoerid: A small extinct early artiodactyl ungulate.

Leptomerycid: A small extinct deer-like artiodactyl ungulate.

Lithified: A sedimentary deposit that has become rock.

Lithology: The variety or varieties of rock in a formation, member, bed, or other division.

Locality: A distinct site, especially one known to field fossils or other unique features.

Ma: An abbreviation for "mega-annum," but more easily understood as "million years ago."

Mantle plume: A hot, buoyant mass that rises up through the mantle. It is a proposed mechanism of convection, which is thought to drive tectonic activity and volcanism.

Member: A subdivision of a formation.

Merostomate: A member of the group including horseshoe crabs, sea scorpions (eurypterids), and putative relatives, now recognized as informal.

Mesozoic: A geologic era, dated approximately 252 to 66 Ma, noted for the dominance of dinosaurs on land and the appearance of birds, mammals, and flowering plants; the term means "middle life".

Metagraywacke: Metamorphosed graywacke, a poorly sorted sandstone with clay matrix.

Microfossil: A fossil, typically a millimeter (0.04 inches) or less in size, that must be studied with a microscope.

Mississippian: In North America, the de facto fifth geologic period of the Paleozoic Era (internationally a subperiod of the Carboniferous Period); approximately 359 to 323 Ma.

Mold: An impression of an organism left in sediment.

Mollusk: Any of a diverse group of invertebrates noted for their combination of a muscular foot, a shell, and a mantle that covers the innards and secretes the shell. Examples include bivalves, cephalopods, and snails.

MORU: Mount Rushmore National Memorial.

Mustelid: A member of the group of mammals including badgers, otters, weasels, and relatives.

NAGPRA: Native American Graves Protection and Repatriation Act.

Nautiloid: A member of the cephalopod group Nautiloidea, represented today by species of chambered nautilus, but in the past including various straight (**orthoconic**) and coiled forms.

Neogene: The second geologic period of the Cenozoic Era; approximately 23 to 2.58 Ma.

Nimravid: An extinct saber-toothed carnivoran mammal; also known as a "false saber-toothed cat".

NPS: National Park Service.

Ophiuroid: An echinoderm with five slender radiating arms; also known as a "brittle star".

Ordovician: The second geologic period of the Paleozoic Era, following the Cambrian; approximately 487 to 443 Ma.

Oreodont: An extinct artiodactyl ungulate with a low-slung pig-like body and a short stocky skull.

Organic: Made of organic compounds (i.e., molecules of carbon, hydrogen, nitrogen, and oxygen); pollen, spores, and cysts, all of which can be fossilized, have organic walls.

Orogen: An area of rock affected by a mountain-building event.

Orogeny: A mountain-building event.

Ostracode: Also spelled "ostracod;" a shelled crustacean, generally microscopic. Ostracodes are known informally as "seed shrimp."

Paleokarst: Karst features formed in the past and now part of the geologic record.

Paleozoic: A geologic era, dated approximately 539 to 252 Ma, noted for the diversification of invertebrates and the appearance of vertebrates and land plants; the term means "early life".

Paraphyletic: In the study of evolutionary relationships of organisms, a paraphyletic group does not include all descendants of a common ancestor. For example, birds are recognized as having evolved from dinosaurian reptiles, but birds are often excluded from discussions of Reptilia and Dinosauria, making these groups paraphyletic in these situations.

Pennsylvanian: In North America, the de facto sixth geologic period of the Paleozoic Era (internationally a subperiod of the Carboniferous Period); approximately 323 to 299 Ma.

Perissodactyl: An odd-toed ungulate mammal (e.g., horses, rhinos).

Permian: The seventh and last geologic period of the Paleozoic Era, ended by the largest mass extinction event in Earth's history; approximately 299 to 252 Ma.

Phytolith: A microscopic silica structure that forms within the cells of some plants.

Pleistocene: The older of two epochs in the Quaternary, noted for ice ages; approximately 2.58 Ma to 11,700 years ago.

Plesiosaur: An extinct marine reptile with four large flippers and often a small head on a long neck; forms with large heads and short necks are often identified by other terms, such as **pliosaur**.

Pliosaur: A plesiosaur with a large head and short neck.

Precambrian: Time before the Cambrian, before approximately 539 Ma.

Protoceratid: An extinct artiodactyl ungulate resembling a deer; males had large bony horns behind the eyes and on the snout.

PRPA: Paleontological Resources Preservation Act (2009).

Quartzite: 1) Moderately metamorphosed quartz sandstone in which the quartz sand grains have recrystallized into an interlocking mosaic (also known as **metaquartzite**); 2) Unmetamorphosed quartz-cemented quartz sandstone (also known as **orthoquartzite**).

Quaternary: The most recent geologic period, third and last in the Cenozoic Era, noted for multiple ice ages; approximately 2.58 Ma to the present.

(Marine) Regression (noun), regressive (adjective): A marine retreat, exposing land.

Repository: A place, often an institution, where artifacts such as fossils are permanently held.

Reworked: A fossil that has been eroded from an older rock unit and redeposited in a younger unit.

Rhizolith: Opening in soil left by the root of a plant that was later filled by sediments.

Rugose coral: An extinct type of coral, with the name in reference to the wrinkled surfaces of their fossils. Rugose corals included both colonial and solitary forms, with the solitary forms known as horn corals.

Scaphopod: A mollusk with an elongate conical shell; also known as a tusk shell.

Schist: A medium-grade metamorphic rock characterized by platy minerals (such as micas) aligned in planes.

Scolecodont: A jaw element of a bristle worm, a common microfossil.

Silica: The compound SiO_2, the building block of the common mineral quartz.

Sill: A tabular igneous intrusion, emplaced along beds or layers of older rock units.

Stratigraphy: The study of rock layers.

Stromatolite: A layered microbial mat, typically columnar or domal.

Tabula: In corals, a tabula (plural: tabulae) is a horizontal plate within a corallite.

Tabulate coral: A type of extinct colonial coral, commonly encrusting other fossils; fossils may resemble honeycombs.

Talus: Broken rock shed from cliffs through rock falls; also known as scree.

Taxonomy: The classification of organisms.

Terrane: A fragment of crustal material that has broken off of one plate and become attached to another.

Trace fossil: Fossils of biological activity, such as root casts; burrows, tracks, and eggshells; also known as ichnofossils.

(Marine) Transgression (noun), transgressive (adjective): A marine encroachment, submerging land.

Triassic: The first geologic period of the Mesozoic Era; approximately 252 to 201 Ma.

Trilobite: An extinct marine arthropod with a roughly oval body featuring an axial lobe and two lateral lobes (the three lobes of the name), also divided into three sections (cephalon for the head, thorax, and pygidium for the tail); trilobites vaguely resembled woodlice (roly-poly bug or pillbug).

Tuff: A rock which contains more than 75% volcanic ash. Rock with significant but lesser ash content (25% to 75%) is called tuffaceous.

Unconformity: A general term for any erosional or non-depositional surface between two rock units.

Ungulate: In general usage, a hoofed mammal (Ungulata also includes whales and relatives).

Uplift: Vertical elevation of part of the Earth's crust caused by plate tectonics.

Ursid: A member of the group of mammals including bears and relatives.

USGS: United States Geological Survey.

Valve: A shell; usually applied to mollusks but sometimes to brachiopods as well. Snails and monoplacophorans are univalved (one shell) and bivalves and brachiopods are bivalved (two shells).

Vuggy: A rock containing cavities or other large pores (**vugs**).

WICA: Wind Cave National Park.

Wood rat middens: Collections of plant matter and other small objects cemented by wood rat urine.

Appendix E: Paleontological Resource Law and Policy

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

In March 2009, the Paleontological Resources Preservation Act (PRPA) (16 USC 460aaa) was signed into law (Public Law 111–11). This act defines paleontological resources as

> *…any fossilized remains, traces, or imprints of organisms, preserved in or on the [E]arth's crust, that are of paleontological interest and that provide information about the history of life on [E]arth.*

The law stipulates that the Secretary of the Interior should manage and protect paleontological resources using scientific principles. The Secretary should also develop plans for

> *…inventory, monitoring, and deriving the scientific and educational use of paleontological resources.*

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

The Paleontological Resources Management section of NPS Reference Manual 77 provides guidance on the implementation and continuation of paleontological resource management programs. Administrative options include those listed below and a park management program will probably incorporate multiple options depending on specific circumstances:

- **No action**—no action would be taken to collect the fossils as they erode from the strata. The fossils would be left to erode naturally and over time crumble away, or possibly be vandalized by visitors, either intentionally or unintentionally. This is the least preferable plan of action of those listed here.
- **Surveys**—will be set up to document potential fossil localities. All sites will be documented with the use of GPS and will be entered into the park GIS database. Associated stratigraphic and depositional environment information will be collected for each locality. A preliminary fossil list will be developed. Any evidence of poaching activity will be recorded. Rates of erosion will be estimated for the site and a monitoring schedule will be developed based upon this information. A NPS Paleontological Locality Database Form will also be completed for each locality. A standard version of this form will be provided by the Paleontology Program of the Geologic Resources Division upon request and can be modified to account for local conditions and needs.

- **Monitoring**—fossil-rich areas would be examined periodically to determine if conditions have changed to such an extent that additional management actions are warranted. Photographic records should be kept so that changes can be more easily ascertained.
- **Cyclic prospecting**—areas of high erosion which also have a high potential for producing significant specimens would be examined periodically for new sites. The periodicity of such cyclic prospecting will depend on locality-specific characteristics such as rates of sediment erosion, abundance or rarity of fossils, and proximity to visitor use areas.
- **Stabilization and reburial**—significant specimens which cannot be immediately collected may be stabilized using appropriate consolidants and reburied. Reburial slows down but does not stop the destruction of a fossil by erosion. Therefore, this method would be used only as an interim and temporary stop-gap measure. In some situations, stabilization of a locality may require the consideration of vegetation. For example, roots can destroy in situ fossils, but can also protect against slope erosion, while plant growth can effectively obscure localities, which can be positive or negative depending on how park staff want to manage a locality.
- **Shelter construction**—it may be appropriate to exhibit certain fossil sites or specimens in situ, which would require the construction of protective shelters to protect them from the natural forces of weathering and erosion. The use of shelters draws attention to the fossils and increases the risk of vandalism or theft, but also provides opportunities for interpretation and education.
- **Excavation**—partial or complete removal of any or all fossils present on the surface and potentially the removal of specimens still beneath the surface which have not been exposed by erosion.
- **Closure**—the area containing fossils may be temporarily or permanently closed to the public to protect the fossil resources. Fossil-rich areas may be closed to the public unless accompanied by an interpretive ranger on a guided hike.
- **Patrols**—may be increased in areas of known fossil resources. Patrols can prevent and/or reduce theft and vandalism. The scientific community and the public expect the NPS to protect its paleontological resources from vandalism and theft. In some situations a volunteer site stewardship program may be appropriate (for example the "Paleo Protectors" at Chesapeake & Ohio Canal National Historical Park).
- **Alarm systems/electronic surveillance**—seismic monitoring systems can be installed to alert rangers of disturbances to sensitive paleontological sites. Once the alarm is engaged, a ranger can be dispatched to investigate. Motion-activated cameras may also be mounted to visually document human activity in areas of vulnerable paleontological sites.

National Park Service Management Policies (2006; Section 4.8.2.1) also require that paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. In 2010, the National Park Service established National Fossil Day as a celebration and partnership organized to promote public awareness and stewardship of fossils, as well as to foster a greater appreciation of their scientific and educational value (https://www.nps.gov/subjects/fossilday/index.htm). National Fossil Day occurs annually on Wednesday of the second full week in each October in conjunction with Earth Science Week.

Related Laws, Legislation, and Management Guidelines

National Park Service Organic Act

The NPS Organic Act directs the NPS to manage units

> *…to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner as will leave them unimpaired for the enjoyment of future generations.* (16 U.S.C. § 1).

Congress reiterated this mandate in the Redwood National Park Expansion Act of 1978 by stating that the NPS must conduct its actions in a manner that will ensure no

> *…derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress.* (16 U.S.C. § 1 a-1).

The Organic Act prohibits actions that permanently impair park resources unless a law directly and specifically allows for the acts. An action constitutes an impairment when its impacts

> *…harm the integrity of park resources or values, including the opportunities that otherwise would be present for the enjoyment of those resources and values.* (Management Policies 2006 1.4.3).

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

Section 6302 states

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

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

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

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

NPS Management Policies 2006

NPS Management Policies 2006 include direction for preserving and protecting cultural resources, natural resources, processes, systems, and values (National Park Service 2006). It is the goal of the NPS to avoid or minimize potential impacts to resources to the greatest extent practicable consistent with the management policies. The following is taken from section 4.8.2.1 of the NPS Management Policies 2006, "Paleontological Resources and their contexts":

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

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

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

(See Natural Resource Information 4.1.2; Studies and Collections 4.2; Independent Research 5.1.2; Artifacts and Specimens 10.2.4.6. Also see 36 CFR 2.5.)

NPS Director's Order-77, Paleontological Resources Management

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

Excerpt from Clites and Santucci (2012):

Monitoring

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

Climatological Data Assessments

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

Rates of Erosion Studies

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

Assessment of Human Activities, Behaviors, and Other Variables

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

Condition Assessment and Cyclic Prospecting

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

Periodic Photographic Monitoring

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

Appendix F: Paleontological Locality Data

Key for fossil abbreviations:

- V = Vertebrate. For species-level identification, see Appendix A.
- G = Gastropods. For species-level identification, see Appendix A.
- P = Pupa
- D = Dung Beetle Balls
- R = Rhizoliths
- H = Hackberry Seeds
- C = Coprolites

Appendix Table F-1. Surface fossil localities, their WICA number (if applicable), UTM coordinates, formation/age, and the fossils they have yielded.

Site Name	WICA #	Formation or Age	Fossils	Notes
Klukas #1, *Leptomeryx*	WICA-1	White River Group	V, G, D, H	–
Klukas #2, Channel	WICA-2	White River Group	V, G, R, H	–
Klukas #3, Rattler	WICA-3	White River Group	V, G, P, D, R, H	–
Klukas #4, *Ischyromys*	WICA-4	White River Group	V, G, P, D, R, H	–
Klukas #5, Boundary	WICA-5	White River Group	V, G, P, D	–
Klukas #6	WICA-6	White River Group	V, G, P, D, R, H	–
Klukas #7, Guardian	WICA-7	White River Group	V, G	–
Burrow	WICA-8	White River Group	V	–
Beetle	WICA-9	White River Group	V, G	–
Lagoon Conodont	WICA-10	Minnelusa Formation	Conodonts, Brachiopods	–
Centennial	WICA-11	White River Group	V, G, R, C	See Figure 11
[redacted]	WICA-12	Lakota Formation	Petrified Wood	See Figure 10
Chamber of Lost Souls	WICA-13	Quaternary	V	In Wind Cave
Cottonwood	WICA-14	White River Group	V, G	–
Bull Elk (Hehaka)	WICA-15	White River Group	V, G, P, D, R, H, C	–
Antler	WICA-16	White River Group	G	–
Poison Ivy	WICA-17	White River Group	V, G, R	–
Bison Wallow	WICA-18	White River Group	R	–
Claw	WICA-19	White River Group	V, R H	–
Rhizo	WICA-20	White River Group	V, G, D, R	–
Ant Lion	WICA-21	White River Group	V, G, R	–
Carapace	WICA-22	White River Group	D, R	–
Clay Marble	WICA-23	White River Group	D, R, H	–
Omega	WICA-24	White River Group	V, D, R	–

Appendix Table F-1 (continued). Surface fossil localities, their WICA number (if applicable), UTM coordinates, formation/age, and the fossils they have yielded.

Site Name	WICA #	Formation or Age	Fossils	Notes
Double Exposure	WICA-25	White River Group	V, G, D, R	–
Salamander Cave	WICA-26	Quaternary	V	–
Graveyard Cave	WICA-27	Quaternary	V, G	–
Beaver Creek Shelter	WICA-28	Quaternary	V, G, bivalves, plants	See Figure 20
Persistence Cave	WICA-29	Quaternary	V, mollusks, plant matter	–
Waterfall Dome	WICA-30	Quaternary	V	In Wind Cave
Valley	WICA-31	White River Group	G, R	–
Lagomorph	WICA-32	White River Group	V, G, P, D, R	–
Red Valley	WICA-33	Quaternary	V	–
[redacted]	WICA-34	White River Group	H	–
Femur Spring	WICA-35	White River Group	V, R	–
Hidden Point	WICA-36	White River Group	G, D, R	–
Little Site	WICA-37	White River Group	V, P, D, R, H	–
Ivy Cave	WICA-38	Quaternary	V	–
Unnamed	WICA-39	White River Group	G, P, D, R	–
Collapsed Pit	–	Quaternary	V	–
[redacted]	–	Madison Limestone	Brachiopods	–
Brachiopod Cave	–	Madison Limestone	Brachiopods	–
Boundary Cave	–	Quaternary	V	–
Just Within Reach Cave	–	Quaternary	V	–
Coyote Cave	–	Quaternary	V	–
Rat Midden Cave	–	Quaternary	V	–
Animal Shelter	–	Quaternary	V	–
Campground Shelter	–	Quaternary	V	–

Appendix Table F-1 (continued). Surface fossil localities, their WICA number (if applicable), UTM coordinates, formation/age, and the fossils they have yielded.

Site Name	WICA #	Formation or Age	Fossils	Notes
Mall of America Shelter	–	Quaternary	V	–
Creature Feature	–	Quaternary	V	–
Feature 141	–	Quaternary	V	–

Appendix Table F-2. Notable Wind Cave invertebrate localities in the Madison Limestone, their station number (if applicable), and the fossils they have yielded.

Site Name	Station #	Fossils	Notes
Laugh Tale	BI32	Brachiopods	Massive death assemblage
Fairgrounds Tour Route	–	Brachiopods	Public Route
Garden of Eden Tour Route	–	Brachiopods	Public Route
–	GE8/GE8a	Tabulate coral, brachiopods	–
Silent Lake	C54E	Brachiopods	–
Pyramid Room	JF16	Brachiopods	–
Silent Expressway	SE17	Disc-shaped coral	Possibly largest fossil in cave (0.6 x 0.3 m [2 x 1 ft])
Calcite Lake	JF110	Stromatolites or bacterial filaments	–
Filamental Fissure	WB72	Undescribed fossils, burrows	–
Fissure Kingdom	WB24	Gastropods	–
Gastro Flats	NFP2B	–	–
Dead Sea Stroll	WFS16	Brachiopods, gastropods, crinoids, worm tubes	–
OK Coral	LOG4I	Colonial corals	–
Gastropod in Boxwork	BB26	Gastropod	Cover image
Tin Can Room	NS159	Juvenile corals	–

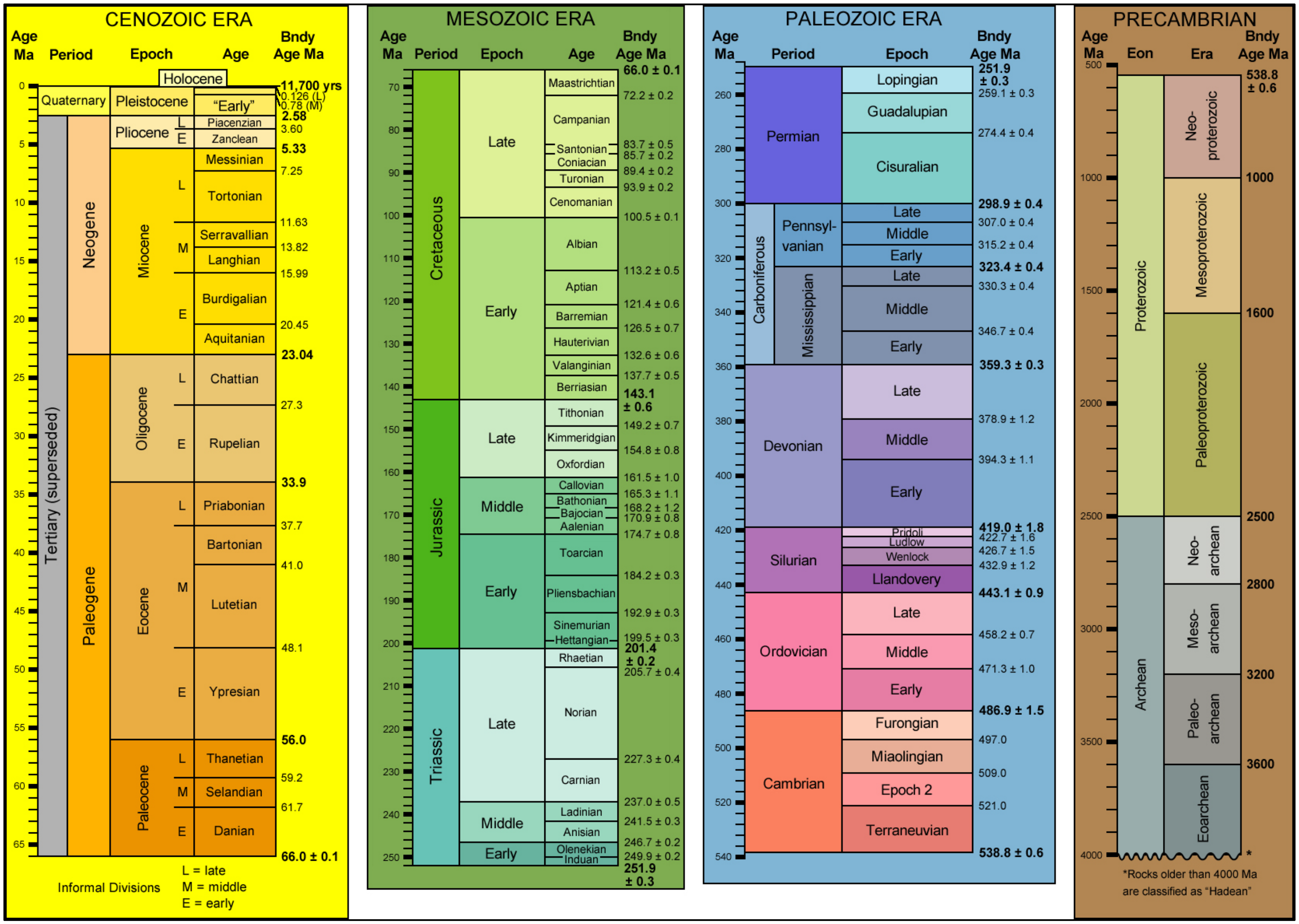
Appendix Table F-2 (continued). Notable Wind Cave invertebrate localities in the Madison Limestone, their station number (if applicable), and the fossils they have yielded.

Site Name	Station #	Fossils	Notes
Hollow Earth	UH1515D	Corals, worm burrows	–
The Oyster Coral	LOG5C	Brachiopods	–
Brachdown Room	GY7	Brachiopods	–
Clam Bake	LSU35	Brachiopods	–
Nokay Coral	LOG26	Brachiopods	–
Gastropod Gallery	CH13	Gastropods	–
Bryce Canyon Causeway	CC16A	Coral	–
White Coral Room	UQ49	Coral	Inferred based on name

Fossil vertebrate localities listed by room name and/or station number, separated by fossil type:

- Probable bat localities: EHB11, CP11, NYY11A, HB62, MF127, MF72, MI57, BI34, HZ17, KB2H, MD12P, NS1E, OX45, QC75, UQA58, V75, AJ53, KB1, NWT28D, PF21, NYY11, NYY11E, NYY12D
- Probable wood rat localities: IZ30K, IS30, UQ15H, NB33, R64, Chimera Room (KX37), BI7F, C34AB, HB90, HB151, HB161A, MF111, MF121. MF148, AK25, MI28, MI29, EX78, EV6, GX22, LK26, E9R21, PGC46, AT12, Gollum's Den, DL83H, F6, PK6U, UK4, FU9B
- Localities with various and/or unidentified bones: FP3, PK1C, BI7F, NM18A, NA7, AT105, Chamber of Lost Souls (WICA-13), Rainfall Hall (SKB5), ID34, UN34F, VX12, GX41, LK4D, UQ32B, XF4, CV145, CV148, K'3, K'4, NS22G, FU survey, Cobble Maze, T1B, CV117, RS10Y, RS10Z, Root Cellar, UI22I, Waterfall Dome (PK1, WICA-30)
- Pine marten localities: MF18, MF146
- Historical localities: BFL (bird breastbone, likely an early caver's meal from the 1890s)

Appendix G: Geologic Time Scale



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

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.

NPS 108/189648, June 2023

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