National Park Service
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Natural Resource Stewardship and Science

Devils Tower National Monument

Paleontological Resources Inventory (Non-Sensitive Version)

Natural Resource Report NPS/DETO/NRR—2019/1969

ON THE COVER

A block of fossiliferous rock from the Redwater Shale Member of the Sundance Formation showing bivalves. Photo by Justin Tweet (NPS).

Devils Tower National Monument

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Natural Resource Report NPS/DETO/NRR—2019/1969

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Executive Summary

Devils Tower National Monument (DETO), the first United States national monument, is world-famous for the monument's namesake feature, Devils Tower, an unusual igneous feature rising over the plains and bluffs of northeastern Wyoming within the northwestern Black Hills. This feature, of long-debated origin, formed in surroundings composed of much older sedimentary rocks deposited in and around shallow seas from the Permian to Cretaceous periods. The youngest sedimentary rocks long ago eroded to nothing but residuum, in the process exposing the igneous body that erosion has sculpted into the Tower. However, several formations of Permian to Jurassic age are exposed around the Tower within DETO. Fossils are found at various locations throughout the monument, primarily from the Middle–Upper Jurassic Sundance Formation.

The presence of fossils near Devils Tower has been known since at least the beginning of the 20th century, but geologic work at DETO has almost always been focused on the Tower itself, with the overall character and depositional settings of the sedimentary rocks as a secondary focus and fossils considered only in passing until recently. Exploration of the monument over the past few years has located several new fossil localities, expanding and illuminating the scope of the monument's paleontological resources. These fossils and the information they provide about the rocks help to provide a more complete picture of the story of DETO.

In ascending order (oldest to youngest), the geologic formations at DETO include the Spearfish Formation (Permian–Triassic), Gypsum Spring Formation (Middle Jurassic), and four distinct members of the Sundance Formation (Middle–Upper Jurassic), with an unconfirmed report of a Morrison Formation (Upper Jurassic) outlier. These formations are frequently overlain by unconsolidated deposits, such as talus from the Tower, residuum possibly from the Lakota Formation, and alluvium in the floodplain of the Belle Fourche River. The Spearfish and Gypsum Spring formations appear to be unfossiliferous. On the other hand, the Sundance Formation preserves a variety of marine fossils, primarily fragments of belemnite cephalopods and beds of bivalve shells in DETO. Rare evidence of vertebrates has also been found. This unit was deposited approximately 167 to 160 million years ago during multiple marine transgressions (advances) and regressions (retreats), which are responsible for the different members of the formation. Exposures of the most fossiliferous parts of the Sundance Formation are limited in DETO, but they show thriving shallow marine ecosystems. Small numbers of fossils have also been reported from the Upper Jurassic Morrison Formation, Lower Cretaceous ?Lakota Formation, and an unusual "agglomerate" unit of igneous origin, although all but possibly the Morrison Formation occurrence are displaced from their original contexts.

Many of the fossils of DETO are accessible from trails or roads, which increases their risk of loss through unauthorized collection or damage (intentional or unintentional), and there is anecdotal evidence of occasional collecting at the monument. In addition, the deep cultural significance of the Tower and associated resources leads to some complications for paleontological resource management. DETO has had site monitoring programs in the past, and it is recommended that they resume.

Acknowledgments

Every paleontological resource inventory project requires the support of numerous individuals. For this inventory, we would like to begin by recognizing the support of the staff of DETO, who have consistently stepped up to provide information and assistance, particularly with Justin's June 2019 visit. We thank in particular DETO Superintendent Amnesty Kochanowski and Chief of Resource Management Rene Ohms, as well as Nick Bossenbroek, Alex Heyer, and Phil Knecht, and former Chief of Resource Management Mark Biel. Chris Racay, now at Rocky Mountain National Park (ROMO), provided the impetus for this inventory with his discoveries and was an excellent field companion. Zane Martin, museum specialist for DETO, Jewel Cave National Monument (JECA), and Mount Rushmore National Memorial (MORU), provided additional information on DETO's museum and archival collections. Tim Connors of the Geologic Resources Division provided the maps for the report, as well as contributing a program review. Don Weeks, Physical Resources Program Manager for the NPS Intermountain Region, acted as peer review coordinator, with Diana Boudreau filling in to distribute files when Don was temporarily unavailable. Brent Breithaupt (Bureau of Land Management) provided a second opinion on the possible Hulett Sandstone tracks, and Cassi Knight (Paleoworks Consulting) provided a second opinion on the possible conifer chip. Darrin Pagnac (South Dakota School of Mines and Technology) and Ed Welsh (Badlands National Park) made an earlier assessment of the bone block as part of the ongoing study of DETO paleontological resources. George Engelmann (University of Nebraska–Lincoln) discussed the possibility of the Morrison Formation being exposed at DETO. Alex Hastings (Science Museum of Minnesota) assisted with obtaining photos of the specimens at the Science Museum of Minnesota. Sally Shelton (South Dakota School of Mines and Technology) provided information on the South Dakota School of Mines and Technology's collections. Jonathan Wingerath, deputy paleobotany collections manager for the National Museum of Natural History, provided information about the status of Peck's fossils from DETO. Outside reviews were provided by Steven Holland (University of Georgia) and Andrea Loveland (Wyoming State Geological Survey). We would also like to thank American Geosciences Institute for their assistance with Justin's position.

Dedication

We are pleased to dedicate this report to three people who made this report possible: Amnesty Kochanowski, Chris Racay, and Rene Ohms. The impetus for this project began with Chris's investigations of the paleontology of DETO when he worked at the monument in 2017–2018. While inspecting areas of the monument for potential fossil occurrences, he discovered small bones in a block of the Redwater Shale Member of the Sundance Formation, and possible dinosaur tracks in the Hulett Sandstone Member of the same formation. If these are shown to be tracks, they will be the first reported from the Hulett Sandstone. Chris also assessed and re-identified the fossils in DETO's interpretive collection. For Justin Tweet's site visit in June 2019, Chris returned to DETO to lend his expertise.

If it were not for management support of Chris's activities, the discoveries may well have become footnotes in monument records, similar to the tantalizing but incomplete reports of fossils observed by early Lead Custodian Newell Joyner. Instead, DETO management, led by Superintendent Amnesty Kochanowski and Chief of Resource Management Rene Ohms, has been very supportive of paleontological resource management at the monument. They have facilitated visits by outside researchers, such as the visit by Darrin Pagnac (South Dakota School of Mines and Technology; SDSM&T) and Ed Welsh (Badlands National Park; BADL) to assess the bone block, and the visit by Tweet, and have maintained active dialogue with the Geological Resources Division about these resources. Amnesty and Rene have demonstrated tremendous leadership in paleontological resources stewardship, establishing a new legacy for preservation and protection of DETO's fossil record.

Amnesty Kochanowski, Superintendent of DETO (left), Rene Ohms, Chief of Resource Management (center), and Chris Racay (right).

Introduction

Devils Tower National Monument (DETO) encompasses 545.08 hectares (1,346.91 acres) of land in central Crook County, northeastern Wyoming. All of its land is under federal administration. DETO was established to protect the striking igneous monolith known widely as Devils Tower (Figure 1), situated just northwest of the Belle Fourche River (Figure 2). The Tower, 265 m (867 ft) tall with a fluted or striated appearance due to its columnar internal structure, has inspired people for thousands of years. DETO was the nation's first national monument, being proclaimed September 24, 1906, predating the 1916 establishment of the National Park Service (NPS). Its boundaries have changed once, on August 9, 1955.

Figure 1. Devils Tower viewed from the Joyner Ridge Trail (NPS/JUSTIN TWEET).

DETO is located in the northwestern Black Hills, with the Powder River Basin to the west and south (Love and Christiansen 1985). Devils Tower is near the collapsed center of a large dome (Robinson 1956). The Missouri Buttes, which include igneous rocks that are comparable to those of Devils Tower, are centered about 4 km (2.5 km; distances are straight lines) northwest of DETO, and the Bear Lodge Mountains are centered about 24 km (15 mi) southeast of DETO. The town of Hulett is about 12 km (7.5 mi) northeast of DETO, Sundance is about 32 km (20 mi) to the southeast, and Gillette is about 69 km (43 mi) to the southwest. DETO is one of 16 NPS units included in the Northern Great Plains Inventory & Monitoring Network (NGPN).

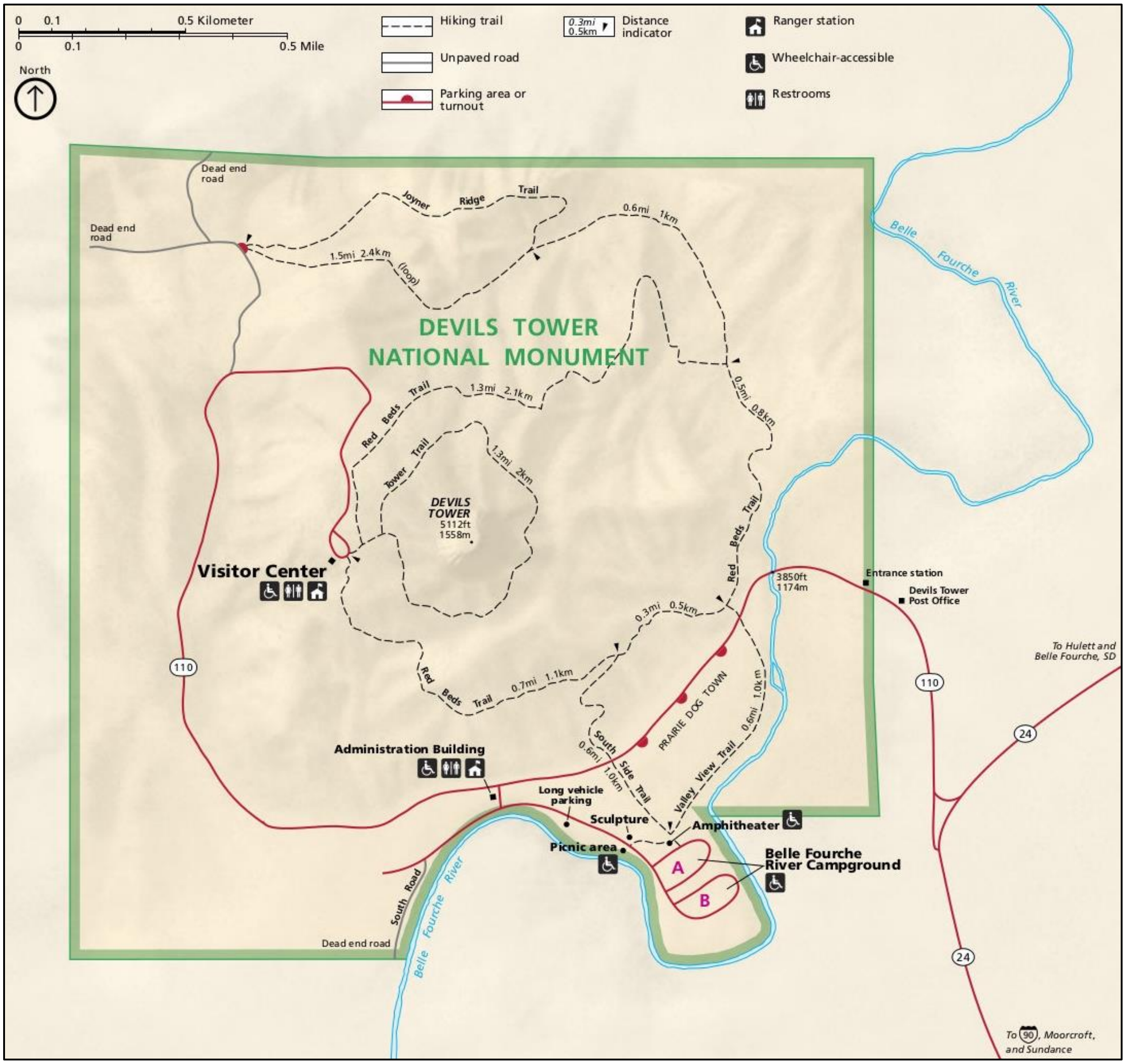

Figure 2. Geography of DETO, showing park boundaries, roads, and other features (NPS map).

The boundaries of DETO encompass a roughly square-shaped parcel, with the square shape interrupted on the southeast by the Belle Fourche River. The parcel is centered on the famous Tower, the exposed portion of an igneous body that intruded into Upper Paleozoic and Mesozoic sedimentary rocks during the Eocene (see Appendix D for a geologic time scale). The Tower is surrounded by a talus field of blocks it has shed over time. Outcrops of several sedimentary formations are visible around it, in ascending order (oldest to youngest) the Spearfish Formation (Permian–Triassic), Gypsum Spring Formation (Middle Jurassic), and Sundance Formation (Middle–Upper Jurassic) (Figure 3). Older units are generally exposed farther from the Tower, except in western and northwestern DETO, and outcrops are absent from the floodplain of the Belle Fourche River in southeastern DETO. Each of the bedrock units represent deposition in or adjacent to shallow continental seas. Fossils have not been found in the two lower formations within or near DETO, but marine fossils such as bivalve shells and belemnite (squid-like animals) hard parts are abundant in certain beds of the Sundance Formation (Figure 4).

Significance of Paleontological Resources at DETO

The fossils of DETO help to show the complete picture of the park. A full understanding of the bedrock is necessary to evaluate the many hypotheses put forward for the origin of the Tower itself, and fossils are an important part of characterizing formations. As such, they are also useful educational and outreach tools; for example, it is easier to explain the nature of the bedrock by showing fossil seashells than by a discussion of sedimentology. In addition, they are of concern for resource management because many of the fossils have characteristics that make them appealing for the casual or souvenir collector: they are portable, durable, and easily recognized as fossils, and in some cases can be found on or near trails or roads.

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. Paleontological resource inventories have been developed by the NPS in order to compile information regarding the scope, significance, distribution, and management issues associated with fossil resources present within parks. This information is intended to increase awareness of park fossils and paleontological issues in order to inform management decisions and actions that comply with these laws, directives, and policies. See Appendix C for additional information on applicable laws and legislation.

Project Objectives

This park-focused paleontological resource inventory project was initiated to provide information to DETO 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 and resource management associated with the paleontological resources at DETO. Methods and tasks addressed in this inventory report include: locating, identifying, and documenting paleontological resource localities through field reconnaissance using photography, GPS data, and standardized forms; relocating and assessing historical localities; assessing collections of DETO fossils maintained within the park collections and in outside repositories; and a thorough search for relevant publications, unpublished geologic notes, and outside fossil collections from DETO.

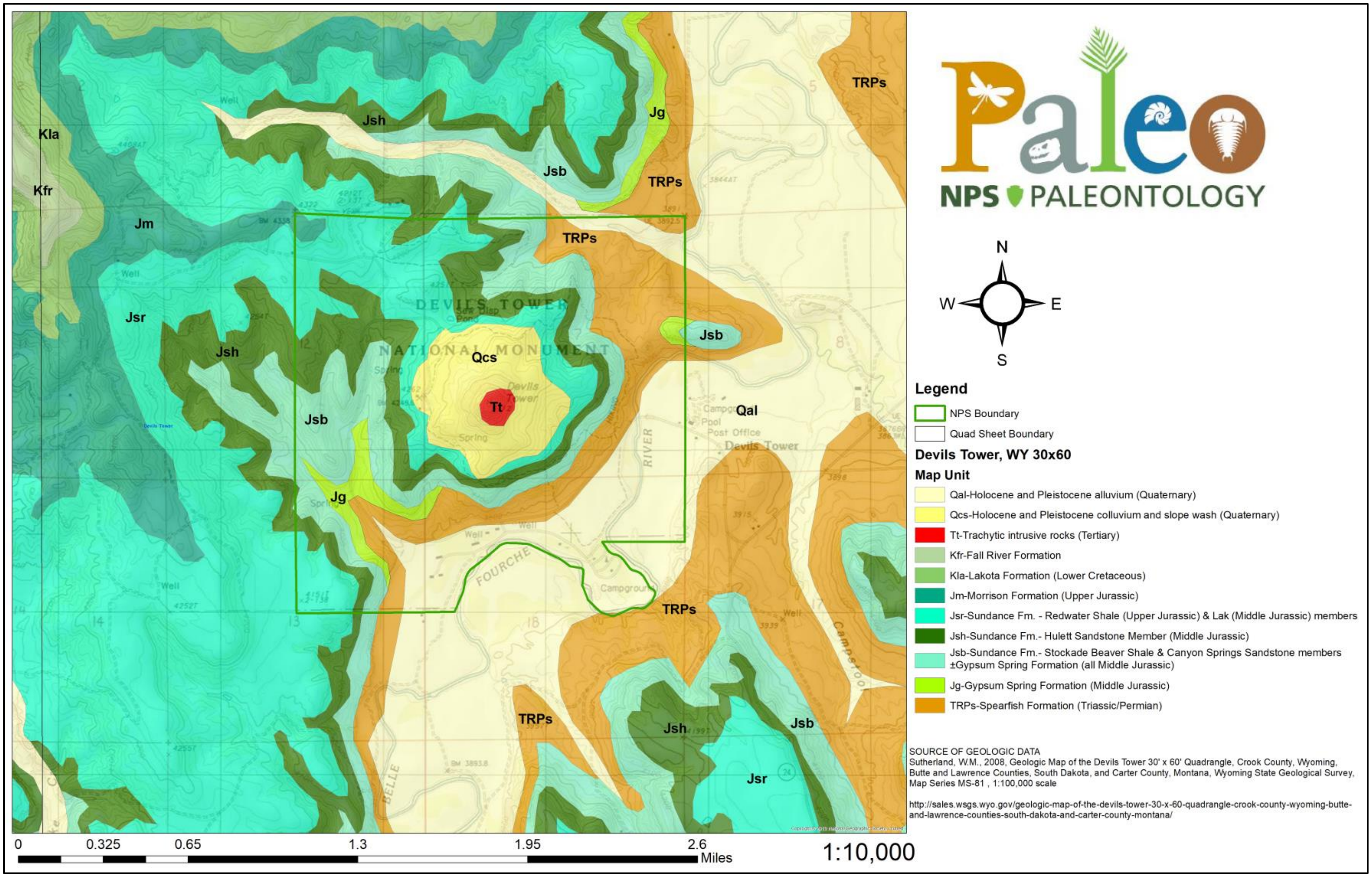

Figure 3. Schematic geologic map of DETO (NPS/TIM CONNORS) adapted from digital geologic map data available at the following URL: https://irma.nps.gov/DataStore/Reference/Profile/1046190. The extent of the Morrison Formation in DETO may be an error in the source map (see text).

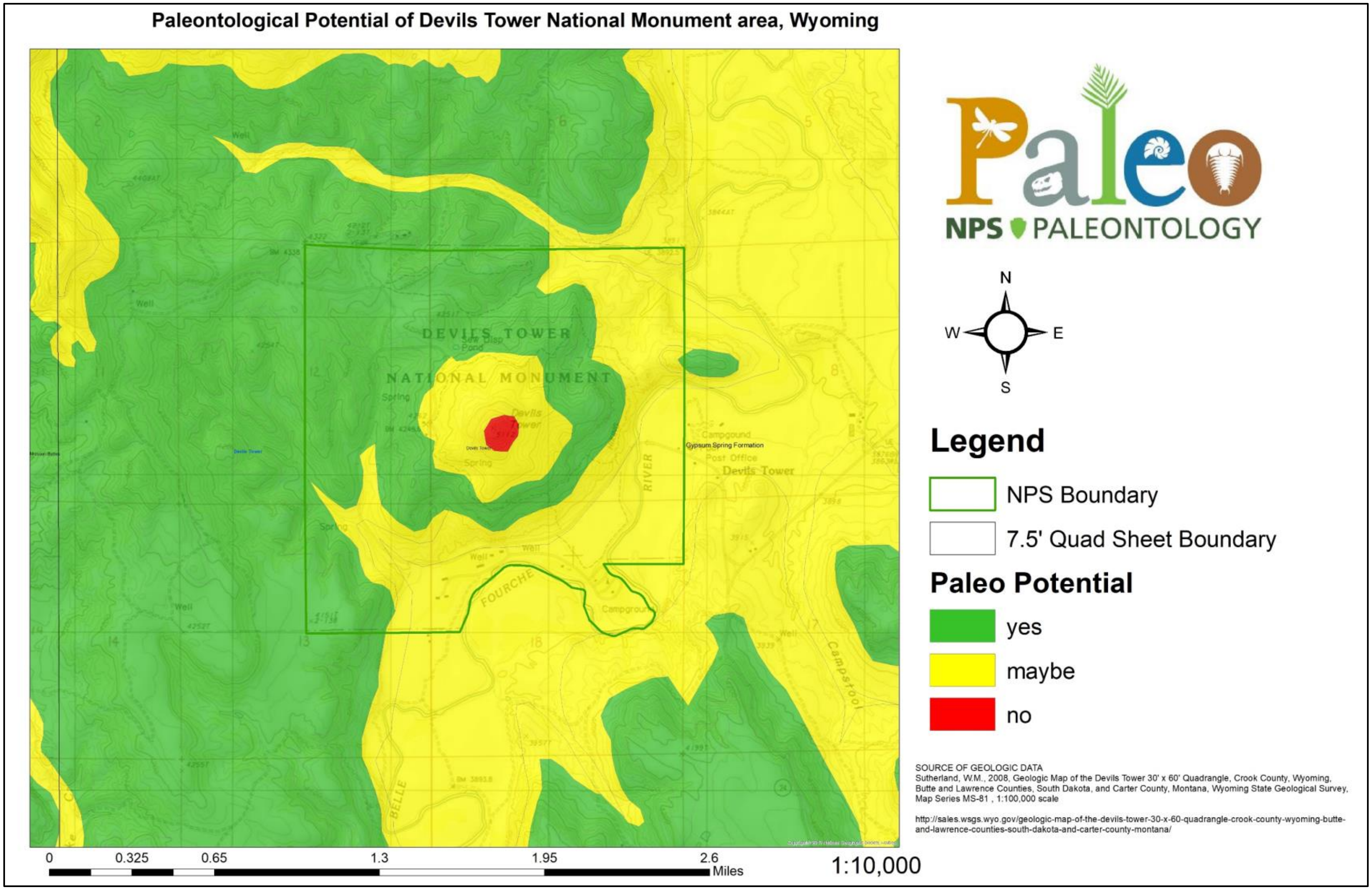

Figure 4. Map indicating paleontological potential of geologic map units within DETO (NPS/TIM CONNORS).

History of Paleontological Work at DETO

The geology of DETO has been described in a number of publications. Most are focused on aspects of Devils Tower, with a few devoted to placing the sedimentary rocks within the broader contexts of their formations as they are known across Wyoming, South Dakota, and other states. Publications that deal more broadly with DETO geology, or include information about the paleontology of the monument, include Jaggar (1901), Darton and O'Harra (1907), Effinger (1934), Robinson (1956), Peck (1957), Bowen (1961), Robinson et al. (1964), Rautman (1975, 1976, 1978), Hall and Stewart (1977), Halvorson (1980), Karner and Halvorson (1987, 1989a, 1989b), Karner and Patelke (1989), Robinson and Davis (1995), Duke et al. (2002), Rogers (2007), Graham (2008), Bossenbroek (2011), Tweet et al. (2011), and Závada et al. (2015). The NPS Geologic Resources Division coordinated a geologic resources inventory scoping session for DETO during June 2002, produced a geologic resources evaluation report for DETO in 2008 (Graham 2008), and produced a network-level NGPN paleontological inventory in 2011 which included a chapter on DETO (Tweet et al. 2011).

The first scientific documentation of Devils Tower occurred in 1875 as part of the expedition led by Richard Irving Dodge, with early accounts of the Tower in Dodge (1876) and Newton and Jenney (1880). The expedition was also the beginning of the controversy over the Tower's name. Prior to Dodge, it had been known on maps as Bear Lodge or Mato Teepee (Newton and Jenney 1880; Russell 1896). Dodge received an apparent mistranslation of "the bad god's tower," which was revised to "Devil's Tower" and has since become "Devils Tower." There persisted some use of Bear Lodge or Mato Teepee/Tipi in geologic reports of the late 19th and early 20th centuries (Newton and Jenney 1880; Carpenter 1888; Russell 1896; Jaggar 1901; Whitfield and Hovey 1906). As has been true throughout the history of geological investigations of DETO, the early investigators focused their attention on the Tower. Whitfield (1880) reported the presence of some Jurassic bivalve and belemnite taxa near the Tower but almost certainly outside of DETO boundaries; most entries mention locations as either south or east of the Belle Fourche River, and there are no outcrops within DETO south or east of the river. The first documentation of fossils at what is now DETO appears to be in Jaggar (1901; Figure 5), but there are few details in this publication. Most of the relevant information is included in passing in a generalized stratigraphic section (repeated in Effinger 1934):

1) Quartzite
2) *Tancredia* [a type of bivalve] limestone
3) Smoky fine limestone
4) Belemnite shale
5) Oyster bed
6) Tender buff (sometimes pink) bluff-forming sandstone
7) Green shale
8) Thick hard shell bed
9) Buff marl over gypsiferous red bed marl

Unfortunately, Jaggar did not include thicknesses for these geologic units, which could have made it possible to determine, for example, if the Spearfish Formation is included with the Gypsum Spring Formation. Based on lithological descriptions and relative positions, it seems probable that Jaggar's section can be interpreted in the following manner:

> Bed 1, the quartzite, is likely remnants of ?Lakota Formation sandstone, also reported by Robinson (1956);
> Beds 2 through 5 appear to be different levels of the Redwater Shale Member of the Sundance Formation;
> Bed 6, the bluff-forming sandstone, is certainly at least the Hulett Sandstone Member of the Sundance Formation, and may also include the poorly exposed overlying Lak Member, which is predominantly sandstone;
> Beds 7 and 8 probably both pertain to the Stockade Beaver Shale Member of the Sundance Formation;
> Bed 9 appears to be a combination of the Gypsum Spring Formation and underlying Spearfish Formation, because both units have red beds, marly beds, and gypsum. Some lower Stockade Beaver Shale Member may also be included in the buff marl.

Jaggar also reported silicified wood and roots in the quartzite, and Carboniferous brachiopods ("lamp shells") in a limestone fragment which came from "agglomerate."

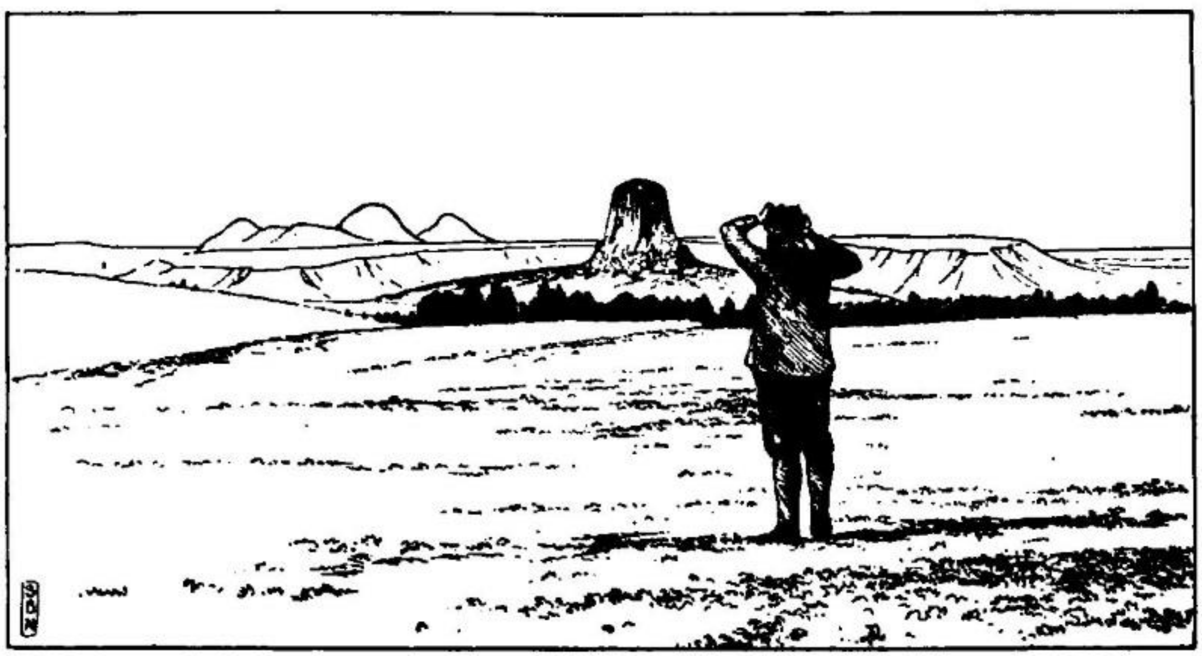

FIG. 95.—Mato Teepee and Little Missouri Buttes from the southeast.

Figure 5. Historical illustration of the Tower (Jaggar 1901).

Over the next few decades, Devils Tower figured briefly in larger discussions of Black Hills geology (Darton and O'Harra 1907; Darton 1909), but nothing was published on its fossils. However, fossil collecting was being done in the Jurassic rocks of the immediate vicinity of DETO in the early 20th century, and some specimens have been described in the literature (Whitfield and Hovey 1906; Reeside 1919; Imlay 1982). A brief geological report on DETO was produced in 1934 (Effinger 1934), although there is little new information on the sedimentary rocks and fossils. In fact, it should be noted that portions of the text in Effinger (1934) are taken verbatim from Jaggar (1901) and Darton (1909) without clear attribution, and the occasional citations of the authors elsewhere in the text give the impression that the copied uncited sections are Effinger's work. It appears that every report of a fossil occurrence or fossiliferous horizon in Effinger (1934) is derived directly from Jaggar (1901). Of greater interest, although less widely known, are the observations of longtime early lead custodian (equivalent to superintendent) Newell Joyner (active 1932–1949). Early in his tenure, Joyner collected examples of the belemnite fossils of the monument, and he brought dinosaur bones to the monument for preparation and exhibition (Rogers 2007). He also made a tantalizing observation that a dinosaur bone had been picked up on what became the Red Beds Trail (1939 proposal reprinted in Rogers 2007). It is not known what happened to any of this material.

Perhaps the most important document from the standpoint of understanding the sedimentary rocks at DETO was published in 1956 by Charles S. Robinson for the U.S. Geological Survey (USGS) (Robinson 1956). This work identified the geological units of the monument and included a detailed (scale 1:4,800) geologic map, omitting only the lands added to southern DETO in 1955. Robinson later included this research in a report of the surrounding area (Robinson et al. 1964), and in a revised version for the public as Robinson and Davis (1995). USGS paleontologists were also active in and around DETO in the 1950s. Peck (1957) documented an assemblage of charophyte algae from a Morrison Formation outlier within DETO, and Sohn (1958) and Sohn and Peck (1963) documented ostracodes ("seed shrimp") from just outside of the monument. In perhaps the most unusual published appearance of a DETO fossil, Bowen (1961) included a belemnite from the monument in a stable isotope study examining paleotemperatures.

Sedimentary units at DETO would play supporting roles in several theses and dissertations over the next few decades (Rautman 1976; Halvorson 1980; Bossenbroek 2011), but fossils were mentioned only in passing, if at all. Most of the recent information on DETO fossils comes from internal NPS documents and personal observations. DETO staff undertook paleontological resource monitoring during 1994–1996 and 2007–2013. The first period of paleontological resource monitoring produced three internal reports (Moroge 1994; Holbeck 1995, 1996). Tweet et al. (2011) provided the first summary of DETO paleontology, although it overlooked some important reports.

The immediate stimulus for this report was the discovery by Chris Racay in late 2017 of vertebrate material within the monument. Vincent L. Santucci, NPS Senior Paleontologist, was contacted about the fossil discovery at DETO and the park submitted a technical assistance request (STAR #7061) in 2018 to develop a strategy for assessment and preservation of the fossil specimen. To satisfy this STAR, Darrin Pagnac (SDSM&T) and Ed Welsh (BADL) visited DETO January 25, 2018 to investigate the vertebrate body fossils, which they documented in an internal report (Pagnac and Welsh 2018). They recommended collection, but a tribal consultation (October 18–19, 2018) was against this. Planning and communication between DETO staff and the NPS Paleontology Program staff shortly before the tribal consultation resulted in planning for a field-based paleontological resource inventory for DETO during 2019 and the original technical assistance request was incorporated into a new request (STAR #9309). In response, lead author Justin Tweet visited DETO June 3–6, 2019. This technical assistance request was the genesis for this report.

Summary of 2019 Paleontological Resource Inventory

Justin Tweet visited DETO June 3–6, 2019 to perform field work for STAR #9309. On June 3, after meeting Superintendent Amnesty Kochanowski and discussing the project, he gave presentations on DETO paleontology and NPS paleontological resources and management to staff, then made preliminary visits to some sites with Phil Knecht, assessed the archival material that was on-hand, and made an initial exploration along part of the Red Beds Trail. On June 4, he met Chief of Resource Management Rene Ohms, who provided him with additional digital archival material. Chris Racay also visited on June 4 from Rocky Mountain National Park and showed Tweet the localities he had recorded, as well as the interpretive collections. On June 5–6, Tweet made solo excursions across the monument, including all trails except the Valley View Trail (omitted as over recent alluvium). Through these activities, Tweet was able to assess the known paleontological localities, identify some new localities, and assess the trails for access to fossiliferous sites, and received a fuller accounting of park paleontological resource management and interpretive efforts. Detailed locality information is included in a restricted-access version of this report. The most significant result of this survey was locating two previously unreported locations with abundant surface belemnite fossils, adjacent to roads or trails. Tweet also found evidence concerning the fates of some of the paleontological specimens previously in DETO collections, with two of them present in collections as late as 2001 and one still at the monument in the interpretive collection.

Geology

Geologic History

The rocks and sediments exposed at DETO almost all date to four general spans of geologic time: the Permian–Triassic, the Middle and early Late Jurassic, the early Eocene, and the Quaternary (see Appendix D for a geological time scale). Potential outliers and residuum may represent the later Late Jurassic and Early Cretaceous, and an “agglomerate” includes rock fragments as old as the Precambrian. In general, the Permian, Triassic, and Jurassic rocks record periods of marine advances and retreats (transgression–regression cycles). The Black Hills as a whole have exposures of rocks from approximately the past 2.5 billion years, and the other NPS units of the Black Hills and the vicinity include much of this geologic history.

The oldest rocks found in situ at DETO are assigned to the Spearfish Formation, and record events that occurred sometime near the Permian–Triassic boundary of 251.9 Ma (million years ago). The Permian–Triassic boundary was marked by a marine incursion in northeastern Wyoming, as a shallow sea advanced into the area (Sabel 1984). Following the Triassic marine regression, there was uplift and erosion in the DETO area (Robinson 1956).

Marine deposition returned to what is now northeastern Wyoming during the Jurassic, as a shallow seaway (average depth less than 100 m, or 330 ft) spread south from the Arctic (Kvale et al. 2001). The seaway, known as the Sundance Seaway, submerged significant parts of what are now Montana and Wyoming and stretched into neighboring states (Danise and Holland 2018). Between approximately 170 and 155 Ma, the geography of the shoreline underwent several large-scale shifts, resulting in a variety of different rock types as the depositional environment changed. Coastal desert, carbonate ramp marine, and wave-dominated shelf marine deposition prevailed at various times in the DETO area, as recorded in the Gypsum Spring Formation and Sundance Formation (Danise and Holland 2018). At the same time, regional climate changed from arid to a more semi-arid state, perhaps due to overall global cooling and the northward movement of North America bringing northern Wyoming out of the arid subtropical belt (Danise and Holland 2017, 2018). By the time of deposition of the upper Sundance Formation, approximately 160 Ma, northern Wyoming had reached a paleolatitude near 35° N (Danise and Holland 2018); DETO is presently at 44.6° N latitude. Terrestrial deposition resumed in the area following the retreat of the Sundance Sea, with rocks from this time (the Morrison Formation) represented in the area around DETO but not present within monument boundaries, except perhaps as a small outlier (Peck 1957).

The Black Hills, a large asymmetric doubly plunging anticline (more generally speaking, a dome; rock deformation has caused the uplift of a central area), formed during a great mountain-building event known as the Laramide Orogeny (Karner 1989). The core of the Black Hills is made up of very old rocks, formed during the Precambrian and metamorphosed when two large continental blocks collided during part of the assembly of North America (Karner 1989). The initial uplift of the Black Hills occurred during the Paleocene, with the exposure of its ancient Precambrian core possibly dating to the late Eocene (Evans 1999). Erosion produced much of its present surface by the late Oligocene (Karner and Halvorson 1989a). Unlike today, eroding material was transported to the northeast. During the middle Cenozoic, more than 30 million years ago, a drainage divide ran east to west across Wyoming. DETO was on the north side of the divide, with drainage flowing to the Arctic Ocean. It is thought that a river ("Pumpkin Buttes River") flowed near where DETO is now situated (Seeland 1985).

Devils Tower was formed as part of a larger igneous event that occurred during the Paleocene and Eocene in the Black Hills–Bear Lodge Mountains area. It was one of 13 major igneous centers (Karner and Patelke 1989). Igneous activity in the northern Black Hills began approximately 58 Ma and moved west, with episodes at 55 to 54 Ma and 49.6 to 46 Ma. Devils Tower and the Missouri Buttes formed at about the same time during the most recent episode, with Devils Tower dated to 49.04 ± 0.16 Ma, and the Missouri Buttes dated to 49.24 ± 0.28 Ma (Duke et al. 2002). For such a well-known feature, the origin of Devils Tower is still not clear. Interpretations of Devils Tower include: a volcanic neck (Karner and Halvorson 1989b); part of a larger tabular igneous body that vented under the Missouri Buttes to the northwest (Karner and Halvorson 1989b); a sill (an intruding igneous body that follows preexisting bedding) (Karner and Halvorson 1989b); a laccolith (an igneous body similar to a sill but under enough pressure to cause doming) (Jaggar 1901; Karner and Halvorson 1989b); a stock (a small igneous body, not primarily horizontal like a laccolith or sill) (Robinson 1956); a volcanic conduit (Halvorson 1980); and an erosional remnant of lava and other volcanic rocks that filled a maar (a crater formed by groundwater flash-boiling on contact with a buried magmatic body) (Závada et al. 2015).

Wyoming landforms have been sculpted by various processes during the Neogene (23 Ma to the present, including the Miocene, Pliocene, Pleistocene, and Holocene), including uplift, faulting, the establishment of precursors to the modern drainage systems, and climate changes (Flanagan and Montagne 1993). Neogene uplift in the Black Hills region occurred near the Oligocene–Miocene boundary at 23 Ma and in a pulse beginning approximately 17 Ma and continuing to the Pleistocene (Steidtmann et al. 1989; Flanagan and Montagne 1993; Mears 1993). Downfaulting occurred in western Wyoming between 17 and 13 Ma (Flanagan and Montagne 1993). More recently, Devils Tower has been exposed in its present form by the action of the Belle Fourche River drainage system (Graham 2008).

During the past 12,000 years, the climate has shifted to a drier and warmer climatic regime compared to the cold late Pleistocene (Reider 1980), with a corresponding shift from tundra to grasslands (Walker and Frison 1980). During the Holocene there have been distinct regional dry periods from 7,500 to 5,400 years ago and 2,800 years ago to the present (Lyford et al. 2003). The Black Hills may have been an oasis of humidity during the dry episodes (Frison et al. 1976).

Geologic units exposed in DETO include, in ascending order (oldest to youngest), the Spearfish Formation (Permian–Triassic), the Gypsum Spring Formation (Middle Jurassic), the Sundance Formation (Stockade Beaver Shale, Hulett Sandstone, Lak, and Redwater Shale members, Middle–Upper Jurassic), "agglomerate" and the phonolite porphyry of Devils Tower (lower Eocene), talus (rock fragments surrounding cliffs and rock walls) and landslide deposits (shed during the Pleistocene and Holocene), and stream terrace deposits and alluvium (Pleistocene–Holocene) (Table 1) (Figure 3) (Robinson 1956; Graham 2008; Závada et al. 2015). A small outlier of the Morrison

Formation (Peck 1957) and ?Lakota Formation erosional residuum (Robinson 1956) have also been reported. Several of these formations are fossiliferous within DETO, including the Sundance Formation, the Morrison Formation outlier, the ?Lakota Formation residuum, and the “agglomerate” (Table 1). The Spearfish Formation and Gypsum Spring Formation are not known to be fossiliferous within DETO, but are potentially fossiliferous.

Table 1. Summary of DETO stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text and in Tweet et al. (2011).

Formation	Age	Fossils Within DETO	Depositional Environment
Quaternary rocks and sediments	Pleistocene–Holocene	None to date	Primarily deposition associated with the Belle Fourche River
Talus and landslide deposits	Post-early Eocene erosion	None to date	Primarily phonolite shed from Tower and Sundance Formation sandstone shed from bluffs
Phonolite of Devils Tower	early Eocene	Unfossiliferous	Not applicable (igneous)
“Agglomerate”	early Eocene, with components as old as Precambrian	Early Cretaceous? coal, Carboniferous-aged brachiopods, and other unspecified fossils from included clasts	Rock fragments of various ages entrained in volcanic matrix or as xenoliths in intrusive rocks
?Lakota Formation residuum	Early Cretaceous?	Petrified wood and tree roots	Fluvial and floodplain deposition
Morrison Formation	Late Jurassic	Charophytes	Fluvial, floodplain, lacustrine, etc.
Sundance Formation	Middle–Late Jurassic	Brachiopods, bivalves, belemnites, other marine invertebrates, vertebrates (most likely ray-finned fish), and bioturbation; likely isolated invertebrate burrows; possibly conifer fragments, ammonites, and vertebrate tracks	Shallow marine and coastal terrestrial, including tidal flats
Gypsum Spring Formation	Middle Jurassic	None to date	Coastal marine, tidal flat, and desert mudflat
Spearfish Formation	Permian–Triassic	None to date	Restricted marine to coastline terrestrial

Geologic Formations

Spearfish Formation (Permian–Triassic)

<u>Lithology</u>: Generally slope-forming red to maroon siltstone and sandstone, interbedded with mudstone or shale, with local greenish-blue shale partings (Figure 6). The upper contact with the Gypsum Spring Formation is unconformable. Outcrops can be seen in southern and northeastern DETO along the Belle Fourche River valley, forming brownish to maroon cliffs (Robinson 1956). Approximately the upper 30 m (100 ft) is exposed in DETO (Robinson 1956), out of an overall thickness of 450–600 m (140–180 ft) in the northern Black Hills region (Darton 1909).

Figure 6. The Spearfish Formation as viewed from the southeastern Red Beds Trail. More resistant beds can be seen interrupting the smooth profile of the eroding red hills. The overlying light-colored rocks belong to the Gypsum Spring Formation and the Stockade Beaver Shale Member of the Sundance Formation. On the right is the Belle Fourche River (NPS/JUSTIN TWEET).

The Spearfish Formation was deposited in various shallow marine and terrestrial settings. Various lithologies have been ascribed to certain depositional settings and conditions. For example, gypsum is interpreted as representing restricted marine or ephemeral lake deposition; siltstone is interpreted as low energy marine or lake deposition; limestone is interpreted as having been deposited under hypersaline water, with oil shale as hypersaline algal mats; and dolomite is interpreted as having been deposited on a sabkha (salt flat). These rock types also reflect changes in the depositional basin over time, as the marine waters of the shallow continental sea retreated, and the environment shifted from dominantly nearshore marine to salt flat to transitional terrestrial. Deposition occurred during the Permian and Triassic (Sabel 1984).

<u>Fossils found within DETO</u>: None to date, although fossils eroded from the overlying Sundance Formation are sometimes found as float (loose specimens) on Spearfish Formation outcrops.

Fossils found elsewhere: The Spearfish Formation is sparsely fossiliferous in general. To date, fossils reported from the formation include stromatolites and other microbial structures in limestone and oil shale beds, and bivalve casts and trace fossils in siltstone (Sabel 1984).

Gypsum Spring Formation (Middle Jurassic)

Lithology: White gypsum and lesser dark maroon mudstone, sometimes conspicuous between the underlying red Spearfish Formation and overlying gray-green shale of the lower Sundance Formation (Figure 6). The upper contact with the Sundance Formation is unconformable. The Gypsum Spring Formation crops out within DETO in a thin, nearly continuous band running around the Tower on its northeast to southwest sides. It is 4.6–11 m (15–35 ft) thick in DETO, with this variation due to erosion that occurred before the deposition of the Sundance Formation. The lower 3.6–6 m (12–20 ft) of the formation is primarily gypsum, with beds of red or darker brown mudstone appearing above this interval (Robinson 1956).

The Gypsum Spring Formation was deposited in marine and marine-adjacent settings (Wright 1974; Clement and Holland 2016; Danise and Holland 2018). It is divisible into informal lower, middle, and upper members. In the northwestern Black Hills, the lower and upper members are truncated, so the middle member makes up most of the formation. The lower and upper members primarily represent desert mudflat deposition in the northwestern Black Hills, but the middle member includes the shallow end of the marine carbonate ramp of the Sundance Seaway, with subtidal and peritidal deposition, and more terrestrial settings to the south (Danise and Holland 2018). The climate has been interpreted as at least seasonally arid (Kvale et al. 2001). Deposition occurred during the middle Middle Jurassic, primarily in the Bajocian Age (Imlay 1980; Danise and Holland 2018), between approximately 170.3 and 168.3 Ma.

Fossils found within DETO: None to date; a sparse, low-diversity fauna of mostly bivalves and gastropods is possible in subtidal rocks (S. Holland, University of Georgia, pers. comm., July 2019).

Fossils found elsewhere: The Gypsum Spring Formation is sparsely fossiliferous in general. Some reports of Gypsum Spring Formation fossils from the vicinity of DETO (Imlay 1947) instead appear to have come from the overlying Sundance Formation (Mapel and Bergendahl 1956). The nearest known fossil-bearing locality is about 24 km (15 miles) northeast of DETO, where ostracodes ("seed shrimp") have been reported from the upper part of the formation (Mapel and Bergendahl 1956; Robinson et al. 1964).

Sundance Formation (Middle–Upper Jurassic)

Lithology: In general, alternating "greenish-gray shale, light-gray to yellowish-brown sandstone and siltstone, and gray limestone" (Robinson 1956). Of the five members of the Sundance Formation defined by Imlay (1947), the upper four are mapped within DETO, in ascending order the Stockade Beaver Shale Member, the Hulett Sandstone Member, the Lak Member, and the Redwater Shale Member (Robinson 1956).

The Stockade Beaver Shale Member, the lowest member, is a poorly exposed shale unit approximately 26–31 m (85–100 ft) thick. The lower and upper halves of the member are slightly different. At the very base is a conglomeratic sandstone bed 3–61 cm (1–24 in) thick featuring dark chert pebbles. Above this, the rest of the lower half is primarily gray-green shale with local limy sandstone, impure limestone, and thin beds of red siltstone. The upper half is composed of dark-gray to gray-green shale with beds of fine-grained limy sandstone 0.3–2 m (1–6 ft) thick. Within DETO, the lower part is best exposed on the hill at the east boundary and on the steep slope south of the Tower (Figure 7), and the upper part is best exposed on the south side of the ridge north of the Tower. The upper contact with the Hulett Sandstone Member is gradational, and is placed where sandstone first composes more than 50% of the rocks (Robinson 1956).

Figure 7. Thin gray beds of the Stockade Beaver Shale Member south of the Tower have been protected from erosion by fallen blocks of the Hulett Sandstone Member (not visible in this photo) (NPS/JUSTIN TWEET).

The overlying Hulett Sandstone Member is the most visible of the four members in DETO. Its resistant rocks form a cliff around the Tower (Figure 8). This member is mostly made up of massive fine-grained glauconitic (rich in the green mineral glauconite) limy sandstone, generally yellow or brownish yellow with local pink and red beds. Thin partings of gray to greenish-gray shale are found in the lower part of the member, part of the transition from the Stockade Beaver Shale Member. The uppermost beds of the Hulett Sandstone Member are also locally shaly, as the member grades into the overlying Lak Member. Overall, the Hulett Sandstone Member is generally 18–21 m (60–70 ft) thick (Robinson 1956).

Figure 8. A bluff of the Hulett Sandstone Member along the Red Beds Trail (NPS/JUSTIN TWEET).

The Lak Member also contains a significant amount of sandstone, but it is not as resistant to erosion as the Hulett Sandstone Member and thus is not as well exposed. Within DETO it is best exposed on the steep hill east of the Tower and northwest of the bridge over the Belle Fourche River. It is generally about 14 m (46 ft) thick in the area, locally up to about 20 m (65 ft) near the Tower. It is mostly made up of yellow to yellowish brown, intergrading, very-fine-grained limy sandstone and siltstone (Figure 9), with a few thin partings of gray-green shale and a few thin resistant sandstone beds near the base and top of the member (Robinson 1956). Robinson (1956) was only able to find the contact with the overlying Redwater Shale Member at one place in DETO, and he did not offer an interpretation of the type of contact. The contact is reported as disconformable elsewhere (Imlay 1947; Kvale et al. 2001).

Figure 9. A heavily eroded exposure of the Lak Member (NPS/JUSTIN TWEET).

Finally, the uppermost member of the Sundance Formation at DETO is the Redwater Shale Member. It is generally poorly exposed in the monument; it is a non-resistant unit, and over most of the area where it might otherwise be visible it is covered by vegetation or talus (Robinson 1956). Robinson (1956) could not identify a complete section within DETO, and so could not determine a complete thickness, but found it to be at least 30 m (100 ft) thick on the hill in northwestern DETO. A complete section would be significantly thicker, perhaps 46–58 m (150–190 ft) thick (Robinson 1956). The member is primarily composed of light gray to dark gray-green shale in DETO, with some yellow soft sandstone in the lower 6–9 m (20–30 ft), and lenticular beds of fossiliferous limestone in the upper half of the DETO section (Figure 10). There is a possibility that some of the basal Redwater Shale Member of DETO as described by Robinson (1956) belongs to a different unit of the Sundance Formation, the Pine Butte Member of Pipiringos (1968), as implied in Rautman (1978), but a formal division has not been made.

The Sundance Formation is a marine and coastal terrestrial unit, with multiple marine advances and retreats (Danise and Holland 2017, 2018). The Stockade Beaver Shale Member of the DETO area is interpreted as a marine offshore transitional unit with occasional shell beds, while the overlying Hulett Member is interpreted as a shoreface sandstone, both units being part of an open shelf setting (Danise and Holland 2018). The Lak Member is primarily terrestrial in origin, and appears to have been deposited by dryland rivers within a desert in the DETO area (Danise and Holland 2018). Finally, the Redwater Shale Member is an open marine unit (Danise and Holland 2018), deposited under deeper water than the Stockade Beaver Shale Member (Wright 1974). The climate was at least seasonally arid (Kvale et al. 2001), but not as arid as what prevailed during deposition of the Gypsum Spring Formation (Danise and Holland 2018). A belemnite from DETO was subjected to isotopic analysis to determine paleotemperature, and returned a value of 19.6 °C (67.3 °F) (Bowen 1961).

Figure 10. Remnants of a ledge of Redwater Shale Member limestone (NPS/JUSTIN TWEET).

The Sundance Formation was deposited during the Middle and Late Jurassic, from the late Bathonian to the middle Oxfordian in the DETO area (Imlay 1980; Danise and Holland 2018), between approximately 167 and 160 Ma. Faunal zones reported from the Redwater Shale Member (Imlay 1947, 1980) indicate it was deposited during the early and early middle Oxfordian (approximately 163–160.5 Ma). Presumably only an older fraction of this range is represented at DETO due to stratigraphic incompleteness.

Fossils found within DETO: All of the Sundance Formation members appear to be fossiliferous within DETO. The majority of the fossils come from the Redwater Shale Member. Jaggar (1901) reported a shell bed in rocks that can be assigned to the Stockade Beaver Shale Member. Racay and Tweet found a single well-defined small bivalve in float from this unit or the Hulett Sandstone Member (Figure 11A), as well as what may be a small accumulation of shell fragments and a possible example of conifer foliage (Figure 11B), and they observed several thin bivalve-bearing stones lying as float on Spearfish Formation outcrops (Figure 12). These were thinner than the bivalve-rich blocks seen in the Redwater Shale Member and could have easily descended from an original position in the Stockade Beaver Shale up-slope. The float site is similar to the belemnite locality reported in Holbeck (1996), in which a small deposit of belemnites had been found near the main road; the bedrock at this place is the Spearfish Formation, but the belemnites are thought to have been eroded from the Stockade Beaver Shale Member (Holbeck 1996). Tweet was unable to relocate this site, but is of the opinion that similar sporadic occurrences of displaced Sundance Formation fossils are likely present throughout DETO. At a different site, another small well-preserved bivalve was found on a float chip most likely from the Stockade Beaver Shale Member, with a chance of being from the Hulett Sandstone Member.

Rautman (1978)'s stratigraphic column for Devils Tower identified the lower Hulett Sandstone Member as bioturbated. Tweet observed probable simple invertebrate burrows in outcrops of the bluff-forming portion of the member (Figure 13). Racay showed Tweet possible sauropod dinosaur tracks in a massive fallen block of this member.

Racay and Tweet found abundant belemnites and a bivalve fragment at one locality in the Lak Member, and Tweet later observed belemnites at the surface at a similar area of exposures. Other exposures were checked but did not prove to be fossiliferous. Steven Holland is skeptical that any unit at DETO other than the Redwater Shale Member produces belemnites, and proposes that either the fossils had been transported from the Redwater Shale Member or the observed unit is not the Lak Member (pers. comm., July 2019). Because there is no evidence that Robinson (1956) mapped the units incorrectly, and none of the observed fossils were definitely in situ, the first explanation is preferred here.

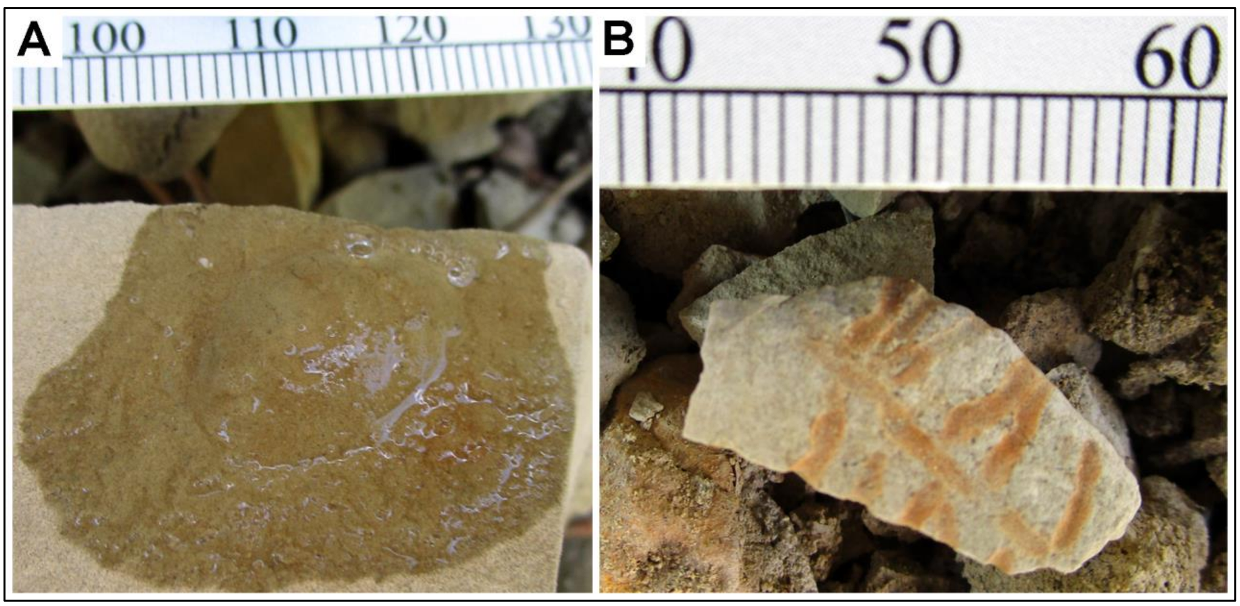

Figure 11. Fossils and possible fossils in float attributed to the Stockade Beaver Shale Member of the Sundance Formation (NPS/JUSTIN TWEET). A. A bivalve cast highlighted by moisture. B. Possible conifer foliage. The scale bar used by Tweet throughout this report is metric, measuring in cm (numbers and checkered squares) and mm (tick marks).

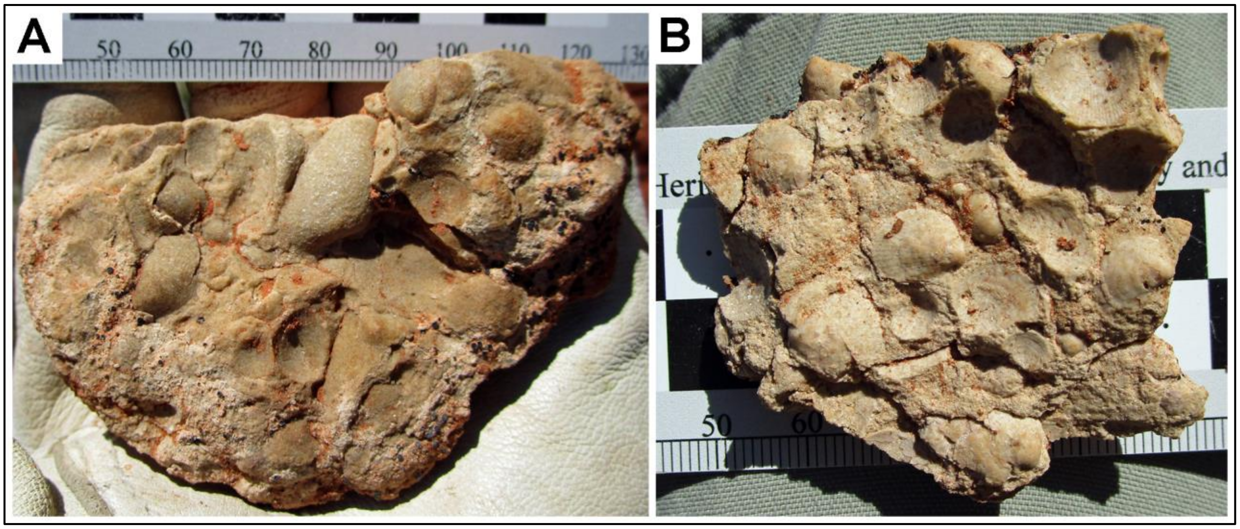

Figure 12. Two examples of bivalve-bearing cobbles found as float on the Spearfish Formation, most likely eroded from the Stockade Beaver Shale Member (NPS/JUSTIN TWEET).

Figure 13. A probable invertebrate burrow exposed in relief on a Hulett Sandstone Member face (NPS/JUSTIN TWEET).

The Redwater Shale Member is the most fossiliferous member. Jaggar (1901) recognized several fossiliferous horizons in rocks that can be attributed to the Redwater Shale Member, including an oyster bed, a bed of shells of the bivalve *Tancredia*, and a belemnite shale layer. The DETO belemnite specimen used for Bowen (1961) is a specimen of *Pachyteuthis densus*. Robinson and Davis (1995) observed the presence of *Ostrea* sp. (an oyster). Based on Racay's and Tweet's observations, bivalves are extremely abundant in some beds, which can be largely composed of these fossils. They appear to be mostly natural molds and casts, with some original shell material remaining. Belemnites are generally not found in the bivalve shell horizons, and were almost entirely found as incomplete loose specimens, presumably having weathered out of finer-grained rocks than the more resistant bivalve-rich horizons. The faunal difference suggests that bivalves and belemnites pertain to different depositional facies.

The vertebrate specimen discovered by Racay appears to be from the Redwater Shale Member as well. Pagnac and Welsh (2018) did not assign the locality to a member of the formation due to lack of suitable outcrops for comparative purposes, but the bivalve-rich rocks match those assigned to the Redwater Shale Member by Robinson (1956), and the only unit mapped in the discovery area by Robinson is the Redwater Shale Member. A shell bed approximately 2.0–3.0 cm (about 1 inch) thick is found on the same block as the bones. The vertebrate remains may pertain to a bony fish or, possibly, a juvenile marine reptile (Pagnac and Welsh 2018). Additional undiagnostic bone fragments can be seen on other nearby blocks. Racay also noted the presence of brachiopods, clams, and belemnites at the site.

Graham (2008) reported that 1997 excavations for a sewage disposal system yielded belemnite fossils from below the surface. These fossils, whether they were in situ or displaced, almost certainly came from the Sundance Formation, based on the known productivity and fossil assemblages of the other formations of DETO. The purported dinosaur bone recovered from the future Red Beds Trail (Rogers 2007), if indeed a fossil bone, could have easily been a bone from a Sundance Formation marine reptile.

<u>Fossils found elsewhere</u>: Of the four Sundance Formation members identified from DETO, the Stockade Beaver Shale Member and the Redwater Shale Member have yielded the greatest quantity and diversity of fossils outside of DETO.

The Stockade Beaver Shale Member is fossiliferous across its depositional area, although it is less fossiliferous in the northern part of the Black Hills than it is in the south (Imlay 1947; Herrick and Schram 1978). Its faunal assemblage includes foraminifera (“amoebas with shells”) (Loeblich and Tappan 1950a), bryozoans (Wright 1973), brachiopods, bivalves, ammonite and belemnite cephalopods (Imlay 1947), ostracodes (Wright 1974), decapod crustaceans (crabs, lobsters, and allies) (Herrick and Schram 1978; Feldmann 1979), ophiuroids (brittle stars) (Pipiringos 1957; Massare et al. 2014), crinoids (“sea lilies”) (Imlay 1947), marine invertebrate trace fossils such as burrows (Wright 1973) and borings (Conroy et al. 2002), sharks, and several types of bony fish (Schaeffer and Patterson 1984). Some surfaces in the upper third of the member near Hulett have evidence of encrusting animals (foraminifera, bryozoans, and polychaete worms) and boring bivalves (Conroy et al. 2002).

The fossil assemblage of the Hulett Sandstone Member includes foraminifera (Loeblich and Tappan 1950b), bivalves, crinoids (Imlay 1947), and invertebrate trace fossils (Picard 1993; Rautman 1975, 1978), with pellets and fossil fragments found throughout (Stone and Vondra 1972). The Lak Member has reportedly so far only yielded belemnites (Karner and Halvorson 1989b; but see discussion above about potential Lak belemnites at DETO) and possible invertebrate trace fossils (Picard 1993).

The Redwater Shale Member is the most heavily fossiliferous member. Invertebrates are abundant, and marine vertebrates are occasionally found (O'Keefe and Street 2009). Fossils are sufficiently abundant to form local coquina (shell hash)-like layers (Imlay 1947; Brenner and Davies 1973), as seen at DETO. Marine invertebrate remains may have been concentrated by storm events (Brenner and Davies 1973; Specht and Brenner 1979). The invertebrate fossil assemblage of the Redwater Shale Member includes foraminifera (Loeblich and Tappan 1950b), brachiopods (Brenner and Davies 1973), bivalves, ammonite (particularly *Cardioceras*) and belemnite cephalopods (Imlay 1947), gastropods (Specht and Brenner 1979), lobsters (Massare et al. 2014), ostracodes (Swain and Peterson 1951, 1952), asteroids (sea stars) (Blake 1981), crinoids, echinoids (sea urchins) (Specht and Brenner 1979), polychaete worm tubes (including "scaphopods" per Palmer et al. 2004), and invertebrate trace fossils (Specht and Brenner 1979). Vertebrates known from the member include sharks, bony fishes, the superficially dolphin-like ichthyosaur *Ophthalmosaurus* (formerly known as *Baptanodon*), the small long-necked plesiosaurs *Pantosaurus* and *Tatenectes*, the pliosaur (short-necked and large-skulled plesiosaur) *Megalneusaurus* (Massare et al. 2014), and indeterminate reptile bones (Specht and Brenner 1979). Several of the marine reptile specimens have remnants of food items in their guts, showing that belemnites were the primary prey (Massare et al. 2014).

Morrison Formation (Upper Jurassic)

<u>Lithology</u>: Limestone and shale (Peck 1957). The only known report of the existence of the Morrison Formation within DETO comes from Peck (1957), who reported finding a small outlier of Morrison Formation limestone and shale near the tower. Such an outlier was not mapped in Robinson (1956), at a scale of 1:4,800, although it could have been too small to map. Alternatively, because of the reported proximity to the Tower, it could be difficult to find amid the talus. It could also be a large block of erosional residuum rather than an in situ outcrop as "outlier" implies, or it could have been lost to erosion or concealed by vegetation. Turner et al. (1998) briefly mentioned DETO without detail in their final report on the Morrison Formation Extinct Ecosystems Project; DETO's inclusion may have been based on Peck's report. George Engelmann (University of Nebraska–Lincoln) did not visit DETO to look for the Morrison Formation during the project and did not recall that anyone else had done so (pers. comm., July 2019). Several stratigraphic sections of the Morrison Formation in the vicinity can be found in Mook (1916).

The more recent but larger-scale map by Sutherland (2008) maps part of extreme northwestern DETO as the Morrison Formation, corresponding to an area mapped as the Redwater Shale Member by Robinson (1956). Sutherland (2008) used Robinson (1956), Mapel et al. (1959), and Robinson et al. (1964) as source maps for the DETO area. Neither Robinson (1956) nor Mapel et al. (1959) mapped the Morrison Formation anywhere within DETO, but Robinson et al. (1964) did, based on an unpublished map from 1923. It is unclear why Robinson et al. (1964) did not instead use Robinson's own 1956 map, which was more recent and is by far the most detailed map of DETO. Thirty years later, Robinson did not include any report of the Morrison Formation within DETO in Robinson and Davis (1995). At any rate, Sutherland (2008) appears to have used the 1964 map and its anomalous Morrison Formation for DETO, which was translated into the Geologic Resources Division map of the monument. Racay and Tweet observed no Morrison Formation in northwestern DETO.

The Morrison Formation is a terrestrial unit. The climate of the Morrison Formation is thought to have been semi-arid and seasonal, like the African savanna (Engelmann et al. 2004; Hasiotis 2004), with conditions becoming more humid higher in the formation (Parrish et al. 2004). Deposition of the formation dates to the middle Late Jurassic, between approximately 155 and 148 Ma (Foster 2007).

Fossils found within DETO: Charophytes (Peck 1957); if the purported dinosaur bone mentioned in Rogers (2007) indeed came from a dinosaur and not another large extinct animal, a detrital Morrison Formation origin is perhaps the most likely possible origin.

Fossils found elsewhere: The Morrison Formation has one of the best terrestrial fossil records of the Mesozoic. There are several recent enumerations of its fossils: Chure et al. (2006) listed all taxa known to that time, Foster (2003, 2007) detailed the vertebrate assemblages, and Foster (2003) included quarry-level lists of vertebrates. Microbial, fungal, or photosynthetic organisms and traces represented in the Morrison Formation include stromatolites, fungi (both body and traces), charophyte algae, bryophytes (mosses and relatives), horsetails, ferns, pteridosperms (seed ferns), cycads, bennettitales, ginkgoes, czekanowskiales, and conifers (Ash and Tidwell 1998; Chure et al. 2006), along with palynomorphs (organic microfossils such as pollen and spores) of rhodophytes (red algae), mosses, lycopsids (clubmosses), ferns, cycads, bennettitales, conifers, gnetales, and unknown plants (Dodson et al. 1980; Tschudy et al. 1980, 1981, 1988a, 1988b; Chure et al. 2006), as well as a variety of plant debris, root casts, indeterminate wood, and seeds (Chure et al. 2006). Invertebrates represented by body fossils include sponges, gastropods, unionid bivalves, conchostracans, ostracodes, and crayfish (Chure et al. 2006). Many other invertebrates are known from traces, including numerous insect groups not yet known from body fossils. Invertebrate trace fossils have been attributed to anthozoans (corals and anemones), brachiopods, gastropods, bivalves, nematodes, annelids, horseshoe crabs, mayflies, orthopterans (grasshoppers, crickets, and locusts), caddisflies, hemipterans (aphids, cicadas, and relatives), flies, beetles, hymenopterans (ants, bees, and wasps), termites, decapod crustaceans, and echinoderms (Hasiotis 2004; Chure et al. 2006). Vertebrates known from body fossils in the Morrison Formation include several varieties of early ray-finned fish like bowfins, lungfish, frogs, salamanders, turtles, sphenodontians (tuatara), lizards, possible snakes, the lizard-like aquatic reptile *Cteniogenys*, terrestrial crocodylomorphs and other extinct crocodile relatives, long-tailed and short-tailed pterosaurs, multiple large (such as *Allosaurus*, *Ceratosaurus*, and *Torvosaurus*) and small (such as *Ornitholestes*) theropods, diverse sauropods (generalized, stocky like *Camarasaurus*, elongate like *Diplodocus*, or long-limbed and long-necked like *Brachiosaurus*), plated dinosaurs such as *Stegosaurus*, armored dinosaurs, bipedal herbivorous dinosaurs (such as *Camptosaurus* and *Dryosaurus*), and triconodont, docodont, multituberculate, and symmetrodont mammals (Foster 2003, 2007; Chure et al. 2006). Tracks are known from most of these groups as well, as well as coprolites (fossil feces) of herbivorous dinosaurs and mammal burrows (Chure et al. 2006). Finally, eggshells from the Morrison Formation have been attributed to turtles, crocodile relatives, and dinosaurs (Hirsch 1994; Bray and Hirsch 1998; Chure et al. 2006).

A handful of fossil sites are known from the Morrison Formation of Crook County (Peck 1957; Sohn 1958; Sohn and Peck 1963; Foster and Martin 1994; Turner and Peterson 1999; Bader 2003; Foster 2003; Foster and Chure 2006; Foster and Lockley 2006; Foster et al. 2006). Deposition at these sites occurred in river, swampy floodplain, dry floodplain, and lake settings (Foster and Martin 1994). The fossil assemblage from the Crook County sites includes charophytes (Peck 1957; Foster and Martin 1994), cycad cones, conifer material (Bader 2003), bivalves, gastropods (Foster and Martin 1994), ostracodes (Sohn 1958; Sohn and Peck 1963), ray-finned fish, lungfish, frogs, salamanders, turtles, sphenodontians, lizards and lizard-like aquatic reptiles, crocodile relatives, the carnivorous dinosaur *Allosaurus*, several sauropod dinosaurs including *Apatosaurus*, *Camarasaurus*, and *Diplodocus*, the plated dinosaur *Stegosaurus*, several taxa of beaked dinosaurs including *Camptosaurus*, and several taxa of early mammals (Foster 2003). The best references for Morrison Formation sites in Crook County are Foster and Martin (1994) and Foster (2003).

?Lakota Formation residuum (Lower Cretaceous?)

Lithology: Medium-grained brownish white sandstone and apparently highly silicified gray or white fine-grained quartzite, found in angular blocks ranging from centimeter-scale to meter-scale (inch-scale to foot-scale) in diameter (Robinson 1956). These rocks are mapped in two patches north of the Tower (Robinson 1956). Tweet observed several patches of cobbles dominated by whitish quartzite with lesser quantities of less strongly silicified white sandstone (Figure 14). Robinson (1956) suggested that these rocks are residuum from the Lakota Formation, a Cretaceous unit known to be found about 61 m (200 ft) higher in section than the Redwater Shale near DETO. Jaggar (1901) mentioned the presence of a white fine-grained quartzite just northwest of the Tower, which could be another example of the residuum. Racay and Tweet observed anomalous cm-scale (in-scale) blocks of yellowish sandstone in northwestern DETO that may also be fragments of Lakota residuum, although there is the possibility that this material is Morrison Formation residuum instead.

Figure 14. An example of quartzite found on the Red Beds Trail (NPS/JUSTIN TWEET).

The Lakota Formation in the vicinity of DETO is mostly composed of sandstone, with some beds of coarser or finer material (Darton and O'Harra 1907; Graham 2008). In neighboring Weston County to the south, it is a point bar and floodplain unit (Rich et al. 1988). It dates to the early Early Cretaceous (Sames et al. 2010).

Fossils found within DETO: Jaggar (1901) reported the presence of silicified wood and abundant tree roots in quartzite. The lithology and types of fossils are suggestive of the Lakota Formation. Most of the material observed by Tweet was very strongly silicified and lacked fossils, but one piece of sandstone appeared to include a small-diameter U-shaped burrow, with one limb in planar cross-section and the other in longitudinal cross-section (Figure 15).

Figure 15. The vertical feature near the left of the photo appears to be one limb of a U-shaped burrow (NPS/JUSTIN TWEET).

Fossils found elsewhere: In the Devils Tower 30' x 30' quadrangle, the Lakota Formation has yielded coal, petrified cycad stems, and fern and conifer fossils (Darton and O'Harra 1907). Reworked Paleozoic marine invertebrates (Graham 2008) and Sundance Formation belemnites (Waage 1959) may also be found.

Other types of plant fossils reported from this formation include fern spores (Gott et al. 1974), carbonized plants (Darton 1909), abundant petrified wood (Darton 1904), ginkgoes, cycads, and cycadeoids (Cahoon 1960). Invertebrates are represented by freshwater bivalves, gastropods (Connor 1963), conchostracans ("clam shrimp"), isopods (pill bugs and allies), and ostracodes (Darton 1909). Finally, vertebrates are represented by sharks (Cicimurri 1996), *Lepidotes* or a similar bony fish (Gregory 1924; Weishampel and Bjork 1989), the gar *Lepisosteus*, turtles, crocodile relatives (Darton 1904), a small assemblage of dinosaurs (Weishampel et al. 2004), early mammals (Cifelli et al. 2014), and tracks of theropod dinosaurs, ornithopod dinosaurs, and birds (Lockley et al. 2001). The dinosaurs include unnamed theropods and sauropods, the armored dinosaur *Hoplitosaurus*, a small beaked herbivore ("*Hypsilophodon wielandi*"), and two larger ornithopods, *Osmakasaurus depressus* (originally named *Camptosaurus depressus*) and *Dakotadon lakotaensis* (originally *Iguanodon lakotaensis*) (Weishampel et al. 2004).

“Agglomerate” (?lower Eocene, with Precambrian to Cretaceous components)

A type of rock known variously as “agglomerate” (Jaggar 1901; Effinger 1934), “alloclastic breccia” (Halvorson 1980), and “volcaniclastic deposits” (Závada et al. 2015) is exposed in at least one small area near the Tower. The site was described by Jaggar (1901) as a “small rounded grassy hill strewn with rounded subangular or irregular fragments of granite, limestone, Jurassic sandstone, Cambrian quartzite and glauconitic sandstone, purplish rhyolite, a little slate or schist, black shale of two varieties, flint, and coarse pegmatite[.]” Tweet walked through part of the area indicated by Jaggar but was unsuccessful in finding the exposure. Závada et al. (2015) placed “volcaniclastic deposits” in this area, but the exact position is unclear due to the large scale of the map. The rock fragments are entrained in a volcanic matrix; the matrix is heavily weathered, so the rock fragments have generally weathered free (Halvorson 1980). The “agglomerate” was originally interpreted as xenolith-rich intrusive rocks (xenoliths are pieces of host rock incorporated into igneous bodies without being destroyed). Later, a volcanic origin was postulated (Halvorson 1980; Závada et al. 2015). Under the maar diatreme–lava coulée hypothesis of Závada et al. (2015), the “agglomerate” represents pyroclastic debris produced in a maar eruption (a type of eruption that occurs when groundwater contacts magma or lava, and turns to steam), subsequently buried when lava filled the maar crater and later exposed by the erosion that sculpted the Tower.

<u>Fossils found within DETO</u>: Jaggar (1901) reported a fossiliferous Carboniferous limestone boulder with a “baked” outer shell. This boulder included Carboniferous spiriferid brachiopods and other, unspecified fossils. The fossiliferous Madison Group (also known in the Black Hills as the Pahasapa Limestone, as in Jaggar 1901 and Závada et al. 2015), widely distributed in the Black Hills and of appropriate age and lithology, is the most obvious candidate for the original source. The boulder would have been brought to the surface via an explosive eruption (the maar of Závada et al. 2015). Halvorson (1980) also reported finding coaly shales, perhaps of Early Cretaceous age.

<u>Fossils found elsewhere</u>: Because this is such a localized unit and all of its fossils are originally from other units, comparisons are of limited value.

Phonolite of Devils Tower (lower Eocene)

<u>Lithology</u>: Phonolite porphyry, light- to dark-gray or greenish gray groundmass with cm-scale (in-scale) white feldspar crystals and smaller dark green pyroxene crystals when fresh, weathering to light gray or brownish gray (Robinson 1956) (Figures 1 and 16). “Phonolite” is a type of volcanic rock of intermediate composition (primarily feldspar minerals), and “porphyry” is a textural term referring to the presence of visible crystals in a groundmass of much smaller indistinguishable crystals. The outstanding visual characteristic of the phonolite of the Tower is the presence of polygonal vertical columns, usually five-sided, with some examples bearing four or six sides. The columnar jointing also provides a means for frost wedging and other erosive processes to “pry out” columns over time; the talus field surrounding the Tower is the result of this weathering. Because this is a paleontological resources report, it is not intended to be comprehensive regarding the topic of the famous phonolite.

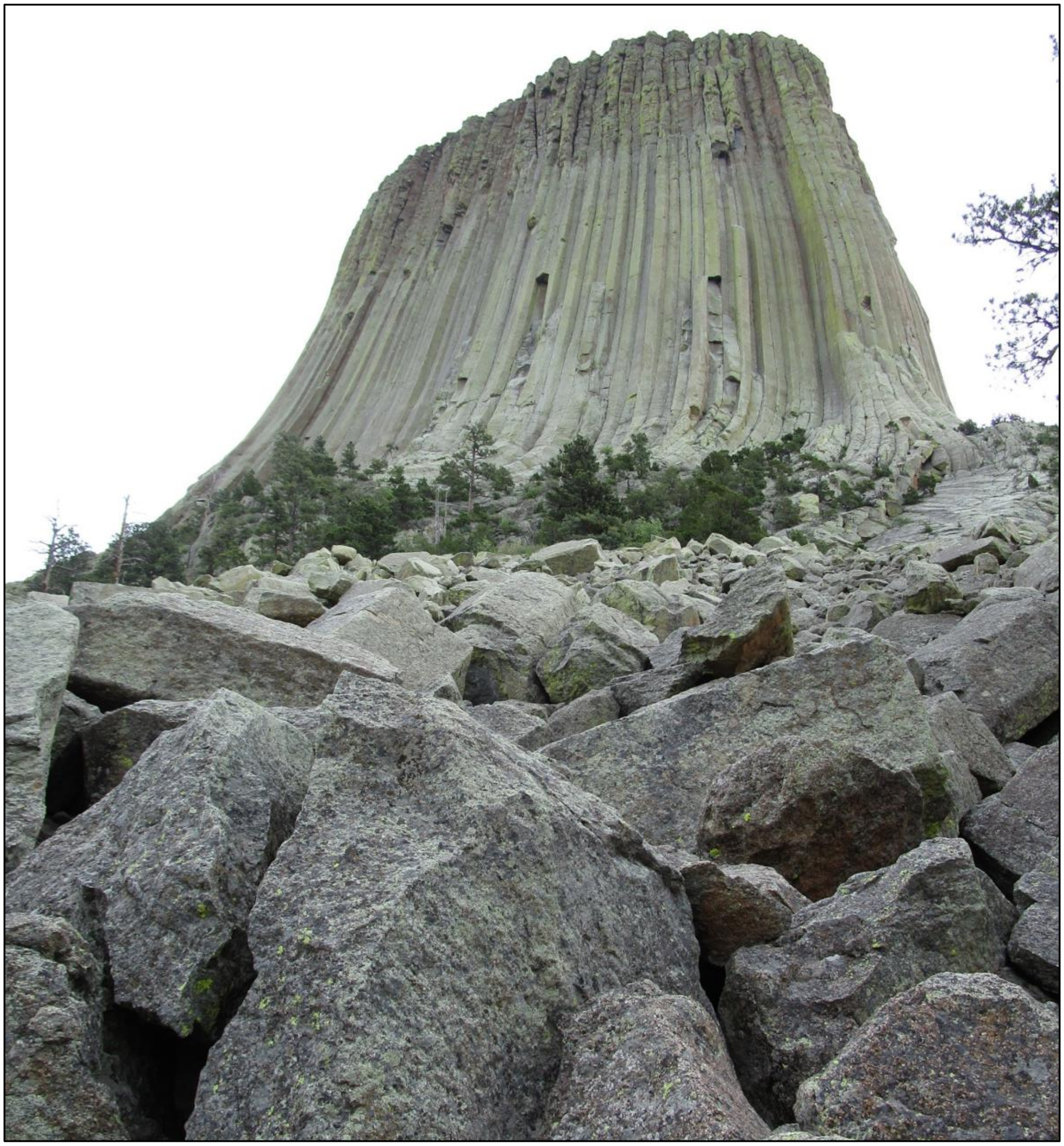

Figure 16. The phonolite of Devils Tower has been shed as vast amounts of talus (NPS/JUSTIN TWEET).

Fossils found within DETO: Fossils are not present within the igneous rocks.

Fossils found elsewhere: This unit is found only within DETO.

Talus and landslide deposits (produced by post-phonolite erosion)

Lithology: Varies. The talus and landslide deposits of DETO are primarily made of rocks shed from Devils Tower or resistant beds of the Hulett Sandstone Member of the Sundance Formation. The igneous talus comes from the columns of the Tower and includes pieces more than 2 m (8 ft) in diameter and 7.6 m (25 ft) long (Figure 16). The sandstone typically takes the form of rectangular blocks shed from the Hulett Sandstone cliffs, centimeter-scale to meter-scale (inch-scale to foot-scale) in largest dimension. Generally the igneous talus is found near the Tower and the sandstone talus is found farther out, but in some places the igneous talus overlaps the sandstone talus (Robinson 1956). “Agglomerate,” which is sometimes included with these units, is described separately because it has a much different origin.

<u>Fossils found within DETO</u>: The igneous talus is unfossiliferous. Sedimentary landslide deposits may include such fossils as are found in the contributing formations, as well as float fossils from overlying units.

<u>Fossils found elsewhere</u>: Talus is local, so comparisons to other talus deposits elsewhere are not as useful as knowing the kinds of fossils that are present in formations that contribute to talus within DETO.

Quaternary rocks and sediments (Pleistocene–Holocene)

<u>Lithology</u>: Unconsolidated mud-sized to gravel-sized clasts in stream alluvium, and sand and gravel in terrace deposits northwest of the Belle Fourche River. Undifferentiated terrace deposits and alluvium are mapped around drainage in DETO, especially in the floodplain of the Belle Fourche River in the eastern and southeastern areas of the monument (Robinson 1956).

<u>Fossils found within DETO</u>: None to date, although another possible source for the mysterious “Red Beds Trail bone” mentioned in Rogers (2007) is a Pleistocene mammal. Fossils eroded from other units may become incorporated into these sediments as well.

<u>Fossils found elsewhere</u>: Quaternary fossils often fall into one of two general categories: Pleistocene megafauna and late Pleistocene–Holocene paleoenvironmental materials. Pleistocene megafaunal fossils include remains of various large extinct mammals, such as extinct horses, mastodons and mammoths, and giant bison. Paleoenvironmental fossils, such as pollen, spores, aquatic microfossils, and packrat middens, are used as proxies for climates of the recent past. In the immediate vicinity of DETO, approximately 40 km (25 mi), the Quaternary record appears to be limited to vertebrates from the Holocene. These include: a site with early Holocene bighorn sheep and bison bones between 18 and 21 km (11 and 13 mi) south of DETO on the Belle Fourche River (FaunMap 2019a); the McKean archeological site, from the vicinity of the Keyhole Reservoir over 22 km (14 mi) south of DETO (Mulloy 1954), with a variety of animal remains from the late middle Holocene, including unspecified mollusks, fish, amphibians, reptiles, and birds, rodents, rabbits, foxes and other canids, sheep, bison, pronghorns, deer, and elk (FaunMap 2019b); and a middle Holocene bison trap/butchering site known as the Hawken site, approximately 40 km (25 mi) south-southeast of DETO, which also has wolf, mule deer, and pronghorn bones, as well as hearth charcoal and bone tools (Frison et al. 1976). The only well-documented Pleistocene site within approximately 100 km (60 mi) of DETO is the Carter/Kerr-McGee or Carter/McGee site, 62 km (39 mi) southwest of DETO, which has evidence of late Pleistocene camel and early Holocene bison butchering by humans (Frison et al. 1978; Reider 1980).

Taxonomy

See Appendix A for complete lists of fossil taxa from DETO.

Fossil Plants

There are several reports of fossil plants from DETO. Interestingly, each of the formations represented by outliers or residuum have yielded plant fossils. Jaggar (1901) recognized silicified wood and tree roots in quartzite blocks that seem most likely to be examples of the possible Lakota Formation residuum described by Robinson (1956). Peck (1957) described a small assemblage of charophytes (freshwater green algae) from microfossils found at a Morrison Formation outlier near the Tower (Figure 17). Finally, Halvorson (1980) reported finding coaly rock fragments in the "agglomerate," and he suggested that they came from Lower Cretaceous formations. During the 2019 visit, Tweet observed possible conifer foliage in a chip from the Stockade Beaver Shale Member of the Sundance Formation (Figure 11B).

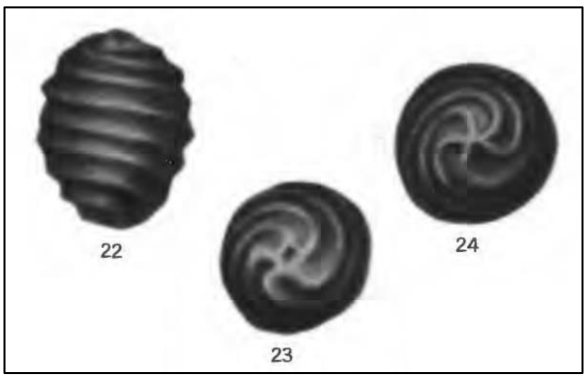

Figure 17. DETO charophyte gyrogonites (fossil casts of charophyte female reproductive structures) illustrated in Plate 27:22–24 of Peck (1957), at approximately 60x natural size. All are examples of *Praechara voluta*. 22. "Lateral view of gyrogonite. USGS type algae 459"; 23. "Basal view of gyrogonite. USGS type algae 460"; 24. "Summit view of gyrogonite. USGS type algae 261." As figured specimens, they may be USNM (National Museum of Natural History) 347559, USNM 347577, and USNM 347578.

Fossil Invertebrates

The great majority of fossils reported from DETO are marine invertebrates from the Sundance Formation, in particular the Redwater Shale Member. Most reported or observed fossils are bivalves or belemnites. In some cases, a report has been made of fossils without specifying the type of fossil beyond "shells." Jaggar (1901) observed a shell bed in a unit that appears to belong to the Stockade Beaver Shale Member of the Sundance Formation, and Graham (2008) reported unspecified shells in the Redwater Shale Member; neither report is tied to a specific location in the monument.

Phylum Brachiopoda (lamp shells)

Brachiopods, like bivalve mollusks, have two shells. Fossils of the two groups can be difficult to distinguish, but in a brachiopod the two shells generally have different shapes and sizes, while bivalve shells are often mirror images. This is because brachiopod shells are upper and lower structures, so the plane of bilateral symmetry runs through each shell, while bivalve shells are left and right structures, so the plane of bilateral symmetry runs on the hinge line of the shells. Brachiopods were most abundant in the Paleozoic, but still exist today. Jaggar (1901) recognized Carboniferous-age spiriferid brachiopods in a limestone boulder weathered from the "agglomerate," brought up from the subsurface by igneous action. Racay observed brachiopods at the Sundance Formation vertebrate site, which he described to Tweet as of a linguloid type (calcium phosphate shell with a "fingernail"-like texture and appearance).

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

Because they are found in shell beds (Figure 18), bivalves are easily the most abundant type of fossils in DETO. Reports of bivalves at DETO go back to Jaggar (1901), which mentioned the presence of a *Tancredia* shell bed and an oyster shell bed in rocks that can be recognized as belonging to the Redwater Shale Member.

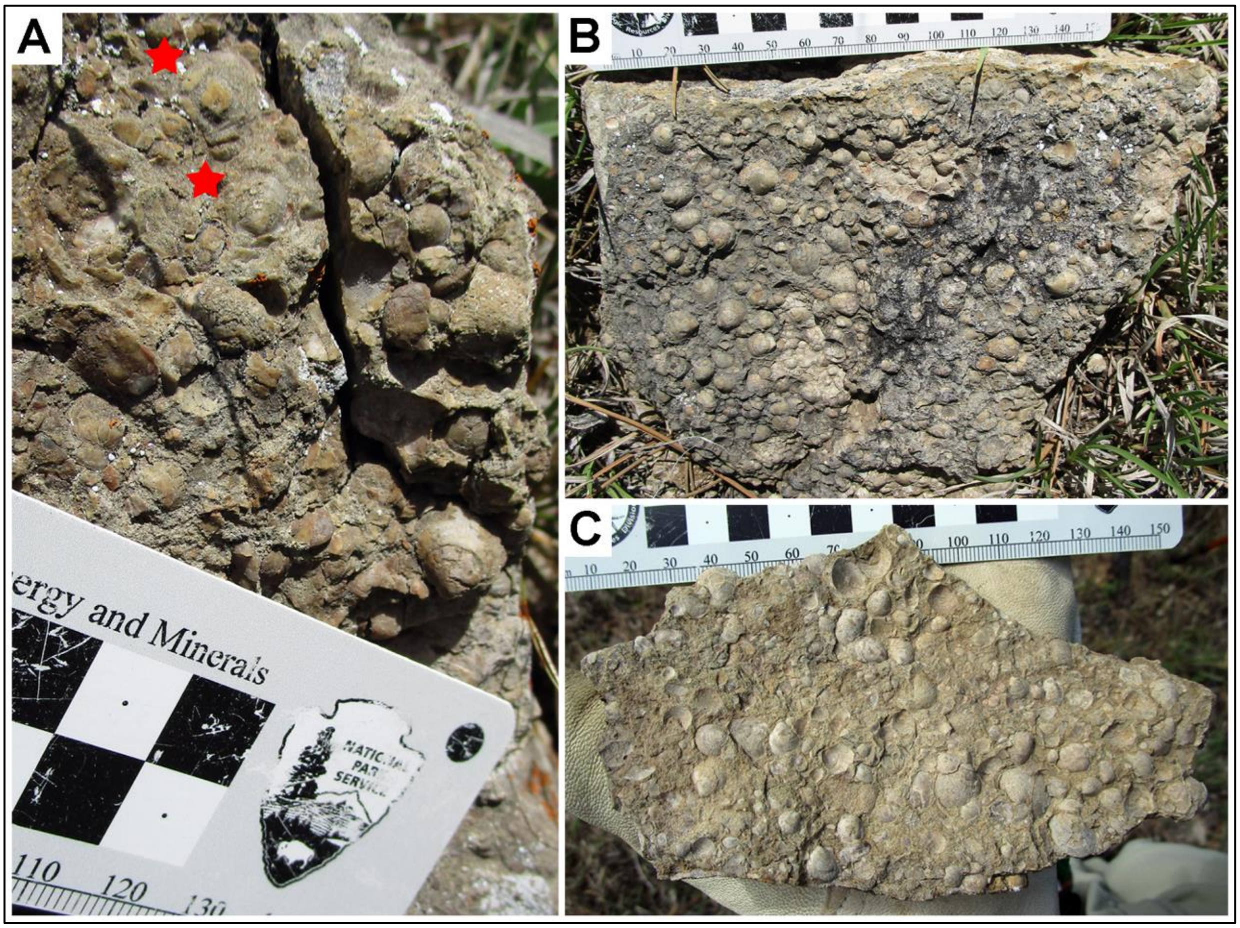

Figure 18. Typical examples of bivalve beds in the Redwater Shale Member at DETO (NPS/JUSTIN TWEET). A. Two examples of *Camptonectes* are highlighted by red stars (above and to the left of the fossils). B and C. Two fairly typical bivalve beds exposed on surfaces, dominated by small subcircular *Camptonectes*.

Bivalves have been found in or associated with the Stockade Beaver, Lak, and Redwater Shale members of the Sundance Formation at DETO (Figure 19). Most of the bivalves at DETO are found in beds, and typically do not erode out whole out of the beds, although there are exceptions (Figure 19). Many of the shells represent the circular, roughly symmetrical scallop *Camptonectes* (Figure 18A). *Camptonectes* beds may have resulted from storm events in a shelf setting (McMullen et al. 2014). It is not uncommon for original shell material to be lost and the shell to be represented by a natural mold or cast (Figure 20). Most of the bivalves at DETO appear to be fairly small, on the order of 2–3 cm (approximately 1 in) at most in longest dimension, but there are depressions on the surfaces of some beds that suggest the loss of much larger examples (Figure 20B). Exposed shell beds are readily recognizable; shell beds exposed in cross-section are more obscure, but they can be identified by the appearance of "eyelashes" or "parentheses" in the rock (Figure 20C).

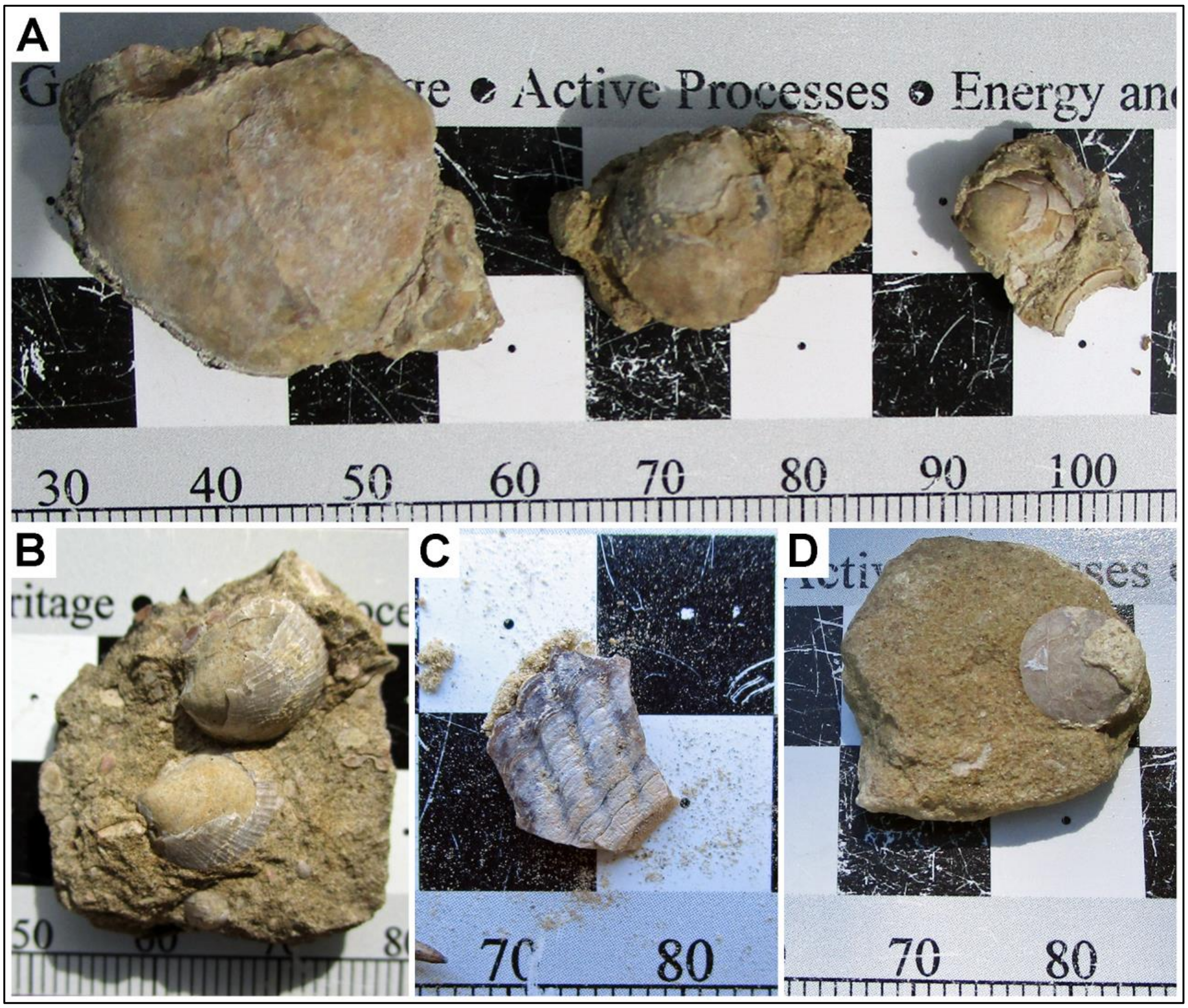

Figure 19. Float bivalves from the Sundance Formation of DETO (NPS/JUSTIN TWEET). A. Three bivalves of various sizes and morphologies from the Redwater Shale Member. B. Two small bivalves with partial shell material, Redwater Shale Member. C. A fragment of oyster shell found as float on the Lak Member. D. A small bivalve in a sandy chip probably from the Stockade Beaver Shale Member.

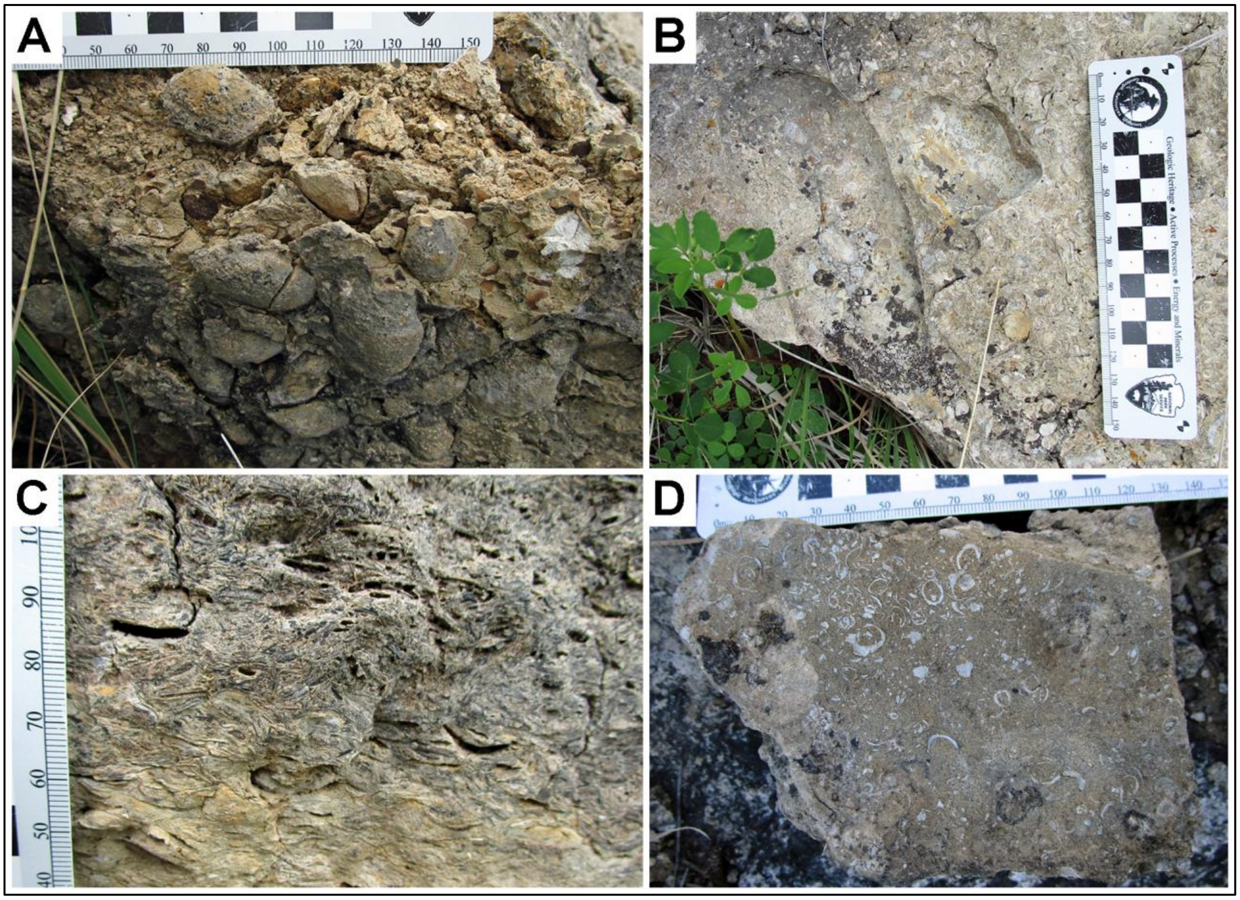

Figure 20. Aspects of bivalve preservation and exposure in the Redwater Shale Member at DETO (NPS/JUSTIN TWEET). A. Bivalve steinkerns (internal casts) beginning to erode from a block. B. Two depressions left of the scale bar may represent large bivalves that have eroded from the block. C. Bivalve molds exposed in cross-section. D. Bivalves are exposed in planar section in this block.

Camptonectes is among the most abundant genera of bivalves in the Redwater Shale Member. Wright (1974) identified *Camptonectes bellistriatus*, *Ostrea strigilecula* (now known as *Liostrea strigilecula*), *Gryphaea nebrascensis*, *Pleuromya newtoni*, *Tancredia* sp., *Meleagrinella curta*, and *Tancredia transversa* as the most abundant species, in that order. They are thought to have lived in dense patches (Wright 1974). *Liostrea strigilecula* and *Meleagrinella curta* are smaller than *Camptonectes*; *L. strigilecula* is ovoid in shape, while *M. curta* resembles *Camptonectes*. *Gryphaea nebrascensis* resembles a cashew. *Pleuromya newtoni* shells are broadly parallelogram-shaped. *Tancredia* is triangular. It would not be surprising to find examples of any of these common bivalves at DETO, and some of the photographed fossils clearly resemble their general shapes. Other information on Sundance Formation bivalve assemblages can be found in Danise and Holland (2017). Comparative images of Sundance bivalves and other fossils have been put online by the University of Georgia Stratigraphy Lab (http://strata.uga.edu/sundance/index.html).

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

Two types of cephalopods have been reported from DETO: ammonoids and belemnites. Both groups went extinct at the end of the Cretaceous, but they have significantly different anatomies.

Ammonoids, also known informally as ammonites, are known almost exclusively from their mineralized shells, in which the nautilus-like or squid-like animal lived; these shells are generally coiled in a flat plane. Belemnites are known from internal hard parts, mostly bullet-shaped guards, but sometimes also the inner conical chambered phragmocone which held internal soft tissues of the animal, and the delicate tongue-like pro-ostracum (or proostracum) that projected to the front of the animal (Figure 21). The only report of ammonoids at DETO is a passing reference to their presence in the Redwater Shale Member (Graham 2008), so there is the possibility of an error or misinterpretation. None were observed during the 2019 visit.

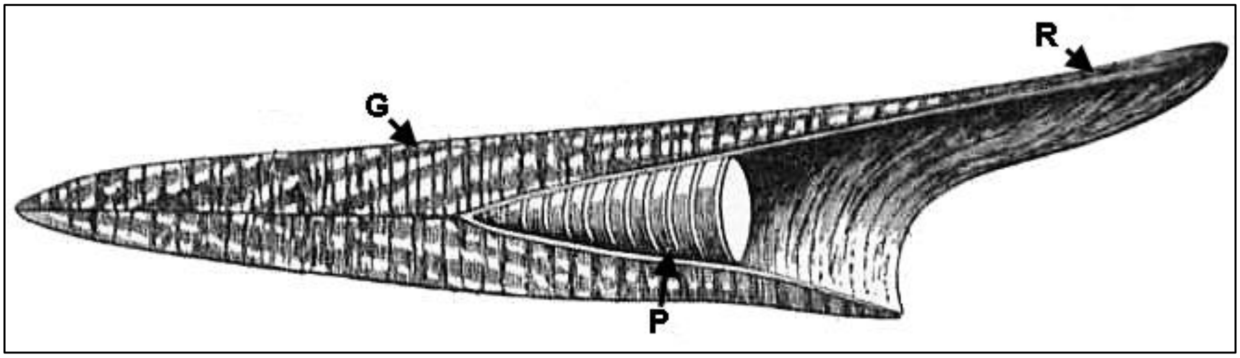

Figure 21. A cutaway diagram of belemnite hard-part anatomy; G = guard; P = phragmocone; R = pro-ostracum. Modified from 1911 Encyclopaedia Britannica diagram, downloaded from Wikimedia Commons (https://commons.wikimedia.org/wiki/File:EB1911_Cephalopoda_Fig._19.%E2%80%94Shell_Belemnite.jpg).

Belemnites, on the other hand, are abundant at DETO. Jaggar (1901) reported a belemnite shale bed in the upper Redwater Shale Member. Lead Custodian Newell Joyner collected specimens from the monument in the 1930s, among them three specimens that not only included the commonly found guard, but also the phragmocone and pro-ostracum (Rogers 2007). Bowen (1961) included a specimen of the belemnite *Pachyteuthis densus* collected from DETO in his study of paleotemperature. Racay and Tweet found belemnite fragments at several locations in DETO, almost exclusively as float, on the Lak and Redwater Shale members of the Sundance Formation; per Steven Holland, they all most likely originated from the Redwater Shale Member (pers. comm. July 2019).

Most belemnites at DETO are found as float fragments of the guard, having eroded out of softer rocks, although they are occasionally found in situ (Figure 22). They typically have been fractured in a flat longitudinal plane and are also truncated at one or both ends, forming cm-scale (in-scale) half-cylinder or half-cone chips (Figure 23). The uncurved inner fractured surface often includes a conical void representing the socket that held the phragmocone. The chips are often two-tone in color when seen in the field, with a dark blue-black side that has been exposed to the elements and a pale off-white side that has been buried in the soil (Figure 23C). It is assumed that the belemnite present at DETO is *Pachyteuthis densus* because that is the primary species reported by other authorities for the Sundance Formation, and Bowen (1961) previously reported it from DETO, but it should be noted that the taxonomy of Sundance Formation belemnites has not been studied in great detail (Massare et al. 2014).

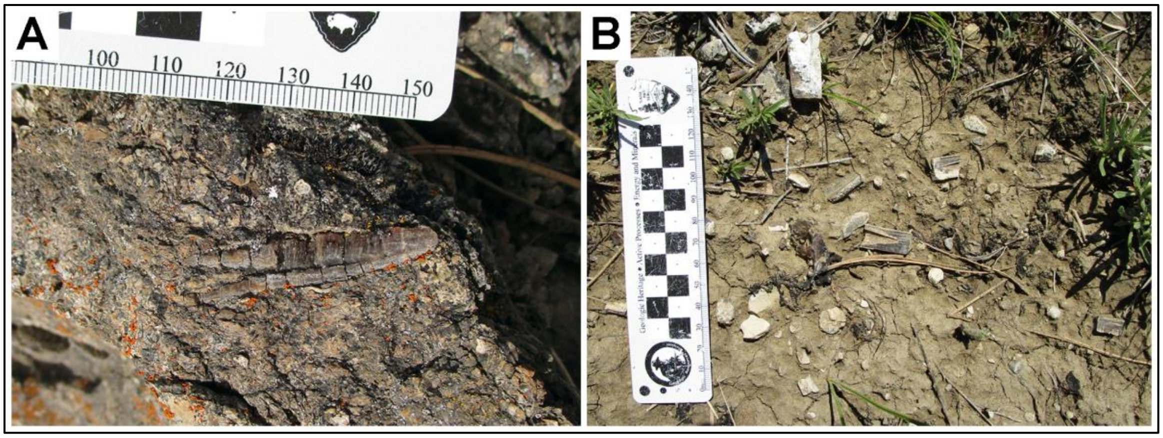

Figure 22. Belemnite preservation at DETO in the Redwater Shale Member (NPS/JUSTIN TWEET). A. An example in situ. B. More typically, specimens are found loose; several are visible in this photo, including one near the center with the triangular socket for the phragmocone evident.

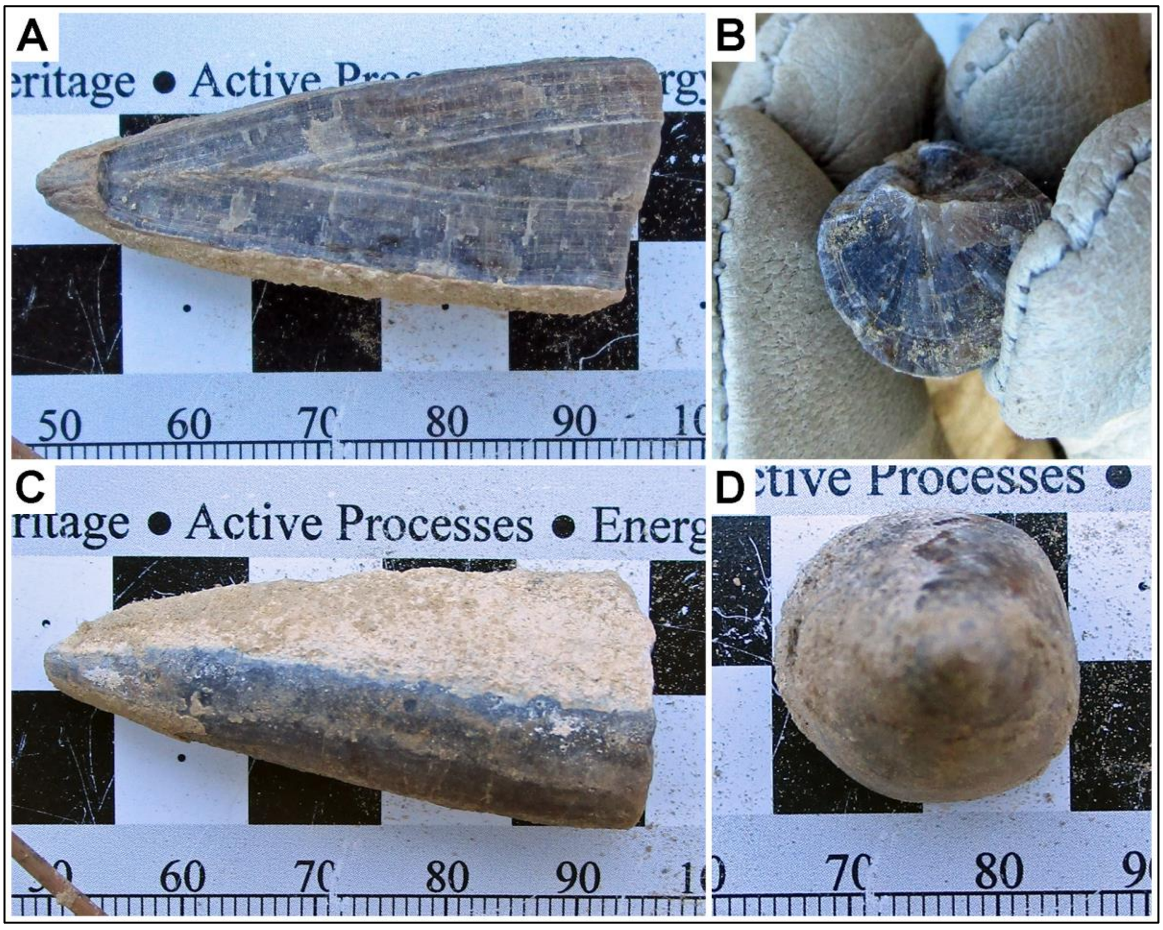

Figure 23. Well-preserved partial belemnites found as float on the Lak Member at DETO (NPS/JUSTIN TWEET). A. An internal longitudinal section, showing the internal v-shaped structures that would surround the phragmocone (not preserved). B. A piece in cross-section. C. The specimen in A in external view, showing the common two-tone appearance. D. A conical section viewed from the point.

Fossil Vertebrates

There are a few reports of vertebrate fossils from DETO. Joyner (internal report reprinted in Rogers 2007), in a proposal to create what became the Red Beds Trail, mentioned that the future trail included “the spot where a dinosaur bone was picked up sometime ago.” No other information is known about this find, so it is not possible to determine if the bone was indeed dinosaurian, in which case it was likely eroded and transported from the Morrison Formation, or came from some other type of animal; other candidates include a large marine reptile from the Sundance Formation, or a large Pleistocene mammal.

More recently, there is Chris Racay’s Sundance Formation vertebrate find (Figure 24). Pagnac and Welsh (2018) described the vertebrate specimen as including five sections of possible ribs or fin rays in an adhering cobble of sandstone, and four similar sections adjacent in the slab proper. The specimen may be part of a bony fish or, possibly, a juvenile marine reptile (Pagnac and Welsh 2018). Other small bone fragments are visible in nearby blocks, most notably a bone approximately a cm across (0.4 in) visible as an oval cross-section (Figure 24D).

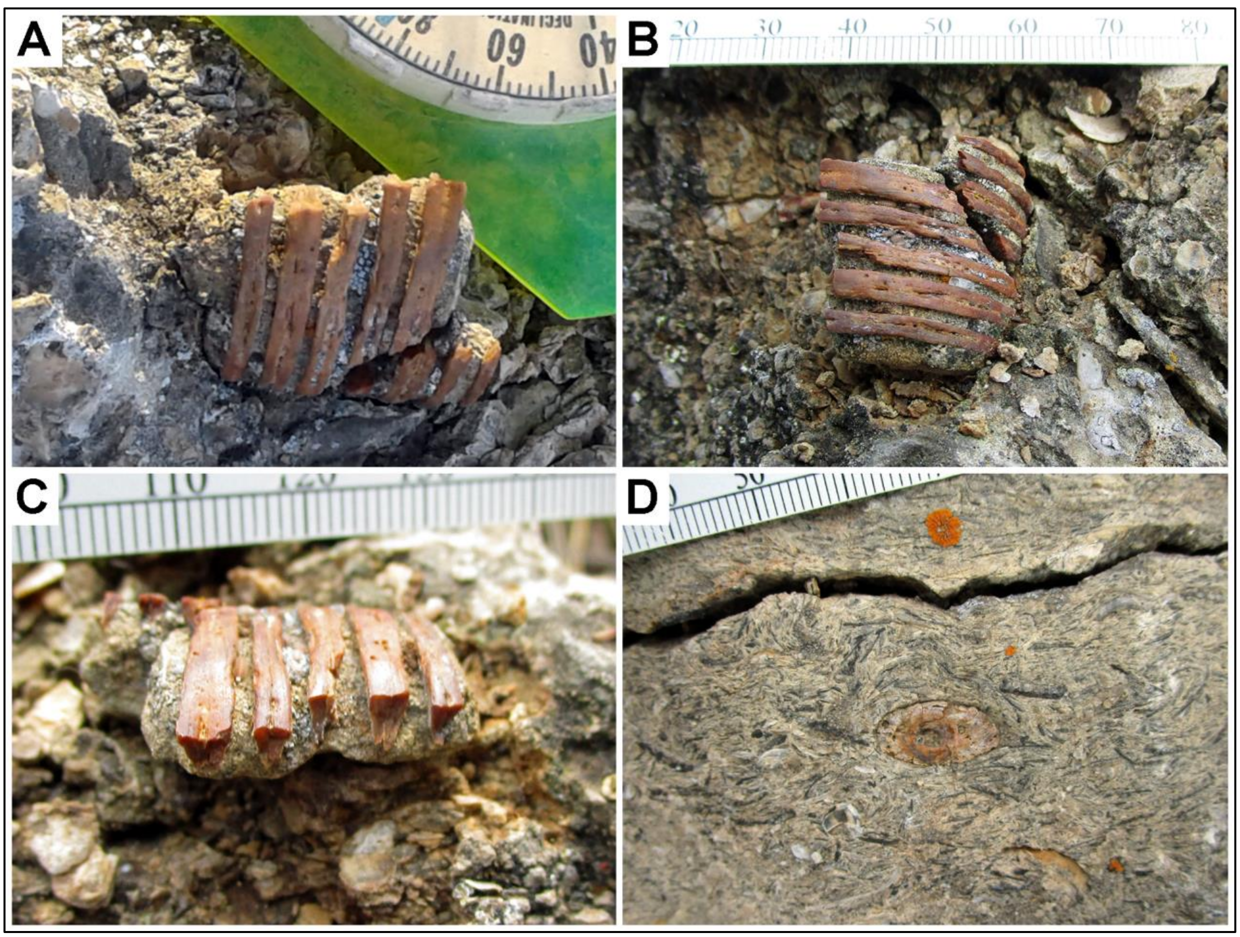

Figure 24. Vertebrate specimens in the Redwater Shale Member at DETO (NPS/JUSTIN TWEET except A). A. The bone series as originally discovered in December 2017 (NPS/CHRIS RACAY). B. The bone series as observed in June 2019. C. The bone series on end, showing slightly triangular cross-sections. D. An oval cross-section through a bone in a shell bed.

Ichnofossils

Trace fossils and potential trace fossils have been reported from the Hulett Sandstone Member of the Sundance Formation and ?Lakota Formation residuum at DETO. A stratigraphic section prepared from DETO by Rautman (1978) depicted the lower Hulett Sandstone Member as bioturbated, a condition in which organisms, generally burrowing invertebrates, have disturbed sediment so greatly that sedimentary structures have been erased. Tweet observed probable vertical invertebrate burrows in this unit (Figure 13). Tweet and Racay also observed features indicative of a U-shaped invertebrate burrow in a loose block of sandstone perhaps originally from the Lakota Formation (Figure 15).

Racay has found possible sauropod dinosaur tracks in the Hulett Sandstone Member in DETO as well. If these are indeed dinosaur tracks, they would be significant as the first dinosaur tracks known from the Hulett Sandstone Member. The features are found on one large displaced block of the Hulett Sandstone and include one well-defined feature and one less-defined feature (Figures 25 and 26). Racay interpreted the features as sauropod manus prints, with a travel direction right-to-left across the block as it now sits. Tweet agrees that the features are consistent with the general size and shape of sauropod prints, but thinks that if they are tracks, they look more like a pes print (large feature) and manus print (smaller feature) going bottom-to-top across the block, or perhaps one well-defined pes print and a second but more poorly defined pes print going bottom-to-top. In any case, Tweet finds it unusual that, if these are indeed tracks, there are no other prints on the block given the depth and definition of the large feature. Brent Breithaupt (Bureau of Land Management), evaluating the large feature from photos, reported "It looks like a pseudo-track, probably a pothole. I don't see a good bedding plain [sic] nor deformation of layers," but noted that it might look different in person (pers. comm., June 2019). Second author Santucci supports a pothole identification.

Figure 25. The two questionable Hulett Sandstone features are visible in this photo; the higher feature, in the upper left, is poorly defined but has a similar right margin to the lower feature (NPS/JUSTIN TWEET).

Figure 26. The better-defined lower feature (NPS/JUSTIN TWEET).

Cultural Resource Connections

Because of the sacred nature of Devils Tower, all of the natural resources at DETO are touched in some way by cultural considerations. Therefore, it may be considered misleading to speak of DETO's paleontological resources as separate from the cultural milieu; they are part of the cultural landscape. As such, management of paleontological resources at DETO is more strongly subject to cultural considerations than at most NPS units. In particular, it is unlikely that excavations will be supported under most circumstances, which means management plans should focus on fossils as they are in the field, whether in situ or as float.

In stricter terms, 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, projectile 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.

At this time, there are no known records of fossils with specific cultural resource connections at DETO. However, it would not be surprising if connections exist. The lands now encompassed in DETO's boundaries have probably been visited by humans for thousands of years. Humans have been present in northeastern Wyoming for at least the past 11,500 years (Reider 1980), and the Tower, which is a sacred site for several tribes, has doubtless inspired interest since it was first seen. With its long history in human consciousness, there is the possibility that people have dropped or left modified or unmodified fossils within what is now DETO. Tools made of paleontological materials have been found in eastern Wyoming, such as ivory projectile points (Reider 1982), bone tools (Frison et al. 1976, 1978), and tools of fossiliferous Knife River flint (Frison et al. 1976) (imported from central North Dakota). Additionally, people from many Plains tribes, including the Arapaho, Blackfoot, Cheyenne, Crow, Lakota, and Pawnee, collected fossils for various purposes. Of interest for DETO, in light of its marine fossils, is the use of ammonites and belemnites as amulets and charms. Among these are *iniskim* ("buffalo stones"), fragments of the elongate conical Upper Cretaceous ammonite *Baculites*, which breaks naturally into buffalo-like shapes (Mayor 2005). DETO's interpretive collection contains larger examples of *Baculites*.

Paleontological Localities near DETO

Invertebrate and vertebrate fossils have been reported from several localities within a few kilometers or miles of DETO:

Whitfield and Hovey (1906) found examples of two new Jurassic bivalve species just outside of DETO: *Modiolarca jurassica* (2.4 km/1.5 mi northeast of Devils Tower, Belle Fourche Valley) and *Trigonia sturgisensis* (3.2 km/2 mi northeast of Devils Tower, Belle Fourche Valley);

Reeside (1919) reported Jurassic ammonites of the genus *Cardioceras* from sites 6.4 km (4 mi) west of Devils Tower and 3.2 km (2 mi) south of the Belle Fourche River near the Tower; these localities were later included in Imlay (1982);

Sohn (1958) and Sohn and Peck (1963) discussed ostracodes found in the Morrison Formation at a locality 1.6 km (1 mi) west of DETO in the northwest corner of section 11, Township 53 North, Range 66 West;

Schaeffer and Patterson (1984) noted that two specimens of the shark *Hybodus* sp. had been collected from 3.2 km (2 mi) west of DETO, probably from the Stockade Beaver Shale Member of the Sundance Formation, by Hovey in 1891. These specimens are in the collections of the American Museum of Natural History (AMNH; New York, New York) as AMNH 8726 and 8728;

Finally, Karner and Halvorson (1989b) mentioned that belemnites had been found in the Lak Member on Highway 14 just southeast of the junction with Highway 24 to DETO, approximately 10 road km (6 road mi) from the monument.

In addition, Whitfield (1880) reported examples of Jurassic bivalves and belemnites “near Bear Lodge” or “Bear Lodge Butte,” on, east, or south of the Belle Fourche River, but this information is too general to place the localities with any confidence.

Museum Collections and Curation

Park Collections

In the 2011 inventory (Tweet et al. 2011), there was a brief summary of fossils in DETO collections based on information supplied by Mark Biel (DETO Chief of Resource Management at the time). It is reproduced here with some updates and changes:

DETO park collections currently include one catalog number for fossils: DETO 156, a belemnite collected in DETO along the Belle Fourche River (Figure 27). The provenance suggests it had eroded out of a higher formation. It includes a partial phragmocone as well as part of the guard. There is a possibility that it is one of the belemnites collected by Newell Joyner that included a phragmocone (mentioned in Rogers 2007).

Figure 27. Belemnite DETO 156 (no scale provided). This specimen is unusual in that it includes the phragmocone (slightly orange inner cone) (NPS).

Several other specimens have been in DETO collections over the years but have been deaccessioned. Most of them are now lost. These specimens include:

- DETO 121, a bison bone from an unknown site;
- DETO 155, possible fossil bark from an unknown locality;
- DETO 166, fossilized plants and animals from multiple collections and unknown localities;
- DETO 212, a dinosaur or crocodile vertebra from an unknown locality;
- DETO 213, an ammonite from Badlands National Park;
- DETO 214, an ammonite from an unknown locality;
- DETO 217, a cycad from Fossil Cycad National Monument, which was deauthorized in 1956;
- DETO 218, a mammal bone from an unknown locality;
- and DETO 225, a specimen of the straight ammonite *Baculites* from south of Newcastle, Wyoming, 92 km (57 miles) southeast of DETO (M. Biel, pers. comm., April 2010).

Photos taken in 2001 exist of DETO 218 (Figure 28) and 225. During the 2019 visit, DETO 225 was located in DETO’s interpretive collection (Figure 29), and it is possible that others of the above specimens were placed in the interpretive collection after being deaccessioned. The specimens may have been deaccessioned because their provenance is either unclear or outside of DETO.

Figure 28. DETO 218, a broken mammal bone, as photographed in 2001 (no scale provided) (NPS).

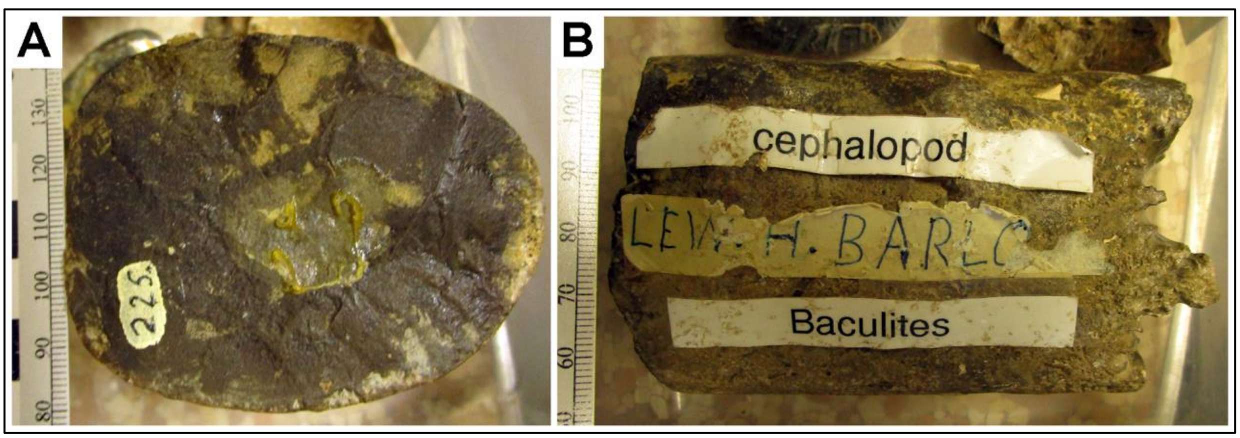

Figure 29. DETO 225 relocated in DETO interpretive collections (NPS/JUSTIN TWEET). A. Cross-sectional view showing the old specimen number. B. Side view showing labels applied to it.

Interestingly, early in Joyner's custodianship, in May 1933, fossil bones were being reconstructed in the park museum. They were sauropod bones discovered in the area (Rogers 2007). It is possible that one or more of the deaccessioned specimens in the list above, such as DETO 166 or 212, pertain to this material, but there is no evidence to support this speculation. One of these numbers may have also been applied to the "Red Beds Trail bone" of Rogers (2007).

Non-catalogued park collections are maintained for interpretive purposes and include a small number of fossils, generally with little to no provenance information. Chris Racay identified some of the material in 2017–2018. The paleontological material includes a container of mollusk fossils (including DETO 225), a partial vertebra of a marine reptile, bone fragments that may belong to an ichthyosaur jaw (Figure 30A), various Sundance Formation invertebrates (slabs of bivalve shells and crinoids), and specimens farther removed from the Jurassic of northeastern Wyoming, such as Cretaceous-aged *Gryphaea* bivalves, brachiopods, and fenestrate bryozoans (Figure 30B). A kit used for interpretive programs contains a small box holding two belemnites, a bivalve-bearing cobble, and a piece of a *Baculites*.

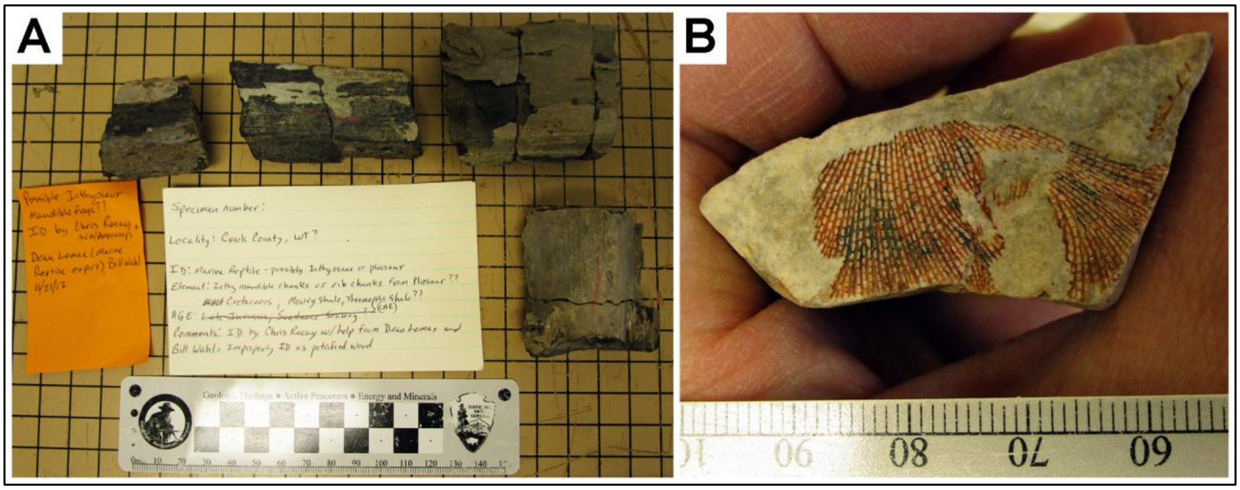

Figure 30. Specimens in DETO interpretive collections (NPS/JUSTIN TWEET). A. Possible ichthyosaur jaw fragments. B. A rock with a fenestrate bryozoan; the provenance is unknown, but it resembles Paleozoic bryozoans, and a Paleozoic source outside of DETO would be unsurprising.

Collections in Other Repositories

DETO has been a monument since 1906, and over this period the fossils of the monument have attracted little formal scientific attention, so there has been little in the way of formal collection. However, the rocks of the monument yield fossils that are portable, durable, and recognizable as fossils, appealing for "souvenir" collection. During March 2016, Tweet was investigating a large private collection of fossils that had been acquired by the Science Museum of Minnesota in the 1990s but never fully assessed. In this collection he observed a group of belemnites and a palm-sized fossiliferous stone with limited locality information including "Devils Tower" (Figure 31). It is not certain whether the specimens came from the monument or nearby, but based on the known fossils resources of DETO it is certainly possible that they came from DETO. It is also possible that they came from just outside of the monument, and the label is generalized; for example, "minnbuckeye," a member of the online community "The Fossil Forum," reported collecting cephalopods just outside of DETO on the grounds of the Devils Tower Lodge (adjoining DETO on the north) with the permission of the landowner (http://www.thefossilforum.com/index.php?/topic/94705-visiting-devils-tower-area/&do=findComment&comment=1044429). Wherever they were collected, the context of the specimens in the private collection acquired by the Science Museum of Minnesota indicates they are "souvenir" fossils. Others probably exist.

Figure 31. Uncatalogued specimens from DETO or the immediate vicinity, found in a collection donated to the Science Museum of Minnesota (NPS/JUSTIN TWEET). A) Belemnites. B) A bivalve hash plate.

Charophytes described from DETO by Peck (1957) (USGS locality D296) are preserved in slides originally held by the U.S. Geological Survey, and later transferred to the Smithsonian Institution's National Museum of Natural History (USNM; Washington, D.C.). Per Jonathan Wingerath (USNM deputy paleobotany collections manager, pers. comm., February 2019), catalog numbers for D296 specimens are as follows:

- USNM 347495, *Clavator harrisi*
- USNM 347559, *Praechara voluta*
- USNM 347560, *Sphaerochara verticillata*
- USNM 347561, *Latochara latitruncata*
- USNM 347562, *Aclistochara jonesi*
- USNM 347563, *Aclistochara jonesi*
- USNM 347564, *Aclistochara jonesi*
- USNM 347565, *Aclistochara bransoni*
- USNM 347577, *Praechara voluta*
- USNM 347578, *Praechara voluta*
- USNM 347587, *Aclistochara bransoni*
- USNM 347588, *Aclistochara bransoni*
- USNM 347589, *Aclistochara bransoni*

The *Pachyteuthis* specimen included in Bowen (1961) is no longer extant, because the study required destructive analysis to determine the isotopic data. It is not stated in the text how the specimen was obtained or whether additional belemnites had been collected, and there is no way of reconstructing this history from the text. A number of individuals are thanked in the acknowledgments for having supplied specimens, but affiliations are not given; neither of DETO's superintendents from the late 1950s and early 1960s (Raymond W. McIntyre and James F. Hartzell) are among them, but this does not preclude someone else from the monument having sent a specimen to Bowen. Alternatively, a non-NPS party may have given Bowen the specimen with or without the knowledge of DETO staff, or Bowen could have collected it himself, again with or without the knowledge of DETO staff. Bowen's institutional affiliation at the time was the University of California, San Diego.

At one time in the recent past there were discussions between DETO and the South Dakota School of Mines and Technology about the School's Museum of Geology serving as a repository for the monument, but this did not happen. The Museum of Geology has no DETO material (S. Shelton, Associate Director, Museum of Geology and Paleontology Research Laboratory, pers. comm., November 2018).

Type Specimens

To date, no fossil taxa have been named based on specimens found at DETO. Peck included illustrations of some of the charophyte specimens now at the USNM (e.g., Figure 17), but he did not use the DETO material to define any new taxa.

Paleontological Research

Current Research

No research on paleontological resources is ongoing at DETO, although Chris Racay has expressed interest in further study at the monument, particularly concerning the potential sauropod tracks.

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.*

The NPS maintains an online Research and Collecting Permit (RPRS) database system for researchers to submit applications for research in NPS areas. Applications are reviewed at the park level and either approved or rejected. Current and past paleontological research and collecting permits and the associated Investigator's Annual Reports (IARs) are available on the RPRS website (https://irma.nps.gov/rprs/). Additional information on NPS law and policy can be found in Appendix C.

Interpretation

Current Long-Range Interpretive Plan

DETO currently does not have a long-range interpretive plan for paleontological resources, but it does have an interpretive collection as described above. The collection includes a wide range of fossils for its size, most of which can be tied to the Jurassic and Cretaceous geology of the area. A brief document describing the types of fossils and their significance would make the collection more useful for staff.

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 DETO. 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 not be disturbed or collected within park boundaries. Fossils, as non-renewable resources found in natural settings, can considered in terms of "Leave No Trace" principles, in particular "Leave What You Find."

- 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. Some of the topics they illustrate include: what past environments and ecosystems looked like; how life has changed over time in response to changing conditions and selective pressures; and how we can use some fossils as time indicators in the geologic column.
- When paleontologists survey for paleontological resources, the most important tool 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 small picks and brushes, glue-like material called vinac, 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 (i.e., "Leave What You Find" under "Leave No Trace"). 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 DETO

A program could be developed to educate the public on what types of fossils are present in DETO and what they tell scientists about Earth's dynamic history. The goal of this program would be to increase visitors' understanding of local geology and paleontology. Therefore, information regarding fossils from the vicinity of DETO can be included. Such a program would inevitably increase the exposure of DETO fossils to the public, so a careful balance would need to be struck between education and resource management.

III. Further Interpretation Themes

DETO should be sure to promote their paleontological resources and provide additional opportunities or programs for visitors to learn about fossils on National Fossil Day. National Fossil Day is celebrated annually on Wednesday of the second full week in October, which is Earth Science Week. The National Park Service coordinates the National Fossil Day partnership (https://www.nps.gov/subjects/fossilday/index.htm) and hosts fossil-focused events across the country. For 2019, October 16 is National Fossil Day. Conducting one of the suggested paleontology-focused talks on this day would be a perfect opportunity to not only increase public awareness about paleontological resources in DETO, but also connect with other parks and museums who are also participating in this national event. The NPS Geologic Resources Division can assist with planning for National Fossil Day activities in the monument and provide supplies of 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 419 official units of the National Park System, plus national rivers, national trails, and affiliated units that are not included in the official tally. Of these, 271 are known to have some form of documented paleontological resources, and paleontological resources are mentioned in the enabling legislation of 17 units. Fossils possess scientific and educational values and are of great interest to the public; therefore, it is exceedingly important that appropriate management attention be placed on protecting, monitoring, collecting, and curating of these paleontological specimens from federal lands. In 2009, the Paleontological Resources Preservation Act (PRPA) was signed into law as part of the Omnibus Public Land Management Act of 2009. The new paleontology-focused legislation includes provisions related to inventory, monitoring, public education, research and collecting permits, curation, and criminal/civil prosecution associated with fossils from designated DOI lands. Paleontological resource protection training is available for NPS staff through the NPS Geologic Resources Division (GRD). GRD is also available to provide support in investigations of paleontological resource theft or vandalism.

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

National Park Service management policies state

> *…management actions will be taken to prevent illegal collecting [of fossil resources] and may be taken to prevent damage from natural processes such as erosion. Protection may include construction of shelters over specimens for interpretation in situ, stabilization in the field [which can include reburial] or collection, preparation, and placement of specimens in museum collections. The locality and geologic data associated with a specimen will be adequately documented at the time of specimen collection. Protection may also include, where necessary, the salvage collection of threatened specimens that are scientifically significant*.

Effective paleontological resource management serves to protect fossil resources by implementing strategies that mitigate, reduce, or eliminate loss of fossilized materials and their relevant data. Because fossils are representatives of adaptation, evolution, and diversity of life through deep time, they have intrinsic scientific value beyond that of the physical objects themselves. Their geological and geospatial contexts provide additional critical data concerning paleoenvironmental, paleogeographic, paleoecologic, and a number of other conditions that together allow for a more complete interpretation of the physical and biological history of 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. Thus, when a fossil weathers and erodes from its surrounding sediments and geologic context, it begins to lose significant ancillary data until, at some point, it becomes more a scientific curiosity than a useful piece of scientific data. A piece of loose fossil "float" can still be of scientific value; however, when a fossil has been completely removed from its original context, such as an unlabeled personal souvenir or a specimen with no provenance information in a collection, it is of very limited scientific utility. Similarly, fossils inadvertently exhumed during roadway construction or a building excavation may result in the loss or impairment of the scientific and educational values associated with those fossils. It is not necessary to list here all of the natural and anthropogenic factors that can lead to the loss of paleontological resources; rather it is sufficient to acknowledge that anything which disturbs native sediment or original bedrock has potential to result in the loss of the paleontological resources that occur there, or the loss of the associated paleontological resource data.

Unpermitted fossil collecting may be of concern for DETO. At the onset of a period of monitoring in 1994–1996, it was noted on the monitoring form for one of the localities that fossils were rare on one of the ridges where they had been common over the previous five years. The report recommended that staff discontinuing identifying the site as fossiliferous in communication with the public, which has been done. There is also the evidence of the "Devils Tower" specimens in the Science Museum of Minnesota collections. Belemnites, abundant at DETO, are appealing as "souvenir" fossils. They are portable, durable, and easily recognizable as fossils by many fossil enthusiasts, and can be found along trails and near roads. They may also be mistaken for artifacts by visitors without paleontological knowledge. However, visitor usage is concentrated near the Tower, where fossils and fossiliferous rocks are not found, and the Tower itself far overshadows paleontological resources. Visitors are known to take and occasionally return pieces of Tower phonolite (A. Kochanowski and R. Ohms, pers. comm., June 2019).

Cave localities are in a distinct class for management due to the close connection with archeological resources and unique issues affecting cave resources. DETO lacks stereotypical subterranean caves, but the talus field surrounding the Tower has abundant small rock shelters. From the long-term shedding of phonolite blocks from the Tower, there may well be a sort of layering of buried rock shelters within the talus field, which could include the remains of various organisms such as small vertebrates (snakes, lizards, bats, rodents, etc.). It is unlikely that this stratigraphy of rock shelters will ever be accessed, but it may exist. There are also some very small caves and rock shelters elsewhere in DETO, some of which are documented dens for porcupines and other wildlife (R. Ohms, pers. comm., July 2019). See Santucci et al. (2001) for additional discussion of paleontological resources in cave settings.

Management strategies to address any of these conditions and factors could also incorporate the assistance of qualified specialists to collect and document resources rather than relying solely on staff to accomplish this task at DETO. Active recruitment of paleontological research scientists may 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 DETO, taxonomic groups that have been reported within DETO boundaries, and localities that were previously reported. This report can serve as a baseline source of information for future research, inventory reports, monitoring, and paleontological decisions. The Paleontological Resource Inventory and Monitoring report for the Northern Great Plains Network (Tweet et al. 2011) and the references cited within were important baseline paleontological resource data sources for this DETO-specific report.

Paleontological Resource Monitoring

Paleontological resource monitoring is a significant part of paleontological resource management, and one which usually requires little to implement beyond time and equipment already on hand, such as cameras and GPS units. Monitoring enables the evaluation of the condition and stability of in situ paleontological resources. 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 and 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. One of the previous monitoring programs at DETO visited localities every two weeks during the summer and early fall, but in most cases site visits are scheduled on a yearly or longer basis.

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. 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?

For various reasons, it is unlikely that DETO will embark on a systematic collecting regimen, so paleontological resource monitoring becomes even more significant as a potential management tool. Historically, several sites in DETO were monitored at regular intervals during two time periods: 1994–1996 and 2007–2013. The second period of monitoring ended in part because staff did not feel confident dealing with the subjectivity of the locality condition forms. Briefly, locality condition forms are 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, such as inherently soft rapidly eroding sediment or mass wasting on steep hillsides. “Abundance” judges both the natural condition and number of specimens actually preserved in the deposits as well as the risk of being easily recognized as a fossil-rich area which could lead to the possibility of unpermitted collecting. “Site Access” assesses the risk of a locality being visited by large numbers of visitors or the potential for easy removal of large quantities of fossils or fossil-bearing sediments as a result of proximity to public use areas or other access (along trails, 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 unscheduled visits by monument staff, documentation of in situ specimens, and/or frequent law enforcement patrols. Further information on paleontological resource monitoring can be found in Santucci and Koch (2003) and (Santucci et al. 2009).

Foundation Documents and Resource Stewardship Strategies

Foundation documents and Resource Stewardship Strategies are two types of park planning documents that may contain and reference paleontological resource information. A foundation document is intended to provide basic guidance about a park for planning and management. It briefly describes a given park and its purpose, significance, fundamental resources and values, other importance resources and values, and interpretative themes. Mandates and commitments are also identified, and the state of planning is assessed. Foundation documents may include paleontological information, and they are also useful as a preliminary assessment of what park staff know about their paleontological resources, the importance they place on these resources, and the present state of these non-renewable resources. A foundation document for DETO has been published (NPS 2014).

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. DETO began the RSS process in 2018, and the completed RSS will be published in 2019. DETO’s RSS includes goals to improve understanding of paleontological resources, encourage paleontological research by universities and other institutions, update the paleontological inventory (which is being addressed through this report), and ensure paleontological resources are protected.

Geologic Maps

Geologic maps are one of the foundational elements of a paleontological resource management program. Knowing which sedimentary rocks and deposits underlie a park and where they are exposed are essential for understanding the park's paleontological resources. Ideally, geologic bedrock maps at a scale of 1:24,000 or finer will exist for parks located in the 48 contiguous states (maps for areas in Alaska tend to be coarser); if suitable maps do not exist, it would be worthwhile for park management to look into having them made, because geologic maps are useful for much more than just paleontology; for example, the distributions of certain rock types dictate the distribution of karst and the development of biomes, and geologic maps are necessary for understanding geological hazards such as rockslides and faulting. The GRD has been working to compile geologic maps for parks with significant natural resources, and it is making them available in GIS formats. Whenever possible, page-sized geologic maps derived from the GRD's files are included in paleontological resource inventory reports for reference, but park staff are encouraged to download the GRD's source files from IRMA. The source files can be explored in much greater detail and incorporated into the park GIS database.

Paleontological Resource Sensitivity Maps

Paleontological resource sensitivity maps (PRSMs) are also included in these inventory reports. These maps show the distribution of geologic units within a park based on whether they are known to have yielded fossils within the park, have not yielded fossils within the park but are fossiliferous elsewhere, or have not yielded fossils and are practically unfossiliferous (most igneous and metamorphic units). These maps give a quick indication of areas with elevated potential for fossil discovery, which in turn can provide suggestions for areas to survey or monitor, or areas where the discovery of fossils may be of concern during work that disturbs the ground (road work, building construction, etc.).

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 DETO, or additional questions arise regarding paleontological resources, contact the NPS Senior Paleontologist & Paleontology Program Coordinator Vincent Santucci, vincent_santucci@nps.gov. Park staff are also encouraged to communicate new discoveries to the NPS Paleontology Program, not only when support is desired, but in general, so that this information can be incorporated into the archives. A description of the Archives and Library can be found in Santucci et al. (2018).

E&R Files

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

Paleontological Resource Management Recommendations

The paleontological resource inventory at DETO has documented a variety of fossils, confirming and expanding upon previous reports of paleontological resources from within monument boundaries. This report captures the scope, significance, and distribution of fossils at DETO as well as provides recommendations to support the management and protection of the monument's non-renewable paleontological resources.

- DETO staff should be encouraged to observe exposed rocks and sedimentary deposits for fossil material while conducting their usual duties. To promote this, staff should receive guidance regarding how to recognize common local fossils. When opportunities arise to observe paleontological resources in the field and take part in paleontological field studies with trained paleontologists, staff should take advantage of them, as funding and time permit.
- DETO 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.
- Site monitoring should resume. DETO should request technical assistance from GRD staff for help with developing a simple monitoring protocol, and to address any issues with the existing monitoring forms. There are a small number of productive areas with easy public access that are recommended for monitoring. It is expected that additional occurrences of small quantities of float fossils will be found from time to time, but these are ephemeral on the landscape and do not require long-term monitoring.
- Tweet has further suggestions of areas to visit (see restricted version).
- Chris Racay has indicated an interest in further work at DETO, particularly concerning the potential dinosaur tracks. Tweet supports this and recommends that a track specialist offer an opinion on the block, due to the potential importance as the first possible tracks from the Hulett Sandstone Member of the Sundance Formation. If the features are confirmed as tracks, it is recommended that they be documented via photogrammetry.
- With the tribal consultation recommending the vertebrate specimen be left in situ, it is recommended that the host block be covered in the winter (provided this does not interfere with other management concerns) and the site be included in periodic monitoring; repeat photography at close range should allow for an assessment of erosion. It is another candidate for photogrammetry, but the bone material is quite small. The covering given it for the winter of 2018–2019 appeared to be more than sufficient to protect it, although a more camouflaged outer covering may be advisable. A smaller area of the block may be covered, but a full-block covering has the advantage of blocking the entrance of moisture from all sides. Because the greater part of the bones is part of a projection from the block, and there are

fractures in the rock, the staff doing the covering may choose to place additional padding around the projection when covering the block, but should avoid contact with the bones themselves. In the event that the projecting bone-bearing piece is found to have broken off but is still at the site, it should be secreted somewhere at the site with the position recorded, so that it can potentially be retrieved following further consultation.

- A document detailing the interpretive collection should be produced to make the collection more useful.
- Fossil theft is one of the greatest threats to the preservation of paleontological resources and any methods to minimize these activities should be utilized by staff. Any occurrence of paleontological resource theft or vandalism should be investigated by a law enforcement ranger. When possible, the incident should be fully documented, and the information should be submitted for inclusion in the annual law enforcement statistics. There is anecdotal evidence for unauthorized collections of fossils at DETO; the monument’s fossils have low commercial value, but belemnites are appealing “souvenir” fossils.
- Fossils found in a cultural context should be documented like other fossils, but they will also require the input of an archeologist or a cultural resource specialist. Any fossil which has a cultural context may be culturally sensitive as well (e.g., subject to NAGPRA) and should be regarded as such until otherwise established. The Geologic Resources Division can coordinate additional documentation/research of such material.
- The park may fund and recruit paleontology interns as a cost-effective means of enabling some level of paleontological resource support. The Geoscientists-in-the-Parks Program is an established program for recruitment of geology and paleontology interns. A general geological project, incorporating such tasks as mapping the area of southern DETO not covered in Robinson (1956), identifying fossil bivalve taxa, creating a guide to the interpretive collection, and restarting paleontological site monitoring, might be of interest.
- Contact the NPS Geologic Resources Division for additional technical assistance with paleontological resource management issues.

If fossil specimens are found by DETO 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 DETO and position within the rock if applicable. If possible, revisit the site when a GPS unit is available.
- Document associated data, such as rock type, general description of the fossil, type of fossil if identifiable, general location in DETO, sketch of the fossil, position within the rock wall or if it is loose on the ground, any associated fossils, and any other additional information that may be useful for relocating or characterizing the site.

- Because of the cultural sensitivity of DETO, removing or collecting fossils is not recommended. However, concealing fossils found in high-traffic areas is appropriate, particularly if further documentation is desired. In such cases it is imperative to record enough locality information to relocate the specimen. Documenting fossils and leaving them in place is the best course of action until natural resource staff is contacted.
- DETO resource management staff should be alerted to discoveries of fossil resources.

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Appendix A. Paleontological Species List

The following table (Table A-1) documents the fossil species found at DETO in stratigraphic context, as reported in the literature, in museum collections, and through personal observations. The rows are organized systematically, placing taxa of the same broad groups together, with gray rows providing summaries for each group. The columns are organized by formation, which are presented in ascending order (oldest to youngest) left to right. The columns also include the taxon (first column) and references (last column; included in "Literature Cited" above). If a taxon is present in a given formation at a locality that can be placed within DETO, that cell is marked "Y" and given a blue fill. If there is some question about the stratigraphy or presence of a taxon, the cell is marked "?" and given a yellow fill. A null record is marked "–" with no color fill.

The formations are abbreviated as follows, presented in descending order (youngest to oldest, top to bottom). Formations that have not yielded fossils in DETO are omitted to save space. Per Steven Holland's comments (pers. comm., July 2019), belemnites not found in situ are regarded as most likely sourced from the Redwater Shale Member of the Sundance Formation. This affects specimens which have been found on the surface of the Lak Member or eroded and attributed to the Stockade Beaver Shale Member. The diversity of bivalves and ichnofossils is certainly greater than depicted (several distinct bivalve morphologies can be recognized in the photos, for example), but historical references did not include detailed taxonomic identifications, and lead author Tweet is not a specialist and did not want to introduce unnecessary confusion with tentative, untrained identifications.

U = unknown
Ta = "agglomerate"
Kl = ?Lakota Formation residuum
Jm = Morrison Formation
Jsr = Sundance Formation, Redwater Shale Member
Jsl = Sundance Formation, Lak Member
Jsh = Sundance Formation, Hulett Sandstone Member
Jss = Sundance Formation, Stockade Beaver Shale Member

Table A-1. Fossil taxa reported from DETO in stratigraphic context. References are provided where appropriate. If a taxon is present in a given formation at a locality that can be placed within DETO, that cell is marked "Y" and given a blue fill. If there is some question about the stratigraphy or presence of a taxon, the cell is marked "?" and given a yellow fill. A null record is marked "–" with no color fill.

Taxon	Jss	Jsh	Jsl	Jsr	Jm	Kl	Ta	U	References
FOSSIL PLANTS	**–**	**–**	**–**	**–**	**Y**	**Y**	**Y**	**–**	**–**
Charophyta (some freshwater green algae)	**–**	**–**	**–**	**–**	**Y**	**–**	**–**	**–**	**–**
Aclistochara bransoni	–	–	–	–	Y	–	–	–	Peck 1957
Aclistochara jonesi	–	–	–	–	Y	–	–	–	Peck 1957
Clavator harrisi	–	–	–	–	Y	–	–	–	J. Wingerath pers. comm.
Latochara latitruncata	–	–	–	–	Y	–	–	–	Peck 1957
Praechara voluta	–	–	–	–	Y	–	–	–	Peck 1957
Sphaerochara verticillata	–	–	–	–	Y	–	–	–	Peck 1957
Stellatochara arguta	–	–	–	–	Y	–	–	–	Peck 1957
Stellatochara obovata	–	–	–	–	Y	–	–	–	Peck 1957
Other plants	**–**	**–**	**–**	**–**	**–**	**Y**	**Y**	**–**	**–**
Coaly shale	–	–	–	–	–	–	Y	–	Halvorson 1980
Silicified wood and tree roots	–	–	–	–	–	Y	–	–	Jaggar 1901, Effinger 1934
FOSSIL INVERTEBRATES	**Y**	**–**	**–**	**Y**	**–**	**–**	**Y**	**–**	**–**
Phylum Brachiopoda (lamp shells)	**–**	**–**	**–**	**Y**	**–**	**–**	**Y**	**–**	**–**
Reworked Carboniferous spiriferids	–	–	–	–	–	–	Y	–	Jaggar 1901, Effinger 1934
Brachiopoda undetermined	–	–	–	Y	–	–	–	–	Racay pers. obs.
Phylum Mollusca	**Y**	**–**	**–**	**Y**	**–**	**–**	**–**	**–**	**–**
Mollusca: Class Bivalvia (clams, oysters, etc.)	**Y**	**–**	**–**	**Y**	**–**	**–**	**–**	**–**	**–**
Camptonectes sp.	–	–	–	Y	–	–	–	–	Tweet pers. obs.
Ostrea sp.*	–	–	–	Y	–	–	–	–	Robinson and Davis 1995
Tancredia sp.	–	–	–	Y	–	–	–	–	Jaggar 1901, Effinger 1934
Undetermined clams	–	–	–	Y	–	–	–	–	Racay pers. obs.
Undetermined oysters	–	–	–	Y	–	–	–	–	Jaggar 1901, Effinger 1934
Bivalvia undetermined	Y**	–	float	Y	–	–	–	–	Tweet pers. obs.

*"Ostrea" is often used broadly for any fossil oyster; Liostrea or Deltoideum are more likely (S. Holland, pers. comm., July 2019).

**It is possible that one or more of the bivalve occurrences found as float and attributed to the Stockade Beaver Shale Member may actually derive from a higher unit.

Table A-1 (continued). Fossil taxa reported from DETO in stratigraphic context. References are provided where appropriate. If a taxon is present in a given formation at a locality that can be placed within DETO, that cell is marked "Y" and given a blue fill. If there is some question about the stratigraphy or presence of a taxon, the cell is marked "?" and given a yellow fill. A null record is marked "–" with no color fill.

Taxon	Jss	Jsh	Jsl	Jsr	Jm	Kl	Ta	U	References
Mollusca: Class Cephalopoda (squids, octopuses, *Nautilus*, etc.)	**–**	**–**	**–**	**Y**	**–**	**–**	**–**	**–**	**–**
Cephalopoda: Subclass Ammonoidea (ammonites)	**–**	**–**	**–**	**?**	**–**	**–**	**–**	**–**	**–**
Ammonidea undetermined	–	–	–	?	–	–	–	–	Graham 2008
Cephalopoda: Order Belemnitida (belemnites)	**–**	**–**	**–**	**Y**	**–**	**–**	**–**	**–**	**–**
Pachyteuthis densus	–	–	–	Y	–	–	–	–	Bowen 1961
Belemnitida undetermined	–	–	float	Y	–	–	–	–	Jaggar 1901, Effinger 1934, Holbeck 1996, Racay and Tweet pers. obs.
Other invertebrates	**Y**	**–**	**–**	**Y**	**–**	**–**	**–**	**–**	**–**
Unspecified shells	Y	–	–	Y	–	–	–	–	Jaggar 1901, Effinger 1934, Graham 2008, Racay pers. obs.
FOSSIL VERTEBRATES	**–**	**–**	**–**	**Y**	**–**	**–**	**–**	**Y**	**–**
Ray-finned fish or juvenile marine reptile	–	–	–	Y	–	–	–	–	Racay pers. obs., Pagnac and Welsh 2018
"Dinosaur bone"	–	–	–	–	–	–	–	Y	Joyner cited in Rogers 2007
Undetermined bone	–	–	–	Y	–	–	–	–	Tweet pers. obs.
ICHNOFOSSILS	**–**	**Y**	**–**	**–**	**–**	**?**	**–**	**–**	**–**
General bioturbation	–	Y	–	–	–	–	–	–	Rautman 1978
Possible invertebrate burrows	–	Y	–	–	–	?	–	–	Tweet pers. obs.
Possible sauropod tracks	–	Y	–	–	–	–	–	–	Racay pers. obs.

*"*Ostrea*" is often used broadly for any fossil oyster; *Liostrea* or *Deltoideum* are more likely (S. Holland, pers. comm., July 2019).

**It is possible that one or more of the bivalve occurrences found as float and attributed to the Stockade Beaver Shale Member may actually derive from a higher unit.

Appendix B: Outside Repositories of DETO Fossils

This list incorporates those institutions that are known to be repositories of DETO fossils, or are potential repositories, as of June 2019. The list has been assembled through a combination of literature searches and online museum collections databases.

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

SCIENCE MUSEUM OF MINNESOTA
120 Kellogg Blvd W
St. Paul, MN 55102
(651) 221-9444
https://www.smm.org/
science@smm.org

Appendix C: Paleontological Resource Law and Policy

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

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 earth's crust, that are of paleontological interest and that provide information about the history of life on earth.*

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

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

Paleontological resources are considered park resources and values that are subject to the "no impairment" standard in the National Park Service Organic Act (1916). In addition to the Organic Act, PRPA will serve as a primary authority for the management, protection and interpretation of paleontological resources. 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.

Surveys—will be set up to document potential fossil localities. All sites will be documented with the use of GPS and will be entered into the park GIS database. Associated stratigraphic and depositional environment information will be collected for each locality. A preliminary faunal list will be developed. Any evidence of poaching activity will be recorded. Rates of erosion will be estimated for the site and a monitoring schedule will be developed based upon this information. A NPS Paleontological Locality Database Form will also be completed for each locality. A standard version of this form will be provided by the Paleontology Program of the Geologic Resources Division upon request, and can be modified to account for local conditions and needs.

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

Cyclic monitoring—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 erosion. The use of shelters draws attention to the fossils and increases the risk of vandalism or theft, but also provides opportunities for interpretation and education.

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

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

Patrols—may be increased in areas of known fossil resources. Patrols can prevent and/or reduce theft and vandalism. The scientific community and the public expect the NPS to protect its paleontological resources from vandalism and theft. In some situations a volunteer site stewardship program may be appropriate (for example, the "Paleo Protectors" at Chesapeake & Ohio Canal National Historical Park).

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

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

Related Laws, Legislation, and Management Guidelines

National Park Service Organic Act

The NPS Organic Act directs the NPS to manage units

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

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

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

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

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

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.

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

Section SEC. 6302 states

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

<u>NPS Director's Order-77, Paleontological Resources Management</u>

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 monitoring, 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.

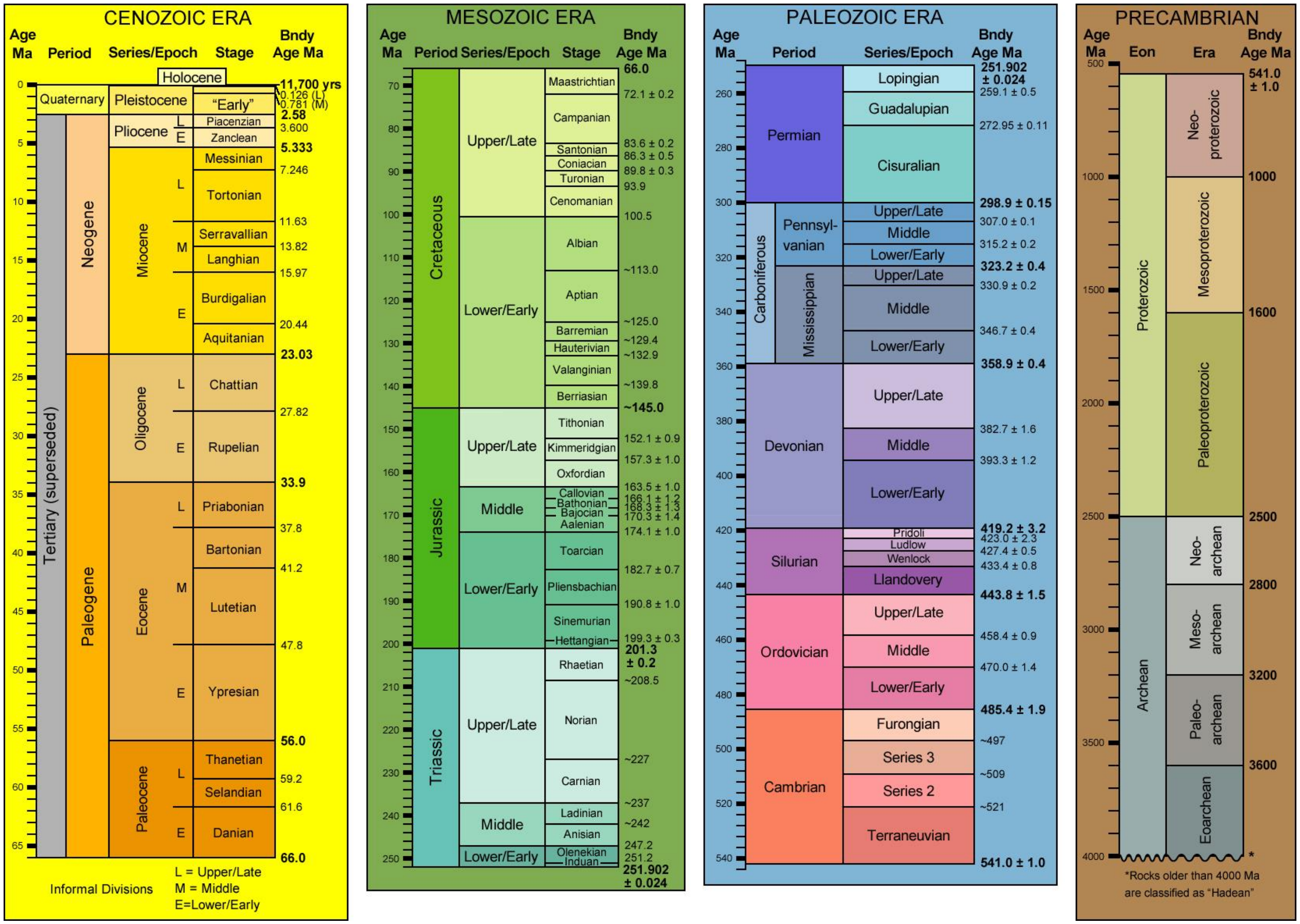
Condition Assessment and Cyclic Prospecting

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 D: Geologic Time Scale



Ma=Millions of year old. **Bndy Age**=Boundary Age. Colors are standard USGS colors for geologic maps. Modified from 1999 Geological Society of America Timescale (https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf). Dates and additional information from International Commission on Stratigraphy update 2018/08 (http://www.stratigraphy.org/index.php/ics-chart-timescale) and USGS Fact Sheet 2007-3015 (https://pubs.usgs.gov/fs/2007/3015/).

NPS 109/159706, August 2019

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U.S. Department of the Interior

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