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Camp Nelson National Monument

Paleontological Resource Inventory (Public Version)



Two brachiopods, *Zygospira* sp.? and *Rafinesquina* sp., in coquina of the Curdsville/Grier Member (lower Lexington Limestone) in Camp Nelson National Monument.

NPS / EMILY JACKSON

Camp Nelson National Monument: Paleontological Resource Inventory (Public Version)

Science Report NPS/SR—2025/369

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Abstract

Camp Nelson National Monument (CANE) in the Inner Bluegrass Region of Kentucky protects the grounds of a Civil War camp known for having been a massive recruitment center for United States Colored Troops and a refugee camp for their families. This report serves as the first step toward documenting abundant paleontological resources within the park that have undoubtedly been known to those who have inhabited this area, but had not been thoroughly documented until now.

As part of the ongoing effort to record the natural, historical, and cultural resources within National Park Service properties, this 2025 paleontology resource inventory set out to catalogue the fossils of CANE. Over a three-month period, a survey of fossiliferous outcrops took place at the park, revealing a rich geologic history including the oldest rocks exposed in the state of Kentucky, and diverse Ordovician marine fossils. Outcrops of Late Ordovician age, extending from the oldest Camp Nelson Limestone of the High Bridge Group to the youngest Tanglewood Member of the Lexington Limestone, showcase a variety of shallow marine environments and fossil assemblages. Fossil taxa commonly found within the park include brachiopods, bryozoans, nautiloids, corals, bivalves, gastropods, crinoids, and a variety of trace fossils left behind by these invertebrates. This project produced descriptions and geolocation data for CANE fossils, a map of outcrop locations with their associated geologic formations, and various educational outreach materials to allow CANE staff to continue educating visitors about park paleontology resources post project completion.

List of Terms or Acronyms

Alluvial (adjective), **alluvium** (noun)**:** Unconsolidated terrestrial sediment moved by running water (e.g., rivers), deposited in settings such as floodplains and alluvial fans.

Asteroid: A member of the class Asteroidea, a group of echinoderms familiar for their five radiating arms; also known as "sea stars" or "starfish", asteroids are known from the Ordovician to the present.

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

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

Bivalve: A member of the class Bivalvia, a group of mollusks with two shells or valves joined by a hinge; 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). Modern examples include clams, oysters, mussels, and scallops. Bivalves are known from the Cambrian to the present. These organisms may look very similar to brachiopods, though are distinguished via their symmetry, which runs between the two shells that are typically mirror images of each other.

Brachiopod: A member of the class Brachiopoda, a group of marine filter-feeding animals with unequal valves, often compared to bivalves but more closely related to bryozoans. They are distinguished from bivalves via their symmetry which runs down the center of their valves rather than between them, a stalk that protrudes from the larger valve, and very different feeding structures. Colloquially termed "lamp shells", they are known from the Cambrian to the present.

Breccia: A rock composed of large (pebble sized) angular rock fragments in a finer-grained matrix.

Brevicone (noun), **breviconic** (adjective)**:** A conical nautiloid shell that is proportionally short rather than elongate.

Bryozoan: A member of the phylum Bryozoa, a group of small filter-feeding aquatic colonial animals that build delicate skeletal structures made up of calcite often likened in appearance to small corals, twigs, branches, lace, and moss.

Calcarenite: A limestone made up of sand-sized calcareous fragments, a "limestone sandstone".

Calcareous: Describes rock or sediment comprising the mineral calcium carbonate ($CaCO_3$); "lime-rich".

Calcisiltite: A variety of limestone composed of greater than 50% silt-size carbonate grains; a "limestone siltstone".

Calcite: A mineral made up of calcium carbonate ($CaCO_3$) with a hexagonal crystal.

Calcium carbonate: A compound with the chemical formula $CaCO_3$. Calcite is a common form.

Cambrian: The first geologic period of the Paleozoic Era, noted for the abrupt diversification of life ("Cambrian explosion"); approximately 539 to 485 Ma.

CANE: Camp Nelson National Monument

Carbonate: A term for rocks and minerals containing carbonate ions (CO_3^{-2}), such as limestone made of calcite ($CaCO_3$) and dolostone made of dolomite.

Cephalopod: A member of the class Cephalopoda, a group of mollusks with a prominent head fringed by tentacles. Examples include squids, octopuses, nautiloids (such as *Nautilus*), and many extinct forms, such as ammonoids. Cephalopods are known from the Cambrian to the present.

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

Clast: A rock fragment of any size. A rock made up of clasts, such as sandstone or shale, is called clastic.

Columnal: An individual stalk segment from an echinoderm; these usually resemble donuts or gears.

Conodont: An extinct marine animal with an appearance similar to modern day lamprey but with tiny tooth-like elements that are very important microfossils; these were some of the very first vertebrates to exist.

Contact (geology)**:** The horizon or plane where two formations meet.

Coquina: A bed consisting primarily of shells and/or other invertebrate body fragments. "Coquinoid" may also be used.

Corallite: The dwelling cell of an individual coral animal.

Crinoid: A member of the order Crinoidea, a group of echinoderms known today as feather stars and sea lilies. During the Ordovician these organisms lived mainly attached to the sea floor with a "stalk" and had a "flower-like" body with feathery appendages. They first appeared in the Ordovician.

Cryptograined: Refers to the texture or the size of individual mineral grains in a rock, in this case requiring extreme magnification to view with the human eye.

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

Dolomite: A mineral made of calcium-magnesium carbonate with the chemical formula $CaMg(CO_3)_2$; the term is also used inaccurately for rock made of dolomite (see dolostone). Most

dolomite is formed by the replacement of some of the calcium ions in calcium carbonate by magnesium, a process called dolomitization.

Dolostone: A rock made mainly of calcium-magnesium carbonate, formed by replacement of calcite with dolomite.

Echinoderm: A member of the phylum Echinodermata, a group of invertebrates known for their special features such as five-fold symmetry and specialized tube feet for locomotion and feeding. Sea stars, sea urchins, sea lilies, and sea cucumbers are some examples. Echinoderms are known from the Cambrian to the present.

Extralimital (biology)**:** Individuals found outside of the normal geographic range of the species. Fossils of modern species are often found in areas that would be considered extralimital today, due to changes in range over time.

Float (geology)**:** Loose rock or fossiliferous material that is no longer attached to an outcrop.

Formation: A section of rock that is distinguished from surrounding rocks via its position and physical characteristics such as rock type, fossils, and minerals; the basic unit of stratigraphy.

Fossiliferous: Containing fossils.

Gastropod: A member of the class Gastropoda, a group of mollusks with a one-part (univalved) usually helically coiled shell; also known as snails; known from the Cambrian to the present.

GRD: Geologic Resources Division of the National Park Service.

Group (geology)**:** A lithostratigraphic unit comprising several related formations classified together.

GSRI: Geologic & Soil Resources Inventories.

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.

Ichnofossil: Fossilized evidence of biological activity such as burrows, tracks, trails, fossilized dung, or root marks in soil; also known as trace fossils.

In situ: Something found in place, in the case of fossils this means remaining in the context of the outcrop they were preserved in.

Intertidal: Within the range from low tide to high tide.

Isotope: Varieties of a chemical element that differ in the number of neutrons in the nucleus. Some are radioactive and decay at predictable rates, permitting radiometric dating. Others are stable; the

slight differences in mass allow them to be used to study processes that prefer lighter or heavier isotopes, such as evaporation preferring lighter oxygen isotopes.

Karst: A characteristic topography of sinkholes, caves, and other features formed by the dissolution of carbonate rocks at or near the surface.

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

Locality: A location known to contain fossils or other notable features.

MACA: Mammoth Cave National Park

Magnesian: Rich in magnesium.

Member: A rock unit that is a subdivision of a formation (e.g., Tanglewood Member of the Lexington Limestone Formation).

Micrite: Microcrystalline (microscopic crystals of) calcite.

Microfossil: A fossil or fossil fragment that requires a microscope to see, typically 1 mm (0.04 in) or less in size; many kinds are important for relative dating of rocks.

Mollusk: A member of the phylum Mollusca, a diverse group of invertebrates noted for their soft unsegmented bodies and combination of a muscular foot, a shell, and a mantle that covers the innards and secretes the shell. Examples include bivalves, cephalopods, and gastropods (snails). They are known from the Cambrian to the present.

Monoplacophoran: A member of the class Monoplacophora, a group of shelled mollusks known from the Cambrian to the present. Most monoplacophorans have a cap-like or limpet-like shell, but some extinct forms had shells coiled in a flat plane.

Nautiloid: A member of the subclass Nautiloidea, a group of shelled cephalopod mollusks represented today by species of chambered nautilus, but in the past including various straight (**orthoconic**) and coiled forms, known from the Cambrian to the present.

Ordovician: The second period of the Paleozoic Era, dating from 485 to 443 million years ago.

Orthocone (noun)**, orthoconic** (adjective)**:** A type of nautiloid shell that is straight and gently tapering.

Ostracod: A member of the class Ostracoda, a group of two-shelled and generally microscopic crustaceans known informally as “seed shrimp”, known from the Ordovician to the present.

Palisade: A line of cliffs.

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.

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

Phosphate (geology)**:** A general term for minerals and other materials containing phosphate (PO_4^{-3}), such as apatite, found in bones, teeth, and some shells (the phosphatic shells of some inarticulate brachiopods, for example).

Planktonic: An organism that floats freely but cannot swim against a current.

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

Polyplacophoran: A member of the class Polyplacophora, a group of marine mollusks with ovoid bodies protected by a series of eight overlapping plates, known from the Cambrian to the present; also known as a chiton.

PRPA: Paleontological Resources Preservation Act.

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

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

Rugose coral: A member of the subclass Rugosa, an extinct group of corals, known from the Ordovician to the end of the Permian. The name is derived from the term for a wrinkled surface which alludes to the appearance of these fossils' exteriors. These corals included colonial and solitary forms, with the solitary forms being known as "horn corals".

Septum: In corals, a septum (plural: septa) is a vertical plate in a corallite; in shelled cephalopods, the wall between chambers.

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

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

SIP: Scientists in Parks.

Siphuncle: The internal passage between chambers in a cephalopod shell.

Skeletal limestone: A variety of limestone formed of fossils and fossil fragments.

Stratigraphy: The analysis of the order and relative position of layers of rock, and their relationship through geologic time.

Stromatoporoid: A member of the class Stromatoporoidea, a group of coral-like reef-building sponges that formed layered stony skeletons. Stromatoporoids were abundant from the Ordovician into the Devonian. They are regarded as extinct, although some modern sponges are similar.

Stylophoran: A member of the class Stylophora, an extinct group of enigmatic echinoderms featuring broad or ovoid bodies with a single appendage, known from the Cambrian into the Pennsylvanian.

Subtidal: Below the normal low tide level, so rarely or never exposed to the air.

Tabulate coral: A member of the class Tabulata, an extinct type of colonial coral that existed from the Ordovician to the end of the Permian, known for their hexagonal cells that resemble honeycombs.

Trace fossil: Preserved evidence of biological activity such as burrows, tracks, trails, or roots. Also known as ichnofossils.

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

Trilobite: A member of the class Trilobita, an extinct group of marine arthropods, often likened to modern woodlice or horseshoe crabs, that got their name from their three distinct “lobes” (one axial lobe and two lateral lobes). They existed from the Cambrian to the end of the Permian.

Type section: A section of a given geologic exposure that serves as the basis on which a stratigraphic unit is defined.

Unconformity: A general term for any erosional or non-depositional surface between two rock units, representing a time gap in the rock record.

USGS: United States Geological Survey.

Valve: A shell. Snails and monoplacophorans are univalved (one shell), whereas bivalves, brachiopods, and ostracods are bivalved (two shells).

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I'd like to recognize the support given to me by all CANE staff over the course of my internship, especially CANE Resource Manager Abigail Peeples for her continued support of this project and myself. I'd also like to thank William Andrews (Nevada Bureau of Mines and Geology) for his advice on interpreting the rock units found within CANE. William Andrews and Carlton E. Brett (University of Cincinnati) provided reviews.

Dedication

For all the lovely staff and volunteers at CANE: Your comradery and continual dedication to uplifting and educating the public about the history of the land you protect is truly admirable.



Staff and volunteers of Camp Nelson National Monument, summer 2025.
NPS / AVA GOETZ

Introduction

Camp Nelson National Monument (CANE) in north-central Kentucky protects a diverse array of cultural and natural resources of the Inner Bluegrass Region, including historic structures, migratory birds, and fossil-rich Ordovician bedrock. This report provides detailed information on the paleontological resources of CANE, 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 three appendices: Appendix A, tables of paleontological species arranged by stratigraphy; Appendix B, paleontological resource law and policy; and Appendix C, a geologic time scale.

Geographic and Historical Setting

The following geographic and historical background is based on the Cultural Landscape Report prepared for CANE in 2022, by WLA Studio and W. Stephen McBride:

Prior to the Civil War, the area that comprised Camp Nelson consisted of several properties used for agricultural, residential, and commercial purposes. Often, these properties had many buildings such as a main residence, storage sheds, barns, mills, and housing for enslaved individuals. When the need arose, the US Army designated this land as the ideal location to protect and strengthen transportation networks and train troops. Between 1863 and 1865, thirteen defensive structures, including ten earthwork forts, two stone walls, and a battery were erected to deter Confederate raids. Remnants of these structures can be found throughout CANE to this day. After the war, the parcels of land used to create Camp Nelson were distributed back to the original families who owned them. In 1997 Jessamine County began to purchase land to form the Camp Nelson Civil War Heritage Park, which operated from 2000 to 2018.

As one of the largest recruitment and training centers for African-American soldiers during the Civil War, the cultural significance of Camp Nelson is undeniable. Due to its cultural and historical significance, CANE was officially made a unit of the National Park Service (NPS) on October 16th, 2018. At the time of its creation, CANE encompassed approximately 380 acres of land. Since being elevated to national monument status in 2018, 77 acres of land in the middle of the park and a small (~7 acres) detached parcel to the southwest were acquired by the NPS, increasing the total acreage managed by CANE staff to 464 acres (Figure 1).

CANE is located in southern Jessamine County, about 32 km (20 mi) southwest of Lexington, Kentucky. The eastern portion of the park is wooded, and includes infantry entrenchments, Fort Jones, two stone walls, and curated walking trails. The southern and central parts of the park encompass several agricultural buildings, pastures, remnants of warehouse and industrial buildings, and a small brick house that serves as office space for Facilities and Resource Management. The detached parcel to the southwest holds the Fee Memorial Church and the remains of a modern amphitheater. The northern section of CANE is host to the main interpretive features of the park, including the Visitor Center, White House, Barracks, Officer's Spring, Cemetery #1, entrenchments, forts, curated walking trails, and agricultural and storage buildings.



Figure 1. Park map of Camp Nelson National Monument.
NPS

Karst topography sets the landscape for Camp Nelson, producing rolling hills, several sinkholes, caves, and a natural spring. Much of the camp is still used for agricultural purposes and is hayed or bushhogged once or twice each summer, prior to which many migratory birds nest in the tall grasses. Along the eastern border of the park is a stretch of woods that grows throughout the palisades created by the downcutting of the Kentucky River. Walking trails are maintained throughout the grassy northern and wooded eastern portions of the park, with more planned to be added in the coming years. The trail network does not extend to Hickman Creek at this time.

Significance of Paleontological Resources at Camp Nelson National Monument

Camp Nelson National Monument includes outcrops of the oldest exposed rocks and fossils in the state of Kentucky, dated to the early Late Ordovician, more than 453 million years ago. Despite the rich fossil history known from the geologic units surrounding the park, very few studies have examined the fossils and fossil-bearing units within Camp Nelson. The lack of existing research focused on the paleontological resources of CANE has resulted in a need for a paleontological

inventory to establish a baseline understanding of these resources. This inventory is essential to inform park staff about CANE fossils and how best to educate about and preserve them.

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

Project Objectives

This park-focused paleontological resource inventory project was initiated to provide information to CANE 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 CANE. Methods and tasks addressed in this inventory report include:

- Locating, identifying, and documenting fossil localities through field reconnaissance and perusal of archives, using photography, GPS data, standardized forms, and surveyor reports.
- Documenting current information on faunal assemblages and paleoecological reconstructions.
- Interviewing park staff and relevant experts to gather information on the current status of paleontological resources, to aid in formulating plans for management, ideas for interpretation, and recommendations for future actions and activities involving fossils.
- Conducting a thorough search for relevant publications and geologic maps pertaining to CANE.

History of Paleontological Work at Camp Nelson National Monument

Since the establishment of CANE as a park in 2018, no thorough investigation of its paleontological resources has occurred. However, the existence of fossils within CANE boundaries has been informally documented over the years via stops on geology- and history-based field trips (Camp Nelson Civil War Heritage Park 2004; Andrews 2005), and as features of bedrock units noted on geologic maps (Wolcott 1969). Because CANE was known to have fossils but little was known about them, NPS paleontologist Vincent Santucci and NPS associate J.-P. Hodnett visited on April 25, 2021, to make a reconnaissance. They prepared a brief report on this visit (Santucci et al. 2021), establishing that the park has abundant Ordovician fossils and setting the stage for the present report.

Summary of 2025 Paleontological Survey

Before this survey, no park-wide paleontological resource inventory had been performed at CANE. This inventory involved mapping and field documentation of fossiliferous units, compiling data from published sources, and discussions with current park staff and relevant experts to obtain first-hand accounts of paleontological resources within CANE. Field inventories, mapping of paleontological resources, and an extensive literature review were conducted by Scientists in Parks (SIP) intern Emily Jackson under permit CANE-2025-SCI-0002 with guidance from Justin Tweet. Fossiliferous regions were identified by this survey; these regions were extensively photographed with an iPhone 13 Pro, and documented via written field notes, a Leica handheld GPS, and the mobile app Field Maps.

A comprehensive list of taxa found within CANE was created as part of this project (Appendix A). As taxonomic nomenclature evolves, the names assigned to specimens identified in this survey are subject to change over time. Further research is likely to add taxa to this list.

A paleontological resource map was also developed during this survey for use by CANE staff. This map serves to direct staff to where fossils are exposed, and to educate staff about the condition, composition, and specific location of various paleontological outcrops throughout CANE.

Future research regarding CANE fossil resources is highly recommended to add to the results of this inventory. Additional work is needed to further identify fossils to the genus and species levels. These resources are susceptible to vandalism and theft, as well as natural weathering and dissolution over time. Additions to this inventory will serve to broaden the understanding of park fossil resources and how best to manage them in the future.

Geology

Geologic History

The geology of CANE dates back to the Late[1] Ordovician (see Appendix C for a geologic time scale). The oldest rocks within the park, and by extension the state of Kentucky, are from the Camp Nelson Limestone, named after the Civil War camp that CANE now preserves. The type locality is near but not within CANE. Above the Camp Nelson Limestone within CANE are three other formations: the Oregon Limestone; the Tyrone Limestone, which is dated to more than 453 million years old; and the Lexington Limestone (Figure 2). Each of these formations reflects deposition in shallow seas and adjacent shallow subtidal to intertidal flat environments, with an overall deepening trend depicting the marine transgression that occurred in this area during the Late Ordovician (Cressman and Peterson 1986; Kolata 2021). (Note that older references describe these formations as Middle Ordovician, but redating of the Middle–Late Ordovician boundary places them all in the Late Ordovician. The oldest, the Camp Nelson Limestone, is Turinian in age [Hoare and Pojeta 2006], now dated to near the beginning of the Late Ordovician, approximately 455 million years ago.)

[1] Note that in geological terminology, positional terms (“lower”, “upper”) are used when describing rock units as physical things, whereas chronological terms (“early”, “late”) are used when describing the age of a unit. These terms are capitalized if formal, lowercase if not, e.g., the divisions of the Ordovician are formal, but the late or upper Cambrian is informal.

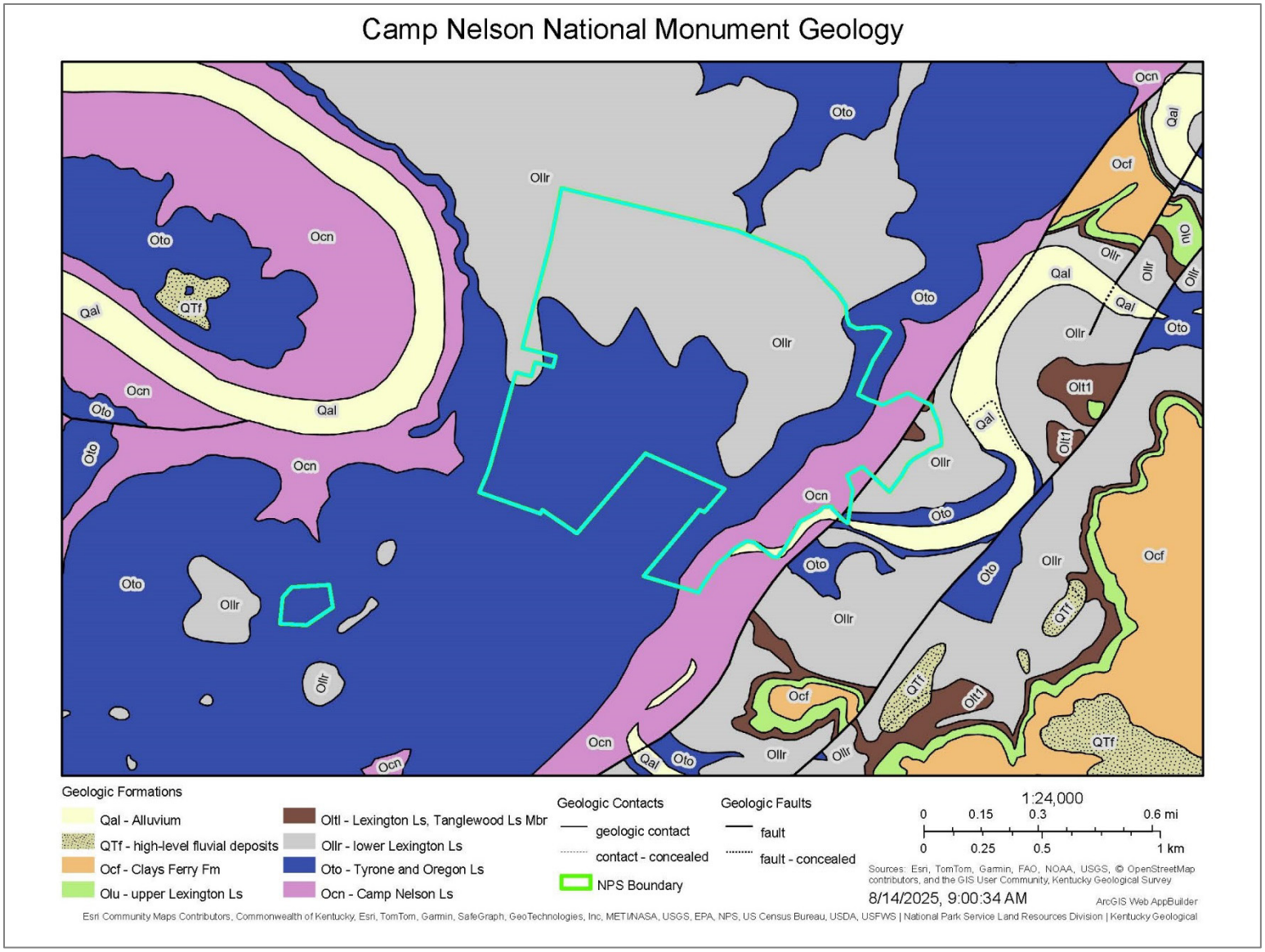


Figure 2. Geologic map of CANE, based on Wolcott (1969).

USGS

During the Late Ordovician, the area represented by CANE today was south of the equator, within the submerged continental shelf of the paleocontinent Laurentia, during a time when sea levels were significantly higher than they are today (Cressman and Peterson 1986; Kolata 2021). Active volcanism took place throughout the Late Ordovician, leaving behind layers of ash that have weathered into thin layers of bentonite clay (Black et al. 1965; Cressman and Peterson 1986; Kolata et al. 1996; Kolata 2021). Coincidentally, the first report of an Ordovician bentonite bed in eastern North America came from the Tyrone Limestone near High Bridge, Kentucky, about 10 km (7 mi) northwest of CANE (Ulrich 1888; Kolata et al. 1996). The two most significant bentonites, the Deicke and Millbrig K-bentonites ("K" refers to potassium), are in the upper Tyrone Limestone, and can be traced across most of the eastern half of the United States west of the Appalachians (Kolata et al. 1996). Because volcanic ash layers contain crystals of minerals, notably zircon, that contain concentrations of uranium, some of them can be radiometrically dated, using rates of decay of uranium (U) isotopes to stable lead (Pb) daughter isotopes together with the measured ratio of U/Pb. The Deicke and Millbrig have recently been dated to essentially 453.35 million years ago (Metzger et al. 2021), placing them and the Tyrone Limestone firmly in the Late Ordovician. The eruptions that produced them are among the largest known volcanic eruptions in Earth's history, with the Deicke event estimated as having produced at least 943 km^3 (226 mi^3) of ash, and the Millbrig event estimated as having produced even more: at least 1,509 km^3 (362 mi^3) (Huff et al. 1996). These extensive ashfalls allow direct correlation of rock units between many NPS units hundreds of kilometers/miles apart. The Deicke K-bentonite alone permits correlation (age matching) of Late Ordovician-age rocks of 12 different NPS units across 10 different states (Figure 3). A few unnamed layers of bentonite clay, though not typically visible, exist within CANE, most notably acting as barriers to groundwater flow resulting in one of the park's most prominent features, the Officer's Spring. After millions of years of weathering and erosion, Quaternary soils formed over the Ordovician carbonate rocks, forming the fertile soils supporting the grassland that helped give this region its name, the "Bluegrass Region" (McFarlan 1943).

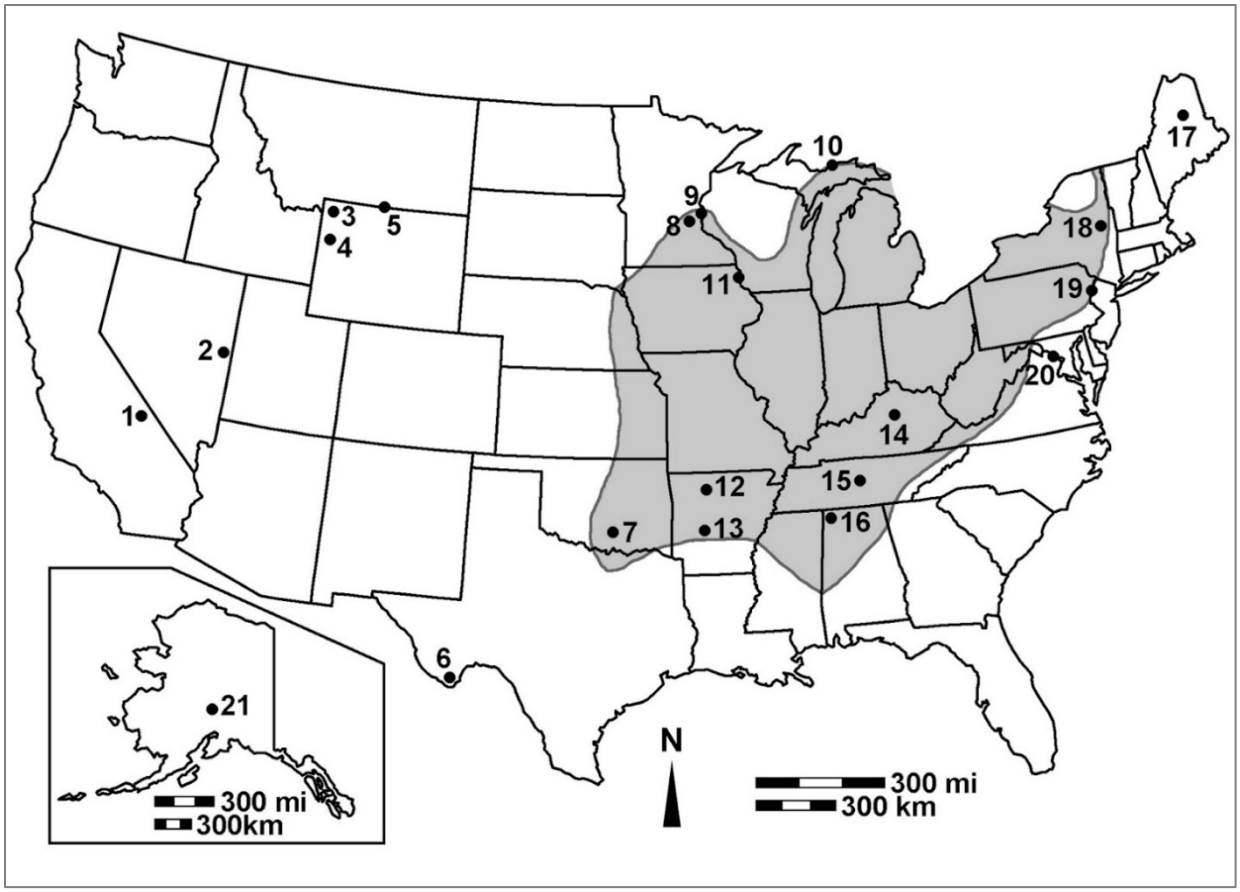


Figure 3. NPS units with Upper Ordovician fossils. 1. Death Valley National Park; 2. Great Basin NP; 3. Yellowstone NP; 4. Grand Teton NP; 5. Bighorn Canyon National Recreation Area; 6. Big Bend NP; 7. Chickasaw NRA; 8. Mississippi National River and Recreation Area; 9. Saint Croix National Scenic Riverway; 10. Pictured Rocks National Lakeshore; 11. Effigy Mounds National Monument; 12. Buffalo National River; 13. Hot Springs NP; 14. Camp Nelson NM; 15. Stones River National Battlefield; 16. Natchez Trace Parkway; 17. Katahdin Woods & Waters NM; 18. Saratoga National Historical Park; 19. Delaware Water Gap NRA; 20. Chesapeake and Ohio Canal NHP; 21. Denali NP & Preserve; 22. Yukon-Charley Rivers National Preserve. The gray area is the known extent of the Deicke K-bentonite (after Kolata et al. 1996).

NPS / JUSTIN TWEET

Geologic Formations

CANE contains outcrops of the oldest bedrock found in Kentucky, and the formations known to crop out within the park only span a portion of Late Ordovician time (currently dated to approximately 458–443 million years ago). In total, there are four formations that crop out within CANE (Figure 2; Table 1). The lower three belong to the High Bridge Group and the upper unit, the Lexington Limestone, is distinct (McFarlan 1943; Wolcott 1969). See also Brett et al. (2018) for a recent summary.

Table 1. Summary of CANE stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text; depth suggestions after C. Brett (pers. comm., September 2025).

Formation	Age	Fossils Within CANE	Depositional Environment
Quaternary rocks and sediments	Pleistocene–Holocene	Unfossiliferous to date	Alluvial
Lexington Limestone	Late Ordovician	Brachiopods in lower members; bryozoans, brachiopods, gastropods, and crinoids in Tanglewood Member	Moderately deep (>30 m/100 ft) offshore marine (lower); shallow (10–20 m/30–70 ft) high energy shoal (Tanglewood)
Tyrone Limestone	Late Ordovician	Rugose and tabulate corals, bryozoans, brachiopods, bivalves, nautiloids, gastropods, ostracods, crinoids, and invertebrate burrows and feeding traces	Shallow marine; deeper lagoonal to tidal flat (0–15 m/0–50 ft)
Oregon Limestone	Late Ordovician	Unfossiliferous to date	Shallow marine; inner saline lagoon and tidal flat
Camp Nelson Limestone	Late Ordovician	Gastropods, invertebrate burrows	Shallow marine; lagoonal to shallow shelf (<30 m/100 ft)

The High Bridge Group comprises the Camp Nelson, Oregon, and Tyrone Limestones (Wolcott 1969; Cressman and Peterson 1986). The members of this group make up most of the outcrops within the park, most notably within the southern, eastern, and central sections of CANE. Some of the members of the overlying Lexington Limestone, the undifferentiated Curdsville/Logana/Grier Members and the Tanglewood Member, also crop out within the park. These units are seen mainly as small surface exposures in CANE.

The members of the High Bridge Group all contain tongues of rocks that are characteristic of the other members (e.g., “Oregon-type” or “Tyrone-type” within the Camp Nelson Limestone), and as such their descriptions in published literature may cause confusion when identifying them in the field (Wolcott 1969). As determined by this survey, the best way to quickly distinguish between the three members within CANE is by position and fossil assemblages, as fossil occurrences and diversity differ enough between the units to tell them apart with relative ease.

High Bridge Group: Camp Nelson Limestone (Upper Ordovician)

Description: The oldest exposed rock unit in the state of Kentucky, this pale grey cryptograined limestone was named after the same Civil War camp CANE now commemorates. This is a thick unit, with about 91 m (300 ft) of exposed rock above local rivers and streams (Wolcott 1969; Cressman and Peterson 1986). The Camp Nelson Limestone is mainly a micrite limestone with abundant yellowish-weathering dolomite-filled burrow traces (Wolcott 1969; Cressman and Peterson 1986). However, irregular patches of granular limestone of the “Oregon-type” are distributed throughout the cryptograined “Tyrone-type” body of the unit (Wolcott 1969). Fossils are infrequent within this

member; however, gastropods, nautiloids, and brachiopods are common in patches (Wolcott 1969; Cressman and Peterson 1986). A thin (1.5–3.5 m; 5–12 ft) dolomitic shale occurs near the top of the formation, and is widely laterally continuous, capable of being traced on subsurface gamma-ray logs (Wolcott 1969; Cressman and Peterson 1986). The packages of "Tyrone-type" and "Oregon-type" rock within the Camp Nelson are indicative of adjacent shallow marine and tidal flat depositional facies (Wolcott 1969; Cressman and Peterson 1986).

Fossils found within CANE: Few fossils are known from the outcrops of Camp Nelson Limestone found within CANE. As this survey learned, preservation is relatively poor in this unit, and trace fossils are more abundant than body fossils. The following fossils were recorded over the course of this project:

- *Lophospira* sp. (gastropod)
- *Chondrites* (branching burrows)
- *Skolithos* (vertical burrows)

Fossils found elsewhere: Though fossils from the Camp Nelson Limestone were not very abundant within park boundaries, and are not common in general, studies of the same formation elsewhere in Kentucky reveal more diversity (McFarlan 1943; Bergström et al. 1974; Howe 1979; Pope 1982):

- *Escharopora ramosa* (bryozoan)
- *Rhinidictya trentonensis* (bryozoan)
- *Camerella bella* (brachiopod)
- *Oepikina minnesotensis* (brachiopod)
- Nautiloidea indet. (nautiloid)
- *Maclurites bigsbyi* (gastropod)
- *Appalachignathus delicatulus* (conodont)

Carlton Brett (University of Cincinnati) reports finding small brachiopods and trilobite remains in a thin limestone above the shale unit mentioned above (pers. comm., September 2025).

High Bridge Group: Oregon Limestone (Upper Ordovician)

Description: Colloquially termed the "Kentucky River Marble", the Oregon Limestone is a grey to buff-colored granular magnesian limestone that is largely devoid of fossils (McFarlan 1943; Cressman and Peterson 1986). It spans between 4.5–11 m (15–35 ft) in thickness and is interpreted as having been deposited in a tidal flat environment (Wolcott 1969; Cressman and Peterson 1986). Though largely cryptograined limestone, this unit may also contain tongues of calcareous dolostone and thin laminae of clear calcite (McFarlan 1943; Cressman and Peterson 1986). These dolomitic tongues contain mud cracks (Figure 4) and mud-chip breccias (Figure 5) reflective of the wet-dry cycles typical of the depositional environment (McFarlan 1943; Cressman and Peterson 1986).

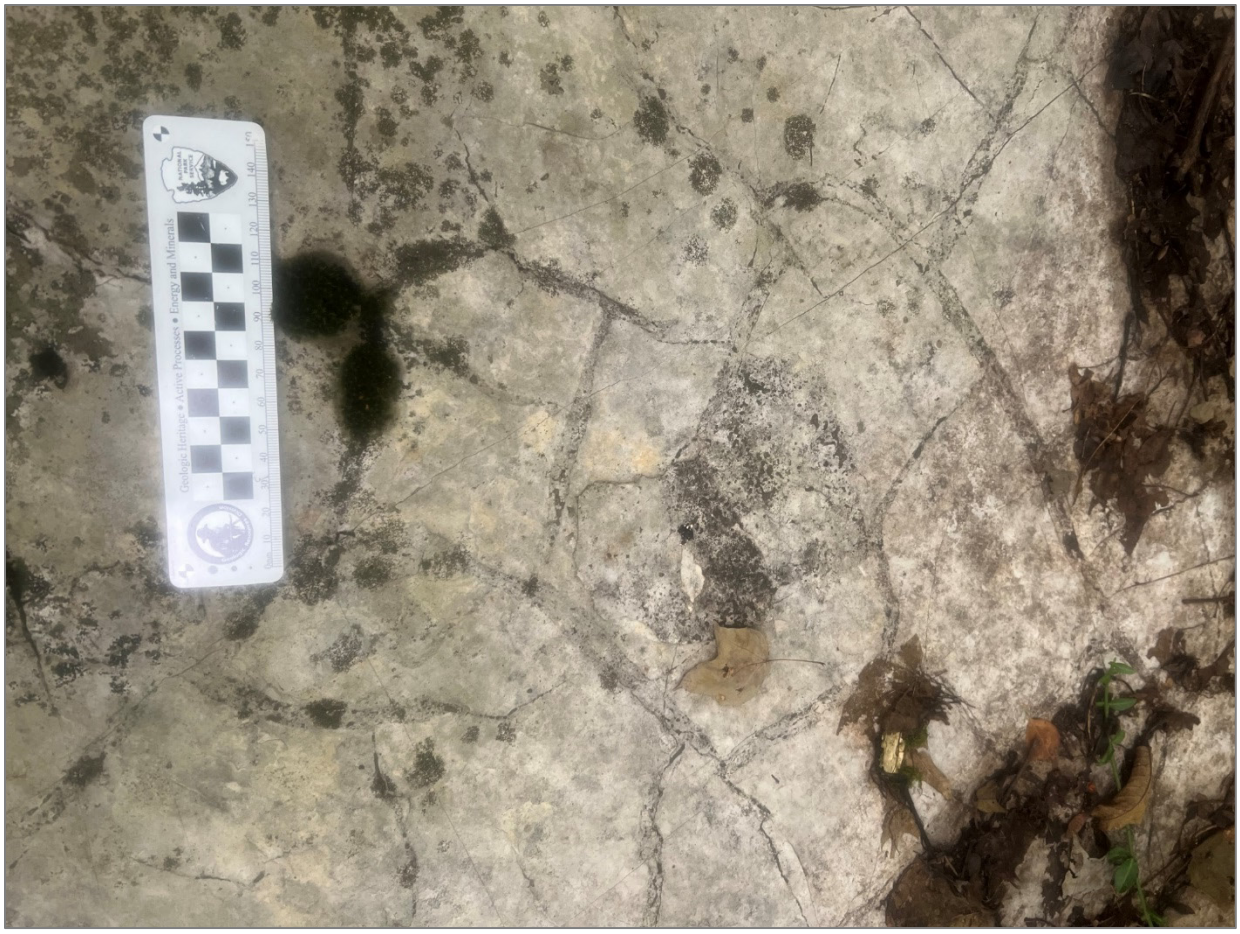


Figure 4. Preserved mud cracks within the Oregon Limestone.
NPS / EMILY JACKSON



Figure 5. Angular clasts preserved within the Oregon Limestone, referred to as breccia in some literature (Cressman and Peterson 1986).
NPS / EMILY JACKSON

Fossils found within CANE: No fossils have been reported from the Oregon Limestone within CANE to date, though they have been reported from elsewhere. Therefore, it is possible that further paleontological research within the park may find fossils in this unit.

Fossils found elsewhere: While fossils are rare, the Oregon Limestone has been recorded as having fossiliferous silty skeletal limestones containing fragments of the following organisms (Wahlman 1992):

- Tabulata indet. (tabulate coral)
- Bryozoa indet. (bryozoan)
- Brachiopoda indet. (brachiopod)
- Gastropoda indet. (gastropod)
- Trilobita indet. (trilobite)
- Ostracoda indet. (ostracod)

- Crinoidea indet. (crinoid)

High Bridge Group: Tyrone Limestone (Upper Ordovician)

Description: A somewhat problematic unit as it lacks a modern formally established type section, the Tyrone Limestone records a range of shallow marine lagoonal to tidal flat environments (McFarlan 1943; Wolcott 1969; Cressman and Peterson 1986). In the CANE area the formation is between 20–30 m (65–100 ft) thick and composed of light brownish-grey limestone (Figure 6), with irregular bodies of chert or dolomite (Wolcott 1969). Due to the range of environments composing the Tyrone Limestone, fossil content can range from few or no fossils to moderately and even highly fossiliferous. In the case of the Tyrone Limestone at CANE, most of the exposed outcrops are of the shallow marine type, containing abundant and rather diverse fossil assemblages. Some strata exhibiting mud cracks consistent with tidal flat deposits and few to no fossils can be found in the eastern wooded portion of the property, intertongued with the more fossiliferous shallow marine facies. Feeding traces and burrows are common in this unit, particularly in the moderately fossiliferous strata found in CANE. Several layers of yellowish-tan or green-grey bentonite clay are known from the Tyrone, having formed from the weathered ash deposited by volcanic eruptions. The two thickest bentonite layers are the Mud Cave and Pencil Cave bentonites. The Mud Cave is the uppermost bentonite, near the top of the Tyrone. It is typically the thickest and weathers to a pale tan, very sticky clay. The Pencil Cave bentonite is typically an emerald green clay that occurs about 5–9 m (16–30 ft) below the top of the Tyrone (McFarlan 1943; Cressman and Peterson 1986). The Mud Cave and Pencil Cave are local names for the widespread bentonites mentioned above: the Mud Cave bentonite is the Millbrig K-bentonite and the Pencil Cave bentonite is the Deicke K-bentonite (Kolata et al. 1996). Three other bentonites are recognized from lower in the Tyrone, but they are unnamed due to their thin and discontinuous nature (McFarlan 1943; Cressman and Peterson 1986). The contact with the overlying Lexington Formation is unconformable, and erosion took place between the end of Tyrone deposition and the beginning of Lexington deposition (Brett et al. 2004).

Fossils found within CANE: Of the geologic units within CANE, the Tyrone Limestone proved to have the most diverse fossil assemblage. However, preservation is not always great and most fossils are exposed only as semi-identifiable cross-sections. The fossils identified over the course of this inventory include tabulate and solitary rugose corals, bryozoans, brachiopods, bivalves, nautiloids, gastropods, ostracods, crinoids, invertebrate burrows, and other trace fossils (see Appendix A for the full list of taxa).



Figure 6. A typical Tyrone Limestone outcrop in CANE.
NPS / EMILY JACKSON

Fossils found elsewhere: The fossil content of the Tyrone Limestone varies significantly, and the strata of CANE show a great deal but not all of the diversity that this unit encompasses. Other genera are known from studies of the Tyrone Limestone just outside park boundaries along US Highway 27 (Layou 2007; "Camp Nelson" localities [stratigraphy per Layou's comments on sites in the Paleobiology Database, https://paleobiodb.org/#/]):

- *Rhinidictya* sp. (bryozoan)
- *Strophomena* sp. (brachiopod)
- *Ctenodonta* sp. (bivalve)
- *Cyrtodonta* sp. (bivalve)
- *Whitella* sp. (bivalve)
- *Maclurites* sp. (gastropod)
- *Hormotoma* sp. (gastropod)

Lexington Limestone: Curdsville/Logana/Grier Members (Upper Ordovician)

Description: The three lowest units of the Lexington Limestone, the Curdsville, Logana, and Grier Members, comprise the lower Lexington Limestone and are frequently grouped together on geologic maps (McFarlan 1943; Wolcott 1969; Cressman and Peterson 1986). The Curdsville Member comprises 6–12 m (20–40 ft) of bioclastic calcarenite that is sandy and chert-bearing but becomes increasingly finer grained and fossiliferous near the top (McFarlan 1943; Black et al. 1965; Cressman and Peterson 1986). This unit is laterally continuous throughout the Inner Bluegrass Region, and represents a shallow marine environment affected by turbulent waters (Cressman and Peterson 1986). The Logana Member, not present everywhere, has three distinct units measuring up to 15 m (50 ft) total (Black et al. 1965; Cressman and Peterson 1986). The lowest unit consists of interbedded calcisiltite and shale, the middle unit of a coquina containing mainly *Heterorthina* (formerly *Dalmanella*; Jin and Harper 2015) *sulcata*, and the uppermost unit is another, though thinner, interval of calcisiltite and shale (Cressman and Peterson 1986). The Logana was largely deposited in a somewhat deeper and muddier marine setting below the effects of waves, where the wave base affected preservation of shelled organisms (Brett et al. 2004; C. Brett, pers. comm., September 2025). Finally, the Grier Member comprises mainly poorly sorted fossiliferous calcarenite and modularly bedded fossiliferous calcisiltite, with alternating beds of poorly sorted fossiliferous calcarenite (Black et al. 1965; Cressman and Peterson 1986). The Grier ranges in thickness from about 30–55 m (100–180 ft), and due to its abundant fossils is interpreted as having been deposited in a shallow subtidal marine setting, shallower than the Logana but deeper than the high-energy Curdsville or Tanglewood (Cressman and Peterson 1986; C. Brett, pers. comm., September 2025). The three members were products of alternating transgression and regression, reflecting the movement of the shoreline inland and then seaward (Cressman and Peterson 1986; Brett et al. 2004). All outcrops of the Lexington Limestone accessible within CANE occur as small surficial exposures (Figure 7).

Fossils found within CANE: The exposures of the lower Lexington Limestone within CANE, particularly the Logana Member, include shell hash in which only brachiopods appear to be present. The assemblages of these brachiopods are more evenly mixed at more central exposures in the park (probably in the Grier Member), whereas northeastern exposures (probably Logana) contain only *Heterorthina* sp.:

- *Heterorthina* sp. (brachiopod)
- *Rafinesquina* sp. (brachiopod)
- *Zygospira* sp. (brachiopod)



Figure 7. A typical surficial exposure of the Lexington Limestone in CANE.
NPS / EMILY JACKSON

Fossils found elsewhere: Extensive studies just outside of CANE boundaries along US Highway 27 have sampled from the lowest few members of the Lexington Limestone, revealing much greater diversity than what was seen within CANE (Howe 1979; Parsley 1981; Pope 1982; Wahlman 1992; Layou 2007):

USGS, Curdsville Member (USGS 7784-CO and 7785-CO):

- *Camerella* sp. aff. *C. immatura* (brachiopod)
- *Rhynchotrema increbescens* (brachiopod)
- *Sowerbyella curdsvillensis* (brachiopod)
- *Tetraphalerella* cf. *T. musculosa* (brachiopod)
- *Archinacella* cf. *A. simulatrix* (monoplacophoran)
- *Micropileus variabilis* (monoplacophoran)
- *Vallatotheca unguiformis* (monoplacophoran)

- *Bucania subangulata* (gastropod)
- *Carinaropsis acuta* (gastropod)
- *Pterotheca angusta* (gastropod)
- *Pterotheca* cf. *P. expansa* (gastropod)
- *Salpingostoma kentuckyense* (gastropod)
- *Sinuites obesus* (gastropod)
- *Tropidodiscus subacutus* (gastropod)
- *Carabocrinus* sp. (crinoid)
- *Cupulocrinus* sp. (crinoid)
- *Hybocystites problematicus* (crinoid)
- *Enoploura* cf. *E. punctata* (stylophoran)

Layou, Grier Member ("Vineyard" localities [stratigraphy per Layou's comments on sites in the Paleobiology Database, https://paleobiodb.org/#/]):

- *Escharopora* sp. (bryozoan)
- *Prasopora* sp. (bryozoan)
- *Rhinidictya* sp. (bryozoan)
- *Hebertella* sp. (brachiopod)
- *Heterorthina* sp. (=*Dalmanella* sp.) (brachiopod)
- *Rafinesquina* sp. (brachiopod)
- *Zygospira* sp. (brachiopod)
- Nautiloidea indet. (nautiloid)
- *Lophospira* sp. (gastropod)
- *Sinuites* sp. (gastropod)
- Ostracoda indet. (ostracod)
- Trilobita indet. (trilobite)
- Crinoidea indet. (crinoid)

Lexington Limestone: Tanglewood Member (Upper Ordovician)

Description: One of the units of the upper Lexington Limestone, the Tanglewood Member has a complex intertonguing relationship with the other members of the formation. It is recognized for its medium-coarse grained bioclastic "hash" texture and locally abundant bryozoan fragments. This unit ranges in thickness from 18–30 m (60–100 ft), and consists largely of a pink-grey, fossil fragment calcarenite (Black et al. 1965; Cressman and Peterson 1986). Most fossils found within the

Tanglewood are fragmental, likely due to deposition at or above the local wave base where they were subjected to breakage and abrasion (Cressman and Peterson 1986). Due to the complexity of this member's position relative to others within the Lexington Limestone, the Tanglewood may be divided into two, as it is at its type section (Black et al. 1965; Cressman and Peterson 1986), and recent publications drop it altogether (e.g., Brett et al. 2004, 2018). In some areas the so-called Tanglewood is divided into two or more tongues, with the Millersburg and/or Devils Hollow Members between the two Tanglewood units, whereas in other instances, the upper Tanglewood unit is lumped with the Devils Hollow or overlying Point Pleasant members (Black et al. 1965; Cressman and Peterson 1986; C. Brett, pers. comm., September 2025). The lumping or splitting is up to the discretion of the author and may cause confusion when comparing literature and field sites (Black et al. 1965; Cressman and Peterson 1986). The stratigraphy of the Lexington Formation is under revision, and a summary of proposed changes can be found in McLaughlin et al. (2008). The Tanglewood is poorly exposed within CANE boundaries. Here, the Tanglewood Member is uninterrupted and conformably overlies the lower Lexington Formation (Black et al. 1965; Cressman and Peterson 1986).

Fossils found within CANE: The Tanglewood Member only crops out as small surficial slabs within CANE; however, these rocks are abundantly fossiliferous with an assemblage that is bryozoan-dense, characteristic of the lower Tanglewood. Although many of the fossils found in this unit are damaged or incomplete, a number of taxa were identified by this survey, including:

- *Ceramopora* sp.? (bryozoan)
- *Eridotrypa* sp.? (bryozoan)
- *Escharopora* sp.? (bryozoan)
- *Stictopora* sp. (bryozoan)
- Bryozoa indet. (bryozoan)
- Brachiopoda indet. (brachiopod)
- Gastropoda indet. (gastropod)
- Crinoidea indet. (crinoid)

Fossils found elsewhere: Outside of CANE, the Tanglewood Member remains bryozoan-dominant; however, crinoids and brachiopods are common, and when divided, the upper portion of the Tanglewood Member was noted as containing stromatoporoid sponges, though not identified to genus nor species level (Wolcott 1969). A list of recognized taxa from this and similar units is as follows:

- *Amplexopora* sp. (bryozoan)
- *Constellaria* cf. *C. teres* (bryozoan)
- *Eridotrypa* sp. (bryozoan)
- *Heterotrypa* sp.? (bryozoan)

- *Stictopora* sp. (bryozoan)

Quaternary Rocks and Sediments (Pleistocene–Holocene)

Description: Unconsolidated alluvium associated with Hickman Creek, as well as very well-established phosphatic soils (Figure 8) formed from weathered limestone bedrock (McFarlan 1943; Wolcott 1969).



Figure 8. Quaternary soils exposed along the edge of a sinkhole in CANE.
NPS / EMILY JACKSON

Fossils found within CANE: No Quaternary fossils have been found in the sediments within Camp Nelson National Monument. However, reworked or eroded fossiliferous material from the surrounding Ordovician limestones may be found as part of Quaternary fluvial deposits. As CANE has prevalent karstic features such as caves and sinkholes (Figure 9), it is possible that fossils of Quaternary fauna may be found in and around these features. A survey of the caves and sinkholes within CANE is recommended to determine the presence or absence of Quaternary fossils.



Figure 9. Perhaps the biggest of the many caves found on CANE property.
NPS / EMILY JACKSON

Fossils found elsewhere: Quaternary fossils are known throughout the state of Kentucky from caves as they served as shelter for many animals, and as traps for others. The nearest reported Quaternary fossil to CANE is about 10 km (6 mi) west of the park near Wilmore, Kentucky (Guilday 1968). The fossil reported is grizzly bear teeth (*Ursus arctos horribilis*) from the Pleistocene, found in Welch Cave just west of Wilmore, Kentucky (Guilday 1968). More well known are the Quaternary fossils found within the Mammoth Cave system and its smaller associated caves and sinkholes (Toomey and Olson 2025), about 145 km (90 mi) southwest of CANE.

Quaternary taxa reported from Mammoth Cave National Park (MACA) include the following extinct and extralimital forms (Toomey and Olson 2025) († = extinct):

- *Dasypus bellus* † (beautiful armadillo)
- *Desmodus stocki* † (Stock's vampire bat)
- *Tadarida* sp. (free-tailed bat)
- *Geomys* sp. (pocket gopher)

- *Neofiber leonardi* † (muskrat)
- *Mammut americanum* † (American mastodon)
- Proboscidea indet. † (relative of elephants, mammoths, and mastodons)
- *Smilodon* sp. † (saber-toothed cat)
- *Arctodus simus* † (short-faced bear)
- *Martes americana* (American marten)
- *Mustela nivalis* (least weasel)
- *Equus* sp. † (horse)
- *Tapirus* cf. *T. veroensis* † (extinct tapir)
- *Platygonus compressus* † (flat-headed peccary)
- *Platygonus* sp. † (extinct peccary)
- cf. *Platygonus* sp. † (extinct peccary)
- *Cervus canadensis* (American elk)
- *Bison* sp. (bison)

This list is non-exhaustive, omitting taxa that are found in the MACA area today.

Taxonomy

See Appendix A for full lists of taxa.

Fossil Invertebrates

The majority of fossils reported from the units exposed within CANE are gastropods and brachiopods (Appendix A). However, additional taxa such as bryozoans, nautiloids, corals, crinoids, and bivalves do occur within the park in lower abundance. Assemblages from the same rock units but outside of CANE provide even greater taxa diversity, such as sponges, trilobites, and algae (McFarlan 1943; Wolcott 1969; Layou 2007). It's worth noting that fossils of conodonts, small eel-like vertebrates with tiny tooth-like elements, did exist at this time and have been recognized from the same units found within CANE (Howe 1979); however, this survey was not able to recognize any as they only occur as microfossils.

Phylum Cnidaria (Jellyfish and Corals)

Two of the three major Paleozoic coral groups are represented at CANE: tabulate corals and solitary rugose corals. Tabulate corals are a now extinct group of colonial corals that built structures of often hexagonal living chambers (corallites). Tabulate corallites are generally a few millimeters or less across, unlike the larger corallites of colonial rugose corals (closer to 1 cm or 0.4 in), providing one key to distinguish them if other anatomical features are not visible. Solitary rugose corals, also known as horn corals for the horn-like appearance of their corallites, had relatively complex radial spoke-like structures (septa) compared to tabulates. Corals are stationary and feed with stinging tentacles and, in some cases, symbiotic microorganisms.

Possible tabulate corals belonging to *Tetradium*[2] and an indeterminate species have been found within CANE over the course of this survey (Figure 10); however, they occur only in out-of-context slabs (float), likely from the Tyrone Limestone. Tabulate corals have been reported from the same geologic units as those found within CANE (Wahlman 1992), though they are far less common than rugose corals. The condition of the examples found in CANE left it difficult to identify the animals to the genus and species level.

Horn corals are uncommon in CANE and are most likely to be found in the Tyrone and "Tyrone-type" exposures of the park. Most examples of horn corals within CANE are exposed in cross section, though there is at least one instance where the body fossil retained its three-dimensionality (Figure 11). In this instance, it was determined that this specimen was either of genus *Streptelasma* or *Lambeophyllum*.

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[2] The fossil called *Tetradium* is a problematic colonial skeleton made of closely packed, four-sided, fiber-like tubes. It has generally been interpreted as a tabulate coral. Steele-Petrovich interpreted it as a red alga (Steele-Petrovich 2009) and used the name *Prismostylus* for it because another plant was already named *Tetradium* (Steele-Petrovich 2011). However, this is not universally accepted and many paleontologists prefer non-algal interpretations and regard *Tetradium* as the correct name. The term *Tetradium* will be used here.



Figure 10. A possible *Tetradium* sp. found on a float Tyrone Limestone? slab.
NPS / EMILY JACKSON

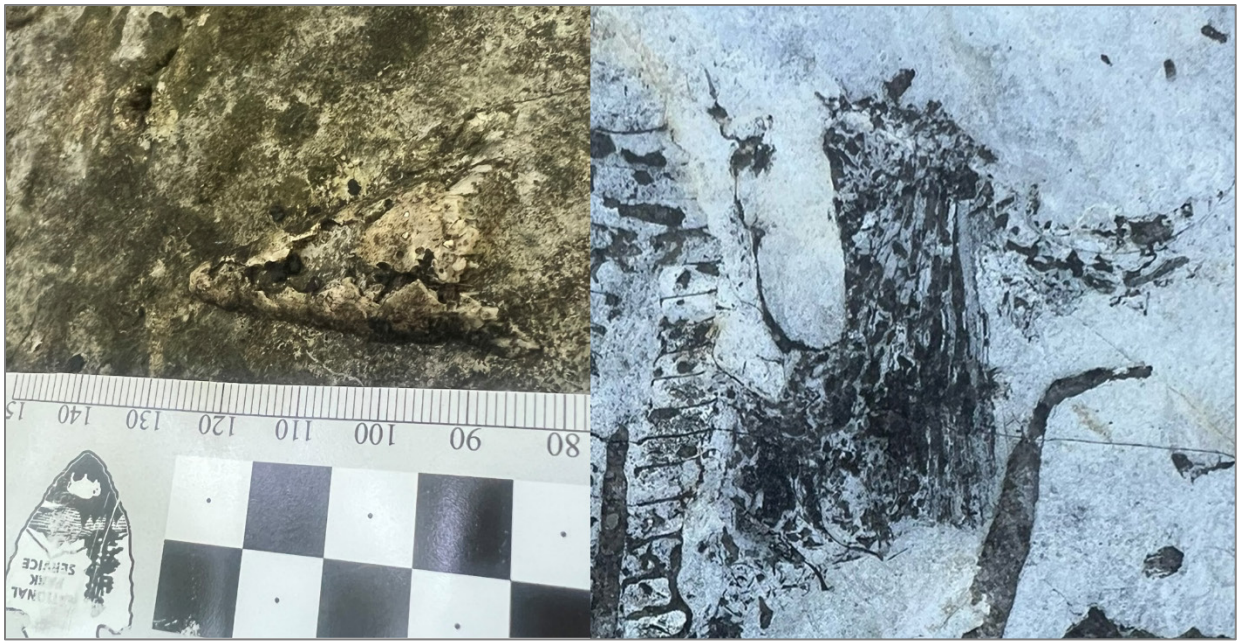


Figure 11. Two horn corals from the Tyrone Limestone within CANE. One is preserved with some three-dimensionality (left), and the other is preserved as a cross-section (center of right; note also a nautiloid cephalopod in cross-section to the left of it).
NPS / EMILY JACKSON

Phylum Bryozoa (Moss Animals)

Bryozoans are small colonial filter feeders with delicate coral-like appearances (Figure 12). These colonies can hold hundreds to thousands of individuals in the space of only a few square centimeters. While their fossils may look similar to corals, they are easily told apart by the differences in their size and internal structures. Bryozoan animals and their living spaces, pores in the skeleton called zooecia, are much smaller than corals, and the pores do not show the spoke-like septa that corals have. Of those recorded by this survey, the genera *Eridotrypa* sp., *Escharopora* sp., and *Stictopora* sp. (Figures 13 and 14) were common in the Tyrone Limestone and Tanglewood Member.

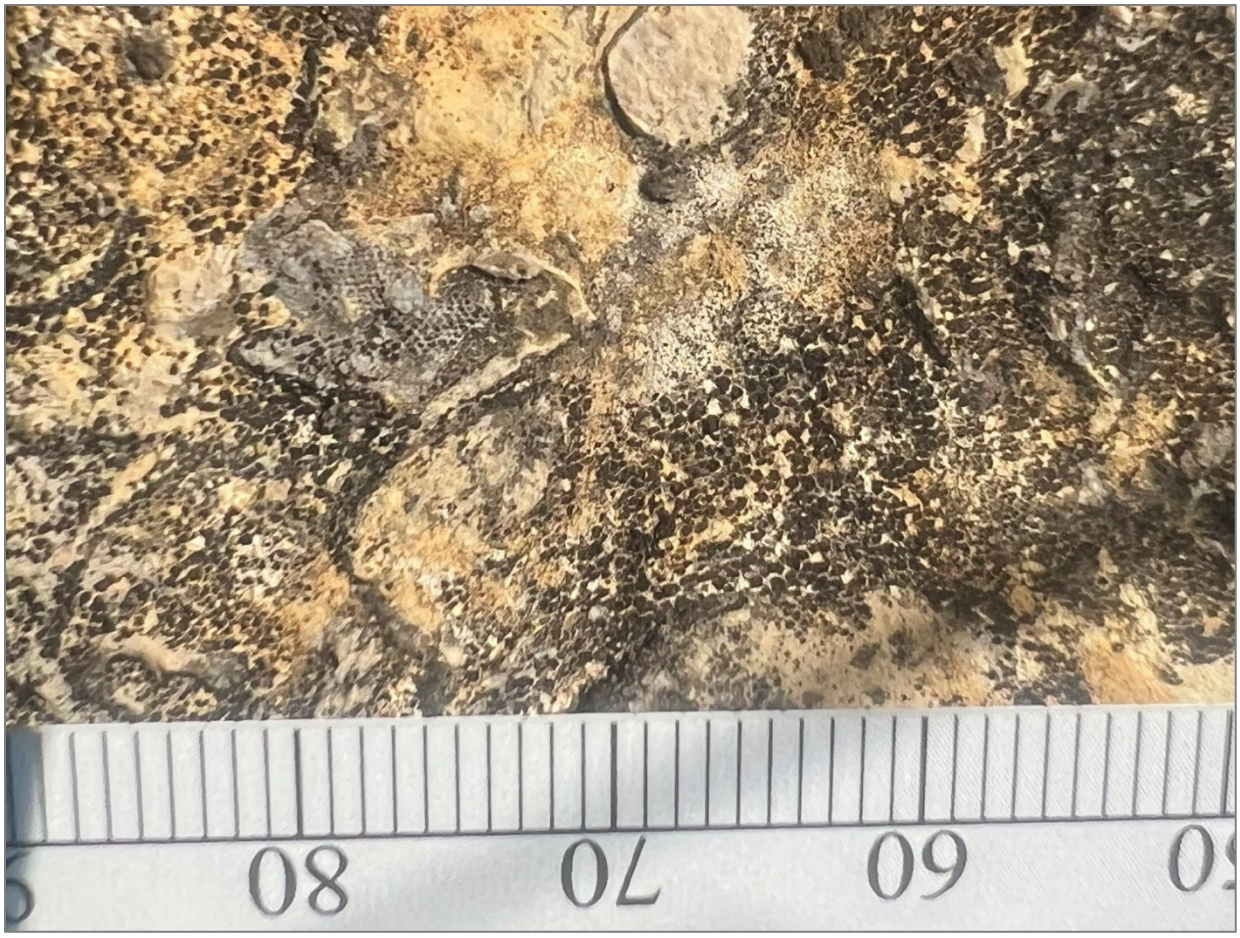


Figure 12. An encrusting bryozoan from a loose Tyrone Limestone? slab.
NPS / EMILY JACKSON



Figure 13. An encrusting bryozoan from a Tyrone Limestone outcrop.
NPS / EMILY JACKSON



Figure 14. A branching bryozoan colony (white stick-like objects) in a float stone in CANE, presumably from the Tanglewood Member of the Lexington Limestone.
NPS / EMILY JACKSON

Phylum Brachiopoda (Lamp Shells)

Brachiopods during the Ordovician occupied many of the niches that bivalves do today as solitary filter feeders, and as such they tend to have been deposited in similar environments and not infrequently with bivalves. When full shells are visible, brachiopods can usually be distinguished from bivalves by symmetry: individual brachiopod valves are usually symmetric but the two valves of a brachiopod are not symmetric with each other, whereas the opposite is usually true of bivalves. Brachiopod valves and fragments can be found throughout the park's extensive exposures of the Tyrone Limestone and lower Lexington Limestone, though only a few are both complete enough and sufficiently preserved to identify. Throughout most of the northern region of the park, the exposed lower Lexington Limestone is full of mixed brachiopod hash, with the occasional intact *Rafinesquina* sp. and *Zygospira* sp. (Figure 15). In the northwestern parts of the park are coquina beds of mainly *Heterorthina* sp. (formerly *Dalmanella*) (Figure 16), identified in other research as *Dalmanella sulcata* (Cressman and Peterson 1986) or *Dalmanella* (=*Heterorthina*) *bassleri* (McFarlan 1943; Walker 1982).



Figure 15. Brachiopod coquina near the base of the Lexington Limestone containing *Zygospira* sp. and possibly *Rafinesquina* sp. in addition to *Heterorthina* sp.

NPS / EMILY JACKSON



Figure 16. Dalmanellid brachiopod coquina in CANE; smaller brachiopods are *Heterorthina*, and the two larger shells are *Rafinesquina*; probably Logana Member of the Lexington Limestone.
NPS / EMILY JACKSON

Phylum Mollusca

Three different classes of mollusks were recorded during the survey of CANE fossils. Most of the mollusks found within the park belong to Class Gastropoda (snails), being found in both the oldest (Camp Nelson Formation) and youngest (Lexington Limestone) geologic units present at CANE. However, nautiloids and bivalves do occur within CANE as well. In most instances these organisms' fossils occur in cross section, making their identification difficult.

Class Bivalvia (Clams, Scallops, Oysters, Mussels, etc.)

Bivalves are a group of mollusks that are represented today by a host of genera. These animals are characterized by their two mirror-image valves attached at a hinge. While bivalves are very diverse today, this was not so in the Ordovician, and we see this reflected in the assemblages found within CANE, where only one variety of bivalve, potentially a modiomorphid (Figure 17), was identified.



Figure 17. Two bivalve valves (Modiomorphida?) found in a float stone, thought to be from the Tyrone Limestone.
NPS / EMILY JACKSON

Class Cephalopoda (Octopuses, Squids, Nautiloids, etc.)

Nautiloids are shelled squid-like creatures with chambered shells, related to the modern-day nautilus. These animals' fossils can often be found in the Tyrone Limestone and occur with a fair amount of diversity in the shape and size of their shells, the most common shell shape being orthoconic (straight and slightly tapering) (Figures 18 and 19). As most of these fossils are preserved in cross section, it can be difficult to identify them to the genus and species level (Figure 20). However, two genera were identified in this survey, the orthoconic *Treptoceras* sp. and the breviconic (rapidly tapering) *Diestoceras* sp.



Figure 18. A relatively large nautiloid found during the 2021 fossil survey.
NPS



Figure 19. A relatively well-preserved indeterminate orthoconic nautiloid.
NPS / EMILY JACKSON



Figure 20. An indeterminate nautiloid from the Tyrone Limestone in CANE. Most nautiloids found within the park are preserved like this fossil, probably an actinocerid; note the large siphuncle (tube through chambers used in buoyancy control) with bulbous chambers.
NPS / EMILY JACKSON

Class Gastropoda (Snails)

Gastropods, or snails, are frequently found throughout CANE, and are especially abundant in parts of the Tyrone Limestone. They are also present in the Camp Nelson Limestone and parts of the Lexington Limestone. Gastropods are capable of many different modes of life, living in different parts of the water column or terrestrially and consuming anything from detritus to other snails. Although they are very abundant, most of the snail fossils within CANE are preserved as cross sections (Figures 21, 22, and 23), though the genera *Asgardaspira* sp., *Lophospira* sp., and *Paupospira* sp. were identified during this survey.



Figure 21. A close-up of a gastropod (*Lophospira* sp.?) in cross-section in the Camp Nelson Limestone of CANE.

NPS / EMILY JACKSON

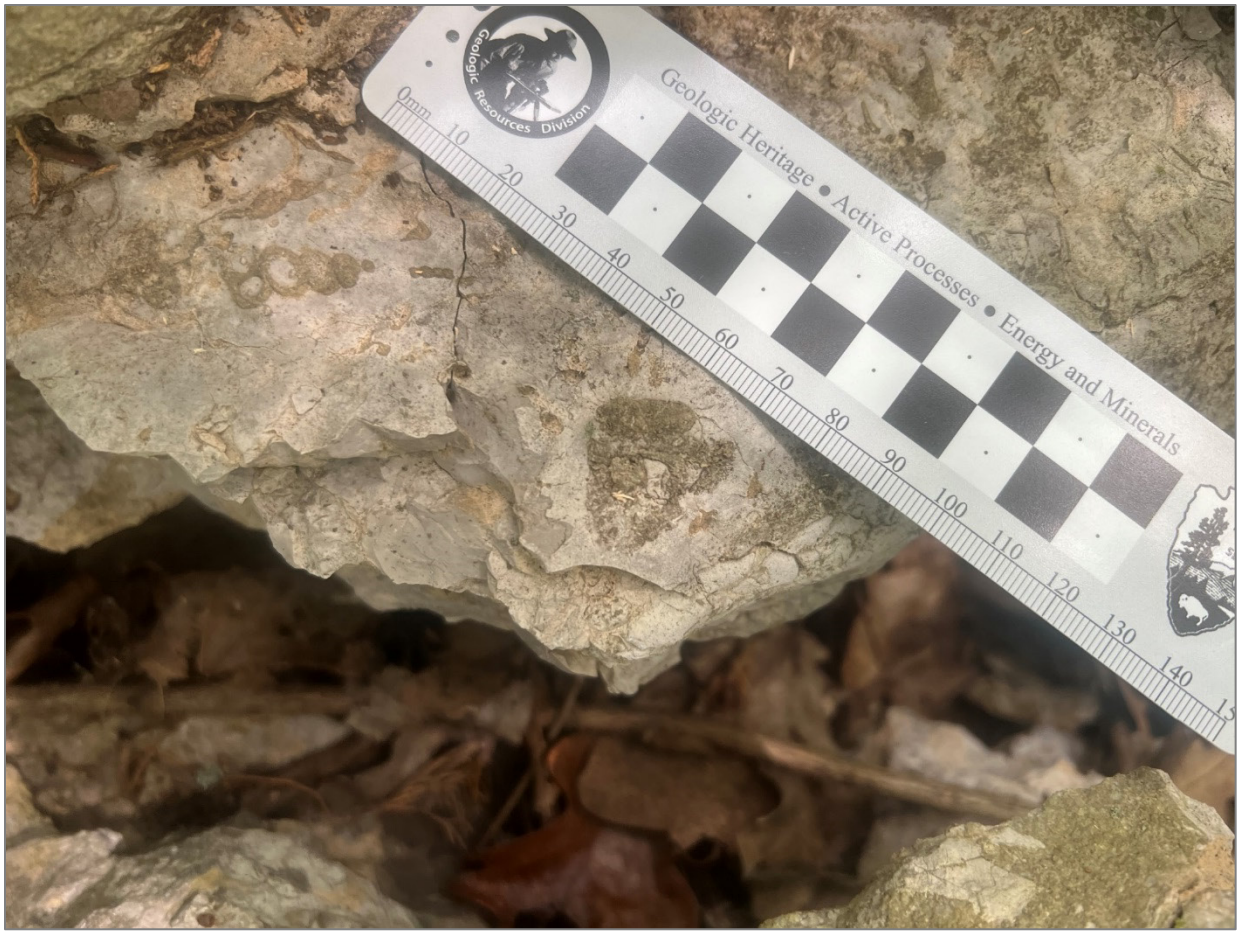


Figure 22. A close-up of a tall gastropod (*Paupospira* sp.?) in the Tyrone Limestone at CANE.
NPS / EMILY JACKSON



Figure 23. A floated stone from the Tyrone Limestone in CANE with numerous gastropods in cross-section.

NPS / EMILY JACKSON

Phylum Arthropoda: Class Ostracoda (Ostracods)

Ostracods are small, two-shelled bottom-dwelling or planktonic crustaceans that consume detritus, plankton, algae, or other small particles. It is likely that some are preserved in cross-section in the Tyrone and Lexington Limestones within CANE, though such preservation makes them difficult to identify. Possible ostracods found in the Tyrone Limestone within CANE (Figure 24) may represent the large genus *Eoleperditia*.

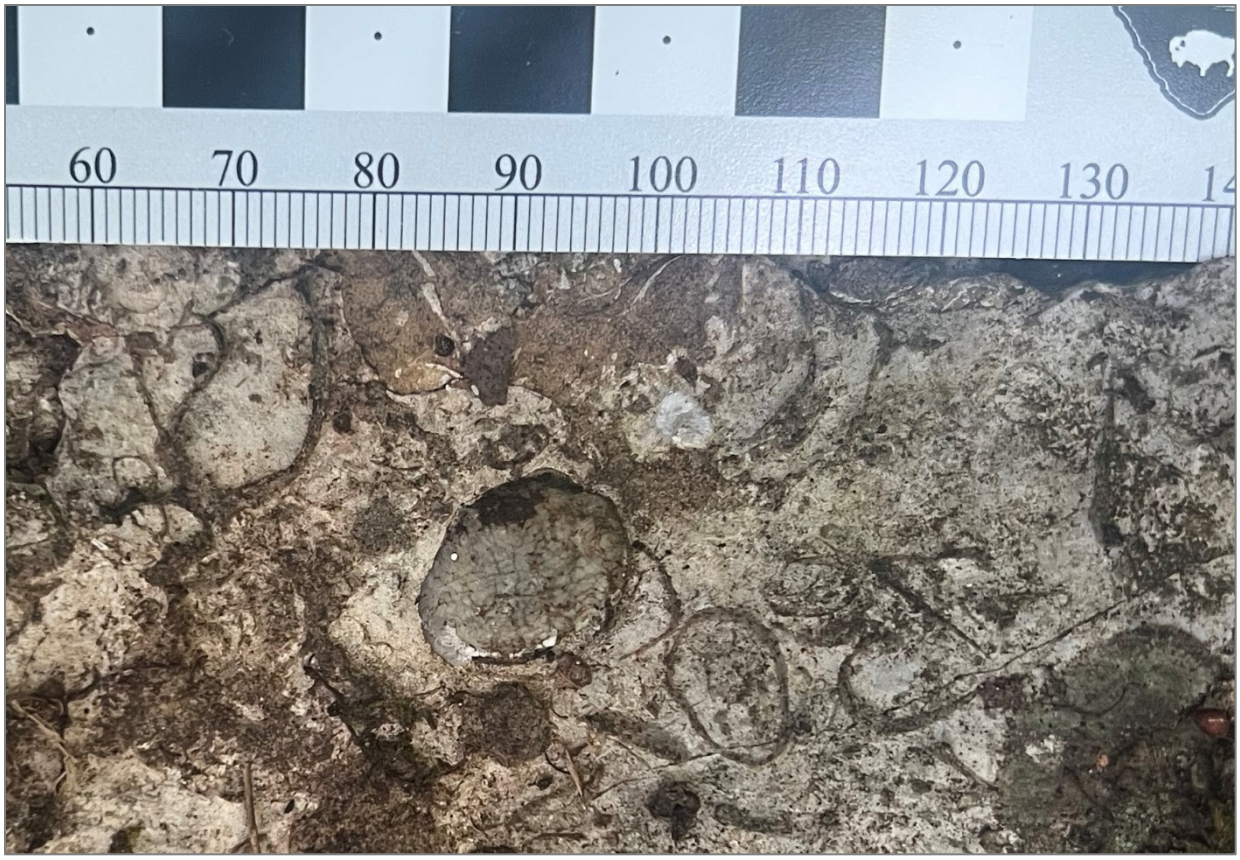


Figure 24. Possible *Eoleperditia* sp. to the lower right of a small brachiopod from the Tyrone Limestone. *NPS / EMILY JACKSON*

Phylum Echinodermata: Class Crinoidea (Crinoids)

Crinoids, also known as "sea lilies" or "feather stars", are filter-feeding animals that use their feather-like appendages to capture plankton and detritus and transport it to their mouths. Modern crinoids get their names "sea lily" (if supported by a stalk) and "feather star" (if not) from their food-catching appendages, which give the appearance of flower petals or feathers. Crinoids during the Ordovician were exclusively stalked, and these stalks usually disaggregated upon the death of the animal, leaving behind many small gear- or ring-shaped fossils. All echinoderm fossils found within CANE are pieces of those stalks (Figure 25), called crinoid columnals, which makes identifying specimens beyond their class very difficult.

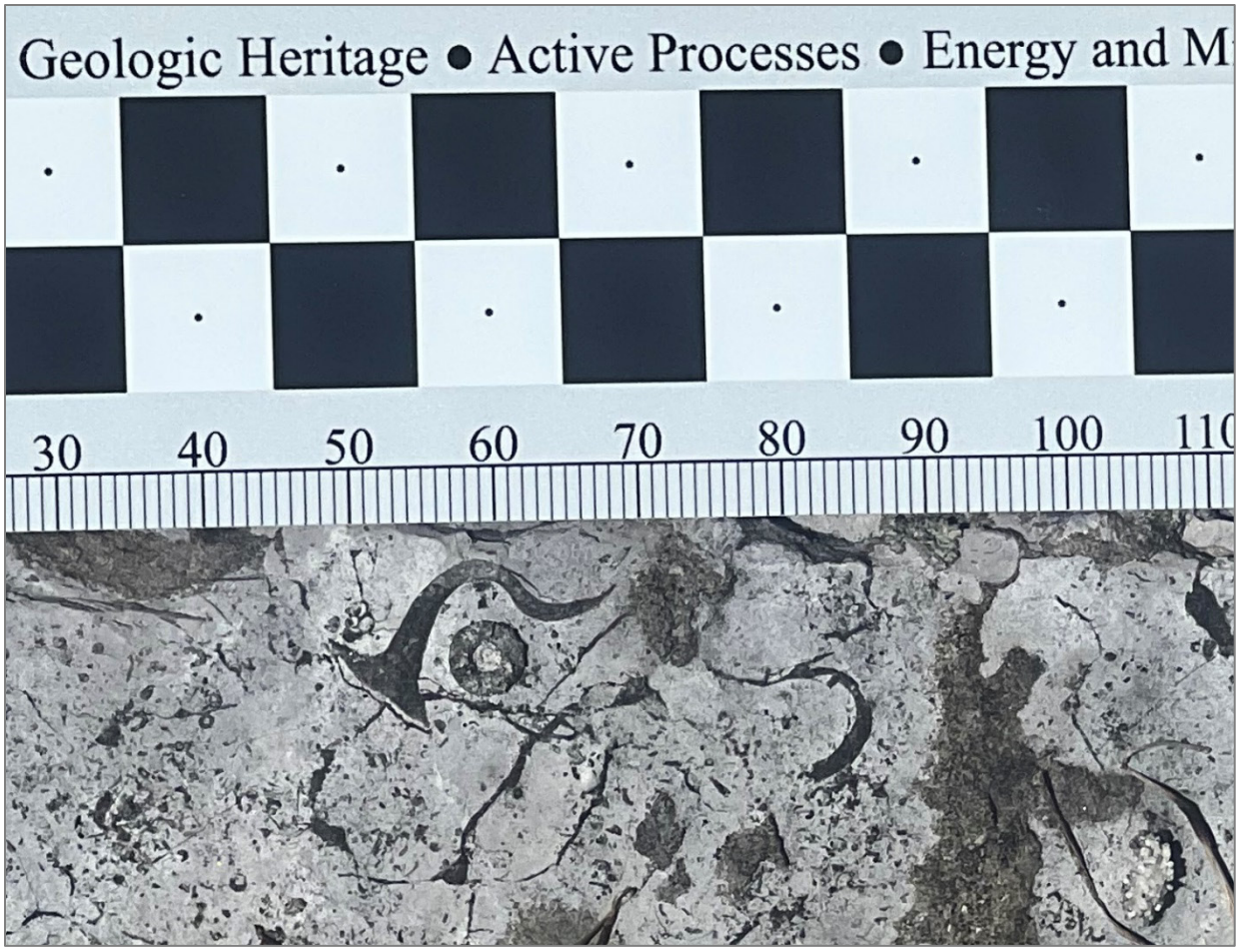


Figure 25. One of the few crinoid stalk segments found in the Tyrone Limestone in CANE.
NPS / EMILY JACKSON

Ichnofossils

Ichnofossils, or trace fossils, can be found throughout CANE, and are records of behavior left behind by the organisms that once lived in this area. The most common traces found within the park are branching burrows, likely a form of *Chondrites* (Figure 26). Vertical burrows, likely *Skolithos* (Figure 27) are present, found only where not obscured by other traces. Also, sinuous feeding traces, possibly *Cosmorhaphe* (Figure 28), are present alongside the branching burrows, in areas where burrowing behavior is less prevalent.



Figure 26. Branching burrows (*Chondrites*) in the Tyrone Limestone in CANE.
NPS / EMILY JACKSON



Figure 27. Solitary vertical burrows (*Skolithos*) in the lower Tyrone Limestone of CANE.
NPS / EMILY JACKSON



Figure 28. *Cosmorhaphe* trace in the Tyrone Limestone in CANE.
NPS / EMILY JACKSON

Fossil Localities

Paleontological Localities within CANE

Many paleontological localities have been documented in CANE, almost all identified during this 2025 paleontology inventory. This inventory documented a total of 10 sites: one in the Camp Nelson Limestone, six in the Tyrone Limestone, two in the Curdsville–Logana–Grier interval of the Lexington Limestone, and one in the Tanglewood Member of the Lexington Limestone. Two sites were previously identified by park staff and investigated by NPS paleontologist Vincent Santucci and paleontologist J.-P. Hodnett in April of 2021. These two sites were named "Region 1" and "Region 2", and both represent the Tyrone Limestone (Santucci et al. 2021). A summary of these localities is provided below in Table 2. Details are on file at CANE and are available to qualified researchers.

Table 2. Summary data for CANE paleontological sites.

Locality	Geologic Unit	Fossils
CANEPAL01 / Region 1	Tyrone	Nautiloids, gastropods, brachiopods
CANEPAL02 / Region 2	Tyrone	Nautiloids, bryozoans, horn corals, gastropods, brachiopods
CANEPAL03	Lexington	Brachiopods
CANEPAL04	Tyrone	Trace fossils, brachiopods, gastropods, nautiloids, crinoids, bryozoans
CANEPAL05	Tyrone	Trace fossils, brachiopods, gastropods
CANEPAL06	Tyrone	Trace fossils, nautiloids, brachiopods, gastropods
CANEPAL07	Tyrone	Brachiopods, gastropods, nautiloids, bivalves, crinoids, ostracods
CANEPAL08	Tyrone	Nautiloids, brachiopods, gastropods, crinoids
CANEPAL09	Camp Nelson	Trace fossils, gastropods
CANEPAL10	Tyrone	Trace fossils, nautiloids, bryozoans, brachiopods, horn corals, gastropods
CANEPAL11	Lexington	Brachiopods
CANEPAL12	Lexington	Bryozoans, brachiopods, crinoids

Paleontological Localities near CANE

Several paleontological studies have identified fossiliferous localities near CANE. As the rock units found within CANE are part of the Cincinnati Arch, there are many faraway fossil localities that hold similar organisms and depositional histories to those of the park.

Wolcott (1969) mentions a number of fossil collections around CANE. The collections are described in detail in the 1066-A–P series of U.S. Geological Survey professional papers, with the locations described in PP 1066-A (Pojeta 1979). Several of the localities are in two clusters near the park: "*Along road up from Kentucky River lock number 7 to High Bridge, Ky. and junction with Kentucky Route 29; 1,000 ft* [300 m] *west of high-level railroad bridge over Kentucky River. Base of section taken at U-shaped bend in road, between two pillars on road leading to dam at lock number 7*" and

"*Section on U.S. Route 27, 1 mi* [1.6 km] *south of intersection with road to Camp Nelson National Cemetery*" (Pojeta 1979). Another significant description of localities and the fossils found in them in the CANE vicinity is Cressman (1973), focused on the Lexington Limestone.

US Highway 27: Roadcuts nearby CANE along US Highway 27 have been used in several paleontological studies (Howe 1979; Wahlman 1992; Layou 2007). Altogether these studies report many of the same fossils as recorded by this survey, they have also yielded many genera that have yet to be reported from within CANE as well; see sections above for lists for the Camp Nelson Limestone, Tyrone Limestone, and Curdsville and Grier Members of the Lexington Limestone from these roadcuts.

East of Wilmore: Several parts of the lower Lexington Limestone were studied as a part of the 1066 series by the USGS. USGS 6419-CO, a site just east of Wilmore, Kentucky (~13 km or 8 mi from CANE), produced nautiloids (Frey 1995), a trilobite (Ross 1979), and an asteroid (Branstrator 1979).

- *Allumettoceras tenerum* (nautiloid)
- *Isorthoceras albersi* (nautiloid)
- *Decoroproetus* informal sp. (trilobite)
- *Mesopalaeaster finei* (asteroid)

Daniel Boone YMCA Camp [near Hickman Creek]: As Hickman Creek exposed much of the Upper Ordovician limestones in the area, sites like this one are relatively common. Here the study by Hoare and Pojeta (2006) identified bivalves, gastropods, brachiopods, a nautiloid, and a polyplacophoran in the Grier Member.

- *Hebertella frankfortensis* (brachiopod)
- *Pionodema* sp. (brachiopod)
- *Rafinesquina* sp. (brachiopod)
- *Zygospira* sp. (brachiopod)
- *Cyrtolites retrorsus* (monoplacophoran)
- *Byssonychia radiata* (bivalve)
- *Ctenodonta socialis* (bivalve)
- *Cycloconcha* aff. *C. ovata* (bivalve)
- *Deceptrix* cf. *D. hartsvillensis* (bivalve)
- *Modiolodon oviformis* (bivalve)
- *Isorthoceras albersi* (nautiloid)
- *Bucania* cf. *B. sublata* (gastropod)
- *Bucanopsis carinifera* (gastropod)

- *Clathrospira subconica* (gastropod)
- *Liospira progne* (gastropod)
- *Paupospira burginensis* (gastropod)
- *Helminthochiton blacki* (polyplacophoran)

Paleontological Localities farther from CANE

Platteville Formation: As much of the land we now inhabit was covered in shallow seas during the Ordovician, there are many areas far from CANE with comparable fossiliferous deposits (Kolata 2021). The Platteville Formation of the upper Midwest is well known for its Upper Ordovician fossils and bears assemblages similar to those found within CANE (Kolata 2021).

Cultural Resource Connections

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

While no written record exists regarding specific interactions between previous residents of this land and its fossils, the many uses for limestone in construction, agriculture, cleaning, and many other daily chores, and the abundance of limestone in the environment, mean that people have likely encountered this region's fossils for thousands of years. In the case of CANE, many of the historic buildings of the camp used the local fossiliferous limestone, thought to be mainly Tyrone in origin, as foundational blocks, and the karst topography was used for storage and tactical placement of warehouses and shops to hide them from the enemy (WLA Studio and McBride 2022).

Museum Collections and Paleontological Archives

Museum Collections and Curation

To date there are no known fossils sampled from CANE in external museums or collections. Samples from studies that occurred outside CANE boundaries but within the same formations found inside the park do exist, however.

Park Collections

Currently, CANE is not capable of accommodating fossil collections, and no samples from CANE exist in other NPS collections either. Should future paleontological research occur within the park, correspondence with MACA for guidance on how to reposit fossil samples is recommended.

Collections in other Repositories

No fossil specimens from CANE are currently being held in any external repositories.

Type Specimens

There are no type specimens known to have come from CANE.

Archives

NPS Paleontology Archives

All data, references, images, maps and other information used in the development of this report are maintained in the NPS Paleontology Archives and Library. These records consist of both park-specific and servicewide information pertaining to paleontological resources documented throughout the NPS. If any resources are needed by NPS staff at CANE, or additional questions arise regarding paleontological resources, contact the NPS Paleontology Program at paleontology@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). No E&R files are known for lands now within CANE, although some may exist for nearby areas in connection with the mapping for Wolcott (1969) or the Professional Paper 1066 series.

Photographic Archives

Many photos were taken of park fossils for the purpose of this survey. They and their associated geolocation data are in the care of CANE Resource Management.

Park Paleontological Research

Current and Recent Research

Aside from the permit this inventory operated under (CANE-2025-SCI-0002), there is no ongoing nor recent paleontological research to occur within CANE.

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 B.

Interpretation

Current Long Range Interpretive Plan

CANE does not include paleontological resources in its long-range interpretive plan. However, plans to introduce paleontological resources into the plan have been discussed. As part of the same project as this survey, several educational materials were created for the CANE interpretive team to use for future reference. Park staff and interns received some training on CANE fossils through a presentation delivered by SIP intern Emily Jackson, and this survey should serve as further background to aid the interpretive team in paleontological education.

Recommended Interpretive Themes

I. General Paleontological Information

All of the following interpretation topics include a section instructing visitors how to be paleontologically aware while in the 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. Other tools that a paleontologist takes into the field include a field notebook for recording data and observations, small picks and brushes, consolidants to stabilize fossils, GPS, camera, topographic maps, and appropriate First Aid and safety equipment. 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 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 CANE

- A program could be developed to educate the public on what types of fossils are present in CANE 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 CANE can be included.

III. Caves and Fossil Resources

- It is recommended that further research into the karstic features and fossils of CANE take place to better develop this inventory and increase understanding of these resources for park

staff. Just as this park has a rich cultural history, the geologic history of this region is also important to teach, and often intertwines with it.

IV. Further Interpretation Themes

CANE 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 CANE, but also to connect with other parks and museums that are also participating in this national event. The NPS Geologic Resources Division 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 433 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, 288 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 B. 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. In 2022, the DOI Paleontological Resources Preservation Act final regulation was published in the Federal Register and approved by the Office of Management and Budget. It 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 of 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 class for management due to the close connection with archeological resources and unique issues affecting cave resources. See Santucci et al. (2001) for additional discussion of paleontological resources in cave settings.

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

Baseline Paleontology Resource Data Inventories

A baseline inventory of paleontological resources is critical for implementing effective management strategies, as it provides information for decision-making. This inventory report has compiled information on previous paleontological research done in and near CANE, taxonomic groups that have been reported within CANE boundaries, and localities that were previously reported. This report can serve as a baseline source of information for future research, inventory reports, monitoring, and paleontological decisions.

Paleontological Resource Monitoring

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

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

Collection is recommended to be reserved for fossils possessing exceptional value (e.g., rare or high scientific significance) or at immediate risk of major degradation or destruction by human activity and natural processes. Therefore, paleontological resource monitoring is a more feasible potential management tool. The first step in establishment of a monitoring program is identification of

localities to be monitored, as discussed previously. Locality condition forms are then used to evaluate factors that could cause loss of paleontological resources, with various conditions at each locality rated as good, fair, or poor. Risks and conditions are categorized as Disturbance, Fragility, Abundance, and Site Access. “Disturbance” evaluates conditions that promote accelerated erosion or mass wasting resulting from human activities. “Fragility” evaluates natural conditions that may influence the degree to which fossil transportation is occurring. Sites with elevated fragility exhibit inherently soft rapidly eroding sediment or mass wasting on steep hillsides. A bedrock outcrop that is strongly lithified has low fragility. “Abundance” judges both the natural condition and number of specimens preserved at the locality as well as the probability of being recognized as a fossil-rich area by non-paleontologists, which could lead to unpermitted collecting. “Site Access” assesses the risk of a locality being visited by large numbers of visitors or the potential for easy removal of large quantities of fossils or fossil-bearing sediments. A locality with high access would be in close proximity to public use areas or other access (along trails, at roadcuts, at beach or river access points, and so on).

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

Foundation Documents and Resource Stewardship Strategies

Foundation documents and Resource Stewardship Strategies are two types of park planning documents that may contain and reference paleontological resource information. A foundation document is intended to provide basic guidance about a park for planning and management. It briefly describes a given park, its purpose and significance, its fundamental resources and values, other important resources and values, and its interpretive 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 a park’s 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 CANE has been published (NPS 2020).

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 CANE has not yet been published.

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at or beneath the land surface (Evans 2016). Colors and symbols on geologic maps correspond to geologic map units. The unit symbols consist of an uppercase letter indicating the age and lowercase letters indicating the formation's name. The NPS Geologic and Soil Resources Inventory (GSRI) has been digitizing existing maps of NPS units and making them available to parks for resource management. At this time, maps have not been compiled for CANE, a recent addition to the NPS. Wolcott (1969) is the best published map to use at this time.

Geologic maps are one of the foundational elements of a paleontological resource management program. Knowing which sedimentary rocks and deposits underlie a park and where they are exposed are essential for understanding the distribution of known or potential paleontological resources. The ideal scale for resource management in the 48 contiguous states is 1:24,000 (maps for areas in Alaska tend to be coarser). Whenever possible, page-sized geologic maps derived from GSRI files are included in paleontological resource inventory reports for reference, but it is recommended that GSRI source files be downloaded from IRMA for use when they exist.

Paleontological Resource Potential Maps

Paleontological resource maps show the distribution of geologic units within a park that are known to have yielded fossils within the park (green), have not yielded fossils within the park but are fossiliferous elsewhere (yellow), or have not yielded fossils (red). Such maps give 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.). Because all of the bedrock units of CANE have yielded fossils within the park except for the Oregon Limestone, and the best available map lumps this formation with a formation that has yielded fossils in CANE, the entire map would be green and therefore not informative. Therefore, one was not generated for this report.

Paleontological Resource Management Recommendations

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

- CANE staff should be encouraged to observe exposed rocks for fossil material while conducting their usual duties. To promote this, staff should receive guidance regarding how to recognize common local fossils. When opportunities arise to observe paleontological resources in the field and take part in paleontological field studies with trained paleontologists, staff should take advantage of them, if funding and time permit.
- CANE staff should photo-document and monitor any occurrences of paleontological resources that may be observed in situ. Fossils and their associated geologic context (surrounding rock) should be documented but left in place unless they are subject to imminent degradation. A Geologic Resource Monitoring Manual published by the Geological Society of America and NPS Geologic Resources Division (GRD) includes a chapter on paleontological resource monitoring (Santucci et al. 2009). Santucci and Koch (2003) also present information on paleontological resource monitoring.
- CANE staff should take precautions when maintaining trails such that the use of mowers or other machinery does not damage fossils exposed along and nearby these areas.
- Completing a Geologic Resources Inventory would provide additional context for interpretation and management of paleontological resources at CANE.
- Fossil theft is one of the greatest threats to the preservation of paleontological resources and while less likely to occur in CANE, methods to minimize these activities should still be utilized by staff. Any occurrence of paleontological resource theft or vandalism should be 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.
- Fossils found in a cultural context should be documented like other fossils but will also require the input of an archeologist or a cultural resource specialist. Any fossil which has a cultural context may be culturally sensitive as well (e.g., subject to NAGPRA) and should be regarded as such until otherwise established. The Geologic Resources Division can coordinate additional documentation/research of such material. Additionally, already collected/documented cultural materials known to have come from the geologic units within CANE should be retroactively inspected for fossils when possible.
- CANE may fund and recruit paleontology interns as a cost-effective means of enabling some level of paleontological resource support. The Scientists in Parks Program is an established program for recruitment of geology and paleontology interns.

- CANE may consider preparing a small display of fossils for interpretation and education, discussing topics such as their age, paleoenvironment, and biology.
- Contact the NPS Paleontology Program for technical assistance with paleontological resource management issues.

If fossil specimens are found by CANE 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 CANE and height within the outcrop, if applicable. 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.
- Write down associated data, such as rock type, general description of the fossil, type of fossil if identifiable, general location in CANE, 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. Because CANE has many culturally important sites, simply documenting the fossil and leaving it in place is the best course of action until natural resource staff is contacted.

CANE staff are encouraged to further develop programming on the paleontological resources of the park. The following resources are recommended to aid in research and creation of such educational programs.

- Consultation of this survey will aid with initial understanding of park paleontological resources and their locations related to understood cultural resources. This survey should act as the baseline for educational programming, on which CANE staff are encouraged to build.
- Many other NPS units contain correlative or similar paleontological resources and should be considered when developing educational materials. There are currently 22 NPS units known to contain Upper Ordovician fossils and another nine that have potentially fossiliferous Upper Ordovician rocks. Among those NPS units several include rocks that can be directly correlated to the Tyrone Limestone by the presence of bentonite clays; these units include Appalachian National Scenic Trail, Cedar Creek and Belle Grove National Historical Park, Chesapeake and Ohio Canal National Historical Park, Mississippi National River and Recreation Area, and more.

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Appendix A: Paleontological Species

The following table (Table 3) documents the fossil species found at CANE in stratigraphic context, as reported in the literature, in museum collections, and through personal observations. 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).

Table 3. Fossil taxa reported from CANE in stratigraphic context. References are provided where appropriate; others were identified for the first time during this inventory. If a taxon is present in a given formation at a locality that can be placed within CANE, that cell is marked “Y”; if there is some question about the formation or whether the locality is within CANE, the cell is marked “?”. A null record is marked “–”.

Group	Taxon	Camp Nelson	Oregon	Tyrone	Lexington	References
Cnidaria	*Lambeophyllum* sp.	–	–	Y	–	–
	Streptelasma sp.	–	–	Y	–	–
	Tabulata indet.	–	–	?	–	Present, stratigraphy uncertain
Cnidaria?	*Tetradium* sp.	–	–	?	–	Present, stratigraphy uncertain
Bryozoa	*Ceramopora* sp.	–	–	Y	?	–
	Eridotrypa sp.	–	–	Y	Y	–
	Escharopora sp.	–	–	Y	Y	–
	Stictopora sp.	–	–	Y	Y	–
Brachiopoda	*Heterorthina* sp.	–	–	Y	Y	–
	Rafinesquina sp.	–	–	?	Y	–
	Zygospira sp.	–	–	?	Y	–
	Brachiopoda indet.	–	–	?	Y	Wolcott (1969); Santucci et al. (2021)
Mollusca: Bivalvia	Modiomorphida? indet.	–	–	?	–	–
Mollusca: Nautiloidea	*Diestoceras* sp.	–	–	Y	–	Santucci et al. (2021)
	Treptoceras sp.	–	–	Y	–	Santucci et al. (2021)
	Nautiloidea indet.	–	–	Y	–	Santucci et al. (2021)
Mollusca: Gastropoda	*Asgardaspira* sp.	–	–	Y	?	–
	Lophospira sp.	Y	–	Y	?	–
	Paupospira sp.	–	–	Y	–	–
Arthropoda: Ostracoda	*Eoleperditia* sp.	–	–	Y	–	–
Echinodermata: Crinoidea	Crinoidea indet.	–	–	Y	?	–
Trace Fossils	*Chondrites* isp.	Y	–	Y	–	–
	Cosmorhaphe isp.	–	–	Y	–	–

Table 3 (continued). Fossil taxa reported from CANE in stratigraphic context. References are provided where appropriate; others were identified for the first time during this inventory. If a taxon is present in a given formation at a locality that can be placed within CANE, that cell is marked “Y”; if there is some question about the formation or whether the locality is within CANE, the cell is marked “?”. A null record is marked “–”.

Group	Taxon	Camp Nelson	Oregon	Tyrone	Lexington	References
Trace Fossils (continued)	*Skolithos* isp.	Y	–	Y	–	–
Other Fossils	Fossil debris	Y	–	Y	Y	Santucci et al. (2021)
	Fossils indet.	Y	–	Y	Y	Santucci et al. (2021)

Appendix B: 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. An 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 and 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 of 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 (NPS 2006). It is the goal of the NPS to avoid or minimize potential impacts to resources to the greatest extent practicable consistent with the management policies. 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; and Artifacts and Specimens 10.2.4.6 in NPS 2006, available here. Also see 36 CFR 2.5.)

NPS Director's Order-77, Paleontological Resources Management

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

Excerpt from Clites and Santucci (2012):

Monitoring

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

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

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

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

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

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

Appendix C: Geologic Time Scale

A geologic time scale (Figure 29) is provided below for reference.

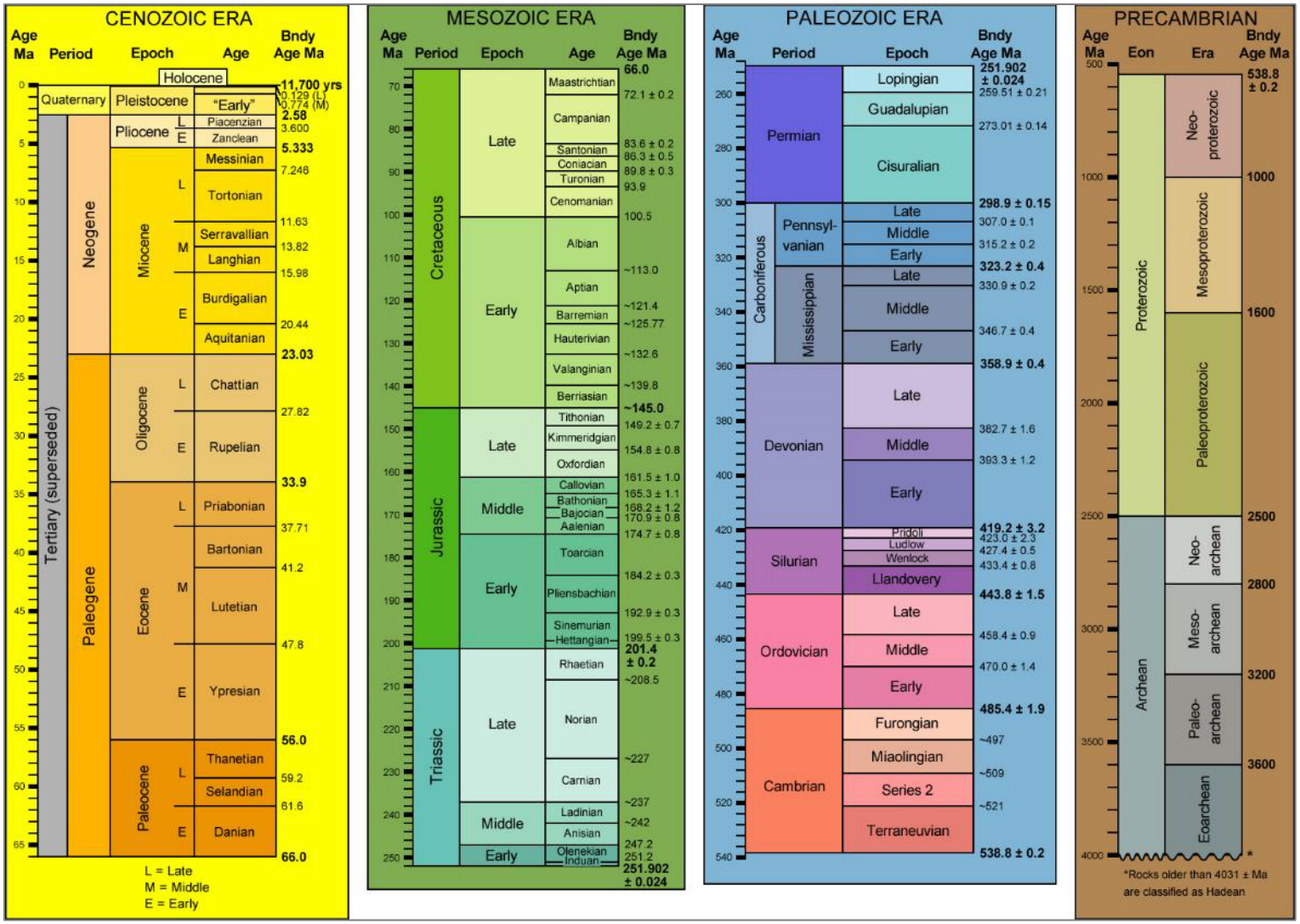


Figure 29. Geologic time scale. Ma=Millions of years old. Bndy Age=Boundary Age. Layout after 1999 Geological Society of America Time Scale (https://rock.geosociety.org/net/documents/gsa/timescale/timescl-1999.pdf). Dates after International Commission on Stratigraphy version 2023/09.

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