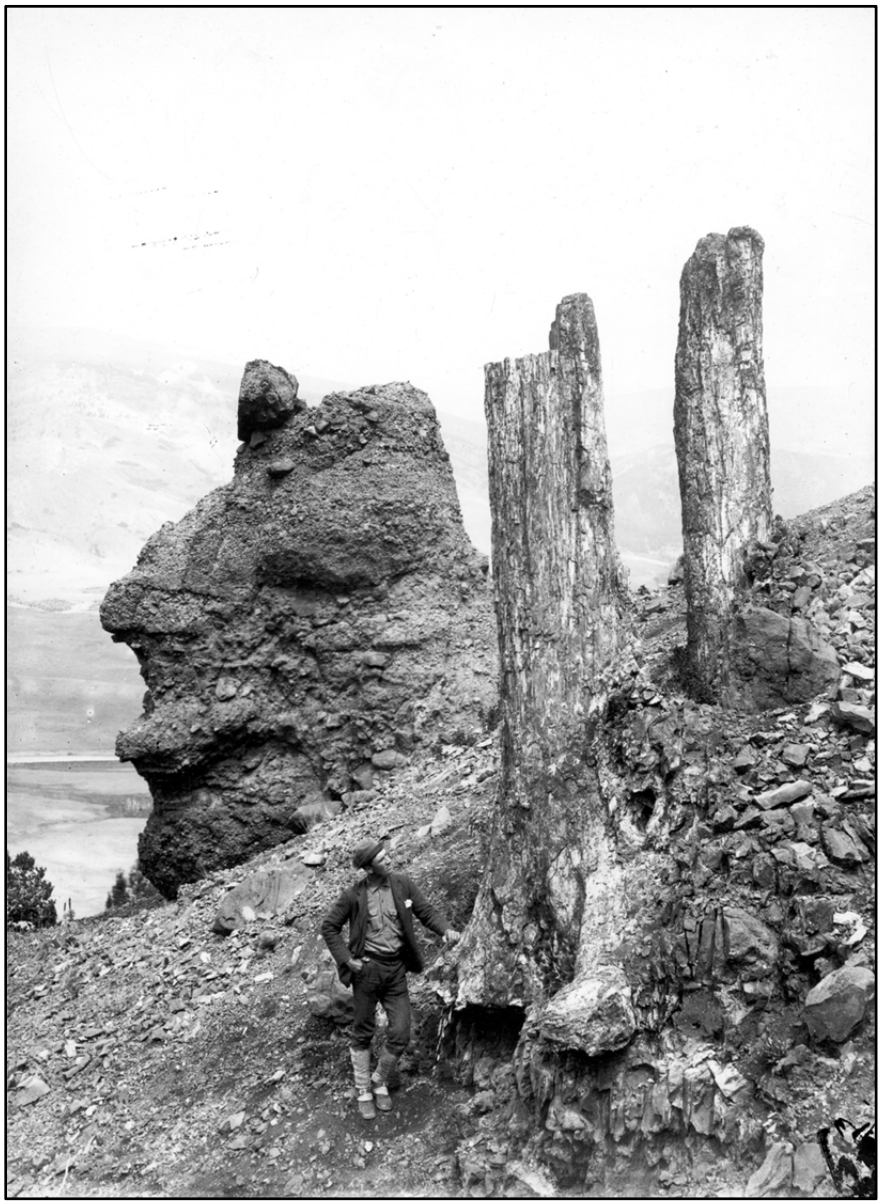
National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Paleontological Resource Inventory and Monitoring

Greater Yellowstone Network

Natural Resource Technical Report NPS/GRYN/NRTR—2013/794



ON THE COVER

A photo of Specimen Ridge in Yellowstone National Park (YELL) taken circa 1890 shows two upright stumps of the conifer *Pityoxylon aldersoni* in what is now known as the Lamar River Formation. Specimen Ridge is one of several notable paleobotanical sites in YELL, hosting the remains of multiple forests that existed near twin chains of volcanoes during the Eocene.

Photograph: U.S. Geological Survey

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NOTE:

This report provides baseline paleontological resource data to National Park Service administration and resource management staff. The report contains information regarding the location of non-renewable paleontological resources within NPS units.

It is *not* intended for distribution to the public.

August 2013

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

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Executive Summary

Paleontological resources (fossils) are any remains of past life preserved in a geologic context. Paleontological resources are non-renewable resources found in at least 240 National Park System units. Despite the abundance and diversity of these resources throughout the National Park Service (NPS), until recently, few parks have had adequate baseline paleontological resource data.

The NPS National Inventory and Monitoring (I&M) Program and the NPS Geologic Resources Division have developed various strategies to provide parks with the baseline paleontological resource data necessary for greater understanding and appropriate management of these resources. This report presents a paleontological resource summary for the parks of the Greater Yellowstone Network (GRYN). The summary was compiled through extensive literature reviews and interviews with park staff and professional geologists and paleontologists. Preliminary paleontological resource management recommendations are also included for each park. Summaries have now been prepared for all of the 32 NPS I&M Networks.

The parks of the GRYN have some of the best fossil records in the National Park System, with every significant division of the Phanerozoic Eon represented by fossils except for the Silurian, Oligocene, and possibly the Pliocene (see the appendix for a geological timescale). The oldest, well-documented reports of fossils come from the 1870s, in both the eventual Grand Teton National Park (GRTE) and Yellowstone National Park (YELL), although it is thought that mountain men had known of the petrified forests of YELL since the first half of the 19th century. The geology and paleontology of GRTE, John D. Rockefeller, Jr. Memorial Parkway (JODR), and YELL were first described in detail in a landmark U.S. Geological Survey monograph from 1899. The geology and paleontology of Bighorn Canyon National Recreation Area (BICA) were first described shortly thereafter, in the first decade of the 20th century. Since that time, the geology and paleontology of Bighorn Canyon, the Tetons and Jackson Hole (GRTE and JODR), and YELL have been the subjects of numerous publications. The rocks of GRTE, JODR, and YELL are the source for the type or name-bearing fossils of at least 190 taxa, primarily marine invertebrates and Eocene plants. The three park areas (BICA, GRTE/JODR, and YELL) have overlapping and complimentary stratigraphy from the Middle Cambrian (approximately 515 Ma [million years ago]) to the early Late Cretaceous (approximately 90 Ma), with two broadly equivalent sets of formations: one shared by the Wyoming side of BICA, GRTE/JODR, and southern YELL, and one shared by the Montana side of BICA and northern YELL. Localized but still related formations make up the rest of the Cretaceous and the Cenozoic. Fossils from GRYN units can be found at several museums and universities across the United States, with the largest collection at the National Museum of Natural History. Connections between paleontological resources and cultural resources are known from the middle Holocene to the present. Archeological finds with a paleontological component are common in the network, but the GRTE/JODR and YELL areas were not favored for settlement because of the climate, particularly the harsh winters.

Of the four GRYN units, fossils from GRTE and YELL are best known. BICA has substantial fossil resources as well, but it has been overlooked in comparison, in part because of its remoteness.

JODR's fossil resources are least known because it is the most recent (established in 1972) and it is somewhat "hidden," by being sandwiched between two paleontological heavyweights (GRTE and YELL) and by usually being discussed with GRTE. The fossils of the GRYN units are dominated by common Paleozoic marine fossils (such as microbial structures, brachiopods, bryozoans, trilobites, crinoids, and enigmatic forms), Jurassic and Cretaceous marine invertebrates (mostly mollusks), and Quaternary paleoecological fossils (such as diatoms, spores, pollen, and packrat middens); examples of all three categories are found in BICA, GRTE/JODR, and YELL. GRTE and YELL also have significant Cretaceous paleobotanical records. BICA's fossil record is distinguished by the presence of Middle and Upper Jurassic vertebrate tracks and swim traces. GRTE's fossil record is distinguished by its Miocene mammals. YELL has the most abundant and diverse fossils in the network, and is best known for its Eocene plant fossils, including abundant foliage and petrified logs and stumps. Together, the fossil records of the four GRYN units give an excellent picture of the area's biota from the middle Cambrian to the present.

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Dedication

We dedicate the Greater Yellowstone Inventory and Monitoring Network Paleontological Resource Inventory and Monitoring report to two individuals who exemplify leadership in resource preservation and stewardship, Laura Joss (below, left) and Sue Consolo-Murphy (below, right). Currently the Deputy Regional Director, Chief of Staff for the NPS Intermountain Regional Office, Laura has been instrumental in supporting paleontological resource management and research during her assignments at Yellowstone National Park, Wyoming, and Arches National Park, Utah. From the beginning of her career with the NPS at Badlands National Park, South Dakota, Sue has been aware of the importance of scientific management of paleontological resources. She has worked in three of the Greater Yellowstone Network parks including Yellowstone National Park and her current position as Chief of Science and Resource Management at Grand Teton National Park and the John D. Rockefeller, Jr. Memorial Parkway. Our thanks to Laura and Sue for their many contributions to the NPS throughout their careers.





Introduction

Paleontological resources, or fossils, are any remains of past life preserved in geologic context. There are two main types of fossils: body fossils and trace fossils. Body fossils are the physical remains of an actual organism (shells, bones, teeth, plant leaves, etc.), while trace fossils (burrows, coprolites, footprints, trackways, etc.) preserve evidence of an organism's activity or behavior. Fossils are non-renewable natural resources that possess scientific, educational, and interpretive value. In the National Park Service (NPS) there are three fossil context categories: *in situ* (fossils found in rock layers), in museum collections, or in cultural resource contexts (building stones, archeological resources, historic documents, and ethnographic legends or stories). This report addresses fossil discoveries in all of these contexts.

The establishment of baseline paleontological resource data is essential for the appropriate management of fossils found within National Park System units. Although at least 240 units have been identified with paleontological resources, few parks have adequate baseline paleontological resource data.

In conjunction with the NPS Geologic Resources Division (GRD) and the NPS Inventory and Monitoring (I&M) Program, paleontological resource inventories have been initiated in dozens of parks and are further described in the Methodology and Inventory Strategies section of this report. This report presents paleontological resource inventory and monitoring data compiled for the parks of the Greater Yellowstone I&M Network (GRYN).

The Greater Yellowstone Network includes four NPS areas in northern Wyoming, southern Montana, and eastern Idaho as shown in Figure 1: Bighorn Canyon National Recreation Area (BICA), Grand Teton National Park (GRTE), John D. Rockefeller, Jr. Memorial Parkway (JODR) (administered through GRTE and usually discussed with it), and Yellowstone National Park (YELL). The GYRN includes some of the largest NPS units in the lower 48 states: the smallest is JODR at 9,622.30 ha (23,777.22 acres), and the largest is YELL at 898,317.43 ha (2,219,790.71 acres), larger than the state of Delaware. All four units were established primarily in recognition of their natural resource values, and GRTE and YELL are among the most well-known parks of the NPS. Together, the NPS units of the GRYN protect substantial portions of the relatively intact Greater Yellowstone Ecosystem and surroundings. All four units have noteworthy geology and significant paleontological resources, and the three largest units (BICA, GRTE, and YELL) are among the most fossiliferous units in the NPS.

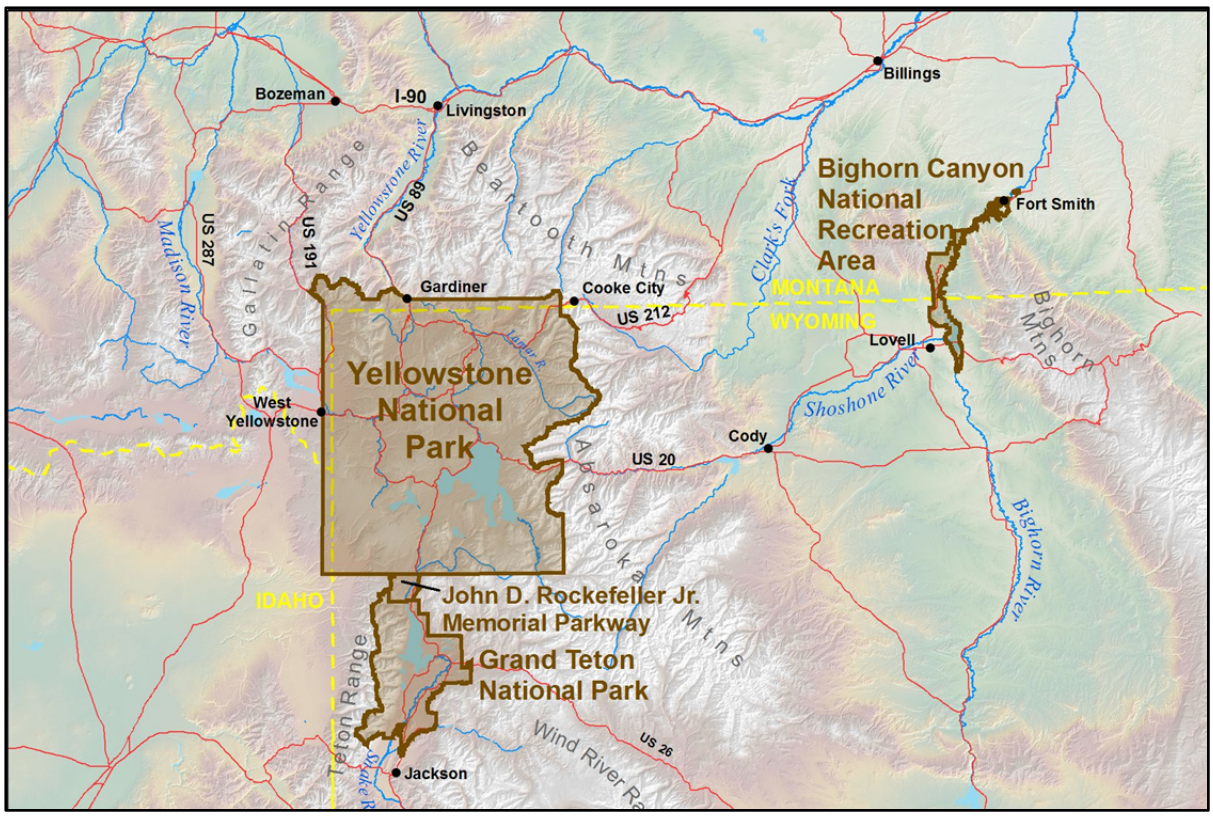


Figure 1. Map of Greater Yellowstone Network parks. [Courtesy GRYN Staff.]

GRYN Geological Background

The geologic history of the GRYN (discussed in greater detail in the individual park summaries that follow) is among the best and most complete in the NPS. BICA, GRTE, and YELL include some of the oldest rocks in the NPS, and BICA, GRTE, JODR, and YELL together contain excellent overlapping and complementary rock records from the Middle Cambrian to the present. The Paleozoic and Mesozoic rocks are primarily a record of shallow marine and coastal terrestrial deposition near the western margin of North America. Subduction and related tectonic activity along the west coast built out the continent to the west and raised western North America by the end of the Cretaceous, ending the cycle of marine transgressions (advances) and regressions (retreats). The Cenozoic of the GRYN has been marked by significant volcanic activity, particularly during the Eocene (Absaroka Volcanic Supergroup) and Pleistocene (Yellowstone Group and other rocks of the Yellowstone Plateau volcanic field).

The oldest exposed rocks in the GRYN are from the Archean (4.0 to 2.5 Ga [billion years ago]). A variety of intrusive igneous and high-grade metamorphic rocks from this era can be found on the flank of East Pryor Mountain in BICA, within the Teton Range in GRTE, and in the Beartooth and Gallatin mountains in YELL. These rocks began as part of the Wyoming Province, one of the ancient building blocks of the North American continent. Extensive deformation has rendered them difficult to interpret, but it appears that the Archean rocks of YELL and GRTE show the presence of several smaller crustal blocks that became firmly bound to the Wyoming

Province and each other by roughly 2.6 Ga. There is evidence for modern-style plate tectonics by roughly 2.68 Ga. Following the assembly of the Wyoming Province, the GRYN park units have been relatively distant from plate margins and thus have only been affected indirectly by large-scale plate tectonics. A lengthy depositional hiatus followed the Archean rocks; the period between approximately 2.6 Ga and 515 Ma is represented only by rare igneous dikes in the GRYN parks.

This great hiatus ended during the Cambrian with the approach of a shallow sea, known as the Sauk Sea. The arrival of the sea is represented by the widespread Flathead Sandstone, a coastal sandstone. It is succeeded by the Gros Ventre Formation and Gallatin Limestone, or their equivalents. These formations record the progress of marginal marine and deeper marine deposition as the shoreline fluctuated, and include diverse Cambrian assemblages of sponges, brachiopods (lamp shells), trilobites, some early echinoderms, conodonts (extinct eel-like chordates), and various enigmatic extinct shelled forms. Stromatolites and other microbial structures and invertebrate trace fossils are also commonly found. Over time, the marine waters became generally deeper, but the record is cut off at some point in the Late Cambrian by a period of erosion. Middle and Upper Cambrian rocks are exposed in BICA, GRTE, and YELL.

The Ordovician, Silurian, and Devonian (approximately 485 to 359 Ma) are sparsely represented in the GRYN parks, with two episodes of deposition found in BICA, GRTE, and YELL. The older rocks belong to the Bighorn Dolomite, another widespread Western formation. It was deposited between approximately 450 and 445 Ma under a shallow sea. At this time, the GRYN parks were near the equator, and the world was undergoing a change from “greenhouse” to “icehouse” conditions. Although a robust fossil assemblage is known from this formation, it is not particularly fossiliferous in the GRYN parks. Another extended episode of erosion and nondeposition prevented the preservation of any Silurian rocks. The rock record resumes in the Late Devonian with the Darby Formation and equivalent Jefferson and Three Forks formations, dating to between approximately 383 and 372 Ma. These rocks represent another interval of dominantly shallow marine deposition. A variety of sponges, corals, bryozoans (moss animals), brachiopods, gastropods, and echinoderms populated the seafloor.

The Upper Devonian rocks are the first in an exceptional series of formations that present over 300 million years of history with few substantial gaps. At its most complete, in GRTE, the record goes from the Late Devonian into the Eocene, and it is likely that the only major absences are the Late Permian and probably the Middle Triassic. For most of this history, into the Late Jurassic, the basic configuration featured a shallow sea covering or near at least part of the GRYN parks, advancing and retreating from what is now the west, but would then have been more northwest. During the more dominantly marine phases of deposition, marine life was abundant, leaving behind many body and trace fossils. One of the most fossiliferous units is the Madison Group or Limestone, deposited during the Early and Middle Mississippian as part of a marine transgression across much of the northwestern United States. Rocks from this unit preserve a wealth of marine invertebrates in BICA, GRTE, and especially

YELL. By this time in the Paleozoic, the corals, brachiopods, bryozoans, trilobites, and crinoids (sea lilies) common in older seas were joined by diverse mollusks, particularly bivalves, nautiloid and ammonite cephalopods, and gastropods. A brief depositional hiatus after the deposition of the Madison limestones resulted in an episode of cave and void formation, later expanded into larger caves during the late Cenozoic, as seen at BICA.

Similar marine fossils are found in BICA, GRTE, and YELL in the succeeding Amsden Formation, a primarily marine Mississippian-Pennsylvanian formation with notably time-transgressive deposition: it was deposited by a marine transgression that spread slowly across Wyoming from the west, giving its rocks substantially different ages from west to east. It was followed by coastal terrestrial deposition in the form of the Tensleep Sandstone of BICA, GRTE, and southern YELL, and the Quadrant Sandstone of northern YELL. These Upper Pennsylvanian formations record the presence of a large coastal dune field. Fossils are sparse in these formations, but foraminifera (amoeba-like protists that form “shells”) have been recovered from BICA, GRTE, and YELL. The GRYN was then near 10°N, and may have resembled the modern Qatar Peninsula in the Persian Gulf.

The Permian and Triassic are marked by several large-scale and numerous smaller transgression-regression cycles, producing a complex interval of intertonguing lithologies representing different coastal and nearshore settings deposited under a warm, arid climate. The Permian section is particularly complex, with tongues of three formations in western Wyoming: the Park City Formation is predominately carbonate rocks and was deposited in mudflat and shallow shelf settings; the Phosphoria Formation is composed of phosphatic shales, carbonaceous rocks, and cherts, deposited in deeper marine basins; and the Shedhorn Sandstone is composed of eolian and beach sandstone. Fossils are found in these rocks in GRTE and YELL, particularly fish teeth and bones. Fossils are much rarer in the rocks of the succeeding Triassic, represented primarily by the Lower Triassic Dinwoody Formation and Lower and Upper Triassic Chugwater Formation. The Lower Triassic rocks include evidence of multiple transgression-regression cycles, but the Upper Triassic rocks are terrestrial. In the BICA area, the Permian and Triassic rocks below the Chugwater Formation represent more insoluble interfingering, and are identified as the “grab bag” Goose Egg Formation.

The Early Jurassic is poorly known in the parks of the GRYN, being represented only by a small unfossiliferous exposure of the Nugget Sandstone in GRTE. This is a remnant of a much larger dune system, the bulk of which spread through the Four Corners. Marine deposition returned during the Middle and early Late Jurassic, leaving some of the most fossiliferous rocks of the network parks in the form of the Gypsum Spring and Sundance formations of southern BICA, GRTE, JODR, and southern YELL, and the roughly equivalent Ellis Group of northern BICA and northern YELL. A shallow sea known as the Sundance Sea arrived from the northwest and advanced and retreated several times. During marine deposition, marine invertebrates flourished, including a characteristic assemblage of bivalves, belemnite cephalopods, and crinoids found in all four GRYN units. During periods of marine

regression, dinosaurs and other vertebrates left tracks in the coastal regions and in shallow water, as seen at BICA.

With the final retreat of the Sundance Sea in the early Late Jurassic, a sustained period of terrestrial deposition began, lasting about 50 million years. The Jurassic portion is represented by the Morrison Formation, and the Early Cretaceous portion is represented by the Cloverly Formation in southern BICA, GRTE, JODR, and southern YELL, and the Kootenai Formation in northern BICA and YELL. These formations were predominantly deposited by fluvial and lacustrine processes in a variety of channel, floodplain, and lake settings. The Morrison and Cloverly formations are famous for their terrestrial fossils, particularly their abundant and diverse dinosaur fossils, but to date the terrestrial rocks have been only sparsely fossiliferous in the four units of the GRYN. YELL has yielded some terrestrial and freshwater invertebrates, as well as some pieces of petrified wood and dinosaur bone. BICA has diverse trace fossils from the Morrison Formation, and is near some important Cloverly and Morrison localities in the Bighorn Basin.

A complex and controversial interval of rocks above the main bodies of the Cloverly and Kootenai formations represents the approach of the final shallow continental sea to submerge central North America. This sea, known as the Western Interior Seaway or Cretaceous Interior Seaway, was a major feature of the geography of North America for much of the Cretaceous, at its greatest extent bisecting the landmass into eastern and western sections and connecting the Arctic Ocean to the Gulf of Mexico. Seaway deposition often resulted in thick, dark marine shales with occasional pulses of coarser sediment and thin beds of bentonite, the remains of layers of volcanic ash. In the GRYN parks, near the western margin of the seaway, marine deposition existed for approximately 30 million years, between approximately 100 and 70 Ma, although in GRTE, JODR, and YELL marine deposition was mostly over by about 85 Ma. All four units share the marine Thermopolis and Mowry shales and the marginal marine to terrestrial Frontier Formation. The Thermopolis and Mowry shales are not heavily fossiliferous in the GRYN units, but there are significant paleobotanical remains in the Frontier Formation at GRTE and YELL. The stratigraphic column at BICA ends in the Frontier Formation, with the exception of Quaternary sediments, but younger rocks are found near it, and GRTE, JODR, and YELL also include a variety of younger formations. The last dominantly open marine formation in the GRYN units, the Cody Shale, yields mollusk fossils in JODR and YELL. Although the Seaway persisted to the east for another 15 million years, high sedimentation rates eventually joined by tectonic uplift prevented it from making more than an occasional geologically brief return to the western GRYN units. Instead, a sequence of marginal marine and coastal plain rocks was deposited, rich in coal and plant fossils, until the marine influence had disappeared by roughly the end of the Cretaceous. GRTE and northwestern YELL (Mount Everts) have the best rocks from this timeframe among the GRYN units, with strong plant micro- and macrofossil records.

Near the end of the Cretaceous, as the Seaway was retreating, western North America was affected by a major mountain-building event known as the Laramide Orogeny. The

Laramide Orogeny is thought to have resulted from a marine plate subducting at a shallow angle under western North America and interacting with the underside of the North American plate, causing large blocks of crust to rise. This process lasted into the Eocene, creating much of the current form of the Rocky Mountains. The Bighorn Basin and its surrounding mountains are Laramide structures. An example of the dramatic and relatively rapid activity can be seen in the contact of the Harebell Formation and Pinyon Conglomerate, formations found in GRTE and YELL. The two formations are separated by at most a few million years, yet the contact is an angular disconformity where in some locations the Harebell Formation beds are perpendicular to the Pinyon Conglomerate beds.

With the advent of higher, more mountainous geography similar to the present, the geological record in the GRYN units becomes more discontinuous, with formations covering small areas instead of entire states. BICA has no formal formations from the entire Cenozoic, although at one time it may have: the Bighorn Basin was mostly filled with sediment during the Paleogene, but more recent uplift has resulted in the erosion of almost all of it. YELL's Cenozoic section is limited to the Eocene and the past few million years; however, the eastern half of GRTE and adjacent areas of Jackson Hole and the vicinity include a number of Cenozoic formations, in part because the area has been a long-standing depositional basin (the Teton Range itself has only risen in the past few million years). GRTE, JODR, and YELL all have rocks related to the Absaroka volcanic field, active between approximately 55 and 44 Ma. The heart of the volcanic field consisted of two subparallel chains of stratovolcanoes, each roughly 240 km (150 miles) long. The chains crossed YELL from the northwest to the southeast, with a basin approximately 30 to 50 km (20 to 30 miles) wide between them. The volcanoes left a thick sequence of flows, intrusions, and associated layers of sedimentary rocks composed of volcanic debris, today known as the Absaroka Volcanic Supergroup. Several of the formations are fossiliferous, especially the Sepulcher and Lamar River formations of northern YELL. These two formations represent complex and dynamic systems of rivers, lakes, mudslide deposits, and airfall volcanic debris. They are famous for their paleobotanical records, including abundant foliage of horsetails, ferns, conifers, and angiosperms, petrified wood and logs, and even "fossil forests" of *in situ* stumps.

Oligocene rocks are not exposed at the surface in any GRYN unit, but the Miocene is well-represented at GRTE, primarily by the Colter and Teewinot formations. The Colter Formation is composed of volcanic debris, indicating the presence of a volcano near what is now the north end of Jackson Lake between about 20 and 13 Ma. The succeeding Teewinot Formation was deposited in a large lake of more recent vintage. Both have produced a variety of small mammal fossils, and the lacustrine rocks of the Teewinot Formation also produce diatoms (a type of algae with cell walls of silica), pollen, and invertebrates. A local volcanic center, the Jackson Hole volcanic field, was active around 8 Ma, but much more extensive volcanism arrived near the end of the Miocene in the form of the Yellowstone Hotspot.

The Yellowstone Hotspot is first known to be active as the source of the voluminous Columbia River Plateau flood basalts,

approximately 16 Ma. As the North American plate has moved west-southwest, volcanic activity stemming from the hotspot has formed a trail of eruptive centers becoming younger going northeast. Following the Columbia River Plateau eruptions, the hotspot's activity has been more constrained, expressed in comparatively smaller caldera-forming events. It first entered the immediate vicinity of the GRYN near the end of the Miocene, creating the Heise volcanic field in eastern Idaho between 7 and 4 Ma. Evidence of these eruptions is either absent or buried at YELL, but small remnants of the 5.51 Ma Conant Creek Tuff can be found in GRTE and JODR. By about 2 Ma, the hotspot was beneath the Yellowstone Plateau. From here, it has produced three major calderas: the Huckleberry Ridge Caldera (Huckleberry Ridge Tuff) at about 2.05 Ma; the Henry's Fork Caldera (Mesa Falls Tuff) at about 1.3 Ma; and the Yellowstone Caldera (Lava Creek Tuff) at about 0.64 Ma. These enormous eruptions profoundly altered the geography of YELL and the vicinity. The mere presence of the hotspot created general uplift in northwestern Wyoming and helped promote glaciation in YELL, and may have spurred movement on the Teton Fault. This structure has produced 6 to 9 km (4 to 6 miles) of vertical offset through subsidence and uplift, beginning 3±1 Ma.

Glaciation has been common at high elevations in the GRYN units over the Quaternary, from about 2.6 Ma to the present. Alpine glaciation was periodically present in the Bighorn Mountains, although apparently not in BICA itself, and GRTE, JODR, and YELL all show sediments and geographic features illustrating their glacial histories. Small glaciers are present in GRTE today. It is unknown how many major glaciations occurred during the Quaternary; it is common to think in terms of the Pinedale glaciation (approximately 35,000 to 16,000 or 14,000 years ago), the Bull Lake glaciation (approximately 150,000 to 100,000 years ago), and more nebulous pre-Bull Lake events, which are regarded collectively. Glacial activity sculpted the surface and is responsible for features such as the Jackson Lake basin. Between periods of glaciation, lakes and bogs appeared in the GRTE-YELL area, and preserved diatoms, pollen, spores, fragments of plants, and invertebrates in their sediments. The sediments now offer detailed pictures of the climates and biota of the interglacial stages, and have been widely studied since the 1970s. Caves have also sheltered fossil remains, especially via packrat middens in YELL. Humans have been present in the GRYN since essentially the end of major glaciation between 14,000 and 10,000 years ago. It appears that humans have generally been uncommon in the Tetons and the plateaus of YELL, perhaps because of the harsh winters and lesser abundance of the largest game animals. These higher regions may have served as a refuge during the middle Holocene, when the climate on the plains to the east was warmer and drier.

Organized geological study began first in the GRTE-YELL area in the early 1870s, with major paleontological investigations published in 1899. The first geologic publications on the BICA area were produced in the first decade of the 1900s. Most fossils collected from these areas are now in the National Museum of Natural History; smaller collections are present in a handful of other institutions. Paleontological research at BICA has been sporadic; in most cases, fossils have been reported as an aside to another topic, or as one of a number of occurrences, but recently there

has been some dedicated work on its Jurassic trace fossils and Quaternary packrat middens. Research at GRTE (with JODR as adjunct) has been a steady stream, with a handful of relevant publications every decade, although the last ten years has been fairly quiet. Research at YELL has been episodic. Following the 1899 monograph, there was a large burst in interest in the Eocene fossil plants in the 1970s and 1980s, and the past 40 years have seen a number of publications on Quaternary fossils. Many of its other fossil resources have only been touched on in passing since 1899, though. All four NPS units of the GRYN are fertile ground for further paleontological exploration; BICA is almost virgin ground, and the large, rugged YELL-JODR-GRTE corridor (about seven-tenths the size of the state of Connecticut) doubtless harbors many unexplored outcrops.

Collectively, the paleontological resources of the GRYN park units contribute to a greater understanding of the history of life on earth. Continued paleontological resource inventories will serve to expand this ever-widening base of paleontological knowledge represented throughout the NPS. Although at least 240 parks have already been identified as containing paleontological resources, much of what is to be known about the history of life on earth remains to be discovered.

Report Organization and Methodology

This report summarizes the paleontological resources of park units in the Greater Yellowstone Inventory & Monitoring Network (GRYN). The report consolidates baseline paleontological resource data for each network park to support management operations, planning, and science-based decision making as required by NPS management policies and the Paleontological Resources Preservation Act (2009). This section of the report details the organization of the report and summarizes how the report was written.

Each network report includes an executive summary, introduction with geologic background, methodology chapter (this chapter), description of resource management strategies, and individual park narratives, which are described below. Some network reports include information for non-network parks, those that are not officially part of the Inventory and Monitoring Network, but are within the geographic boundaries of the network. Such parks were included in instances where paleontological resources were documented. For more information regarding different paleontological resource inventory strategies, refer to the chapter on Paleontological Resource Management.

This 2013 Greater Yellowstone Network Paleontological Resource Inventory and Monitoring report represents a substantial update of the previous GRYN paleontology summary completed by Koch and Santucci (2003). The methodology section below describes the changes between the original report and this document.

Organization of the Park Narratives

Each park narrative contains the following sections.

Geologic Background

The Geologic Background section contains basic geographic information for the park and lists pertinent geology and paleontology references. A brief geologic history is included to provide context for the fossils discovered within or near the park.

Sources of Paleontological Resources

The Sources of Paleontological Resources section reviews each fossil-bearing rock unit within the park. The history of paleontological resource field work in the park is summarized. A brief geologic description is included as well as the scope and significance of paleontological resources known to occur within the park. The section is organized stratigraphically from oldest rock unit to youngest.

Potential Sources of Paleontological Resources

The rock units listed in the Potential Sources section are units mapped within the park that potentially contain fossils. Although fossils have not been previously documented from those units within the park, fossils have been discovered within those units at localities outside of the park. In some cases, the lack of documented fossils within a particular park or a specific geologic unit in a park, may simply be due to the fact that field inventories for fossils have never been undertaken in the park. As with the Sources section, the geologic units are listed stratigraphically from oldest to youngest.

Park Collections

The Park Collections section summarizes museum collections of fossils associated with the park. Such collections may be housed within the park or in external museum or

university repositories. Fossil collections maintained by the park may include specimens discovered both from within and outside the park. It is important to recognize that the park's museum Scope of Collections may include fossils from localities outside of the park boundaries. Regional museums and other outside repositories may curate fossils collected within the park prior to or subsequent to the park's establishment. Both contexts are included in the report. The Smithsonian Institution National Museum of Natural History maintains significant collections of National Park Service fossils, and the U.S. Geological Survey has much relevant documentary material.

Cultural Resource Contexts

Resource stewardship strategies and management plans typically address paleontological resources that are known to occur within the rocks of the park. Fossils may also occur in a variety of cultural resource contexts, including: in association with archeological resources, ethnographic stories and legends, prehistoric and historic structures, or other documented historical occurrences. Fossils may be found as tools, jewelry, spiritual or ceremonial objects, or other cultural objects in archeological sites. A few ethnographic stories and legends told by American Indians and "mountain men" of the American West incorporate fossils. Building stones often contain fossils. In addition, archives, journals, memoirs, and photographs include other historical accounts of fossils in NPS areas. Kenworthy and Santucci (2006) summarizes such occurrences and provides examples.

Paleontological Resource Management, Preliminary Recommendations

In addition to geology and paleontology content, the authors suggest "next steps" for paleontological resource management and stewardship at each park. The recommendations are based on discussion with park staff and other geologists or paleontologists, or as part of broader NPS paleontological resource management strategies. These strategies are summarized in the next chapter. Parks may choose to address the recommendations based upon available staff time, training, and budget. Contact the NPS Geologic Resources Division for technical assistance or further guidance.

Literature Cited and Additional References

Each park narrative has a bibliography that is divided into two sections. References mentioned in the park narrative are included in the Literature Cited section. References discovered during the data-mining process that maybe of secondary value or interest are listed in the Additional References section. These publications were not included in the narrative, but are relevant to the park, commonly containing additional detail beyond the scope of the narrative.

Data Sets

The Data Sets section includes a list of research projects, museum collections, NPS Geologic Resources Inventory-produced geologic map data, archives, or other files and information relevant to the fossils of a particular park.

Figures, Photographs and Graphics

The first network-based paleontological resource summaries (completed between 2002 and 2011) did not include figures, photographs or other graphics aside from the report cover and a network map. This second generation of

Inventory & Monitoring Network-based paleontological resource inventory reports include basic geologic maps, stratigraphic columns, paleontological resource summary tables, and photographs for each park when available. Many of the geologic maps are adapted from the NPS Geologic Resources Inventory (GRI) map data for each park. These data are available in GIS format and support accompanying GRI reports, all of which are available from the GRI publications page: http://www.nature.nps.gov/geology/inventory/gre_publications.cfm. The stratigraphic columns illustrates a compiled section of all the rock units mapped in the park along with rock unit name, age, map symbol, thickness, and lithology. Also new to the second generation network-based reports is a summary table listing all the fossiliferous geologic units within the park, fossils collected within the park and the inferred depositional environment. Photographs of park fossils are inserted where appropriate.

Report Methodology

Inventory & Monitoring Network-based paleontological resource inventories compile baseline paleontological resource data for each of the parks within a particular network, and as such, require considerable research and data mining. To minimize costs, field work is not normally conducted as part of the report preparation process. This section details the research methodology and report preparation, review, publication, and distribution for network-based paleontological inventories.

Between 2002 and 2011, network-based inventories were completed for all of the 32 I&M networks. In 2001, the Northern Colorado Plateau Network technical committee supported a modest funding proposal to develop a prototype paleontological resource inventory for the network. Koch and Santucci (2002) represented the first attempt at compiling baseline paleontological resource data at a network level. That report laid the foundation upon which similar work would be completed for each of the I&M Networks in the National Park System. Between 2002 and 2006, 13 network reports were completed using small amounts of funds provided from each network. Funding from the NPS I&M Program was designated to systematically complete the remaining 19 reports between 2006 and 2011.

This second-generation report represents a substantial revision of the original Greater Yellowstone Network summary, completed in 2003 (Koch and Santucci 2003). This updated network-based paleontological resource inventory report represents a new template and format for future revisions to other network summaries.

Although field work is still not typically performed in association with network-based reports, in a few instances, field work complimented the original park inventories. In some cases, field work has been conducted in response to recommendations provided in the initial network-based paleontological resource inventory reports. Any new field data are incorporated into the updated reports.

Research

One of the most important components of any paleontological resource inventory is an intensive literature search and data mining. The American Geological Institute's GeoRef is the leading database for geology references, indexing more than 3.3 million references to North American geology dating back to the

1660s. To compile the appropriate literature base for this report, the authors conducted intensive GeoRef searches for general and park-specific publications.

Additional databases or information catalogs include the NPS Integrated Resource Management Applications (IRMA) portal (https://irma.nps.gov/app/portal/home), the U.S. Geological Survey (USGS) library system (http://library.usgs.gov/) and publications warehouse (http://pubs.er.usgs.gov/), as well as museum, university, and other institutional libraries and archives.

The literature search also includes un-published material, or "gray literature," from park files, museum archives, local newspapers, field notes, and other sources. In addition to literature searches, interviews with park staff, university faculty, geologists from the USGS and state geological surveys, and even local amateur geologists or paleontologists can often yield unpublished information regarding park paleontological resources. These interviews frequently result in capturing data that might otherwise be undocumented and potentially lost or unrecognized.

Report authors develop a comprehensive list of geologic units within each park by consulting published geologic maps and other sources. Geologic maps show the types of rocks and the associated geological formations within a park area. These maps alone can often suggest the potential for paleontological resources to occur within a park. The NPS GRI Program is producing standardized digital geologic map data (GIS) for all I&M Program parks. When available, the updated network-based paleontological resource inventory reports adapt GRI map data for each of the parks.

The nomenclature for geologic formations evolves over time and can differ based upon different geological interpretations. To maximize consistency with other NPS geology products, this report generally followed the geologic nomenclature used in GRI maps and report when they were available. The USGS maintains the National Geologic Map Database (NGMDB), which includes a searchable lexicon of valid geologic formation names (http://ngmdb.usgs.gov/Geolex/geolex_home.html). This lexicon provides a basic summary for each formation, summarizes current and past usage of the various formation names found in the literature, and provides an annotated bibliography for each formation.

Narrative

Information from these various sources is compiled into a narrative report for each park. The narrative is organized according to the scheme detailed earlier in this section.

Review

The park narratives and compiled report are extensively peer reviewed by professional geologists or paleontologists, as well as NPS staff from each park and the NPS Geologic Resources Division. Upon completion of a compiled, draft report, network staff have the opportunity to provide review. Network staff also determine if the previous technical review was adequate for publication.

Publication and Distribution

The peer-reviewed, network-approved reports are published in the NPS Natural Resource Report series. To minimize production costs, hard copies are not generally produced. The reports are distributed in PDF format to park

and network staff and available to other NPS staff via the Integrated Resource Management Applications portal. Report reviewers and paleontologists working in the parks may also receive copies. The reports are not intended for, or distributed to, the general public due to the sensitive nature of paleontological resource locality information.

Literature Cited

Kenworthy, J. P. and V. L. Santucci. 2006. A preliminary inventory of NPS paleontological resources found in cultural resource contexts, part 1: General overview. Pages 70-76 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Accessible online at: http://www.nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf

Koch, A. L. and V. L. Santucci. 2003. Paleontological resource inventory and monitoring: Greater Yellowstone Network. TIC# D-1025. National Park Service, Denver, Colorado.

Koch, A. L. and V. L. Santucci. 2002. Paleontological resource inventory and monitoring: Northern Colorado Plateau Network. TIC# D-206. National Park Service, Denver, Colorado.

Inventory and Monitoring Strategies and Resource Management Guidance

Paleontological Resource Inventory Strategies

In order to better document fossil occurrences and to provide baseline paleontological resource data to NPS areas, the NPS GRD and the NPS I&M Program have established three paleontological resource inventory strategies. These strategies include: comprehensive park-specific inventories, Service-wide thematic inventories, and I&M Network-based summaries.

Comprehensive Park-Specific Surveys

Comprehensive park-specific surveys identify all known paleontological resources within a single NPS unit. A team of specialists from within the NPS and from educational institutions and cooperators work with the targeted park to identify and address all aspects of its paleontological resources. The surveys commonly include sections addressing: park geology, paleontological resources inventory (species list and other compilations), localities, museum collections and curation, interpretation, management and protection, and recommendations. Paleontological resource training for park staff is an important component of many comprehensive park paleontological resource inventories.

Park-specific comprehensive paleontological resource inventories have been completed for Amistad National Recreation Area (Visaggi et al. 2009), Arches National Park (Swanson et al. 2005), Bighorn Canyon National Recreation Area (Santucci et al. 1999), Chesapeake and Ohio Canal National Historical Park (Clites and Santucci 2010), Death Valley National Park (Nyborg and Santucci 1999), Santa Monica Mountains National Recreation Area (Koch et al. 2004), Walnut Canyon National Monument (Santucci and Santucci 2001), Yellowstone National Park (Santucci 1998, the first park to have such a survey completed), and Zion National Park (DeBlieux et al. 2005). As of April 2013, similar paleontological resource inventories are currently underway at Big Bend National Park, Glacier Bay National Park and Preserve, and Golden Gate National Recreation Area.

Service-wide Thematic Inventories

Service-wide thematic paleontological resource inventories compile data regarding specific types of paleontological resources that occur in parks throughout the NPS. These reports offer brief summaries of each occurrence of a particular type or category of fossils documented within a particular park. These reports are based primarily on literature review and communication with park staff and professional geologists and paleontologists.

The first thematic paleontological resource inventory identified 19 NPS units that preserve fossil vertebrate tracks (Santucci et al. 1998). Subsequent discoveries have increased the number of parks identified with fossil vertebrate tracks to 25 and warranted an updated publication (Santucci et al. 2006). Another thematic inventory identified paleontological resources associated with NPS caves in 35 parks (Santucci et al. 2001). Service-wide thematic inventories have also been initiated for fossil fish (Hunt et al. 2006), fossil coprolites (Hunt et al. 2012), fossil packrat middens (Tweet et al. 2012), and fossils found in cultural resource contexts (Kenworthy and Santucci 2006).

Inventory and Monitoring Network-Based Summaries

Network-based paleontological resource inventories compile baseline paleontological resource data for each of the parks within a particular I&M Network. Between 2002 and 2011, network-based inventories were completed for all 32 I&M Networks. This report represents an overhaul and substantial revision of the GRYN report, the second I&M Network report completed. For more information on the content of network-based summaries and how they are completed, refer to the Report Organization and Methodology chapter. Citations for the completed reports are listed in the Literature Cited section.

A comprehensive summary report is currently being developed to present an overview and highlights of the 10-year effort to document fossils throughout the NPS using the network-based strategy. Four summary reports are planned, including reports that present data based on geologic time, taxonomy, museum collections and fossil type specimens. These reports are anticipated to be finalized in 2013.

Paleontological Resource Monitoring Strategies

Following the compilation of baseline paleontological resource inventories, monitoring of fossil localities represents the next phase in paleontological resource management. Santucci and Koch (2003) presented a preliminary strategy for monitoring paleontological resources and identified natural and human-related impacts to fossils. Santucci et al. (2009) presented a more comprehensive strategy for paleontological resource monitoring that identified natural and human-related stressors upon paleontological resources, described five vital signs, and provided examples of study design and case studies. The five vital signs include: (1) erosion, geologic factors; (2) erosion, climatic factors; (3) catastrophic geohazards; (4) hydrology/bathymetry; and (5) human access/public use. The vital signs discussions provide detailed recommendations for resource managers, incorporating expertise, personnel, and equipment needed, approximate cost, and labor intensity. Santucci et al. (2009) is one chapter in the Geological Monitoring manual that provides guidance for monitoring various geologic resources and processes. The manual (Young and Norby 2009) was published by the NPS Geologic Resources Division and Geological Society of America.

Paleontological Resource Management Legislation and Guidance

I&M Network reports such as this are meant to provide network parks with sound baseline paleontological resource data that can stimulate future research, interpretation, education, or resource management projects. Science-based management of resources identified through these inventories is mandated by many NPS policies including the newly enacted Paleontological Resource Preservation Act (PRPA).

2009 Paleontological Resource Preservation Act

The Paleontological Resource Preservation Act (P.L. 111-11; "PRPA") was signed into law on March 30, 2009 as part of the Omnibus Public Lands Act of 2009. PRPA will serve as explicit authority for the management, protection and interpretation of paleontological resources in parks. PRPA regulations are currently (March 2012) being finalized by the National Park Service, Bureau of Land Management, and the U.S. Forest Service. PRPA specifically provides the NPS with the following mandates to enhance paleontological resources stewardship:

- §6302 calls for the management and protection of paleontological resources using scientific principles and expertise. The NPS should develop plans for inventory, monitoring, and the scientific and educational use of paleontological resources. Planning should emphasize interagency coordination and collaboration and where possible include non-federal partners, the scientific community, and the public.
- §6303 calls for the establishment of education programs to increase public awareness about the significance of paleontological resources.
- §6304 calls for the development of a specific permit for the collection of NPS paleontological resources. The new legislation and other existing authorities clarify and reaffirm issues of property ownership, accountability, access and confidentiality of locality information associated with the management of NPS paleontological resources.
- §6305 calls for the curation of NPS paleontological resources, along with any associated data or records, in approved repositories.
- §6306 provides clarity regarding prohibited acts involving paleontological resources and specifies criminal penalties associated with these prohibited acts.
- §6307, along with other existing authorities, enables the NPS to seek civil penalties and restitution for the violation of any prohibited activities involving paleontological resources.
- §6308 provides the NPS a confidentiality provision with an exemption from the disclosure of any information associated with the nature and specific location of NPS paleontological resources.
- §6310 directs the Secretaries of the Interior and Agriculture to issue regulations appropriate to carry out the Act

NPS Management Policies

In addition to the PRPA, several other authorities influence the management of NPS paleontological resources. The 2006 National Park Service Management Policies (§1.4.6) stipulates that paleontological resources are considered park resources and values that are subject to the "no impairment" standard set

forth by the NPS Organic Act in 1916. Basic guidelines for management of paleontological resources are found in sections 4.8.2 and 4.8.2.1 of the 2006 NPS Management Policies (http://www.nps.gov/policy/MP2006.pdf).

Other Resources

Paleontological resource management issues were the subject of a Report of the Secretary of the Interior in May 2000, viewable online at: http://www.blm.gov/heritage/docum/fossilrpt.pdf. That report was prepared in response to a Congressional request for an assessment of the need for a unified federal policy on the collection, storage and preservation of fossils and for standards that would maximize the availability of fossils for scientific study.

The Paleontological Resources Management section of Natural Resource Management Reference Manual 77 provides guidance and additional information regarding the implementation and continuation of paleontological resource management programs (http://www.nature.nps.gov/rm77/paleo.cfm).

As described above, Santucci et al. (2009) provided guidance for paleontological resource monitoring.

The NPS manages more than 445,000 catalogued fossil specimens in collections across the country. Many thousands more specimens await cataloging. For information regarding fossils in museum collections, refer to the NPS Museum management handbook, particularly Part I, Appendix U (http://www.nps.gov/museum/publications/handbook.html).

Education and Outreach Opportunities

Fossils occupy an enduring place in the hearts and mind of the public, presenting excellent opportunities for education and outreach. These opportunities support provisions in the Paleontological Resources Preservation Act (above) as well as the NPS natural resource stewardship mission. The NPS Geologic Resources Division coordinates two fossil-related education and outreach opportunities with a national scope: National Fossil Day and the Junior Paleontologist program. National Fossil Day is a celebration organized to promote public awareness and stewardship of fossils, as well as to foster a greater appreciation of their scientific and educational value. Learn more at the NFD website: http://nature.nps.gov/geology/nationalfossilday/index.cfm. The Junior Paleontologist program (part of the Junior Ranger program) provides opportunities for children to explore the ways that paleontologists work, learn about earth's history, and protect fossils and the rocks in which they are found. For more information, visit the Junior Paleontologist program webpage: http://nature.nps.gov/geology/nationalfossilday/jrpaleo.cfm. Contact the Geologic Resources Division for information on how to participate in either program.

In conclusion, our knowledge of the fossil record is only as good as our previous field season. The potential for new paleontological discoveries is proportionally related to our understanding as managers and stewards of this non-renewable evidence of life from the past. We believe that the baseline information provided in these reports and the resulting increased understanding of paleontological resources will inevitably result in paving the way for future fossil discoveries in NPS areas.

Literature Cited

Clites, E. C. and V. L. Santucci. 2010. Preliminary paleontological resource field survey: Chesapeake and Ohio Canal National Historical Park. Natural Resource Report NPS/NRPC/NRR—2010/197. National Park Service, Fort Collins, Colorado.

DeBlieux, D. D., J. A. Smith, J. L. McGuire, J. I. Kirkland, and V. L. Santucci. 2005. Zion National Park paleontological survey. Utah Geological Survey, Salt Lake City, Utah.

Hunt, R. K., V. L. Santucci, and J. P. Kenworthy. 2006. A preliminary inventory of fossil fish from NPS units. Pages 63-69 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available online at: http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/8%20Hunt%202.pdf. Accessed March 2012.

Kenworthy, J. P. and V. L. Santucci. 2006. A preliminary inventory of NPS paleontological resources found in cultural resource contexts, part 1: General overview. Pages 70-76 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available online at: http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed March 2012.

Koch, A. L., V. L. Santucci, and T. R. Weasma. 2004. Santa Monica Mountains National Recreation Area paleontological survey. NPS Geologic Resources Division, Denver, Colorado. Technical Report NPS/NRGRD/GRDTR—04/01. Available online at: http://nature.nps.gov/geology/paleontology/surveys.cfm. Accessed March 2012.

Nyborg, T. G. and V. L. Santucci. 1999. The Death Valley National Park paleontological survey. National Park Service, Geologic Resources Division, Denver, Colorado. Technical Report NPS/NRGRD/GRDTR—99/01. Available online at: http://nature.nps.gov/geology/paleontology/surveys.cfm. Accessed March 2012.

Santucci. V. L. 1998. The Yellowstone paleontological survey. Yellowstone Center for Resources, National Park Service, Yellowstone National Park, Wyoming. Report YCR-NR-98-1. Available online at: http://nature.nps.gov/geology/paleontology/surveys.cfm. Accessed March 2012.

Santucci, V. L. and A. L. Koch. 2003. Paleontological resource monitoring strategies for the National Park Service. *Park Science* 22(1):22-25. Available online at: http://www.nature.nps.gov/parkscience/index.cfm?ArticleID=16. Accessed March 2012.

Santucci, V. L. and V. L. Santucci, Jr. 1999. An inventory of paleontological resources

from Walnut Canyon National Monument, Arizona. *in* V. L. Santucci and L. McClelland, editors. Paleontological research volume 4. Technical Report NPS/NRGRD/GRDTR-99/03. National Park Service, Geologic Resources Division, Lakewood, Colorado. Available online at: http://nature.nps.gov/geology/paleontology/pub/grd4/nsp_paleo_vol4.pdf. Accessed March 2012.

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring *in situ* paleontological resources. Pages 189-204 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado. Available online at: http://nature.nps.gov/geology/monitoring/paleo.cfm. Accessed March 2012.

Santucci, V. L., A. P. Hunt, T. Nyborg, and J. P. Kenworthy. 2006. Additional fossil vertebrate tracks in National Park Service areas. Pages 152-158 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available online at: http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/21%20Santucci%20et%20al..pdf. Accessed March 2012.

Santucci, V. L., J. Kenworthy, and R. Kerbo. 2001. An inventory of paleontological resources associated with National Park Service caves. NPS Geologic Resources Division, Denver. Technical Report NPS/NRGRD/GRDTR-01/02. TIC# D-2231. Available online at: http://nature.nps.gov/geology/paleontology/pub/cavepaleo.pdf. Accessed March 2012.

Santucci, V. L., D. Hays, J. Staebler, and M. Milstein. 1999. A preliminary assessment of paleontological resources at Bighorn Canyon National Recreation Area, Montana and Wyoming. Pages 18–22 *in* V. L. Santucci and L. McClelland, editors. Paleontological Research Volume 4. Technical Report NPS/NRGRD/GRDTR-99/03. National Park Service, Geologic Resources Division, Lakewood, Colorado. Available online at: http://nature.nps.gov/geology/paleontology/pub/grd4/nsp_paleo_vol4.pdf. Accessed March 2012.

Santucci, V. L., A. P. Hunt, and M. G. Lockley. 1998. Fossil vertebrate tracks in National Park Service areas. *Dakoterra* **5**:107-114.

Tweet, J. S., V. L. Santucci, and A. P. Hunt. 2012. An inventory of packrat (*Neotoma* spp.) middens in National Park Service areas. Pages 355-368 *in* A. P. Hunt, J. Milàn, S. G. Lucas, and J. A. Spielmann, editors. Vertebrate coprolites. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 57.

Swanson, B. A., V. L. Santucci, S. K. Madsen, A. S. Elder, and J. P. Kenworthy. 2005. Arches National Park paleontological survey. NPS Geologic Resources Division, Denver, Colorado. Technical Report NPS/NRGRD/GRDTR—05/01.

Visaggi, C. C., J. G. Johnson, A. S. Johnson, J. P. Kenworthy, and V. L. Santucci. 2009. Paleontological resource survey: Amistad

National Recreation Area. Natural Resource Report NPS/NRPC/GRD/NRR—2009/133. National Park Service, Fort Collins, Colorado.

Young, R. and L. Norby, editors. 2009. Geological monitoring. Geological Society of America, Boulder, Colorado. Available online at: http://nature.nps.gov/geology/monitoring/index.cfm. Accessed March 2012.

Citations for I&M Network-Based Summaries

Citations are listed alphabetically by network

Appalachian Highlands Network (APHN)

Santucci, V. L., R. T. P. McKenna, J. P. Kenworthy, and T. Connors. 2008. Paleontological resource inventory and monitoring: Appalachian Highlands Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/080. National Park Service, Fort Collins, Colorado.

Arctic Network (ARCN)

Elder, W., V. L. Santucci, J. P. Kenworthy, R. B. Blodgett, and R. T. P. McKenna. 2009. Paleontological resource inventory and monitoring: Arctic Network. Natural Resource Technical Report NPS/NRPC/NRTR—2009/276. National Park Service, Fort Collins, Colorado.

Central Alaska Network (CAKN)

Santucci, V. L., R. B. Blodgett, W. P. Elder, J. S. Tweet, and J. P. Kenworthy. 2011. Paleontological resource inventory and monitoring: Central Alaska Network. Natural Resource Technical Report NPS/NRSS/NRTR—2011/510. National Park Service, Fort Collins, Colorado.

Chihuahuan Desert Network (CHDN)

Santucci, V. L., J. P. Kenworthy, and C. C. Visaggi. 2007. Paleontological resource inventory and monitoring: Chihuahuan Desert Network. National Park Service TIC# D-500.

Cumberland Piedmont Network (CUPN)

Hunt-Foster, R., J. P. Kenworthy, V. L. Santucci, T. Connors, and T. L. Thornberry-Ehrlich. 2009. Paleontological resource inventory and monitoring: Cumberland Piedmont Network. Natural Resource Technical Report NPS/NRPC/NRTR—2009/235. National Park Service, Fort Collins, Colorado.

Eastern Rivers and Mountains Network (ERMN)

Koch, A. L. and V. L. Santucci. 2004. Paleontological resource inventory and monitoring: Eastern Rivers and Mountains Network. TIC# D-265. National Park Service, Denver, Colorado.

Great Lakes Network (GLKN)

Hunt, R. K., J. P. Kenworthy, and V. L. Santucci. 2008. Paleontological resource inventory and monitoring: Great Lakes Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/120. TIC# D-65. National Park Service, Fort Collins, Colorado.

Greater Yellowstone Network (GRYN)

[Original Report] Koch, A. L. and V. L. Santucci. 2003. Paleontological resource inventory and monitoring: Greater Yellowstone Network. TIC# D-1025. National Park Service, Denver, Colorado.

[Updated Report] Tweet, J. S., V. L. Santucci, and T. Connors. 2013. Paleontological resource inventory and monitoring—

Greater Yellowstone Network. Natural Resource Technical Report NPS/NRR—2013/xxx. National Park Service, Fort Collins, Colorado.

Gulf Coast Network (GULN)

Kenworthy, J. P., V. L. Santucci, and C. C. Visaggi. 2007. Paleontological resource inventory and monitoring: Gulf Coast Network. TIC# D-750. National Park Service, Denver, Colorado.

Heartland Network (HTLN)

Hunt, R. K., J. P. Kenworthy, and V. L. Santucci. 2008. Paleontological resource inventory and monitoring: Heartland Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/132. TIC# D-66. National Park Service, Fort Collins, Colorado.

Klamath Network (KLMN)

Santucci, V. L. and J. P. Kenworthy. 2009. Paleontological resource inventory and monitoring: Klamath Network. Natural Resource Technical Report NPS/NRPC/NRTR—2009/208. TIC# D-22. National Park Service, Fort Collins, Colorado.

Mediterranean Coast Network (MEDN)

[Original Report] Koch, A. L. and V. L. Santucci. 2003. Paleontological resource inventory and monitoring: Mediterranean Coast Network. TIC# D-177. National Park Service, Denver, Colorado.

[Updated Report] Tweet, J. S., V. L. Santucci, and T. Connors. 2012. Paleontological resource inventory and monitoring: Mediterranean Coast Network. Natural Resource Technical Report NPS/MEDN/NRTR—2012/640. National Park Service, Fort Collins, Colorado

Mid-Atlantic Network (MIDN)

Kenworthy, J. P., C. C. Visaggi, and V. L. Santucci. 2006. Paleontological resource inventory and monitoring: Mid-Atlantic Network. TIC# D-800. National Park Service, Denver, Colorado.

Mojave Desert Network (MODN)

Santucci, V. L., A. L. Koch, and J. P. Kenworthy. 2004. Paleontological resource inventory and monitoring: Mojave Desert Network. TIC# D-305. National Park Service, Denver, Colorado.

Northeast Coastal and Barrier Network (NCBN)

Kenworthy, J. P. and V. L. Santucci. 2003. Paleontological resource inventory and monitoring: Northeast Coastal and Barrier Network. TIC# D-340. National Park Service, Denver, Colorado.

North Coast and Cascades Network (NCCN)

Fay, L. C., J. P. Kenworthy, and V. L. Santucci. 2009. Paleontological resource inventory and monitoring: North Coast and Cascades Network. Natural Resource Technical Report NPS/NRPC/NRTR—2009/250. National Park Service, Fort Collins, Colorado.

Northern Colorado Plateau Network (NCPN)

[Original Report] Koch, A. L. and V. L. Santucci. 2002. Paleontological resource inventory and monitoring: Northern Colorado Plateau Network. TIC# D-206. National Park Service, Denver, Colorado.

[Updated Report] Tweet, J. S., V. L. Santucci, T. Connors, and J. P. Kenworthy. 2012. Paleontological resource inventory and monitoring: Northern Colorado Plateau

Network. Natural Resource Technical Report NPS/NCPN/NRTR—2012/585. National Park Service, Fort Collins, Colorado.

National Capital Region Network (NCRN)
Kenworthy, J. P. and V. L. Santucci. 2004. Paleontological resource inventory and monitoring: National Capital Region. TIC# D-289. National Park Service, Denver, Colorado.

Northeast Temperate Network (NETN)
Tweet, J., V. L. Santucci, and J. P. Kenworthy. 2010. Paleontological resource inventory and monitoring: Northeast Temperate Network. Natural Resource Technical Report NPS/NRPC/NRTR—2010/326. TIC# 962/102111. National Park Service, Fort Collins, Colorado.

Northern Great Plains Network (NGPN)
Tweet, J. S., V. L. Santucci, and J. P. Kenworthy. 2011. Paleontological resource inventory and monitoring: Northern Great Plains Network. Natural Resource Technical Report NPS/NRPC/NRTR—2011/437. National Park Service, Fort Collins, Colorado.

Pacific Islands Network (PACN)
Hunt, R. K., V. L. Santucci and J. P. Kenworthy. 2007. Paleontological resource inventory and monitoring: Pacific Islands Network. TIC# D-24. National Park Service, Denver, Colorado.

Rocky Mountain Network (ROMN)
Koch, A. L., J. P. Kenworthy, and V. L. Santucci. 2004. Paleontological resource inventory and monitoring: Rocky Mountain Network. TIC# D-436. National Park Service, Denver, Colorado.

Southern Colorado Plateau Network (SCPN)
Tweet, J., V. L. Santucci, J. P. Kenworthy, and A. L. Mims. 2009. Paleontological resource inventory and monitoring: Southern Colorado Plateau Network. Natural Resource Technical Report NPS/NRPC/NRTR—2009/245. TIC# D-59. National Park Service, Fort Collins, Colorado.

Southeast Alaska Network (SEAN)
Santucci, V. L. and J. P. Kenworthy. 2008. Paleontological resource inventory and monitoring: Southeast Alaska Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/108. TIC# D-155. National Park Service, Fort Collins, Colorado.

Southeast Coast Network (SECN)
Tweet, J., V. L. Santucci, and J. P. Kenworthy. 2009. Paleontological resource inventory and monitoring: Southeast Coast Network. Natural Resource Technical Report NPS/NRPC/NRTR—2009/197. TIC# D-89. National Park Service, Fort Collins, Colorado.

San Francisco Bay Area Network (SFAN)
Elder, W. P., T. Nyborg, J. P. Kenworthy, and V. L. Santucci. 2008. Paleontological resource inventory and monitoring: San Francisco Bay Area Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/078. TIC# D-20. National Park Service, Fort Collins, Colorado.

South Florida-Caribbean Network (SFCN)
Toscano, M. A. , J. P. Kenworthy, and V. L. Santucci. 2010. Paleontological resource inventory and monitoring: South Florida /

Caribbean Network. Natural Resource Technical Report NPS/NRPC/NRTR—2010/335. National Park Service, Fort Collins, Colorado.

Sierra Nevada Network (SIEN)

Santucci, V. L. and J. P. Kenworthy. 2007. Paleontological resource inventory and monitoring: Sierra Nevada Network. Natural Resource Technical Report NPS/NRPC/NRTR—2007/053. TIC # D-21. National Park Service, Fort Collins, Colorado.

Sonoran Desert Network (SODN)

Tweet, J., V. L. Santucci, and J. P. Kenworthy. 2008. Paleontological resource inventory and monitoring: Sonoran Desert Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/130. TIC# D-58. National Park Service, Fort Collins, Colorado.

Southern Plains Network (SOPN)

Koch, A. L. and V. L. Santucci. 2003. Paleontological resource inventory and monitoring: Southern Plains Network. TIC# D-107. National Park Service, Denver, Colorado.

Southwest Alaska Network (SWAN)

Kenworthy, J. P. and V. L. Santucci. 2003. Paleontological resource inventory and monitoring: Southwest Alaska Network. TIC# D-93. National Park Service, Denver, Colorado.

Upper Columbia Basin Network (UCBN)

Kenworthy, J. P., V. L. Santucci, M. McNerney, and K. Snell. 2005. Paleontological resource inventory and monitoring: Upper Columbia Basin Network. TIC# D-259. National Park Service, Denver, Colorado.

General GRYN Information
Greater Yellowstone I&M Network:
http://science.nature.nps.gov/im/units/GRYN/index.cfm

Geological Survey Websites
American Geological Institute:
http://www.agiweb.org/

Geological Society of America:
http://www.geosociety.org/

Idaho Geological Survey:
http://www.idahogeology.org/

Montana Bureau of Mines and Geology:
http://www.mbmg.mtech.edu/

Wyoming State Geological Survey:
http://www.wsgs.uwyo.edu/

U.S. Geological Survey: http://www.usgs.gov/

Library Catalogs
Smithsonian Institution Research Information System: http://www.siris.si.edu/

U.S. Geological Survey Library Catalog:
http://library.usgs.gov/

WorldCat.org: http://www.worldcat.org/

Museums
National Park Service Museum Collections Catalog:
http://www.museum.nps.gov/splashsearch.htm

Smithsonian National Museum of Natural History Dept. of Paleobiology:
http://paleobiology.si.edu/

University of California Museum of Paleontology: http://www.ucmp.berkeley.edu/

Other Websites of Interest for GRYN Geology
Greater Yellowstone Science Learning Center:
http://www.greateryellowstonescience.org/

Montana Geological Society:
http://www.montanags.com/

Tobacco Root Geological Society:
http://trgs.org/

Wyoming Geological Association:
http://www.wyogeo.org/

Yellowstone Database:
http://refbase.wsulibs.wsu.edu/yellowstone/index.php

Resource Management/Legislation Documents
NPS 2006 Management Policies (§1.4; Park Management):
http://www.nps.gov/policy/mp/chapter1.htm

NPS 2006 Management Policies (§4.8.2.1; Paleontological Resources):
http://www.nps.gov/policy/mp/chapter4.htm

NPS 1998 Omnibus Management Act (paleontological resource summary):
http://www.nature.nps.gov/geology/paleontology/paleo_5_1/index.htm

NPS Natural Resource Management Reference Manual #77 (paleontology section):
http://www.nature.nps.gov/rm77/paleo.cfm

Assessment of Fossil Management on Federal & Indian Lands:
http://www.fs.fed.us/geology/fossil.pdf

National Park Service Paleontology Program Sites
NPS Geologic Resources Division:
http://www.nature.nps.gov/geology/

NPS GRD Geologic Resource Inventory Products (scoping summaries, GRI reports, digital geologic maps): http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

NPS Paleontology Program: http://www.nature.nps.gov/geology/paleontology/

NPS Park Paleontology Newsletter (published 1999-2004): http://www.nature.nps.gov/geology/paleontology/newsletter.cfm

I&M Network paleontological resource summary project website and PDFs of all reports (InsideNPS): http://inside.nps.gov/waso/custommenu.cfm?lv=4&prg=753&id=4518

NPS Technical Information Center (Denver, repository for technical (TIC) documents): http://etic.nps.gov/

Other Geology/Paleontology Tools

Bates, R. L. and J. A. Jackson, editors. American Geological Institute dictionary of geological terms (3rd edition). Bantam Doubleday Dell Publishing Group, New York.

NeoMap (Neogene Mammal Mapping Portal): http://www.ucmp.berkeley.edu/neomap/

Neotoma (Quaternary fossil database): http://www.neotomadb.org/

NOAA Paleoclimatology: http://www.ncdc.noaa.gov/paleo/paleo.html

Paleobiology Database (search for fossil taxonomy, localities, or geologic formations): http://paleodb.org/cgi-bin/bridge.pl

Paleontology Portal (general fossil info based on geographic location or geologic time): http://www.paleoportal.org/

University of California-Berkeley Museum of Paleontology online paleontology exhibits: http://www.ucmp.berkeley.edu/

U.S. Geological Survey digital state geology maps: http://tin.er.usgs.gov/geology/state/

U.S. Geological Survey Geologic Terms Glossary: http://www.nature.nps.gov/geology/usgsnps/misc/glossaryAtoC.html#A

U.S. Geological Survey Paleontological Terms Glossary: http://geology.er.usgs.gov/paleo/glossary.shtml

U.S. Geological Survey National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/

U.S. Geological Survey Geologic Names Lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/geolex_home.html

U.S. Geological Survey Geographic Names Information System (GNIS; search for place names and geographic features, and plot them on topographic maps or aerial photos): http://gnis.usgs.gov/

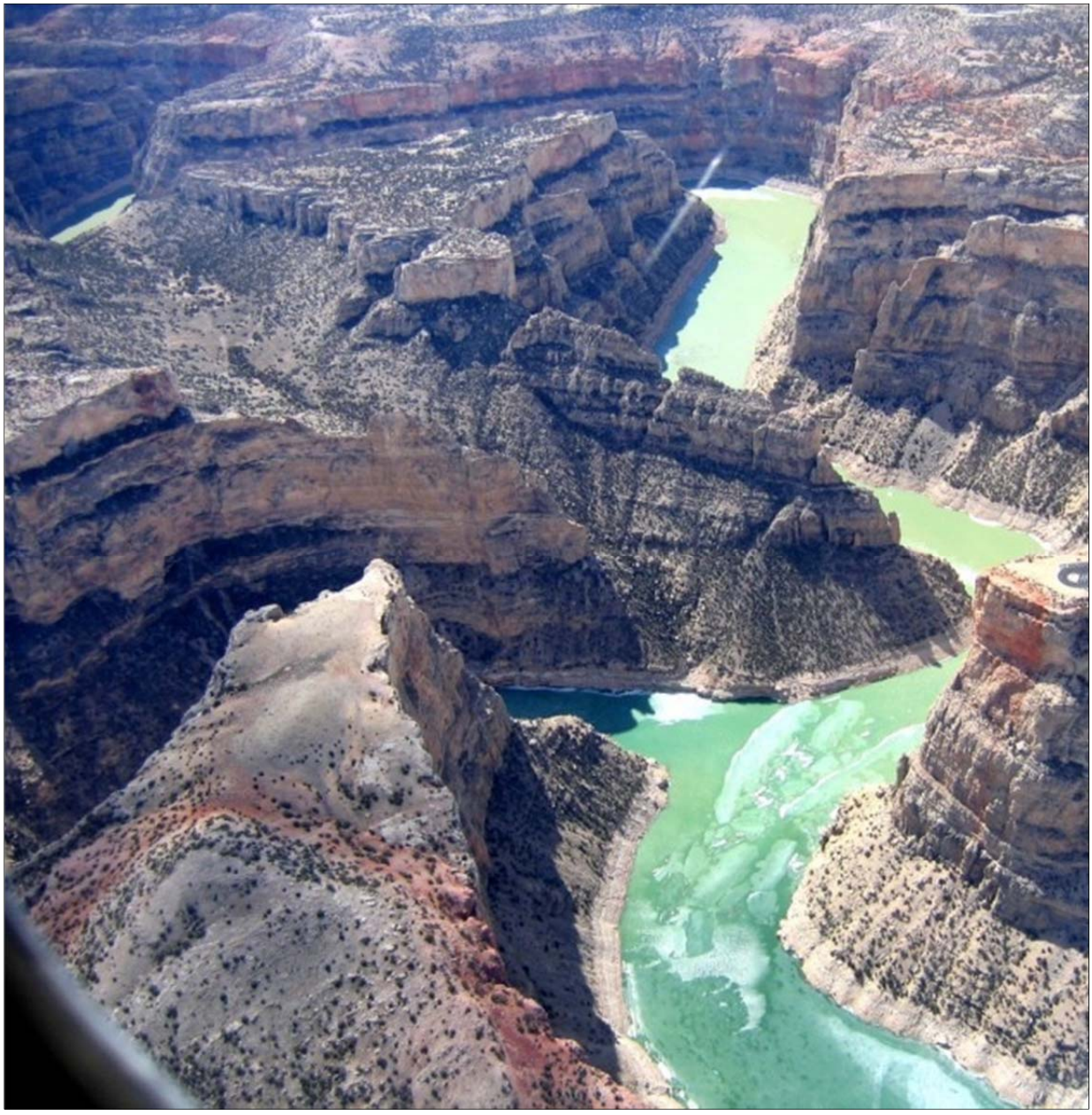
U.S. Geological Survey GeoPDFs (download searchable PDFs of any topographic map in the United States): http://store.usgs.gov (click on “Map Locator”).

U.S. Geological Survey Publications Warehouse (many USGS publications are available online): http://pubs.er.usgs.gov/

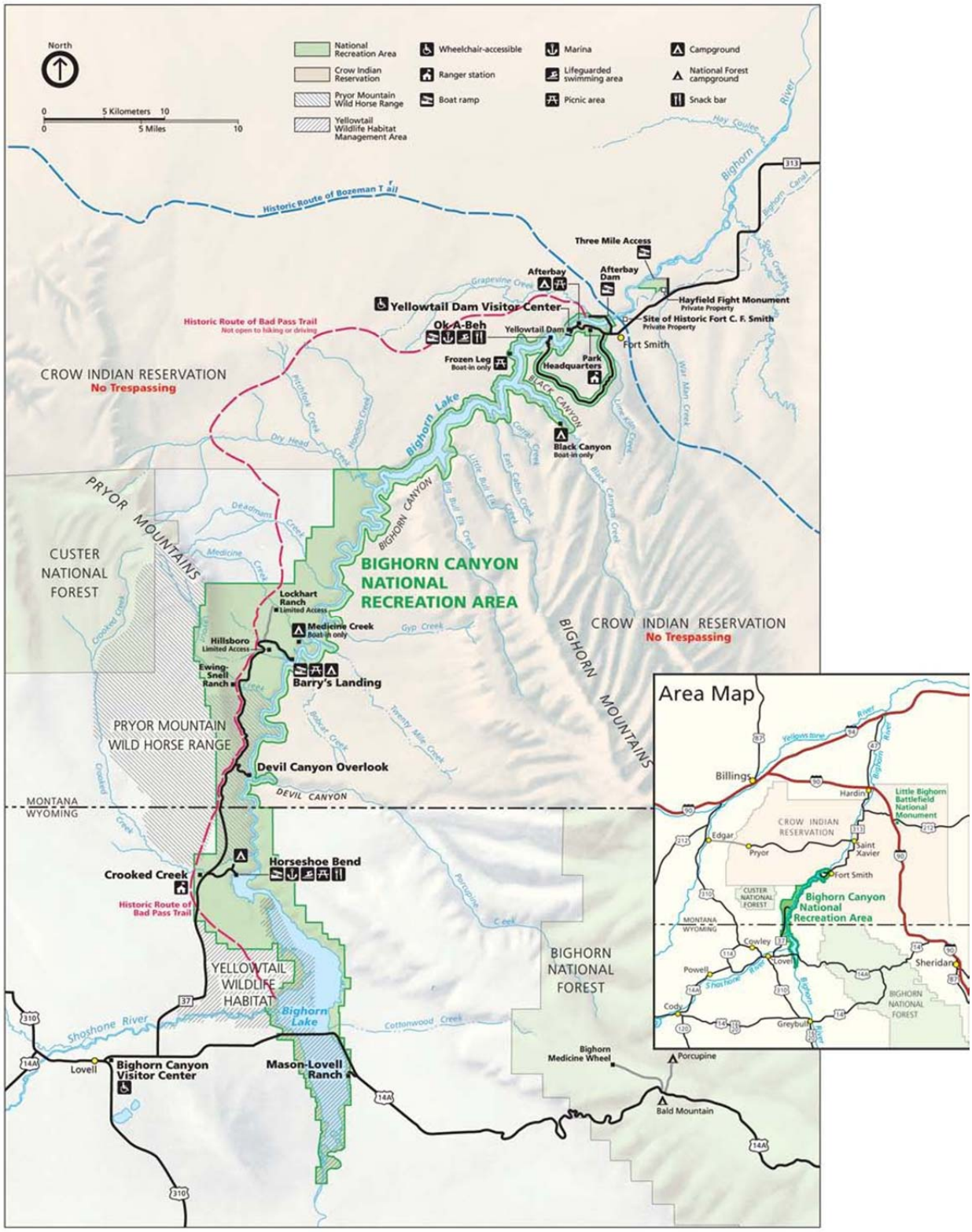
U.S. Geological Survey, description of physiographic provinces: http://tapestry.usgs.gov/Default.html

Bighorn Canyon National Recreation Area

Bighorn Canyon National Recreation Area (BICA) was established to protect Bighorn Lake Reservoir and the associated canyons along the Bighorn River (BICA Figure 1). BICA is known for its recreational opportunities, scenic landscape, and archeological and historical resources. BICA was established October 15, 1966. It encompasses 48,682.15 ha (120,296.22 acres), 27,717.27 ha (68,490.87 acres) of which are under Federal administration (BICA Figure 2). Approximately a third of its land is within the Crow Indian Reservation.



BICA Figure 1. Bighorn Canyon exposes many rock formations along its length (Photo credit:NPS).



BICA Figure 2. Geography of BICA (some areas are omitted; compare to the geologic map boundaries of BICA Figure 4) (NPS).

Executive Summary

BICA has diverse, but poorly known paleontological resources. With the exception of some Jurassic trace fossils and Quaternary packrat middens, fossils from the recreation area have generally been reported in passing. The oldest reports of fossils are found in geological descriptions of the area published in the first decade of the 20th century. The geology of BICA includes unfossiliferous Precambrian rocks, Cambrian and Ordovician rocks, a relatively complete sequence from the Late Devonian to the early Late Cretaceous, and Quaternary sediments (see the appendix for a geologic time scale). Most of the geologic formations are fossiliferous within BICA. Geological research in the BICA area can be confusing, because it includes two states, and the geologists active in the two states prefer different terminology for the same rocks. A geologic survey or mapping effort incorporating both the Montana and Wyoming sides of the recreation area could go a long way to simplifying matters for the future, but anyone working with the literature needs to be aware of the dichotomy. Regardless of the terminology involved, the bedrock of BICA is composed almost entirely of fossiliferous and potentially fossiliferous rocks. Practically any site with exposed bedrock is potentially fossiliferous.

Fossils from the Paleozoic in BICA mostly belong to marine invertebrates and microscopic forms. Although several Paleozoic formations are fossiliferous in the recreation area, most reports of fossils are confined to the Madison Group and, somewhat unusually, the Amsden Formation, which is typically sparsely fossiliferous. The Madison Group has the most fossiliferous Paleozoic rocks in BICA, with a diverse marine assemblage including organisms such as corals, bryozoans (moss animals), brachiopods (lamp shells), crinoids (sea lilies), and sharks, and further investigation of BICA's Paleozoic rocks would probably find many more fossils in this unit. Mesozoic fossils in the recreation area include both marine fossils (mostly invertebrates) and terrestrial trace fossils and vertebrate remains. Marine invertebrates are common in Middle and Upper Jurassic rocks, and differ from the Paleozoic assemblages by being dominated by mollusks, such as bivalves, cephalopods, and gastropods. Jurassic rocks have also preserved terrestrial and coastal trace fossils from plants, invertebrates, and vertebrates, among them reptile swim traces, dinosaur tracks, and enigmatic traces. Dinosaur bones are also known from BICA. Quaternary fossils from the recreation area include part of a series of packrat middens from the Pryor Mountains that has been used to study the tree communities in the region since approximately the end of the Pleistocene, and a vertebra from an extinct musk ox. There is great potential for Quaternary fossils to be found in caves in the recreation area because they have been found in caves in the immediate vicinity.

BICA maintains a collection of fossils (135 catalog numbers), most of which are invertebrates. One outside institution, the Cincinnati Museum Center in Ohio, is supposed to curate some ichnofossils from the recreation area, but there is some question about the current location of this material. At this time, there is no record of fossils from cultural contexts in BICA, but examples are known from just outside of the recreation area and it would not be unusual for them to be found within it.

Although there are many reports of fossils from BICA, research specifically devoted to fossils from the recreation area only began in the 1990s, so there are many areas that have not been explored and topics that have not been studied. BICA is probably most in need of field surveys of the paleontology, to establish a more accurate baseline of knowledge instead of the current record of mostly incidental discoveries. Given what is already known, BICA may have outstanding fossil resources. Further investigations of the paleoclimatological implications of Quaternary fossils, and discoveries of additional Quaternary fossils, are likely to be useful for park management of natural resources.

Paleontological Resource Management, Preliminary Recommendations

- Recreation area staff should be encouraged to observe exposed sedimentary rocks and associated eroded deposits for fossil material while conducting their usual duties. To promote this, they should also 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, recreation area staff should take advantage of them, if funding and time permit.

- Staff should photodocument 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 by artificially accelerated natural processes or direct human impacts. There is some known human interference at this time in the recreation area: Santucci et al. (1999) reported that unauthorized collecting has occurred at Sykes Mountain. A Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. 2009).

- A BICA-specific geologic mapping project should be undertaken. Potential benefits include resolving some of the issues in formation terminology and locating additional fossil sites.

- Field surveying for paleontological resources is necessary, and could be undertaken in conjunction with geological investigation.

- The fossils in BICA's collections should be described in greater detail. It would be especially helpful if more detailed geological provenance information, such as formation, can be established. This might be a suitable project for a GeoCorps America participant.

- Fossils found in a cultural context should be documented like other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g., subject to the Archeological Resources Protection Act [ARPA] or the Native American Graves Protection and Repatriation Act [NAGPRA]) and should be regarded as such until otherwise established. The Geologic Resources Division can coordinate additional documentation/research of such material.

- Fossil packrat middens are typically found in dry caves and rock shelters, and resemble piles or mounds of plant material with a dark glossy coating of crystallized packrat urine. Fossil middens can provide important paleoecological information. If one is located, there are several midden researchers who may be contacted. The Geologic Resources Division maintains a list of active researchers and can facilitate communication between the recreation area and these researchers.

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

Geologic Background

BICA occupies an area spanning the Montana-Wyoming border, along the boundaries of Big Horn and Carbon counties in Montana, and in northern Big Horn County, Wyoming. The recreation area is situated between the Pryor Mountains on the west and the northern Bighorn Mountains on the east, in the northern part of the Bighorn Basin. The Bighorn River flows north through the recreation area on its way to joining the Yellowstone River in Montana. The area had featured a deeper canyon, but the construction of Yellowtail Dam during the 1960s near the northern end of BICA has flooded part of the canyon system, creating Bighorn Lake. The nearest large city is Billings, Montana, which is about 68 km (42 miles) northwest of the northern tip of BICA.

The geology and paleontology of BICA and its immediate vicinity in the northern Bighorn Basin have been described in a number of publications, although until recently most fossil occurrences were only noted in passing. Relevant publications include Darton (1904, 1906), Fisher (1906), Reeside (1923), Thom et al. (1935), Blackstone (1940), Heiny and Walter (1954), Henbest (1954, 1956), Tinsley et al. (1954), Richards (1955), Imlay (1954, 1956), Knetchel and Patterson (1956), Stewart (1958), Moberly (1960), Campau and Garrett (1962) and articles therein, Sandberg and Klapper (1967), Ostrom (1970), Sando and Mamet (1974), Gordon (1975), Sando et al. (1975), Palmquist (1983), Reheis (1985, 1987), Uhlir et al. (1988), Vice and Utgaard (1989), Lopez (1995), Chadwick (1999), Engelmann (1999), Engelmann and Hasiotis (1999), Santucci et al. (1999, 2001), Lyford et al. (2002, 2003), Koch and Santucci (2003), Dunagan and Turner (2004), Harris and Lacovara (2004), Hasiotis (2004), Parrish et al. (2004), Turner and Peterson (2004), Mickelson et al. (2005a, 2005b, 2006a), NPS (2006), KellerLynn (2011), and Tweet et al. (2012). Maps illustrating at least part of the recreation area include Andrews et al. (1947), Hamilton and Paulson (1968), Agard (1988), Rioux (1994), Pierce (1997), Lopez (2000), Vuke et al. (2000), and NPS (2007), which is based on the preceding four maps. Relevant theses and dissertations include Geppert (1984), Orrell (1988), and Lyford (2001). The NPS Geologic Resources Division coordinated a Geologic Resource Inventory workshop for BICA in May 2005 (NPS 2006) and produced a geologic resource evaluation report for the recreation area in 2011 (KellerLynn 2011). The initial paleontological resource inventory and summary was prepared by Koch and Santucci (2003).

The geologic history of BICA is well represented by rocks exposed in the recreation area from the Cambrian to the early Late Cretaceous, between at least 500 Ma (million years ago) and approximately 95 Ma, with the Silurian as the only geologic time period completely absent (see the appendix for a geologic time scale). There are also substantially older rocks and Quaternary sediments. The oldest rocks exposed in BICA are among the oldest rocks to be found in any NPS unit. They are high-grade metamorphic rocks (Lopez 2000, Vuke et al. 2000) present in a small area near the western boundary of the Montana side of the recreation area, on the flank of East Pryor Mountain (NPS 2007). They represent two episodes of magmatism, deformation, and metamorphism that occurred during the Archean, one at 3 billion years ago and the other at 2.8 billion years ago. No major thermal events have occurred in the Bighorn Mountains since about 2.5 billion years ago (Arth et al. 1980).

An unconformity more than 2 billion years in duration separates these Archean rocks from the Cambrian sedimentary rocks that are the next-oldest rocks in the recreation area. During the Middle Cambrian, a marine transgression (advance) arrived in the area from the west (Shaw 1954, Bell and Middleton 1978). Through much of the rest of the Cambrian, sedimentary rocks were deposited in a variety of settings, at first above or below sea level along a coast (Bell and Middleton 1978, Beebe and Cox 1998), then becoming deeper marine (Beebe and Cox 1998), and then returning to coastal deposition (Martin et al. 1980, Clark et al. 2000). Deposition was occasionally interrupted, leaving disconformities within the Cambrian section (Beebe and Cox 1998).

A depositional hiatus followed the Cambrian deposition until the Late Ordovician, represented by the Bighorn Dolomite. This unit was deposited under a shallow sea, when the modern Greater Yellowstone Network (GRYN) area was near the equator (Holland and Patzowsky 2012). This was a time of transition from “greenhouse” to “icehouse” conditions, which is reflected by changes in the Bighorn Dolomite’s cyclicity and the turnover of faunal assemblages (Holland and Patzowsky 2009, 2012). Another substantial hiatus followed, lasting until the Late Devonian, which is represented by a poorly understood interval of shallow marine rocks (Sandberg 1965). The Devonian rocks are the first in a series of formations that present a mostly complete stratigraphic column to the early Late Cretaceous. From the Late Devonian to the Jurassic, the general configuration featured a shallow sea which transgressed and regressed (retreated) several times, arriving from what is now the west but would then have been more northwest. Episodic uplift occurred from the late Paleozoic (Simmons and Scholle 1990) into the Triassic (Picard 1967).

The Madison Group of the Mississippian is a marine unit deposited during a period of overall marine transgression (Gutschick et al. 1976). When the sea retreated and deposition ceased, the limestones of the Madison Group were exposed to the open air, forming a karst surface. An early generation of voids and caves formed (Sando 1988), prefiguring the modern generation of caves (Stock et al. 2006). Humidity increased, contributing to the dissolution and erosion of these carbonate rocks (Sando 1988, Smith and Dorobek 1993). After the hiatus that led to the early erosion of the Madison Group, the shallow sea returned from the west, resulting in the primarily marine Amsden Formation (Sando 1988). Sea level fluctuated during deposition (Gorman 1963). The succeeding Tensleep Sandstone is a coastal sand dune and shallow marine formation (Mankiewicz and Steidtmann 1979, Kerr and Dott 1988, Lopez et al. 2007). The setting has been compared to the southeastern part of the Qatar Peninsula in the Persian Gulf (Mankiewicz and Steidtmann 1979). A dune system was moving south out of north-central Wyoming during deposition. At this time, the modern GRYN area was situated near 10° N (Kerr and Dott 1988).

Permian and Triassic deposition in the BICA area, represented by the Goose Egg and Chugwater formations, follows a pattern of alternating terrestrial deposition (redbeds) and marine deposition (carbonates like dolomite and limestone) along a coastal margin (Maughan 1964, 1967, Cavaroc and Flores 1991). Deposition occurred under a warm arid climate (Maughan 1964, 1967, Picard 1966). The Early Jurassic is not represented at BICA; gentle folding occurred during this time (High and

Picard 1969). Marine deposition returned during the Middle and early Late Jurassic; in Wyoming, the rocks are called the Gypsum Spring and Sundance formations, and in Montana, the rocks belong to the Ellis Group. Several marine transgression-regression cycles occurred during this time (Schmude 2000, Kvale et al. 2001). During the Middle and Late Jurassic, a marine body known as the Sundance Sea encroached on the BICA area from the northwest, a volcanic archipelago was present on the west, the Ancestral Rockies were present on the south, and upland continental areas existed to the east (Harris and Lacovara 2004). Deposition occurred on a broad shallow shelf, adjacent to the relatively high Sheridan Arch (Breithaupt et al. 2001); this structure existed along the Montana-Wyoming border, between the BICA area and points east (Porter 1989).

After the Sundance Sea retreated for the last time, terrestrial deposition in the form of the Morrison Formation began. By the time of Morrison deposition, the region had moved out of the low subtropical latitudes (Lockley and Mickelson 1997) and humidity increased (Lockley and Wright 2003), supporting a great diversity of life. The Morrison Formation is interpreted as a semi-arid seasonal savanna-like setting (Engelmann et al. 2004, Hasiotis 2004, Turner and Peterson 2004). The overlying interval, represented by the Early Cretaceous Cloverly Formation of Wyoming and equivalent Kootenai Formation of Montana, is similar, and it can be difficult to differentiate the Morrison Formation from the younger rocks where the Pryor Conglomerate Member is not present at the base of the Lower Cretaceous rocks. The Cloverly/Kootenai section is a primarily fluvial and lacustrine sedimentary sequence, with a substantial amount of sediment derived from volcanoes (volcaniclastics) (Moberly 1960, Condon 2000). Deposition occurred under a warm, seasonal climate, becoming more humid over time (Forster 1984). To the west, a mountain-building episode known as the Sevier Orogeny was active (DeCelles 1986). The upper part of the interval shows an increasing marine influence as a shallow continental sea known as the Western Interior Seaway or Cretaceous Interior Seaway began to encroach upon the area (Forster 1984, DeCelles 1986), from the north (Nydam and Cifelli 2002). The uppermost rocks of this complex interval are interpreted as shallow marine (Moberly 1960, Kvale and Vondra 1993).

The last few million years of Cretaceous rocks exposed at BICA were deposited in the Western Interior Seaway system. The Seaway eventually extended from the Arctic to the Gulf of Mexico, bisecting North America (Elder and Kirkland 1993, 1994). Its waxing and waning influenced the geology of numerous NPS units, although only the early Cretaceous history is represent by stratigraphic units at BICA, including the Fall River Sandstone, Thermopolis Shale, Mowry Shale, and lower Belle Fourche (Montana)/Frontier (Wyoming) formations. Deep marine shales alternated with shallower marine sandstones as the sea transgressed and regressed (Eicher 1960, Condon 2000, Johnson 2010). Numerous bentonite beds in the section indicate that volcanoes to the west contributed significant amounts of ash to the sediment (Reeside and Cobban 1960). Younger rocks from the Western Interior Seaway are found in the vicinity and are exposed within GRTE and YELL.

Throughout much of western North America, the final withdrawal of the Western Interior Seaway occurred concurrently with the beginning of a major mountain-building event known as the Laramide Orogeny (Cather 2003). This event took place from the Late Cretaceous

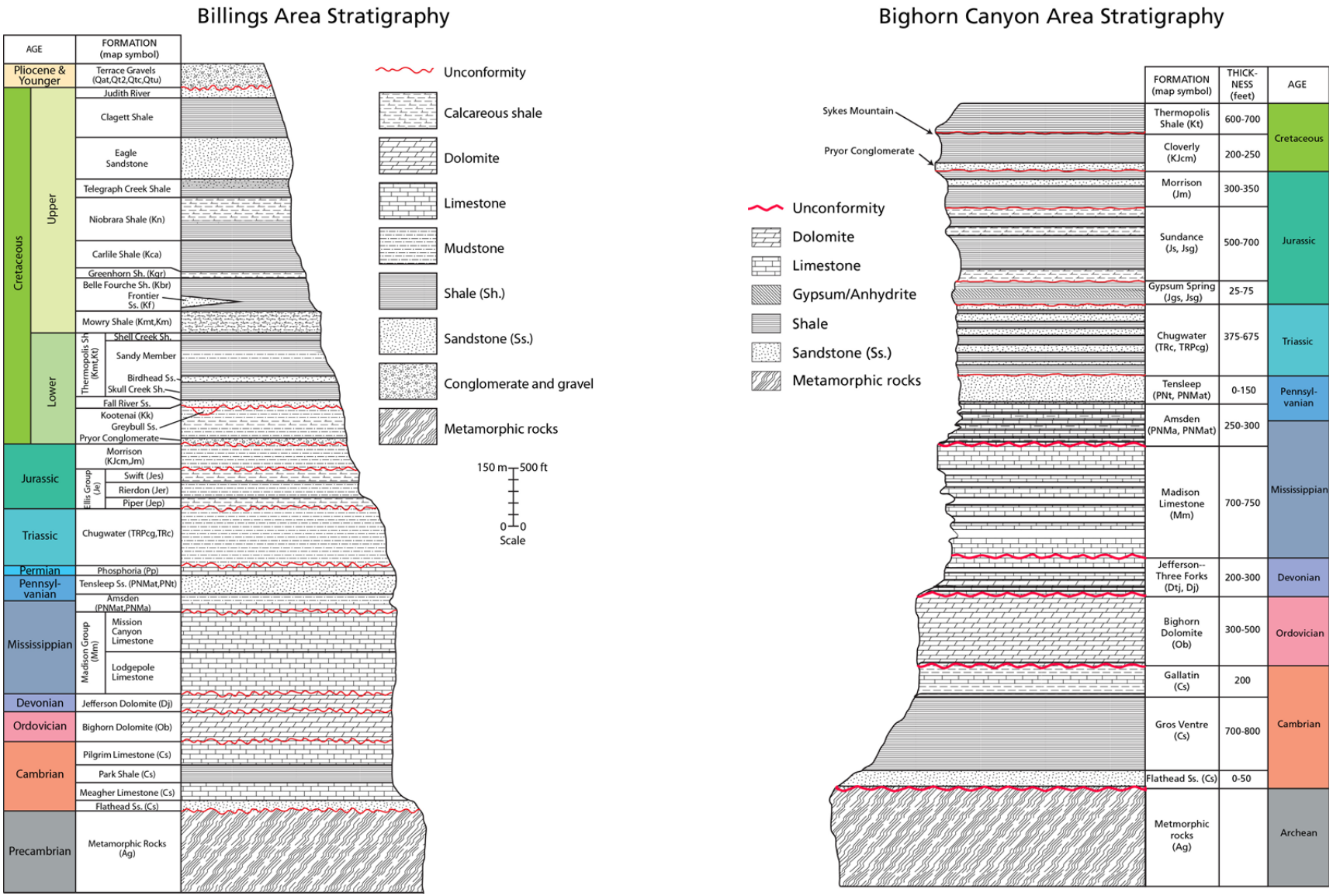
to the Eocene and was responsible for much of the present form of the Rocky Mountains (Aubrey 1991). The Bighorn Basin and surrounding mountains are Laramide structures (Bown 1980, Simmons and Scholle 1990). The northern Bighorn and Pryor mountains began rising in the Late Cretaceous, and the southern Bighorns followed in the Late Paleocene. Sediments filled much of the basin during the Paleogene, but uplift in the Late Oligocene or Early Miocene resulted in much of the sediments eroding away. To the west, volcanism began in the Absaroka-Yellowstone area during the Eocene and has continued sporadically to the present (Bown 1980).

The rock and sediment record of BICA resumes for the most recent part of the Cenozoic. The Yellowstone-Bighorn drainage system has changed significantly over the past few million years. The Clark Fork and Shoshone rivers split between 2.2 and 2.0 Ma and the Shoshone River was captured by the Bighorn River between 1.45 and 0.6 Ma (Reheis and Agard 1984, Reheis 1985). Multiple terraces have formed on the Bighorn River, beginning over a million years ago. Several of them can be indirectly dated by volcanic ash beds (Palmquist 1983, Reheis 1985). These ash beds have also been used to date cave formation (Stock et al. 2006) and changes in the drainage system (Reheis and Agard 1984; Reheis 1985). Important ash beds include the 2.1 Ma Huckleberry Ridge Ash and 0.64 Ma Lava Creek Ash (Christiansen 2001). There also appears to have been modest folding and faulting during the Quaternary, on the order of a few meters or tens of feet (Reheis 1985). Although the Quaternary is famous for its “ice ages,” the continental ice sheets did not reach BICA (Hill 2006). Alpine glaciers did form in the southern Bighorn Mountains (Matthes 1900) and on the Yellowstone Plateau (Walker 1987). Humans appeared in the Bighorn Basin late in the Pleistocene, by at least 11,200±200 radiocarbon years before present (13,280-12,870 calendar years before present) (Frison and Wilson 1975, Walker and Frison 1980) (note that radiocarbon dates are not the same as calendar dates, and that radiocarbon years require calibration to yield calendar years. Dates here were calibrated using Calib 6.0 [http://calib.qub.ac.uk/calib/] where appropriate).

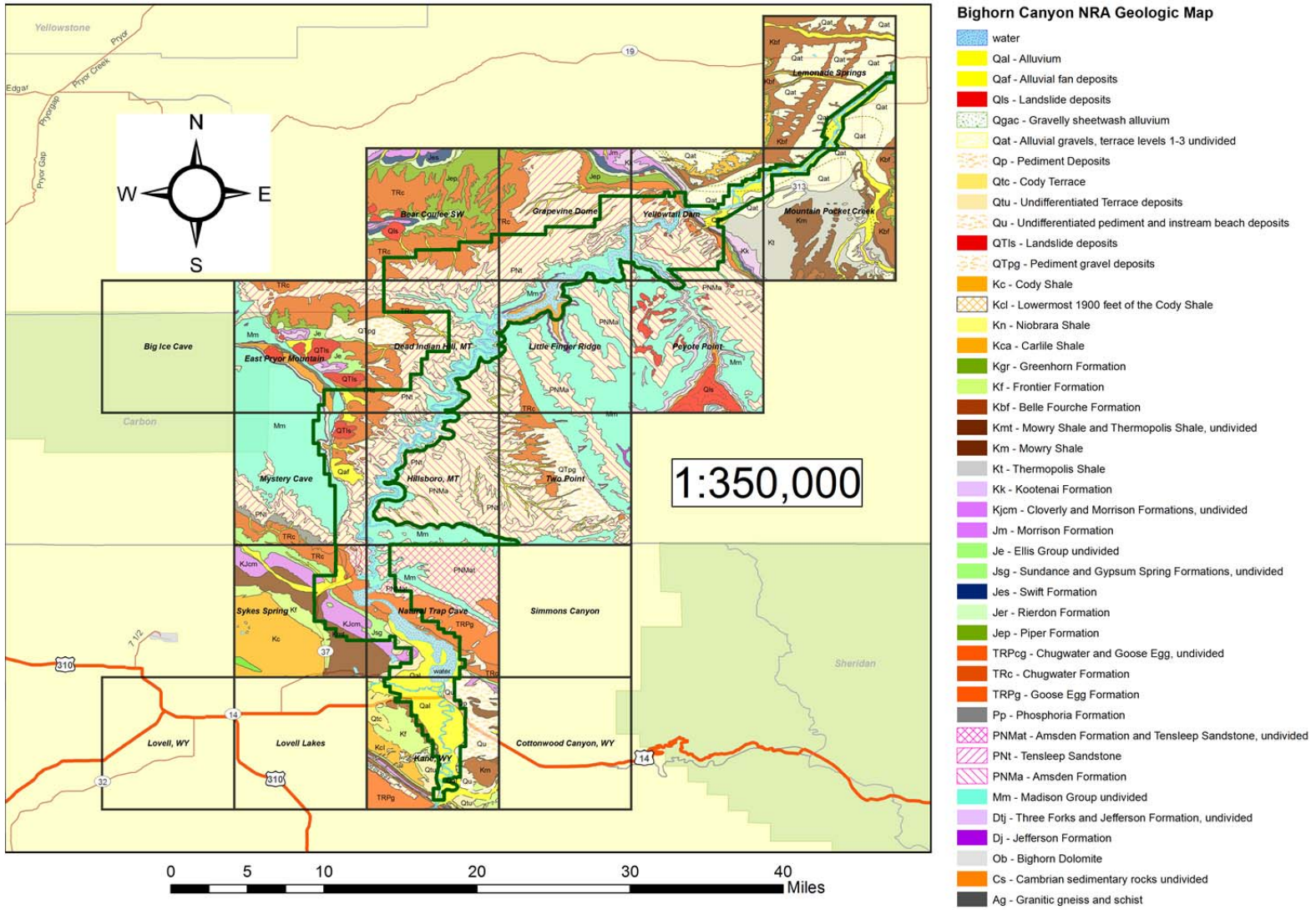
The geology of BICA is artificially complicated by issues of nomenclature and assignment of various rocks. Different workers have employed different naming schemes, usually developed elsewhere and then extended into the northern Bighorn Basin, and created for different purposes; some focus on paleontology, others on lithology, and others on the needs of economic geology. The Cretaceous of this area is particularly affected, and it can seem that no two authors use the same stratigraphic nomenclature or divide the rocks the same way. The nomenclature is further complicated by the presence of different naming systems in Montana and Wyoming. The results of this can be seen in the maps made by the Geologic Resources Division for BICA. A few broad statements can be made: the Belle Fourche Formation on the Montana side is roughly equivalent to the Frontier Formation on the Wyoming side, the Kootenai Formation on the Montana side is equivalent to the Cloverly Formation on the Wyoming side, the Ellis Group (Swift, Rierdon, and Piper formations) of Montana occupies the same interval as the Sundance and Gypsum Spring formations of Wyoming, and the Phosphoria Formation used for part of the Montana side of NPS (2007) is probably a component of the Goose Egg Formation used elsewhere on the map. Stratigraphic columns using the nomenclatures of Montana and Wyoming, from KellerLynn

(2011) are included for comparative purposes (BICA Figure 3).

Rock units exposed within BICA include, in ascending order (oldest to youngest): Archean schist and gneiss; undivided Cambrian rocks (Middle-Upper Cambrian); the Bighorn Dolomite (Upper Ordovician); Devonian rocks attributed to the Jefferson and Three Forks formations (Upper Devonian); the Madison Group (Lower-Middle Mississippian); the Amsden Formation (Upper Mississippian-Middle Pennsylvanian); the Tensleep Sandstone (Middle-Upper Pennsylvanian); the Goose Egg Formation, also identified in part as the Phosphoria Formation (Permian-Lower Triassic); the Chugwater Formation (Triassic); a Middle-Upper Jurassic interval identified as the Gypsum Spring and overlying Sundance Formation in Wyoming and the Ellis Group's Piper, Rierdon, and Swift formations in Montana; the Morrison Formation (Upper Jurassic); a Lower Cretaceous interval with a complex upper section, identified as the Cloverly Formation in Wyoming and the Kootenai Formation in Montana; the Fall River Sandstone (Lower Cretaceous); the Thermopolis Shale, Mowry Shale, and an interval identified as the Frontier Formation in Wyoming and the Belle Fourche Formation in Montana (Upper Cretaceous); Cenozoic terrace sediments (Pliocene?-Holocene); and other Quaternary sediments (Pleistocene-Holocene) (see BICA Figure 4 for a geological map) (NPS 2007). Most of these formations are fossiliferous within BICA, and the rest of them, with the exception of the Archean metamorphic rocks, are potentially fossiliferous. The majority of the fossils found within BICA are from Paleozoic and Jurassic marine invertebrates, but there are some terrestrial vertebrate bones in the Morrison Formation and Quaternary sediments, and some new finds of vertebrate trace fossils in the Middle and Upper Jurassic rocks (BICA Table 1).



BICA Figure 3. Stratigraphic columns using Montana terminology and Wyoming terminology, originally published in KellerLynn (2011).



BICA Figure 4. Schematic geological map of BICA. Map graphic adapted from digital geologic map data available at the following URL: https://irma.nps.gov/App/Reference/Profile?Code=1044595.

BICA Table 1. Concise tabulation of BICA stratigraphy, fossils, and depositional setting; details and references can be found in the text. High-grade metamorphic and igneous rocks are included here for completeness, but are not discussed in detail in the text because they are unfossiliferous.

Formation	Age	Fossils Within BICA	Depositional Environment
Late Cenozoic sediments	Pliocene?–Holocene	A musk ox vertebra (late Pleistocene) and packrat middens (latest Pleistocene-Holocene)	Alluvial, glacial outwash, fluvial, and landslide deposits, and cave sedimentation
Frontier Formation	Late Cretaceous	None to date; bivalves, ammonites, and shark teeth have been found in the vicinity	Nearshore and more open marine
Belle Fourche Formation	Late Cretaceous	None to date; radiolarians and ammonites have been found in the vicinity	Marine, becoming more open over time
Mowry Shale	Late Cretaceous	Fossils have not been explicitly confirmed, but fish scales are ubiquitous in this formation	Open marine
Thermopolis Shale	Late Cretaceous	None to date; bivalves, ammonites, gastropods, shark teeth, fish scales and bones, and reptile bones and teeth have been found in the vicinity	Marine, brackish coastal to open
Fall River Sandstone	Early Cretaceous	None to date; fossils are uncommon in this formation, but leaves and invertebrate traces are most likely	Marginal marine
Kootenai Formation	Early Cretaceous	None to date; plants are most likely	Fluvial, floodplain, and lacustrine settings; marine influence near top
Cloverly Formation	Early Cretaceous	Thin shell beds	Fluvial, floodplain, and lacustrine settings; marine influence near top
Morrison Formation	Late Jurassic	Possible root traces, probable beetle burrows, insect larval burrows, dinosaur bones, sauropod tracks, and possibly plant fossils and other unspecified fossils	Fluvial, floodplain, and lacustrine settings
Swift Formation	Middle–Late Jurassic	Unspecified shells, probably bivalves, belemnites, and/or ammonites, which are known in the vicinity	Shallow marine
Rierdon Formation	Middle Jurassic	Bivalves, belemnites, and crinoids	Shallow marine
Sundance Formation	Middle–Late Jurassic	Bivalves (including an “oyster bed”), gastropods, worm tubes, crinoids, echinoids, and enigmatic tracks, possibly in part from pterosaurs	Primarily shallow marine, occasional tidal flat episodes
Gypsum Spring Formation	Middle Jurassic	Crocodilian and possible dinosaur swim traces, and dinosaur tracks	Coastal terrestrial and restricted marine, lower and upper, and open marine middle
Piper Formation	Middle Jurassic	None to date; bivalves have been found nearby, and corals, mollusks, and echinoderms are most likely	Shallow marine
Chugwater Formation	Triassic	Reworked Tensleep and Amsden fossils	Coastal terrestrial to nearshore marine, changing multiple times
Goose Egg Formation	Permian–Early Triassic	None to date; bryozoans, brachiopods, mollusks, and crinoids are most likely	Coastal terrestrial to nearshore marine, changing multiple times

BICA Table 1. Concise tabulation of BICA stratigraphy, fossils, and depositional setting; details and references can be found in the text. High-grade metamorphic and igneous rocks are included here for completeness, but are not discussed in detail in the text because they are unfossiliferous (continued).

Formation	Age	Fossils Within BICA	Depositional Environment
Phosphoria Formation	Permian	None to date (very thin remnant)	Coastal terrestrial to nearshore marine, changing multiple times
Tensleep Sandstone	Middle–Late Pennsylvanian	Probably foraminifera and sponge spicules	Marine and coastal dunes
Amsden Formation	Late Mississippian–Middle Pennsylvanian	Foraminifera, sponge spicules, brachiopods, and bivalves	Beaches and offshore bars, followed by restricted marine, then offshore marine, with cyclic oscillation
Madison Group	Early–Middle Mississippian	Calcispheres, foraminifera, corals, bryozoans, brachiopods, ostracodes, crinoids, and hybodont shark teeth	Shallow marine
Three Forks Shale and Jefferson Limestone	Late Devonian	Stromatoporoid sponges, corals, and brachiopods	Shallow to marginal marine
Bighorn Dolomite	Late Ordovician	Gastropods	Shallow marine, open and restricted
Undivided Cambrian	Middle–Late Cambrian	Trilobites	Coastal sands followed by shallow marine and shoreline deposition
Granitic schist and gneiss	Archean	Unfossiliferous	Not applicable (originally igneous rocks that solidified at depth)

Sources of Paleontological Resources

The fossils of BICA present opportunities for education, interpretation, and scientific research in the recreation area.

Cambrian Rocks (terminology varies; Middle–Upper Cambrian)

Cambrian rocks are found low in Bighorn Canyon upstream of Yellowtail Dam, and in an area along the western border, both areas in the Montana side of the recreation area (NPS 2007). The Cambrian rocks in the BICA area include limestone, shale, sandstone, quartzite, and flat-pebble conglomerate; the lower part of the section is dominated by gray-green lime-rich shale with a brown sandstone bed at the base, and the upper part includes gray limestone interbedded with grayish-green shale, and conglomerate. The total section is 210 to 240 m (700 to 800 ft) thick (Lopez 2000, Vuke et al. 2000). The rocks are often hidden by talus in the canyon (Richards 1955). The Cambrian rocks of the BICA area are not formally divided in the maps used for NPS (2007), but they are believed to be equivalent to named units elsewhere in Montana and Wyoming. In ascending order, the Montana equivalents are the Flathead Sandstone, Wolsey Shale, Meagher, Park Shale, and Pilgrim Limestone formations, and the Wyoming equivalents are the Flathead Sandstone, Gros Ventre, and Gallatin formations (Lopez 2000, Vuke et al. 2000). This is not as complicated and contradictory as it may appear: the Wolsey Shale and Park Shale are units of the Gros Ventre Group or Formation in Montana, the Meagher Formation is thought to be equivalent to another part of the Gros Ventre Group, and the Pilgrim Limestone is similarly part of the Gallatin Group. Therefore, broadly speaking, the Cambrian section of the BICA area appears to include equivalents or actual rocks from the Flathead, Gros Ventre, and Gallatin formations. Historically, terminology has been a problem for this interval in the BICA area (Hanson 1962a, Cygan and Koucky 1963). The oldest references (Darton 1904, 1906, Thom et al. 1935, Blackstone 1940) simply refer to the entire section as the Deadwood Formation, and a “Grove Creek Formation” is sometimes employed at the top of the section (Shaw 1954, Stewart 1958). Some of the lack of nomenclatural resolution is a result of the absence of some of the more distinctive units found elsewhere, which permit the section to be divided (Shaw 1954).

The Cambrian section of BICA overlies Precambrian rocks, with a significant unconformity (Thom et al. 1935, Blackstone 1940). These rocks are thought to date from the Middle Cambrian to the Late Cambrian (Lopez 2000, Vuke et al. 2000), although it has sometimes been suggested that the Gallatin Formation and its equivalents at the top of the Cambrian section extend into the Ordovician, including in the Bighorn Basin (Cygan and Koucky 1963). The section as a whole becomes younger going west to east, because they were deposited during a marine transgression moving from west to east (Shaw 1954, Bell and Middleton 1978). The marine transgression was not a simple advance, reflected by the presence of depositional hiatuses within the formations (Beebe and Cox 1998). The upper contact with the Bighorn Dolomite is disconformable (Clark et al. 2000).

The various formations that may be present in the BICA area are primarily marine and coastal in origin. The Flathead Sandstone is a coastal sandstone (Bell and Middleton 1978), representing the first stage of the initial Cambrian transgression (Beebe and Cox 1998). Depositional environments include tidal areas,

sand flats, beaches, coastal terraces (Bell and Middleton 1978), and fluvial settings (Beebe and Cox 1998). The Gros Ventre Formation is an offshore mud and carbonate formation (Beebe and Cox 1998). Its upper contact with the Gallatin Formation is disconformable (Martin et al. 1980). The Gallatin Formation was deposited in shallow shelf and shoreline settings (Clark et al. 2000). Depositional environments include lagoons, tidal flats, and shoals (Martin et al. 1980).

The Cambrian rocks appear to be fossiliferous within BICA: Hanson (1962a) detailed a stratigraphic section from near the mouth of Big Bull Elk Creek within BICA and reported trilobites in a limestone unit 30 m (100 ft) above the floor of Bighorn Canyon. The rocks are also fossiliferous in the immediate vicinity. Darton (1904, 1906) found brachiopods (lamp shells) and trilobites in the Bighorn Mountains, including trilobites near the mouth of Tepee Creek. Stewart (1958) reported unspecified Middle and Late Cambrian fossils in the Dryhead–Garvin Basin, and crinoids in the upper part of the section (the "Grove Creek Formation"). Trilobites are known from the Flathead Sandstone in the Bighorn Mountains (Hu 1970). Trilobites (Cygan and Koucky 1963), bradoriid arthropods (extinct ostracode [seed shrimp]-like crustaceans) (Howell 1963), conodonts (extinct eel-like chordates) (Koucky et al. 1961, 1968, Dong et al. 2005), invertebrate burrows (Csonka and Bulinski 2010), and purported fish (Cygan and Koucky 1963) have been reported from the Gros Ventre Formation of the Bighorn Mountains or Basin. Finally, brachiopods (Koucky et al. 1961), trilobites (Cygan and Koucky 1963), and conodonts (Koucky et al. 1961, 1968) have been reported from the Gallatin Formation of the Bighorn Mountains or Basin.

Generally, all of the units that may be present have similar fossil assemblages of modest diversity, including stromatolites and other microbial structures, brachiopods, trilobites, conodonts, and invertebrate trace fossils:

The fossil assemblage of the Flathead Sandstone includes brachiopods (Bell and Middleton 1978), trilobites (Hu 1970), bioturbation (disruption of sedimentary features by biological activity) (Morgan 1998), and burrows, tracks, and other invertebrate trace fossils (Cloud and Beyer 1973), including some unusual large tracks and trails (Boyd 2010). Invertebrate trails and burrows are the only common fossils (Bell and Middleton 1978);

The fossil assemblage of the Wolsey Shale of the Gros Ventre Group includes hyoliths, brachiopods, trilobites (Deiss 1936), fossil hash (Lebauer 1964), bioturbation (Morgan 1998), and invertebrate burrows and trails (Lebauer 1964);

The fossil assemblage of the Meagher Formation includes microbial structures, calcispheres (Lebauer 1965), possible calcareous algae (Kauffman 1975), sponge spicules, enigmatic conical hyoliths, brachiopods, trilobites, echinoderm plates (Lebauer 1965), undetermined conical fossils (Kauffman 1975), invertebrate burrows, and fecal pellets, with fossils concentrated in the lower part of the formation (Lebauer 1965);

The fossil assemblage of the Park Shale of the Gros Ventre Group includes microbial mats, laminations, and filaments (Blackwell et al. 1983), microbial buildups (DeBoer and Middleton 1981), brachiopods (Bell 1941), trilobites (Schwimmer 1975), echinoderm fragments (Martin et al. 1980), and invertebrate burrows (Miller 1936).

Fossils described from the Gros Ventre Formation, without further subdivision, include acritarchs (organic microfossils that cannot be classified as anything else) (Reaugh 1980), trilobites (Beebe and Cox 1998), bradoriid arthropods (Howell 1963), conodonts (Koucky et al. 1961, 1968, Dong et al. 2005), invertebrate burrows (Csonka and Bulinski 2010), and material described as belonging to heterostracan fish (early jawless fish) (Cygan and Koucky 1963; the age of the fossils indicates either a stratigraphic or taxonomic misidentification).

The fossil assemblage of the Pilgrim Limestone of the Gallatin Group includes various microbial structures, up to mounds and reefs in size (Breuninger 2000), calcareous algae (Lochman and Duncan 1944), possible corals (Fritz and Howell 1955), sponge spicules, chancellorids (extinct sponge-like animals), hyoliths (Bonem 1972), enigmatic shelled *Hypseloconus* and *Kinsabia* (Lochman and Duncan 1944), brachiopods (Bonem 1972), monoplacophorans (cap-shelled mollusks) (Breuninger 2000), trilobite-like aglaspid arthropods (Lochman and Duncan 1944), trilobites, eocrinoids (early stalked echinoderms) (Bonem 1972), fragments of other echinoderms (Lochman and Duncan 1944), conodonts (Witkind 1969), and invertebrate burrows (Breuninger 2000).

Finally, fossils described from the Gallatin Formation, without further subdivision, include microbial structures such as thrombolites (clotted microbial structures) (Hawkins et al. 2001), stromatolites (layered sedimentary structures created by algae and microbes), and laminations (Martin et al. 1980), acritarchs (Reaugh 1980), sponges, brachiopods, trilobites (Okulitch and Bell 1955), echinoderm fragments (Martin et al. 1980), conodonts (Koucky et al. 1968, Clark et al. 2000), and invertebrate burrows (Miller 1936).

Bighorn Dolomite (Upper Ordovician)

The Bighorn Dolomite of the BICA area reaches approximately 150 m (500 ft) thick. It is composed primarily of light gray to pale orange dolomite and dolomitic limestone, and forms cliffs because of its resistant nature (Lopez 2000, Vuke et al. 2000). In BICA, it is exposed in two areas, both on the Montana side: the lower part of the main gorge near Yellowtail Dam, and along part of the western border (NPS 2007). The Bighorn Dolomite is a marine formation, dominated by open marine shallow subtidal deposits (Holland and Patzowsky 2012). Deposition occurred during the Late Ordovician, approximately 450 to 446 Ma (Holland and Patzowsky 2012).

The Bighorn Dolomite in the vicinity of BICA is divisible into up to four members. In ascending order, they are the Lander, Steamboat Point, Leigh, and Horseshoe Mountain members (Zenger 1992, Holland and Patzowsky 2012). The Lander and Steamboat Point members are interpreted as representing primarily shallow subtidal marine deposition, becoming shallower near the top of the sequence. The Leigh Member is interpreted as a shallow restricted marine deposit. Above it, the Horseshoe Mountain Member shows a return to open marine conditions (Holland and Patzowsky 2012). Within BICA and its immediate area, the formation includes an upper thin-bedded limestone and dolomite member sometimes equated to the Leigh Member, and a lower massive (unbedded) dolomitic limestone section (Richards 1955, Stewart 1958). A thin basal sandstone is also present in some areas (Thom et al. 1935). The Lander Member, a sandstone unit, appears to be absent in the vicinity of BICA on the Montana side (Richards

1955). The upper contact of the Bighorn Dolomite with the Devonian rocks is disconformable (Agard 1988), as is the lower contact with the Cambrian rocks (Thom et al. 1935, Blackstone 1940). There are also sometimes internal unconformities (Scott and Asquith 1972, Holland and Patzowsky 2012). A few of the caves in the Bighorn Basin are in the Bighorn Dolomite (Stock et al. 2006).

The Bighorn Dolomite is fossiliferous within BICA: a gastropod has been reported from the canyon (Santucci et al. 1999). A larger assemblage has been reported from the Bighorn Mountains in general, including corals, bryozoans (moss animals), brachiopods , cephalopods (squids, octopuses, and relatives), gastropods, trilobites, ostracodes, crinoids (sea lilies), cystoids (extinct relatives of crinoids), and conodonts (Macomber 1970). Fossils are reportedly abundant in the lower part of the formation at Medicine Mountain, about 20 km (12 miles) east of BICA in Bighorn National Forest (Darton 1906). Nautiloid cephalopods from the Bighorn Mountains have been described by Miller and Carrier (1942), and conodonts have been described by Amsden and Miller (1942).

Overall, the fossil assemblage of the Bighorn Dolomite includes dasycladacean algae, stromatoporoid sponges, corals, bryozoans, brachiopods, bivalves, nautiloids, gastropods, trilobites, ostracodes, crinoids (Holland and Patzowsky 2009, 2012), cystoids (Macomber 1970), graptolites (extinct colonial animals possibly related to the chordates) (Scott and Asquith 1972), conodonts, general bioturbation, and invertebrate trace fossils including burrows (Holland and Patzowsky 2009, 2012). Holland and Patzowsky (2009) provide a detailed assessment of fossil distribution in the Bighorn Dolomite of an area east of BICA. They found five major assemblages or biofacies, correlated to specific environments. Biofacies dominated by brachiopods are thought to represent deep subtidal environments. Gastropod and crinoid biofacies are attributed to different parts of shallow subtidal environments. Dasycladacean biofacies are found in the shallow subtidal settings of the Steamboat Point Member. Finally, coral biofacies are found in the shallow subtidal deposits of the Horseshoe Mountain Member (Holland and Patzowsky 2009).

Jefferson and Three Forks Formations (Upper Devonian)

The Devonian rocks of BICA are problematic. They are often omitted from older reports on the Bighorn Mountains and Basin (Darton 1906, Thom et al. 1935, Blackstone 1940); the unnamed coral-rich limestone in Darton (1904) may be an early reference. Richards (1955) described the rocks in the BICA area as 60 m (200 ft) of sandy or shaly limestone above 30 m (100 ft) of dolomite and dolomitic limestone, which he regarded as belonging to the undifferentiated Three Forks Shale and underlying Jefferson Limestone, although he noted that they did not quite match the lithologies present in the type areas of the formations, and suggested that other names may be more appropriate. More recent reports attribute a thinner section to the Devonian rocks, on the order of 60 to 75 m (200 to 250 ft) (Agard 1988, Lopez 2000, Vuke et al. 2000). The Devonian rocks are found in the same areas of BICA as the Bighorn Dolomite (NPS 2007). The two are difficult to distinguish in the BICA area, and have sometimes been identified as the Darby Formation (roughly equivalent to the two formations combined) in the past (Stewart 1958). A study of the Devonian rocks in the GRYN region indicates that the Three Forks Formation may not even reach the BICA area; in fact, the only part of the two formations that

may be in the area is the unnamed lower member of the Jefferson Formation (Sandberg 1965).

The contact between the Three Forks and Jefferson formations is regarded as generally conformable (Sandberg 1965), but the upper contact with the Madison Group is disconformable (Agard 1988). The two formations are marine in origin. The deposition of the lower member of the Jefferson Formation occurred in a variety of settings, giving it a heterogeneous lithology. The Three Forks Formation above includes restricted marine and evaporite deposition near the bottom of the section, shallow open marine deposition in the middle, and regressive marginal marine deposition near the top. A regression following the deposition of the middle portion (Trident Member) gives an internal disconformity with the overlying rocks (Sappington Member, sometimes raised to a formation) (Sandberg 1965). Fossils in the Jefferson Formation indicate a Late Devonian age (Frasnian, approximately 383 to 372 Ma) (Weigner and Isaacson 2012).

The Devonian rocks are fossiliferous within BICA. Richards (1955) reported fossils from two areas of BICA. In Devil Canyon, he found brachiopods about 20 m (60 ft) below the Madison Group, and an assemblage of stromatoporoid sponges and corals 25 m (80 ft) below the Madison Group. West of the mouth of Big Bull Elk Creek on the north side of the canyon, he reported horn corals and brachiopods from 12 to 19 m (40 to 63 ft) below the Madison Group.

It is typical for these reports to provide an enumeration of the fossil records of each formation present within a park. However, this will not be done here. As noted above, the exact correlatives of the Devonian rocks of BICA are uncertain, and most of the described fossils from the Jefferson and Three Forks formations are from western Montana and eastern Idaho, discovered in members that are not definitely known to be present in the BICA area. Instead, only those fossils from the Bighorn Mountains and vicinity will be considered. In this more restricted area, fossils from the rocks attributed to the two formations include spores, macerated plant material (Blackstone and McGrew 1954), stromatoporoid sponges, corals, brachiopods, bivalves (Richards 1955), conodonts (Koucky et al. 1961), and a fish assemblage including antiarchs (a type of placoderm, early jawed fish), sharks, and sarcopterygians (lobe-finned fish, such as coelacanths and lunghfish) (Blackstone and McGrew 1954). Kottlowski (1950) named a brachiopod from the lower Jefferson Formation near Red Lodge, Montana. Blackstone and McGrew (1954) identified a section of rocks in Cottonwood Canyon east of BICA as including the Three Forks Shale and possibly the Jefferson Limestone. They reported spores, conodonts, and a possible shark tooth from the Three Forks Formation, and a handful of fish fossils (representing antiarchs and sarcopterygians including possible lungfish) in the Jefferson Limestone, with macerated plant material common in the rocks. Koucky et al. (1961) reported on Devonian conodonts from the Bighorn Mountains.

Madison Group (Lower–Middle Mississippian)

The Madison Group of the BICA area is a prominent gray to brown limestone and dolomitic limestone unit that varies greatly in thickness, from 150 m (490 ft) to 300 m (990 ft) (Rioux 1994, Pierce 1997, Lopez 2000, Vuke et al. 2000). The upper part has an eroded zone (Richards 1955, Lopez 2000, Vuke et al. 2000), resulting from subaerial exposure during the

depositional hiatus between the Madison Group and overlying Amsden Formation (Sando 1988, Palmer and Palmer 1995). Redbed rocks and fragments of limestone fill the channels, sink holes, and fractures of this zone in the BICA area (Richards 1955).

The Madison Group is a fossiliferous unit, divisible into at least two formations throughout the area. The lower part is thin bedded to thick bedded, and usually identified as the Lodgepole Limestone. The upper part is thick bedded to massive, and is usually identified the Mission Canyon Limestone (Pierce 1997, Lopez 2000). A third part, the Cottonwood Canyon Member, is occasionally found under the Lodgepole Limestone. It is composed of dolomite, siltstone, and sandstone, and is only 4.6 m (15 ft) thick (Pierce 1997). The Cottonwood Canyon Member is sometimes used as a member of the Lodgepole Limestone (Vice and Utgaard 1989). Other names are occasionally used: Agard (1988) assigned the upper rocks to the Little Tongue Member and the lower rocks to an unnamed member of the Madison Limestone, while Sando et al. (1975) assigned the upper part of the formation in the Bighorn Basin to the Bull Ridge Member of the Madison Limestone. Vice and Utgaard (1989) divided the Madison Group in the Bighorn Basin into, in ascending order, the Cottonwood Canyon, Little Bighorn, and Woodhurst members of the Lodgepole Limestone, and the Big Goose, Little Tongue, and Bull Ridge members of the Mission Canyon Limestone.

The rocks of the Madison Group are of marine origin, and record a marine transgression moving rapidly west to east. Sea-level fluctuations during Mission Canyon time led to occasional periods of evaporitic conditions, but overall the sea was transgressing (Gutschick et al. 1976). The sea departed after deposition of the Mission Canyon Limestone, leading to subaerial exposure with large river systems cutting across the former marine deposits, and the formation of an early generation of voids and caves (Sando 1988). The formation of caves resumed again during the Pleistocene, and today most of the caves in the Bighorn Basin are in the Madison Group (Stock et al. 2006). An example is Bighorn Cavern, partially within BICA on Little Mountain. It may be the longest cave in Idaho, Montana, or Wyoming (Santucci et al. 2001).

Deposition of the Madison Group occurred during the Mississippian. The Cottonwood Canyon Member is Kinderhookian (360 to 348 Ma) in age (Sando [1972]; purported Devonian fossils are actually reworked from older rocks), the Lodgepole Limestone is Kinderhookian to Osagean (348 to 340 Ma) in age (Stanley and Burke 2000), and the Mission Canyon Limestone is Osagean to early Meramecian in age (Smith and Dorobek 1993), providing an age range of approximately 360 to 335 Ma. The upper contact of the Madison Group with the Amsden Formation is unconformable in the BICA area (Richards 1955). The depositional hiatus is longer going eastward, reflecting the west to east transgression of the sea that deposited the overlying rocks (Palmer and Palmer 1995).

The Madison Group is fossiliferous within BICA, with several published reports. Thom et al. (1935) found rugose and tabulate corals and brachiopods in the upper Madison Group on the east side of the north end of Bighorn Canyon. Richards (1955) found pieces of bryozoans, brachiopods, and crinoids in thin layers in the lower Madison Group of Devil Canyon and other locations in the area. Sando and Mamet (1974) reported calcisphere microfossils, foraminifera (amoeba-like protists that form

"shells"), tabulate and rugose corals, and ostracodes from a loose block of Madison Group limestone in Devils Canyon. These fossils are of Meramecian age. Fossils of corals, brachiopods, and bivalves can be seen in the walls of Bighorn Cavern, partially within BICA (Chadwick 1999). Finally, Santucci et al. (1999) reported corals, bryozoans, brachiopods, crinoids, and the shark *Hybodus* from the recreation area.

Similar assemblages have been found just outside of BICA. The Cottonwood Canyon Member at the base of the section has yielded crinoid molds, conodonts, invertebrate burrows, and fish bones, teeth, and scales just east of BICA (Sandberg and Klapper 1967), and Thom et al. (1935) found rugose and tabulate corals, bryozoans, brachiopods, and gastropods in the upper Madison Group on the east rim of Black Canyon about 1 km (a half-mile) north of the trail from Soap Creek. Maps of the BICA region recognize the Madison Group as fossiliferous in general (Lopez 2000, Vuke et al. 2000), with stromatolites, corals, brachiopods, and crinoids (Vuke et al. 2000). The fossil assemblage recorded from the Madison Group in the Bighorn Basin and Mountains includes stromatolites, oncolites (spherical microbial structures), calcispheres, foraminifera, "phylloid" algae (flake or leaf shaped fragments), red algae, dasycladacean algae, sponges, corals, bryozoans, brachiopods, bivalves, gastropods, ostracodes, trilobites, crinoids, conodonts, invertebrate pellets and burrows (Vice and Utgaard 1989), and fragmentary fish remains (Sandberg and Klapper 1967).

Overall, including areas outside of BICA, the Cottonwood Canyon Member has a fossil assemblage including corals, crinoid molds (Sandberg and Klapper 1967), echinoids (sea urchins) (Benson 1966), conodonts, invertebrate burrows (Sandberg and Klapper 1967), fish plates and teeth (Benson 1966), and coprolites (fossil feces) (Sandberg and Klapper 1967); marine palynomorphs (organic microfossils, like spores, pollen, and resting cysts), conulatans (extinct coral relatives that formed pyramidal structures from rods), bryozoans, and brachiopods are also known, but in a part of the unit not found in BICA (Sandberg and Klapper 1967). Fossils reported from the Lodgepole Limestone include possible microbial structures (Moore 1973), calcispheres (Gutschick et al. 1976), foraminifera (Gutschick et al. 1961), sponges (Gutschick 1966, Gutschick et al. 1976), conulatans (Tysdal 1976), corals, bryozoans (Sando and Dutro 1974), brachiopods (Rodriguez and Gutschick 1968), microconchid tentaculitid mollusks (formerly identified as spirobid worm tubes; Witkind 1969), rostroconchs (Girty 1899), bivalves (Chen and Webster 1994), ammonites (Stanley and Burke 2000), gastropods (Sando and Dutro 1974), trilobites (Stanley and Burke 2000), ostracodes, blastoids (sea buds), crinoids (Rodriguez and Gutschick 1968), echinoids (Smith 1982), holothurians (sea cucumbers), conodonts (Gutschick 1966; Gutschick et al. 1961), indeterminate spicules (needle-like skeletal structures), invertebrate burrows (Smith 1982), and fragmentary fish remains (Gutschick et al. 1961, Gutschick and Lamborn 1975). Finally, the Mission Canyon Limestone has yielded stromatolites, oncolites, calcispheres, foraminifera, "phylloid" algae, red algae, dasycladacean algae (Vice and Utgaard 1989), fragments of *Lepidodendron* and other land plants (Houlik 1973), sponges, corals, bryozoans, brachiopods, bivalves, gastropods, ostracodes, trilobites, crinoids, conodonts, and invertebrate pellets and burrows (Vice and Utgaard 1989).

Amsden Formation (Upper Mississippian–Middle Pennsylvanian)

The Amsden Formation is widely exposed in BICA (NPS 2007). It is a variegated, heterogeneous marine formation, and in the Bighorn Mountains, the lithology of the formation varies greatly laterally and vertically (Gorman 1963). In the vicinity of BICA, shale, siltstone, sandstone, limestone, and dolomite are all part of the formation, which is between 40 and 90 m (140 and 300 ft) thick (Rioux 1994, Lopez 2000, Vuke et al. 2000). The formation can be divided into several members depending on location. In central Wyoming, the sequence from oldest to youngest is typically the Darwin Sandstone, Horseshoe Shale, and Ranchester members (Sando et al. 1975). The Darwin Sandstone Member is interpreted as mostly beach and offshore bar deposition following a marine transgression (Sando et al. 1975). It is recognized in the BICA area (Rioux 1994). The Horseshoe Shale Member is interpreted as a stable restricted marine basin, like a lagoon. The Ranchester Member is interpreted as a shallow offshore marine unit with some evaporation (Sando et al. 1975). The initial transgression proceeded from west to east, beginning in what is now western Wyoming (Sando 1988). In the Bighorn Mountains, events following the initial transgression included a regression and then another transgression, then cyclic sea level oscillations becoming more numerous over time during an overall regression (Gorman 1963).

As mentioned in the Madison Group section, the Amsden Formation is time-transgressive, with older sediments at the base in the west than the east. The oldest sediments are found in western Wyoming, where the Mississippian–Pennsylvanian boundary (323 Ma) is high in the formation (within the Ranchester Member); in east–central Wyoming, this boundary is much lower, below the Horseshoe Shale Member (Gordon 1975). In the Bighorn Mountains, the lowest part of the formation is Chesterian (333 to 326 Ma) (Sando and Mamet 1974), and there are Atokan (318 to 311 Ma) foraminifera in BICA (Richards 1955). The upper contact with the Tensleep Sandstone is generally regarded as transitional (Sando et al. 1975), and the two can be difficult to distinguish (Fisher 1963).

There are several reports of fossils from the Amsden Formation in BICA. Thom et al. (1935) reported brachiopods and bivalves in red limestone near the base of the formation on the east side of the lower end of Bighorn Canyon in BICA (collection 3903). USGS locality f8009 in BICA, about 1 km (a half mile) west of the canyon in 9 m (30 ft) of chert, 30 m (100 ft) from the base of the formation, has yielded fusulinids and other foraminifera (Henbest 1954; Richards 1955), and sponge spicules (Richards 1955). Finally, Gordon (1975) reported silicified (replaced by silica) brachiopods from the base of the Horseshoe Shale Member across from the mouth of Devils Canyon in BICA. Fossils tend to be rare in this formation in the wider Bighorn Mountains, where foraminifera (Gorman 1963), corals, brachiopods, bivalves, gastropods, trilobites, and echinoids (Darton 1906) have been reported. Brachiopods have been reported from Sheep Mountain, 7.5 miles (12 km) south of BICA (Brainerd and Keyte 1927).

The Amsden Formation is sparsely fossiliferous, but has a distinctive assemblage. Fossil groups represented include foraminifera, marine algae including *Girvanella*, land plants (including calamitaceans, *Sphenopteris*, and *Lepidodendron*), the sponge *Chaetetes* (formerly identified as a hydrozoan, related to corals), conulatans, corals, bryozoans, brachiopods, rostroconchs (extinct bivalved

mollusks), bivalves, cephalopods, gastropods, microconchid worm tubes formerly identified as *Spirorbis*, ostracodes, trilobites, blastoids, crinoids, echinoids, the possible worm *Cornulitella*, conodonts, invertebrate burrows, and fish (including cartilaginous and ray-finned fish) (Sando et al. 1975). Several groups were described in detail in a group of 1975 publications: foraminifera, algae, and other microfossils (Mamet 1975), corals and *Chaetetes* (Sando 1975a), brachiopods (Gordon 1975), bivalves and rostroconchs (Gordon and Pojeta 1975), ammonites, nautiloids, gastropods, and trilobites (Gordon and Yochelson 1975), and ostracodes (Sohn 1975). Representatives of all groups are generally found throughout the members above the Darwin Sandstone, although a few are more limited: rostroconchs are only known from the Ranchester Member (Gordon and Pojeta 1975), which also lacks corals (Sando 1975a), and cephalopods (Gordon and Yochelson 1975) and ostracodes are only known from the Horseshoe Shale Member (Sohn 1975). The Darwin Sandstone Member is not known for its fossils; Sando (1975b) reported foraminifera from the west flank of the Bighorn Basin, and Barker (1984) reported a brachiopod.

Tensleep Sandstone (Middle–Upper Pennsylvanian)

As its name suggests, the Tensleep Sandstone is primarily composed of sandstone, generally brown and with prominent crossbedding. There are also some limestone, dolomite, and shale beds, and chert (Rioux 1994, Lopez 2000, Vuke et al. 2000, Lopez et al. 2007). It is roughly 30 to 60 m (100 to 200 ft thick) in the BICA area (Rioux 1994, Lopez 2000, Vuke et al. 2000), thinning to the north (Fisher 1963, Hamilton and Paulson 1968). Historically, it has been interpreted as marine, but more recent interpretations have suggested more terrestrial deposition, with a combination of marine beds and eolian sandstone (Mankiewicz and Steidtmann 1979, Kerr and Dott 1988, Lopez et al. 2007).

The Tensleep Sandstone spans at least the middle and late Pennsylvanian, possibly into the early Permian. Fossils ranging from Desmoinesian (308 to 306.5 Ma) (Driscoll and Newton 1969, Stamm and Wardlaw 2003) to Missourian (306.5 to 305 Ma) (Verville et al. 1970) to possibly Wolfcampian (299 to 294.5 Ma) (Fisher 1963) have been recovered from the Bighorn Mountains. The upper contact with Permian rocks (Embar, Goose Egg, or Phosphoria, depending on the author) is disconformable (Blackstone 1940, Agard 1988, Simmons and Scholle 1990). It can be difficult to find the Tensleep–Phosphoria contact (Mettes and Boyd 1985), which has some bearing on the BICA area where a thin section of Phosphoria Formation is sometimes thought to be present.

The Tensleep Sandstone is probably fossiliferous within BICA. Henbest (1954, 1956) and Richards (1955) reported microfossils from USGS locality f8008, in an area on the border of BICA in a canyon just east of the Kane–Dryhead road. The fossils include foraminifera and sponge spicules (Richards 1955); sponge spicules were not included in Henbest (1956), so possibly their inclusion is erroneous. Fossils have also been found in the immediate vicinity. Foraminifera and sponge spicules have been found just north of BICA (USGS f8003) (Henbest 1954, 1956), and a fossiliferous chert zone at the top of the Tensleep Sandstone on Sheep Mountain has yielded bryozoans, gastropods, and crinoids (Brainerd and Keyte 1927). In the wider vicinity of BICA, including the Bighorn Basin, Bighorn Mountains, and Pryor Mountains, fossils

include microbial mats (Mankiewicz and Steidtmann 1979), foraminifera (Verville 1957, Verville et al. 1970), the sponge *Chaetetes* (Agatston 1952), sponge spicules (Richards 1955), brachiopods (Darton 1906, Driscoll and Newton 1969, Mankiewicz and Steidtmann 1979), bivalves (Mankiewicz and Steidtmann 1979), gastropods (Darton 1906), crinoids (Agatston 1952, Mankiewicz and Steidtmann 1979), conodonts (Stamm and Wardlaw 2003), general bioturbation, invertebrate burrows, organic borings of plant or invertebrate origin (Mankiewicz and Steidtmann 1979), and tetrapod footprints, named *Steganoposaurus belli* and originally identified as amphibian (Branson and Mehl 1932), but now thought to be reptilian (Lockley and Hunt 1995). The lower part of the Tensleep Sandstone in the eastern Bighorn Basin has yielded fossil debris of foraminifera, brachiopods, bivalves, and crinoids in subtidal lagoonal deposits represented by dolomite beds, and invertebrate burrows and bioturbation in sandstone. Microbial structures and organic borings are present in the upper Tensleep Sandstone (Mankiewicz and Steidtmann 1979). The above account essentially covers the known fossil groups of the Tensleep Sandstone in its entire depositional area, with the exception of corals (Driscoll and Newton 1969), scaphopods (tusk shells), and trilobites (Hoare and Burgess 1960).

Chugwater Formation (Triassic)

The Chugwater Formation of the BICA area is a heterogeneous red or reddish brown formation, including sandstone, siltstone, mudstone, gypsum, and limestone beds. It varies in thickness, reaching thicknesses of 180 to 250 m (600 to 820 ft) (Rioux 1994, Pierce 1997, Lopez 2000). It can be found in the western part of the recreation area in Montana and the northernmost part of Wyoming (NPS 2007). For the first few decades of geologic research, beds that would now be considered part of other formations, particularly the underlying Goose Egg and overlying Gypsum Spring formations, were included in the Chugwater Formation (Darton 1904, 1906, Richards 1955, High and Picard 1967).

The Chugwater Formation can be divided into several members, or formations, when the Chugwater is raised to a group. Units used in the Bighorn Basin, in ascending order, include the Red Peak, Crow Mountain Sandstone, and Popo Agie members or formations, with a thin limestone associated with the Crow Mountain interval called the Alcova Limestone. The units are distinctive but the contacts can be difficult to place (High and Picard 1967). Picard's publications presented the Alcova Limestone as within the Crow Mountain interval, but other authors have preferred to include "Crow Mountain" rocks below the Alcova Limestone in the Red Peak Member or Formation (Cavaroc and Flores 1991, Lovelace and Lovelace 2012). Richards (1955) identified a limestone bed in the upper part of the formation in the BICA area as possibly the Alcova Limestone Member. The Red Peak (Picard 1967), Crow Mountain Sandstone (Tohill and Picard 1966), and Popo Agie members (High and Picard 1965) can each be further subdivided. The upper contact of the Chugwater Formation with Jurassic rocks is disconformable (Richards 1954).

The Chugwater Formation is interpreted as the result of both marine and terrestrial deposition near a coast (Cavaroc and Flores 1991). This is a similar depositional setting to the partly contemporaneous Moenkopi Formation exposed in many NPS units of the Colorado Plateau. The Chugwater Formation grades into fully marine beds going westward (Stewart 1958). The climate was semi-arid to arid, at least during deposition of the lower part of the formation

(Picard 1966). The various interpretations of the depositional environment differ in the relative contributions of marine and terrestrial deposition preferred by a given author, and will vary by study area. The Red Peak Member is variously interpreted as alternating nearshore marine and tidal flat deposition (Picard 1967), fluvial, deltaic, and nearshore marine deposition (Cavaroc and Flores 1991), and fluvial and lacustrine deposition becoming marine higher in the section (Lovelace and Lovelace 2012). The Alcova Limestone Member is usually interpreted as a marine incursion from the west (High and Picard 1969, Cavaroc and Flores 1991), although some authors have suggested a lacustrine origin (Cartwright et al. 2005, Lovelace 2011). There may have been marine evaporation near the top, as shown by local gypsum beds (Picard 1967). The Crow Mountain Sandstone Member encompasses the regression of the marine body responsible for the Alcova Limestone Member, transitioning from shallow nearshore marine deposition to tidal and beach deposition over time (Tohill and Picard 1966, Cavaroc and Flores 1991). The Popo Agie Member is a fluvial and lacustrine unit (High and Picard 1965, 1969), with a volcanic source for some sediments (High and Picard 1965).

The Chugwater Formation spans much of the Triassic (High and Picard 1969, Cavaroc and Flores 1991), but there is an internal disconformity between the Crow Mountain Sandstone and Popo Agie members that eliminates part of the Middle and Late Triassic (Tohill and Picard 1966). This may be the regional disconformity seen for example between the Moenkopi and Chinle formations (High and Picard 1969). Some older sources report it as Permian to Triassic in age (Richards 1955), but this includes older rocks now assigned to other formations. Dating has been hindered by the generally sparse fossils, particularly the absence of biostratigraphically useful fossils.

Fossils have been reported from the Chugwater Formation of BICA, although they are reworked from older rocks: Richards (1955) reported that reworked Pennsylvanian fossils have been found in gray chert pebbles in the basal conglomerate of the formation on Grapevine Creek. Over its entire depositional area, the Chugwater Formation has a restricted fossil assemblage, but each of the four members discussed above is fossiliferous. The Red Peak Member has yielded root traces, a bivalve, conchostracans (clam shrimp), invertebrate burrows, invertebrate tracks, fish scales, and tracks of turtle-like reptiles, lepidosaurs (lizards and relatives), enigmatic cheirotheres (terrestrial reptiles probably distantly related to crocodiles), and dinosauromorphs (dinosaurs and relatives), with most finds from central Wyoming (Lovelace and Lovelace 2012). Apparent plant molds were later shown to be inorganic (Boyd and Ore 1963). The Alcova Limestone Member has stromatolites (Lovelace 2011), plates from phylloid algae, bivalves, gastropods (Picard 1993), ostracodes (Branson 1947), and the marine reptile *Corosaurus*, an early relative of plesiosaurs (Storrs 1991, Rieppel 1998). The Crow Mountain Sandstone Member has only invertebrate burrows (Tohill and Picard 1966). Finally, the Popo Agie Member has probably the best-known fossils of the Chugwater Formation, and certainly the best-known vertebrates, which were first described near the turn of the 20th century (Williston 1904). Its fossil assemblage includes horsetails, cycadophytes (cycads and relatives), plant fragments, freshwater bivalves (High and Picard 1965), invertebrate burrows (Picard 1993), lungfish, metoposaur amphibians, therapsids (“mammal-like reptiles”), phytosaurs

(crocodile-like aquatic reptiles) (High and Picard 1965), early relatives of crocodilians (High and Picard 1965, Dawley et al. 1979) which in some cases were mistakenly thought to be dinosaurs (Mehl 1915, Colbert 1961, High and Picard 1965), and reptile tracks (Lockley 1990). Darton (1906) reported bivalves, gastropods, and ostracodes in a limestone in the upper Chugwater Formation of the Bighorn Mountains, but this may be a reference to the modern Gypsum Spring Formation, which was removed from the Chugwater Formation.

Gypsum Spring Formation (Middle Jurassic)

The Gypsum Spring Formation of the BICA area is composed of red, brown, and gray shale, fossiliferous limestone, dolomite, and gypsum, between 20 and 70 m (65 and 230 ft) thick. There is a white gypsum bed at the base of the formation, up to 30 m (100 ft) thick (Rioux 1994, Pierce 1997). Within BICA, it is identified in several areas on the Wyoming side (NPS 2007). It is sometimes mapped undivided with the overlying Sundance Formation (Pierce 1997). Both the lower and upper contacts are disconformable, and represent the regional J-1 (lower) and J-2 (upper) unconformities (Kvale et al. 2001). It is often absent in older references, such as Darton (1904) and (1906), and was first described as a member of the Chugwater Formation (Love 1939, High and Picard 1967). It is roughly equivalent to the Piper Formation, which is preferred in Montana (Imlay 1956, Kvale et al. 2001), and sometimes in the Wyoming part of the Bighorn Basin the upper Gypsum Spring Formation is identified as the Piper Formation (Schmude 2000, Parcell and Williams 2005). The Gypsum Spring Formation is dated to the Middle Jurassic, and is usually assigned at least in part to the Bajocian (170 to 168 Ma) (Kvale et al. 2001, Mickelson et al. 2006b).

Typically, the Gypsum Spring Formation can be split into distinct lower, middle, and upper parts. Generally the lower part of the formation is composed of red gypsum, claystone, and siltstone, the middle is composed of marine limestone, dolomite, and claystone, and the upper part is similar to the lower part, except with less gypsum (Picard 1993). This division becomes less clear going east, where the middle section disappears (Mapel and Bergendahl 1956). This is because the middle section was deposited under open marine conditions, and the seaway was not as extensive in northeastern Wyoming as in other areas (Peterson 1957a). The tripartite division can be seen in the Bighorn Basin (Kvale et al. 2001), including the BICA area (Mickelson et al. 2006b). Deposition occurred during two transgression-regression cycles, with the lower unit representing one cycle and the middle and upper representing a second, more extensive cycle (Parcell and Williams 2005). The lower and upper portions are interpreted as representing lagoonal, intertidal, and supratidal settings adjacent to an open marine shelf to the west, and the middle is interpreted as marine deposition under normal conditions (not hypersaline or brackish, not anoxic, etc.) (Wright 1974). The formation becomes more limestone-rich to the west, eventually grading into a marine formation (Picard 1993). The climate was seasonally arid (Clark and Brett-Surman 2008).

The Gypsum Spring Formation of BICA is fossiliferous. It includes examples of two intervals with many reptile trace fossils (Mickelson et al. 2005b, 2006a). The lower level belongs to an interval about a meter thick (3 ft) in the middle Gypsum Spring Formation that has multiple horizons with dinosaur tracks. The interval is found throughout the Bighorn Basin, and is thought to date to the end of the Bajocian. The tracks are entirely those of

tridactyl bipedal dinosaurs, at least in part theropods (generally carnivorous). They are found on tidal flat sediments, and were preserved by the growth of microbial mats (Kvale et al. 2001). A meter above this level is a horizon with swim traces made by crocodile relatives and possible bipedal dinosaurs. These traces can be found throughout BICA (Mickelson et al. 2005a, 2006a).

As a whole, the Gypsum Spring Formation is only notably fossiliferous in the middle section. The middle part of the formation has yielded stromatolites (Kvale et al. 2001), microbial reefs and other microbial structures, blue-green algae, coralline red algae, green algae, foraminifera, sponges, corals, bryozoans (Ploynoi and Parcell 2005), ammonites (Kvale et al. 2001), bivalves, gastropods, ostracodes (Peterson 1957b), crabs, shrimp (Guyer et al. 1995), crinoids, echinoids (Imlay 1967), invertebrate trace fossils (Kvale et al. 2001), and the above-mentioned reptile swim traces (Mickelson et al. 2006a, 2006b) and dinosaur megatracksite (Kvale et al. 2001, Clark and Brett-Surman 2008). Most of these fossils are known from the Bighorn Basin (Imlay 1956, Guyer et al. 1995, Kvale et al. 2001, Ploynoi and Parcell 2005, Mickelson et al. 2006a, 2006b, Clark and Brett-Surman 2008), or the adjacent Wind River Basin to the south (Peck 1957, Peterson 1957b). Thrombolites are found in a widespread horizon of the middle part of the formation (Parcell et al. 2004).

Ellis Group: Rierdon Formation (Middle Jurassic)

The Rierdon Formation of the BICA area is composed of slope-forming gray fossiliferous shale, limestone, and sandstone, between 45 and 55 m (150 and 180 ft) thick (Lopez 2000, Vuke et al. 2000) and thinning north to south (Richards 1955). Mappable outcrops are limited to an area near Yellowtail Dam, but equivalent rocks in the Sundance Formation are present in the Wyoming part of the recreation area (NPS 2007). The Rierdon Formation is roughly equivalent to the lower Sundance Formation as used in Wyoming (Imlay 1956, Kvale et al. 2001), and sometimes members of the Sundance Formation are extended from Wyoming into the Rierdon Formation (Imlay 1954; for reference, he extended the Hulett, Stockade Beaver, and Canyon Springs members). The upper contact with the Swift Formation is disconformable (Stewart 1958, Swain 1998), representing the regional J-3 unconformity (Kvale et al. 2001).

The Rierdon Formation is a marine formation, including a transgression-regression cycle (Parcell and Williams 2005). The Sheridan Arch extending east-west through north-central Wyoming and southeast Montana divided deposition (Peterson 1954a). Deposition occurred during the latter part of the Middle Jurassic, probably including some part of the late Bathonian (Swain 1998) and early Callovian ages (Imlay 1956), roughly 167 to 165 Ma.

The Rierdon Formation is fossiliferous within BICA. It has yielded fossils of bivalves (*Gryphaea*), belemnites (relatives of squid, represented by bullet-shaped internal guards), and star-shaped crinoid columnals north of the mouth of Bighorn Canyon in lime-rich shale (Richards 1955). Note that Santucci et al. (1999) and Koch and Santucci (2003) attribute this occurrence to the lower Sundance Formation, the Wyoming equivalent. These fossils are here kept with their original designations, to follow the usage of NPS (2007). Fossils are also well-known from the vicinity. Fossils of bivalves, belemnites, and crinoids are common in the BICA area, and are

often found as float (Lopez 2000). Fish fossils have been found in a sandstone bed at the south end of the Pryor Mountains (Lopez 2000), and there is a fossiliferous pink limestone at the base of the formation in the vicinity (Tinsley et al. 1954). Thom et al. (1935) reported bivalves and belemnites from a handful of locations east of BICA in the Sundance Formation, but because the locations are in Montana, Rierdon and/or Swift formation terminology would be more appropriate. Farther afield, fossils are common near Red Dome on the west side of the Pryor Mountains (Imlay 1956) and going north to Fivemile Creek, an area about 40 km (25 miles) west of BICA (Imlay 1954). The overall fossil assemblage of the Rierdon Formation includes foraminifera (Lalicker 1950), bryozoans (Imlay 1956), brachiopods, bivalves, ammonites (Imlay 1953, 1954, 1956), belemnites (Cobban 1945), nautiloids (Kummel 1954), gastropods (Imlay 1954, 1956), ostracodes (Peterson 1954a, 1954b, Sherrington and Lord 1975, Lord and Sherrington 1976), crinoids, echinoids (Imlay 1954, 1956), and fish (Lopez 2000).

Ellis Group: Swift Formation (Middle–Upper Jurassic)

The Swift Formation of the BICA area is composed of predominantly grayish sandstone, shale or claystone, and limestone, approximately 30 to 35 m (100 to 115 ft) thick. There is a notable sandy limestone at the top of the formation that is described as a coquina, a bed made up of shells; other heavily fossiliferous beds are scattered throughout the formation (Agard 1988, Lopez 2000, Vuke et al. 2000). Like the underlying Rierdon Formation, beds mapped as the Swift Formation are only found within BICA near Yellowtail Dam, but equivalent beds are present in the Wyoming side of the recreation area as part of the Sundance Formation (NPS 2007). It becomes finer-grained from west to east in the Bighorn Basin (Imlay 1956). It is sometimes considered to include two vertically and horizontally gradational members in the BICA area, the lower being composed primarily of claystone and the upper composed of sandstone with bivalve-rich beds (Imlay 1954). The Swift Formation, preferred in Montana, is roughly equivalent to the upper Sundance Formation as used in Wyoming and the Black Hills, and the Stump Formation as used in eastern Idaho and western Wyoming (Brenner and Davies 1974). The upper contact with the Morrison Formation is conformable (Swain 1998), but can appear abrupt (Imlay 1956).

The Swift Formation is a marine unit. In the BICA area, it is interpreted as a combination of marine mud deposition and bar sands (Brenner and Davies 1974). There is at least one and possibly two transgression-regression cycles in the Swift–upper Sundance interval, with the two possible cycles divided by an internal disconformity (Kvale et al. 2001). Deposition occurred between the late Callovian age of the Middle Jurassic and the late Oxfordian or early Kimmeridgian of the Late Jurassic (Swain 1998), between approximately 164 and 157 Ma.

The Swift Formation is fossiliferous in and around BICA. It is known for its heavily fossiliferous beds, some of which are found near the mouth of Bighorn Canyon in the recreation area (Richards 1955). Richards (1955) did not specify what types of fossils were found, but bivalves and belemnites are common fossils in the BICA area (Stewart 1958, Lopez 2000, Vuke et al. 2000), and ammonites have also been found (Imlay 1954, 1956). Santucci et al. (1999) and Koch and Santucci (2003) attribute this occurrence to the upper Sundance Formation, the Wyoming equivalent. Overall, including areas outside of

BICA, the fossil assemblage of the Swift Formation includes dinoflagellates (a type of algae that moves using flagella), coal, plant fragments (Sablock and Sablock 1988), wood (Cobban 1945), wood bored by invertebrates (Porter 1989), pollen from ginkgoes and other plants (Sablock and Sablock 1988), bivalves, ammonites (Cobban 1945, Sablock and Sablock 1988), belemnites (Cobban 1945), gastropods (Sablock and Sablock 1988), ostracodes (Swain and Peterson 1952, Peterson 1954a, Lord and Sherrington 1976, Swain 1998), possible worm tubes (Cobban 1945), invertebrate burrows (Cobban 1945, Meyers et al. 1992), and fish teeth (Cobban 1945, Sablock and Sablock 1988).

Sundance Formation (Middle–Upper Jurassic)

The Sundance Formation of the BICA area is composed of gray and green sandstone, siltstone, shale, and thin bed of fossiliferous limestone, about 110 to 140 m (360 to 460 ft) thick (Rioux 1994, Pierce 1997). It is mapped in the Wyoming section of BICA, where it can be found on the west side of Bighorn Lake in the Crooked Creek area within the borders of the recreation area (NPS 2007). The Sundance Formation is frequently divided into a number of members. Usually in the BICA area it is broadly divided into a "lower" and "upper" Sundance (Kvale et al. 2001, Mickelson et al. 2006b). The "lower" and "upper" Sundance are roughly equivalent to the Rierdon and Swift formations as used in Montana, respectively, and are separated by the J-3 regional disconformity (Kvale et al. 2001). The "lower" Sundance includes strata that are equivalent to, from oldest to youngest, the Canyon Springs Sandstone, Stockade Beaver Shale, Hulett Sandstone, and Lak members of the Sundance Formation, and the "upper" Sundance includes equivalents of the Pine Butte and Redwater Shale members (Imlay 1953, Kvale et al. 2001, Mickelson et al. 2006b).

The Sundance Formation is primarily a marine unit, deposited by the Sundance Sea, a shallow continental marine body that encroached from the northwest (Harris and Lacovara 2004). The various members track the extent of the sea. In ascending order, the Canyon Springs Sandstone Member has been interpreted broadly as representing littoral marine deposition, the Stockade Beaver Shale as a brackish lagoon, the Hulett Sandstone Member as littoral, the Lak Member as a hypersaline lagoon, the Pine Butte Member as littoral, the Redwater Shale Member as an open marine shelf, and the Windy Hill Member as littoral (Wright 1974). The presence of terrestrial tracks shows some periods of subaerial exposure during the deposition of both the lower (Kvale et al. 2001, Mickelson et al. 2006b) and upper Sundance Formation (Harris and Lacovara 2004). Tidal flats facing the sea on the southwest were sometimes present in the Bighorn Basin during deposition of the early part of the lower Sundance Formation, under a climate that was at least seasonally arid (Mickelson et al. 2006b). Tidal flats behind barrier islands were present in the BICA area during deposition of part of the upper Sundance Formation (Harris and Lacovara 2004). It appears that one large transgression-regression cycle with three smaller subcycles occurred during deposition of the lower part of the formation, and one or two occurred during deposition of the upper part. The lower Sundance cycle is separated from the upper Sundance cycle or cycles by the J-3 unconformity mentioned above, and another regional unconformity (J-4) marks the division of the two potential Upper Sundance cycles (Kvale et al. 2001). Deposition of the Sundance Formation occurred during the Middle and Late Jurassic, from the Bathonian to the Oxfordian

ages (between 168 and 157 Ma) (Schmude 2000, Kvale et al. 2001, Mickelson et al. 2006b), albeit with significant internal hiatuses (Kvale et al. 2001).

The Sundance Formation of the BICA area has long been recognized as fossiliferous. Darton (1904, 1906) noted the presence of fossils, including crinoids and abundant bivalves and belemnites (Darton 1906); there is some possibility that modern usage would substitute the Rierdon or Swift formations for at least some of the study area. Imlay (1956) recorded Sundance Formation fossils at Sykes Mountain within BICA, including bivalves, gastropods, worm tubes, crinoids, and echinoids in the lower Sundance Formation, and an "oyster bed" in the upper Sundance Formation. Harris and Lacovara (2004) described unusual tracks and trackways from the upper Sundance Formation at Sykes Mountain. There is some possibility that one of the trackways might represent a pathological or unknown pterosaur (Harris and Lacovara 2004). Note that Santucci et al. (1999) and Koch and Santucci (2003) attributed the fossils (bivalves, belemnites, and crinoids) reported by Richards (1955) from the Rierdon and Swift formations in the Montana part of BICA to the Sundance Formation.

Fossils are also common in the vicinity. Tracks have been found in a level at or near the top of the "basal member" of the lower Sundance Formation (Canyon Springs Sandstone member equivalent) (Kvale et al. 2001, Mickelson et al. 2006b). Small- to medium-sized tridactyl bipedal dinosaurs, many heading south-southwest possibly to the shore, left abundant tracks on a tidal flat. Microbial films then helped to preserve the tracks (Mickelson et al. 2006b). The best-known locality for these tracks is probably the Red Gulch Dinosaur Tracksite, 43 km (27 miles) southeast of BICA near Greybull (Kvale et al. 2001; Breithaupt et al. 2001). The Red Gulch Dinosaur Tracksite occupies an area of 1,600 m^2 (17,000 ft^2) and features roughly 1,000 dinosaur tracks ranging from 8 to 30 cm (3 to 12 in) long, attributed to theropod dinosaurs. A statistical analysis indicates that one species is responsible for the tracks. At least 125 trackways of 2 to 45 steps have been found, with an estimated average speed of 6 km/hr (4 mph), and many trackways form parallel to subparallel groupings, suggesting gregarious animals. Invertebrate trace fossils and body remains of bivalves, gastropods, and crinoids are also present (Breithaupt et al. 2001). In addition to the abundant dinosaur tracks, the Red Gulch Dinosaur Tracksite is also notable for the extensive and innovative documentation of the tracks (Breithaupt and Matthews 2001, Matthews et al. 2006), and the integration of research and the public (Breithaupt et al. 2001, Breithaupt et al. 2002, 2006). Several other track-rich localities have been found at the same horizon, such as the Flitner Ranch, Melinda 2, and Yellow Brick Road dinosaur tracksites (Adams et al. 2004). The Yellow Brick Road Dinosaur Tracksite, about 2.5 km (1.5 miles) from the Red Gulch site, has hundreds more theropod tracks (Adams 2001).

Aside from dinosaur tracks, the lower Sundance Formation in the Bighorn Basin has yielded dinoflagellates and other microfossils, corals, bryozoans (Kvale et al. 2001), bivalves, ammonites, belemnites, gastropods, worm tubes, crinoids, echinoids (Imlay 1956), invertebrate burrows, and bone fragments (Kvale et al. 2001). The upper Sundance Formation in the basin has yielded brachiopods, bivalves (sometimes in coquina beds), belemnites, ammonites (Imlay 1956), the ichthyosaur (dolphin-like marine reptile) *Opthalmosaurus* (formerly known as

Baptanodon), the long-necked plesiosaurs *Pantosaurus* and *Tatanectes* (O'Keefe et al. 2009, 2011, Wilhelm and O'Keefe 2010), including one instance of a *Pantosaurus* with embryonic ichthyosaur remains as gut contents (O'Keefe et al. 2009), and the unusual BICA tracks (Harris and Lacovara 2004). The marine vertebrates are known from sites in the southern part of the basin, in the Redwater Shale equivalent (O'Keefe et al. 2009, 2011, Wilhelm and O'Keefe 2010). The coquinas are found above the Redwater Shale equivalent, and make up one or more beds depending on the location. Two coquina beds are known from the vicinity of BICA. They were deposited in a regressive coastal marine sequence as the Sundance Sea retreated to the north (Uhlir et al. 1988).

Overall, rocks from the lower Sundance Formation (Canyon Springs Sandstone to Lak members) have yielded a variety of marine fossils, mostly from the Stockade Beaver Shale Member. The assemblage includes foraminifera (Loeblich and Tappan 1950), dinoflagellates, other microfossils, corals, bryozoans (Kvale et al. 2001), brachiopods, bivalves, ammonites, belemnites (Imlay 1947), gastropods (Breithaupt et al. 2001), worm tubes (Imlay 1956), ostracodes (Peterson 1954b, Wright 1974, Swain 1998) and other crustaceans (Herrick and Schram 1978, Feldmann 1979), asteroids (sea stars) (Miller and Unklesbay 1943), crinoids (Imlay 1947), echinoids (Imlay 1956), general bioturbation (Rautman 1975), marine invertebrate trace fossils such as borings (Tang 1997, Conroy et al. 2002) and fecal pellets (Stone and Vondra 1972), hybodont sharks, several types of early bony fish (Schaeffer and Patterson 1984), and dinosaur tracks (Kvale et al. 2001, Breithaupt et al. 2001).

Fossils from the upper Sundance Formation across its depositional area are best known from the Redwater Shale Member, which has a very diverse fossil assemblage. Plants are represented by wood (Brenner and Davies 1974, Pipiringos and Imlay 1979). Invertebrates are abundant, and marine vertebrates are occasionally found (O'Keefe and Street 2009). The invertebrate fossil assemblage of the Redwater Member includes foraminifera (Loeblich and Tappan 1950), brachiopods (Brenner and Davies 1973), bivalves, ammonites, belemnites (Imlay 1947), gastropods, scaphopods (Specht and Brenner 1979), the lobster-like decapod crustacean *Eryma* (Wahl 2004), ostracodes (Swain and Peterson 1951, 1952), asteroids (Blake 1981), crinoids, echinoids, polychaete worm tubes, and other invertebrate trace fossils (Specht and Brenner 1979). Vertebrates reported from the member include hybodont sharks (Wahl 2005), a more derived shark (Massare et al. in press), the ichthyosaur (dolphin-like marine reptile) *Opthalmosaurus* (formerly known as *Baptanodon*) (Massare et al. 2006), plesiosaurs *Megalneusaurus* (Wahl et al. 2007), *Pantosaurus* (O'Keefe et al. 2009), and *Tatenectes* (O'Keefe and Street 2009), a purported crocodylomorph (Marsh 1895), and indeterminate reptile bones (Specht and Brenner 1979). The unusual BICA tracks are also from the upper Sundance Formation (Harris and Lacovara 2004). Ichthyosaurs are the most common large reptiles, and belemnites appear to have been a major food source (Massare et al. in press).

Finally, there are some reports of fossil material from an unspecified or undetermined member or portion of the Sundance Formation. Most notable among these are pollen of conifers and other gymnosperms, and insect fossils,

including hemipterans (true bugs), beetles, and caddisfly larvae (Santiago-Blay et al. 2001).

Morrison Formation (Upper Jurassic)

The Morrison Formation is a widespread heterogeneous and variegated unit. In the BICA region, it is composed primarily of reddish-brown or greenish-gray mudstone, with sandstone beds, particularly near the middle of the formation (Lopez 2000, Vuke et al. 2000). It ranges from 90 to 105 m (300 to 350 ft) thick (Lopez 2000, Vuke et al. 2000), and is frequently mapped with the overlying Cloverly Formation, which is lithologically very similar (Richards 1955, Rioux 1994, Pierce 1997). The Morrison Formation can be found within the Montana side of BICA near Yellowtail Dam, and in the Sykes Mountain area within the Wyoming side (NPS 2007). The formation is often divisible into several members, although this has not been formally done in the Bighorn Basin. Three members were created by Allen (1996) for southern Wyoming, but they have limited applicability because type sections were not established. From oldest to youngest, they are the Lake Como, Talking Rocks, and Indian Fort members (Foster 2003).

The Morrison Formation is a terrestrial unit. Rocks with fluvial, lacustrine, and floodplain origins have been reported from the northern Bighorn Basin (Moberly 1960). Conglomerates show an east-northeast direction of transport (Winslow and Heller 1983). 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 about 155 and 148 Ma (Foster 2007).

The position of the contact of the Morrison and Cloverly formations has been a point of contention since the two formations were recognized in the Bighorn Basin, with many different interpretations (Moberly 1960). Authors do not even agree on whether the contact is conformable or disconformable; Moberly (1960), for example, interpreted the contact as disconformable north of Sykes Mountain and transitional south of it, and Winslow and Heller (1983) proposed that the contact was transitional and the two formation shared the same fluvial system. If proponents of a conformable contact are correct, it would have significant implications for the ages of the two formations (Winslow and Heller 1983), which are traditionally thought to be separated by approximately 25 million years. The two formations both include a variety of rock types, without an obvious break except where the Pryor Conglomerate Member of the Cloverly Formation is present. This distinctive unit sometimes cuts channels into the Morrison Formation (Moberly 1960). The contact with the overlying Kootenai Formation in Montana is disconformable (DeCelles 1986).

The Morrison Formation is fossiliferous within BICA. Santucci et al. (1999) reported the presence of a sauropod dinosaur track site on the west side of Sykes Mountain and fragmentary dinosaur bones. Engelmann and Hasiotis (1999) included a photograph of a sauropod track on the underside of a sandstone ledge low in the formation on the west side of Sykes Mountain. Engelmann (1999) implied that fossils from the Morrison Formation of BICA were included in his study, but did not provide any details. Parrish et al. (2004) included Sykes Mountain as a paleobotanical site on a figure, but did not discuss it in the text, leaving open the possibility of an error. Hasiotis (2004) reported the presence of six types of

traces from the lower Morrison Formation of Sykes Mountain, including structures interpreted as root traces, probable beetle burrows, insect larval burrows, and the aforementioned sauropod tracks.

There are a handful of published fossil sites in the vicinity of BICA as well. Turner and Peterson (1999) and Foster (2003) provide enumerations of vertebrate localities, but they are becoming outdated. In the three counties that include part of BICA, seven sites as of 2003 had yielded bones and teeth of lungfish, pterosaurs, and theropod, sauropod, plated, and ornithopod dinosaurs (Foster 2003). The most famous fossil sites are probably the Howe Quarry and the Big Al site, near Shell, Wyoming, 40 km (25 miles) southeast of BICA. The Howe Quarry is notable for its abundant fossils of sauropod dinosaurs, excavated in the 1930s for the American Museum of Natural History (Brown 1935, Bird 1985, Foster 2007). The Big Al site, which has yielded most of the skeleton of the *Allosaurus* nicknamed "Big Al", was found near the Howe Quarry in 1991 (Breithaupt 1996, 2001, Laws 1996, Hanna 2002, Bates et al. 2009). As of 2003, vertebrates reported from the Big Al site included a pterosaur, the carnivorous dinosaur *Allosaurus*, the sauropod dinosaur *Diplodocus*, and the plated dinosaur *Stegosaurus*. Vertebrates reported from the Howe Quarry to that point include the lungfish *Ceratodus*, *Allosaurus*, the sauropod dinosaurs *Apatosaurus*, *Diplodocus* or *Barosaurus*, and *Camarasaurus*, *Stegosaurus*, and the beaked herbivorous dinosaurs *Othnielia* (now generally known as *Othnielosaurus*), *Dryosaurus*, and *Camptosaurus* (Foster 2003). A number of discoveries in the Bighorn Basin have been published since 2003, the year of the original GRYN paleontological inventory (Good 2004, Harris and Dodson 2004, Hasiotis 2004, Parrish et al. 2004, Platt et al. 2004a, 2004b, Brett-Surman et al. 2005, Kubarek and Swor 2005, Derby et al. 2006, Jennings et al. 2006, Platt and Hasiotis 2006, 2008, Wilborn 2006a, Anderson 2007, Carballido et al. 2012, Tschopp and Mateus in press), although most of these publications are abstracts. Notable finds include: the new sauropod *Suuwassea emilieae* from an undisclosed BLM locality near BICA in southern Carbon County, Montana (Harris and Dodson 2004); microvertebrate sites near Shell (Brett-Surman et al. 2005, Derby et al. 2006, Wilborn 2006a), including one yielding abundant dinosaur eggshell fragments as well as mammal fossils (Brett-Surman et al. 2005); trace fossils, including diverse invertebrate traces and sauropod tracks with skin impressions found near Shell (Platt and Hasiotis 2006), and dinosaur tail traces (Platt and Hasiotis 2008); a juvenile brachiosaurid sauropod from near Shell (Carballido et al. 2012); and the new sauropod *Kaatedocus siberi* from Howe Quarry (Tschopp and Mateus in press). Plants and invertebrates are also known from body fossils in the Morrison Formation of the Bighorn Basin. These groups are represented by chlorophyte algae, lignite, petrified wood (Moberly 1960), ferns, cycads (Tidwell et al. 1977), plant cuticle (Murphy et al. 2005), fungal attacks on plants (Tidwell et al. 1977), bivalves (Good 2004) and freshwater gastropods (Moberly 1960). Two fern species have been named from the upper Morrison Formation near BICA: *Solenostelopteris leithii* and *S. medlynii* (Tidwell and Skog 1999).

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 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, *Goniopholis* (closely related to the ancestry of modern crocodilians) and other extinct crocodylomorphs, 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 like *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 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).

Cloverly/Kootenai Formation (Lower Cretaceous)

The Cloverly and Kootenai formations are here described together. They represent essentially the same complex stratigraphic interval in the BICA area, and it would be confusing to treat them separately. In the BICA area, they are described as a variegated interval of mudstone and sandstone, with a conglomeratic unit at the base (the Pryor Conglomerate Member) and some limestone zones (Rioux 1994, Pierce 1997, Vuke et al. 2000). The thickness ranges from 35 to 75 m (115 to 245 ft) (Pierce 1997, Vuke et al. 2000), but note that definitions of these two formations can vary substantially, based on inclusions and exclusions of beds at the top and bottom of the interval. Within BICA, they are found at Sykes Mountain (detailed in Ostrom [1970]) and near Yellowtail Dam (NPS 2007).

Although it can be broadly said that the Cloverly Formation is the Wyoming equivalent of Montana's Kootenai Formation, the Cloverly Formation is used widely in the Bighorn Basin and surrounding mountains in southern

Montana. Historically, the Cloverly Formation was preferred over the Kootenai Formation in this part of Montana (Reeside 1923, Thom et al. 1935, Blackstone 1940, Andrews et al. 1947, Heiny and Walter 1954, Richards 1954, Moberly 1960, 1962, Hamilton and Paulson 1968, Agard 1988); the turning point was Rice (1976), which recommended using the Kootenai Formation instead of the Cloverly Formation in south-central Montana, including the BICA area. While this change may have taken with mapping geologists, paleontologists have resisted adopting the Kootenai name for what had been the Cloverly in Montana (see as recent as Oreska et al. [2013]). Because of this usage pattern, the majority of this section will deal with the Cloverly Formation.

The Cloverly Formation of the Bighorn Basin is usually understood to include three members, long recognized (Reeside 1923, Thom et al. 1935), but not all formally named until 1960: the Pryor Conglomerate Member, a conglomeratic unit that thins from north to south, disappearing at Sykes Mountain; the Little Sheep Mudstone Member, predominantly composed of bentonitic mudstone (bentonite is a clay mineral that forms from the decomposition of volcanic ash), with some limestone; and the Himes Member at the top of the formation, a claystone and sandstone unit. Depending on location, the Pryor Conglomerate or Little Sheep Mudstone is the basal member. The Little Sheep Mudstone and Himes members have a disconformable contact with channels (Moberly 1960). Occasionally, “Fuson” and/or “Lakota,” stratigraphic terms from the Black Hills, have been used as subdivisions of the Cloverly (Darton 1904, Richards 1954), but this is not a common practice. Vertebrate paleontologists commonly use a parallel scheme introduced in Ostrom (1970), with Roman numerals to designate units. In this scheme, numerals I to III denote three parts of the underlying Morrison Formation, numeral IV denotes the Pryor Conglomerate Member, numeral V denotes the Little Sheep Mudstone Member, numeral VI denotes the channel sands of the lower Himes Member, numeral VII denotes the claystone interval of the upper Himes Member, and numeral VIII denotes the lower sands of the Sykes Mountain Formation (Ostrom 1970; now generally assigned to the Cloverly Formation [see below]). At Sykes Mountain, Ostrom (1970) reported 14 m (45) of unit IV, 23 m (75 ft) of unit V, 25 m (81 ft) of VI, 16 m (53 ft) of VII, and 4 m (11 ft) of VII.

The definition of the Cloverly Formation has varied widely over time. Both the upper and lower contacts have proven difficult to establish (Moberly 1960). The contact with the underlying Morrison Formation has already been discussed. The upper contact has been controversial because of a pair of units, the Greybull Sandstone and overlying “rusty beds,” a sandstone and shale unit named for its characteristic color. These two units have variously been included in the Cloverly/Kootenai interval, given their own formation (the Sykes Mountain Formation of Moberly [1960]), included in the overlying Thermopolis Shale, or distributed separately (Moberly 1960). The Greybull Sandstone and “rusty beds” are not intended to describe the same rocks, but they can be difficult to separate (Richards 1955). Both the Greybull Sandstone and the “rusty beds” are present in the BICA area (Rioux 1994, Pierce 1997, Lopez 2000, Vuke et al. 2000). Maps of the BICA area in Wyoming used for NPS (2007) (Rioux 1994, Pierce 1997) have included both units in the Cloverly Formation, and the Montana maps (Lopez 2000, Vuke et al. 2000) include at least the Greybull Sandstone in the Kootenai Formation (their placement of the “rusty beds”

is not stated), so these two units will be included in this section of the inventory as well. Note, though, that the vertebrate paleontology literature frequently employs the Sykes Mountain Formation name. A few publications include a third unit, another sandstone bed known as the Birdhead Sandstone Member, in this nebulous upper Cloverly–lower Thermopolis interval; it has been assigned to both the Cloverly Formation, for example in Richards (1955), and the Thermopolis Shale, for example in Thom et al. (1935), and to further confuse matters has sometimes been used for the Muddy or middle sandstone of the Thermopolis Shale (Wulf 1962). This unit is now identified as the Fall River Sandstone (Rice 1976), discussed in its own section. Clearly, anyone wishing to do research on the Cloverly–Kootenai interval must pay attention to a given publication's definitions.

The Cloverly Formation has proven difficult to date (Oreska et al. 2013). Traditionally, it has been regarded as Aptian and Albian in age (125 to 100.5 Ma), although as noted in the Morrison Formation section its base may be older (Winslow and Heller 1983). Recent interpretations suggest that there is a significant disconformity within the formation (Zaleha and Wiesemann 2005, Zaleha 2006), which could account for this. Recent dates from the Cloverly Formation include 108.5±0.2 Ma (Burton et al. 2006) and 104.4 Ma (D'Emic and Foreman 2012), placing at least part of it in the middle Albian age. The contact of the Greybull/"rusty" interval with the rest of the Cloverly/Kootenai interval has been variously described as conformable (D'Emic and Foreman 2012) or unconformable (Kvale and Vondra 1993, Zaleha and Wiesemann 2005, Zaleha 2006). The upper contact of the Greybull/"rusty" interval with the Thermopolis Shale is transitional (Moberly 1960).

The Cloverly Formation was deposited under a warm, seasonal climate, becoming more humid over time as the Western Interior Seaway approached. Deposition of the Little Sheep Mudstone Member occurred under an arid to semi-arid climate, with droughts. Later, a savannah environment appeared in the upper Himes Member (Forster 1984). A substantial part of the sediment is of volcanic origin (Moberly 1960, 1962). Above the conglomeratic channels of the Pryor Conglomerate Member, the Little Sheep Mudstone Member is interpreted as having been deposited in playas (ephemeral lakes) and streams (Moberly 1960, Kvale and Vondra 1993). These settings persisted into the lower Himes Member (Moberly 1960). Higher in the member, fluvial deposition predominated (Moberly 1960). Floodplains appeared as the seaway approached (D'Emic and Foreman 2012). The sea advanced from the north (Nydam and Cifelli 2002).

The Kootenai Formation is a combination of fluvial and lacustrine deposits (DeCelles 1986, Condon 2000). As with the Cloverly Formation, a marine influence appears at the top (James 1980, DeCelles 1986). Large paleochannels and valleys have been found in the formation (Hopkins 1985), including just outside of BICA on the Crow Indian Reservation (Lopez 1998). Four major west-trending valley systems have been found in outcrops on the reservation, including the Greybull Channel running across the north ends of the Pryor and Bighorn ranges (Lopez 1998). At least some of the channels are distributaries around lacustrine systems (Hopkins 1985). The Greybull Sandstone fills paleovalleys on the reservation (Lopez 2001).

The Greybull/"rusty" interval was deposited during the transition to the full marine conditions of the overlying rocks (Zaleha and

Wiesemann 2005, D'Emic and Foreman 2012). The Greybull Sandstone has been interpreted as a meandering river similar to the Brazos River (Shelton 1972), and as estuarine (Kvale and Vondra 1993). The "rusty beds" above are shallow marine in origin (Moberly 1960, Kvale and Vondra 1993).

If Moberly's (1960) Sykes Mountain Formation strata are included in the Cloverly Formation, as done by NPS's (2007) source maps, the Cloverly–Kootenai interval is fossiliferous in BICA: Ostrom (1970) reported thin shell interbeds in the Sykes Mountain Formation from his Sykes Mountain section. Vertebrate sites are known within a few km/miles of the recreation area (Ostrom 1970), and plant hash is present at Sykes Spring, just outside of it (Oreska et al. 2013).

The Cloverly Formation below the contested Greybull/"rusty" interval has a substantial fossil assemblage, and is best known for its dinosaurs. The Pryor Conglomerate Member is not known for its fossils. Coal, carbonaceous debris, and wood have been reported (Moberly 1960). The Sheep Mountain Mudstone and Himes members are much more fossiliferous. Fossils are most commonly represented in the upper part of the Sheep Mountain Mudstone Member (upper V) and the lower part of the Himes Member claystone section (lower VII) (Ostrom 1970). Until recently, identifiable plant remains were sparse in the Cloverly Formation, and plants were only represented by charophytes (Peck 1957), coal and coalified wood (Mirsky 1962), petrified wood (Moberly 1960), leaf and needle fragments (Darton 1904, 1906), spores and pollen (Mirsky 1962), and root traces (Zaleha and Wiesemann 2005). Recently, a paleoflora was discovered in the Bighorn Basin, including spores, pollen, ferns, cycadophytes, conifers, and angiosperms, the latter only present near the top of the formation (Wilborn 2006b, Ju, and Wing 2010, Haiar and Lupia 2011, Jud 2011). Invertebrates are represented by bivalves, gastropods (Reeside 1923, Yen 1949, 1951), caddisfly casings (Jud 2011), shell fragments (Thom et al. 1935), crayfish gastroliths ("stomach stones") (Oreska et al. 2013), and burrows (Zaleha and Wiesemann 2005). Vertebrates are enumerated in Oreska et al. (2013), which also includes a discussion of their stratigraphic distribution within the formation. The following list is drawn from this publication, with annotations as needed. Vertebrates found in the Sheep Mountain Mudstone and Himes members include hybodont sharks, rays, several types of ray-finned fish, the lungfish *Ceratodus*, extinct salamander-like albanerpetontid amphibians, salamanders, frogs, several types of turtles and tortoises, lizards, representatives of four lineages of crocodile relatives, theropod dinosaurs including large *Acrocanthosaurus* and small *Deinonychus*, *Microvenator*, and an unnamed "ostrich-mimic", possible birds, sauropod dinosaurs including *Rugocaudia* and the giant *Sauroposeidon*, the armored dinosaurs *Sauropelta* and *Tatankacephalus*, an early horned dinosaur, the small ornithopod dinosaur *Zephyrosaurus*, the common large ornithopod *Tenontosaurus*, the triconodont mammals *Corviconodon* and *Gobiconodon*, several forms of multituberculate mammals, a symmetrodont mammal, additional unnamed early mammals, and dinosaur eggshells (Maxwell and Horner 1994). Rounded isolated stones are often identified as dinosaur gastroliths, but this identification cannot be established for certain (Wings 2007, 2009), and they may be ordinary stones moved by special flow conditions (Zaleha and Wiesemann 2005). Finally, reworked Paleozoic clasts have been found in the formation; some have foraminifera, sponge

spicules, bryozoans, brachiopods, gastropods, and echinoderms (Zaleha and Wiesemann 2005).

The Kootenai Formation below the Greybull/ "rusty" interval is primarily known for its paleobotanical record. Plants represented in the Kootenai Formation include charophytes (Peck 1941, 1957), mosses (Brown and Robison 1972, 1974), liverworts (Brown and Robison 1976, LaPasha and Miller 1985), hornworts, quillworts, horsetails, ferns, seed ferns (LaPasha and Miller 1985), cycads (Horner 1989), cycadeoids (LaPasha and Miller 1985), ginkgoes (Brown 1975), conifers (LaPasha 1977, Miller and LaPasha 1984), and unclassified plants (Brown 1972, LaPasha and Miller 1985). Plants are often found in coal seams (Horner 1989). In addition to plants, many other groups are represented, including algal or microbial limestone (Holm et al. 1977), dinoflagellates (Hopkins 1985), bivalves, gastropods (Yen 1949, 1951, James 1980), ostracodes (Peck 1941, Yen 1951), general bioturbation (DeCelles 1986), hybodont sharks, holostean fish (Horner 1989), the turtle *Naomichelys* (Joyce et al. 2011), the herbivorous sphenodontian *Toxolophosaurus* (Olson 1960, Throckmorton et al. 1981), crocodile relatives (Horner 1989), and indeterminate dinosaurs (Weishampel et al. 2004).

The Greybull/"rusty" interval, sometimes known as the Sykes Mountain Formation, has a small fossil assemblage. Fossils specifically reported from the Greybull Sandstone include dinoflagellates (Kvale and Vondra 1993), carbonized wood (Shelton 1972), gymnosperms, angiosperms, invertebrate burrows, and fragmentary turtle and crocodile relative remains (Kvale and Vondra 1993). The "rusty beds" have yielded plant fossils (Darton 1904), stem impressions (Love et al. 1948), freshwater bivalves and gastropods (Love 1956), and invertebrate traces (Love et al. 1948). References to fossils that could be from either unit, or the Sykes Mountain Formation, include tintinnids (protozoans with protein-based shells), carbonaceous debris, peat (Eicher 1960), petrified wood, leaves of ferns, fern-like plants, conifers, and angiosperms (Walton et al. 2007), bivalves (Kvale and Vondra 1993), possible casts of bivalves and gastropods (Eicher 1960), thin shell interbeds (Ostrom 1970), invertebrate trails and burrows (Eicher 1960, Moberly 1960, Kvale and Vondra 1993), invertebrate castings (feces), and fish teeth and fragments, most of which are known from the Bighorn Basin (Eicher 1960).

Mowry Shale (Upper Cretaceous)

The Mowry Shale of the BICA area is a resistant formation composed of hard dark gray fissile (splits easily into thin sheets) shale and lighter gray sandstone and siltstone. Beds of bentonite are common, and fish scales are abundant (Rioux 1994, Lopez 2000, Vuke et al. 2000). Most exposures within BICA are either along the western border of the Wyoming section, or in isolated areas of the thin northern corridor of the Montana section (NPS 2007). Its thickness is given as between 75 and 120 m (250 and 400 ft) (Lopez 2000, Vuke et al. 2000), although the extent of the Mowry Shale varies between publications; both the upper and lower contacts are difficult to place because of the lack of obvious disconformities or changes in lithology. Historically, the U.S. Geological Survey has included a sandstone bed known as the Muddy Sandstone and an overlying interval of shale in the underlying Thermopolis Shale, but other authors have elected to include the upper Thermopolis Shale in the Mowry Shale, giving the Muddy Sandstone its own formation or including it in the Mowry Shale as well

(Reeside and Cobban 1960). Examples of publications defining the base of the Mowry Shale using the Muddy Sandstone include Vuke (1984), Dyman et al. (1994), and Johnson (2010). The upper contact with the Frontier Formation/Belle Fourche Formation has also varied, based on authors' opinions regarding an upper volcanic tuff zone (Reeside and Cobban 1960). Recent works have tended to bracket the formation with a pair of bentonite beds, which also date the formation precisely within the early Late Cretaceous. They are the Arrow Creek Bentonite, dated to 98.52±0.41 Ma, and the Clay Spur Bentonite, dated to 97.17±0.69 Ma (Scott et al. 2009) (although note that Merewether et al. [2010] preferred slightly older dates in the BICA area, based on fossils).

The Mowry Shale is an offshore marine formation (Merewether 1996), deposited within the Western Interior Seaway (Franczyk et al. 1992). The sea arrived from the north-northwest, transgressing from what is now Alberta and Saskatchewan (Wulf 1962). In Wyoming, it spread west to east (Byers and Larson 1979). It is uncertain if the northern part of the Seaway system, which included the GRYN, was connected to the southern part during the deposition of the Mowry Shale; they may have been connected near the end of deposition (Eicher 1965). Volcanoes west of the seaway, perhaps in what is now Idaho, contributed to the rocks of the formation (Reeside and Cobban 1960).

Although we have yet to locate an unambiguous reference to a discrete fossiliferous locality within BICA, the Mowry Shale should be regarded as fossiliferous within the recreation area. This is because of the ubiquity of fish scales in the formation, which are common enough to be used as a defining characteristic of the formation in the region (Richards 1955, Lopez 2000). Publications including general references to the abundant fish scales in areas including BICA include Darton (1904, 1906), Thom et al. (1935), Richards (1955), Hamilton and Paulson (1968), Agard (1988), Pierce (1997), Santucci et al. (1999), Lopez (2000), and Vuke et al. (2000). A few other types of fossils have been found in the vicinity. Cobban and Reeside (1951) described ammonites from the Pryor Mountains and Bighorn Basin. Bivalves, ammonites, and fish remains have been found near Lovell (Reeside and Cobban 1960). Knetchel and Patterson (1956) found abundant fish scales and bones in the Soap Creek area east of BICA. Wulf (1962), describing middle Cretaceous rocks of the BICA area, reported bivalves, ammonites, and fish teeth and bones in the Pryor Mountains, and invertebrate traces elsewhere, but found the only common fossils to be the fish scales.

The Mowry Shale over its entire depositional area has a small but growing fossil assemblage. Non-animal organisms are represented by foraminifera, radiolarians (another type of "shelled" protist), dinoflagellates, spores, pollen (Oboh-Ilkuenobe et al. 2007), coal (Uyger and Picard 1985), tree ferns (Ash and Read 1976), angiosperm leaves (Stewart et al. 1994), and other plant remains (Uyger and Picard 1985). Invertebrates include bryozoans (Maione 1971), bivalves (Reeside and Cobban 1960), and ammonites (Maione 1971, Molenaar and Wilson 1990); they are also represented by impressions of cephalopods (Brown and Vokes 1944, Connely and Talbot 2005), burrows, and local bioturbation (Davis et al. 1989, Merewether et al. 2010). The bottom sediments often show little evidence of burrowing animals, indicating anaerobic bottom waters (Byers and Larson 1979). Vertebrates are represented by sharks and other cartilaginous fish (Hamblin et al. 2000, Cicimurri 2004,

Gregson et al. 2010), ray-finned fish (Hamblin et al. 2000, Stewart and Hakel 2006), the ichthyosaur *Platypterygius* (Nace 1939, Massare and Dain 1989, Maxwell and Kear 2010), a long-necked elasmosaurid plesiosaur, a short-necked plesiosaur, a crocodylomorph (Massare and Dain 1989), a pterosaur (Bennett 1989), and possible vertebrate trace fossils (Burford 1985, Connely and Talbot 2005, Trumbull and Connely 2010). Fish scales and bone fragments are abundant (Maione 1971, Molenaar and Wilson 1990).

Upper Cenozoic Rocks and Sediments (Pliocene?–Holocene)

Upper Cenozoic deposits are scattered throughout BICA, typically concentrated in the vicinity of the Bighorn River (NPS 2007). Grain sizes in the recreation area and the vicinity generally range in size from gravel to clay, but can be substantially larger. Deposits are up to 15 m (50 ft) thick, and include alluvial, glacial outwash, landslide, pediment, and stream terrace deposits. Most of them are Pleistocene or Holocene in age, but some are thought to be older (Rioux 1994, Pierce 1997, Lopez 2000, Vuke et al. 2000).

Common Quaternary fossils of northern Wyoming and southern Montana include bones of large mammals and fossil material useful for paleoecological and paleoclimatological studies, such as pollen and packrat middens. BICA has examples of both: a late Pleistocene musk ox vertebra was found about a kilometer north of Highway 14A almost on Bighorn Lake (Reheis 1987, KellerLynn 2011), and Lyford and colleagues (Lyford 2001, Lyford et al. 2002, 2003) described a series of packrat middens from the Pryor Mountains, including a group from the east slope of East Pryor Mountain to Bighorn Canyon on the Montana side of BICA. Packrat middens are collections of plant material and food waste constructed by packrats (*Neotoma* spp.) and cemented by their viscous urine. They can be well-preserved in dry caves, and illustrate the environment of the builder's foraging range. Middens are important tools for reconstructing the ecology and climate of the late Pleistocene and Holocene of the southwestern United States (Strickland et al. 2001). The BICA middens were found at elevations of between 1,275 to 1,590 m (4,180 to 5,215 ft) (Lyford et al. 2002). Lyford et al. (2002) reported on 53 of these middens. Many of them were dated by radiocarbon, with most dates between a few hundred years ago and 6,800 years ago, but three of them dated to between 10,400 and 12,300 years ago, near the Pleistocene–Holocene boundary. Lyford et al. (2002) used the middens to track the evolution of the tree community over the late Quaternary, finding changes in the juniper and pine species to indicate an arid period during the middle Holocene, followed by a brief moister period ending around 3,000 years ago. Lyford et al. (2003) is a similar study, focused on juniper species and implications for climate, but with a longer record: in this case, the East Pryor midden record is extended to over 30,000 years ago. Ancient packrat middens are probably more widely distributed in BICA than only the East Pryor Mountain area.

Faunmap (http://www.ucmp.berkeley.edu/faunmap/index.html) and the Neotoma database (http://www.neotomadb.org/) show over 30 Quaternary fossil sites of both types within approximately 100 km (60 miles) of BICA. The great majority are Holocene mammal sites. The best known of the fossil sites is Natural Trap Cave, just over 2 km (about 1.25 miles) east of BICA and 2.5 km (1.5 miles) south of the Devil Canyon arm of the recreations area. Natural Trap Cave is a treacherous void that formed in Madison Group limestone. The remains of

many animals can be found in this pit, apparently distributed around a now-melted cone of snow and ice. Natural Trap Cave cannot be escaped without the aid of tools, and was not used for habitation (although a few artifacts have been reported), shelter, or a raptor roost; all vertebrate remains appear to have come from animals that fell in (Martin and Gilbert 1978a). Animals have been trapped in the cave for tens of thousands of years; an ash dated to 110,000 years ago is present near the base of the cave sediments. This great age makes the cave valuable for studies of animals that lived during the most recent interglacial (Gilbert and Martin 1984). The best-represented period is the latest Pleistocene, between about 21 and 11 thousand years old (Chomko and Gilbert 1987). Fossils found in the cave include phytoliths (microscopic bits of minerals found in the cells of some plants), pollen, and the bones of shrews, rodents, rabbits, pikas, bats, American cheetahs and lions, foxes, wolves, the short-faced bear *Arctodus*, mustelids including weasels and wolverines, mammoths, multiple species of horses, camels, pronghorns, muskox, mountain sheep, and bison (Martin and Gilbert 1978a, Gilbert and Martin 1984). The material shows a steppe-tundra assemblage similar to what has been seen in Alaska, unlike other assemblages south of the continental ice sheets (Gilbert and Martin 1984). Other references to the cave and its fauna include Martin et al (1977, 1979), Martin and Gilbert (1978b), Gilbert (1984, 1985), Wang (1985), Chom et al. (1988), and Williams (2006). BICA, like the surrounding Bighorn and Pryor mountains, has caves, and it is likely that Quaternary fossils will eventually be found in them. The most extensive known cave, Bighorn Cavern, has a debris pile at the entrance that may have fossils in it, but has not yet been investigated (Santucci et al. 2001).

Other vertebrate sites shown in the immediate vicinity of BICA by Faunmap and Neotoma include Big Lip, False Cougar Cave, Mangus, Shield Trap, Sorensen, and Wortham Shelter. Big Lip, False Cougar Cave, and Shield Trap were detailed by Graham et al. (1987). False Cougar Cave has a fossil record going back to the latest Pleistocene; Pleistocene and early/middle Holocene fossils from this site include shrews, rodents, rabbits, pikas, bats, canids, mustelids, horses, camels, mountain sheep, and bison. Shield Trap spans the Holocene; its early/middle Holocene fossils include shrews, rodents, rabbits, bears, mustelids, mountain sheep, and bison. Big Lip's fossils only date to the middle and early Holocene, and include rodents, deer, mountain sheep, and bison. False Cougar Cave and Big Lip also have evidence of human utilization (Graham et al. 1987).

Ice caves, which have sheltered deposits of ice, are known from the Pryor Mountains (Campbell 1978); should one be found in BICA, it is possible that microfossils like pollen may be found in the ice. At least three pollen sites are known from within the 100 km radius, but they are lake sites: Beaver Lake, Floating Island Lake, and Sherd Lake. All three were described in Burkart's (1976) dissertation, and Late Pleistocene and Holocene radiocarbon dates from Beaver Lake and Floating Island Lake were reposted by Bender et al. (1977).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within BICA. However, they are known to preserve fossils elsewhere, and future field investigations within the recreation area may locate fossils in one or more of them.

Goose Egg and Phosphoria Formations (Permian–Lower Triassic)

It can be seen from NPS (2007) that the rocks identified by one of the source maps as the Phosphoria Formation in Montana are the same as rocks that the Wyoming maps identify as the Goose Egg Formation. Because mappable instances of this stratigraphic interval are identified solely as the Goose Egg Formation within BICA (either alone or mapped undivided with the Chugwater Formation), and because the Goose Egg Formation includes units also included in the Phosphoria Formation, the interval will be discussed under the Goose Egg name. The Goose Egg Formation of the BICA area is up to 82 m (270 ft) thick and includes several divisions. The basal 40 m (130 ft) is red shale with lesser amounts of gypsum and dolomite, and phosphorite and chert near the top. The next 27 m (90 ft) is mostly limestone and dolomite. Finally, the uppermost 15 m (50 ft) is gray shale with some dolomite and gypsum. The lower division may correlate to the Phosphoria Formation, the middle division is equivalent to the Ervay Tongue of the Park City Formation, and the upper division is equivalent to the Triassic-age Dinwoody Formation (Rioux 1994). Hanson (1962b) specifically identified the lower part of the interval as the Phosphoria Formation and the upper part as the Dinwoody Formation at Sykes Mountain. The formation appears to be thicker in the southern part of the recreation area than the northern part, where it is mapped undivided with the Chugwater Formation (Vuke et al. 2000). The Goose Egg Formation has mappable outcrops in two general areas of BICA: in the vicinity of Yellowtail Dam (mapped with the Chugwater Formation) in Montana, and in a northwest-southeast band beginning at the state line and cutting across BICA in Wyoming (NPS 2007).

The Goose Egg Formation is unusual: functionally, it is a sort of “grab bag” of alternating thin carbonate and redbed strata that can be correlated to much thicker formations to the east and west. “Contributing” formations include the Dinwoody and Spearfish formations for Triassic rocks, and the Minnekahta, Opeche, Park City, and Phosphoria formations for Permian rocks (Burk and Thomas 1956, Cavaroc and Flores 1991). The historical nomenclature of this interval is complicated (Burk and Thomas 1956, McKelvey et al. 1959). In many publications, it is identified as one or more of the Dinwoody, Park City, Phosphoria or Embar formations (Richards 1955, Burk and Thomas 1956), the latter being a now-abandoned term (McKelvey et al. 1959). Darton initially reported this stratigraphic interval within another formation, identifying some basal units of his Chugwater Formation with rocks now included in the Goose Egg Formation (a basal shale that was possibly the Opeche Shale, and a succeeding limestone that was possibly the Minnekahta Limestone) (Darton 1904). By 1906, he had split then from the Chugwater Formation entirely, as the Embar Formation, which he only found in the southern Bighorn Mountains (Darton 1906). The Embar identification persisted for several decades (Blackstone 1940, Andrews et al. 1947, Richards 1955). Burk and Thomas (1956) introduced the Goose Egg name for the interval, recognizing a number of subdivisions, further refined by Maughan (1964, 1967). In ascending

order, they are the Opeche Shale, Minnekahta Limestone, Glendo Shale, Forelle Limestone, Difficulty Shale or Lower Freezeout Shale, Ervay, Freezeout Shale, and Little Medicine members. An additional unit, the Tosi Member, is sometimes included between the Ervay and Difficulty members in the Bighorn Basin (Simmons and Scholle 1990). Redbed members extend from the east, and the others extend from the west (Burk and Thomas 1956). They correspond to alternating environments of deposition around a coast under a warm arid climate (Maughan 1964, 1967). Episodes of faulting and uplift occurred during deposition (Simmons and Scholle 1990).

The Goose Egg Formation includes Permian and Lower Triassic rocks (Burk and Thomas 1956, Cavaroc and Flores 1991), but is not dated precisely. There is an inferred disconformity between the Permian and Lower Triassic rocks, but it is difficult to locate (Burk and Thomas 1956). The upper contact with the Chugwater Formation is variously described as disconformable (Blackstone 1940) or conformable (Burk and Thomas 1956).

The Goose Egg Formation is not known to be fossiliferous within BICA (Santucci et al. 1999), and there do not appear to be any reports from the immediate vicinity. Many of the constituent units of the Goose Egg Formation are fossiliferous in other areas, and the Phosphoria and Park City formations are extensively fossiliferous elsewhere, but it is not clear which parts are present in BICA: at least two important fossiliferous divisions of this complex, the Meade Peak and Retort members, are known to be absent from the BICA area (Wardlaw and Collinson 1986). Therefore, the following discussion has been limited to the Goose Egg Formation, with some attention given to the Ervay Member and Dinwoody Formation because they were specifically mentioned by Rioux (1994). Darton (1906) reported brachiopods, bryozoans, and indeterminate fossils in central Wyoming and the south end of the Bighorn Mountains. Goose Egg carbonate units have fossils of bryozoans, brachiopods, gastropods, and crinoids (Simmons and Scholle 1990); they are sometimes common in the Bighorn Canyon area where not destroyed by post-depositional processes (Hanson 1962b). Conodonts and fragments of fish have been reported from the Minnekahta and Forelle members; the latter also has molds of bivalves and gastropods (Pearson 1971). The Ervay Member, as a member of the Park City Formation, has yielded stromatolites (Maughan 1987), bryozoans, brachiopods, bivalves, nautiloids, gastropods, scaphopods, crinoids, echinoids (McKelvey et al. 1959), conodonts (Behnken et al. 1986), and fish fragments (Yochelson and van Sickle 1968). Finally, fossils from the Dinwoody Formation are not notably abundant (Paull and Paull 1983), but include brachiopods, bivalves, ammonites, gastropods, scaphopods, “serpulid worm tubes” (these are often misidentified), crinoids, echinoids, ophiuroids, conodonts, bioturbation (Paull et al. 1985) invertebrate burrows and trails, and fish (Paull and Paull 1987). However, the marine fauna is only present in the western part of the formation, west of BICA (Paull and Paull 1993).

Ellis Group: Piper Formation (Middle Jurassic)

The Piper Formation is a gray, brown, and red slope-forming formation primarily composed of limestone, shale, and gypsum (Lopez 2000, Vuke et al. 2000). There are three non-mappable members in the BICA region, described as a lower redbed and gypsum member, a middle limestone member, and an upper redbed member (Imlay 1954, Richards

1955); this is broadly similar to the Gypsum Spring Formation, its Wyoming equivalent. These units have been named the Tampico Shale, Firemoon Limestone, and Bowes members (Parcell and Williams 2005). The formation as a whole is 22 to 45 m (75 to 150 ft) thick (Lopez 2000). Like the other formations of the Ellis Group, it is only exposed within BICA near Yellowtail Dam, but rocks that are probably equivalent to it in the Gypsum Spring Formation can be found within the Wyoming side of the recreation area (NPS 2007). The Piper Formation is roughly equivalent to the Gypsum Spring Formation as used in Wyoming (Imlay 1956, Kvale et al. 2001), although it is sometimes extended from Montana into the Wyoming part of the Bighorn Basin by reassigning the upper Gypsum Spring Formation to it (Schmude 2000, Parcell and Williams 2005). In this interpretation, the only portion present in Wyoming is the upper redbed member (the Bowes Member) (Schmude 2000). The contact with the overlying Rierdon Formation has been described as disconformable (Imlay 1954) or conformable (Pipiringos and O'Sullivan 1978, Mickelson et al. 2006b); it may simply vary by location. Deposition occurred during two transgression-regression cycles, with the lower unit representing one cycle and the middle and upper representing a second, more extensive cycle (Parcell and Williams 2005), and occurred during the late Bajocian and early Bathonian stages (Swain 1998), approximately 169 to 167 Ma.

The Piper Formation is not known to be fossiliferous within BICA (Santucci et al. 1999), although it is fossiliferous just outside of it. Richards (1955) reported molds of bivalves and other fossils from a site just north of BICA on Grapevine Creek, and Imlay (1956) reported that the middle limestone was fossiliferous just west of the recreation area on Gypsum Creek. The Piper Formation as a whole is not known for its fossils, but the Firemoon Limestone Member (the "limestone member" of older reports) is fossiliferous (Imlay 1956). Fossils that have been reported from the BICA region include corals, bivalves (sometimes in coquinas), ammonites, gastropods, crinoids, echinoids, and ophiuroids (brittle stars) (Imlay 1954, 1956). Other fossils reported from the formation include thrombolites and possible microbial laminations (Parcell and Williams 2003), foraminifera (Parcell 1996), charophytes (Peck 1957), and ostracodes (Lord and Sherrington 1976).

Fall River Sandstone (Lower Cretaceous)

The Fall River Sandstone and Thermopolis Shale are commonly mapped together in the BICA area, where they form a section 180 to 210 m (600 to 700 ft) thick (Lopez 2000, Vuke et al. 2000). The Fall River Sandstone of the area is composed of interbedded brown sandstone and gray shale, coarsening upward (Lopez 2000, Vuke et al. 2000). Because it is mapped with the Thermopolis Shale, its exact distribution is not known, but it should be found with the Thermopolis Shale upstream of Yellowtail Dam and in the vicinity of Sykes Mountain (NPS 2007). The Fall River Sandstone is one of the units involved in the complex nomenclature of the "middle" Cretaceous of Bighorn Basin (Moberly 1960), as discussed above. It is sometimes considered an equivalent to the Greybull/"rusty" interval (Moberly 1960) and sometimes considered a member of the Thermopolis Shale (Dyman et al. 1994).

The Fall River Sandstone dates to the Albian age of the Early Cretaceous (113 to 100.5 Ma) (Zaleha and Wiesemann 2005, Zaleha 2006). It represents more of the marine transgression

seen in the underlying Greybull/"rusty" beds of the Cloverly/Kootenai interval (Lopez 2001). It was primarily deposited in tidal flat, estuarine, coastal swamp, deltaic, and other marginal marine settings (Waage 1959, Wulf 1962, Campbell and Oaks 1973, Condon 2000), with some fluvial and floodplain deposits as well (Campbell and Oaks 1973). The contact with the overlying lower Thermopolis Shale (Skull Creek Shale) can be conformable, as in the Bighorn Mountains (Wulf 1962) or disconformable (Campbell and Oaks 1973, Druckenmiller 2002).

Fossils are generally uncommon in the Fall River Formation, perhaps because mixing of marine and freshwater had just begun (Waage 1959). The fossil assemblage of the formation includes dinoflagellates (Campbell and Oaks 1973), coal (Wulf 1962, Condon 2000), spores, pollen, plant stem and leaf impressions (Campbell and Oaks 1973), silicified tree trunks (Gott et al. 1974), possible foraminifera (Braddock 1963), bivalves, invertebrate trace fossils (Waage 1959), a single report of a crocodile relative (Farke et al. 2001), and possible fish egg cases (Connor 1963). Leaves and invertebrate trace fossils are the most abundant paleontological resources (Farke et al. 2001). Burrows and bioturbation can be found in the BICA region (Lopez 2000).

Thermopolis Shale (Upper Cretaceous)

As noted under the Cloverly/Kootenai and Mowry Shale sections, the definition of the Thermopolis Shale has long been in dispute. The maps used for NPS (2007) employ something similar to the USGS conception of a basal and upper section of shale separated by a middle sandstone, probably the Muddy Sandstone (Rioux 1994, Pierce 1997, Lopez 2000, Vuke et al. 2000). The Thermopolis Shale of the BICA region is approximately 120 to 180 m (400 to 600 ft) thick (Pierce 1997), and composed primarily of soft dark shale with bentonite beds, and a light gray sandstone unit in the middle (Rioux 1994, Pierce 1997, Lopez 2000, Vuke et al. 2000). It can be found within BICA upstream of Yellowtail Dam and in the vicinity of Sykes Mountain (NPS 2007). In the Bighorn Basin and Mountains, the lower shale is occasionally called the Skull Creek Member (Rice 1976), and the upper shale is occasionally called the Shell Creek Member (Moberly 1962). Researchers need to pay attention to what configuration is in use in a given publication: both the upper shale and the middle or Muddy Sandstone are sometimes given their own formations or assigned to the overlying Mowry Shale (Eicher 1960, Reeside and Cobban 1960), and additional beds are sometimes assigned to the base of the formation, as discussed under the Cloverly/Kootenai section. Some authors even abandon the Thermopolis name in the BICA area altogether (Wulf 1962, Rice 1976).

The Thermopolis Shale is a marine formation, with evidence of parts of two transgressions and an intervening regression (Condon 2000). Deposition was primarily under the northern arm of the Western Interior Seaway. The transgression that deposited the lower shale (Skull Creek) was eventually extensive enough that the northern and southern arms of the seaway connected (Eicher 1960). A regression followed during deposition of the middle or Muddy sandstone, and the two arms were separated, leaving only northern waters over the GRYN area (Druckenmiller 2002); authors have variously interpreted it as having a basal unconformity (Druckenmiller 2002) or upper unconformity (Condon 2000). Deposition of the sandstone is associated with a delta (Vuke 1984), found to the east (Wulf 1962); various brackish shallow depositional settings are present (Eicher 1960). A renewed transgression

is responsible for deposition of the upper shale, but in this case the arms of the seaway did not connect during deposition, with the northern arm over the GRYN area (Eicher 1960). Deposition of the formation included volcanic ash (Vuke 1984). The age of the formation is earliest Late Cretaceous; the base of the middle sandstone dates to around 98.5 Ma, and ammonites of the upper shale indicate that it dates to between 98.74±0.59 and 98.54±0.70 Ma (Druckenmiller 2002).

The Thermopolis Shale is not known to be fossiliferous within BICA, but it is fossiliferous in the vicinity. Bivalves, ammonites, gastropods, shark teeth, fish scales and bones, turtles, and reptile bones and teeth have been found just east of BICA in Montana (Knetchel and Patterson 1956). Similar fossils were found in the Crow Indian Reservation and nearby areas (Reeside 1923, Thom et al. 1935). Eicher (1960) provided a detailed breakdown of fossils in the three Thermopolis Shale members of the Bighorn Basin. The lower shale unit (Eicher's Thermopolis Shale) yielded foraminifera, tintinnids, sponge spicules, bivalves, invertebrate trails, burrows, and castings, teeth and fragments of fish, and fragments of crocodile relatives. The middle sandstone (Eicher's Muddy Sandstone) yielded foraminifera, angiosperms, bivalves, shark teeth and spines, chimaeroid fish spines, holostean (gars and bowfin) scales, fragments of teleost fish and turtles, and crocodile relative teeth. The upper shale (Eicher's Shell Creek Shale) yielded foraminifera, radiolarians, bivalves, ammonites, crabs, fish scales, and fragments of turtles (Eicher 1960).

Overall, including areas outside of the Bighorn Basin and Mountains, macrofossils are rare in the Thermopolis Shale, but microfossils are common (Eicher 1958). Fossils attributed to the shaly parts of the formation include foraminifera, radiolarians, tintinnids (Eicher 1958, 1960), palynomorphs including dinoflagellates (Schwab 1977), the tree fern *Tempskya* (Ash and Read 1976), sponges (Eicher 1958, 1960), bivalves, ammonites (Reeside and Cobban 1960), crabs, invertebrate burrows, trails, and castings (Eicher 1960), hybodont sharks, sawfish, rays, bony fish, turtles (Lash and Schmitt 2008), the plesiosaur *Edgarosaurus* (Druckenmiller 2002), marine crocodile relatives, and coprolites (Lash and Schmitt 2008). The middle sandstone interval has yielded foraminifera, angiosperms (Eicher 1960), brachiopods, bivalves, asteroids (Wulf 1962), invertebrate traces (Tillman and Dresser 1976), and vertebrate remains such as teeth, spines, and bone fragments, representing cartilaginous and bony fish, turtles, and crocodile relatives (Eicher 1960, Wulf 1962, Kausch and Giffin 1993).

Belle Fourche Formation (Upper Cretaceous)

The Belle Fourche Formation is exposed in small areas in extreme northern BICA, along the west and northwest side of the Bighorn River downstream of the Yellowtail Dam (NPS 2007). It consists of dark shale with bentonite beds and concretions, and generally 110 to 120 m (350 to 400 ft) thick, up to 145 m (475 ft) (Lopez 2000, Vuke et al. 2000). The Belle Fourche Formation is commonly used as the lowest part of the Frontier Formation in Wyoming (see for example Merewether et al. 1979 or 2010); therefore, the Frontier Formation outcrops in Wyoming could potentially be considered the Belle Fourche, but this is muddied by Lopez (2000), which states that the Belle Fourche Formation is replaced by the Frontier Formation near the Wyoming border in the BICA area.

The Belle Fourche Formation is a marine formation, becoming more open marine over time (Eicher 1967). Sandstone beds represent shelves and shale beds represent deeper deposition (Condon 2000). A delta existed in the southeast Bighorn Mountains during deposition (Merewether et al. 1979). The formation dates to the Cenomanian age of the early Late Cretaceous. The base of the formation is marked by the Clay Spur Bentonite of 97.17±0.69 Ma (Scott et al. 2009), and deposition continued after a bentonite bed dated to 95.78 Ma (Gani and Bhattacharya 2007).

The Belle Fourche Formation is not known to be fossiliferous within BICA. Radiolarians (Blome and Eicher 1994) and ammonites (Knetchel and Patterson 1956, Cobban 1987) have been found in the vicinity of BICA. The formation as a whole has a variety of microfossils, invertebrates, and marine vertebrates. The microfossil assemblage of the Belle Fourche Formation includes acritarchs (Merewether 1996), calcareous nannofossils (Fisher and Hay 1999), foraminifera (Eicher 1967), radiolarians (Blome and Eicher 1994), dinoflagellates, and spores and pollen (Merewether 1996). Invertebrates are represented by corals (Merewether 1996), bivalves, ammonites (Cobban 1984), gastropods (Williston 1905), and invertebrate burrows and general bioturbation (Merewether 1996). Finally, vertebrate are represented by sharks, bony fish, coelacanths, turtles (Cicimurri 2001), the ichthyosaur *Platypterygius* (Maxwell and Kear 2010), long-necked and short-necked plesiosaurs, pterosaurs (Cicimurri 2001), crocodile relatives (Williston 1905), and washed-in skeletons of the armored dinosaurs *Nodosaurus* and *Stegopelta* (Carpenter and Kirkland 1998).

Frontier Formation (Upper Cretaceous)

The Frontier Formation of the BICA region is a gray shale and sandstone formation between 135 and 180 m (440 and 600 ft) thick (Rioux 1994, Pierce 1997). It is exposed in small areas along the western boundary of the recreation area on the Wyoming side, at Sykes Mountain and near the southern end (NPS 2007). The small exposures imply that only the lower part of the formation is present in BICA; per Rioux (1994), the lower part of the formation in the area includes sandstone, shale, bentonite, conglomerate, and the 20 m (70 ft) thick Peay Sandstone Member, about 24 m (80 ft) from the base. The Frontier Formation is stratigraphically complex (Merewether et al. 1979), and includes a number of internal hiatuses (Merewether et al. 1979, 2010). Thus, the duration of deposition varies between areas. In the vicinity of BICA, the formation ranges in age from slightly after 98.9 Ma to sometime around 94 Ma (Merewether et al. 2010), which is approximately the same age range occupied by the Belle Fourche Formation as used on the Montana side.

The Frontier Formation is a marine unit, but with variable deposition. In the Bighorn Basin, it includes two to four sandstone beds deposited in nearshore marine, shelf, and estuarine settings, interbedded with marine shale (Johnson 2010). Unlike the underlying Mowry Formation, the northern and southern parts of the Western Interior Seaway were connected during Frontier Formation deposition (Scott et al. 2001). A series of deltas formed on the western side of the seaway (Burgess 1971, Ryer 1977).

The Frontier Formation is not known to be fossiliferous within BICA, but is fossiliferous in the immediate vicinity. Bivalves and ammonites were found on Crooked Creek just west of

BICA (Merewether et al. 2010), and shark teeth were found on the Crow Indian Reservation east of BICA (Reeside 1923). Overall, the Frontier Formation includes diverse fossils, befitting its transitional coastal origin; note, though, that because of the formation's stratigraphic complexity and variability, at least some of these reports may not be relevant to BICA, or refer to units described elsewhere in this report (particularly the Belle Fourche Formation). Palynomorphs and inorganic microfossils include acritarchs (Merewether 1996), microspheres (Upshaw 1963), foraminifera (Young 1951, Eicher 1967, Molenaar and Wilson 1990), chlorophyte algae (Tysdal et al. 1990), charophyte algae (Jones 1954), dinoflagellates and other microplankton, spores, and pollen (Upshaw 1964, Tysdal et al. 1990). The formation has a significant floral assemblage, first collected by the explorer John C. Frémont from southwestern Wyoming in 1843. It includes horsetails, ferns, cycadophytes, conifers, and monocot and dicot angiosperms (Knowlton 1917, Berry 1930, Andrews and Pearsall 1941). Coal and wood are common (Uygur and Picard 1985, Moslow and Tillman 1986, Merewether et al. 2010), and root traces have also been found (Moslow and Tillman 1986). Invertebrates are represented by bryozoans (Merewether and Cobban 2008), brachiopods (Merewether et al. 2010), bivalves, ammonites (Young 1951, Upshaw 1964, Merewether et al. 1984, Merewether and Cobban 2008), nautiloids (Cobban 1990), gastropods (Young 1951, Upshaw 1964; Merewether et al. 1984, Merewether and Cobban 2008), worm tubes (Merewether and Cobban 2008), nonmarine ostracodes (Jones 1954), crabs (Merewether and Cobban 2008), echinoids (Upshaw 1964, Merewether and Cobban 2008), and trace fossils, including invertebrate burrows (Merewether et al. 1979, Molenaar and Wilson 1990), and general bioturbation (Maione 1971). Vertebrates are represented by sharks, rays, gars, pycnodont fish, turtles, squamates (lizards and snakes), and dinosaurs (Breithaupt 1985). Reworked Paleozoic clasts with fossils including corals, bryozoans, brachiopods, crinoids, and conodonts have also been found (Dyman et al. 1989).

Park Collections

BICA houses a number of fossils in its collections (BICA Figure 5). According to records provided by Cindy Hagen (BICA Cultural Resource Management, pers. comm., February 2013), there are 135 catalog numbers for fossils or possible fossils in the recreation area's collections. They range in age from Cambrian to at least the Eocene and potentially the Quaternary, and were collected from BICA and the immediate vicinity. Taxonomically, the catalog numbers can be broken down as following: 6 numbers are assigned to algal or microbial specimens, 3 to wood, 3 to sponges, 23 to corals, 2 to bryozoans, 8 to brachiopods, 15 to bivalves, 10 to ammonites, 6 to belemnites, 5 to nautiloids, 6 to gastropods, 2 to worm tubes (potentially other invertebrate ichnofossils), 8 to crinoids, 2 to echinoids, 3 to invertebrate ichnofossils, 8 to sharks, 3 to turtles, 8 to crocodiles or crocodile relatives, 5 to dinosaurs, 2 to mammals, 2 to "gastroliths" (possibly naturally rounded stones), and 5 unknown. BICA's interpretative exhibits are drawn from these specimens, and include: a stromatolite and trilobite (Cambrian); a sponge, coral, and mollusk (Ordovician); brachiopods and coral (Mississippian); coral (Triassic); bivalves, belemnites, dinosaur bone fragments, and gastroliths (Jurassic); and bivalves, ammonites, shark teeth, and crocodile teeth (Cretaceous) (Santucci et al. 1999). Most of these fossil lack stratigraphic information beyond a general assessment of age. Given the size of the collection it should be logistically feasible to reconstruct the stratigraphy for many of the fossils using a combination of taxonomy and locality information.

At least one outside institution has a collection of fossils from BICA: Harris and Lacovara (2004) reported that slabs of Upper Sundance Formation rocks with vertebrate tracks from the recreation area were to be reposited at the Cincinnati Museum of Natural History and Science, which has its collections at the Cincinnati Museum Center. They are not currently there, though, and are thought to be at Drexel University in Philadelphia (G. Storrs, curator of vertebrate paleontology, Cincinnati Museum Center, pers. comm., April 2013).



BICA Figure 5. Examples of fossils in BICA collections. Left: an echinoid. Right: a fossiliferous rock fragment; note the partial crinoid stalk. Photos courtesy Christy Fleming, BICA chief of interpretation.

Cultural Resource Contexts

Fossil-cultural resource associations have not yet been reported from BICA, but there is the potential for there to be a diverse and lengthy record because BICA is noted for its archeological resources and the Bighorn Basin has a long history of human occupation. Among the oldest human site in the basin are False Cougar Cave, just west of BICA on East Pryor Mountain, and the Colby Mammoth Site, about 90 km (55 miles) south of BICA near Worland. False Cougar Cave appears to have been inhabited by humans for thousands of years, and includes human hair dating to between 14,590±300 radiocarbon years before present (18,520-17,060 calendar years before present) and 10,530±140 radiocarbon years before present (12,690-12,000 calendar years before present). The site also contains artifacts, charcoal, plant macrofossils, bones of grouse, shrews, rodents, pikas, rabbits, felids, canids, mustelids, bears, horses, camels, deer, pronghorns, bison, and mountain sheep, and hair from shrews, rodents, pikas, rabbits, mustelids, bears, horses, elk, deer, bison, and mountain sheep (Bonnichsen and Bolen 1985). The Faunmap and Neotoma services depict the cave as within BICA, but the elevation of the site at about 8,600 m (2,600 ft) (Committee on Ungulate Management in Yellowstone National Park 2002) shows that the coordinates used by the online services are inaccurate. The Colby Mammoth Site has mammoth fossils and Clovis points dating to 11,200±200 radiocarbon years before present (13,280-12,870 calendar years before present) (Walker and Frison 1980). A variety of fossiliferous formations found in the region are known as sources of material for stone tools (Frison 1991). Among the rocks used for tools are potential “gastroliths” from the Morrison Formation (Frison and Bradley 1980). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Literature Cited

Adams, T. L. 2001. The "Yellow Brick Road": Middle Jurassic dinosaur tracks in the northeastern Bighorn Basin, Wyoming. *Journal of Vertebrate Paleontology* 21(supplement to 3):27A.

Adams, T., B. Breithaupt, J. Shinn, E. Southwell, and N. Matthews. 2004. The Sundance vertebrate ichnofaunal province: evidence for population structures of Bathonian dinosaurs from tracksites in the Bighorn Basin, Wyoming. *Journal of Vertebrate Paleontology* 24(supplement to 3):33A.

Agard, S. S. 1988. Preliminary geologic map of the Yellowtail Dam Quadrangle, Big Horn County, Montana. U.S. Geological Survey, Reston, VA. Miscellaneous Field Studies Map 2039. Scale 1:24,000. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_5637.htm. Accessed February 2013.

Agatston, R. S. 1952. Tensleep formation of the Big Horn Basin. Pages 44-48 *in* R. W. Spalding and J. S. Wold, editors. Southern Big Horn Basin, Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 7.

Allen, A. 1996. Morrison Formation stratigraphy between the classic Como Bluff and Thermopolis areas. Pages 19-26 in R. A. Hunter, editor. Paleoenvironments of the Jurassic. Tate Geological Museum, Casper, WY. Guidebook 1.

Amsden, T. W. and A. K. Miller. 1942. Ordovician conodonts from the Bighorn Mountains of Wyoming. *Journal of Paleontology* 16(3):301-306.

Anderson, A. K. 2007. Stratigraphic and taphonomic interpretations of the lower bone-bearing quarry of the Red Canyon Ranch dinosaur site in the Upper Jurassic Morrison Formation, Shell, Wyoming. Abstracts with Programs. *Geological Society of America* 39(3):9.

Andrews, D. A., W. G. Pierce, and D. H. Eargle. 1947. Geologic map of the Big Horn Basin, Wyoming and Montana, showing terrace deposits and physiographic features. Oil and Gas Investigations Map 71. U.S. Geological Survey, Washington, DC. Scale 1:126,720. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_5432.htm. Accessed February 2013.

Andrews, H. N., Jr. and C. S. Pearsall. 1941. On the flora of the Frontier Formation of southwestern Wyoming. *Annals of the Missouri Botanical Garden* 28(2):165-192.

Arth, J. G., F. Barker, and T. W. Stern. 1980. Geochronology of Archean gneisses in the Lake Helen area, southwestern Big Horn Mountains, Wyoming. *Precambrian Research* 11(1):11-22.

Ash, S. R. and C. B. Read. 1976. North American species of *Tempskya* and their stratigraphic significance. U.S. Geological Survey, Reston, VA. Professional Paper 874. Available online at: http://pubs.er.usgs.gov/publication/pp874. Accessed February 2013.

Ash, S. R. and W. D. Tidwell. 1998. Plant megafossils from the Brushy Basin Member of the Morrison Formation near Montezuma Creek Trading Post,

southeastern Utah. *Modern Geology* 22(1-4):321-340.

Aubrey, W. M. 1991. Geologic framework of Cretaceous and Tertiary rocks in the Southern Ute Indian Reservation and adjacent areas in the northern San Juan Basin, southwestern Colorado. Pages B1-B24 *in* R. S. Zech, editor. Geologic framework and stratigraphy of Cretaceous and Tertiary rocks of the Southern Ute Indian Reservation, southwestern Colorado. U.S. Geological Survey, Reston, VA. Professional Paper 1505-B, C. Available online at: http://pubs.er.usgs.gov/publication/pp1505BC. Accessed March 2011.

Barker, K. S. 1984. Stratigraphy, petrography, and paleoenvironmental interpretation of Mississippian-Pennsylvanian Amsden Formation south of La Barge Guard Station, Salt River Range, western Wyoming. *AAPG Bulletin* 68(7):932.

Bates, K. T., P. L. Falkingham, B. H. Breithaupt, D. Hodgetts, W. I. Sellers, and P. L. Manning. 2009. How big was "Big Al"? Quantifying the effect of soft tissue and osteological unknowns on mass predictions for *Allosaurus* (Dinosauria, Theropoda). *Palaeontologia Electronica* 12(3):12.3.14A. Available online at: http://palaeo-electronica.org/2009_3/186/. Accessed June 2013.

Beebee, R. A. and R. Cox. 1998. Dynamics of marine transgression onto a non-linear shoreline: the Middle Cambrian Flathead Sandstone, Clarks Fork Valley, Wyoming. *Mountain Geologist* 35(3):91-101.

Behnken, F. H., B. R. Wardlaw, and L. N. Stout. 1986. Conodont biostratigraphy of the Permian Meade Peak phosphatic shale member, Phosphoria Formation, southeastern Idaho. *Contributions to Geology* 24(2):169-190.

Bell, L. H. and L. T. Middleton. 1978. An introduction to the Cambrian Flathead Sandstone, Wind River basin, Wyoming. Pages 79-88 *in* R. G. Boyd, W. W. Boberg, and G. M. Olson, editors. Resources of the Wind River basin. Wyoming Geological Association, Casper, WY. Guidebook 30.

Bell, W. C. 1941. Cambrian Brachiopoda from Montana. *Journal of Paleontology* 15(3):193-255.

Bender, M. M., R. A. Bryson, and D. A. Baerreis. 1977. University of Wisconsin radiocarbon dates XIV. *Radiocarbon* 19(1):127-137. Available online at: https://journals.uair.arizona.edu/index.php/radiocarbon/article/view/478/483. Accessed February 2013.

Bennett, S. C. 1989. A pteranodontid pterosaur from the Early Cretaceous of Peru, with comments on the relationships of Cretaceous pterosaurs. *Journal of Paleontology* 63(5):669-677.

Benson, A. L. 1966. Devonian stratigraphy of western Wyoming and adjacent areas. *Bulletin of the American Association of Petroleum Geologists* 50(12):2566-2603.

Berry, E. W. 1930. The flora of the Frontier Formation. Pages 129-135 *in* Shorter contributions to general geology, 1929. U.S. Geological Survey, Reston, VA. Professional Paper 158.

Bird, R. T. 1985. Bones for Barnum Brown. Texas Christian University Press, Fort Worth, TX.

Blackstone, D. L., Jr. 1940. Structure of the Pryor Mountains, Montana. *Journal of Geology* 48(6):590-618.

Blackstone, D. L., Jr. and P. O. McGrew. 1954. New occurrence of Devonian rocks in north central Wyoming. Pages 38-43 *in* P. W. Richards, editor. Pryor Mountains-northern Bighorn Basin, Montana, September 9-11, 1954. Billings Geological Society, Billings, MT. Guidebook 5.

Blackwell, W. H., W. D. Martin, and R. G. McWilliams. 1983. Algal remains in cryptalgal laminated carbonates of the upper Middle Cambrian of Northwest Wyoming. *American Journal of Botany* 70(5, Part 2):68.

Blake, D. B. 1981. The new Jurassic sea star genus *Eokainaster* and comments on life habits and the origins of the modern Asteroidea. *Journal of Paleontology* 55(1):33-46.

Blome, C. D. and D. L. Eicher. 1994. Radiolarian paleoceanography of the Upper Cretaceous Western Interior Seaway, southern Montana. Abstracts with Programs. *Geological Society of America* 26(7):A-159.

Bonem, R. M. 1972. Stratigraphic and faunal studies of the Pilgrim Formation in south-central Montana. Pages 11-17 *in* J. Lynn, C. Balster, and J. Warne, editors. Crazy Mountains Basin. Montana Geological Society, Billings, MT. Guidebook 21.

Bonnichsen, R. and C. W. Bolen. 1985. A hair, faunal, and flaked stone assemblage: a Holocene and late Pleistocene record from False Cougar Cave, Montana. Pages 6-15 *in* C.W. Brott, editor. Woman, poet, scientist: essays in New World anthropology honoring Dr. Emma Louise Davis. Ballena Press, Los Altos, CA.

Bown, T. M. 1980. Summary of latest Cretaceous and Cenozoic sedimentary, tectonic, and erosional events, Bighorn Basin, Wyoming. *Papers on Paleontology* 24:25-32. Available online at: http://hdl.handle.net/2027.42/48624. Accessed February 2013.

Boyd, D. W. 2010. Morphology and taphonomy of an exceptional trackway from the Flathead Sandstone (Middle Cambrian) of Wyoming. *Contributions to Geology* 45(1):23-34.

Boyd, D. W. and H. T. Ore. 1963. A Wyoming specimen of *Dendrophycus*. *Contributions to Geology* 2(1):63-68.

Braddock, W. A. 1963. Geology of the Jewel Cave SW Quadrangle, Custer County, South Dakota. U.S. Geological Survey, Washington. Bulletin 1063-G. Available online at: http://www.nps.gov/history/history/online_books/geology/publications/bul/1063-G/index.htm. Accessed February 2013.

Brainerd, A. E. and I. A. Keyte. 1927. New faunal evidence from the Tensleep Formation. *Journal of Paleontology* 1(2):173-174.

Branson, E. B. 1947. Triassic (Chugwater) footprints from Wyoming. *Journal of Paleontology* 21(6):588-590.

Branson, E. B. and M. G. Mehl. 1932. Footprint records from the Paleozoic and

Mesozoic of Missouri, Kansas and Wyoming. *Bulletin of the Geological Society of America* 43(2):383-398.

Bray, E. and K. F. Hirsch. 1998. Eggshell from the Upper Jurassic Morrison Formation. *Modern Geology* 23(1-4):219-240.

Breithaupt, B. H. 1985. Nonmammalian vertebrate faunas from the Late Cretaceous of Wyoming. Pages 159-175 *in* G. E. Nelson, editor. The Cretaceous geology of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 36.

Breithaupt, B. H. 1996. The discovery of a nearly complete *Allosaurus* from the Jurassic Morrison Formation, eastern Bighorn Basin, Wyoming. Pages 309-313 *in* C. E. Brown, S. C. Kirkwood, and T. S. Miller, editors. Resources of the Bighorn Basin. Wyoming Geological Association, Casper, WY. Guidebook 47.

Breithaupt, B. H. 2001. The case of "Big Al" the *Allosaurus*: a study in paleodetective partnerships. Pages 95-106 *in* V. L. Santucci and L. McClelland, editors. Proceedings of the 6th fossil resource conference: 2001 a fossil odyssey. NPS Geological Resources Division, Denver, CO. Technical Report NRS/NRGRD/GRDTR-01/01. Available online at: http://www2.nature.nps.gov/geology/paleontology/pub/fossil_conference_6/breithaupt.htm. Accessed June 2013.

Breithaupt, B. H. and N. A. Matthews. 2001. Preserving paleontological resources using photogrammetry and geographic information systems. Pages 62-70 *in* D. Harmon, editor. From crossing boundaries in park management: proceedings of the 11th conference on research and resource management in parks and on public lands. The George Wright Society, Hancock, MI. Available online at: http://www.georgewright.org/12breith.pdf. Accessed June 2013.

Breithaupt, B. H., E. H. Southwell, T. L. Adams, and N. A. Matthews. 2001. Innovative documentation methodologies in the study of the most extensive dinosaur tracksite in Wyoming. Pages 113-122 *in* V. L. Santucci and L. McClelland, editors. Proceedings of the 6th fossil resource conference: 2001 a fossil odyssey. NPS Geological Resources Division, Denver, CO. Technical Report NRS/NRGRD/GRDTR-01/01. Available online at: http://www.nature.nps.gov/geology/paleontology/pub/fossil_conference_6/breithaupt_3.htm. Accessed June 2013.

Breithaupt, B. H., T. L. Adams, and E. H. Southwell. 2002. Tracks of gregarious dinosaurs do not necessarily lead to cooperative research alliances: effectiveness of partnerships and policies at the Red Gulch dinosaur tracksite. Abstracts with Programs. *Geological Society of America* 34(6):73.

Breithaupt, B. H., E. H. Southwell, T. Adams, and N. A. Matthews. 2006. The Red Gulch dinosaur tracksite: public participation in the conservation and management of a world-class paleontological site. Page 10 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal

lands. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 34.

Brenner, R. L. and D. K. Davies. 1973. Storm-generated coquinoid sandstone: genesis of high-energy marine sediments from the Upper Jurassic of Wyoming and Montana. *Geological Society of America Bulletin* 84(5):1685-1698.

Brenner, R. L. and D. K. Davies. 1974. Oxfordian sedimentation in Western Interior United States. *AAPG Bulletin* 58(3):407-428.

Brett-Surman, M., S. Jabo, P. Kroehler, M. T. Carrano, and E. Kvale. 2005. A new microvertebrate assemblage from the Upper Jurassic Morrison Formation, including mammals, theropods, and sphenodontians. *Journal of Vertebrate Paleontology* 25(supplement to 3):39A.

Breuninger, R. H. 2000. Zoned microbial reef complex in the Pilgrim Formation, Upper Cambrian age, western Montana. Abstracts with Programs. *Geological Society of America* 32(5):3.

Brown, B. 1935. Sinclair dinosaur expedition, 1934. *Natural History* 36:2-15.

Brown, B. and H. E. Vokes. 1944. Fossil imprints of unknown origin: further information and a possible explanation. *American Journal of Science* 242:656-672.

Brown, J. T. 1972. *Sagenopteris* from the Kootenai Formation (Early Cretaceous) of Montana. *American Journal of Botany* 59(6, Part 2):659.

Brown, J. T. 1975. Upper Jurassic and lower Cretaceous ginkgophytes from Montana. *Journal of Paleontology* 49(4):724-730.

Brown, J. T. and C. R. Robison. 1972. A moss gametophyte from the Kootenai Formation (lower Cretaceous) of Montana. *American Journal of Botany* 59(6, Part 2):659-660.

Brown, J. T. and C. R. Robison. 1974. *Diettertia montanensis*, gen. et sp. nov., a fossil moss from the lower Cretaceous Kootenai Formation of Montana. *Botanical Gazette* 135(3):170-173.

Brown, J. T. and C. R. Robison. 1976. Observations on the structure of *Marchantiolites blairmorensis* (Berry) n. comb. from the lower Cretaceous of Montana, U.S.A. *Journal of Paleontology* 50(2):309-311.

Burford, A. E. 1985. Reptilian markings on the upper Mowry Shale, Emigrant Gap area, Natrona County, Wyoming. Pages 157-158 *in* G. E. Nelson, editor. The Cretaceous geology of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 36.

Burgess, J. D. 1971. Palynological interpretation of Frontier environments in central Wyoming. *Geoscience and Man* 3:69-82.

Burk, C. A. and H. D. Thomas. 1956. The Goose Egg Formation (Permo-Triassic) of eastern Wyoming. Geological Survey of Wyoming, Laramie, WY. Report of Investigations 6.

Burkart, M.R. 1976. Pollen biostratigraphy and late Quaternary vegetation history of the Bighorn Mountains, Wyoming.

Dissertation. University of Iowa, Iowa City, Iowa, USA.

Burton, D., B. W. Greenhalgh, B. B. Britt, B. J. Kowallis, W. S. Elliott, Jr., and R. Barrick. 2006. New radiometric ages from the Cedar Mountain Formation, Utah and the Cloverly Formation, Wyoming: implications for contained dinosaur faunas. Abstracts with Programs. *Geological Society of America* 38(7):52.

Byers, C. W. and D. W. Larson. 1979. Paleoenvironments of Mowry Shale (lower Cretaceous), western and central Wyoming. *AAPG Bulletin* 63(3):354-361.

Campau, D. E. and L. Garrett, editors. 1962. Float trip: Big Horn River from Kane, Wyoming to Yellowtail dam site. Billings Geological Society, Billings, MT. Guidebook 12.

Campbell, C. V. and R. Q. Oaks Jr. 1973. Estuarine sandstone filling tidal scours, lower Cretaceous Fall River Formation, Wyoming. *Journal of Sedimentary Petrology* 43(3):765-778.

Campbell, N. P. 1978. Caves of Montana. Montana Bureau of Mines and Geology, Butte, MT. Bulletin 105.

Carballido, J. L., J. S. Marpmann, D. Schwarz-Wings, and B. Pabst. 2012. New information on a juvenile sauropod specimen from the Morrison Formation and the reassessment of its systematic position. *Palaeontology* 55(3):567-582.

Carpenter, K. and J. I. Kirkland. 1998. Review of Lower and Middle Cretaceous ankylosaurs from North America. Pages 249-270 *in* S. G. Lucas, J. I. Kirkland, and J. W. Estep, editors. Lower and middle Cretaceous terrestrial ecosystems. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 14.

Cartwright, A. M., T. P. Cleland, S. F. Derby, E. E. Ergas, H. I. Fay, K. M. Loughney, J. A. Riedel, M. K. Rocheford, C. L. Scott, and K. L. Skaggs. 2005. Aspects of the paleontology and stratigraphy of the lower Triassic-lower Cretaceous strata of the eastern Bighorn Basin, WY. Abstracts with Programs. *Geological Society of America* 37(7):302.

Cather, S. M. 2003. Polyphase Laramide tectonism and sedimentation in the San Juan Basin, New Mexico. Pages 119-132 *in* S. G. Lucas, S. C. Semken, W. Berglof, and D. Ulmer-Scholle, editors. Geology of the Zuni Plateau. New Mexico Geological Society, Socorro, NM. Guidebook 54.

Cavaroc, V. V. and R. M. Flores. 1991. Red beds of the Triassic Chugwater Group, southwestern Powder River basin, Wyoming. U.S. Geological Survey, Reston, VA. Bulletin 1917-E. Available online at: http://pubs.er.usgs.gov/publication/b1917E. Accessed February 2013.

Chadwick, D. 1999. Coral in peril. *National Geographic* 195(1):31-37.

Chen, X. and G. D. Webster. 1994. Sedimentology, tectonic control and evolution of a lower Mississippian carbonate ramp with offshore bank, central Wyoming to eastern Idaho and northeastern Utah, U.S.A. Pages 557-587 *in* A. F. Embry, B. Beauchamp, and D. J. Glass, editors. Pangea: global environments and resources. Canadian

Society of Petroleum Geologists, Calgary, Canada. Memoir 17.

Chorn, J., B. A. Frase, and C. D. Frailey. 1988. Late Pleistocene pronghorn, *Antilocapra americana*, from Natural Trap Cave, Wyoming. *Transactions of the Nebraska Academy of Sciences and Affiliated Societies* 16:127-139. Available online at: http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1176&context=tnas. Accessed February 2013.

Chomko, S. A. and B. M. Gilbert. 1987. The late Pleistocene/Holocene faunal record in the northern Bighorn Mountains, Wyoming. Pages 394-408 *in* R. W. Graham, H. A. Semken, and M. A. Semken, editors. Late Quaternary mammalian biogeography and environments of the Great Plains and prairies. Illinois State Museum, Springfield, IL. Scientific Papers 22.

Christiansen, R. L. 2001. The Quaternary and Pliocene Yellowstone Plateau Volcanic Field of Wyoming, Idaho, and Montana. U.S. Geological Survey, Reston, VA. Professional Paper 729-G. Available online at: http://pubs.usgs.gov/pp/pp729g/. Accessed February 2013.

Chure, D. J., R. Litwin, S. T. Hasiotis, E. Evanoff, and K. Carpenter. 2006. The fauna and flora of the Morrison Formation: 2006. Pages 233-249 *in* J. R. Foster and S. G. Lucas, editors. Paleontology and geology of the upper Jurassic Morrison Formation. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 36.

Cicimurri, D. 2001. Fossil selachians from the Belle Fourche Shale (Cretaceous, Cenomanian), Black Hills region of South Dakota and Wyoming. *Mountain Geologist* 38(4):181-192.

Ciccimuri, D. J. 2004. Early Cenomanian (Late Cretaceous) elasmobranchs from the Mowry Shale, Fall River County, South Dakota. *The Mosasaur* 7:69-73.

Clark, B. E., P. M. Myrow, R. L. Ripperdan, R. L. Ethington, and J. Taylor. 2000. Cambro-Ordovician stratigraphy: north-central Wyoming. Abstracts with Programs. *Geological Society of America* 32(5):A-6.

Clark, N. D. L. and M. K. Brett-Surman. 2008. A comparison between dinosaur footprints from the middle Jurassic of the Isle of Skye, Scotland, UK, and Shell, Wyoming, USA. *Scottish Journal of Geology* 44(2):139-150.

Cloud, P. and J. E. Bever. 1973. Trace fossils from the Flathead Sandstone, Fremont County, Wyoming, compared with early Cambrian forms from California and Australia. *Journal of Paleontology* 47(5):883-885.

Cobban, W. A. 1945. Marine Jurassic formations of Sweetgrass arch, Montana. *Bulletin of the American Association of Petroleum Geologists* 29(9):1262-1303.

Cobban, W. A. 1984. Molluscan record from a Mid-Cretaceous borehole in Weston County, Wyoming. U.S. Geological Survey, Reston, VA. Professional Paper 1271. Available online at: http://pubs.er.usgs.gov/publication/pp1271 Accessed February 2013.

Cobban, W. A. 1987. Some middle Cenomanian (upper Cretaceous) acanthoceratid ammonites from the western interior of the United States. U.S. Geological Survey, Reston, VA. Professional Paper 1445. Avbailable online at: http://pubs.er.usgs.gov/publication/pp1445 . Accessed February 2013.

Cobban, W. A. 1990. Ammonites and some characteristic bivalves from the upper Cretaceous Frontier Formation, Natrona County, Wyoming. U.S. Geological Survey, Reston, VA. Bulletin 1917-B. Available online at: http://pubs.er.usgs.gov/publication/b1917B. Accessed February 2013.

Cobban, W. A. and J. B. Reeside, Jr. 1951. Lower Cretaceous ammonites in Colorado, Wyoming, and Montana. *Bulletin of the American Association of Petroleum Geologists* 35(8):1892-1893.

Colbert, E. H. 1961. The Triassic reptile, *Poposaurus*. Fieldiana. *Geology* 14(4):59-78. Available online at: http://www.biodiversitylibrary.org/item/25266. Accessed February 2013.

Committee on Ungulate Management in Yellowstone National Park. 2002. Ecological dynamics on Yellowstone's northern range. National Academy Press, Washington, DC. Available online at: http://www.nap.edu/catalog.php?record_id=10328. Accessed April 2013.

Condon, S. M. 2000. Stratigraphic framework of lower and upper Cretaceous rocks in central and eastern Montana. U.S. Geological Survey, Reston, VA. Digital Data Series 57. Available online at: http://pubs.er.usgs.gov/publication/ds57. Accessed February 2013.

Connely, M. and B. Talbot. 2005. Trace fossils in marine sediments of the Mowry Shale (early Cretaceous) of Wyoming are possibly vertebrate in origin. *Journal of Vertebrate Paleontology* 25(supplement to 3):47A.

Connor, J. J. 1963. Geology of the Angostura Reservoir Quadrangle, Fall River County, South Dakota. U.S. Geological Survey, Washington, DC. Bulletin 1063-D:85-126. Available online at: http://pubs.er.usgs.gov/publication/b1063D. Accessed February 2013.

Conroy, J., M. A. Wilson, and C. M. Tang. 2002. Bored and encrusted carbonate cobbles and hardgrounds at the base of a regressive sequence (lower Sundance Formation, middle Jurassic, eastern Wyoming). Abstracts with Programs. *Geological Society of America* 34(2):95.

Csonka, J. and K. V. Bulinski. 2010. The *Chondrites* ichnofossil: a comparative study. Abstracts with Programs. *Geological Society of America* 42(2):93.

Cygan, N. E. and F. L. Koucky. 1963. The Cambrian and Ordovician rocks of the east flank of the Big Horn Mountains, Wyoming. Pages 26-37 *in* G. C. Cooper, D. F. Cardinal, H. W. Lorenz, and J. R. Lynn, editors. Northern Powder River basin, Wyoming and Montana. Wyoming Geological Association and Billings Geological Society, Casper, WY. Joint Guidebook 1.

D'Emic, M. D. and B. Z. Foreman. 2012. The beginning of the sauropod dinosaur hiatus

in North America: insights from the lower Cretaceous Cloverly Formation of Wyoming. *Journal of Vertebrate Paleontology* 32(4):883-902.

Darton, N. H. 1904. Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range. *Geological Society of America Bulletin* 15:379-448.

Darton, N. H. 1906. Geology of the Bighorn Mountains. U.S. Geological Survey, Washington, DC. Professional Paper 51. Available online at: http://pubs.er.usgs.gov/publication/pp51. Accessed February 2013.

Davis, H. R., C. W. Byers, and L. M. Pratt. 1989. Depositional mechanisms and organic matter in Mowry Shale (Cretaceous), Wyoming. *AAPG Bulletin* 73(9):1103-1116.

Dawley, R. M., J. M. Zawiskie, and J. W. Cosgriff. 1979. A rauisuchid thecodont from the Upper Triassic Popo Agie Formation of Wyoming. *Journal of Paleontology* 53(6):1428-1431.

DeBoer, D. A. and L. T. Middleton. 1981. Paleoenvironmental and paleogeographic significance of middle Cambrian algal buildups, Teton Range, Wyoming. Abstracts with Programs. *Geological Society of America* 13(4):194.

DeCelles, P. G. 1986. Sedimentation in a tectonically partitioned, nonmarine foreland basin: the Lower Cretaceous Kootenai Formation, southwestern Montana. *Geological Society of America Bulletin* 97(8):911-931.

Deiss, C. F. 1936. Revision of type Cambrian formations and sections of Montana and Yellowstone National Park. *Geological Society of America Bulletin* 47(8):1257-1342.

Derby, S. F., B. E. Bodenbender, and T. M. Demko. 2006. An investigation of microvertebrates in the Morrison Formation near Shell, Wyoming. Abstracts with Programs. *Geological Society of America* 38(4):67.

Dodson, P., A. K. Behrensmeyer, R. T. Bakker, and J. S. McIntosh. 1980. Taphonomy and paleoecology of the dinosaur beds of the Jurassic Morrison Formation. *Paleobiology* 6(2):208-232.

Dong, X., P. C. J. Donoghue, and J. E. Repetski. 2005. Basal tissue structure in the earliest euconodonts: testing hypotheses of developmental plasticity in euconodont phylogeny. *Palaeontology* 48(2):411-421.

Driscoll, E. G. and G. B. Newton. 1969. A new species of the coral *Syringopora* from the Tensleep Formation (Pennsylvanian) of Montana. *Journal of Paleontology* 43(2):531-534.

Druckenmiller, P. S. 2002. Osteology of a new plesiosaur from the Lower Cretaceous (Albian) Thermopolis Shale of Montana. *Journal of Vertebrate Paleontology* 22(1):29-42.

Dunagan, S. P. and C. E. Turner. 2004. Regional paleohydrologic and paleoclimatic settings of wetland/lacustrine depositional systems in the Morrison Formation (upper Jurassic),

Western Interior, USA. *Sedimentary Geology* 167(3-4):269-296.

Dyman, T. S., W. J. Perry, Jr., D. J. Nichols, L. E . Davis, and J. C. Haley. 1989. Stratigraphy, petrology, and provenance of the Cenomanian to Turonian Frontier Formation near Lima, southwestern Montana. Pages 103-114 *in* D. E. French and R. F. Grabb, editors. Montana Geological Society 1989 field conference guidebook: Montana centennial edition: Geologic resources of Montana, Volume I. Montana Geological Society, Bozeman, MT. Field Conference 1989(1).

Dyman, T. S., W. A. Cobban, J. E. Fox, R. H. Hammond, D. J. Nichols, W. J. Perry, Jr., K. W. Porter, D. D. Rice, D. R. Setterholm, G. W. Shurr, R. G. Tysdal, J. C. Haley, and E. B. Campen. 1994. Cretaceous rocks from southwestern Montana to southwestern Minnesota, Northern Rocky Mountains, and Great Plains region. Pages 5-26 *in* G. W. Shurr, G. A. Ludvigson, and R. H. Hammond, editors. Perspectives on the eastern margin of the Cretaceous Western Interior Basin. Geological Society of America, Boulder, CO. Special Paper 287.

Eicher, D. L. 1958. The Thermopolis shale in eastern Wyoming. Pages 79-83 *in* J. Strickland, F. Byrne, and J. Barlow, editors. Powder River Basin. Wyoming Geological Association, Casper, WY. Guidebook 13.

Eicher, D. L. 1960. Stratigraphy and micropaleontology of the Thermopolis Shale. Peabody Museum of Natural History Bulletin 15. Available online at: http://peabody.yale.edu/sites/default/files/documents/scientific-publications/ypmB15_1960.pdf. Accessed February 2013.

Eicher, D. L. 1965. Foraminifera and biostratigraphy of the Graneros Shale. *Journal of Paleontology* 39(5):875-909.

Eicher, D. L. 1967. Foraminifera from Belle Fourche Shale and equivalents, Wyoming and Montana. *Journal of Paleontology* 41(1):167-188.

Elder, W. P. and J. I. Kirkland. 1993. Cretaceous paleogeography of the Colorado Plateau and adjacent areas. Pages 129-151 *in* M. Morales, editor. Aspects of Mesozoic geology and paleontology of the Colorado Plateau. Museum of Northern Arizona, Flagstaff, AZ. Bulletin 59.

Elder, W. P. and J. I. Kirkland. 1994. Cretaceous paleogeography of the southern Western Interior region. Pages 415-440 *in* M. V. Caputo, J. A. Peterson, and K. J. Franczyk, editors. Mesozoic system of the Rocky Mountain region, USA. Rocky Mountain Section, Society for Sedimentary Geology, Denver, CO.

Engelmann, G. F. 1999. Stratigraphic and geographic distribution of fossils in the upper part of the Morrison Formation of the Rocky Mountain region. Pages 115-120 *in* D. D. Gillette, editor. Vertebrate Paleontology in Utah. Utah Geological Survey, Salt Lake City, UT. Miscellaneous Publication 99-1.

Engelmann, G. F. and S. T. Hasiotis. 1999. Deep dinosaur tracks in the Morrison Formation: sole marks that are really sole marks. Pages 179-183 *in* D. D. Gillette, editor. Vertebrate Paleontology in Utah.

Utah Geological Survey, Salt Lake City, UT. Miscellaneous Publication 99-1.

Engelmann, G. F., D. J. Chure, and A. R. Fiorillo. 2004. The implications of a dry climate for the paleoecology of the fauna of the upper Jurassic Morrison Formation. *Sedimentary Geology* 167(3-4):297-308.

Farke, A. A., F. J. Varriale, D. B. Lien, J. L. Cavin, and J. T. Sankey. 2001. First trackway evidence of vertebrate animals from the Fall River Formation (lower Cretaceous) of western South Dakota, USA. *Journal of Vertebrate Paleontology* 21(supplement to 3):48A.

Feldmann, R. M. 1979. *Eryma foersteri*, a new species of lobster (Decapoda) from the Jurassic (Callovian) of North America. American Museum Novitates 2668.

Fisher, C. A. 1906. Geology and water resources of the Bighorn Basin. U.S. Geological Survey, Washington, DC. Professional Paper 53. Available online at: http://pubs.er.usgs.gov/publication/pp53. Accessed May 2013.

Fisher, C. G. and W. W. Hay. 1999. Calcareous nannofossils as indicators of Mid-Cretaceous paleofertility along an ocean front, U. S. Western Interior. Pages 161-180 *in* E. Barrera and C. C. Johnson, editors. Evolution of the Cretaceous ocean-climate system. Geological Society of America, Boulder, CO. Special Paper 332.

Fisher, J. H. 1963. Tensleep Sandstone of the eastern Big Horn Mountains, Wyoming. Pages 54-60 *in* G. C. Cooper, D. F. Cardinal, H. W. Lorenz, and J. R. Lynn, editors. Northern Powder River basin, Wyoming and Montana. Wyoming Geological Association and Billings Geological Society, Casper, WY. Joint Guidebook 1.

Forster, C. A. 1984. The paleoecology of the ornithopod dinosaur *Tenontosaurus tilletti* from the Cloverly Formation, Big Horn Basin of Wyoming and Montana. *Mosasaur* 2:151-163.

Foster, J. R. 2003. Paleoecological analysis of the vertebrate fauna of the Morrison Formation (upper Jurassic), Rocky Mountain region, U.S.A. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 23.

Foster, J. 2007. Jurassic West: the dinosaurs of the Morrison Formation and their world. Indiana University Press, Bloomington and Indianapolis, IN.

Franczyk, K. J., T. D. Fouch, R. C. Johnson, C. M. Molenaar, and W. A. Cobban. 1992. Cretaceous and Tertiary paleogeographic reconstructions for the Uinta-Piceance Basin Study Area, Colorado and Utah. U.S. Geological Survey, Reston, VA. Bulletin 1787-Q. Available online at: http://pubs.er.usgs.gov/publication/b1787Q. Accessed September 2011.

Frison, G. C. 1991. Prehistoric hunters of the high plains (2nd edition). Academic Press, New York, NY.

Frison, G. C. and B. Bradley. 1980. Folsom tools and technology at the Hanson site, Wyoming. University of New Mexico Press, Albuquerque, NM.

Frison, G. C. and M. Wilson. 1975. An introduction to Bighorn Basin archeology. Pages 19-35 *in* F. A. Exum and G. R.

George, editors. Geology and mineral resources of the Bighorn Basin. Wyoming Geological Association, Casper, WY. Guidebook 27.

Fritz, M. A. and B. F. Howell. 1955. An upper Cambrian coral from Montana. *Journal of Paleontology* 29(1):181-183.

Gani, M. R. and J. P. Bhattacharya. 2007. Basic building blocks and process variability of a Cretaceous delta: internal facies architecture reveals a more dynamic interaction of river, wave, and tidal processes than is indicated by external shape. *Journal of Sedimentary Research* 77(4):284-302.

Geppert, T. J. 1984. Small mammals of Shield Trap, East Pryor Mountain, Montana. Thesis. University of Iowa, Iowa City, IA.

Gilbert, B. M. 1984. A brief synopsis of Natural Trap Cave. Pages 17-18 *in* A. J. Flurkey, editor. Guidebook of the 1984 NSS Convention. National Speleological Society, Morgantown, WV.

Gilbert, B. M. 1985. 1979 fieldwork at Natural Trap Cave, Wyoming. Research Reports. *National Geographic Society* 19:225-233.

Gilbert, B. M. and L. D. Martin. 1984. Late Pleistocene fossils of Natural Trap Cave, Wyoming, and the climatic model of extinction. Pages 138-147 *in* P. S. Martin and R. G. Klein, editors. Quaternary extinctions: a prehistoric revolution. University of Arizona Press, Tucson, AZ.

Girty, G. H. 1899. Devonian and Carboniferous fossils. Pages 479-599 *in* Geology of the Yellowstone national park. U.S. Geological Survey, Washington, D.C. Monograph 32. Available online at: http://archive.org/details/geologyofyellows00hagu. Accessed March 2013.

Good, S. C. 2004. Paleoenvironmental and paleoclimatic significance of freshwater bivalves in the Upper Jurassic Morrison Formation, Western Interior, USA. *Sedimentary Geology* 167(3-4):163-176.

Gordon, M., Jr. 1975. Brachiopoda of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 858-D. Available online at: http://pubs.er.usgs.gov/publication/pp848D. Accessed February 2013.

Gordon, M., Jr. and J. Pojeta, Jr. 1975. Pelecypoda and Rostroconchia of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 848-E. Available online at: http://pubs.er.usgs.gov/publication/pp848E. Accessed February 2013.

Gordon, M., Jr. and E. L. Yochelson. 1975. Gastropoda, Cephalopoda, and Trilobita of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 848-F. Available online at: http://pubs.er.usgs.gov/publication/pp848F. Accessed February 2013.

Gorman, D. R. 1963. Stratigraphic-sedimentational aspects of the Amsden Formation, Big Horn Mountains, Wyoming. Pages 67-70 *in* G. C. Cooper, D. F. Cardinal, H. W. Lorenz, and J. R. Lynn, editors. Northern Powder River

basin, Wyoming and Montana. Wyoming Geological Association and Billings Geological Society, Casper, WY. Joint Guidebook 1.

Gott, G. B., D. E. Wolcott, and C. G. Bowles. 1974. Stratigraphy of the Inyan Kara Group and localization of uranium deposits, southern Black Hills, South Dakota and Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 763. Available online at: http://pubs.er.usgs.gov/publication/pp763. Accessed February 2013.

Graham, M. A., M. C. Wilson, and R. W. Graham. 1987. Paleoenvironments and mammalian faunas of Montana, southern Alberta, and southern Saskatchewan. Pages 410-459 *in* R. W. Graham, H. A. Semken, and M. A. Semken, editors. Late Quaternary mammalian biogeography and environments of the Great Plains and prairies. Illinois State Museum, Springfield, IL. Scientific Papers 22.

Gregson, J. D., D. Chure, and D. A. Sprinkel. 2010. Geology and paleontology of Dinosaur National Monument, Utah-Colorado. Pages 161-192 *in* D. A. Sprinkel, T. C. Chidsey, Jr., and P. B. Anderson, editors. Geology of Utah's parks and monuments (3rd edition). Utah Geological Association, Salt Lake City, UT. Publication 28.

Gutschick, R. C. 1966. Transitional Devonian to Mississippian environmental changes in western Montana. Pages 171-181 *in* Symposium on cyclic sedimentation. Kansas Geological Survey, Lawrence, KS. Bulletin 169. Available online at: http://www.kgs.ku.edu/Publications/Bulletins/169/Gutschick/index.html. Accessed February 2013.

Gutschick, R. C. and R. Lamborn. 1975. *Bifungites*, trace fossils from Devonian-Mississippian rocks of Pennsylvania and Montana, U.S.A. *Palaeogeography, Palaeoclimatology, Palaeoecology* 18(3):193-212.

Gutschick, R. C., J. L. Weiner, and L. Young. 1961. Lower Mississippian arenaceous Foraminifera from Oklahoma, Texas, and Montana. *Journal of Paleontology* 35(6):1193-1221.

Gutschick, R. C., M. McLane, and J. Rodriguez. 1976. Summary of late Devonian-early Mississippian biostratigraphic framework in western Montana. Pages 91-124 *in* Guidebook of selected areas in southwestern Montana. Montana Bureau of Mines and Geology, Butte, MT. Special Publication 73.

Guyer, G. S., C. F. Vondra, and R. D. Cody. 1995. Paleoenvironments of the Jurassic Gypsum Spring Formation, Big Horn Basin, Wyoming. Abstracts with Programs. *Geological Society of America* 27(3):54-55.

Haiar, B. and R. Lupia. 2011. Paleobotany and paleoecology of localities from the Cretaceous Cloverly Formation, Bighorn Basin, Wyoming. Abstracts with Programs. *Geological Society of America* 43(5):312.

Hamblin, A. H., S. A. Bilbey, and J. E. Hall. 2000. Prehistoric animal tracks at Red Fleet State Park, northeastern Utah. Pages 569-578 *in* D. A. Sprinkel, T. C. Chidsey, Jr., and P. B. Anderson, editors. Geology

of Utah's parks and monuments. Utah Geological Association, Salt Lake City, UT. Publication 28. Available online at: http://www.utahgeology.org/pub28_pdf_files/HamblinRedFleet.pdf. Accessed September 2011.

Hamilton, L. J. and Q. F. Paulson. 1968. Geology and groundwater resources of the lower Bighorn Valley, Montana. U.S. Geological Survey, Reston, VA Water-Supply Paper 1876. Available online at: http://pubs.er.usgs.gov/publication/wsp1876. Accessed February 2013.

Hanna, R. R. 2002. Multiple injury and infection in a sub-adult theropod dinosaur (*Allosaurus fragilis*) with comparisons to allosaur pathology in the Cleveland-Lloyd Dinosaur Quarry Collection. *Journal of Vertebrate Paleontology* 22(1):76-90.

Hanson, A. M. 1962a. Cambrian system in the Big Horn Canyon area. Pages 51-57 *in* D. E. Campau and L. Garrett, editors. Float trip: Big Horn River from Kane, Wyoming to Yellowtail dam site. Billings Geological Society, Billings, MT. Guidebook 12.

Hanson, A. M. 1962b. Permo-Triassic of Big Horn Canyon area. Pages 27-35 *in* D. E. Campau and L. Garrett, editors. Float trip: Big Horn River from Kane, Wyoming to Yellowtail dam site. Billings Geological Society, Billings, MT. Guidebook 12.

Harris, J. D. and P. Dodson. 2004. A new diplodocoid sauropod dinosaur from the upper Jurassic Morrison Formation of Montana, USA. *Acta Palaeontologica Polonica* 49(2):197-210. Available online at: http://www.app.pan.pl/archive/published/app49/app49-197.pdf. Accessed February 2013.

Harris, J. D. and K. J. Lacovara. 2004. Enigmatic fossil footprints from the Sundance Formation (upper Jurassic) of Bighorn Canyon National Recreation Area, Wyoming. *Ichnos* 11:151-166. Available online at: http://cactus.dixie.edu/jharris/Sundance_Tracks.pdf. Accessed February 2013.

Hasiotis, S. T. 2004. Reconnaissance of upper Jurassic Morrison Formation ichnofossils, Rocky Mountain Region, USA: paleoenvironmental, stratigraphic, and paleoclimatic significance of terrestrial and freshwater ichnocoenoses. *Sedimentary Geology* 167(3-4):177-268.

Hawkins, B. J., P. M. Myrow, R. L. Ripperdan, and J. Taylor. 2001. Shoaling cycles in the Cambro-Ordovician Gallitan Formation: northern Wyoming and central Montana. Abstracts with Programs. *Geological Society of America* 33(5):13.

Heiny, L. W. and H. G. Walter. 1954. Road log: Billings to Red Lodge via Pryor Gap. Pages 9-17 *in* P. W. Richards, editor. Pryor Mountains-northern Bighorn Basin, Montana, September 9-11, 1954. Billings Geological Society, Billings, MT. Guidebook 5.

Henbest, L. G. 1954. Pennsylvanian Foraminifera in Amsden Formation and Tensleep sandstone, Montana and Wyoming. Pages 50-53 *in* P. W. Richards, editor. Pryor Mountains-northern Bighorn Basin, Montana, September 9-11, 1954. Billings Geological Society, Billings, MT. Guidebook 5.

Henbest, L. G. 1956. Foraminifera and correlation of the Tensleep Sandstone of Pennsylvanian age in Wyoming. Pages 58-63 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Herrick, E. M. and F. R. Schram. 1978. Malacostracan crustacean fauna from the Sundance Formation (Jurassic) of Wyoming. *American Museum Novitates* 2652. Available online at: http://hdl.handle.net/2246/2966. Accessed February 2013.

High, L. R., Jr. and M. D. Picard. 1965. Sedimentary petrology and origin of analcime-rich Pogo Agie Member, Chugwater (Triassic) Formation, west-central Wyoming. *Journal of Sedimentary Petrology* 35(1):49-70.

High, L. R., Jr. and M. D. Picard. 1967. Rock units and revised nomenclature, Chugwater Group (Triassic), western Wyoming. *Mountain Geologist* 4(2):73-81.

High, L. R., Jr. and M. D. Picard. 1969. Stratigraphic relations within upper Chugwater group (Triassic), Wyoming. *American Association of Petroleum Geologists Bulletin* 53(5):1091-1104.

Hill, C. L. 2006. Stratigraphic and geochronologic contexts of mammoth (*Mammuthus*) and other Pleistocene fauna, upper Missouri Basin (Northern Great Plains and Rocky Mountains), U.S.A. *Quaternary International* 142-143:87-106.

Hirsch, K. F. 1994. Upper Jurassic eggshells from the Western Interior of North America. Pages 137-150 *in* K. Carpenter, K. F. Hirsch, and J. R. Horner, editors. Dinosaur eggs and babies. Cambridge University Press, Cambridge, United Kingdom.

Hoare, R. D. and J. D. Burgess. 1960. Fauna from the Tensleep sandstone in Wyoming. *Journal of Paleontology* 34(4):711-716.

Holland, S. M. and M. E. Patzkowsky. 2009. The stratigraphic distribution of fossils in a tropical carbonate succession: Ordovician Bighorn Dolomite, Wyoming, USA. *Palaios* 24(5):303-317.

Holland, S. M. and M. E. Patzkowsky. 2012. Sequence architecture of the Bighorn Dolomite, Wyoming, USA: transition to the Late Ordovician icehouse. *Journal of Sedimentary Research* 82(8):599-615.

Holm, M. R., W. C. James, and L. J. Suttner. 1977. Comparison of the Peterson and Draney limestones, Idaho and Wyoming, and the calcareous members of the Kootenai Formation, western Montana. Pages 259-270 *in* E. L. Heisey, D. E. Lawson, E. R. Norwood, P. H. Wach, and L. A. Hale, editors. Rocky Mountain Thrust Belt: geology and resources. Wyoming Geological Association, Casper, WY. Guidebook 29.

Hopkins, J. C. 1985. Channel-fill deposits formed by aggradation in deeply scoured, superimposed distributaries of the lower Kootenai Formation (Cretaceous). *Journal of Sedimentary Petrology* 55(1):42-52.

Horner, J. R. 1989. The Mesozoic terrestrial ecosystems of Montana. Pages 153-162 *in* D. E. French and R. F. Grabb, editors. Montana Geological Society 1989 field

conference guidebook: Montana centennial edition: Geologic resources of Montana, Volume I. Montana Geological Society, Bozeman, MT. Field Conference 1989(1).

Houlik, C. W., Jr. 1973. Interpretation of carbonate-detrital silicate transitions in the Carboniferous of western Wyoming. *American Association of Petroleum Geologists Bulletin* 57(3):498-509.

Howell, B. F. 1963. New Cambrian conchostracans from Wyoming and Newfoundland, brachiopods from Vermont, and worm, hydrozoan and problematicum from Newfoundland. *Journal of Paleontology* 37(1):264-267.

Hu, C.-h. 1970. The ontogenies of *Ponumia obscura* (Lochman), n.g., and of *Housia canadensis* (Walcott) (Trilobita) from the upper Cambrian of the Big Horn mountains, Wyoming. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series* 78:253-263.

Imlay, R. W. 1947. Marine Jurassic of Black Hills area, South Dakota and Wyoming. *Bulletin of the American Association of Petroleum Geologists* 31(2):227-273.

Imlay, R. W. 1953. Callovian (Jurassic) ammonites from the United States and Alaska: Part 1, Western Interior United States; Part 2, Alaska Peninsula and Cook Inlet regions. U.S. Geological Survey, Washington, DC. Professional Paper 249-A. Available online at: http://pubs.er.usgs.gov/publication/pp249A. Accessed February 2013.

Imlay, R. W. 1954. Marine Jurassic formations in the Pryor Mountains and north Bighorn Mountains, Montana. Pages 54-65 *in* P. W. Richards, editor. Pryor Mountains-northern Bighorn Basin, Montana, September 9-11, 1954. Billings Geological Society, Billings, MT. Guidebook 5.

Imlay, R. W. 1956. Marine Jurassic exposed in Bighorn Basin, Pryor Mountains, and northern Bighorn Mountains, Wyoming and Montana. *Bulletin of the American Association of Petroleum Geologists* 40(4):562-599.

Imlay, R. W. 1967. Twin Creek Limestone (Jurassic) in the Western Interior of the United States. U.S. Geological Survey, Reston, VA. Professional Paper 540. Available online at: http://pubs.er.usgs.gov/publication/pp540. Accessed February 2013.

James, W. C. 1980. Limestone channel storm complex (lower Cretaceous), Elkhorn Mountains, Montana. *Journal of Sedimentary Petrology* 50(2):447-455.

Jennings, D. S., B. F. Platt, and S. T. Hasiotis. 2006. Distribution of vertebrate trace fossils, Upper Jurassic Morrison Formation, Bighorn Basin, USA: implications for differentiating paleoecological and preservational bias. Pages 183-192 *in* J. R. Foster and S. G. Lucas, editors. Paleontology and geology of the Upper Jurassic Morrison Formation. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 36.

Johnson, R. C. 2010. Detailed west to east cross section of Cretaceous and lower Tertiary rocks across the south part of the Bighorn Basin, Wyoming. U.S.

Geological Survey, Reston, VA. Digital Data Series 69-V. Available online at: http://pubs.er.usgs.gov/publication/ds69V. Accessed February 2013.

Jones, D. J. 1954. Non-marine Frontier microfauna, Coalville area, Utah. *Journal of Sedimentary Petrology* 24(2):140.

Joyce, W. G., S. D. Chapman, R. T. J. Moody, and C. A. Walker. 2011. The skull of the solemydid turtle *Helochelydra nopcsai* from the Early Cretaceous of the Isle of Wight (UK) and a review of Solemydidae. Pages 75-97 *in* P. M. Barrett and A. R. Milner, editors. Studies on fossil tetrapods. Palaeontological Association, London, United Kingdom. Special Papers in Palaeontology 86.

Jud, N. A. 2011. Diversity of a Lower Cretaceous pre-angiosperm flora in the Cloverly Formation, WY. Abstracts with Programs. *Geological Society of America* 43(5):312.

Jud, N. A. and S. L. Wing. 2010. Angiosperms from the Early Cretaceous of Wyoming. Abstracts with Programs. *Geological Society of America* 42(5):482.

Kauffman, M. E. 1975. Paleoecologic significance of "*Girvanella*", a calcareous fossil alga? from the Cambrian of Montana. Page 16 *in* International Symposium on Fossil Algae: program and abstracts. Institute of Palaeontology, Erlangen, Germany. Available online at: http://web.ku.edu/~ifaa/pdf/Erlangen_1975_abstracts.pdf. Accessed February 2013.

Kausch, T. K. and E. Giffin. 1993. Early Cretaceous vertebrates of the Muddy Sandstone, Big Horn Basin, Wyoming. *Journal of Vertebrate Paleontology* 13(supplement to 3):43A-44A.

KellerLynn, K. 2011. Bighorn Canyon National Recreation Area geologic resources inventory report. Natural Resource Report NPS/NRPC/GRD/NRR—2011/447. National Park Service, Denver, CO. Available online at: http://nature.nps.gov/geology/inventory/publications/reports/bica_gri_rpt_view.pdf. Accessed February 2013.

Kenworthy, J. P. and V. L. Santucci. 2006. A preliminary investigation of National Park Service paleontological resources in cultural resource contexts, Part 1: general overview. Pages 70-76 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 34. Available online at: http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed February 2013.

Kerr, D. R. and R. H. Dott, Jr. 1988. Eolian dune types preserved in the Tensleep Sandstone (Pennsylvanian-Permian), north-central Wyoming. *Sedimentary Geology* 56(1-4):383-402.

Knechtel, M. M. and S. H. Patterson. 1956. Bentonite deposits in marine Cretaceous formations, Hardin District, Montana and Wyoming. U.S. Geological Survey, Washington, DC. Bulletin 1023. Available online at: http://pubs.er.usgs.gov/publication/b1023. Accessed February 2013.

Knowlton, F. H. 1917. A fossil flora from the Frontier Formation of southwestern Wyoming. Pages 73-107 *in* Shorter contributions to general geology, 1917. U.S. Geological Survey, Reston, VA. Professional Paper 108.

Koch, A. L. and V. L. Santucci. 2003. Bighorn Canyon National Recreation Area. Pages 6-8 *in* A. L. Koch and V. L. Santucci. Paleontological resource inventory and monitoring—Greater Yellowstone Network. TIC# D-1025. National Park Service, Denver, CO.

Kottlowski, F. E. 1950. A new species of *Atrypa* from the Devonian of Montana. *Proceedings of the Indiana Academy of Science* 59:246-250. Available online at: http://archive.org/details/proceedingsofin591949indi. Accessed February 2013.

Koucky, F. L., Jr., N. E. Cygan, and F. H. T. Rhodes. 1961. Conodonts from the eastern flank of the central part of the Big Horn Mountains, Wyoming. *Journal of Paleontology* 35(4):877-879.

Koucky, F. L., F. H. T. Rhodes, and C. H. Hu. 1968. Upper Cambrian-lower Ordovician conodont sequences of the Big Horn Mountains, Wyoming. Pages 123-124 *in* Abstracts for 1967. Geological Society of America, Boulder, CO. Special Paper 115.

Kubarek, S. and E. Swor. 2005. Taphonomy, taxonomy, and anatomy of sauropod and theropod dinosaur remains from the Morrison Formation, Shell, WY. *Journal of Vertebrate Paleontology* 25(supplement to 3):81A.

Kummel, B. 1954. Jurassic nautiloids from western North America. *Journal of Paleontology* 28(3):320-324.

Kvale, E. P. and C. F. Vondra. 1993. Effects of relative sea-level changes and local tectonics on a Lower Cretaceous fluvial to transitional marine sequence, Bighorn Basin, Wyoming, USA. Pages 383-399 *in* M. Marzo and C. Puigdefabregas, editors. Alluvial sedimentation. Blackwell, Oxford. Special Publication of the International Association of Sedimentologists 17.

Kvale, E. P., G. D. Johnson, D. L. Mickelson, K. Keller, L. C. Furer, and A. W. Archer. 2001. Middle Jurassic (Bajocian and Bathonian) dinosaur megatracksites, Bighorn Basin, Wyoming, U.S.A. *Palaios* 16(3):233-254.

Lalicker, C. G. 1950. Foraminifera of the Ellis group, Jurassic, at the type locality. *University of Kansas Paleontological Contributions* 5(2). Available online at: http://kuscholarworks.ku.edu/dspace/handle/1808/3779. Accessed February 2013.

LaPasha, C. A. 1977. Comparison of compressed foliage from two sites in the Kootenai Formation of Great Falls, Montana. Abstracts with Programs. *Geological Society of America* 9(6):741-742.

LaPasha, C. A. and C. N. Miller, Jr. 1985. Flora of the early Cretaceous Kootenai Formation in Montana: bryophytes and tracheophytes excluding conifers. *Palaeontographica. Abteilung B: Palaeophytologie* 196(4-6):111-145.

Lash, C. E. and J. G. Schmitt. 2008. Depositional environment and taphonomy of marine vertebrate biofacies in the Lower Cretaceous (Albian) Thermopolis Shale, south-central Montana. Abstracts with Programs. *Geological Society of America* 40(6):378.

Laws, R. R. 1996. Paleopathological analysis of a sub-adult *Allosaurus fragilis* (MOR 693) from the Upper Jurassic Morrison Formation with multiple injuries and infections. Thesis. Montana State University, Bozeman, MT.

Lebauer, L. R. 1964. Petrology of the middle Cambrian Wolsey Shale of southwestern Montana. *Journal of Sedimentary Petrology* 34(3):503-511.

Lebauer, L. R. 1965. Genesis and environment of deposition of the Meagher Formation in southwestern Montana. *Journal of Sedimentary Petrology* 35(2):428-447.

Lochman, C. L. and D. Duncan. 1944. Early upper Cambrian faunas of central Montana. Geological Society of America, Boulder, CO. Special Paper 54.

Lockley, M. 1990. Tracking the rise of dinosaurs in eastern Utah. *Canyon Legacy* 6:2-8.

Lockley, M. and A. P. Hunt. 1995. Dinosaur tracks and other fossil footprints of the western United States. Columbia University Press, New York, NY.

Lockley, M. G. and D. L. Mickelson. 1997. Dinosaur and pterosaur tracks in the Summerville and Bluff (Jurassic) beds of eastern Utah and northeastern Arizona. Pages 132-138 *in* O. J. Anderson, B. Kues, and S. G. Lucas, editors. Mesozoic geology and paleontology of the Four Corners Region. New Mexico Geological Society, Socorro, NM. Guidebook 48.

Lockley, M. G. and J. L. Wright. 2003. Pterosaur swim tracks and other ichnological evidence of behaviour and ecology. Pages 297-313 *in* E. Buffetaut and J.-M. Mazin, editors. Evolution and palaeobiology of pterosaurs. Geological Society, London, United Kingdom. Special Publication 217.

Loeblich, A. R., Jr. and H. N. Tappan. 1950. The type Redwater shale (Oxfordian) of South Dakota, Part 1 of North American Jurassic Foraminifera. *Journal of Paleontology* 24(1):39-60.

Lopez, D. A. 1995. Field guide to the northern Pryor-Bighorn structural block, south central Montana. Montana Bureau of Mines and Geology, Butte, MT. Open-File Report 330.

Lopez, D. A. 1998. Valley-fill sandstones in the Kootenai Formation on the Crow Indian Reservation, south-central Montana. Federal Energy Technology Center, Morgantown, WV. DE-FG22-96BC14996-07. Available online at: http://www.osti.gov/energycitations/purl.cover.jsp?purl=/1597-RyuxNI/webviewable/Valley-FillStandstonesintheKootenaiFormationontheCrowIndianReservation,South-CentralMontana.pdf. Accessed February 2013.

Lopez, D. A. 2000. Geologic map of the Bridger 30’ x 60’ Quadrangle, Montana. Montana Bureau of Mines and Geology, Butte, MT. Geologic Map 58. Scale 1:100,000.

Lopez, D. A. 2001. The Greybull Sandstone, Lower Cretaceous valley-fill on the Crow and northern Cheyenne Indian reservations, south-central Montana. Annual Meeting Expanded Abstracts. *American Association of Petroleum Geologists* 2001:120.

Lopez, D. A., S. W. Van DeLinder, M. L. Hendricks, G. S. Bayliss, and W. L. Ewert. 2007. The Tensleep play of south-central Montana, a part of the Permo-Pennsylvanian petroleum system of Montana and Wyoming. Montana Bureau of Mines and Geology, Butte, MT. Report of Investigations RI-18.

Lord, A. and P. F. Sherrington. 1976. Ostracods from the Rierdon Formation (Jurassic) of Montana. *Bulletin of Canadian Petroleum Geology* 24(2):305-309.

Love, J. D. 1939. Geology along the southern margin of the Absaroka Range, Wyoming. Geological Society of America, Boulder, CO. Special Paper 20.

Love, J. D. 1956. Cretaceous and Tertiary stratigraphy of the Jackson Hole area, northwestern Wyoming. Pages 75-94 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Love, J. D., H. R. Bergquist, and R. K. Hose. 1948. Stratigraphic sections of Jurassic and Cretaceous rocks in the Jackson Hole area, northwestern Wyoming. Geological Survey of Wyoming, Laramie, WY. Bulletin 40. Available online at: http://www.wsgs.uwyo.edu/public-info/onlinepubs/docs/B-40.pdf. Accessed March 2013.

Lovelace, D. M. 2011. Sedimentology and ichnology from the Early and Middle Triassic formations of the Chugwater Group, central Wyoming, USA. Abstracts with Programs. *Geological Society of America* 43(5):266.

Lovelace, D. M. and S. D. Lovelace. 2012. Paleoenvironments and paleoecology of a Lower Triassic invertebrate and vertebrate ichnoassemblage from the Red Peak Formation (Chugwater Group), central Wyoming. *Palaios* 27(9):636-657.

Lyford, M. E. 2001. The roles of dispersal, climate, and topography in the Holocene migration of Utah juniper into Wyoming and southern Montana. Dissertation. University of Wyoming, Laramie, WY.

Lyford, M. E., J. L., Betancourt, and S. T. Jackson. 2002. Holocene vegetation and climate history of the northern Bighorn Basin, southern Montana. *Quaternary Research* 58:171-181.

Lyford, M. E., S. T. Jackson, J. L. Betancourt, and S. T. Gray. 2003. Influence of landscape structure and climate variability on a Late Holocene plant migration. *Ecological Monographs* 73(4):567-583.

Macomber, R. W. 1970. Articulate brachiopods from the upper Bighorn Formation (late Ordovician) of Wyoming. *Journal of Paleontology* 44(3):416-450.

Maione, S. J. 1971. Stratigraphy of the Frontier Sandstone Member of the Mancos Shale (upper Cretaceous) on the south flank of the eastern Uinta Mountains, Utah and Colorado. *Earth Science Bulletin* 4(3):27-58.

Mamet, B. L. 1975. Carboniferous foraminifera and algae of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 848-B. Available online at: http://pubs.er.usgs.gov/publication/pp848B. Accessed February 2013.

Mankiewicz, D. and J. R. Steidtmann. 1979. Depositional environments and diagenesis of the Tensleep Sandstone, eastern Big Horn Basin, Wyoming. Pages 319-336 *in* P. A. Scholle and P. R. Schluger, editors. Aspects of diagenesis. Society of Economic Paleontologists and Mineralogists, Tulsa, OK. Special Publication 26.

Mapel, W. J. and M. H. Bergendahl. 1956. Gypsum Spring Formation, northwestern Black Hills, Wyoming and South Dakota. *Bulletin of the American Association of Petroleum Geologists* 40(1):84-93.

Marsh, O. C. 1895. The Reptilia of the *Baptanodon* beds. *American Journal of Science* 50(299):405-406.

Martin, L. D. and B. M. Gilbert. 1978a. Excavations at Natural Trap Cave. *Transactions of the Nebraska Academy of Sciences* 6:107-116. Available online at: http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1335&context=tnas. Accessed February 2013.

Martin, L. D. and B. M. Gilbert. 1978b. An American lion, *Panthera atrox*, Natural Trap Cave, north central Wyoming. *Contributions to Geology* 16(2):95-101.

Martin, L. D., B. M. Gilbert, and D. B. Adams. 1977. A cheetah-like cat in the North American Pleistocene. *Science* 195(4282):981-982.

Martin, L. D., B. M. Gilbert, and S. A. Chomko. 1979. *Dicrostonyx* (Rodentia) from the late Pleistocene of northern Wyoming. *Journal of Mammalogy* 60(1):193-195.

Martin, W. D., J. H. Fischer, R. J. Keogh, and K. Moore. 1980. The petrology of the limestones in the upper Gros Ventre and Gallatin Limestone formations (middle and upper Cambrian), northwestern Wind River basin, Wyoming. Pages 37-51 *in* S. Hollis, editor. Stratigraphy of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 31.

Massare, J. A. and L.E. Dain. 1989. The marine reptiles of the Mowry Shale (Albian) of northeastern Wyoming. *Journal of Vertebrate Paleontology* 9(supplement to 3):32A.

Massare, J. A., E. A. Buchholtz, J. M. Kenney, and A.-M. Chomat. 2006. Vertebral morphology of *Ophthalmosaurus natans* (Reptilia: Ichthyosauria) from the Jurassic Sundance Formation of Wyoming. *Paludicola* 5:242-254.

Massare, J. A., W. R. Wahl, M. Ross, and M. V. Connely. In press. Palaeoecology of the marine reptiles of the Redwater Shale Member of the Sundance Formation (Jurassic of central Wyoming, USA. Geological Magazine.

Matthes, F. E. 1900. Part 2: Glacial sculpture of the Big Horn Mountains, Wyoming.

U.S. *Geological Survey Annual Report* 21(Part 2):167-190.

Matthews, N. A., T. A. Noble, and B. H. Breithaupt. 2006. The application of photogrammetry, remote sensing and geographic information systems (GIS) to fossil resource management. Pages 119-131 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 34.

Maughan, E. K. 1964. The Goose Egg Formation in the Laramie Range and adjacent parts of southeastern Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 501-B:B53-B60. Available online at: http://pubs.er.usgs.gov/publication/pp501B. Accessed February 2013.

Maughan, E. K. 1967. Eastern Wyoming, eastern Montana, and the Dakotas. U.S. Geological Survey, Washington, DC. Professional Paper 515-G. Available online at: http://pubs.usgs.gov/pp/0515/report.pdf. Accessed February 2013.

Maughan, E. K. 1987. Wind River canyon, Wyoming. Pages 191-196 *in* S. S. Beus, editor. Rocky Mountain Section of the Geological Society of America. Geological Society of America, Boulder, CO. Centennial Field Guide 2.

Maxwell, W. D. and J. R. Horner. 1994. Neonate dinosaurian remains and dinosaurian eggshell from the Cloverly Formation, Montana. *Journal of Vertebrate Paleontology* 14(1):143-146.

Maxwell, E. E. and B. P. Kear. 2010. Postcranial anatomy of *Platypterygius americanus* (Reptilia, Ichthyosauria) from the Cretaceous of Wyoming. *Journal of Vertebrate Paleontology* 30(4):1059-1068.

McKelvey, V. E., T. M. Cheney, E. R. Cressman, R. P. Sheldon, R. W. Swanson, and J. S. Williams. 1959. Geology of Permian rocks in the western phosphate field: the Phosphoria, Park City, and Shedhorn formations in the western phosphate field. U.S. Geological Survey, Washington, DC. Professional Paper 313-A. Available online at: http://pubs.er.usgs.gov/publication/pp313A. Accessed February 2013.

Mehl, M. G. 1915. *Poposaurus gracilis*, a new reptile from the Triassic of Wyoming. *Journal of Geology* 23(6):516-522.

Merewether, E. A. 1996. Stratigraphy and tectonic implications of Upper Cretaceous rocks in the Powder River basin, northeastern Wyoming and southeastern Montana. U.S. Geological Survey, Reston, VA. Bulletin 1917-T. Available online at: http://pubs.er.usgs.gov/publication/b1917T. Accessed February 2013.

Merewether, E. A. and W. A. Cobban. 2008. Outcrop descriptions and fossils from the Upper Cretaceous Frontier Formation, Wind River basin and adjacent areas, Wyoming. U.S. Geological Survey, Reston, VA. Digital Data Series 69-J. Available online at: http://pubs.usgs.gov/dds/dds-069/dds-069-j/chapters.html. Accessed September 2011.

Merewether, E. A., W. A. Cobban, and E. T. Cavanaugh. 1979. Frontier Formation and equivalent rocks in eastern Wyoming. *Mountain Geologist* 16(3):67-102.

Merewether, E. A., P. D. Blackmon, and J. C. Webb. 1984. The Mid-Cretaceous Frontier Formation near the Moxa Arch, southwestern Wyoming. U.S. Geological Survey, Reston, VA. Professional Paper 1290. Available online at: http://pubs.er.usgs.gov/publication/pp1290 Accessed March 2013.

Merewether, E. A., W. A. Cobban, and R. W. Tillman. 2010. Outcrops, fossils, geophysical logs, and tectonic interpretations of the Upper Cretaceous Frontier Formation and contiguous strata in the Bighorn Basin, Wyoming and Montana. U.S. Geological Survey, Reston, VA. Scientific Investigations Report 2009-5256. Available online at: http://pubs.er.usgs.gov/publication/sir20095256. Accessed February 2013.

Mettes, K. J. and D. W. Boyd. 1985. The contact and boundary beds of the late Paleozoic Tensleep Sandstone and Phosphoria Formation in northwest Wyoming. Abstracts with Programs. *Geological Society of America* 17(4):256.

Meyers, J. H., C. M. Graves, P. J. O'Malley, and R. K. Schwartz. 1992. Environments of deposition in the late Jurassic marine to nonmarine transition, Swift and Morrison formations, southwestern Montana. Pages 47-48 *in* SEPM 1992 theme meeting; Mesozoic of the Western Interior; abstracts. Society for Sedimentary Geology, Tulsa, OK.

Mickelson, D. L., E. P. Kvale, G. D. Johnson, M. R. King, K. A. Mickelson, and P. Getty. 2005a. Subaqueous tetrapod swim tracks from the Middle Jurassic: Big Horn Basin, Wyoming U.S.A. Abstracts with Programs. *Geological Society of America* 37(6):37.

Mickelson, D. L., M. R. King, P. Getty, and K. A. Mickelson. 2005b. Subaqueous tetrapod swim tracks from the Middle Jurassic: Bighorn Canyon National Recreation Area (BCNRA), Wyoming U.S.A. Abstracts with Programs. *Geological Society of America* 37(7):440.

Mickelson, D. L., M. R. King, P. Getty, and K. A. Mickelson. 2006a. Subaqueous tetrapod swim tracks from the Middle Jurassic: Bighorn Canyon National Recreation Area (BCNRA), Wyoming, U.S.A. Page 26 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 34.

Mickelson, D. L., K. A. Mickelson, M. R. King, and P. Getty. 2006b. Jurassic dinosaur tracksites from the American West. Pages 138-140 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 34.

Miller, A. K. and J. B. Carrier. 1942. Ordovician cephalopods from the Bighorn Mountains of Wyoming. *Journal of Paleontology* 16(5):531-548.

Miller, A. K. and A. G. Unklesbay. 1943. A new asteroid from the Jurassic of central Wyoming. *Journal of Paleontology* 17(2):179-180.

Miller, B. M. 1936. Cambrian stratigraphy of northwestern Wyoming. *Journal of Geology* 44(2, part 1):113-144.

Miller, C. N., Jr. and C. A. LaPasha. 1984. Flora of the Early Cretaceous Kootenai Formation in Montana, conifers. *Palaeontographica. Abteilung B: Palaeophytologie* 193(1-4):1-17.

Mirsky, A. 1962. Stratigraphy of non-marine Upper Jurassic and Lower Cretaceous rocks, southern Big Horn Mountains, Wyoming. *Bulletin of the American Association of Petroleum Geologists* 46(9):1653-1680.

Moberly, R. M., Jr. 1960. Morrison, Cloverly, and Sykes Mountain formations, northern Bighorn Basin, Wyoming and Montana. *Geological Society of America Bulletin* 71(8):1137-1176.

Moberly, R., Jr. 1962. Lower Cretaceous history of the Bighorn Basin, Wyoming, Pages 94-101 *in* R. L. Enyert and W. H. Curry, III, editors. Symposium on Early Cretaceous rocks of Wyoming and adjacent areas. Wyoming Geological Association, Casper, WY. Guidebook 17.

Molenaar, C. M. and B. W. Wilson. 1990. The Frontier Formation and associated rocks of northeastern Utah and northwestern Colorado. U.S. Geological Survey, Reston, VA. Bulletin 1787-M. Available online at: http://www.nps.gov/history/history/online_books/geology/publications/bul/1787-m/contents.htm. Accessed September 2011.

Moore, G. T. 1973. Lodgepole Limestone facies in southwestern Montana. *American Association of Petroleum Geologists Bulletin* 57(9):1703-1713.

Morgan, D. 1998. Paleoenvironmental interpretation of the Middle Cambrian Flathead Sandstone and Wolsey Shale, Clarks Fork region, Wyoming. *Keck Research Symposium in Geology* 11:275-278. Available online at: http://keckgeology.org/files/pdf/symvol/11th/Wyoming/morgan.pdf. Accessed February 2013.

Moslow, T. F. and R. W. Tillman. 1986. Sedimentary facies and reservoir characteristics of Frontier Formation sandstones, southwestern Wyoming. Pages 271-295 *in* C. W. Spencer and R. F. Mast, editors. Geology of tight gas reservoirs. American Association of Petroleum Geologists, Tulsa, OK. AAPG Studies in Geology 24.

Murphy, J. C., E. C. Clites, T. M. Demko, and B. E. Bodenbender. 2005. Fluvial sedimentology and plant taphonomy of a dinosaur site and associated strata, Upper Jurassic Morrison and Lower Cretaceous Cloverly formations, Bighorn Basin, WY. Abstracts with Programs. *Geological Society of America* 37(5):32.

Nace, R. L. 1939. A new ichthyosaur from the upper Cretaceous Mowry Formation of Wyoming. *American Journal of Science* 237(9):673-686.

National Park Service, Geologic Resources Division. 2006. Geologic resources

evaluation scoping summary, Bighorn Canyon National Recreation Area. National Park Service, Geologic Resources Division, Denver, CO. Available online at: http://nature.nps.gov/geology/inventory/publications/s_summaries/BICA_scoping_summary_2006-0309.pdf. Accessed February 2013.

National Park Service, Geologic Resources Division. 2007. Digital geologic map of Bighorn Canyon National Recreation Area and vicinity, Montana and Wyoming (NPS, GRD, GRE, BICA). National Park Service, Geologic Resources Division, Denver, CO. Scale varies; 1:31,680, 1:100,000, and 1:250,000 source maps. Available online at: https://irma.nps.gov/App/Reference/Profile?Code=1044595. Accessed February 2013.

Nydam, R. L. and R. L. Cifelli. 2002. Lizards from the lower Cretaceous (Aptian-Albian) Antlers and Cloverly formations. *Journal of Vertebrate Paleontology* 22(2):286-298.

O'Keefe, F. R. and H. P. Street. 2009. Osteology of the cryptocleidoid plesiosaur *Tatenectes laramiensis*, with comments on the taxonomic status of the Cimoliasauridae. *Journal of Vertebrate Paleontology* 29(1):48-57.

O'Keefe, F. R., H. P. Street, J. P. Cavigelli, J. J. Socha, and R. D. O'Keefe. 2009. A plesiosaur containing an ichthyosaur embryo as stomach contents from the Sundance Formation of the Bighorn Basin, WY. *Journal of Vertebrate Paleontology* 29(4):1306-1310.

O'Keefe, F. R., H. P. Street, B. C. Wilhelm, C. D. Richards, and H. Zhu. 2011. A new skeleton of the cryptoclidid plesiosaur *Tatenectes laramiensis* reveals a novel body shape among plesiosaurs. *Journal of Vertebrate Paleontology* 31(2):330-339.

Oboh-Ikuenobe, F. E., D. G. Benson, R. W. Scott, J. M. Holbrook, M. J. Evetts, and J. Erbacher. 2007. Re-evaluation of the Albian-Cenomanian boundary in the U.S. Western Interior based on dinoflagellate cysts. *Review of Palaeobotany and Palynology* 144(1-2):77-97.

Okulitch, V. J. and W. G. Bell. 1955. *Gallatinospongia*, a new siliceous sponge from the Upper Cambrian of Wyoming. *Journal of Paleontology* 29(3):460-461.

Olson, E. C. 1960. A trilophosaurid reptile from the Kootenai Formation (lower Cretaceous). *Journal of Paleontology* 34(3):551-555.

Oreska, M. P. J., M. T. Carrano, and K. M. Dzikiewicz. 2013. Vertebrate paleontology of the Cloverly Formation (lower Cretaceous), I: faunal composition, biogeographic relationships, and sampling. *Journal of Vertebrate Paleontology* 33(2):264-292.

Orrell, S. A. 1988. Evidence of transpressional tectonics, southeastern terminus of East Pryor Mountain, Pryor Mountains, Montana and Wyoming. Thesis. University of Massachusetts at Amherst, Amherst, MA.

Ostrom, J. H. 1970. Stratigraphy and paleontology of the Cloverly Formation (lower Cretaceous) of the Bighorn Basin area, Wyoming and Montana. Peabody

Museum of Natural History Bulletin 35. Available online at: http://peabody.yale.edu/sites/default/files/documents/scientific-publications/ypmB35_1970.pdf. Accessed February 2013.

Palmer, A. N., and M. V. Palmer. 1995. The Kaskaskia paleokarst of the northern Rocky Mountains and Black Hills, northwestern U.S.A. *Carbonates and Evaporites* 10(2):148-160.

Palmquist, R. 1983. Terrace chronologies in the Bighorn Basin, Wyoming. Pages 217-231 *in* W. W. Boberg, editor. Geology of the Bighorn Basin. Wyoming Geological Association, Casper, WY. Guidebook 34.

Parcell, W. C. 1996. Depositional environments and facies changes of the Sawtooth and Piper Formations of southwestern Montana and northcentral Wyoming. Abstracts with Programs. *Geological Society of America* 28(4):34-35.

Parcell, W. C. and M. K. Williams. 2003. Thrombolite buildups in the Middle Jurassic Piper and Gypsum Spring Formations, Bighorn Basin, Wyoming. Annual Meeting Expanded Abstracts. *American Association of Petroleum Geologists* 12:132.

Parcell, W. C. and M. K. Williams. 2005. Mixed sediment deposition in a retro-arc foreland basin: lower Ellis Group (M. Jurassic), Wyoming and Montana, U.S.A. *Sedimentary Geology* 177(3-4):175-194.

Parcell, W. C., L. Kasten, K. Minks, and M. K. Williams. 2004. Mapping Middle Jurassic microbial buildups, Cody, Wyoming: implications for stratigraphic correlation of Middle Jurassic units across the Bighorn Basin. Annual Meeting Expanded Abstracts. *American Association of Petroleum Geologists* 13:108.

Parrish, J. T., F. Peterson, and C. E. Turner. 2004. Jurassic “savannah”: plant taphonomy and climate of the Morrison Formation (Upper Jurassic, Western USA). *Sedimentary Geology* 167(3-4):137-162.

Paull, R. K. and R. A. Paull. 1983. Revision of type Lower Triassic Dinwoody Formation, Wyoming, and designation of principal reference section. *Contributions to Geology* 22(2):83-90.

Paull, R. A. and R. K. Paull. 1987. Lower Triassic rocks within and adjacent to the thrust belt of Wyoming, Idaho, Utah. Pages 149-161 *in* W. R. Miller, editor. The thrust belt revisited. Wyoming Geological Association, Casper, WY. Guidebook 38.

Paull, R. A. and R. K. Paull. 1993. Stratigraphy of the Lower Triassic Dinwoody Formation in the Wind River basin area, Wyoming. Pages 31-47 *in* W. R. Keefer, W. J. Metzger, and L. H. Godwin, editors. Wyoming Geological Association special symposium on oil and gas and other resources of the Wind River basin, Wyoming. Wyoming Geological Association, Casper, WY.

Paull, R. K., R. A. Paull, and A. L. Anderson. 1985. Conodont biostratigraphy and depositional history of the Lower Triassic Dinwoody Formation in the Meade Plate, southeastern Idaho. Pages 55-66 *in* G. J. Kerns and R. L. Kerns, editors. Orogenic

patterns and stratigraphy of north-central Utah and southeastern Idaho. Utah Geological Association, Salt Lake City, UT. Publication 14.

Pearson, E. F. 1971. Conodonts from the lower Goose Egg Formation (Permian) of southeastern Wyoming. *Contributions to Geology* 9(2):102-104.

Peck, R. E. 1941. Lower Cretaceous Rocky Mountain nonmarine microfossils. *Journal of Paleontology* 15(3):285-304.

Peck, R. E. 1957. North American Mesozoic Charophyta. U.S. Geological Survey, Washington, DC. Professional Paper 294-A.

Peterson, J. A. 1954a. Distribution of marine upper Jurassic ostracodes, Western Interior United States. *Journal of Sedimentary Petrology* 24(2):141-142.

Peterson, J. A. 1954b. Jurassic Ostracoda from the "lower Sundance" and Rierdon formations, western interior United States. *Journal of Paleontology* 28(2):153-176.

Peterson, J. A. 1957a. Marine Jurassic of northern Rocky Mountains and Williston Basin. *Bulletin of the American Association of Petroleum Geologists* 41(3):399-440.

Peterson, J. A. 1957b. Gypsum Spring and Sundance formations, central Wyoming. Pages 47-54 *in* Southwest Wind River basin. Wyoming Geological Association, Casper, WY. Guidebook 12.

Picard, M. D. 1966. Petrography of Red Peak Member, Chugwater Formation (Triassic), west-central Wyoming. *Journal of Sedimentary Petrology* 36(4):904-926.

Picard, M. D. 1967. Stratigraphy and depositional environments of the Red Peak Member of the Chugwater Formation (Triassic), west-central Wyoming. *Contributions to Geology* 6(1):39-67.

Picard, M. D. 1993. The early Mesozoic history of Wyoming. Pages 210-248 *in* A. W. Snoke, J. R. Steidtmann, and S. M. Roberts, editors. Geology of Wyoming. Wyoming State Geological Survey, Laramie, WY. Memoir 5.

Pierce, W. G. 1997. Geologic map of the Cody 1° x 2° quadrangle, northwestern Wyoming. U.S. Geological Survey, Reston, VA. Miscellaneous Geologic Investigations Map 2500. Scale 1:250,000. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_13047.htm. Accessed March 2013.

Pipiringos, G. N. and R. W. Imlay. 1979. Lithology and subdivisions of the Jurassic Stump Formation in southeastern Idaho and adjoining areas. U.S. Geological Survey, Reston, VA. Professional Paper 1035-C. Available online at: http://pubs.er.usgs.gov/publication/pp1035C. Accessed September 2011.

Pipiringos, G. N. and R. B. O'Sullivan. 1978. Principal unconformities in Triassic and Jurassic rocks, Western Interior United States—a preliminary survey. U.S. Geological Survey, Reston, VA. Professional Paper 1035-A. Available online at: http://pubs.er.usgs.gov/publication/pp1035A. Accessed February 2013.

Platt, B. F. and S. T. Hasiotis. 2006. Newly discovered sauropod dinosaur tracks with skin and foot-pad impressions from the

upper Jurassic Morrison Formation, Bighorn Basin, Wyoming, U.S.A. *Palaios* 21(3):249-261.

Platt, B. F. and S. T. Hasiotis. 2008. A new system for describing and classifying tetrapod tail traces with implications for interpreting the dinosaur tail trace record. *Palaios* 23(1):3-13.

Platt, B. F., S. T. Hasiotis, and E. P. Kvale. 2004a. A new theropod trackway with an associated tail trace from the Upper Jurassic Morrison Formation, Bighorn Basin, Wyoming, USA. Abstracts with Programs. *Geological Society of America* 36(5):66-67.

Platt, B. F., S. T. Hasiotis, and M. J. Kraus. 2004b. Integrating ichnofossils and substrates to interpret avulsion in floodplain deposits in the upper Jurassic Morrison Formation, Big Horn Basin, Wyoming. Annual Meeting Expanded Abstracts. *American Association of Petroleum Geologists* 13:112.

Ploynoi, M. and W. C. Parcell. 2005. Development of middle Jurassic microbial buildups in Bighorn Basin, Wyoming. Abstracts with Programs. *Geological Society of America* 37(7):17.

Porter, K. W. 1989. Marine Jurassic rocks of western Montana: new considerations, Pages 91-102 *in* D. E. French and R. F. Grabb, editors. Montana Geological Society 1989 field conference guidebook: Montana centennial edition: Geologic resources of Montana, Volume I. Montana Geological Society, Bozeman, MT. Field Conference 1989(1).

Rautman, C. A. 1975. Sedimentology of the "lower Sundance" Formation (upper Jurassic) Wyoming region. *Wyoming Geological Association Earth Science Bulletin* 8(4):1-16.

Reaugh, A. B. 1980. Cambrian acritarchs from the Gallatin, Gros Ventre and Death Canyon formations, Sublette Co., Wyoming. *Palynology* 4:248.

Reeside, J. B., Jr. 1923. A new fauna from the Colorado Group of southern Montana. Pages 25-33 *in* Contributions to general geology, 1923. U.S. Geological Survey, Washington, DC. Professional Paper 132.

Reeside, J. B., Jr., and W. A. Cobban. 1960. Studies of the Mowry shale (Cretaceous) and contemporary formations in the United States and Canada. U.S. Geological Survey, Washington, DC. Professional Paper 355. Available online at: http://pubs.er.usgs.gov/publication/pp355. Accessed February 2013.

Reheis, M. C. 1985. Evidence for Quaternary tectonism in the northern Bighorn Basin, Wyoming and Montana. *Geology* 13(5):364-367.

Reheis, M. C. 1987. Gypsic soils on the Kane alluvial fans, Big Horn County, Wyoming. U.S. Geological Survey, Reston, VA. Bulletin 1590-C. Available online at: http://pubs.er.usgs.gov/publication/b1590C. Accessed February 2013.

Reheis, M. C. and S. S. Agard. 1984. Timing of stream captures in the Bighorn Basin, WY and MT, determined from ash-dated gravels. Abstracts with Programs. *Geological Society of America* 16(6):632.

Rice, D. D. 1976. Revision of Cretaceous nomenclature of the northern Great Plains in Montana, North Dakota, and South Dakota. Pages A66-A67 *in* G. V. Cohee and W. B. Wright, editors. Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1975. U.S. Geological Survey, Washington, DC. Bulletin 1422-A. Available online at: http://pubs.er.usgs.gov/publication/b1422A. Accessed February 2013.

Richards, P. W., editor. 1954. Pryor Mountains-northern Bighorn Basin, Montana, September 9-11, 1954. Billings Geological Society, Billings, MT. Guidebook 5.

Richards, P. W. 1955. Geology of the Bighorn Canyon-Hardin area, Montana and Wyoming. U.S. Geological Survey, Washington, DC. Bulletin 1026. Available online at: http://pubs.er.usgs.gov/publication/b1026. Accessed February 2013.

Rieppel, O. 1998. *Corosaurus alcovensis* Case and the phylogenetic interrelationships of Triassic stem-group Sauropterygia. *Zoological Journal of the Linnean Society* 124(1):1-41.

Rioux, R. L. 1994. Geologic map of the Sheep Mountain-Little Sheep Mountain area, Big Horn County, Wyoming. U.S. Geological Survey, Reston, VA. Open-File Report 94-191. Scale 1:31,680. Available online at: http://pubs.er.usgs.gov/publication/ofr94191 Accessed April 2013.

Rodriguez, J. and R. C. Gutschick. 1968. *Productina*, *Cyrtina*, and *Dielasma* (Brachiopoda) from the Lodgepole Limestone (Mississippian) of southwestern Montana. *Journal of Paleontology* 42(4):1027-1032.

Ryer, T. A. 1977. Age of Frontier Formation in north-central Utah. *AAPG Bulletin* 61(1):112-116.

Sablock, J. M. and P. E. Sablock. 1988. A new fossil locality in southwestern Montana, Late Jurassic Swift Formation. Abstracts with Programs. *Geological Society of America* 20(6):466.

Sandberg, C. A. 1965. Nomenclature and correlation of lithologic subdivisions of the Jefferson and Three Forks formations of southern Montana and northern Wyoming. U.S. Geological Survey, Washington, DC. Bulletin 1194-N:N1-N18. Available online at: http://pubs.er.usgs.gov/publication/b1194N. Accessed February 2013.

Sandberg, C. A. and G. Klapper. 1967. Stratigraphy, age, and paleotectonic significance of the Cottonwood Canyon Member of the Madison Limestone in Wyoming and Montana. U.S. Geological Survey, Washington, DC. Bulletin 1251-B. Available online at: http://pubs.er.usgs.gov/publication/b1251B. Accessed February 2013.

Sando, W. J. 1972. Madison Group (Mississippian) and Amsden Formation (Mississippian and Pennsylvanian) in the Beartooth Mountains, northern Wyoming and southern Montana. Pages 57-63 *in* J. Lynn, C. Balster, and J. Warne, editors. Crazy Mountains Basin. Montana Geological Society, Billings, MT. Field Conference 21.

Sando, W. J. 1975a. Stratigraphic sections of the Madison Limestone and Amsden Formation, west flank of the Bighorn Basin, Wyoming. Pages 129-137 *in* F. A. Exum and G. R. George, editors. Geology and mineral resources of the Bighorn Basin. Wyoming Geological Association, Casper, WY. Guidebook 27.

Sando, W. J. 1975b. Coelenterata of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey Professional Paper 848-C. Available online at: http://pubs.er.usgs.gov/publication/pp848C. Accessed February 2013.

Sando, W. J. 1988. Madison Limestone (Mississippian) paleokarst: a geologic synthesis. Pages 256-277 *in* N. P. James and P. W. Choquette, editors. Paleokarst. Springer-Verlag, New York, NY.

Sando, W. J. and J. T. Dutro, Jr. 1974. Type sections of Madison Group (Mississippian) and its subdivisions in Montana. U.S. Geological Survey, Washington, DC. Professional Paper 842. Available online at: http://pubs.er.usgs.gov/publication/pp842. Accessed February 2013.

Sando, W. J. and B. L. Mamet. 1974. New evidence on the age of the top of the Madison Limestone (Mississippian), Bighorn Mountains, Wyoming and Montana. *Journal of Research of the U.S. Geological Survey* 2(5):619-624.

Sando, W. J., M. Gordon, Jr., and J. T. Dutro, Jr. 1975. Stratigraphy and geologic history of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 848-A. Available online at: http://pubs.er.usgs.gov/publication/pp848A. Accessed February 2013.

Santiago-Blay, J. A., C. C. Labandeira, L. Pribyl, C. Hotton, and L. D. Martin. 2001. The Sundance insect fauna (Middle Jurassic) of northern Wyoming and southern Montana. Abstracts with Programs. *Geological Society of America* 33(6):266.

Santucci, V. L., D. Hays, J. Staebler, and M. Milstein. 1999. A preliminary assessment of paleontological resources at Bighorn Canyon National Recreation Area, Montana and Wyoming. Pages 18-22 *in* V. L. Santucci and L. McClelland, editors. National Park Service paleontological research volume 4. National Park Service Geologic Resource Technical Report, NPS/NRGRD/GRDTR-99/03. Available online at: http://nature.nps.gov/geology/paleontology/pub/grd4/BICA.doc. Accessed February 2013.

Santucci, V. L., J. Kenworthy, and R. Kerbo. 2001. An inventory of paleontological resources associated with National Park Service caves. NPS Geological Resources Division, Denver, CO. Technical Report NPS/NRGRD/GRDTR-01/02. TIC# D-2231. Available online at: http://www.nature.nps.gov/geology/paleontology/pub/cavepaleo.pdf. Accessed February 2013.

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring *in situ* paleontological resources. Pages 189-204 *in* R. Young and L. Norby, editors.

Geological monitoring. Geological Society of America, Boulder, CO.

Schaeffer, B. and C. Patterson. 1984. Jurassic fishes from the western United States, with comments on Jurassic fish distribution. American Museum Novitates 2796. Available online at: http://hdl.handle.net/2246/5270. Accessed February 2013.

Schmude, D. C. 2000. Interplay of paleostructure, sedimentation and preservation of Middle Jurassic rocks, Big Horn Basin, Wyoming. *Mountain Geologist* 37(4):145-155.

Schwab, K. W. 1977. Palynology of the lower Thermopolis and Cloverly formations (Albian), Gros Ventre Mountains, Wyoming. *Palynology* 1:176.

Schwimmer, D. R. 1975. Quantitative taxonomy and biostratigraphy of middle Cambrian trilobites from Montana and Wyoming. *Journal of the International Association for Mathematical Geology* 7(2):149-166.

Scott, R. W. and D. O. Asquith. 1972. Dendroid graptolites from the Bighorn Dolomite (Ordovician), southeastern Idaho. *Contributions to Geology* 11(2):73-82.

Scott, R. W., Holbrook, J. M. Evetts, and M. J. Oboh-Ikuenobe, F. E. 2001. Albian-Cenomanian depositional cycles transgressed from Chihuahua Trough to Western Interior. Pages 221-228 *in* S. G. Lucas and D. S. Ulmer-Scholle, editors. Geology of the Llano Estacado. Guidebook - New Mexico Geological Society 52. New Mexico Geological Society, Socorro, NM. Guidebook 48.

Scott, R. W., F. E. Oboh-Ikuenobe, D. G. Benson, Jr., and J. M. Holbrook. 2009. Numerical age calibration of the Albian/Cenomanian boundary. *Stratigraphy* 6(1):17-32.

Shaw, A. B. 1954. The Cambrian and Ordovician of the Pryor Mountains, Montana, and northern Bighorn Mountains, Wyoming. Pages 32-37 *in* P. W. Richards, editor. Pryor Mountains-northern Bighorn Basin, Montana, September 9-11, 1954. Billings Geological Society, Billings, MT. Guidebook 5.

Shelton, J. W. 1972. Trend and depositional environment of Greybull Sandstone, northern part of the Pryor Uplift. Pages 75-79 *in* J. Lynn, C. Balster, and J. Warne, editors. Crazy Mountains Basin. Montana Geological Society, Billings, MT. Guidebook 21.

Sherrington, P. F. and A. Lord. 1975. On *Lophocythere* (*Neurocythere*) *minuta* (Peterson). *Stereo-Atlas of Ostracod Shells* 2(4).

Simmons, S. P. and P. A. Scholle. 1990. Late Paleozoic uplift and sedimentation, northeast Bighorn Basin, Wyoming. Pages 39-55 *in* R. W. Specht, editor. Wyoming sedimentation and tectonics. Wyoming Geological Association, Casper, WY. Guidebook 41.

Smith, D. L. 1982. Waulsortian bioherms in the Paine Member of the Lodgepople Limestone (Kinderhookian) of Montana, U.S.A. Pages 51-64 *in* K. Bolton, H. R. Lane, and D. V. LeMone, editors.

Symposium on the paleoenvironmental setting and distribution of the Waulsortian facies. El Paso Geological Society, El Paso, TX.

Smith, T. M. and S. L. Dorobek. 1993. Early Mississippian climate change: isotopic evidence from meteoric calcite. *Geophysical Monograph* 78:77-88.

Sohn, I. G. 1975. Mississippian Ostracoda of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 848-G. Available online at: http://pubs.er.usgs.gov/publication/pp848G. Accessed February 2013.

Specht, R. W. and R. L. Brenner. 1979. Storm-wave genesis of bioclastic carbonates in upper Jurassic epicontinental mudstones, east-central Wyoming. *Journal of Sedimentary Petrology* 49(4):1307-1321.

Stamm, R. G. and B. R. Wardlaw. 2003. Conodont faunas of the late Middle Pennsylvanian (Desmoinesian) lower Kittanning cyclothem, U.S.A. Pages 95-121 *in* C. B. Cecil and N. T. Edgar, editors. Climate controls on stratigraphy. Society for Sedimentary Geology, Tulsa, OK. Special Publication 77.

Stanley, G. and R. Burke. 2000. The Mississippian Lodgepole Limestone (Madison Group), Little Belt Mountains, central Montana: lower Mississippian carbonate rocks and reef-like buildups. Pages 197-208 *in* S. Roberts and D. Winston, editors. Geologic field trips, western Montana and adjacent areas. Geological Society of America, Rocky Mountain Section, Boulder, CO. Guidebook 52.

Stewart, J. C. 1958. Geology of the Dryhead-Garvin Basin, Bighorn and Carbon counties, Montana. Montana Bureau of Mines and Geology, Butte, MT. Special Publication 17.

Stewart, J. D. and M. Hakel. 2006. Ichthyofauna of the Mowry Shale (early Cenomanian) of Wyoming. Pages 161-163 *in* S. G. Lucas and R. M. Sullivan, editors. Late Cretaceous vertebrates from the Western Interior. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 35.

Stewart, J. D., S. A. Bilbey, D. J. Chure, and S. K. Madsen. 1994. Vertebrate fauna of the Mowry Shale (Cenomanian) in northeastern Utah. *Journal of Vertebrate Paleontology* 14(supplement to 3):47A.

Stock, G. M., C. A. Riihimaki, and R. S. Anderson. 2006. Age constraints on cave development and landscape evolution in the Bighorn Basin of Wyoming, USA. *Journal of Cave and Karst Studies* 68(2):76-84.

Stone, R. and C. F. Vondra. 1972. Sediment dispersal patterns of oolitic calcarenite in the Sundance Formation (Jurassic), Wyoming. *Journal of Sedimentary Petrology* 42(1):227-229.

Storrs, G. W. 1991. Anatomy and relationships of *Corosaurus alcovensis* (Diapsida: Sauropterygia) and the Triassic Alcova Limestone of Wyoming. *Bulletin of the Peabody Museum of Natural History Yale University* 44. Available online at:

http://www.peabody.yale.edu/sites/default/files/documents/scientific-publications/ypmB44_1991.pdf. Accessed June 2013.

Strickland, L. E., R. S. Thompson, and K. H. Anderson. 2001. USGS/NOAA North American packrat midden database data dictionary. U.S. Geological Survey, Reston, VA. Open File Report 01-022. Available online at: http://pubs.er.usgs.gov/publication/ofr0122. Accessed March 2013.

Swain, F. M. 1998. Ostracoda from the Swift Formation (Upper Jurassic) of Montana and Wyoming. *Revista Espanola De Micropaleontologia* 30(1):139-158.

Swain, F. M., Jr. and J. A. Peterson. 1951. Ostracoda from the Upper Jurassic Redwater shale member of the Sundance Formation at the type locality in South Dakota. *Journal of Paleontology* 25(6):796-807.

Swain, F. M., Jr. and J. A. Peterson. 1952. Ostracodes from the upper part of the Sundance Formation of South Dakota, Wyoming, and southern Montana. U.S. Geological Survey, Washington, DC. Professional Paper 243-A. Available online at: http://pubs.er.usgs.gov/usgspubs/pp/pp243A. Accessed February 2013.

Tang, C. M. 1997. Evolutionary paleoecology of Jurassic hard-substrate assemblages from the U. S. Western Interior. Abstracts with Programs. *Geological Society of America* 29(6):107.

Thom, W. T., Jr., G. M. Hall, C. H. Wegemann, and G. F. Mouton. 1935. Geology of Big Horn County and the Crow Indian Reservation, Montana, with special reference to the Water, Coal, Oil and Gas Resources. U.S. Geological Survey, Washington, DC. Bulletin 856. Available online at: http://pubs.er.usgs.gov/publication/b856. Accessed February 2013.

Throckmorton, G. S., J. A. Hopson, and P. Parks. 1981. A redescription of *Toxolophosaurus cloudi* Olson, a lower Cretaceous herbivorous sphenodontid reptile. *Journal of Paleontology* 55(3):586-597.

Tidwell, W. D. and J. E. Skog. 1999. Two new species of *Solenostelopteris* from the upper Jurassic Morrison Formation in Wyoming and Utah. *Review of Palaeobotany and Palynology* 104(3-4):285-298.

Tidwell, W. D., D. A. Medlyn, and J. D. Shane. 1977. Fossil fungi from the Upper Jurassic Morrison Formation near Greybull, Wyoming. Abstracts with Programs. *Geological Society of America* 9(4):515-516.

Tillman, R. W. and H. Dresser. 1976. Subtidal trace fossils, Muddy and Frontier formations, Wyoming and Montana. *AAPG Bulletin* 60(4):727-728.

Tinsley, F., T. Zagurski, and E. Robbins. 1954. Road log from Red Lodge to Bighorn Canyon. Pages 18-26 *in* P. W. Richards, editor. Pryor Mountains-northern Bighorn Basin, Montana, September 9-11, 1954. Billings Geological Society, Billings, MT. Guidebook 5.

Tohill, B. and M. D. Picard. 1966. Stratigraphy and petrology of Crow Mountain Sandstone Member (Triassic), Chugwater Formation, northwestern Wyoming. *Bulletin of the American Association of Petroleum Geologists* 50(12):2547-2565.

Trumbull, C. B. and M. V. Connely. 2010. New ichnotaxa from the Mowry Shale of Wyoming may be vertebrate in origin. Abstracts with Programs. *Geological Society of America* 42(3):41-42.

Tschopp, E. and O. Mateus. In press. The skull and neck of a new flagellicaudatan sauropod from the Morrison Formation and its implication for the evolution and ontogeny of diplodocid dinosaurs. *Journal of Systematic Palaeontology*.

Tschudy, R. H., B. D. Tschudy, S. Van Loenen, and G. Doher. 1980. Illustrations of plant microfossils from the Morrison Formation. I. Plant microfossils from the Brushy Basin Member. U.S. Geological Survey, Reston, VA. Open-File Report 81-35. Available online at: http://pubs.er.usgs.gov/publication/ofr8135. Accessed January 2012.

Tschudy, R. H., B. D. Tschudy, and S. Van Loenen. 1981. Illustrations of plant microfossils from the Morrison Formation. II. Plant microfossils from the Westwater Canyon Member. U.S. Geological Survey, Reston, VA. Open-File Report 81-1154. Available online at: http://pubs.er.usgs.gov/publication/ofr811154. Accessed January 2012.

Tschudy, R. H., B. D. Tschudy, and S. D. Van Loenen. 1988a. Illustrations of plant microfossils from the Morrison Formation. III. Plant microfossils from the Recapture Member. U.S. Geological Survey, Reston, VA. Open-File Report 88-234. Available online at: http://pubs.er.usgs.gov/publication/ofr88234 Accessed January 2012.

Tschudy, R. H., B. D. Tschudy, and S. D. Van Loenen. 1988b. Illustrations of plant microfossils from the Morrison Formation. IV. Plant microfossils from the Salt Wash Member. U.S. Geological Survey, Reston, VA. Open-File Report 88-235. Available online at: http://pubs.er.usgs.gov/publication/ofr88235 Accessed January 2012.

Turner, C. E. and F. Peterson. 1999. Biostratigraphy of dinosaurs in the Upper Jurassic Morrison Formation of the Western Interior, U.S.A. Pages 77-114 *in* D. D. Gillette, editor. Vertebrate paleontology in Utah. Utah Geological Survey, Salt Lake City, UT. Miscellaneous Publication 99-1.

Turner, C. E. and F. Peterson. 2004. Reconstruction of the upper Jurassic Morrison Formation extinct ecosystem—a synthesis. *Sedimentary Geology* 167(3-4):309-355.

Tweet, J. S., V. L. Santucci, and A. P. Hunt. 2012. An inventory of packrat (*Neotoma* spp.) middens in National Park Service areas. Pages 355-368 *in* A. P. Hunt, J. Milàn, S. G. Lucas, and J. A. Spielmann, editors. Vertebrate coprolites. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 57.

Tysdal, R. G. 1976. Paleozoic and Mesozoic stratigraphy of the northern part of the Ruby Range, southwestern Montana. U.S.

Geological Survey, Washington, DC. Bulletin 1405-I. Available online at: http://pubs.er.usgs.gov/publication/b1405I Accessed April 2013.

Tysdal, R. G., T. S. Dyman, D. J. Nichols, and W. A. Cobban. 1990. Correlation chart of Frontier Formation from Greenhorn Range, southwestern Montana, to Mount Everts in Yellowstone National Park, Wyoming. U.S. Geological Survey, Reston, VA. Miscellaneous Field Studies Map 2116. Available online at: http://pubs.er.usgs.gov/publication/mf2116. Accessed April 2013.

Uhlir, D. M. A., Akers, and C. F. Vondra. 1988. Tidal inlet sequence, Sundance Formation (upper Jurassic), north-central Wyoming. *Sedimentology* 35(5):739-752.

Upshaw, C. F. 1963. Occurrences of *Aequitriradites* in the Upper Cretaceous of Wyoming. Micropaleontology **9**(4):427-431.

Upshaw, C. F. 1964. Palynological zonation of the upper Cretaceous Frontier Formation near Dubois, Wyoming. Pages 153-168 *in* Palynology in oil exploration—a symposium. Society of Economic Paleontologists and Mineralogists, Tulsa, OK. Special Publication 11.

Uygur, K. and M. D. Picard. 1985. Mesozoic stratigraphy of Uinta Basin, northeast Utah. Pages 21-37 *in* M. D. Picard, editor. Geology and energy resources, Uinta Basin of Utah. Utah Geological Association Publication 12.

Verville, G. J. 1957. Wolfcampian fusulinids from the Tensleep sandstone in the Big Horn Mountains, Wyoming. *Journal of Paleontology* 31(2):349-352.

Verville, G. J., G. A. Sanderson, and B. D. Rea. 1970. Missourian fusulinids from the Tensleep sandstone, Bighorn Mountains, Wyoming. *Journal of Paleontology* 44(3):478-479.

Vice, M. A. and J. E. Utgaard. 1989. Depositional environments in the Mission Canyon Limestone (Madison Group, Mississippian), northern Bighorn Basin region, Montana and Wyoming. Pages 55-64 *in* D. E. French and R. F. Grabb, editors. Montana Geological Society 1989 field conference guidebook: Montana centennial edition: Geologic resources of Montana, Volume I. Montana Geological Society, Bozeman, MT. Field Conference 1989(1).

Vuke, S. M. 1984. Depositional environments of the Early Cretaceous Western Interior seaway in southwestern Montana and the northern United States. Pages 127-144 *in* D. F. Stott and D. J. Glass, editors. The Mesozoic of middle North America. Canadian Society of Petroleum Geologists, Calgary, Canada. Memoir 9.

Vuke, S. M., E. M. Wilde, D. A. Lopez, and R. N. Bergantino. 2000. Geologic map of the Lodge Grass 30’ x 60’ quadrangle, Montana. Montana Bureau of Mines and Geology, Butte, MT. Geologic Map 56. Scale 1:100,000.

Waage, K. M. 1959. Stratigraphy of the Inyan Kara Group in the Black Hills. U.S. Geological Survey, Washington, DC. Bulletin 1081-B. Available online at: http://pubs.er.usgs.gov/publication/b1081B. Accessed February 2013.

Wahl, W. R., Jr. 2004. A large specimen of the genus *Eryma* (Crustacea, Decopoda) from the latest Callovian of North America. Abstracts with Programs. *Geological Society of America* 36(5):363.

Wahl, W. R. 2005. A hybodont shark from the Redwater Shale Member, Sundance Formation (Jurassic), Natrona County, Wyoming. *Paludicola* 5(1):15-19.

Wahl, W. R., M. Ross, and J. A. Massare. 2007. Rediscovery of Wilbur Knight's *Megalneusaurus rex* site: new material from an old pit. *Paludicola* 6(2):94-104.

Walker, D. N. 1987. Late Pleistocene/Holocene environmental changes in Wyoming: the mammalian record. Pages 334-393 *in* R. W. Graham, H. A. Semken, and M. A. Semken, editors. Late Quaternary mammalian biogeography and environments of the Great Plains and prairies. Illinois State Museum, Springfield, IL. Scientific Papers 22.

Walker, D. N., and G. C. Frison. 1980. The late Pleistocene mammalian fauna from the Colby Mammoth Kill site, Wyoming. *Contributions to Geology* 19(1):69-79.

Walton, K. A., B. M. Blake, Jr., B. E. Bodenbender, and T. M. Demko. 2007. Paleobotany of the Sykes Mountain Formation (Early Cretaceous), Bighorn Basin, Shell, Wyoming. Abstracts with Programs. *Geological Society of America* 39(3):10.

Wang, X. 1985. Late Pleistocene bighorn sheep (*Ovis canadensis*) of Natural Trap Cave, Wyoming. *Proceedings of the Nebraska Academy of Sciences and Affiliated Societies* 95:58.

Wardlaw, B. R. and J. W. Collinson. 1986. Paleontology and deposition of the Phosphoria Formation. *Contributions to Geology* 24(2):107-142.

Weigner, M. M. and P. Isaacson. 2012. Late Devonian shelly fossils from the Jefferson Formation, Grandview Canyon, east-central Idaho. Abstracts with Programs. *Geological Society of America* 44(7):88.

Weishampel, D. B., P. M. Barrett, R. A. Coria, J. Le Loueff, Xu X., Zhao X., A. Sahni, E. M. P. Gomani, and C. N. Noto. 2004. Dinosaur distribution. Pages 517-606 *in* D. B. Weishampel, P. Dodson, and H. Osmólska, editors. The Dinosauria (2nd edition). University of California Press, Berkeley, CA.

Wilborn, B. 2006a. Microvertebrate assemblage from a dinosaur quarry in the lower Morrison Formation, Bighorn Basin, Wyoming. *Journal of Vertebrate Paleontology* 26(supplement to 3):138A-139A.

Wilborn, B. 2006b. Macrofloral assemblages of the Cloverly Formation, Bighorn Basin, Wyoming. Abstracts with Programs. *Geological Society of America* 38(1):29.

Wilhelm, B. C. and F. R. O'Keefe. 2010. A new partial skeleton of a cryptocleidoid plesiosaur from the upper Jurassic Sundance Formation of Wyoming. *Journal of Vertebrate Paleontology* 30(6):1736-1742.

Williams, D. R. 2006. The fossil Leporidae of Natural Trap Cave, Wyoming.

Transactions of the Kansas Academy of Science 109(3-4):267.

Williston, S. W. 1904. Notice of some new reptiles from the upper Trias of Wyoming. *Journal of Geology* 12(8):688-697.

Williston, S. W. 1905. A new armored dinosaur from the Upper Cretaceous of Wyoming. *Science* 22(564):503-504.

Wings, O. 2007. A review of gastrolith function with implications for fossil vertebrates and a revised classification. *Acta Palaeontologica Polonica* 52(1):1-16. Available online at: http://app.pan.pl/archive/published/app52/app52-001. Accessed May 2013.

Wings, O. 2009. A simulated bird gastric mill and its implications for fossil gastrolith authenticity. *Fossil Record* 12(1):91-97.

Winslow, N. S. and P. L. Heller. 1987. Evaluation of unconformities in upper Jurassic and lower Cretaceous nonmarine deposits, Bighorn Basin, Wyoming and Montana, U.S.A. *Sedimentary Geology* 53(3-4):181-202.

Witkind, I. J. 1969. Geology of the Tepee Creek Quadrangle, Montana-Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 609. Available online at: http://pubs.er.usgs.gov/publication/pp609. Accessed April 2013.

Wright, R. P. 1974. Jurassic bivalves from Wyoming and South Dakota: a study of feeding relationships. *Journal of Paleontology* 48(3):425-433.

Wulf, G. R. 1962. Lower Cretaceous Albian rocks in northern Great Plains. *Bulletin of the American Association of Petroleum Geologists* 46(8):1371-1415.

Yen, T.-C. 1949. Review of the lower Cretaceous fresh-water molluscan faunas of North America. *Journal of Paleontology* 23(5):465-470.

Yen, T.-C. 1951. Fresh-water mollusks of Cretaceous age from Montana and Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 233-A. Available online at: http://pubs.er.usgs.gov/publication/pp233A. Accessed February 2013.

Yochelson, E. L. and D. H. van Sickle. 1968. Biostratigraphy of the Phosphoria, Park City, and Shedhorn Formations, with a section on fish. U.S. Geological Survey, Washington, DC. Professional Paper 313-D. Available online at: http://pubs.er.usgs.gov/publication/pp313D. Accessed February 2013.

Young, K. P. 1951. Foraminifera and stratigraphy of the Frontier Formation (upper Cretaceous), southern Montana. *Journal of Paleontology* 25(1):35-68.

Zaleha, M. J. 2006. Sevier orogenesis and nonmarine basin filling: implications of new stratigraphic correlations of lower Cretaceous strata throughout Wyoming, USA. *Geological Society of America Bulletin* 118(7-8):886-896.

Zaleha, M. J. and S. A. Wiesemann. 2005. Hyperconcentrated flows and gastroliths: sedimentology of diamictites and wackes of the upper Cloverly Formation, Lower Cretaceous, Wyoming, U.S.A. *Journal of Sedimentary Research* 75(1):43-54.

Zenger, D. H. 1992. Burrowing and dolomitization patterns in the Steamboat Point Member, Bighorn Dolomite (upper Ordovician), northwest Wyoming. *Contributions to Geology* 29(2):133-142.

Additional References

Adams, T. L. and B. H. Breithaupt. 2003. Middle Jurassic dinosaurs of northern Wyoming: evidence from the Yellow Brick Road Dinosaur Tracksite, Bighorn Basin, Wyoming. *Wyoming Geo-Notes* 78:39-46.

Anderson, E. 1974. A survey of the late Pleistocene and Holocene mammalian fauna of Wyoming. Pages 78-87 *in* M. V. Wilson, editor. Applied geology and archaeology: the Holocene history of Wyoming. Geological Survey of Wyoming, Laramie, WY. Report of Investigations 10.

Baker, R. G. 1983. Holocene vegetational history of the western United States. Pages 109-127 *in* H. E. Wright, Jr., editor. Late-Quaternary environments of the United States. Volume 2: the Holocene. University of Minnesota Press, Minneapolis, USA.

Betancourt, J. L., T. R. Van Devender, and P. S. Martin, editors. 1990. Packrat middens: the last 40,000 years of biotic change. University of Arizona Press, Tucson, AZ.

Bonnichsen, R., R. W. Graham, T. Geppert, J. S. Oliver, S. G. Oliver, D. Schnurrenberger, R. Stuckenrath, A. Tratebas, and D. E. Young. 1986. False Cougar and Shield Trap caves, Pryor Mountains, Montana. *National Geographic Research* 2(3):276-290.

Branson, E. B. and M. G. Mehl. 1929. Triassic amphibians from the Rocky Mountain region. *The University of Missouri Studies* 4:1-87.

Breithaupt, B. H., E. H. Southwell, and E. P. Kvale. 1998. The middle Jurassic Red Gulch dinosaur tracksite: the largest occurrence of dinosaur footprints and trackways in Wyoming. *Journal of Vertebrate Paleontology* 18(supplement to 3):29A.

Breithaupt, B. H., E. H. Southwell, T. L. Adams, and N. A. Matthews. 2000. A Sundance seaside dinosaur community: 1000 footprints on the Jurassic shores of ancient Wyoming. Abstracts with Programs. *Geological Society of America* 32(7):497-498.

Breithaupt, B. H., E. H. Southwell, T. L. Adams, and N. A. Matthews. 2001. Preservational and morphological variations in theropod tracks and trackways on a middle Jurassic tidal flat: implications for paleobiological and paleoecological analysis. Abstracts with Programs. *Geological Society of America* 33(6):335.

Breithaupt, B. H., E. H. Southwell, T. L. Adams, and N. A. Matthews. 2001. Gregarious theropods strolling on a middle Jurassic tidal flat: interpretations from the most extensive dinosaur tracksite in Wyoming. *Journal of Vertebrate Paleontology* 21(supplement to 3):35A.

Breithaupt, B. H., E. H. Southwell, T. L. Adams, and N. A. Matthews. 2002. Middle Jurassic dinosaur community dynamics in northern Wyoming: theropod

family values. Abstracts with Programs. *Geological Society of America* 34(4):48.

Breithaupt, B. H., E. H. Southwell, T. Adams, J. Sizemore, and N. A. Matthews. 2002. Statistically valid population analyses of Middle Jurassic dinosaur ichnocoenoses. *Journal of Vertebrate Paleontology* 22(supplement to 3):38A.

Breithaupt, B. H., T. Adams, E. H. Southwell, and N. A. Matthews. 2004. Carmelopodus and the Sundance Vertebrate Ichnofaunal Province: insights into the preservational complexities of vertebrate ichnotaxa. Abstracts with Programs. *Geological Society of America* 36(5):93.

Breithaupt, B. H., E. Campbell-Stone, and N. A. Matthews. 2010. Public paleontological sites as teaching tools in geology field camps: resource protection through resource education. Abstracts with Programs. *Geological Society of America* 42(3):9.

Breithaupt, B. H., E. H. Southwell, T. L. Adams, and N. A. Matthews. 2011. Wyoming's Red Gulch Dinosaur Tracksite: public participation, conservation, and management. *Geology Studies* 49A:5.

Cifelli, R. L., J. R. Wible, and F. A. Jenkins, Jr. 1998. Triconodont mammals from the Cloverly Formation (lower Cretaceous), Montana and Wyoming. *Journal of Vertebrate Paleontology* 18(1):237-241.

Clark, N. D. L. and M. K. Brett-Surman. 2008. A comparison between dinosaur footprints from the middle Jurassic of the Isle of Skye, Scotland, UK, and Shell, Wyoming, USA. *Scottish Journal of Geology* 44(2):139-150. Available online at: http://eprints.gla.ac.uk/4807/. Accessed June 2013.

Cobban, W. A. 1988. *Tarrantoceras* Stephenson and related ammonoid genera from Cenomanian (upper Cretaceous) rocks in Texas and the Western Interior of the United States. U.S. Geological Survey, Reston, VA. Professional Paper 1473. Available online at: http://pubs.er.usgs.gov/publication/pp1473 Accessed February 2013.

Cobban, W. A. and W. J. Kennedy. 1989. The ammonite *Metengonoceras* Hyatt, 1903, from the Mowry Shale (Cretaceous) of Montana and Wyoming. U.S. Geological Survey, Reston, VA. Bulletin 1787-L. Available online at: http://pubs.er.usgs.gov/publication/b1787L. Accessed February 2013.

D'Emic, M. D., K. M. Melstrom, and D. R. Eddy. 2012. Paleobiology and geographic range of the large-bodied Cretaceous theropod dinosaur *Acrocanthosaurus atokensis*. *Palaeogeography, Palaeoclimatology, Palaeoecology* 333-334:13-23.

Denson, M. E., Jr. and N. S. Morrisey. 1954. Subsurface correlations within the Madison Group, Bighorn and Wind River basins. Pages 44-49 *in* P. W. Richards, editor. Pryor Mountains-northern Bighorn Basin, Montana, September 9-11, 1954. Billings Geological Society, Billings, MT. Guidebook 5.

Douglass, D. N. and G. D. Johnson. 1984. Isochronous interpretation of fluviatile-lacustrine paleoenvironments, Morrison and Cloverly formations (Jurassic-

Cretaceous), central Wyoming. Pages 79-84 *in* Third symposium on Mesozoic terrestrial ecosystems: short papers. Tübingen University Press, Tübingen, Federal Republic of Germany.

Ellwood, B. B. 1996. Geology and America's National Park areas. Prentice Hall, Upper Saddle River, NJ.

Forster, C. A. 1990. The postcranial skeleton of the ornithopod dinosaur *Tenontosaurus tilletti*. *Journal of Vertebrate Paleontology* 10(3):273-294.

Gillette, D. D. and M. G. Lockley, editors. 1989. Dinosaur tracks and traces. Cambridge University Press, Cambridge, United Kingdom.

Greco, D. 2001. Trip report—evaluation of roadcuts and abandoned roads at Big Horn Canyon National Recreation Area. Memorandum to Superintendent, Bighorn Canyon National Recreation Area (November 19, 2001). National Park Service, Geologic Resources Division, Lakewood, CO.

Green, T. L., B. H. Breithaupt, E. H. Southwell, and N. A. Matthews. 2007. Ichnological evidence for family groups of middle Jurassic dinosaurs in Wyoming: evidence from footprints and growth rates of emus and theropods. Abstracts with Programs. *Geological Society of America* 39(6):325.

Hamilton, L. J. and Q. F. Paulson. 1968. Geology and ground-water resources of the lower Bighorn Valley, Montana. U.S. Geological Survey, Washington, DC. Water-Supply Paper 1876. Available online at: http://pubs.er.usgs.gov/publication/wsp1876 Accessed February 2013.

Hay, O. P. 1924. The Pleistocene of the middle region of North America and its vertebrated animals. Carnegie Institute of Washington Publication 322A.

Hay, O. P. 1927. The Pleistocene of the western region of North America and its vertebrated animals. Carnegie Institute of Washington Publication 322B.

Hill, C., W. Sutherland, and L. Tierney. 1976. Caves of Wyoming. Geological Survey of Wyoming, Laramie, WY. Bulletin 59.

Hill, C. L. 2007. Pleistocene mammals in the greater Yellowstone ecosystem. *Northwest Geology* 36:151-166. Available online at: http://sspa.boisestate.edu/anthropology/files/2010/06/mammals-greater-yellowstone.pdf. Accessed May 2013.

Husted, W. M. 1969. Bighorn Canyon archeology. Smithsonian Institution River Basin Survey, Publications in Salvage Archaeology 12.

Jenkins, F. A., Jr. and C. R. Schaff. 1988. The early Cretaceous mammal *Gobiconodon* (Mammalia, Triconodonta) from the Cloverly Formation in Montana. *Journal of Vertebrate Paleontology* 8(1):1-24.

Keller, K., G. D. Johnson, E. P. Kvale, and J. Farlow. 2000. Microbial mediation in the stabilization and preservation of dinosaur trackways in intertidal depositional environments. Abstracts with Programs. *Geological Society of America* 32(7):450.

Kohn, M. J. and M. McKay. 2012. Paleoecology of late Pleistocene-Holocene faunas of eastern and central Wyoming,

USA, with implications for LGM climate models. *Palaeogeography, Palaeoclimatology, Palaeoecology* 326-328:42-53.

Kvale, E. P., A. W. Archer, B. H. Breithaupt, M. K. Brett-Surman, G. D. Johnson, N. A. Matthews, D. L. Mickelson, M. T. Naus, and B. Southwell. 1998. Red Gulch dinosaur tracksite: a newly discovered middle Jurassic (165 Ma) dinosaur tracksite in Wyoming. Abstracts with Programs. *Geological Society of America* 30(7):A-385.

Kvale, E. P., D. L. Mickelson, S. T. Hasiotis, and G. D. Johnson. 2004. The history of dinosaur footprint discoveries in Wyoming with emphasis on the Bighorn Basin. *Ichnos* 11(1-2):3-9.

Lucas, S. G. 1993. Vertebrate biochronology of the Jurassic-Cretaceous boundary, North American Western Interior. *Modern Geology* 18(3):371-390.

Lull, R. S. 1942. Chugwater footprints from Wyoming. *American Journal of Science* 240(7):500-504.

Matthews, N., B. H. Breithaupt, and E. H. Southwell. 2000. Photogrammetric documentation of a Middle Jurassic dinosaur tracksite in the Sundance Formation of the Bighorn Basin of Wyoming. *Journal of Vertebrate Paleontology* 20(supplement to 3):57A.

Matthews, N., T. Noble, and B. Breithaupt. 2011. Taking measure of technology: where we have been and where we are going with 3D image capture and close-range photogrammetry. *Geology Studies* 49A:23-24.

Maxwell, W. D. and J. H. Ostrom. 1995. Taphonomy and paleobiological implications of *Tenontosaurus-Deinonychus* associations. *Journal of Vertebrate Paleontology* 15(4):707-712.

Mayor, A. 2005. Fossil legends of the first Americans. Princeton University Press, Princeton, NJ.

Mead, J. I. 1982. Packrat middens and Holocene environments in the Pryor Mts., Montana. Program and Abstracts. *American Quaternary Association Conference* **7**:137.

Merewether, E. A. and W. A. Cobban. 1986. Biostratigraphic units and tectonism in the mid-Cretaceous foreland of Wyoming, Colorado, and adjoining areas. Pages 443-468 *in* J. A. Peterson, editor. Paleotectonics and sedimentation in the Rocky Mountain region, United States. American Association of Petroleum Geologists, Tulsa, OK. Memoir 41.

Merewether, E. A., W. A. Cobban, and R. T. Ryder. 1975. Lower Upper Cretaceous strata, Bighorn Basin, Wyoming and Montana. Pages 73-84 *in* F. A. Exum and G. R. George, editors. Geology and mineral resources of the Bighorn Basin. Wyoming Geological Association, Casper, WY. Guidebook 27. Available online at: http://www.netl.doe.gov/kmd/cds/disk7/disk2/WGS%5CLower%20Upper%20Cretaceous%20Strata,%20Bighorn%20Basin,%20WY%20and%20MT.pdf. Accessed February 2013.

Missouri Basin Project. 1952. Appraisal of the Archeological - Paleontological Resources of the Yellowtail Reservoir site, Montana

and Wyoming. Smithsonian Institution Missouri Basin Project 21.

Olsen, S. J. 1971. Zooarchaeology: animal bones in archaeology and their interpretation. Addison-Wesley Publishing Company, New York, NY.

Ostrom, J. H. 1969. Osteology of *Deinonychus antirrhopus*, an unusual theropod from the lower Cretaceous of Montana. Peabody Museum of Natural History Bulletin 30. Available online at: http://peabody.yale.edu/sites/default/files/documents/scientific-publications/ypmB30_1969.pdf. Accessed February 2013.

Parsons, W. L. and K. M. Parsons. 2009. A new ankylosaur (Dinosauria, Ankylosauria) from the lower Cretaceous Cloverly Formation of central Montana. *Canadian Journal of Earth Sciences* 46(10):721-738.

Reheis, M. C. 1984. Drainage history of the northern Bighorn Basin—chronology and tectonic effects. Pages 11-25 (Part I) *in* M. C. Reheis, D. F. Ritter, and R. C. Palmquist, field trip leaders. Late Cenozoic History and Soil Development, Northern Bighorn Basin, Wyoming and Montana. Guidebook for the Joint Trip of the Friends of the Pleistocene, Rocky Mountain Cell, and the American Quaternary Association, August 10–11, 1984, Wyoming and Montana, USA.

Samuelson, A. C. 1974. Introduction to the geology of the Big Horn Basin and adjacent areas, Wyoming and Montana. Pages 11-17 *in* B. Voight and M. A. Voight, editors. Rock mechanics, the American Northwest. Pennsylvania State University, University Park, PA.

Schultz, R. L., editor. 1969. Caves of the Big Horn: Pryor Mountains of Montana and Wyoming. National Speleological Society, Morgantown, WV. Guidebook 10.

Southwell, E. H., B. H. Breithaupt, T. L. Adams, and N. A. Matthews. 2001. Thousands of footprints; thousands of eyes: successes and failures of collaborative efforts at the Red Gulch Dinosaur Tracksite. Abstracts with Programs. *Geological Society of America* 33(6):33.

Sues, H.-D. 1980. Anatomy and relationships of a new hypsilophodontid dinosaur from the lower Cretaceous of North America. *Palaeontographica. Abteilung A: Palaeozoologie-Stratigraphie* 169(1-3):51-72.

Tidwell, W. D. 1975. Common fossil plants of western North America. Brigham Young University Press, Provo, UT.

Wang, X. 1988. Systematics and population ecology of late Pleistocene bighorn sheep (*Ovis canadensis*) of Natural Trap Cave, Wyoming. *Transactions of the Nebraska Academy of Sciences and Affiliated Societies* 16:173-183. Available online at: http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1193&context=tnas. Accessed February 2013.

Woodruff, D. C. 2012. A new titanosauriform from the early Cretaceous Cloverly Formation of Montana. *Cretaceous Research* 36:58-66.

Data Sets

Bighorn Canyon National Recreation Area Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Bighorn Canyon National Recreation Area Collections
1966–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by BICA staff; status: Active.

Bighorn Canyon National Recreation Area Digital Geologic Map
2007–present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Available online at: https://irma.nps.gov/App/Reference/Profile?Code=1044595.

Cincinnati Museum Center, collections of the Cincinnati Museum of Natural History and Science
2004–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by CMC staff; status: Active.

Grand Teton National Park and John D. Rockefeller, Jr. Memorial Parkway

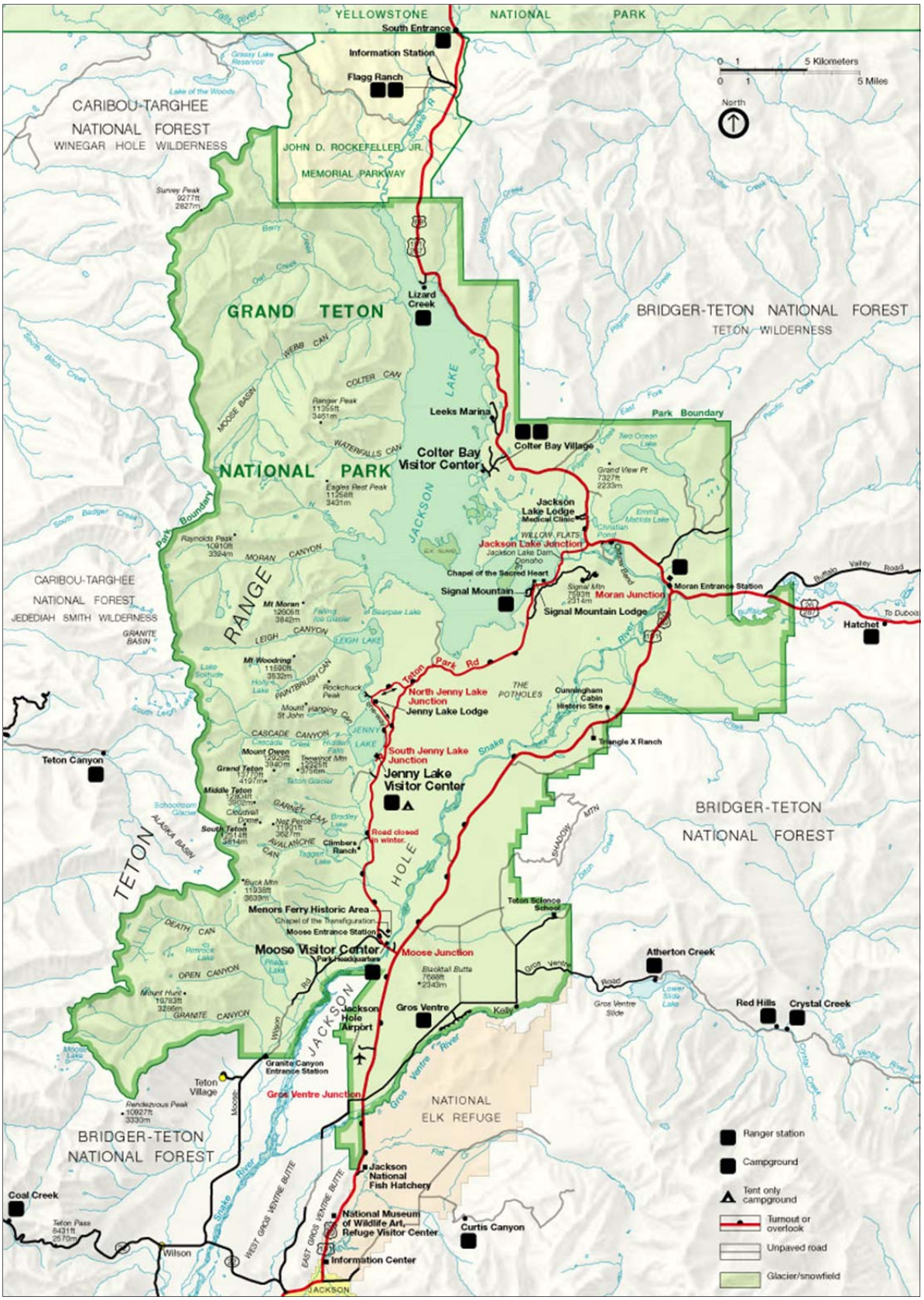
Grand Teton National Park (GRTE) is renowned for the rugged peaks of the Teton Range, the youngest range of the Rocky Mountain system (GRTE Figure 1). GRTE also includes large Jackson Lake and many smaller lakes, small glaciers and a variety of glacial features, and much of Jackson Hole. The park was established February 26, 1929. GRTE's boundaries have changed once, on September 14, 1950, when most of the former Jackson Hole National Monument was added to it. GRTE presently encompasses 125,470.50 ha (310,044.36 acres); all but 930.63 ha (2,299.63 acres) are federal (GRTE Figure 2).

The former National Park Service unit Jackson Hole National Monument existed between March 15, 1943 to September 14, 1950. It encompassed essentially all of what is now GRTE east of the western shore of Lake Jackson, as well as most of its northwestern section. A small part of eastern Jackson Hole National Monument along Highway 287 is now part of Bridger-Teton National Forest. The southernmost part of the former monument, south of the Gros Ventre River and along Highway 191, is now part of the National Elk Refuge.

John D. Rockefeller, Jr. Memorial Parkway (JODR) encompasses the corridor between GRTE and Yellowstone National Park (YELL). It commemorates Rockefeller's role as a conservationist who helped establish and enlarge various National Park Service (NPS) units, including Jackson Hole National Monument and ultimately GRTE. It was established August 25, 1972. JODR encompasses 9,622.30 ha (23,777.22 acres), all of which is federal land (GRTE Figure 2). JODR is administered by GRTE and therefore is included here.



GRTE Figure 1. The Teton Range is geologically very young, and thus steep and rugged. Below them, the Snake River passes through Jackson Hole (Photo credit: NPS).



GRTE Figure 2. Geography of GRTE and JODR (NPS).

Executive Summary

GRTE and JODR have diverse and scientifically important paleontological resources with a history of study possibly extending back to the 1870s. Fossils are much better known from GRTE, which encompasses a larger area and has many more geologic formations than JODR. The geology of GRTE includes unfossiliferous Precambrian rocks that make up the core of the Teton Range, Cambrian and Ordovician rocks, and a relatively complete rock record from the Late Devonian to the present (see the appendix for a geologic time scale). The latter section covers a time span representing roughly 380 million years. Most of the geologic formations are fossiliferous within the park.

JODR has a more restricted geologic record, featuring bedrock ranging in age from the Middle Jurassic to the Eocene. JODR's fossil record is poorly known, and information is limited to reports (mostly with equivocal locality information) made during the course of U.S. Geological Survey work on the Yellowstone National Park (YELL) area in the late 19th century. Bedrock mapping of GRTE and JODR shows that fossiliferous or potentially fossiliferous rocks and deposits are primarily present east of the Teton Fault and at the northern and southern ends of the Teton Range (Love et al. 1992), although soil and vegetation cover some potentially fossiliferous outcrops and other exposures are inaccessible because of topography. Several potentially fossiliferous formations expected to be present at or near the surface in the parks have been difficult to identify from outcrops, and further assessment should be a priority. Most of the Paleozoic and Precambrian rocks are west of the fault, and most of the Mesozoic and Cenozoic rocks are east of the fault.

Broadly speaking, Cambrian to Jurassic rocks in GRTE and JODR have yielded fossils of shallow marine invertebrates; Cretaceous rocks have yielded paleobotanical and marine invertebrate fossils; mammals are well-known from Miocene rocks; and microfossils useful for studies of paleoclimates are known from Quaternary deposits. The oldest fossiliferous rocks have an assemblage of stromatolites (laminar microbial sedimentary structures) and other microbial structures, brachiopods (lamp shells), and trilobites. Middle- and late-Paleozoic fossils include sponges, corals, bryozoans (moss animals), brachiopods, bivalves, cephalopods, gastropods, crinoids (sea lilies), and fragments of fish. Bryozoans, brachiopods, mollusks, crinoids, and echinoids have been found in Jurassic marine rocks. Cretaceous rocks include marine formations with mollusks and coastal terrestrial formations with foliage and fragments of ferns, horsetails, conifers, and angiosperms. Volcanic debris and lake sediments from the Miocene preserved microfossils, freshwater and terrestrial mollusks, and bones of predominantly small mammals such as insectivores, rodents, and lagomorphs. Freshwater and terrestrial mollusks are also represented in the Quaternary deposits, but the best-known Quaternary fossils are plant spores and pollen from Hedrick Pond.

GRTE maintains a small collection of fossils (~65 specimens), and at least four outside institutions also have fossils from GRTE and JODR, with the largest collection at the National Museum of Natural History (USNM) in Washington, D.C. The holotype or name-bearing specimens of sixteen fossil taxa came from GRTE or JODR, the majority being either Cambrian stromatolites or small Miocene mammals. There are also cases of

faunal remains found from archeological sites dating to the past 2,000 years, which illustrate the potential for older examples.

Although there are many reports of fossils from GRTE and JODR, research has been episodic, with topics of study scattered throughout the entire stratigraphic column of the parks, and there has only been one attempt at a full field inventory (Tracy 2003). Thus, there is great potential for further discoveries. Further investigations of the paleo-climatological implications of Quaternary fossils, and discoveries of additional Quaternary fossils, are likely to be useful for park management of natural resources. Several of the formations not seen by Tracy (2003), such as the Morrison, Cloverly, and Mesaverde formations, are elsewhere noted for Mesozoic terrestrial vertebrates such as dinosaurs, and if these units are explored they could add an important new dimension to the GRTE/JODR fossil record. In practical terms, many of the formations, especially the Paleozoic formations, are abundantly fossiliferous within and near the parks, but the extent of paleontological resources is only known in broad strokes, showing the need for more detailed field inventories.

Paleontological Resource Management, Preliminary Recommendations

- Park staff should be encouraged to observe exposed sedimentary rocks and associated eroded deposits for fossil material while conducting their usual duties. To promote this, they should also 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, recreation area staff should take advantage of them, if funding and time permit.

- Staff should photodocument 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 by artificially accelerated natural processes or direct human impacts. A Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. 2009).

- Field surveys and finer-scale geologic mapping are needed at GRTE and JODR before effective monitoring can be established.

- Tracy (2003) was unable to find outcrops of some formations (the Amsden Formation, Tensleep Sandstone, Gypsum Spring Formation, Cloverly Formation, Thermopolis Formation, Cody Shale, Bacon Ridge Sandstone, Sohare Formation, and Meeteetse Formation) and did not visit others (the Gallatin Limestone, Dinwoody Formation, Chugwater Formation, Morrison Formation, Mesaverde Formation, Pinyon Conglomerate, and Huckleberry Ridge Tuff). Future surveying efforts should endeavor to investigate outcrops and suspected areas of outcrops of these formations. Tracy (2003) recommended further investigation of the Gros Ventre Formation, Chugwater Formation, Mesaverde Formation, Sohare Formation, and Bacon Ridge Sandstone.

- Unauthorized collection and vandalism are known risks to paleontological resources at GRTE and JODR (Tracy 2003). Formations and fossiliferous float (eroded rock fragments) found along popular trails and sightseeing locations are at the most risk of fossil theft and vandalism. Tracy (2003) reported vandalism to fossils in the Darby Formation and Madison Limestone along Granite Canyon Trail. Fossiliferous float is easily accessible at Blacktail Butte and along the shore of Jackson Lake, and unauthorized collecting may occur on Fossil Mountain, because the locality spans NPS and non-NPS lands (Tracy 2003).

- Fossils found in a cultural context should be documented like other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to the Archeological Resources Protection Act [ARPA] or the Native American Graves Protection and Repatriation Act [NAGPRA]) and should be regarded as such until otherwise established. The Geologic Resources Division can coordinate additional documentation/ research of such material.

- The fossils from GRTE and JODR at the National Museum of Natural History (USNM) should be inventoried.
- Fossil packrat middens are typically found in dry caves and rockshelters, and resemble piles or mounds of plant material with a dark glossy coating of crystallized packrat urine. Fossil middens can provide important paleoecological information. If one is located, there are several midden researchers who may be contacted. The Geologic Resources Division maintains a list of active researchers and can facilitate communication between GRTE and these researchers.
- Contact the NPS Geologic Resources Division for technical assistance with paleontological resource management issues.

Geologic Background

GRTE and JODR occupy a large portion of western Teton County, Wyoming. Mountains dominate the immediate landscape. Aside from the Teton Range, the eastern half of which is found in GRTE, there is the Wind River Range to the east, the Gros Ventre Range to the southeast, the Wyoming Range to the south, and the Snake River Range to the southwest and west. The Snake River flows north to south through the two parks, and the Gros Ventre River flows along the southeastern border of GRTE on its way to joining the Snake River a short distance to the southwest. Northeastern GRTE features Jackson Lake, enlarged by the Jackson Lake Dam. The lake essentially ends at the GRTE-JODR border. A network of streams, lakes, and canyons can be found around Jackson Lake and the Snake River, and the western border of GRTE follows the divide of the Snake River drainage system. Other large lakes include Two Ocean Lake and Emma Matilda Lake, east of Jackson Lake, and Leigh Lake and Jenny Lake, to the south. The Jackson Hole basin, including the lakes, is found in the eastern half of GRTE and continues south. The community of Jackson is just south of the southeastern tip of GRTE. Various federal lands also surround GRTE and JODR. Yellowstone National Park (YELL) borders JODR to the north, Bridger-Teton National Forest borders the two parks to the east, the National Elk Refuge borders the southeastern segment of GRTE, another section of Bridger-Teton National Forest borders GRTE to the south, and Caribou-Targhee National Forest borders the two parks on the west.

The geology of GRTE and JODR and the immediate vicinity has been described in a number of publications. Most of these publications are focused on non-paleontological aspects of the local geology, such as glacial history, the astonishing uplift of the Teton Range over the past few million years, and the ancient Precambrian core of the range. Relevant publications concerning one of these aspects, or the more general geology of the Teton Range and Jackson Hole, include Fryxell (1944), Love et al. (1948, 1965, 1978), Edmund (1951), Love (1953, 1956a, 1956b, 1956c, 1973a, 1977a, 1987, 1989a), Horberg et al. (1955), Wanless et al. (1955), Andrichuk (1956), Sheldon (1956), McKelvey et al. (1959), Reeves (1964), Behrendt et al. (1968), Lindsey (1972), Reed and Zartman (1973), Cox (1974), Hill et al. (1976), Christiansen and Love (1978), Medville et al. (1979), Wright (1980), Jones (1982), Harrington (1985), Barnosky and LaBar (1989), Pierce and Good (1990, 1992), Tuttle (1990), Roberts and Burbank (1993), Smith and Siegel (1993), Smith et al. (1993a, 1993b), Good and Pierce (1996), NPS (1996), Zartman and Reed (1998), Lageson et al. (1999), Hiatt and Budd (2001), Covington and Ransmeier (2005), Frost et al. (2006, 2009), Leopold et al. (2007), Licciardi and Pierce (2008), Leier and Steidtmann (2009), KellerLynn (2010), and Pierce et al. (2011).

Publications discussing GRTE and JODR fossils include Iddings and Weed (1899), Girty (1899), Stanton (1899), Walcott (1901, 1902, 1912), Sokolov (1914), Clark and Twitchell (1915), Miller (1928, 1936a), Fenton and Fenton (1939), Bell (1941), Fenton (1943), Henbest (1956), Love (1956a, 1987, 1989b), Cobban et al. (1958), Hibbard (1957, 1959, 1970), Ciriacks (1963), Sheldon (1963), Black (1968), Love and Reed (1968), Yochelson and van Sickle (1968), Sutton and Black (1972), Gordon (1975), Gordon and Pojeta (1975), Gordon and Yochelson (1975), Mamet (1975), Sando et al. (1975), Love and Love (1980), Barnosky (1984a, 1986), Steventon and

Kutzbach (1988), Paull et al. (1989), Love et al. (1990), Cannon (1991), Whitlock (1992, 1993), Saltzman (1999), Santucci and Wall (1999), Koch and Santucci (2003), Tracy (2003), and Jacobs and Whitlock (2006, 2008). Maps illustrating at least part of GRTE or JODR include Schroeder (1972), Reed and Love (1971), Love (1973b, 1975), Love and Reed (1973, 1975), Richmond (1973a, 1973b), Christiansen et al. (1978), Love et al. (1992), and NPS (2010). Relevant theses and dissertations include Tracy (2003). The NPS Geologic Resources Division coordinated a Geologic Resource Inventory workshop for GRTE in June 2005 (Covington and Ransmeier 2005) and produced a geologic resource evaluation report for the park in 2010 (KellerLynn 2010). The initial paleontological resource inventory and summary was prepared by Koch and Santucci (2003).

The geologic history of GRTE and JODR includes very ancient rocks and a fairly complete record from the Cambrian to the present, with only the Silurian and Oligocene completely unrepresented (see the appendix for a geologic time scale). The oldest rocks are a variety of intrusive igneous and high-grade metamorphic rocks that make up the core of the Teton Range. GRTE, JODR, and YELL are found near the western edge of the Wyoming Province, one of the ancient components of the core of the North American continent (Frost et al. 2006). These rocks show evidence for modern-style plate tectonics, with a Himalayan-like orogeny (mountain-building event) between approximately 2.685 and 2.671 Ga (billion years ago) (Frost et al. 2009). The most recent interpretation, albeit still largely published in abstracts, proposes that two terranes (distinct continental blocks) are present north of Mount Moran, and a third is present to the south. The two northern terranes collided during the 2.685-2.671 Ga event, and the third arrived sometime between 2.625 and 2.615 Ga, during a period when other terranes were accreting along the "southern" margin of the Wyoming province (Frost et al. 2011). After this period of late Archean metamorphism and tectonic activity, there is a long hiatus in the rock record of the Teton Range and Jackson Hole, punctuated by occasional small magmatic events. Dikes intruded the basement rocks during the Proterozoic, including at approximately 1.45 Ga (Reed and Zartman 1973) and 775 Ma (million years ago) (Love and Love 1980).

Recognizable sedimentary rocks first appear during the Middle Cambrian, over 500 million years ago. During the Middle Cambrian, a marine transgression (advance) arrived in the area from the west (Shaw 1954, Bell and Middleton 1978). The Cambrian sea, also known as the Sauk Sea, had several transgression-regression (marine retreat) cycles, beginning during deposition of the Flathead Sandstone and continuing into the Gallatin Formation (Saltzman 1999). Sedimentary rocks were deposited in a variety of settings, at first above or below sea level along a coast (Bell and Middleton 1978, Beebe and Cox 1998), then becoming deeper marine (Beebe and Cox 1998), and then returning to coastal deposition (Martin et al. 1980, Clark et al. 2000). Deposition was occasionally interrupted, leaving disconformities within the Cambrian section (Miller 1936a, Beebe and Cox 1998).

A depositional hiatus followed the Cambrian deposition until the Late Ordovician, represented by the Bighorn Dolomite. This unit was deposited under a shallow sea, when the modern Greater Yellowstone Network (GRYN) area was near the equator (Holland and Patzowsky 2012). This was a time of transition from "greenhouse" to "icehouse" conditions,

which is reflected by changes in the Bighorn Dolomite's cyclicity and the turnover of faunal assemblages (Holland and Patzowsky 2009, 2012). Another substantial hiatus followed, lasting until the Late Devonian. Devonian rocks are represented by the marine Darby Formation, deposited during a transgression (Andrichuk 1956) in a restricted basin (Wanless et al. 1955). The Darby Formation is the first in a series of formations that present a mostly complete stratigraphic column into the early Cenozoic. From the Late Devonian to the Jurassic, the general configuration featured a shallow sea which transgressed and regressed several times, arriving from what is now the west but would then have been more northwest. Episodic uplift occurred in the region from the late Paleozoic (Simmons and Scholle 1990) into the Triassic (Picard 1967).

The Madison Limestone of the Mississippian is a marine unit deposited during a period of overall marine transgression (Gutschick et al. 1976). When the sea retreated and deposition ceased, the limestones of the Madison Limestone were exposed to the open air, forming a karst surface. An early generation of voids and caves formed. After the hiatus that led to the early erosion of the Madison Limestone, the shallow sea returned from the west, resulting in the primarily marine Amsden Formation (Sando 1988). Sea level fluctuated during deposition (Gorman 1963). The succeeding Tensleep Sandstone is a coastal sand dune and shallow marine formation (Mankiewicz and Steidtmann 1979, Kerr and Dott 1988, Lopez et al. 2007). The setting has been compared to the southeastern part of the Qatar Peninsula in the Persian Gulf (Mankiewicz and Steidtmann 1979). A dune system was moving south out of north-central Wyoming during deposition. At this time, the modern GRYN area was situated near 10° N (Kerr and Dott 1988).

By the Permian, the GRYN area had moved to about 20° N (Hiatt and Budd 2001). Another shallow warm sea inundated the land surface (Hiatt and Budd 2001), arriving from the west (Sheldon 1956). Two transgression-regression cycles moving from west to east produced a variety of lithologies now represented in the complex Phosphoria stratigraphic interval (Sheldon 1956). At this time, the sea was bounded on the north by some ancient topographic highs, on the south by the Ancestral Rockies, on the east by evaporitic basins, and on the west by an island arc system (Hiatt and Budd 2001). Three more transgression-regression cycles occurred during the Triassic, with the sea spreading from west to east. The Dinwoody Formation, the oldest Triassic unit of GRTE, was deposited during the first transgression (Paull and Paull 1993). Further marine fluctuations are represented in the overlying Chugwater Formation (Cavaroc and Flores 1991). Deposition occurred under a warm arid climate (Maughan 1964, 1967, Picard 1966), with some volcanism (High and Picard 1965). After the Triassic sea retreated, an extensive dune field spread over the area, as seen in the Nugget Sandstone (Poole and Stewart 1964a, 1964b). Marine deposition returned during the Middle and early-Late Jurassic, as represented by the Gypsum Spring and Sundance formations. Several marine transgression-regression cycles occurred during this time (Schmude 2000, Kvale et al. 2001). During the Middle and Late Jurassic, a marine body known as the Sundance Sea encroached on the GRYN area from the northwest, a volcanic archipelago was present on the west, the Ancestral Rockies were present on the south, and upland continental areas existed to the east (Harris and Lacovara 2004).

After the Sundance Sea retreated for the last time, terrestrial deposition in the form of the Morrison Formation began. By the time of Morrison deposition, the region had moved out of the low subtropical latitudes (Picard 1993) and humidity increased (Lockley and Wright 2003), supporting a great diversity of life. The Morrison Formation is interpreted as a semi-arid seasonal savanna-like setting (Engelmann et al. 2004, Hasiotis 2004, Turner and Peterson 2004). The overlying Cloverly Formation of the Early Cretaceous is similar, and it can be difficult to differentiate the Morrison Formation from the younger rocks. The Cloverly Formation is a primarily fluvial and lacustrine sedimentary sequence with a substantial amount of sediment derived from volcanoes (volcaniclastics) (Moberly 1960). Deposition occurred under a warm, seasonal climate, becoming more humid over time (Forster 1984). To the west, a mountain-building episode known as the Sevier Orogeny was active (DeCelles 1986). The upper part of the interval shows an increasing marine influence as a shallow continental sea known as the Western Interior Seaway or Cretaceous Interior Seaway began to encroach upon the area (Forster 1984, DeCelles 1986), from the north (Nydam and Cifelli 2002). The uppermost rocks of this complex interval are interpreted as shallow marine (Moberly 1960).

The next sequence of Cretaceous rocks exposed at GRTE, ranging in age from the late Early Cretaceous to the late Late Cretaceous, was deposited in the Western Interior Seaway system. The Seaway eventually extended from the Arctic to the Gulf of Mexico, bisecting North America (Elder and Kirkland 1993, 1994). Its waxings and wanings influenced the geology of numerous NPS units. Deep marine shales alternated with shallower marine sandstones as the sea transgressed and regressed (Eicher 1960, Condon 2000, Johnson 2010). Numerous bentonite beds in the section indicate that volcanoes to the west contributed significant amounts of ash to the sediment (Reeside and Cobban 1960). The last major marine formation of the Jackson Hole area is the Bacon Ridge Sandstone (Love 1956c), although a marine tongue advanced as far as the Two Ocean Lake area during deposition of the Harebell Formation, several million years later (Kauffman 1973). Otherwise, coastal plain deposition dominated the rest of the Cretaceous (Lindsey 1972, Kauffman 1973, Johnson 2008). Near the end of the Cretaceous, deposition occurred within a large fluvial system bringing sediment from young uplifts and nearby volcanoes (Love 1973a), under a warm humid climate in the vicinity of the receding sea (Lindsey 1972).

Throughout much of western North America, the final withdrawal of the Western Interior Seaway occurred concurrently with the beginning of a major mountain-building event known as the Laramide Orogeny (Cather 2003). This event took place from the Late Cretaceous to the Eocene and was responsible for much of the present form of the Rocky Mountains (Aubrey 1991). Some early Laramide activity was occurring during deposition of the Meeteetse Formation (Johnson 2008), around 70 Ma. The dramatic changes brought about by the orogeny can be seen in the contact of the Harebell Formation and Pinyon Conglomerate: although the two were not separated by more than a few million years, the Harebell–Pinyon contact is an angular unconformity that is perpendicular in some locations (Love 1973a). It appears that the nearby Washakie Range was uplifted, thrust to the west, and eroded down to its Paleozoic core during the relatively brief hiatus between the two formations (Love 1990).

Although the Teton Range is a recent feature, there were previous uplifts, including a low broad uplift where the Teton and Gros Ventre ranges later formed, and the larger Targhee uplift, which existed from the Late Cretaceous to the Middle Eocene (Love et al. 1978), when it subsided around 48 Ma (Love 1989a). The first major volcanic activity of the area, included in the well-known Absaroka volcanic field, began during the Eocene. Rocks associated with these early eruptions are preserved in the Hominy Peak Formation (Love et al. 1978). The next 25 to 30 million years are not directly represented within GRTE or JODR, but small outcrops of various formations deposited during this hiatus are found in the vicinity (Love 1953, 1956a, 1989a, 1989b, Sutton and Black 1975, McKenna 1980, Barnosky 1984a, Love et al. 1992, NPS 2010). Erosion occurred during the Early Miocene, followed by extension and subsidence to about 14.8 Ma. Uplift occurred until about the end of the Miocene in northern YELL to the north, leading to tilting, erosion, and faster subsidence (Barnosky and LaBar 1989).

Deposition resumed within GRTE and JODR in the Miocene, represented by the Colter and Teewinot formations. The Colter Formation is another volcanic formation (Barnosky 1984a), with a source near the north end of Jackson Lake (Love 1989a). The overlying Teewinot Formation represents deposition in a large lake, known as Teewinot Lake (Love 1989a). The mammals of the Colter Formation indicate a semi-arid to arid climate (Barnosky and LaBar 1989), while pollen in the Teewinot Formation suggests that summers, at least, had become moist by that time (Leopold et al. 2007). Lakes were sporadically present after Teewinot Lake, as shown by the nearby Shooting Iron Formation in southern Jackson Hole (Barnosky 1985, Love 1989b). Pollen in this Lower Pleistocene unit indicates a drying climate (Leopold et al. 2007).

Volcanism has long been part of the geologic history of northwestern Wyoming. The most recent episode is due to the activity of the Yellowstone Hotspot, responsible for some of the largest known volcanic events on Earth. The hotspot is first recognized as the source of the voluminous Columbia River Plateau flood basalts of approximately 16 Ma. Volcanic activity from this mantle plume has moved east-northeast as the North American continent has moved west-southwest; Craters of the Moon National Monument in central Idaho represents another eruptive phase. After the Columbia River eruptions, activity has been focused into smaller, caldera-producing eruptions. The hotspot entered the immediate vicinity of northwestern Wyoming between 7 and 4 Ma, creating the Heise volcanic field just to the west. Major eruptions from this field include those that produced the Blacktail Creek Tuff (6.62±0.4 Ma), the Walcott Tuff (6.27±0.04 Ma), the Conant Creek Tuff, which is found in GRTE and JODR (5.51±0.13 Ma), and the Kilgore Tuff (4.45±0.05 Ma). By about 2 Ma, the hotspot was beneath the Yellowstone Plateau. From here, it has produced three major calderas: the Huckleberry Ridge Caldera (Huckleberry Ridge Tuff) at about 2.05 Ma; the Henry's Fork Caldera (Mesa Falls Tuff) at about 1.3 Ma; and the Yellowstone Caldera (Lava Creek Tuff) at about 0.64 Ma (Morgan et al. 2008). A smaller and more local volcanic source, the Jackson Hole volcanic field, was active about 8 Ma (Lageson et al. 1999).

The Laramide Orogeny was not the end of major tectonic activity in northwestern Wyoming. The Yellowstone portion of the Washakies rose during the Oligocene. The modern Gros Ventre–Teton system began

stirring during the Pliocene, with the Gros Ventre Range rising first (Love 1969). The Teton Range is the result of extensional tectonics that caused some 6 to 9 km (3.7 to 5.6 miles) of vertical offset (Smith et al. 1993a) through a combination of uplift and subsidence, raising the range and dropping Jackson Hole (Roberts and Burbank 1993). The feature responsible for this is the Teton Fault. The movement on the Teton Fault began around 3±1 Ma (Anders et al. 2009), and major uplift postdates the nearby Shooting Iron Formation (2.4 to 1.9 or 1.7 Ma) (Leopold et al. 2007). The appearance of the fault and movement on it may be related to the Yellowstone Hotspot, or to the Basin and Range extension that created the modern topography of the Great Basin (Smith et al. 1993a). The Teton Fault is still active; two earthquakes producing over 3 m (10 ft) of offset have occurred in the past 8,000 years (Smith et al. 1993a).

Glaciation in the GRTE-JODR area has a long history, beginning perhaps in the Pliocene with what is known as the “ghost glaciation” (Love [1989a]; note that the Pliocene–Pleistocene boundary was moved back to 2.588 Ma in 2009, so many “Pliocene” events in older references are now considered Pleistocene in age). In nearby YELL, glacial events possibly occurred between 5.89 and 2.01 Ma, and definitely occurred after 2.01 Ma (Richmond 1986). More than ten events may have occurred in the area (Smith et al. 1993b). One of the glaciations now obscured by more recent glacial deposits led to the deposition of the Leidy Formation sometime after 0.75 Ma (Love et al. 1992); this unit represents an ice-dammed lake (Love 1994). Several of the glacial events escaped the mountains and reached Jackson Hole. Traditionally, the glaciations of the basin are known from oldest to youngest as the Buffalo, Bull Lake, and Pinedale glaciations (Tuttle 1990), but this may be too simplistic. Deposits of three distinct glacial phases are mapped in GRTE, as well as a more general unit for older glaciations (Love et al. 1992). The Bull Lake and Pinedale events are well-supported. The Bull Lake glaciation reached its maximum and retreated between about 140,000 and 130,000 years ago (Licciardi and Pierce 2008, Pierce et al. 2011). It is thought to have scoured the basins now occupied by Emma Matilda Lake and Two Ocean Lake (Tuttle 1990). Deposits from this glaciation are known as Munger deposits (Pierce and Good 1992). The Pinedale glaciation, as the most recent extensive glaciation, is by far the best known. It took place between about 35,000 and 16,000 to 14,000 years ago (Hampel et al. 2007), reaching its maximum between roughly 19,000 and 16,000 years ago (Licciardi and Pierce 2008, Pierce et al. 2011). The age of the maximum varied by location, and is slightly younger in the GRTE-YELL area than the Wind River Mountains, for example (Licciardi and Pierce 2008). The Pinedale glaciation includes three phases. The deposits from these phases, from oldest to youngest, are the Burned Ridge, Hedrick Pond, and Jackson Lake deposits (Pierce and Good 1992). Ice, up to a kilometer (0.62 miles) thick, covered some 16,500 km^2 (6,300 mi^2) of the area, capping Yellowstone and the Teton Range (Hampel et al. 2007). Jackson Lake was scoured by the Pinedale glaciation in two sections. The eastern trough was scoured by a west-flowing lobe of ice between 75,000 and 25,000 years ago, and the western trough was excavated by a south-flowing lobe between 40,000 and 15,000 years ago (Smith et al. 1993b). Following glaciation, there has been tectonic rebound, mostly before 8,000 years ago (Hampel et al. 2007).

Following the Bull Lake glaciation, the area attained its warmest recent climate around

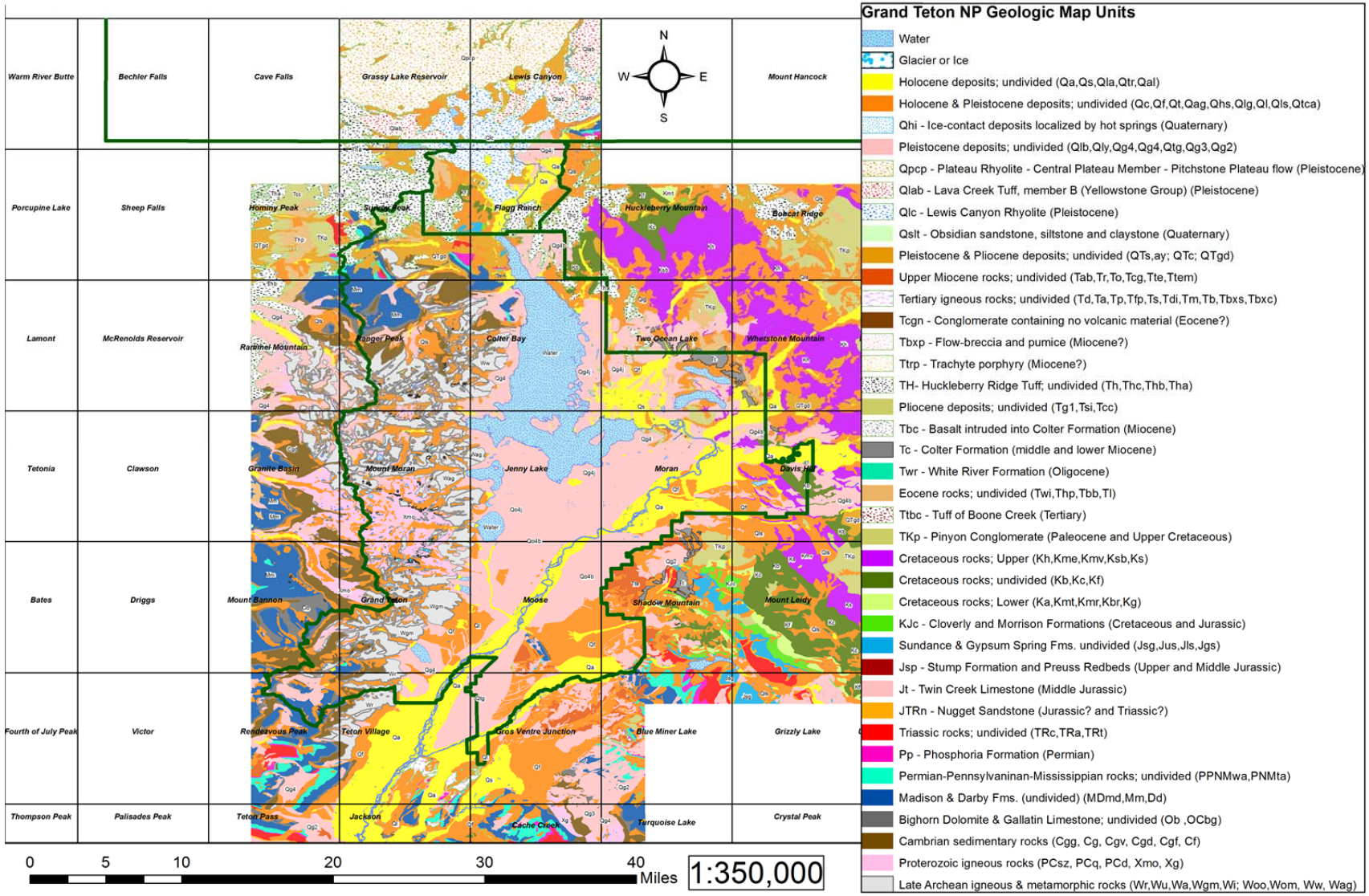
82,000 years ago. Tundra conditions existed between 70,000 and 50,000 years ago, followed by the Pinedale glaciation. Deglaciation occurred around 14,000 years ago (Baker 1986). Meadow communities grew before 11,500 years ago. As the climate grew warmer, spruce parkland entered the area, followed by subalpine conifers. The climate turned significantly drier and warmer, conditions which lasted until about 5,000 years ago. The climate then became cooler and wetter, leading to the spread of closed forests (Whitlock 1992). Humans arrived in the Jackson Hole area between 14,000 and 10,000 years ago (Pierce et al. 2003); however, it appears that they did not live there persistently until several thousand years later. Jackson Hole did not support large populations of buffalo, so human occupation instead was based around gathering at various elevations as different food supplies became available. The inhabitants left the area several hundred years ago and were replaced by the Shoshone people (Wright 1980).

Rock units exposed within GRTE include, in ascending order (oldest to youngest): several igneous and high-grade metamorphic units dated to the Archean, including the Webb Canyon Gneiss, Rendezvous metagabbro, Mount Owens Quartz Monzonite, and unnamed gneisses; Proterozoic dikes; the Flathead Sandstone (Middle Cambrian); the Gros Ventre Formation (Middle–Upper Cambrian); the Gallatin Limestone (Upper Cambrian); the Bighorn Dolomite (Upper Ordovician); the Darby Formation (Upper Devonian); the Madison Limestone or Group (Lower–Middle Mississippian); the Amsden Formation (Upper Mississippian–Middle? Pennsylvanian); the Tensleep Sandstone (Middle–Upper Pennsylvanian); a complex Lower–Middle Permian interval dominated by the Phosphoria Formation; the Dinwoody Formation (Lower Triassic); the Chugwater Formation (Triassic); the Nugget Sandstone (Upper Triassic–Lower Jurassic); the Gypsum Spring Formation (Middle Jurassic); the Sundance Formation (Middle–Upper Jurassic); undivided Upper Jurassic and Lower Cretaceous rocks identified as the Morrison Formation (Upper Jurassic; these rocks in the GRTE area are often identified as the Morrison? Formation, to show some uncertainty about the identification, but to avoid confusion the question mark will be left out in this document) and Cloverly Formation (Lower Cretaceous); the Thermopolis Shale, Mowry Shale, Frontier Formation, Cody Shale, Bacon Ridge Sandstone, Sohare Formation, Mesaverde Formation, Meeteetse Formation, and Harebell Formation (Upper Cretaceous); the Pinyon Conglomerate (Upper Cretaceous–Paleocene); the Hominy Peak Formation (Lower–Middle Eocene); the Colter Formation (Lower–Middle Miocene); the Teewinot Formation (Middle?–Upper Miocene); an unnamed conglomerate and Conant Creek Tuff (Upper Miocene); glacial sediments (Pliocene?–Holocene); the Huckleberry Ridge Tuff (Lower Pleistocene); the Leidy Formation (Pleistocene); and other Quaternary rocks and sediments (Pleistocene–Holocene) (see GRTE Figure 3 for a geological map) (Love et al. 1992, KellerLynn 2010, NPS 2010). It should be noted that small outcrops of several Cenozoic formations are found in the immediate vicinity of GRTE, such as the Devils Basin Formation (Upper Paleocene), Langford Formation, Wiggins Formation (Eocene), White River Formation (Eocene–Oligocene), Camp Davis Formation (Upper Miocene–Lower Pliocene) and Shooting Iron Formation (Pleistocene) (Love 1953, 1956a, 1989a, 1989b, Sutton and Black 1975, McKenna 1980, Barnosky 1984a, Love et al. 1992, NPS 2010; note that the formation names assigned to these outcrops has been subject to

revision over the years), and it is possible that small outliers of any of them could eventually be found within the park.

Rock units exposed within JODR include, in ascending order: the Gypsum Spring Formation (Middle Jurassic); the Sundance Formation (Middle–Upper Jurassic); undivided Upper Jurassic and Lower Cretaceous rocks identified as the Morrison Formation (Upper Jurassic) and Cloverly Formation (Lower Cretaceous); the Thermopolis Shale, Mowry Shale, Frontier Formation, Cody Shale, and Bacon Ridge Sandstone (Upper Cretaceous); the Pinyon Conglomerate (Upper Cretaceous–Paleocene); the Hominy Peak Formation (Lower–Middle Eocene); glacial sediments (Pliocene?–Pleistocene); the Huckleberry Ridge Tuff (Lower Pleistocene); the Lewis Canyon Rhyolite and Lava Creek Tuff (Middle Pleistocene); and other Quaternary rocks and sediments (Pleistocene–Holocene) (GRTE Figure 3) (Christiansen et al. 1978, Love et al. 1992, KellerLynn 2010, NPS 2010).

Many of these formations are fossiliferous within GRTE and JODR, and the rest of them, with the exception of the Precambrian metamorphic and igneous rocks, are potentially fossiliferous. The fossil record of the two parks is quite diverse, from Paleozoic and Jurassic marine invertebrates to Cretaceous plant fossils to Cenozoic mammals to a variety of Quaternary paleoecological fossils (GRTE Table 1).



GRTE Figure 3. Schematic geological map of GRTE and JODR. Map graphic adapted from digital geologic map data available at the following URL: https://irma.nps.gov/App/Reference/Profile?Code=2165235.

GRTE Table 1. Concise tabulation of GRTE and JODR stratigraphy, fossils, and depositional setting; details and references can be found in the text. High-grade metamorphic rocks are included here for completeness, but are not discussed in detail in the text because they are unfossiliferous.

Formation (*=also in JODR; #=only in JODR)	Age	Fossils (GRTE except where noted as JODR)	Depositional Environment
*Nonglacial Quaternary sediments	Pleistocene-Holocene	Late Pleistocene wood, Late Pleistocene–Holocene spores and pollen from spikemosses, ferns, conifers, and angiosperms, and Holocene mollusks including gastropods	Fluvial, alluvial, lacustrine, swamp, fan, landslide, and other terrestrial settings
#Lava Creek Tuff	Middle Pleistocene	None to date; plant debris and pollen are most likely	Volcanic ash
Leidy Formation	Middle Pleistocene	None to date; plant debris and pollen are most likely	Ice-dammed lake and fluvial
#Lewis Canyon Rhyolite	Middle Pleistocene	None to date; plant debris and pollen are most likely	Volcanic flows
*Huckleberry Ridge Tuff	Early Pleistocene	None to date; fossils are unlikely but not impossible	Volcanic ash
*Glacial sediments	Pliocene?–Holocene	None to date; glacial deposits tend to be sparsely fossiliferous except for resistant material and reworked material	Glacial till
Conant Creek Tuff	Late Miocene	None to date; fossils are unlikely but not impossible	Volcanic ash
Conglomerate	Late Miocene	None to date; reworked Paleozoic and Mesozoic fossils are most likely	Uncertain terrestrial
Teewinot Formation	Middle?–Late Miocene	Diatoms, pollen, freshwater bivalves, freshwater and terrestrial gastropods, ostracodes, shrews, voles, beavers, and bird eggshell	Lacustrine
Colter Formation	Early–Middle Miocene	Root traces, invertebrate burrows, moles, rodents, rabbits, pikas, and camels	Volcanic flows, debris, and ash
*Hominy Peak Formation	Early–Middle Eocene	None to date; plant macrofossils and palynomorphs are most likely	Volcanic flows, debris, and ash
*Pinyon Conglomerate	Late Cretaceous–Paleocene	None to date; pollen and leaves have been found nearby	Fluvial
Harebell Formation	Late Cretaceous	Fragmentary plant fossils	Fluvial coastal plain to marginal marine
Meeteetse Formation	Late Cretaceous	Coal and fragments of horsetails, ferns, and angiosperms	Coastal plain
Mesaverde Formation	Late Cretaceous	None to date; charophytes, coal, plant fossils, and nonmarine mollusks have been found nearby	Marginal marine to predominantly terrestrial
Sohare Formation	Late Cretaceous	None to date; leaves, bivalves, and gastropods are most likely	Predominantly fluvial
*Bacon Ridge Sandstone	Late Cretaceous	Fossils have not been explicitly confirmed, but coal and marine mollusks are almost certainly present; probably the source of Stanton's (1899) "Montana Formation" bivalves and ammonites within JODR from "near the second crossing of the Snake River"	Marginal marine to coastal terrestrial
*Cody Shale	Late Cretaceous	Bivalves, ammonites, and gastropods (JODR)	Open marine

GRTE Table 1. Concise tabulation of GRTE and JODR stratigraphy, fossils, and depositional setting; details and references can be found in the text. High-grade metamorphic rocks are included here for completeness, but are not discussed in detail in the text because they are unfossiliferous (continued).

Formation (*=also in JODR; #=only in JODR)	Age	Fossils (GRTE except where noted as JODR)	Depositional Environment
*Frontier Formation	Late Cretaceous	Foliage of ferns, conifers, and angiosperms	Nearshore and more open marine
*Mowry Shale	Late Cretaceous	Plant fragments	Open marine
*Thermopolis Shale	Early Cretaceous	None to date; marine microfossils, mollusks, and fish remains are most likely	Marine, brackish coastal to open
*Cloverly Formation	Early Cretaceous	None to date; freshwater invertebrates and fragments of dinosaur bones are most likely	Fluvial, floodplain, and lacustrine settings; marine influence near top
*Morrison Formation	Late Jurassic	None to date; wood and dinosaur bone fragments are most likely	Fluvial, floodplain, and lacustrine settings
*Sundance Formation	Middle–Late Jurassic	Bryozoans, brachiopods, bivalves, belemnites, gastropods, crinoids, and echinoids; fossiliferous in both GRTE and JODR, but it is uncertain which fossil localities are in which parks	Primarily shallow marine, occasional tidal flat episodes
*Gypsum Spring Formation	Middle Jurassic	None to date; marine mollusks are most likely	Coastal terrestrial and restricted marine, lower and upper, and open marine middle
Nugget Sandstone	Late Triassic–Early Jurassic	None to date; vertebrate trace fossils are most likely	Large eolian sand dunes
Chugwater Formation	Triassic	None to date; invertebrate and vertebrate trace fossils are most likely	Coastal terrestrial to nearshore marine, changing multiple times
Dinwoody Formation	Early Triassic	Gastropods and conodonts	Shallow marine
Phosphoria Formation and associated rocks	Early–Middle Permian	Sponge spicules, bryozoans, brachiopods, bivalves, gastropods, unspecified mollusks, invertebrate trace fossils including burrows, cartilaginous fish, a possible acanthodian or palaeoniscid denticle, ray-finned fish, and indeterminate fish	Coastal terrestrial to nearshore marine, changing multiple times
Tensleep Sandstone	Middle–Late Pennsylvanian	Foraminifera	Marine and coastal dunes
Amsden Formation	Late Mississippian–Middle? Pennsylvanian	Foraminifera, brachiopods, bivalves, and gastropods	Beaches and offshore bars, followed by restricted marine, then offshore marine, with cyclic oscillation
Madison Limestone	Early–Middle Mississippian	Corals, bryozoans, brachiopods, nautiloids, trilobites, crinoids, unspecified echinoderms, and unspecified marine invertebrates	Shallow marine
Darby Formation	Late Devonian	Stromatolites, bryozoans, brachiopods, echinoderms, and unspecified fossils	Shallow marine
Bighorn Dolomite	Late Ordovician	Possible trace fossils	Shallow marine, open and restricted

GRTE Table 1. Concise tabulation of GRTE and JODR stratigraphy, fossils, and depositional setting; details and references can be found in the text. High-grade metamorphic rocks are included here for completeness, but are not discussed in detail in the text because they are unfossiliferous (continued).

Formation (*=also in JODR; #=only in JODR)	Age	Fossils (GRTE except where noted as JODR)	Depositional Environment
Gallatin Limestone	Late Cambrian	Stromatolites and other microbial structures, cyanobacterial colonies, "algae," brachiopods, trilobites, possible cystoid cups, and invertebrate burrows	Offshore marine
Gros Ventre Formation	Middle–Late Cambrian	Microbial structures, brachiopods, bivalves, trilobites, invertebrate trace fossils, and bioturbation	Offshore marine and tidal flats
Flathead Sandstone	Middle Cambrian	None to date; brachiopods, trilobites, and invertebrate trace fossils are most likely	Coastal sandstone
Precambrian "basement" rocks	Archean igneous and high-grade metamorphic rocks, Proterozoic dikes	Unfossiliferous	Not applicable

Sources of Paleontological Resource

The fossils of GRTE and JODR present opportunities for education, interpretation, and scientific research in the parks. The oldest report of fossils from the area may be Bradley (1872), a note submitted while the author was participating in the Hayden Expedition to the Teton Range. It noted the presence of trilobites of "Quebec Group" (Cambrian) age and horn corals and brachiopods of Carboniferous age (probably the Madison Limestone), in Teton Canyon west of GRTE. This was followed by White (1879), who mentioned additional Carboniferous-age fossils from the Tetons, including the foraminifera (amoeba-like protists that form "shells") *Endothyra ornata*.

Gros Ventre Formation (Middle–Upper Cambrian)

The Gros Ventre Formation is the oldest formation in the Teton Range with significant fossils. It is divisible into three members in GRTE and its immediate vicinity. In ascending order, they are the Wolsey Shale, Death Canyon Limestone, and Park Shale members. The Wolsey Shale Member is a soft green or gray shale unit that grades out of the underlying Flathead Sandstone (see below under "Potential Sources of Paleontological Resources"); unsurprisingly, there are coarser silty or sandstone beds near the base. It is 30 to 40 m (100 to 130 ft) thick. The Death Canyon Limestone Member is a cliff-forming unit primarily composed of blue- to dark-gray limestone. A basal brown dolomite layer is sometimes present, and there is a 10 m (30 ft)-thick interval of gray shale in the middle of the member with abundant trilobites. This member is 90 to 120 m (300 to 370 ft) thick. Finally, the Park Shale Member is composed of olive green shale and thin beds of distinctive "flat pebble" conglomerate. Microbial or "algal" structures are common in the lower part of the member. It is 45 to 105 m (150 to 350 ft) thick. The Wolsey Shale Member is usually mapped with the Flathead Sandstone, and the Park Shale Member is usually mapped with the overlying Gallatin Limestone, while the Death Canyon Limestone Member is mapped separately. Significant outcrops of the Gros Ventre Formation within GRTE are almost entirely limited to the northwestern and southwestern ends of the park (Love et al. 1992). The Death Canyon Limestone Member is an important karst-forming unit in the Teton Range (Medville et al. 1979), so caves may be found in it within GRTE.

The rocks of the Gros Ventre Formation were formerly included in the Flathead Sandstone. Early reports, such as Peale (1893), described a much thicker multi-unit "Flathead Quartzite", which included rocks now assigned to the Gros Ventre Formation. Specifically, Peale's "Flathead Shale" is now recognized as the Wolsey Shale Member, the "Trilobite Limestone" is equivalent to the Death Canyon/Meagher Limestone Member, and the "*Obolella* [a type of brachiopod (lamp shell)] Shale" is now the Park Shale Member (Miller 1936a). The Meagher Limestone Member name is sometimes used for the Death Canyon Limestone Member, but the latter is preferred in the Tetons (Wanless et al. 1955). The Gros Ventre Formation is an offshore mud and carbonate formation (Beebe and Cox 1998). The lower and upper shale units were deposited on tidal flats, and the Death Canyon Limestone Member was deposited farther offshore in clear water (Love and Reed 1968). The upper contact of the formation with the Gallatin Formation is sometimes disconformable (Miller 1936a). The Gros Ventre Formation is thought to span the Middle and Late Cambrian, with the boundary

within the Park Shale Member (Wanless et al. 1955).

A variety of fossils are known from all three members of the Gros Ventre Formation in and around GRTE. Fossils that can be definitely ascribed to the park includes brachiopods, bivalves, trilobites, and invertebrate burrows from an unspecified subdivision, brachiopods from the Wolsey Shale Member, and microbial structures, brachiopods, trilobites, and bioturbation (disruption of sedimentary features by biological activity) from the Death Canyon Limestone Member. In Walcott's (1912) monograph on Cambrian brachiopods, he reported specimens from four horizons at the divide at the head of Jackson or Sheep Creek within GRTE. Three of the sites should be in the Gros Ventre Formation, per Bell (1941), who reported that Walcott's 4n and 4o sites derive from the Meagher (=Death Canyon) Limestone Member; because 4 m is lower than these two sites, and the Flathead Sandstone is not known for its fossils, it should be in the Gros Ventre Formation as well. Locality 4 m is from a sandstone unit 45 m (150 ft) above the base of the Cambrian section, 4n is from a limestone 100 m (325 ft) up, and 4o is from 115 m (375 ft) up. All three horizons have yielded brachiopods (Walcott 1912). A site 3 km (2 miles) south of Buck Mountain on the divide between Death Canyon and the south fork of Teton Canyon, probably within GRTE, has examples of brachiopods in the Wolsey Shale Member and trilobites in the Death Canyon Limestone Member (Miller 1936a). Fenton and Fenton (1939) described the microbial structure *Aulophycus repens* from the "Death Canyon facies" of the head of Death Canyon within GRTE. Love and Reed (1968) included photographs of brachiopods and trilobites found within the park, as well as photographs of microbial structures from the North–South Leigh Creek divide just to the west. Abundant trilobites are present in the Death Canyon Limestone Member along the Granite Canyon Trail of GRTE, and bioturbation can be viewed along the Death Canyon Shelf Trail (Love et al. 1992; Tracy 2003). Finally, Tracy (2003) reported collecting bivalves (potentially misidentified; similar-looking brachiopods are more likely, given the age) and invertebrate burrows from the formation in the park.

Some other reports include some area of the park, but lack specific localities. Abundant trilobite fragments are found 35 m (120 ft) above the base of the formation in the Rendezvous Peak quadrangle, including southwestern GRTE (Schroeder 1972). Love and Reed (1975), mapping the Teton Village Quadrangle, which includes part of southern GRTE, reported that the middle shale of the Death Canyon Limestone Member has abundant trilobites, and observed a zone of microbial structures in the Park Shale Member.

Several other reports have been made from just outside of the park. Miller (1936b) named the trilobites *Bolaspis*? *resseri* and *Marjumia*? *tetonensis* from the Death Canyon Limestone Member on the south fork of Teton Creek Canyon. Wanless et al. (1955) reported brachiopods and trilobites in the Wolsey Shale Member at Granite Creek of the Gros Ventre Range, and in the middle shale of the Death Canyon Limestone Member in a ravine east of Mount Glory in the Teton Pass area. Love and Reed (1968) reported a variety of fossils from the Alaska Basin, just west of the park. They include brachiopods in the Wolsey Shale Member, brachiopods and trilobites in the middle shale of the Death Canyon Limestone Member, and microbial structures, brachiopods, and trilobites in the Park Shale Member.

Over the entire depositional area of the Gros Ventre Formation, the fossil assemblages found in the formation and its members are similar to what is known from the GRTE area. The fossil assemblage of the Wolsey Shale Member includes hyoliths, brachiopods, trilobites (Deiss 1936), fossil hash (Lebauer 1964), bioturbation (Morgan 1998), and invertebrate burrows and trails (Lebauer 1964). The fossil assemblage of the Death Canyon Limestone Member includes acritarchs (organic microfossils that cannot be classified as anything else) (Reaugh 1980), stromatolites (layered sedimentary structures created by algae and microbes) (DeBoer and Middleton 1983), microbial buildups (DeBoer and Middleton 1981), brachiopods (Walcott 1912, Bell 1941), trilobites, burrows (Miller 1936a), and bioturbation (Love et al. 1992, Tracy 2003). The fossil assemblage of the Park Shale Member includes microbial mats, laminations, and filaments (Blackwell et al. 1983), microbial buildups (DeBoer and Middleton 1981), brachiopods (Bell 1941), trilobites (Schwimmer 1975), echinoderm fragments (Martin et al. 1980), and invertebrate burrows (Miller 1936a). Finally, fossils described from the Gros Ventre Formation, without further subdivision, include acritarchs (Reaugh 1980), trilobites (Beebe and Cox 1998), bradoriid arthropods (extinct ostracode [seed shrimp]-like crustaceans) (Howell 1963), conodonts (extinct eel-like chordates) (Koucky et al. 1961, 1968, Dong et al. 2005), invertebrate burrows (Csonka and Bulinski 2010), and material described as belonging to heterostracan fish (early jawless fish) (Cygan and Koucky 1963; the age of the fossils indicates either a stratigraphic or taxonomic misidentification).

Gallatin Limestone (Upper Cambrian)

The Gallatin Limestone of the Teton Range is another cliff-forming unit. In GRTE and its immediate vicinity, it is mostly composed of dark limestone, with some “flat-pebble” conglomerate in the lower section and green shale beds in the middle of the formation. It is 60 to 75 m (200 to 250 ft) thick, and is commonly mapped with the Park Shale Member of the underlying Gros Ventre Formation. Like the other Cambrian formations of GRTE, it is primarily found in the northwestern and southwestern sections of the park, but it also crops out on Blacktail Butte (Love et al. 1992). It is sometimes divided into members, but this has not been formally done in the GRTE area (Wanless et al. 1955). Miller (1936a) reported that Peale’s (1893) basal “mottled limestone” is the Pilgrim Limestone Member, the Dry Creek Shale is the Dry Creek Shale Member, and the “pebbly limestone” is the Yogo Member, but did not use all of these members in the text. Instead, in the Teton Range, he used the newly named Du Noir Limestone Member for the lower part of the formation, with an unnamed middle shaly member and an unnamed upper limestone member above it (Miller 1936a). (The Yogo name was later found to be the result of a mistaken interpretation, and the interval identified as such in northwestern Wyoming is now the Sage pebble conglomerate or Sage Member [Lochman 1950]).

Several other names have also been used in the GRTE area. Fenton and Fenton (1939) used the following formations in ascending order: the Maurice Formation, Pilgrim Formation, and Snowy Range Formation. The Maurice Formation is a deprecated synonym of the Pilgrim Formation (Lochman-Balk 1956), which is used for approximately the same interval as the Du Noir Limestone Member (Shaw 1954). The Snowy Range Formation is equivalent to part of the middle Gallatin Formation (Deiss 1938, Dorf and Lochman 1940). Wanless et al. (1955) preferred to use the

Boysen Formation name instead of the Gallatin Formation. Saltzman et al. (1995) and Saltzman (1999) used a combination of the Pilgrim or Du Noir Limestone and overlying Open Door Formation for the GRTE area; the Open Door Formation was introduced for rocks of the upper Gallatin Group (Shaw and Deland 1955).

The Gallatin Formation dates to the Late Cambrian (Wanless et al. 1955), although it has sometimes been suggested that the Formation and its equivalents at the top of the Cambrian section extend into the Ordovician (Cygan and Koucky 1963). It was deposited offshore, in perhaps 30 to 60 m (100 to 200 ft) of water, with occasional storm events (Love and Reed 1968). Depositional environments include lagoons, tidal flats, and shoals (Martin et al. 1980). Shoal environments were replaced by deeper water deposition over time in the GRTE area (Saltzman et al. 1995). The upper contact with the Bighorn Dolomite is disconformable (Wanless et al. 1955), and there may be a disconformity within the formation in northwestern Wyoming (Miller 1936a).

There are several reports of fossils from the Gallatin Formation of GRTE, including five microbial structures and two brachiopods named from fossils found in the park. The overall assemblage includes stromatolites and other microbial structures, cyanobacterial colonies, "algae," brachiopods, trilobites, possible cystoid cups (extinct relatives of crinoids [sea lilies]), and invertebrate burrows. USNM locality 4e at the Jackson or Sheep Creek site discussed in the Gros Ventre Formation section has yielded brachiopods, including syntypes of the species *Obolus tetonensis* (Walcott 1901) and subspecies *Acrotreta microscopica tetonensis* (Walcott [1902]; raised to its own species as "*Acrotreta*" *tetonensis* by Bell [1941]). According to Bell (1941), this site is in the Dry Creek Shale Member of the Gallatin Limestone. It is a limestone horizon about 290 m (950 ft) above the base of the Cambrian section (Walcott 1912). The Buck Mountain section discussed in the Gros Ventre Formation section has yielded brachiopods, trilobites, and burrows in the lower part of the formation, and brachiopods, possible cystoid cups, and burrows in the upper part (Miller 1936a). Fenton and Fenton (1939) named several forms of microbial structures from the head of Death Canyon in GRTE. *Aulophycus callosus*, *A. parvus*, *Collenia spissa*, and *Tetonophycus blackwelderii* were named from the Maurice Formation, now interpreted as the lower Gallatin Formation, and *Collenia magna* was named from the Snowy Range Formation, now interpreted as the middle Gallatin Formation. Aside from the newly named forms, they found stromatolites in their Snowy Range Formation, stromatolites, brachiopods, and trilobites in their Pilgrim Formation, and stromatolites and other microbial structures including the cyanobacterial colony *Rivularites*, "algae", and annelid burrows in their Maurice Formation. Finally, Saltzman (1999) reported brachiopods, trilobites, and burrows from the "Open Door Formation" of the Death Canyon area of GRTE, including shell beds of the brachiopod *Eoorthis*.

Fossils have also been reported from the immediate vicinity. Ulrich and Cooper (1936) named the brachiopod *Billingsella perfecta* from the upper Gallatin Formation ("Yogo Limestone") south of Muskrat Lake on Teton Creek west of GRTE, three species of trilobites, *Irvingella gibba* (Miller 1936b), *Elvinia tetonensis*, and *Glyphaspis tetonensis* (Resser 1937), have been named from the Gallatin Formation (Dry Creek Shale of Resser [1937]) on the South Fork of Teton Creek Canyon, and

brachiopods and trilobites have been reported from the Alaska Basin (Love and Reed 1968).

As a whole, over its entire depositional area, fossils reported from the Gallatin Formation and its various subdivision include microbial structures such as thrombolites (Hawkins et al. 2001), stromatolites, and laminations (Martin et al. 1980), algal limestone (Saltzman 1999), acritarchs (Reaugh 1980), possible corals (Fritz and Howell 1955), sponge spicules, chancellorids (extinct sponge-like animals), enigmatic conical hyoliths (Bonem 1972), enigmatic shelled *Hypseloconus* and *Kinsabia* (Lochman and Duncan 1944), brachiopods (Walcott 1912, Miller 1936a), monoplacophorans (cap-shelled mollusks) (Breuninger 2000), trilobite-like aglaspid arthropods (Lochman and Duncan 1944), trilobites, possible cystoids (Miller 1936a), eocrinoids (early stalked echinoderms) (Bonem 1972), and other echinoderms (Lochman and Duncan 1944, Saltzman 1999), conodonts (Koucky et al. 1968, Clark et al. 2000), and invertebrate burrows (Saltzman 1999).

Bighorn Dolomite (Upper Ordovician)

The Bighorn Dolomite is a widespread formation of the GRYN and vicinity. It is sometimes divisible into multiple members (Zenger 1992, Holland and Patzowsky 2012), but only two units are distinguished at GRTE: a lower unnamed section and upper Leigh Dolomite Member (Love et al. 1992). Wanless et al. (1955) treated the Leigh Dolomite Member in the GRTE area as a distinct formation, but this has not been widely followed. The lower section of the Bighorn Dolomite is made of cliff-forming light- to dark-gray dolomite, while the Leigh Dolomite Member is a white slope-forming brittle dolomite unit. The thickness of the formation varies, but is typically 60 to 150 m (200 to 500 ft) thick, the upper 15 m (50 ft) of which is the Leigh Dolomite Member. Distribution of Bighorn Dolomite outcrops in GRTE follows the Gallatin Limestone pattern: northwestern and southwestern corners, and Blacktail Butte (Love et al. 1992). Some of the karst in the Teton Range is developed in the Bighorn Dolomite (Medville et al. 1979), so it may host caves within the park.

The Bighorn Dolomite is a marine formation, dominated by open marine shallow subtidal deposits. The lower part of the formation is interpreted as representing primarily shallow subtidal marine deposition, becoming shallower near the top of the sequence. The Leigh Dolomite Member is interpreted as a shallow restricted marine deposit. An additional member above the Leigh Dolomite Member, not present at GRTE, shows a return to open marine conditions (Holland and Patzowsky 2012). Deposition occurred during the Late Ordovician, approximately 450 to 446 Ma (Holland and Patzowsky 2012). The upper contact of the Bighorn Dolomite with the Darby Formation is disconformable (Wanless et al. 1955). There are also sometimes internal unconformities (Scott and Asquith 1972, Holland and Patzowsky 2012), and the lower Bighorn–Leigh Dolomite Member contact has been interpreted as disconformable in the Tetons (Wanless et al. 1955).

The Bighorn Dolomite appears to be fossiliferous within GRTE: Fenton and Fenton (1939) reported possible trace fossils in the Bighorn Dolomite at the head of Death Canyon. It probably has more abundant fossils within the park, based on reports from the west flank of the Tetons. Reeves (1964), reporting on Paleozoic sections from the west flank, noted the presence of fragments of horn corals, bryozoans (moss animals), brachiopods, and

crinoids in the lower part of the formation, and corals, brachiopods, and crinoids in the Leigh Dolomite Member (Reeves 1964). The Alaska Basin, within this area, has yielded horn corals, bryozoans, and brachiopods (Love and Reed 1968). Fish plates and "plant traces" (probably invertebrate burrows) have been reported from the Leigh Dolomite Member in a ravine on the east side of Glory Mountain to the south of GRTE, but these finds may be from the Darby Formation instead because the fish plates appear to be from *Bothriolepis*, a Late Devonian ostracoderm (armored jawless fish) (Wanless et al. 1955).

Overall, the fossil assemblage of the Bighorn Dolomite includes dasycladacean algae, stromatoporoid sponges, corals, bryozoans, brachiopods, bivalves, nautiloid cephalopods, gastropods, trilobites, ostracodes, crinoids (Holland and Patzowsky 2009, 2012), cystoids (Macomber 1970), graptolites (extinct colonial animals possibly related to the chordates) (Scott and Asquith 1972), conodonts, general bioturbation, and invertebrate trace fossils including burrows (Holland and Patzowsky 2009, 2012).

Darby Formation (Upper Devonian)

The Darby Formation is something of a "name of convenience," originally intended for areas where the two most widespread Devonian formations of Wyoming, the Jefferson Limestone and overlying Three Forks Shale, cannot be mapped (Benson 1966). In GRTE and its immediate vicinity, it includes distinct lower and upper sections. The lower section is composed primarily of brown dolomite, with thin beds of limestone and sandstone. The upper portion is composed of variegated siltstone and shale. As a whole, the formation is 85 to 105 m (285 to 350 ft) thick, and, like the Gallatin Limestone and Bighorn Dolomite, is found at Blacktail Butte and in the northwestern and southwestern parts of GRTE (Love et al. 1992). Iddings and Weed (1899) first interpreted these rocks as the Jefferson Limestone (Silurian) and Three Forks Formation (Devonian). Some other authors have chosen to divide the Darby Formation of the GRTE area into Jefferson and Three Forks sections, at least informally (Andrichuk 1956, Sandberg 1965, Benson 1966), but in general the Darby Formation name has been preferred. According to Sandberg (1965), the Devonian section near GRTE includes the lower and Birdbear members of the Jefferson Limestone and the basal member of the Three Forks Shale, the Logan Gulch Member. Benson (1966) found the Trident Member of the Three Forks Shale to be present in the area as well. A thin black shale is sometimes present between the Darby Formation and overlying Madison Limestone. It has occasionally been assigned to the Sappington Formation or member of the Three Forks Shale (Strickland 1956), but it is now thought to be the Cottonwood Canyon Member of the Madison Limestone (Benson 1966, Love and Keefer 1969).

A marine unit, the Darby Formation is interpreted as having been deposited in a restricted basin under a climate humid enough to prevent significant evaporite deposition (Wanless et al. 1955). Deposition occurred during a marine transgression that moved to the east and southeast, reaching the maximum transgression during deposition of the Three Forks Shale equivalent (Andrichuk 1956). The upper contact with the Madison Formation is disconformable, and it appears that more of the upper part of the Darby Formation is eroded going north and east in northwestern Wyoming (Wanless et al. 1955). Fossils in the Jefferson Formation indicate that at least the lower part of the Darby Formation has a Late Devonian age

(Frasnian, approximately 383 to 372 Ma) (Weigner and Isaacson 2012).

The Darby Formation is fossiliferous within GRTE. Iddings and Weed (1899) reported unspecified fossils from the "Threeforks Formation" in a saddle southwest of Forellen Peak. Tracy (2003) reported collecting bryozoans, brachiopods, and echinoderms, and included a photograph of stromatolites from the Granite Canyon Trail on Rendezvous Peak (this trail passes through both NPS and non-NPS areas, but almost all of the potential Darby Formation outcrops are within GRTE, per Love et al. [1992]). Fossils are generally uncommon in the Darby Formation of the GRTE area. The best records are south of GRTE in the Mount Glory/Taylor Mountain area (Wanless et al. 1955). The Jefferson equivalent in this area has yielded possible coral structures, brachiopods, ostracodes, and crinoids, and the Three Forks equivalent has crinoids (Andrichuk 1956). Corals and bryozoans are also present in the rocks (Wanless et al. 1955). Some corals, bryozoans, and brachiopods have been reported from this formation on the west flank of the Tetons (Reeves 1964), including in Alaska Basin (Love and Reed 1968), and fish fossils are known from the Teton Pass area (Denison 1951). Overall, the fossil record of the Darby Formation includes stromatolites (Tracy 2003), corals, bryozoans, brachiopods (Reeves 1964), ostracodes, crinoids (Andrichuk 1956), the ostracoderm *Bothriolepis*, and lobe-finned fish (Denison 1951).

Madison Limestone (Lower–Middle Mississippian)

The Madison Limestone is a widely distributed limestone unit in the GRYN and nearby areas. Within GRTE and in its immediate vicinity, it includes at least four different subunits. At the base of the formation, a black marine shale with fish fragments is locally present. Above this shale interval is an interval of thin-bedded dolomitic limestone, then an interval of thick-bedded to massive limestone with abundant horn corals. These two intervals are light-gray to dark-gray, and have layers and lenses of black chert. Finally, at the top there is locally a fourth interval known as the Bull Ridge Member, composed of red shale and siltstone, orange to tan sandstone, tan to pink dolomite breccia (bed of angular rock fragments), blue-gray limestone, and chert nodules, 15 to 30 m (50 to 100 ft) thick. The formation as a whole is 335 to 455 m (1,100 to 1,500 ft) thick. It is primarily exposed in northwestern GRTE, but is also present in southwestern GRTE, on Blacktail Butte, and along the Gros Ventre River (Love et al. 1992). The lower dark shale can be identified as the Cottonwood Canyon Member (Benson 1966, Love and Keefer 1969), the thin-bedded unit is equivalent to the Lodgepole Limestone Member, and the thick-bedded to massive limestone unit is equivalent to the Mission Canyon Limestone Member (Wanless et al. 1955). Wanless et al. (1955) discussed two additional units of interest in the GRTE area above their Madison Limestone: the Brazer Limestone and overlying Lower Amsden red shale sequence. These units probably correlate at least in part to the Bull Ridge Member of the Madison Limestone, coined by Sando (1968) for rocks between the Madison Limestone and overlying Darwin Sandstone of the Amsden Formation. The Bull Ridge Member is sometimes known as the Sacajawea Formation in older reports, such as Strickland (1956) and Sando (1967). The presence of named members aside from the Bull Ridge Member is not included in the primary map of the GRTE area (Love et al. 1992), but their existence is commonly recognized (Wanless et al. 1955, Strickland 1956, Sando 1960, 1977,

Schroeder 1972, Daley and Boyd 1996), so they will be used in this report. It should be noted that the Madison Limestone is frequently raised to a group. In such cases, the Lodgepole and Madison Canyon members are raised to formations, with the Cottonwood Canyon Member at the base of the Lodgepole Limestone and the Bull Ridge Member at the top of the Mission Canyon Limestone (Sando 1977).

The rocks of the Madison Limestone are of marine origin, and record a marine transgression moving rapidly west to east (Gutschick et al. 1976). The Lodgepole Limestone Member is thought to represent more open marine conditions, and the Mission Canyon Limestone Member more restricted marine conditions (Sando 1977). Sea-level fluctuations during Mission Canyon time led to occasional periods of evaporitic conditions, but overall the sea was transgressing (Gutschick et al. 1976). The sea departed after deposition of the Mission Canyon Limestone, leading to subaerial exposure with large river systems cutting across the former marine deposits, and the formation of an early generation of voids and caves (Sando 1988). Karst and cave formation resumed more recently, and today most of the karst in the Tetons is in the Mission Canyon Limestone Member, with some in the Lodgepole Limestone Member as well (Medville et al. 1979).

Deposition of the Madison Limestone occurred during the Mississippian. The Cottonwood Canyon Member is Kinderhookian (360 to 348 Ma) in age (Sando [1972]; purported Devonian fossils are actually reworked from older rocks), the Lodgepole Limestone Member is Kinderhookian to Osagean (348 to 340 Ma) in age (Stanley and Burke 2000), the Mission Canyon Limestone Member is Osagean to early Meramecian (340 to approximately 335 Ma) in age (Smith and Dorobek 1993), and the Bull Ridge Member is early Meramecian (approximately 335 Ma) in age (Sando 1968). There can be internal disconformities (Strickland 1956), and the upper contact with the Amsden Formation is disconformable in the area (Wanless et al. 1955). The depositional hiatus is longer going eastward, reflecting the west to east transgression of the sea that deposited the overlying rocks (Palmer and Palmer 1995).

The Madison Limestone is abundantly fossiliferous, and fossils have been reported from locations within GRTE since 1899 (Iddings and Weed 1899, Girty 1899). The park assemblage includes corals, bryozoans, brachiopods, nautiloids, trilobites, crinoids, unspecified echinoderms, and unspecified marine invertebrates. Iddings and Weed (1899) reported that the formation is fossiliferous on Berry Creek Canyon, now within the park, and at Survey Peak; this locality may or may not be within GRTE. Girty (1899) reported fossils from several localities within GRTE, including corals, bryozoans, and brachiopods south of Forellen Peak, corals and brachiopods on the south flank of Survey Peak, brachiopods and trilobites on the east flank of Survey Peak, and brachiopods northwest of Forellen Peak and north of Owl Creek. Among these fossils is a syntype of the brachiopod *Productus parviformis*, found south of Forellen Peak (Girty 1899). Love and Reed (1968) included photographs of Madison Limestone slabs from the park with abundant fossils of corals, brachiopods, and other marine invertebrates. Tracy (2003) reported horn corals and brachiopods from Blacktail Butte, and fossils from Rendezvous Mountain and Fossil Mountain, which have Madison Limestone outcrops both within and outside the park.

There is the possibility of unauthorized collection at well-known Fossil Mountain, because it straddles the park boundary. Tracy (2003) also included photographs of a nautiloid and crinoid in Madison Limestone rocks from the park, and reported collecting corals, brachiopods, crinoids, and unspecified echinoderms.

Fossils have also been reported from the immediate vicinity, mostly west of the park. Fossils were found at the head of Conant Creek just west of the park, including bryozoans, brachiopods, and crinoids (Girty 1899). Wanless et al. (1955) found corals and brachiopods at many of their sections south of GRTE. Darby Canyon west of GRTE has yielded many fossils in the Lodgepole Limestone Member, including foraminifera, corals, bryozoans, brachiopods, bivalves, cephalopods, gastropods, trilobites, ostracodes, and crinoids; most of these fossils have been silicified (Daley and Boyd 1996). Among the fossils from Darby Canyon is the holotype of the brachiopod *Camarotoechia inaequa* (Shaw 1962). Conodonts are known from the Cottonwood Canyon and Lodgepole members in Teton Canyon, west of the park (Klapper 1966). Corals, brachiopods, and other fossils are present in Alaska Basin west of the park (Love and Reed 1968). The Lodgepole Limestone is fossiliferous in the Rendezvous Peak Quadrangle, including part of southwestern GRTE (Schroeder 1972). Zeller (1957) named the foraminifera *Granuliferella tumida*, *Plectogyra anteflexa*, and *P. trachida* from specimens found on the east side of Mount Glory south of GRTE. Houlik (1973) reported fragments of *Lepidodendron* and other land plants in the Mission Canyon Limestone Member in Hoback Canyon, south of GRTE.

Overall, including areas outside of GRTE, the Cottonwood Canyon Member has a fossil assemblage including marine palynomorphs (organic microfossils, like spores, pollen, and resting cysts), conulatans (extinct coral relatives that formed pyramidal structures from rods), corals, bryozoans, brachiopods, crinoid molds (Sandberg and Klapper 1967), echinoids (sea urchins) (Benson 1966), conodonts, invertebrate burrows (Sandberg and Klapper 1967), fish plates and teeth (Benson 1966), and coprolites (fossil feces) (Sandberg and Klapper 1967). Fossils reported from the Lodgepole Limestone Member include possible microbial structures (Moore 1973), calcispheres (Gutschick et al. 1976), foraminifera (Gutschick et al. 1961), sponges (Gutschick 1966; Gutschick et al. 1976), conulatans (Tysdal 1976), corals, bryozoans (Sando and Dutro 1974), brachiopods (Rodriguez and Gutschick 1968), microconchid tentaculitid ?mollusks (formerly identified as spirobid worm tubes; Witkind 1969), rostroconchs (Girty 1899), bivalves (Chen and Webster 1994), ammonites (Stanley and Burke 2000), gastropods (Sando and Dutro 1974), trilobites (Stanley and Burke 2000), ostracodes, blastoids (sea buds), crinoids (Rodriguez and Gutschick 1968), echinoids (Smith 1982), holothurians (sea cucumbers), conodonts (Gutschick 1966, Gutschick et al. 1961), indeterminate spicules (needle-like skeletal structures), invertebrate burrows (Smith 1982), and fragmentary fish remains (Gutschick et al. 1961, Gutschick and Lamborn 1975). The Mission Canyon Limestone Member has yielded stromatolites, oncolites, calcispheres, foraminifera, “phylloid” algae, red algae, dasycladacean algae (Vice and Utgaard 1989), fragments of *Lepidodendron* and other land plants (Houlik 1973), sponges, corals, bryozoans, brachiopods, bivalves, gastropods, ostracodes, trilobites, crinoids, conodonts, and

invertebrate pellets and burrows (Vice and Utgaard 1989). Finally, the Bull Ridge Member has yielded stromatolites (Maughan 1987), corals, bryozoans, brachiopods, bivalves, and gastropods (Sando 1967).

Amsden Formation (Upper Mississippian–Middle? Pennsylvanian)

The Amsden Formation is a heterogeneous unit. In GRTE and its immediate vicinity, it is divisible into the Darwin Sandstone Member and overlying unnamed upper section. The Darwin Sandstone Member is a gray to brown sandstone unit with some thin layers of red shale near the top. It is 23 to 30 m (75 to 500 ft) thick. The upper part of the formation is composed of red, brown, and green shale and siltstone and white to pink dolomite and limestone, with chert. This section is 70 to 135 m (230 to 450 ft) thick. The Amsden Formation transitions into the overlying Tensleep Sandstone, and is commonly mapped with it in GRTE. The Amsden and Tensleep formations are only found in a few areas of GRTE: the Conant Pass–Forellen Peak–Survey Peak area of northwestern GRTE, on Elk Ridge and a hill to the south near Jackson Lake, Mount Hunt in southwestern GRTE, and on Blacktail Butte and along the Gros Ventre River in southeastern GRTE (Love et al. 1992). Some publications, such as Wanless et al. (1955), include the modern Cottonwood Canyon Member of the underlying Madison Limestone in the Amsden Formation.

The Amsden Formation can be divided into several members depending on location, although like the Madison Limestone these divisions have not been mapped in GRTE. In most of Wyoming, the sequence from oldest to youngest is typically the Darwin Sandstone, Horseshoe Shale, and Ranchester members, but there is sometimes a fourth member between the Horseshoe Shale and Ranchester members, the Moffat Trail Limestone Member. These four units are present in and around GRTE (Sando et al. 1975). The Darwin Sandstone Member is interpreted as mostly beach and offshore bar deposition following a marine transgression. The Horseshoe Shale Member is interpreted as a stable restricted marine basin, like a lagoon, and the Moffat Limestone Member is thought to have been deposited under similar conditions. The Ranchester Member is interpreted as a shallow offshore marine unit with some evaporation (Sando et al. 1975). The initial transgression proceeded from west to east, beginning in what is now western Wyoming (Sando 1988).

As mentioned in the Madison Limestone section, the Amsden Formation is time-transgressive, with older sediments at the base in the west than the east. The oldest sediments are found in western Wyoming, where the Mississippian–Pennsylvanian boundary (323 Ma) is high in the formation (within the Ranchester Member); in east–central Wyoming, this boundary is much lower, below the Horseshoe Shale Member (Gordon 1975). In the GRTE area, fossils of Chesterian age (333 to 326 Ma) are present just above the Darwin Sandstone Member (Wanless et al. 1955). The age of the upper part of the formation has not been established as precisely in the area, but Desmoinesian fossils (308 to 306.5 Ma) are present in the overlying Tensleep Sandstone in and around GRTE (Henbest 1956). The upper contact with the Tensleep Sandstone is generally regarded as transitional (Wanless et al. 1955, Sando et al. 1975). The two formations can be difficult to distinguish (Fisher 1963).

The Amsden Formation is fossiliferous within GRTE, with foraminifera, brachiopods, bivalves, and gastropods present. Sando et al.

(1975) reported on a number of fossiliferous localities within the park. Their localities 149 through 158 derive from the Horseshoe Shale Member at Berry Creek, locality 159 is in the Horseshoe Shale Member on Elk Ridge, and locality 160 is in the Ranchester Member on Elk Ridge. Localities 149 to 152 and 155 to 158 yielded brachiopods only; localities 153 and 154 had foraminifera and brachiopods; locality 159 had brachiopods, bivalves, and gastropods; and locality 160 had foraminifera, brachiopods, and gastropods. The foraminifera are discussed in more detail in Mamet (1975), the brachiopods are discussed in Gordon (1975), the bivalves are discussed in Gordon and Pojeta (1975), and the gastropods are discussed in Gordon and Yochelson (1975).

Fossils have also been reported from the immediate area. Girty (1899) reported fossils in unspecified rocks above the Madison Limestone at the head of Conant Creek; these rocks may belong to the Amsden, Tensleep, or Phosphoria formations, all of which are present in that area per Love et al. (1992). The Amsden Formation above the Darwin Sandstone Member in Hoback Canyon includes both marine fossils such as fusulinid foraminifera, bryozoans, trilobites, and blastoids, and terrestrial fossils such as carbonaceous plant material and rootlets (Wanless et al. 1955). Trace fossils are present in the formation in the Flat Creek–Sheep Creek area of the Gros Ventre Range (Bachrach 1956).

The Amsden Formation is sparsely fossiliferous, but has a distinctive assemblage. Fossil groups represented include foraminifera, marine algae including *Girvanella*, land plants (including calamitaceans, *Sphenopteris*, and *Lepidodendron*), the sponge *Chaetetes* (formerly identified as a hydrozoan, related to corals), conulatans, corals, bryozoans, brachiopods, rostroconchs (extinct bivalved mollusks), bivalves, cephalopods, gastropods, microconchid worm tubes formerly identified as *Spirorbis*, ostracodes, trilobites, blastoids, crinoids, echinoids, the possible worm *Cornulitella*, conodonts, invertebrate burrows, and fish (including cartilaginous and ray-finned fish) (Sando et al. 1975). Several groups were described in detail in a group of 1975 publications: foraminifera, algae, and other microfossils (Mamet 1975), corals and *Chaetetes* (Sando 1975a), brachiopods (Gordon 1975), bivalves and rostroconchs (Gordon and Pojeta 1975), ammonites, nautiloids, gastropods, and trilobites (Gordon and Yochelson 1975), and ostracodes (Sohn 1975). Representatives of all groups are generally found throughout the members above the Darwin Sandstone, although a few are more limited: rostroconchs are only known from the Ranchester Member (Gordon and Pojeta 1975), which also lacks corals (Sando 1975a), and cephalopods (Gordon and Yochelson 1975) and ostracodes are only known from the Horseshoe Shale Member (Sohn 1975). The Darwin Sandstone Member is not known for its fossils; Sando (1975b) reported foraminifera from the west flank of the Bighorn Basin, east of GRTE, and Barker (1984) reported a brachiopod.

Tensleep Sandstone (Middle–Upper Pennsylvanian)

The Tensleep Sandstone of GRTE and its immediate vicinity is a hard, light gray sandstone, with some quartzite zones, and gray beds of limestone and dolomite in the lower and middle interval of the formation. It is 120 to 135 m (400 to 450 ft) thick, and is commonly mapped with the underlying Amsden Formation (Love et al. 1992). Historically, it has been interpreted as marine, but more recent interpretations have suggested more terrestrial deposition, with a combination of marine beds and eolian sandstone (Mankiewicz and

Steidtmann 1979, Kerr and Dott 1988, Lopez et al. 2007).

The Tensleep Sandstone spans at least the middle and late Pennsylvanian, possibly into the early Permian. Fossils ranging from Desmoinesian (308 to 306.5 Ma) (Driscoll and Newton 1969, Stamm and Wardlaw 2003) to Missourian (306.5 to 305 Ma) (Verville et al. 1970) to possibly Wolfcampian (299 to 294.5 Ma) (Fisher 1963) have been recovered from the Bighorn Mountains to the east. The upper contact with the Phosphoria Formation is disconformable (Wanless et al. 1955). It can be difficult to find the Tensleep–Phosphoria contact (Mettes and Boyd 1985), but in the GRTE area there is a conglomerate at the base of the Phosphoria Formation (Wanless et al. 1955).

The Tensleep Sandstone is fossiliferous within GRTE. Henbest (1956) found fusulinid foraminifera in the northeast quarter of Section 1, T42N, R115W (USGS collection f-12106). The same report identified fusulinids at three other localities in the immediate vicinity of the park, establishing a Desmoinesian age for at least part of the formation in the area. Possible trace fossils were reported from the Flat Creek–Sheep Creek area in the Gros Ventre Range near GRTE as well (Bachrach 1956).

Overall, the fossil assemblage of the Tensleep Sandstone includes microbial mats (Mankiewicz and Steidtmann 1979), foraminifera (Verville 1957, Verville et al. 1970), the sponge *Chaetetes* (Agatston 1952), sponge spicules (Richards 1955), corals (Driscoll and Newton 1969), brachiopods (Darton 1906; Driscoll and Newton 1969; Mankiewicz and Steidtmann 1979), bivalves (Mankiewicz and Steidtmann 1979), gastropods (Darton 1906), scaphopods (tusk shells), trilobites (Hoare and Burgess 1960), crinoids (Agatston 1952, Mankiewicz and Steidtmann 1979), conodonts (Stamm and Wardlaw 2003), general bioturbation, invertebrate burrows, organic borings of plant or invertebrate origin (Mankiewicz and Steidtmann 1979), and tetrapod footprints, named *Steganoposaurus belli* and originally identified as amphibian (Branson and Mehl 1932), but now thought to be reptilian (Lockley and Hunt 1995).

Phosphoria Formation and Associated Rocks (Lower–Middle Permian)

The Phosphoria Formation and associated rocks make up a complex interval of intertonguing redbeds, marine shales and phosphatic shales, chert-rich beds, sandstones, and carbonates. In the GRTE area, they include mudstone, dolomite and other carbonate rocks, sandstone, shale, and black phosphatic shale. The interval is 55 to 60 m (180 to 200 ft) thick. Outcrops have been identified within GRTE in the vicinity of Survey Peak, Forellen Peak, Elk Ridge and a hill to the southeast, and along the Gros Ventre River (Love et al. 1992). The Permian interval of the GRTE area can be divided into smaller units (Wanless et al. 1955, Sheldon 1956, 1963, Ciriacks 1963, Hiatt and Budd 2001), although the exact subdivisions chosen and the names applied, if any, will vary by author and exact location (the lithologies of the rocks vary substantially over relatively short distances; see for example Wanless et al. [1955], McKelvey et al. [1959], or Sheldon [1963]). Modern names that may be used in the GRTE area at the formation level include the Park City, Phosphoria, and Shedhorn formations; the Park City name is usually applied to carbonate rocks and some of the sandstones, the Phosphoria name is applied to phosphatic, carbonaceous, and cherty rocks, and the Shedhorn Sandstone name is applied to other sandstones (Ciriacks 1963). The Quadrant

and Teton formations have also been used historically in this interval in the Tetons (McKelvey et al. 1959). Member- and bed-level names applied in the area include, in ascending order: a cherty unit or the Grandeur Member of the Park City Formation, the Meade Peak Phosphatic Shale Member of the Phosphoria Formation, the Rex Chert Member of the Phosphoria Formation, the Franson Member of the Park City Formation, the Retort Phosphatic Shale Member of the Phosphoria Formation, the Tosi Chert Member of the Phosphoria Formation, the Ervay Member of the Park City Formation, and the Shedhorn Sandstone (Pampeyan et al. 1967, Schroeder 1972, Schmitt and Boyd 1981, Hiatt and Budd 2001).

The Phosphoria interval was deposited in and around a shallow, broad, warm sea (Hiatt and Budd 2001). Two large transgression-regression cycles occurred during deposition, with the sea transgressing from west to east (Sheldon 1956). The maximum transgressions are represented by the Meade Peak and Retort phosphatic shale members (Wardlaw and Collinson 1986). The Park City Formation is interpreted as representing mudflat and marine shelf settings, the Phosphoria Formation is interpreted as deeper marine basins, and the Shedhorn Sandstone is interpreted as sands deposited on or near beaches (Yochelson 1963). The interval dates to the Leonardian and Guadalupian ages of the Early and Middle Permian (between 280 and 260.4 Ma) (Hiatt and Budd 2001). The upper contact with the Dinwoody Formation is disconformable (Paull and Paull 1990), but the hiatus is shorter in the west, nearer GRTE, than in the east (Hiatt and Budd 2001). Internal disconformities are also present depending on location, between the Grandeur and overlying Meade Peak members and the Franson and Retort members (Hiatt and Budd 2001).

The Phosphoria interval is fossiliferous within GRTE, including sponge spicules, bryozoans, brachiopods, bivalves, gastropods, unspecified mollusks, invertebrate trace fossils such as burrows, cartilaginous fish, a possible denticle of an acanthodian or palaeoniscid fish, ray-finned fish, and indeterminate fish. Ciriacks (1963) reported bivalves in the upper Shedhorn Sandstone on the south slope of Forellen Peak. Sheldon (1963) and Yochelson and van Sickle (1968) described the Phosphoria interval and fossils on Forellen Peak. Sheldon (1963) reported sponge spicules in the Rex Chert Member and lower and upper Shedhorn Sandstone. Yochelson and van Sickle (1968) reported the cartilaginous fish *Helodus* and ray-finned fish in the Grandeur Member, brachiopods, gastropods, cartilaginous fish, ray-finned fish, and indeterminate fish in the lower Shedhorn Sandstone, diverse cartilaginous fish, ray-finned fish, and indeterminate fish in the Retort Phosphatic Shale Member, and bryozoans, bivalves, and indeterminate fish in the upper Shedhorn Sandstone. Love (1989b) noted the presence of a brachiopod coquina bed (bed made up of fossils) in the formation at Granite Creek Divide. Tracy (2003) found abundant invertebrate trace fossils on the south side of Harem Hill, particularly *Thalassinoides* burrows, and reported collecting brachiopods, mollusks, and a possible denticle, pertaining to an acanthodian or palaeoniscid ray-finned fish. The Meade Peak Phosphatic Shale Member is not yet known to be fossiliferous in GRTE, but is fossiliferous in the vicinity, having yielded reworked fish teeth at Crystal Creek, east of Lower Slide Lake (Hiatt and Budd 2001). Wanless et al. (1955) found a number of fossils in the Phosphoria interval in the vicinity of GRTE, including conulatans, bryozoans, brachiopods, bivalves, and gastropods.

In general, over its entire depositional area, the Phosphoria interval has an assemblage of abundant but low-diversity brachiopods and mollusks. Sponges, corals, brachiopods, trilobites, crinoids, and fish are less-common components (Kulas and Batten 1997). Park City Formation fossil assemblages are dominated by brachiopods, with bryozoans and bivalves also common. Phosphoria Formation fossil assemblages include abundant sponge spicules as well as brachiopods and mollusks, particularly cephalopods. Finally, the Shedhorn Sandstone fossil assemblage is mostly made up of large bivalves, scaphopods, and resistant fish remains (Yochelson 1963). Fossils have been reported from each of the various members relevant to the GRTE area:

- The Grandeur Member of the Park City Formation has yielded foraminifera (McKelvey et al. 1959), sponges, solitary corals, conulatans, bryozoans, brachiopods, bivalves, straight nautiloids, gastropods, scaphopods, trilobites, crinoids (Yochelson and van Sickle 1968), conodonts (Behnken et al. 1986), and bones and teeth of cartilaginous and ray-finned fish (Yochelson and van Sickle 1968).

- The Meade Peak Phosphatic Shale Member of the Phosphoria Formation has yielded acritarchs (Jacobson et al. 1982), foraminifera (McKelvey et al. 1959), sponges (Hendrix and Byers 2000), conulatans, bryozoans, brachiopods, bivalves, ammonites, belemnites (Yochelson and van Sickle 1968), nautiloids (McKelvey et al. 1959), other cephalopods (Gordon 1966, 1971, Yochelson and van Sickle 1968), gastropods, ostracodes, crinoids (Yochelson and van Sickle 1968), invertebrate burrows and general bioturbation (Hendrix and Byers 2000), conodonts (Behnken et al. 1986), and bones and teeth of fish (McKelvey et al. 1959, Yochelson and van Sickle 1968).

- The Rex Chert Member of the Phosphoria Formation has yielded radiolarians (another type of “shelled” protist), sponges, bryozoans, brachiopods (McKelvey et al. 1959), bivalves (Gilmour and Walker 1986), crinoids, echinoids (McKelvey et al. 1959), and conodonts (Gilmour and Walker 1986).

- The Franson Member of the Park City Formation has yielded acritarchs (Jacobson et al. 1982), phylloid algae (Peterson 1984), sponges, solitary corals, bryozoans, brachiopods, bivalves, nautiloids, gastropods, scaphopods, ostracodes, crinoids (Yochelson and van Sickle 1968), echinoids (McKelvey et al. 1959), conodonts (Jacobson et al. 1982), burrows (Hendrix and Byers 2000), and bones and teeth of fish (Yochelson and van Sickle 1968), including a variety of cartilaginous fish (McKelvey et al. 1959).

- The Retort Phosphatic Shale Member of the Phosphoria Formation has yielded brachiopods, bivalves (McKelvey et al. 1959), aulacocerids (relatives of belemnite cephalopods) (Gordon 1966), gastropods (McKelvey et al. 1959), conodonts (Behnken et al. 1986), and bones and teeth of cartilaginous fish, ray-finned fish, and indeterminate fish (Yochelson and van Sickle 1968).

- The Tosi Chert Member of the Phosphoria Formation has yielded sponge spicules (Sheldon 1963), bryozoans, brachiopods, bivalves, echinoids (McKelvey et al. 1959), conodonts (Behnken et al. 1986), and

invertebrate burrows and general bioturbation (Thornburg 1989).

- The Ervay Member of the Park City Formation, has yielded stromatolites (Maughan 1987), bryozoans, brachiopods, bivalves, nautiloids, gastropods, scaphopods, crinoids, echinoids (McKelvey et al. 1959), conodonts (Behnken et al. 1986), and fish fragments (Yochelson and van Sickle 1968).

- Finally, the Shedhorn Sandstone has yielded sponge spicules (Sheldon 1963), bryozoans, brachiopods, bivalves, gastropods, scaphopods (Yochelson and van Sickle 1968), invertebrate traces (Andersson 1985), and bones and teeth of cartilaginous fish, ray-finned fish, and indeterminate fish (Yochelson and van Sickle 1968).

Dinwoody Formation

The Dinwoody Formation of GRTE and the vicinity is primarily composed of brownish-gray to olive-drab hard siltstone, with thin layers of sandstone and silty limestone. It is 60 to 75 m (200 to 250 ft) thick, and is found on the west slope of Forellen Peak and in the vicinity of Elk Ridge (Love et al. 1992). It is sometimes divided into a basal silty limestone unit, a *Lingula* (brachiopod) zone, and a *Claraia* (bivalve) zone (Ciriacks 1963), but this has been challenged (Paull and Paull 1993), and it may be considered indivisible (Paull et al. 1989). Redbeds and gypsum are more common in the east, and limestone is more common in the west (Paull and Paull 1983).

The Dinwoody Formation is a marine unit, deposited on a shallow, locally restricted shelf during a transgression-regression cycle (Paull and Paull 1993). The transgression arrived from the west and spread rapidly over the level erosional surface (Paull and Paull 1993), followed by a drawn-out and fluctuating regression (Picard 1993). Distinct basinal, outer shelf, inner shelf, and redbed facies are present. Inner shelf facies are succeeded by redbed facies at GRTE (Paull et al. 1985). The formation dates to the Griesbachian age of the Early Triassic (approximately 252 to 251 Ma) (Paull and Paull 1993). The contact with the overlying Chugwater Formation (see below under "Potential Sources of Paleontological Resources") is vertically and laterally transitional (Paull and Paull 1993), and has been plotted differently by different authors (Paull and Paull 1983, 1993).

The Dinwoody Formation is fossiliferous within GRTE. At Wilcox Point, it has yielded bellerophontid gastropods and conodonts (Paull et al. 1989). Nearby, some brachiopods and bivalves have been found in the formation at Moose Creek in the Tetons south of GRTE (Wanless et al. 1955), and the *Lingula* zone of the formation has yielded some fossil fragments and burrow casts in Gros Ventre Canyon east of GRTE (Ciriacks 1963). Fossils from the Dinwoody Formation over its entire depositional area are not notably abundant (Paull and Paull 1983), but include brachiopods, bivalves, ammonites, gastropods, scaphopods, "serpulid" worm tubes (these are often misidentified), crinoids, echinoids, ophiuroids (brittle stars), conodonts, bioturbation (Paull et al. 1985), invertebrate burrows and trails, and fish (Paull and Paull 1987). Bivalves, gastropods, and "serpulids" are known from the inner shelf facies present in the GRTE area (Paull et al. 1985).

Sundance Formation (Middle–Upper Jurassic)

The Sundance Formation of GRTE, JODR, and the immediate vicinity is divisible into lower and upper sections. The lower Sundance

Formation is a fossiliferous unit composed of gray lime-rich shale, red shale, clay-rich limestone, and limestone, 120 to 170 m (400 to 550 ft) thick. The overlying upper Sundance Formation is composed primarily of lime-rich gray, buff, and green sandstone, with a few thin beds of shale and fossiliferous limestone. It is 23 to 43 m (75 to 140 ft) thick. It is mapped with the underlying Gypsum Spring Formation (see below under "Potential Sources of Paleontological Resources") in the area of the parks, and the two can be found in several areas: around Harem Hill and south of Blacktail Butte in GRTE, and in south-central JODR (Love et al. 1992). Some other names have also been applied to these rocks in the Tetons: at least one early reference to the area uses the Ellis Formation name for the Sundance Formation and other rocks (Iddings and Weed 1899), Wanless et al. (1955) identified the lower Sundance Formation as the Twin Creek Formation and the upper Sundance Formation as the Preuss and overlying Stump formations, and some of Imlay's publications (Imlay 1956a, 1967) prefer to use the Twin Creek Limestone name for the Gypsum Spring–lower Sundance rocks in the GRTE area.

The Sundance Formation is sometimes divided into a number of members, but in the GRTE area it is most commonly divided into lower and upper sections. The lower and upper Sundance are roughly equivalent to the Rierdon and Swift formations as used in Montana, respectively, and are separated by the J-3 regional disconformity (Kvale et al. 2001). The lower Sundance includes strata that are equivalent to, from oldest to youngest, the Canyon Springs Sandstone, Stockade Beaver Shale, Hulett Sandstone, and Lak members of the Sundance Formation, and the upper Sundance includes equivalents of the Pine Butte and Redwater Shale members (Imlay 1953, Kvale et al. 2001, Mickelson et al. 2006a).

The Sundance Formation is primarily a marine unit, deposited by the Sundance Sea, a shallow continental marine body that encroached from the northwest (Harris and Lacovara 2004). The various members track the extent of the sea. In ascending order, the Canyon Springs Sandstone Member has been interpreted broadly as representing littoral marine deposition, the Stockade Beaver Shale as a brackish lagoon, the Hulett Sandstone Member as littoral, the Lak Member as a hypersaline lagoon, the Pine Butte Member as littoral, the Redwater Shale Member as an open marine shelf, and the Windy Hill Member as littoral (Wright 1974). The presence of terrestrial tracks shows some periods of subaerial exposure during the deposition of both the lower (Kvale et al. 2001, Mickelson et al. 2006a) and upper Sundance Formation (Harris and Lacovara 2004). Tidal flats facing the sea on the southwest were sometimes present in the Bighorn Basin during deposition of the early part of the lower Sundance Formation, under a climate that was at least seasonally arid (Mickelson et al. 2006a). It appears that one large transgression-regression cycle with three smaller subcycles occurred during deposition of the lower part of the formation, and one or two occurred during deposition of the upper part. The lower Sundance cycle is separated from the upper Sundance cycle or cycles by the J-3 unconformity mentioned above, and another regional unconformity (J-4) marks the division of the two potential Upper Sundance cycles (Kvale et al. 2001). Deposition of the Sundance Formation occurred during the Middle and Late Jurassic, from the Bathonian to the Oxfordian ages (between 168 and 157 Ma) (Kvale et al. 2001, Mickelson et al. 2006a), albeit with significant internal hiatuses (Kvale et al. 2001). The upper contact with the possible Morrison

Formation in the Teton Range may or may not be conformable (Love 1956a).

The Sundance Formation of GRTE and JODR has long been recognized as fossiliferous. Fossils that can be attributed to GRTE or JODR include brachiopods, bivalves, belemnites, gastropods, crinoids, and echinoids. The exact location of some of the localities within the two NPS units is uncertain, but the localities are all in the same general area and systematic prospecting would probably reveal the same fossils in both GRTE and JODR. Iddings and Weed (1899) and Stanton (1899) both reported the presence of fossils in Jurassic rocks within what is now GRTE and JODR; although it cannot be established for certain what modern formation is being discussed, it is most likely that the fossils are from the Sundance Formation because it is by far the most fossiliferous of the Jurassic formations in the area, the fossils are typical for this formation, and similar fossils are definitely known from the formation in the study area, including probably some of the same localities. Iddings and Weed (1899) reported the Ellis Formation as fossiliferous on the north side of a hill north of Owl Creek, which is within JODR, but did not specify what types of fossils were present. Stanton (1899) reported fossils from several localities that appear to be within JODR or GRTE. One locality, 5 km (3 miles) south of the mouth of Glade Creek on the west side of the Snake River, is most likely on the north side of Harem Hill in GRTE; this locality has yielded belemnites. Others of Stanton's (1899) localities are more difficult to precisely place, but are in either JODR or northern GRTE. One locality, north of Berry Creek and west of the Snake River, could also be in the Harem Hill area of GRTE, or in the area of Iddings and Weed's (1899) Ellis Formation locality in JODR; this locality has yielded bivalves, crinoids, and echinoids. The bivalve *Astarte meeki* was described from syntypes possibly including one from this area (Stanton 1899), and the echinoid *Holectypus pealei* was described from this area (not within YELL) in the Sundance Formation (Clark and Twitchell 1915, Miller 1928). Another locality, on a ridge southwest of the second crossing of the Snake River, just south of YELL, is somewhere in JODR; it has yielded bivalves. Finally, there have been several discoveries from a locality 6 km (4 miles) south of the second crossing of the Snake River on the west side. This site may be in south-central JODR, or in the vicinity of Harem Hill in GRTE. Stanton (1899) found brachiopods, bivalves, and belemnites at this site. More recently, Tracy (2003) collected bivalves, belemnites, and gastropods from Harem Hill in GRTE, and reported the presence of bryozoans and brachiopods as well.

Fossils are also common in the vicinity. The lower Sundance Formation east of GRTE has yielded bivalves, and the upper Sundance Formation has bivalves (abundant enough to form coquinas) and crinoids (Love et al. 1948). Brachiopods, bivalves, belemnites, and crinoids are found throughout the sections studied by Wanless et al. (1955) south and east of GRTE in their Twin Creek and Stump formations. The bivalve *Gryphaea* is particularly common, and even dominates beds in the two formations. A variety of bivalves and ammonites are present in Imlay's "Twin Creek Limestone" (lower Sundance Formation equivalent) north of Little Slide Lake (Imlay 1953, 1956a, 1967).

Overall, rocks from the lower Sundance Formation (Canyon Springs Sandstone to Lak members) have yielded a variety of marine fossils, mostly from the Stockade Beaver Shale Member. The assemblage includes foraminifera (Loeblich and Tappan 1950), dinoflagellates (a

type of algae that moves using flagella), other microfossils, corals, bryozoans (Kvale et al. 2001), brachiopods, bivalves, ammonites, belemnites (Imlay 1947), gastropods (Breithaupt et al. 2001), worm tubes (Imlay 1956b), ostracodes (Peterson 1954, Wright 1974, Swain 1998) and other crustaceans (Herrick and Schram 1978, Feldmann 1979), asteroids (sea stars) (Miller and Unklesbay 1943), crinoids (Imlay 1947), echinoids (Imlay 1956b), general bioturbation (Rautman 1975), marine invertebrate trace fossils such as borings (Tang 1997; Conroy et al. 2002) and fecal pellets (Stone and Vondra 1972), hybodont sharks, several types of early bony fish (Schaeffer and Patterson 1984), and dinosaur tracks (Kvale et al. 2001, Breithaupt et al. 2001, 2006, Adams et al. 2004, Matthews et al. 2006).

Fossils from the upper Sundance Formation across its depositional area are best known from the Redwater Shale Member, which has a very diverse fossil assemblage. Plants are represented by wood (Brenner and Davies 1974, Pipiringos and Imlay 1979). Invertebrates are abundant, and marine vertebrates are occasionally found (O'Keefe and Street 2009). The invertebrate fossil assemblage of the Redwater Member includes foraminifera (Loeblich and Tappan 1950), brachiopods (Brenner and Davies 1973), bivalves, ammonites, belemnites (Imlay 1947), gastropods, scaphopods (Specht and Brenner 1979), the lobster-like decapod crustacean *Eryma* (Wahl 2004), ostracodes (Swain and Peterson 1951, 1952), asteroids (Blake 1981), crinoids, echinoids, polychaete worm tubes, and other invertebrate trace fossils (Specht and Brenner 1979). Vertebrates reported from the member include hybodont sharks (Wahl 2005), a more derived shark (Massare et al. in press), the ichthyosaur (dolphin-like marine reptile) *Opthalmosaurus* (formerly known as *Baptanodon*) (Massare et al. 2006), plesiosaurs *Megalneusaurus* (Wahl et al. 2007), *Pantosaurus* (O'Keefe et al. 2009), and *Tatenectes* (O'Keefe and Street 2009), a purported crocodylomorph (Marsh 1895), indeterminate reptile bones (Specht and Brenner 1979), and unusual reptile tracks (Harris and Lacovara 2004). Ichthyosaurs are the most common large reptiles, and belemnites appear to have been a major food source (Massare et al. in press).

Finally, there are some reports of fossil material from an unspecified or undetermined member or portion of the Sundance Formation. Most notable among these are pollen of conifers and other gymnosperms, and insect fossils, including hemipterans (true bugs), beetles, and caddisfly larvae (Santiago-Blay et al. 2001).

Mowry Shale (Upper Cretaceous)

The Mowry Shale of the GRTE and JODR area is a dark, hard, brittle shale unit, with some sandstone and cream-colored bentonite beds. It is 150 to 210 m (500 to 700 ft) thick, and is mapped with the underlying Thermopolis Shale (see below under "Potential Sources of Paleontological Resources") (Love et al. 1992). Historically, the definitions of the Thermopolis Shale, Mowry Shale, and overlying Frontier Formation have varied, because of the lack of obvious disconformities or changes in lithology. The U.S. Geological Survey has preferred to include a sandstone bed known as the Muddy Sandstone and an overlying interval of black shale in the underlying Thermopolis Shale, but other authors have elected to include the upper Thermopolis Shale in the Mowry Shale, giving the Muddy Sandstone its own formation or including it in the Mowry Shale as well (Reeside and Cobban 1960). In the Jackson Hole area, the presence of the "upper black shale of the Thermopolis shale" is equivocal.

Instead, the Muddy Sandstone is the upper part of the Thermopolis Shale, and the contact with the Mowry Shale appears to be intertonguing (Love 1956a). The upper contact with the Frontier Formation has also varied, based on authors' opinions regarding an upper volcanic tuff zone (Reeside and Cobban 1960). Love (1956a) reported that the contact in the Jackson Hole area is at a sharp change between Mowry shales and coarse grained Frontier Formation sandstone. The age of the Mowry Shale is frequently given as late Early Cretaceous in older reports, but advances in radiometric dating and refinement of the Cretaceous time scale have allowed a more precise placement. Recent works have tended to bracket the formation with a pair of bentonite beds dated within the early Late Cretaceous. They are the Arrow Creek Bentonite, dated to 98.52±0.41 Ma, and the Clay Spur Bentonite, dated to 97.17±0.69 Ma (Scott et al. 2009). The base of the formation is probably slightly older in the Jackson Hole area, depending on the presence and assignment of "upper Thermopolis black shale", which has ammonites indicating that it dates to between 98.74±0.59 and 98.54±0.70 Ma (Druckenmiller 2002).

The Mowry Shale is an offshore marine formation (Merewether 1996), deposited within the Western Interior Seaway (Franczyk et al. 1992). If the "upper black shale of the Thermopolis Shale" is included, then there are two transgressions represented, one for the "black shale" (Eicher 1960), and one for the rest of the Mowry Shale. The sea arrived from the north-northwest, transgressing from what is now Alberta and Saskatchewan (Wulf 1962). In Wyoming, it spread west to east (Byers and Larson 1979). It is uncertain if the northern part of the Seaway system, which included the GRYN, was connected to the southern part during the deposition of the Mowry Shale; they were not connected during deposition of the "black shale" (Eicher 1960), but they may have been connected near the end of deposition (Eicher 1965). Volcanoes west of the seaway, perhaps in what is now Idaho, contributed to the rocks of the formation (Reeside and Cobban 1960).

The Mowry Shale is fossiliferous within GRTE, where it has yielded fragmentary plant fossils (Tracy 2003), but is not known to be fossiliferous within JODR. Plant fragments have also been found at Upper Slide Lake to the east of GRTE (Love et al. 1948). The bulk of the reported fossils from the Mowry Shale in the vicinity are sparse fish scales, but ammonites have been reported near the mouth of Slate Creek and near Green River Lakes to the southeast (Love 1956a).

The Mowry Shale over its entire depositional area has a small but growing fossil assemblage. Non-animal organisms are represented by foraminifera, radiolarians, dinoflagellates, spores, pollen (Oboh-Ilkuenobe et al. 2007), coal (Uyger and Picard 1985), tree ferns (Ash and Read 1976), angiosperm leaves (Stewart et al. 1994), and other plant remains (Uyger and Picard 1985). Invertebrates include bryozoans (Maione 1971), bivalves (Reeside and Cobban 1960), and ammonites (Maione 1971, Molenaar and Wilson 1990); they are also represented by impressions of cephalopods (Brown and Vokes 1944, Connely and Talbot 2005), burrows, and local bioturbation (Davis et al. 1989, Merewether et al. 2010). The bottom sediments often show little evidence of burrowing animals, indicating anaerobic bottom waters (Byers and Larson 1979). Vertebrates are represented by sharks and other cartilaginous fish (Hamblin et al. 2000, Cicimurri 2004, Gregson et al. 2010), ray-finned fish (Hamblin et al. 2000, Stewart and Hakel 2006), the

ichthyosaur *Platypterygius* (Nace 1939, Massare and Dain 1989, Maxwell and Kear 2010), a long-necked elasmosaurid plesiosaur, a short-necked plesiosaur, a crocodylomorph (Massare and Dain 1989), a pterosaur (Bennett 1989), and possible vertebrate trace fossils (Burford 1985, Connely and Talbot 2005, Trumbull and Connely 2010). Fish scales and bone fragments are abundant (Maione 1971; Molenaar and Wilson 1990). Fossils from the "upper black shale of the Thermopolis shale," if it is indeed present and included in the Mowry Shale, include foraminifera, radiolarians (Eicher 1960), the tree fern *Tempskya* (Ash and Read 1976), bivalves, ammonites, crabs, ray-finned fish scales, turtle shell fragments (Eicher 1960), and the plesiosaur *Edgarosaurus* (Druckenmiller 2002).

Frontier Formation (Upper Cretaceous)

The Frontier Formation of GRTE, JODR, and the immediate vicinity is composed primarily of gray sandstone, with beds of dark shale and coal throughout, and bentonite and light-colored porcellanite (impure chert) beds in the lower part of the formation. It is up to 330 m (1,000 ft) thick. The formation has been mapped in areas along the northeastern shore of Jackson Lake and a small area on the southeastern boundary of GRTE, and in several areas of central and eastern JODR (Love et al. 1992). Although it has been divided into a variety of members depending on location, members have not been formally designated in GRTE or JODR (Love 1956a, Love and Reed 1973, Love et al. 1992).

The Frontier Formation is stratigraphically complex (Merewether et al. 1979), and includes a number of internal hiatuses (Merewether et al. 1979, 2010). Thus, the duration of deposition varies between areas. At Upper Slide Lake to the east of GRTE, the Frontier Formation includes a lower interval predating 95.73±0.51 Ma, a middle interval dating to between about 93.48±0.58 and 92.46±0.58 Ma, and an upper interval dating before about 88.55±0.59 Ma, separated by hiatuses (Merewether et al. 2010). These intervals are not named, but the lower interval occupies the same time frame as the Belle Fourche Member of greater Wyoming, the middle interval occupies the Emigrant Gap Member zone (Merewether et al. 2010), and the upper interval occupies the Wall Creek Member zone (Johnson 2008). Other members are used to the south and southeast of Jackson Hole, including on the Gros Ventre River. They include in ascending order the Chalk Creek, Coalville, Allen Hollow, Oyster Ridge Sandstone, and Dry Hollow members (Myers 1977, Merewether et al. 1984, Hill 1987). The upper contact of the Frontier Formation with the Cody Shale is gradational and arbitrary (Love et al. 1948), but is rarely exposed (Love 1956a).

The Frontier Formation is primarily a marine unit (Love and Reed 1973), but also has deltaic and fluvial beds in the area (Leier and Steidtmann 2009). Unlike the underlying Mowry Formation, the northern and southern parts of the Western Interior Seaway were connected during Frontier Formation deposition (Scott et al. 2001). A series of deltas formed on the western side of the seaway (Burgess 1971; Ryer 1977). South and southeast of Jackson Hole, the formation includes two wedges of terrestrial deposits, separated in time by a marine transgression (Hill 1987).

The Frontier Formation is fossiliferous in GRTE. Fossils that have been collected from the Frontier Formation on the east side of Jackson Lake in GRTE include foliage of the fern *Anemia*, the conifer *Protophyllocladus*, and the angiosperms *Aralia*, *Dryophyllum*, and *Trochodendroides*. They are found on Frontier

Formation boulders scattered along the shore of the lake (Tracy 2003) (GRTE Figure 4). The Frontier Formation is also extensively fossiliferous in the immediate vicinity. The porcellanites are known as a source of plant fossils similar to those found east of Jackson Lake. Plant fossils have been found in southern YELL, west of Togwotee Pass, and at Little Sheep Mountain southeast of Bacon Ridge. Sandstone beds have yielded abundant bivalves and ammonites (Love 1956a). Cobban (1951) described some ammonites from east of GRTE. Coaly shale beds have also been found (Love 1956a). Coal, plant fragments and stems, a petrified log, bivalves, and gastropods have been found east of GRTE at Upper Slide Lake (Love et al. 1948).



GRTE Figure 4. A leaf (Dryophyllum?) from the Frontier Formation of GRTE (VLS).

Overall, the Frontier Formation includes diverse fossils, befitting its transitional coastal origin note, though, that because of the formation's stratigraphic complexity and variability, at least some of these reports may not be relevant to GRTE or JODR. Palynomorphs and inorganic microfossils include acritarchs (Merewether 1996), microspheres (Upshaw 1963), calcareous nannofossils (Fisher and Hay 1999), foraminifera (Young 1951, Eicher 1967, Molenaar and Wilson 1990), radiolarians (Blome and Eicher 1994), chlorophyte algae (Tysdal et al. 1990), charophyte algae (Jones 1954), dinoflagellates and other microplankton, spores, and pollen (Upshaw 1964, Tysdal et al. 1990). The formation has a significant floral assemblage, first collected by the explorer John C. Frémont from southwestern Wyoming in 1843. It includes horsetails, ferns, cycadophytes (cycads and relatives), conifers, and monocot and dicot angiosperms (Knowlton 1917, Berry 1930, Andrews and Pearsall 1941). Coal and wood are common (Uygur and Picard 1985, Moslow and Tillman 1986, Merewether et al. 2010), and root traces have also been found (Moslow and Tillman 1986). Invertebrates are represented by corals (Merewether 1996), bryozoans (Merewether and Cobban 2008), brachiopods (Merewether et al. 2010), bivalves, ammonites (Young 1951, Upshaw 1964, Merewether et al. 1984, Merewether and Cobban 2008), nautiloids (Cobban 1990), gastropods (Young 1951, Upshaw 1964; Merewether et al. 1984, Merewether and Cobban 2008), worm tubes (Merewether and Cobban 2008), nonmarine ostracodes (Jones 1954), crabs (Merewether and Cobban 2008), echinoids (Upshaw 1964, Merewether and Cobban 2008), and trace fossils, including invertebrate burrows (Merewether et al. 1979, Molenaar and Wilson 1990), and general bioturbation (Maione 1971). Vertebrates are represented by sharks, rays, gars, pycnodont fish (Breithaupt 1985), coelacanths (Cicimurri 2001), turtles (Breithaupt 1985), the ichthyosaur *Platypterygius* (Maxwell and Kear 2010), long-necked and short-necked plesiosaurs (Cicimurri 2001), squamates (lizards and snakes) (Breithaupt 1985), crocodile relatives (Williston 1905), pterosaurs (Cicimurri 2001), and dinosaurs (Breithaupt 1985), including washed-in skeletons of the armored dinosaurs *Nodosaurus* and *Stegopelta* (Carpenter and Kirkland 1998). Reworked Paleozoic clasts with

fossils including corals, bryozoans, brachiopods, crinoids, and conodonts have also been found (Dyman et al. 1989).

Cody Shale (Upper Cretaceous)

The Cody Shale of GRTE, JODR, and the immediate vicinity is composed mostly of gray shale, with some gray and black siltstone and sandstone. It is 425 to 670 m (1,400 to 2,200 ft) thick, and has been mapped northeast of Jackson Lake in GRTE and on the west side of the Parkway in JODR (Love et al. 1992). It thins substantially from southeast to northwest in the Jackson Hole area, and is equivalent to the lower half of the Cody Shale in the Bighorn Basin to the east and the lower Hilliard Shale to the south (Love 1956a). Some researchers prefer the Hilliard Shale name in the area (Boyd 1995).

The Cody Shale is an offshore marine formation (Lillegraven and McKenna 1986, Leier and Steidtmann 2009). It was deposited during a marine transgression with smaller regressive cycles. Volcanism occurred during deposition, contributing to the rocks (Windolph et al. 1986). The upper contact with the Bacon Ridge Sandstone is probably transitional (Love 1956a). The base of the formation dates to around 88.55±0.59 Ma in the area, in the middle Coniacian (Merewether et al. 2010), based on the presence of the ammonite *Scaphites ventricosus*. Although the upper part of the formation can be as young as Campanian (83.6 to 72.1 Ma) (Johnson 2008), this is in areas where the Bacon Ridge and Sohare formations are not present; the Bacon Ridge Sandstone is equivalent in part to the Cody Shale (Davidson 1987), and in the Jackson Hole area has yielded the ammonite *Scaphites ventricosus* var. *stantoni* (now assigned to *S. depressus*) (Love 1956a). The *Scaphites depressus* zone is the next youngest zone, spanning the early Coniacian and including a date of 87.14±0.39 Ma (Cobban et al. 2006). This indicates a relatively short duration for the Cody Shale in the Jackson Hole area.

Stanton (1899) reported a fossiliferous site in a sandstone unit at the mouth of Glade Creek, now within JODR, but the exact formation is unclear. Fossils reported by Stanton (1899) include bivalves *Inoceramus acuteplicatus* (including a syntype of the species; now known as *Inoceramus stantoni* because *acuteplicatus* was preoccupied [Sokolov 1914]), *Anomia* sp., *Avicula nebrascana*, *A. linguaeformis*, *Baroda wyomingensis*, common *Cardium pauperculum*, *Mactra warrenana*, and *M. arenaria*, ammonite *Scaphites* cf. *ventricosus*, and gastropods *Gyrodes depressa* and *Pyrula*? sp. At this time, Cretaceous rocks in this area were divided into formations including the Colorado Formation and overlying Montana Formation, and the Glade Creek site was interpreted as being younger than the Colorado Formation but not necessarily in the Montana Formation. By lithology, modern usage, and geologic maps of the area, the most likely candidates are the Frontier Formation, Cody Shale and Bacon Ridge Sandstone. Cobban et al. (1958) reported that the types of *Inoceramus stantoni* were found in the Cody Shale, and that it is typical of the *Scaphites ventricosus* zone (Upper Coniacian; Cobban et al. [2006]), which further supports such an assignment. Therefore, the Glade Creek site is tentatively interpreted as the Cody Shale; however, there is some possibility that the rocks are actually in the Bacon Ridge Sandstone, at least in JODR, because it also includes the *Scaphites ventricosus* zone (Davidson 1987) and is exposed much more extensively in the relevant area of the parkway (Love et al. 1992).

Microfossils, bivalves and ammonites are found throughout the formation in the Jackson Hole area. One microfossil site at Blackrock Meadows, 20 km (12 miles) east of GRTE, has yielded foraminifera and ostracodes (Love 1956a). Cobban (1952) described ammonites from locations including a site on the east fork of Arizona Creek, just east of GRTE, where inoceramid bivalves were also present. Cody Shale rocks at Upper Slide Lake have yielded bivalves, ammonites, gastropods, and shell fragments (Love et al. 1948). Overall, the fossil record of the Cody Shale includes marine palynomorphs (Entzminger 1979), foraminifera, bivalves, ammonites (Love 1956a), belemnites (Fox 1954), nautiloids (Reeside 1927), serpulid worm tubes (Reeside 1927), ostracodes (Love 1956a), barnacles (Reeside 1927), crinoids (Cobban 1995), invertebrate trace fossils including burrows (Merewether et al. 2010) and strike marks of ammonite shells on the seafloor (Landman and Cobban 2005), and shark teeth (Fox 1954).

Bacon Ridge Sandstone (Upper Cretaceous)

The Bacon Ridge Sandstone and most of the formations above are of limited distribution, often only found in northwestern Wyoming. In GRTE, JODR, and the immediate area, it is primarily composed of tan and gray sandstone bearing abundant marine fossils, with some interbedded gray shale and siltstone, mineable deposits of coal, bentonite beds low and high in the formation, and conglomerate low in the formation. It is 330 to 460 m (1,000 to 1,500 ft) thick, and has been mapped northeast of Jackson Lake and in the Elk Ranch Reservoir area of GRTE, and in south-central JODR (Love et al. 1992).

The Bacon Ridge Sandstone is a marine formation, deposited during the last extensive Cretaceous marine transgression of the Jackson Hole area. At the time, Jackson Hole was near the western shore of the seaway (Love 1956c). Depositional settings of this marginal marine formation include shorefaces, lagoons, rivers, and tidal channels. A long-lived river system feeding a major fan may have passed through Jackson Hole (Leier and Steidtmann 2009). The lower part of the formation has more of a marine influence, and the upper part is more terrestrial. Local uplift resulted in regression, overcoming a rising sea level. Volcanoes to the west in what is now Idaho contributed sediment (Davidson 1987). As discussed above in the Cody Shale section, the formation has yielded the ammonite *Scaphites depressus* var. *stantoni* (Love 1956a), indicating an early Coniacian age circa 87.14±0.39 Ma (Cobban et al. 2006) for part. Deposition continued into the following Santonian age (86.3 to 83.6 Ma) (Love 1990, Leier and Steidtmann 2009). The upper contact with the Sohare Formation (see below under "Potential Sources of Paleontological Resources") is conformable and is defined arbitrarily (Love et al. 1948, Love 1956a).

The Bacon Ridge Sandstone is not definitely known to be fossiliferous at GRTE and JODR, but should be treated as such. Coal beds and abundant marine fossils are reported from the Colter Bay quadrangle of GRTE (Love and Reed 1973) and the Two Ocean Lake quadrangle, which includes part of GRTE (Love 1973b). Although this may be recycled map text, it is safer for the purposes of resource management to consider these fossils as present, de facto. Additionally, there are some Upper Cretaceous ("Montana Formation") fossils from "near the second crossing of the Snake River," which should be within JODR, but the exact location and stratigraphy are uncertain. They include bivalves and ammonites (Stanton 1899). The most likely source is the Bacon Ridge Sandstone, if it is assumed that Stanton's

Inoceramus acuteplicatus assemblage is from the Cody Shale, and that this second fauna is in younger rocks, as Stanton reported.

The Bacon Ridge Sandstone is abundantly fossiliferous in the immediate vicinity of the parks. In the Jackson Hole area, the basal sandstone has abundant fossils of the bivalve *Inoceramus*. Above it, there is a persistent "pearl-gray marker zone" which frequently has thin coal beds, impressions of leaves of *Trapa microphyllum* (water chestnut), and seeds, and sparse marine fossils. The rest of the formation above it has sparse coal beds. Ammonites are also known from the formation in the area (Love 1956a). On Upper Slide Lake, fossils including microfossils, coal, bivalves, ammonites, gastropods, and a coquina of "small poorly preserved shells" have been found (Love et al. 1948). The Bacon Ridge Sandstone is part of the Jackson Hole coal field, mostly found northeast of GRTE but present in the Two Ocean Lake area. It is the most productive of the various formations in the field (Jones 1982). Coal was mined from the formation near Lava Creek Bridge just outside of GRTE along what is now Highway 287, from 1910 to 1916 (Love and Love 1980).

Overall, the fossil assemblage of the Bacon Ridge Sandstone includes foraminifera (Davidson 1987), marine palynomorphs (Entzminger 1979), coal, plant fragments, carbonized wood, petrified wood and stumps (Love et al. 1948), root traces (Davidson 1987), bivalves, ammonites, gastropods, shark teeth, reptile bones, indeterminate fragments (Love et al. 1948), invertebrate trails and burrows (Davidson 1987), and bioturbation (Leier and Steidtmann 2009). Marine microfossils and mollusks are more common low in the formation, while coal and other plant remains are more common higher up (Davidson 1987).

Meeteetse Formation (Upper Cretaceous)

The Meeteetse Formation of GRTE and the immediate vicinity is composed of interbedded white to gray sandstone, yellow, green, or dark gray carbonaceous shale, coal beds, white tuff, yellow to gray bentonite, and conglomerate. It is up to about 330 m (1,000 ft) thick, and is found in a string of outcrops from Two Ocean Lake to Elk Ranch Reservoir in eastern GRTE. Except for one area of outcrops east of the Two Ocean Lake area of the park on the west side of the Whetstone anticline, it appears that all of the mappable areas of this formation in the Jackson Hole area are within GRTE, on the west side of the Spread Creek anticline (Love et al. 1992). This formation is much more widely exposed in the Bighorn and Wind River basins to the east and southeast, and Love (1956a) qualified the identification of the formation in Jackson Hole, reporting that the outcrops "are believed to be a western equivalent of the Meeteetse Formation." More recent reports and maps have not qualified the description; see for example Love and Reed (1968) or Love et al. (1992).

Deposition of the Meeteetse Formation took place on a poorly drained coastal plain west of the Western Interior Seaway (Johnson 2008). To give some idea of the envisioned topography, deposition is thought to have been near sea level in Jackson Hole, but the sea itself was some 150 miles to the east in the Bighorn Basin at the time (Love 1956c). Fluvial, lagoonal, coastal swamp, littoral, and nearshore marine deposits have been reported, with more of a marine influence to the east and southeast in the Bighorn and Wind River basins (Lillegraven and McKenna 1986). In the Bighorn Basin, it intertongues with marine rocks (Wegweiser 2006). A brief westward transgression occurred early on during its deposition, followed by regression (Windolph et al. 1986). Some early Laramide uplift was also

occurring; the seaway's position was influenced by the early Wind River Mountains (Johnson 2008). The Meeteetse Formation is dated to the late Campanian and early Maastrichtian ages (Johnson [2008]; the boundary is at 72.1 Ma). There is a tuff dated to 73.1±0.7 Ma low in the formation (Leier and Steidtmann 2009), and the Big Cedar Ridge tuff near the middle of the formation is dated to 72.7±1.43 Ma (Wing et al. 2012). As a coastal formation, deposition is time-transgressive (Wegweiser 2006).

The Meeteetse Formation appears to be fossiliferous within GRTE. Love (1956a) reported that fragments of horsetails, ferns (*Asplenium* sp.), and angiosperms (*Platanus* sp.) had been found in a "chalky-white tuffaceous sandstone" north of Spread Creek Canyon and on the west limb of the Spread Creek Anticline. By geography and the known distribution of outcrops, this has to be within GRTE, but the exact productive location is not certain; the nearest mappable outcrop in that area is just north of Elk Creek Reservoir (Love et al. 1992), but there could be smaller unmappable outcrops in that area as well. Additionally, thin coal beds are part of the lithology in the Jackson Hole area (Love 1956a, Love et al. 1992), and because almost all of the outcrops are in GRTE, coal should be considered as present too. The coal is not considered mineable in Jackson Hole (Jones 1982).

The fossil assemblage of the Meeteetse Formation in Jackson Hole is limited to the coal and fragmentary horsetail, fern, and angiosperm foliage reported from GRTE (Love 1956a). Fossils reported from the Meeteetse Formation in the Bighorn and Wind River basins include coal (Windolph et al. 1986), lycopsids (clubmosses), ferns, cycads, conifers, angiosperms (Wing et al. 1993, 2012, Strömberg et al. 2007), bioturbation, invertebrate traces including possible sea anemone resting traces (Matthews et al. 2003) and logs and wood bored by shipworms (Wroblewski and Gulas-Wroblewski 2002), ray teeth, gar scales, fragments of turtles and dinosaurs (Shin 2003), digested crocodile teeth (Wegweiser 2006), a fragmentary skeleton of a hadrosaurid dinosaur (Storrs 1991a), and dinosaur tracks (Matthews et al. 2003). Some of the vertebrate remains are marked by ancient fires (Wegweiser 2006). Plant fossils are particularly abundant at the Big Cedar Ridge locality in the southeastern part of the Bighorn Basin in central Wyoming (Wing et al. 1993, 2012).

Harebell Formation (Upper Cretaceous)

The Harebell Formation of GRTE and the immediate vicinity is a variegated unit composed of conglomerate, tuffaceous sandstone and claystone, and tuff. It can be up to 3,300 m (10,000 ft) thick. Within GRTE, it is present in a corner of the park northeast of Two Ocean Lake (Love et al. 1992). Before it was named, the Harebell Formation was known in the literature as a white sandstone sequence and overlying conglomeratic sandstone sequence (Love et al. 1948). The two facies have been designated the Whetstone Falls and overlying Bobcat members. They have a gradational contact (Harris et al. 1996). It appears that the GRTE outcrops of the formation are limited to the lower sandstone facies (Whetstone Falls Member) (Lindsey 1972), although this is the author's (JST) interpretation because the actual outcrop area mapped by Love et al. (1992) is not depicted in Lindsey (1972); the outcrops mapped in this document within GRTE as the Harebell Formation are now mapped as Pinyon Conglomerate (see below under "Potential Sources of Paleontological Resources") (Love et al. 1992). The lower contact of the Harebell Formation is disconformable (Love 1990), and

its upper contact with the Pinyon Conglomerate is an angular unconformity; the angle of unconformity can be perpendicular (Love 1973a).

The Harebell Formation is lithologically very similar to the overlying Pinyon Conglomerate, and the two have frequently been confused (Love 1973a). For example, the brackish-water fossils first mentioned by Kauffman (1969) were initially thought to be from the Pinyon Conglomerate, but are now known to be from the Harebell Formation (Kauffman 1973). Also, one area of exposures described as part of the sandstone facies of the Harebell Formation (now Whetstone Falls Member) mapped south of Emma Matilda Lake in GRTE (Lindsey 1972) is now mapped as the Pinyon Conglomerate (Love et al. 1992), and a fossiliferous Whetstone Falls site was reclassified from the Pinyon Conglomerate to the Harebell Formation (Love 1973a). The Harebell Formation is predominantly olive drab in color and more indurated, has abundant volcanic debris but little coal, and has some marine influence. The Pinyon Conglomerate is light gray to light brown and less indurated, has much less volcanic debris, has coal, and has no marine influence (Love 1973a).

The Harebell Formation was deposited in a coastal plain to marginal marine setting, near sea level (Kauffman 1973). This formation and the overlying Pinyon Conglomerate were deposited predominantly on subsiding alluvial fans near highlands rising rapidly to the north and west. The predominant paleocurrent was east-northeast (Lindsey 1972). Sediment arrived from the Targhee Uplift to the west and from volcanoes to the north and northwest, with large rivers flowing from the uplift (Love 1973a). The climate is thought to have been warm and humid, not too distant from the sea (Lindsey 1972). Marine tongues advanced twice during its deposition (Harris et al. 1996). At least once a marine tongue reached near GRTE, as shown by brackish-water or marine fossils found north of Two Ocean Lake in an estuarine setting (Kauffman 1973). The sea approached from the southeast (Love 1973a). The formation dates to some part of the Maastrichtian age of the Late Cretaceous (72.1 to 66.0 Ma) (Harris et al. 1996).

The Harebell Formation is fossiliferous in GRTE; Tracy (2003) reported fragmentary plant fossils northeast of Two Ocean Lake. Fossils have also been reported from several localities in the immediate vicinity. Terrestrial and estuarine fossils were recovered from north of Two Ocean Lake, just outside of GRTE. These fossils include acritarchs, hystrichosphaerids (a type of cyst), possible dinoflagellates, spores, conifer and other pollen, various plant macrofossils (angiosperm leaves, fruits, and nuts, among others), soil fungus, brackish-water or marine bivalves and other bivalves, gastropods, and ostracodes (Kauffman 1973). Unusual four-toed and possibly webbed theropod dinosaur tracks (*Saurexallopus lovei*) were found in the Whetstone Falls Member on the southeast side of Whetstone Mountain, just east of GRTE, along with leaf impressions and invertebrate trace fossils (Harris et al. 1996, Harris 1997). Other fossils from Whetstone Mountain and Whetstone Falls include pollen, leaves, and freshwater bivalves and gastropods (Love 1973a). Bivalves and bivalve fragments have been recovered from Wolverine Canyon, just east of JODR (Love 1956b). Like the Meeteetse Formation, the Harebell Formation has some coal in Jackson Hole, but it is not considered mineable (Jones 1982).

Overall, the Harebell Formation fossil assemblage includes marine acritarchs and

dinoflagellates (Love 1973a), hystrichosphaerids, unspecified spores (Kauffman 1973), charophytes, chlorophytes, pollen (Love 1973a), coal, carbonized plant fragments, petrified conifer wood, pond weed seeds (Love et al. 1948), leaves of ferns, ginkgoes, possible cycadophytes, conifers, and angiosperms (Love 1956b), angiosperm fruits and nuts, soil fungus (Kauffman 1973), bivalves, gastropods, ostracodes (Love 1973a), invertebrate traces (Harris et al. 1996), bones and teeth of bowfins, salamanders, crocodiles, dinosaurs including tyrannosaurids, duckbills, and horned dinosaurs, and possible mammals (Love 1973a), dinosaur tracks (Harris et al. 1996), and reworked fossils of the tree fern *Tempskya* and Paleozoic fusulinids (Love et al. 1948). Fossils from the Whetstone Falls Member include charophytes, coal, pond weed seeds, leaves of ferns, conifers, and angiosperms, bivalves, gastropods, ostracodes (Love et al. 1948), invertebrate traces, and dinosaur tracks (Harris et al. 1996).

Colter Formation (Lower–Middle Miocene)

The Colter Formation of GRTE and the immediate vicinity is composed of light gray, green, and brown tuff, sandstone, claystone, and conglomerate. It is up to 1,500 m (4,900 ft) thick. Outcrops have been mapped in GRTE, mostly in an arc from northwest of Two Ocean Lake to east of Emma Matilda Lake, with a few small outliers south of the Snake River and east of Lake Jackson (Love et al. 1992). The formation includes two members, separated by a disconformity (Barnosky 1984a), with erosion during the hiatus (Barnosky and LaBar 1989). The hiatus appears to be part of a regional unconformity (Anders et al. 2009). The lower member is the Crater Tuff-breccia Member, composed of andesitic tuff breccia and tuff erupted by compressional volcanism. Above it is the Pilgrim Conglomerate Member, composed of basaltic tuff, conglomerate, sandstone, and claystone, with extensional volcanism (Barnosky 1984a). The Crater Tuff-breccia Member has late Arikareean and early Hemingfordian mammals (the boundary is at 19 Ma). The Pilgrim Conglomerate Member has Barstovian mammals, and is thought to date to about 14.8 to 13.6 Ma (Barnosky and LaBar 1989). Both members are present in GRTE (Barnosky 1984a).

The Colter Formation includes deposits from a variety of volcanic processes, including lahars, surges, air-falls, and pyroclastic flows (Barnosky 1984a). The eruptive source for the volcaniclastics is thought to have been somewhere near the north end of Jackson Lake (Love 1989a). The mammals indicate a semi-arid to arid climate (Barnosky and LaBar 1989). The lower and upper contacts of the Colter Formation are disconformable (Love 1956b). However, there is some question about the upper contact with the Teewinot Formation, and some rocks described as belonging to the upper Colter Formation may actually belong to the Teewinot Formation (Anders et al. 2009).

The Colter Formation is fossiliferous within GRTE. Barnosky (1986), describing the fossiliferous localities of the formation, included two from within the park. North Pilgrim 2 (UWBM [Burke Museum of Natural History and Culture] loc. CO237) in the Pilgrim Conglomerate Member is just barely within GRTE on the west side of the west fork of Pilgrim Creek. This site has yielded fossils of the mole *Domninoides* sp. cf. *D. storeri*, the pika *Oreolagus colteri* (holotype), the rabbit *Hypolagus*, the ground squirrel *Spermophilus* (*Otospermophilus*), the chipmunk *Tamias* cf. *T. ateles*, the squirrel *Petauristodon*, an indeterminate squirrel, the beaver *Monosaulax* cf. *M. curtus*, the pocket mice *Cupidinimus* sp.

and *Perognathus furlongi*, the heteromyid rodents *Diprionomys agrarius*, *Peridiomys* sp., and *Proheteromys* sp., the geomyid rodents *Lignimus transversus* (holotype) and *Mojavemys magnumarcus* (holotype), and the zapodid rodent *Schaubeumys*. Two Ocean Lake (UWBM loc. CO238) in the Pilgrim Conglomerate Member is a short distance north of Two Ocean Lake (Barnosky 1986). It has yielded fossil root traces, burrows (Barnosky 1984a), and the camel *Aepycamelus* (Barnosky 1986).

Several other fossil sites are just outside of GRTE. The Colter Formation is the source of Colbert's (1943) oreodont and camel fossils from just outside of GRTE on the south fork of Pilgrim Creek (Barnosky [1986]; "Saunders locality"). The Cunningham Hill site (UWBM loc. CO236) in the Pilgrim Conglomerate Member is just east of Triangle Ranch and the park boundary. It has yielded fossils of moles, rabbits, rodents, horses, and pronghorns. East Pilgrim 11 (UWBM loc. CO239) is in the Crater Tuff-breccia Member north of the GRTE boundary on the west side of the east fork of Pilgrim Creek. It has yielded fossils of oreodonts. Finally, East Pilgrim 5 (UWBM loc. CO240) is in the Crater Tuff-breccia Member just north of the GRTE boundary on the west side of the east fork of Pilgrim Creek. It has yielded fossils of horses and oreodonts (Barnosky 1986). Sparse, widely dispersed bone fragments have been found along Pilgrim Creek (Love 1956a). Overall, the fossil assemblage of the Colter Formation includes root traces, burrows (Barnosky 1984a), moles, rodents, pikas, rabbits, horses, oreodonts, camels, and pronghorns (Barnosky 1986).

Teewinot Formation (Middle?–Upper Miocene)

The Teewinot Formation of GRTE and the immediate vicinity is a light-colored unit primarily composed of limestone, claystone, and porcellanite. The lower two-thirds of the formation is composed of thick (30 to 60 m [100 to 200 ft] thick) limestone beds interbedded with pumicite, interrupted by a limestone, quartzite, and obsidian conglomerate 35 m (110 ft) thick in the middle of the formation. The upper third is composed of fossiliferous thin-bedded claystone, marlstone, and tuff. The formation can be over 1,800 m (6,000 ft) thick. It has been mapped in many areas in the Jackson Hole portion of GRTE, mostly in small outcrops in the Blacktail Butte area and along the southeastern boundary, east of the Gros Ventre River. A few outliers are present in the vicinity of Jackson Lake Dam (Love et al. 1992). A basal conglomerate is present in some areas, and the lower and upper contacts of the formation are disconformable (Love 1956b).

The Teewinot Formation was deposited in a lake, known as Teewinot Lake. Lake deposition ended when the middle ancestral Teton–Gros Ventre uplift subsided (Love 1989a). The absence of coarse sediments show that this formation predates movement on the Teton Fault (Lageson et al. 1999, Leopold et al. 2007). A variety of volcanic sources contributed to the sediment, located on the Snake River Plain, within YELL, and in Jackson Hole itself (Love et al. 1997). Pollen indicates moist summers (Leopold et al. 2007) and fluctuations between wetter and drier periods (Barnosky 1984b). The formation is generally thought to date to between about 9.2 Ma (Love 1989b) and 7.5 Ma (Lageson et al. 1999, Leopold et al. 2007); however, its base may be significantly older, as old as 16.33 Ma, if some of the Colter

Formation actually pertains to it, and the upper part may be as young as 5.81±0.011 Ma, in which case the Conant Creek Tuff (5.97±0.01 Ma) was deposited within the Teewinot Formation (Anders et al. 2009).

The formation is fossiliferous within GRTE. The most prominent site is the Kelly Road site, just within GRTE on the northwest side of Kelly Road in Section 19, T42N, R115W. The Kelly Road site, also known as UMMP (University of Michigan Museum of Paleontology)-V20766 (Hibbard 1959) or USGS Cenozoic locality 20766 (Hibbard 1970), has yielded fossils including diatoms (a type of algae with cell walls of silica), pollen, mollusks, ostracodes (Love et al. 1990), the holotype of the shrew *Hesperosorex lovei* (Hibbard 1957), the vole *Microtoscoptes disjunctus* (Hibbard 1959), the beaver *Dipoides*, and bird eggshell (Hibbard 1970) (GRTE Figure 5). An obsidian grit 32 m (106 ft) below the vole fossils has been dated to 9.2 Ma (Hibbard 1970). Additionally, Love (1989b) mentioned the presence of mollusks and 45 species of diatoms (diatom locality 4216) on Signal Mountain. The formation is also fossiliferous just outside of GRTE. Freshwater bivalves, freshwater and terrestrial gastropods have been found in an irrigation ditch just southeast of the park in the same area as the Kelly Road site (Taylor 1956).



GRTE Figure 5. A beaver tooth from the Teewinot Formation of GRTE (VLS).

Overall, the fossil assemblage of the Teewinot Formation includes possible algal limestone (Love 1956a), diatoms (Love 1956b), conifer and angiosperm pollen (Barnosky 1984b, Leopold et al. 2007), conifer seeds, wood, and possible cones, pond weeds, freshwater bivalves, freshwater and terrestrial gastropods, ostracodes, caddisfly larval cases, shrews, voles, beavers (Love 1956b), mustelids (Merritt 1956), and bird eggshell (Hibbard 1970). Some beds can be regarded as diatomites (almost entirely composed of diatoms) or nearly coquinas of mollusks and ostracodes (Love 1956b).

Upper Cenozoic Rocks and Sediments (Pliocene?–Holocene)

Both GRTE and JODR have substantial areas covered by unconsolidated Neogene sediments. The oldest are glacial deposits that may be as old as the Pliocene (Love et al. 1992); note, though, that the Pliocene–Pleistocene boundary has been revised to 2.588 Ma from much younger dates, so deposits described as Pliocene in 1992 may now be considered Pleistocene. The sediments range from fine-grained lacustrine deposits to clasts of gravel-size and larger, and represent a variety of environments and depositional processes, including alluvial, colluvial, floodplain, fluvial, glacial, landslide, lacustrine, loess, swamp, and talus deposits (Christiansen et al. 1978, Love et al. 1992, KellerLynn 2010, NPS 2010).

Common Quaternary fossils of northern Wyoming and southern Montana include bones of large mammals and fossil material useful for paleoecological and paleoclimatological studies, such as pollen and packrat middens. Faunmap (http://www.ucmp.berkeley.edu/faunmap/index.html) and the Neotoma database (http://www.neotomadb.org/) show at least 25 Quaternary fossil sites of both types within

approximately 100 km (60 miles) of GRTE and JODR, as well as seven sites with historic or slightly older (to about 400 AD) faunal remains from the Hermitage Point area of GRTE (48TE111, 48TE114, 48TE1090, 48TE1099, 48TE1102, 48TE1107, and Gull Island). Aside from the recent faunal remains, which for the most part have cultural associations and belong to the zone where paleontology and archeology meet, a variety of fossils have been reported from the Quaternary of GRTE. The best-described site is the Hedrick Pond pollen site, near the Snake River Overlook. This site, in southeastern GRTE, provides a record of the latest Pleistocene and Holocene. The oldest date is 17,160±210 radiocarbon years before present (22,000 to 19,850 calendar years before present) (Steventon and Kutzbach 1988); note that radiocarbon dates are not the same as calendar dates, and that radiocarbon years require calibration to yield calendar years. Dates here were calibrated using Calib 6.0 (http://calib.qub.ac.uk/calib/) where appropriate. Hedrick Pond has yielded pollen and spores of spikemosses, ferns, conifers, and angiosperms (Whitlock 1992, 1993). Shorter cores covering the late Holocene have been taken from Pothole Lake and Swan Lake within GRTE, and used to study changes in the frequency of fires (Jacobs and Whitlock 2006). Mollusks are found in lacustrine deposits, such as the gastropods found in marl in a glacial kettle (K. Pierce, USGS geologist emeritus, pers. comm., May 2013) about 3 km (2 miles) south of Signal Mountain (Love 1956a). These are perhaps related to mollusks from a 9,000-year-old marl near the Cunningham Cabin turnout (Love and Love 1980). Wood and charcoal are also present in the Quaternary sediments. For example, carbonized wood dated to 27,100±800 radiocarbon years before present (33,400 to 30,220 calendar years before present) has been found near Pilgrim Mountain (Love 1956a). There is an unusual case, again perhaps too young to be considered truly paleontological, of drowned trees standing upright in the bottom of Jenny Lake. They are dated to 600±100 yr BP, suggesting that what is now the bottom of the lake has dropped 25 m (80 ft) over that time (Love 1987). Just outside of GRTE, in the area of the Fish Hatchery, gastropods have been found in loess (Love and Love 1980), dating to 19,000±600 radiocarbon years before present (24,200 to 21,310 calendar years before present) per Love (1989b). Lower in the section here are bone fragments and a bison ulna (Love 1989b).

Most of the fossil localities in the vicinity of GRTE and JODR are paleoecological sites. Northwestern Wyoming has a number of pollen sites, most of which are in YELL or the national forests that flank GRTE. These sites are comparable to Hedrick Pond in length of record and fossils. Late Pleistocene–Holocene sites in YELL include Blacktail Pond, Buckbean Fen, Cub Creek Pond, Cygnet Lake Fen, Mariposa Lake, and Slough Creek Pond. Sites in Bridger-Teton National Forest in the immediate vicinity of GRTE and JODR include Divide Lake, Emerald Lake, Fallback Lake, and Lily Lake and Fen (Whitlock 1993). Somewhat farther afield is a cluster of five sites in the Fish Creek Park area, 55 km (34 miles) southwest of GRTE (Lynch 1998). These sites are best known for conifer and angiosperm pollen. Lake cores can also yield significant diatom records, as at Crevice Lake (Whitlock et al. 2006), Lewis Lake (Tiller and Kelts 1994), and Yellowstone Lake (Tiller and Kelts 1994, Theriot et al. 2006), all in YELL. Other fossils from these pollen sites include rhizopods (general amoeba-like protists), charophyte and chlorophyte algae, peat, charcoalized plant fragments, wood, angiosperm fruits, leaves and needles of mosses, conifers, and angiosperms,

palynomorphs of mosses, horsetails, spikemosses, quillworts, and ferns, sporangia, freshwater bryozoans, and cladocerans (water fleas) (Baker 1976, Lynch 1998). There are also some older pollen records, dating back to between 130,000 and 80,000 years ago. Such sites have been found near the southeast end of Yellowstone Lake at Beaverdam Creek, and at Grassy Lake Reservoir just west of JODR. These sites have yielded pollen and various plant macrofossils, including seeds, leaves, fruit, and bracts (Baker 1986).

Another type of paleoecological fossil, known from YELL but not yet reported from JODR or GRTE, is packrat middens. Packrat middens are collections of plant material and food waste constructed by packrats (*Neotoma* spp.) and cemented by their viscous urine. They can be well-preserved in dry caves, and illustrate the environment of the builder's foraging range. Middens are important tools for reconstructing the ecology and climate of the late Pleistocene and Holocene of the southwestern United States (Strickland et al. 2001). Lamar Cave in YELL preserves abundant late Holocene (approximately 3,200 calendar years before present to the present) fossils collected by packrats. They include charcoal, wood, sticks, cones, other plant fragments, mollusks, and bones of fish, amphibians, reptiles, birds, and mammals (Hadly 1996, 1999). Birds from the site include grebes, ducks, shorebirds, coots, grouse, and perching birds (van Tuinen and Hadly 2003). The mammal assemblage includes shrews, various rodents, rabbits, pikas, bats, canids, felids, mustelids (weasels and relatives), bears, deer, elk, bighorn sheep, pronghorns, and bison, with bones collected by packrats from carnivore scat, raptor pellets, and corpses (Hadly 1996). Waterfall Locality along Soda Butte Creek in northeastern YELL is another late Holocene packrat midden site, with bones of rodents, rabbits, and pikas (Steele and Hadly 2002). The YELL midden sites are unusual in that the focus of attention is vertebrate fossils, not plant fossils. Tweet et al. (2012) provided a review of National Park Service midden sites, including a discussion of Lamar Cave.

The nearest substantial Pleistocene megafauna site is Palisades Reservoir, about 17 km (11 miles) southwest of the nearest part of GRTE just over the state line in Idaho. This site has bones of mammoths, mastodons, horses, camels or llamas, bighorn sheep, mountain goats, musk oxen, bison, and other megafauna, and tracks of proboscideans, horses, camels, bison or musk oxen, and possibly other ungulates (Robison et al. 2011).

There are two other types of Quaternary fossil resources that may be found in GRTE or JODR. Caves are present in GRTE (Hill et al. 1976), but are not yet known to be fossiliferous. Caves have excellent potential for Quaternary fossils, as discussed in Santucci et al. (2001), which provided a review of fossils in National Park Service caves. Finally, Persico and Meyer (2009) and Meyer et al. (2010) reported on the history of beaver dams in GRTE and YELL. Although the wood from dams often decays, the presence of a dam creates geomorphic changes in its immediate surroundings. The most obvious sign of a former dam is the presence of a berm across a valley. Gnawed stumps have been found in the vicinity of some dams, and the deposits of ponds behind dams often contain fragments of plants, sometimes gnawed by beavers (Persico and Meyer 2009). Beaver pond deposits from throughout the Holocene, mostly the past 4,000 years, have been identified in YELL (Persico and Meyer 2009), and it is entirely possible that older Holocene examples of these structures are present in abandoned watercourses in GRTE.

Note that there are some references to fossils just south of GRTE near Jackson in Pliocene–Pleistocene rocks (Love and Taylor 1962, Love et al. 1965, Love 1977b). These fossils come from lacustrine rocks now described as the Shooting Iron Formation (Love 1989b), which is not mapped within GRTE (Love et al. 1992), although it could potentially be present below younger sediments within the park, given how near the known outcrops are. This formation has yielded fossils of pollen, bivalves, gastropods, ostracodes, fish or frogs, turtles, rodents, and horses, some of which are known from Boyle Ditch just outside of GRTE (Love et al. 1965, Barnosky 1985, Love 1989b, Leopold et al. 2007).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within GRTE or JODR; however, they are known to preserve fossils elsewhere, and future field investigations within the parks may locate fossils in one or more of them.

Flathead Sandstone (Middle Cambrian)

The Flathead Sandstone is a sandstone formation found in Idaho, Montana, and Wyoming. In the GRTE area, it is a cliff-forming white to brown or maroon unit, 60 to 90 m (200 to 300 ft) thick, and mostly sandstone with some conglomeratic beds near the base and thin green shale layers near the top. In GRTE it is usually mapped with the overlying Wolsey Shale Member of the Gros Ventre Formation, which grades out of it. Most outcrops are either in northwestern or southwestern GRTE (Love et al. 1992). As noted in the Gros Ventre Formation section, early usage of the Flathead name in northwestern Wyoming included rocks now assigned to the overlying formation (Miller 1936a).

The Flathead Sandstone is thought to date to the Middle Cambrian (Wanless et al. 1955, Love et al. 1992). The formation becomes younger going west to east, because it was deposited during a marine transgression moving from west to east (Bell and Middleton 1978). It represents the first stage of the initial Cambrian transgression of the area. This transgression was not a simple advance, reflected by the presence of depositional hiatuses within the formation (Beebe and Cox 1998). The Flathead Sandstone is a coastal sandstone (Bell and Middleton 1978). Depositional environments include tidal areas, sand flats, beaches, coastal terraces (Bell and Middleton 1978), and fluvial settings (Beebe and Cox 1998).

The Flathead Sandstone overlies Precambrian rocks, with a significant unconformity (Reeves 1964). Although the unconformity represents the loss of billions of years, based on the age of the underlying rocks (Frost et al. 2006, 2011), the contact is even, indicating that the Precambrian rocks had been eroded to a level plain before deposition of the Flathead Sandstone (Wanless et al. 1955, Reeves 1964).

The Flathead Sandstone is not known to be fossiliferous in GRTE, and is not known for its fossils in general. Some possible invertebrate traces ("fucoids," formerly thought to be seaweed impressions) have been reported from the upper part of the formation in the vicinity, but it otherwise appears to be unfossiliferous in the GRTE region (Wanless et al. 1955). Overall, the fossil assemblage of the Flathead Sandstone includes brachiopods (Bell and Middleton 1978), trilobites (Hu 1970), bioturbation (Morgan 1998), and burrows, tracks, and other invertebrate trace fossils (Cloud and Beyer 1973), including some unusual large tracks and trails (Boyd 2010). Invertebrate trails and burrows are the only common fossils (Bell and Middleton 1978).

Chugwater Formation (Triassic)

The Chugwater Formation of GRTE and the immediate vicinity is a heterogeneous and variegated unit composed of four members. In ascending order, they are the Red Peak, Alcova Limestone, Crow Mountain Sandstone, and Popo Agie members. The Red Peak Member includes red gypsum-rich siltstone and sandstone, and is by far the thickest member at 245 to 390 m (800 to 1,275 ft) thick. The overlying Alcova Limestone Member is a gray and purple limestone and dolomite unit, with some white shale. It is 3 to 18 m (10 to 60 ft) thick. The Crow Mountain Sandstone Member

is a red to pink sandstone unit, 15 to 30 m (50 to 100 ft) thick. Finally, the Popo Agie Member at the top of the formation is composed of ocher and purple claystone, red shale and siltstone, and purple limestone conglomerate, and varies from 23 to 90 (75 to 300 ft) thick. The Chugwater Formation has been found north of Elk Ridge, west of Forellen Peak, east of Harem Hill, a small area at Wilcox Point, and a small area north of the Gros Ventre River on the east boundary of the park (Love et al. 1992). Other names used for equivalents to the lower part of the formation in the vicinity of GRTE include the Woodside Formation (redbeds) and the Thaynes Formation, and the Popo Agie Member is sometimes depicted as the Timothy Formation and overlying Deadman Limestone (Wanless et al. 1955). For the first few decades of geologic research, beds that would now be considered part of other formations, particularly some underlying Permian rocks and the overlying Gypsum Spring Formation, were included in the Chugwater Formation (Darton 1904, 1906, Richards 1955, High and Picard 1967).

The various members of the Chugwater Formation are distinctive but the contacts can be difficult to place (High and Picard 1967). Picard's publications presented the Alcova Limestone as within the Crow Mountain interval, but other authors have preferred to include "Crow Mountain" rocks below the Alcova Limestone in the Red Peak Member or Formation (Cavaroc and Flores 1991, Lovelace and Lovelace 2012). The Red Peak (Picard 1967), Crow Mountain Sandstone (Tohill and Picard 1966), and Popo Agie members (High and Picard 1965) can each be further subdivided. The Chugwater Formation is sometimes raised to a group; in these cases, the members become formations.

The Chugwater Formation is interpreted as the result of both marine and terrestrial deposition near a coast (Cavaroc and Flores 1991). This is a similar depositional setting to the partly contemporaneous Moenkopi Formation exposed in many NPS units of the Colorado Plateau. The Chugwater Formation grades into fully marine beds going westward (Stewart 1958). The climate was semi-arid to arid, at least during deposition of the lower part of the formation (Picard 1966). The various interpretations of the depositional environment differ in the relative contributions of marine and terrestrial deposition preferred by a given author, and will vary by study area. The Red Peak Member is variously interpreted as alternating nearshore marine and tidal flat deposition (Picard 1967), fluvial, deltaic, and nearshore marine deposition (Cavaroc and Flores 1991), and fluvial and lacustrine deposition becoming marine higher in the section (Lovelace and Lovelace 2012). The Alcova Limestone Member is usually interpreted as a marine incursion from the west (High and Picard 1969, Cavaroc and Flores 1991), although some authors have suggested a lacustrine origin (Cartwright et al. 2005, Lovelace 2011). There may have been marine evaporation near the top, as shown by local gypsum beds (Picard 1967). The Crow Mountain Sandstone Member encompasses the regression of the marine body responsible for the Alcova Limestone Member, transitioning from shallow nearshore marine deposition to tidal and beach deposition over time (Tohill and Picard 1966, Cavaroc and Flores 1991). The Popo Agie Member is a fluvial and lacustrine unit (High and Picard 1965, 1969), with a volcanic source for some sediments (High and Picard 1965).

The Chugwater Formation spans much of the Triassic (High and Picard 1969, Cavaroc and Flores 1991), but there is an internal

disconformity between the Crow Mountain Sandstone and Popo Agie members that eliminates part of the Middle and Late Triassic (Tohill and Picard 1966). This may be the regional disconformity seen for example between the Moenkopi and Chinle formations (High and Picard 1969). Some older sources report it as Permian to Triassic in age (Richards 1955), but this includes older rocks now assigned to other formations. Dating has been hindered by the generally sparse fossils, particularly the absence of biostratigraphically useful fossils. The upper contact of the Chugwater Formation with the Nugget Sandstone is disconformable (Picard 1993).

The Chugwater Formation of GRTE is not known to be fossiliferous. KellerLynn (2010) mentions reptile tracks in a table of formations, but it is unclear if the entire depositional area of the formation or the park's outcrops only is intended. Over its entire depositional area, the Chugwater Formation has a restricted fossil assemblage, but each of the four members discussed above is fossiliferous. The Red Peak Member has yielded root traces, a bivalve, conchostracans (clam shrimp), invertebrate burrows, invertebrate tracks, fish scales, and tracks of turtle-like reptiles, lepidosaurs (lizards and relatives), enigmatic cheirotheres (terrestrial reptiles probably distantly related to crocodiles), and dinosauromorphs (dinosaurs and relatives), with most finds from central Wyoming (Lovelace and Lovelace 2012). Apparent plant molds were later shown to be inorganic (Boyd and Ore 1963). The Alcova Limestone Member has stromatolites (Lovelace 2011), plates from phylloid algae, bivalves, gastropods (Picard 1993), ostracodes (Branson 1947), and the marine reptile *Corosaurus*, an early relative of plesiosaurs (Storrs 1991b, Rieppel 1998). The Crow Mountain Sandstone Member has only invertebrate burrows (Tohill and Picard 1966). Finally, the Popo Agie Member has probably the best-known fossils of the Chugwater Formation, and certainly the best-known vertebrates, which were first described near the turn of the 20th century (Williston 1904). Its fossil assemblage includes horsetails, cycadophytes, plant fragments, freshwater bivalves (High and Picard 1965), invertebrate burrows (Picard 1993), lungfish, metoposaur amphibians, therapsids ("mammal-like reptiles"), phytosaurs (crocodile-like aquatic reptiles) (High and Picard 1965), early relatives of crocodilians (High and Picard 1965, Dawley et al. 1979) which in some cases were mistakenly thought to be dinosaurs (Mehl 1915, Colbert 1961, High and Picard 1965), and reptile tracks (Lockley 1990). Darton (1906) reported bivalves, gastropods, and ostracodes in a limestone in the upper Chugwater Formation of the Bighorn Mountains, but this may be a reference to the modern Gypsum Spring Formation, which was removed from the Chugwater Formation.

Nugget Sandstone (Upper Triassic–Lower Jurassic)

The Nugget Sandstone appears to correlate to the entire vertical Glen Canyon Group sequence (Wingate to Kayenta to Navajo formations), seen throughout the Colorado Plateau to the south (Poole and Stewart 1964a, 1964b, Dubiel 1992, Sprinkel et al. 2011). The Nugget Sandstone of GRTE and its immediate vicinity is the northern extreme of the formation; in fact, it wedges out approximately 8 km (5 miles) north of the Gros Ventre River. It is a tan to pink cross-bedded resistant sandstone, 60 m (200 ft) thick just north of the Jackson thrust fault south of GRTE and thinning going north. There is only one mapped area of any size within the park, on the south side of Blacktail Butte (Love et al. 1992).

The great majority of the Nugget Sandstone is eolian, with winds from the north and northeast, but there is a basal unit known as the Bell Springs Member, not present at GRTE, that was deposited by water (Poole and Stewart 1964a, 1964b). The formation is dated to the Late Triassic and Early Jurassic (Gregson et al. 2010), with the Late Triassic–Early Jurassic boundary low in the formation above the Bell Springs Member (Sprinkel et al. 2011). The upper contact with the Gypsum Spring Formation is disconformable (Picard 1993).

The Nugget Sandstone is not known to be fossiliferous within GRTE, and the combination of its small outcropping area within the park and general paucity of fossils indicate limited potential. Overall, the Nugget Sandstone excluding the Bell Springs Member (as best as can be determined) has a fossil assemblage including general bioturbation (Picard 1977), possible microbial structures in interdune carbonates (Chure et al. 2009), plants (Britt et al. 2010; Chambers et al. 2011), bivalves (Picard 1993), molds of freshwater gastropods (Engelmann et al. 2009), crustaceans (Picard 1993), invertebrate trace fossils (Engelmann et al. 2010), including worm and gastropod trails and scorpion or spider tracks (Faul and Roberts 1951), bones of sphenodontians (tuatara) and theropod dinosaurs, including a bonebed (Britt et al. 2010, Chambers et al. 2011), tetrapod tracks including dinosaur tracks (Lockley et al. 1992, Hamblin et al. 2000), and possible burrows of synapsids (mammals and their closest relatives) (Engelmann and Chure 2008). Most fossil localities are far to the south, in Colorado (Faul and Roberts 1951) or Utah (Hamblin et al. 2000, Britt et al. 2010).

Gypsum Spring Formation (Middle Jurassic)

The Gypsum Spring Formation of GRTE, JODR, and the immediate vicinity is primarily composed of dark red soft shale. Gray dolomite and white gypsum are found below and interbedded with the main body of shale, although usually the gypsum has been leached out. The formation is 15 to 45 m (50 to 150 ft) thick, depending on the extent of leaching (Love et al. 1992). Both the lower and upper contacts of the formation are disconformable, and represent the regional J-1 (lower) and J-2 (upper) unconformities (Kvale et al. 2001). It was first described as a member of the Chugwater Formation (Love 1939; High and Picard 1967), and it is sometimes used as a member of the Twin Creek Limestone in the GRTE area (Imlay 1967). The Gypsum Spring Formation is dated to the Middle Jurassic, and is usually assigned at least in part to the Bajocian (170 to 168 Ma) (Kvale et al. 2001, Mickelson et al. 2006a).

Typically, the Gypsum Spring Formation can be split into distinct lower, middle, and upper parts. Generally the lower part of the formation is composed of red gypsum, claystone, and siltstone, the middle is composed of marine limestone, dolomite, and claystone, and the upper part is similar to the lower part, except with less gypsum (Picard 1993). This division becomes less clear going east, where the middle section disappears (Mapel and Bergendahl 1956). This is because the middle section was deposited under open marine conditions, and the seaway was not as extensive in northeastern Wyoming as in other areas (Peterson 1957a). Deposition occurred during two transgression-regression cycles, with the lower unit representing one cycle and the middle and upper representing a second, more extensive cycle (Parcell and Williams 2005). The lower and upper portions are interpreted as representing lagoonal, intertidal, and supratidal settings adjacent to an open marine shelf to the west, and the middle is interpreted as marine

deposition under normal conditions (not hypersaline or brackish, not anoxic, etc.) (Wright 1974). The formation becomes more limestone-rich to the west, eventually grading into a marine formation (Picard 1993). The climate was seasonally arid (Clark and Brett-Surman 2008).

The Gypsum Spring Formation is not known to be fossiliferous within GRTE at this time; Tracy (2003) did report finding a bioturbated piece of float in the Harem Hill area where the formation has been mapped with the Sundance Formation, but was not confident that it actually pertained to the Gypsum Spring Formation. As a whole, the Gypsum Spring Formation is only notably fossiliferous in the middle section. The middle part of the formation has yielded stromatolites (Kvale et al. 2001), microbial reefs and other microbial structures, blue-green algae, coralline red algae, green algae, foraminifera, sponges, corals, bryozoans (Ploynoi and Parcell 2005), ammonites (Kvale et al. 2001), bivalves, gastropods, ostracodes (Peterson 1957b), crabs, shrimp (Guyer et al. 1995), crinoids, echinoids (Imlay 1967), invertebrate trace fossils (Kvale et al. 2001), reptile swim traces (Mickelson et al. 2006a, 2006b) and locally abundant dinosaur tracks (Kvale et al. 2001, Clark and Brett-Surman 2008). Most of these fossils are known from the Bighorn Basin to the east (Imlay 1956b, Guyer et al. 1995, Kvale et al. 2001, Ploynoi and Parcell 2005, Mickelson et al. 2006a, 2006b, Clark and Brett-Surman 2008), or the Wind River Basin to the southeast (Peck 1957, Peterson 1957b).

Morrison Formation (Upper Jurassic)

In the Teton Range, there is an interval of Jurassic and Cretaceous sedimentary rocks mapped as an undivided combination of an Upper Jurassic unit thought to be the Morrison Formation, and the Lower Cretaceous Cloverly Formation. As noted in the Geologic Background, the Jurassic interval is often identified as the Morrison? Formation, to denote uncertainty, but the question mark has been left out here to avoid confusion. The possible Morrison Formation is composed of buff and gray sandstone and red, gray, and green siltstone, 56 to 76 m (185 to 250 ft) thick. It and the Cloverly Formation have been mapped north of Harem Hill in GRTE, in south-central JODR, and along the eastern boundary of JODR (Love et al. 1992). The Morrison Formation is often divisible into several members, although this has not been formally done in northwestern Wyoming.

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 about 155 and 148 Ma (Foster 2007). The contact with the overlying Cloverly Formation is placed arbitrarily in the Teton Range (Wanless et al. 1955), and is a point of contention elsewhere, where the two formations are better known (Moberly [1960]; see discussion in the Bighorn Canyon National Recreation Area [BICA] chapter of this inventory).

The possible Morrison Formation is not known to be fossiliferous in GRTE or JODR, and is not noted for its fossils in the area. Turner and Peterson (1999) reported no dinosaur-bearing localities in Teton County or the immediate vicinity. The nearest locality with identifiable vertebrate remains is at Paint Creek in Park County, over 140 km (85 miles) northeast of GRTE; it has yielded fossils of the sauropod dinosaur *Camarasaurus* (Foster 2003). There is

one published fossil site from the possible Morrison Formation in the immediate vicinity of GRTE and JODR: Smith and Bradley (1954) described plant fragments, radioactive dinosaur bone fragments, and possible gastroliths ("stomach stones") from Lower Slide Lake, just east of GRTE. However, the Morrison Formation is not exposed in this area within GRTE (Love et al. 1992), so the fossil occurrence is unlikely to extend into GRTE. Invertebrates are actually better known from the region than dinosaurs. Yen and Reeside (1946) described a site near Lower Green River Lake, over 65 km (40 miles) to the southeast of GRTE, with charophytes, bivalves, gastropods, ostracodes, and fish vertebrae.

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 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, lizards, possible snakes, the lizard-like aquatic reptile *Cteniogenys*, terrestrial crocodylomorphs, *Goniopholis* (closely related to the ancestry of modern crocodilians) and other extinct crocodylomorphs, 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 like *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 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).

Cloverly Formation (Lower Cretaceous)

The Cloverly Formation of GRTE, JODR, and the immediate vicinity is composed of two units mapped with the Morrison Formation. The lower part is a variegated claystone unit with thin beds of cream-colored limestone, 90 to 165 (290 to 545 ft) thick. Above it is 30 to 60 m (100 to 200 ft) of green, gray, and buff sandstone that weathers to a rusty color, and represents a unit known as the "rusty beds" (Love et al. 1992). The Cloverly Formation is sometimes divisible into multiple members, but named members have not been designated in the Teton Range.

The definition of the Cloverly Formation has varied widely over time. Both the upper and lower contacts have proven difficult to establish (Moberly 1960). The upper contact has been controversial because of a pair of units, the "rusty beds" and an underlying unit found to the east in the Bighorn Basin, the Greybull Sandstone. These two units have variously been included in the Cloverly Formation, given their own formation (the Sykes Mountain Formation of Moberly [1960]), included in the overlying Thermopolis Shale, or distributed separately (Moberly 1960). The "rusty beds" will be included with the Cloverly Formation here to maintain continuity with the Geologic Resources Division documents for GRTE. Note, though, that the vertebrate paleontology literature frequently employs the Sykes Mountain Formation name.

The Cloverly Formation has proven difficult to date (Oreska et al. 2013). Traditionally, it has been regarded as Aptian and Albian in age (125 to 100.5 Ma), but its base may be older (Winslow and Heller 1983). Recent interpretations suggest that there is a significant disconformity within the formation (Zaleha and Wiesemann 2005, Zaleha 2006), which could account for this. Recent dates from the Cloverly Formation include 108.5±0.2 Ma (Burton et al. 2006) and 104.4 Ma (D'Emic and Foreman 2012), placing at least part of it in the middle Albian age. The contact of the Greybull/"rusty" interval with the rest of the Cloverly Formation has been variously described as conformable (D'Emic and Foreman 2012) or unconformable (Kvale and Vondra 1993, Zaleha and Wiesemann 2005, Zaleha 2006). The upper contact of the Greybull/"rusty" interval with the Thermopolis Shale is transitional (Moberly 1960).

The Cloverly Formation was deposited under a warm, seasonal climate, becoming more humid over time as the Western Interior Seaway approached. Deposition began under an arid to semi-arid climate, with droughts. Later, a savannah environment appeared (Forster 1984). A substantial part of the sediment is of volcanic origin (Moberly 1960, 1962). The lower part of the lower Cloverly Formation is interpreted as having been deposited in playas (ephemeral lakes) and streams (Moberly 1960, Kvale and Vondra 1993). Higher in the lower Cloverly Formation, fluvial deposition predominated (Moberly 1960). Floodplains appeared as the seaway approached (D'Emic and Foreman 2012), advancing from the north (Nydam and Cifelli 2002). The Greybull/"rusty" interval was deposited during the transition to the full marine conditions of the overlying rocks (Zaleha and Wiesemann 2005, D'Emic and Foreman 2012). The "rusty beds" are shallow marine in origin (Moberly 1960, Kvale and Vondra 1993).

The Cloverly Formation is not known to be fossiliferous within GRTE or JODR, but it is fossiliferous in the area (Love 1956a, 1990). Ostracodes are present in a zone of limestone nodules at a site just south of YELL and east of JODR, roughly 5 km (3 miles) east of YELL's

South Entrance (Love 1956a). An equivalent limestone bed near Bacon Ridge, southeast of GRTE in the Gros Ventre Mountains, has yielded charophytes, freshwater bivalves and gastropods, and ostracodes (Love 1956a); freshwater gastropods from this site were described by Yen (1951). Palynomorphs have also been found from rocks in the Gros Ventre Mountains (Schwab 1977). Plant stem impressions and invertebrate traces are known from the "rusty beds" east of GRTE (Love et al. 1948), and freshwater bivalves and gastropods have been found from the north flank of the Goosewing Anticline east of Goosewing Creek, about 25 km (15 miles) southeast of GRTE (Love 1956a).

Overall, the Cloverly Formation below the contested Greybull/"rusty" interval has a substantial fossil assemblage, and is best known for its dinosaurs. Until recently, identifiable plant remains were sparse in the Cloverly Formation, and plants were only represented by charophytes (Peck 1957), coal and coalified wood (Mirsky 1962), petrified wood (Moberly 1960), leaf and needle fragments (Darton 1904, 1906), spores and pollen (Mirsky 1962), and root traces (Zaleha and Wiesemann 2005). Recently, a paleoflora was discovered in the Bighorn Basin, including spores, pollen, ferns, cycadophytes, conifers, and angiosperms, the latter only present near the top of the formation (Wilborn 2006, Jud and Wing 2010, Haiar and Lupia 2011, Jud 2011). Invertebrates are represented by bivalves, gastropods (Reeside 1923, Yen 1949, 1951), caddisfly casings (Jud 2011), shell fragments (Thom et al. 1935), crayfish gastroliths (Oreska et al. 2013), and burrows (Zaleha and Wiesemann 2005). Vertebrates are enumerated in Oreska et al. (2013), which also includes a discussion of their stratigraphic distribution within the formation. The following list is drawn from this publication, with annotations as needed. Vertebrates found in the Cloverly Formation include hybodont sharks, rays, several types of ray-finned fish, the lungfish *Ceratodus*, extinct salamander-like albanerpetontid amphibians, salamanders, frogs, several types of turtles and tortoises, lizards, representatives of four lineages of crocodile relatives, theropod dinosaurs including large *Acrocanthosaurus* and small *Deinonychus*, *Microvenator*, and an unnamed "ostrich-mimic," possible birds, sauropod dinosaurs including *Rugocaudia* and the giant *Sauroposeidon*, the armored dinosaurs *Sauropelta* and *Tatankacephalus*, an early horned dinosaur, the small ornithopod dinosaur *Zephyrosaurus*, the common large ornithopod *Tenontosaurus*, the triconodont mammals *Corviconodon* and *Gobiconodon*, several forms of multituberculate mammals, a symmetrodont mammal, additional unnamed early mammals, and dinosaur eggshells (Maxwell and Horner 1994). Rounded isolated stones are often identified as dinosaur gastroliths, but this identification cannot be established for certain (Wings 2007, 2009), and they may be ordinary stones moved by special flow conditions (Zaleha and Wiesemann 2005). Finally, reworked Paleozoic clasts have been found in the formation; some have foraminifera, sponge spicules, bryozoans, brachiopods, gastropods, and echinoderms (Zaleha and Wiesemann 2005).

The Greybull/"rusty" interval, sometimes known as the Sykes Mountain Formation, has a small fossil assemblage. The "rusty beds" have yielded plant fossils (Darton 1904), stem impressions (Love et al. 1948), freshwater bivalves and gastropods (Love 1956a), and invertebrate traces (Love et al. 1948). References to fossils that could be from either unit, or the Sykes Mountain Formation, include tintinnids (protozoans with protein-based

shells), carbonaceous debris, peat (Eicher 1960), petrified wood, leaves of ferns, fern-like plants, conifers, and angiosperms (Walton et al. 2007), bivalves (Kvale and Vondra 1993), possible casts of bivalves and gastropods (Eicher 1960), thin shell interbeds (Ostrom 1970), invertebrate trails and burrows (Eicher 1960, Moberly 1960, Kvale and Vondra 1993), invertebrate castings (feces), and fish teeth and fragments, most of which are known from the Bighorn Basin (Eicher 1960).

Thermopolis Shale (Upper Cretaceous)

The Thermopolis Shale of GRTE, JODR, and the immediate vicinity is a predominantly black shale unit, mapped with the overlying Mowry Shale. The top of the formation is distinguished by an interval of reddish brown to gray sandstone and interbedded dark siltstone and shale, 6 to 30 m (20 to 100 ft) thick, assigned to the Muddy Sandstone Member. The formation as a whole is 45 to 60 m (150 to 200 ft) thick, thinning to 17 m (55 ft) north of Jackson Lake. Outcrops of the Thermopolis and Mowry shales have been mapped near Harem Hill and between the Lizard Creek campground and Arizona Island in GRTE, and in south-central JODR (Love et al. 1992).

As noted under the Cloverly Formation and Mowry Shale sections, the definition of the Thermopolis Shale has long been in dispute. This report will follow the usage of Love et al. (1992) and the Geologic Resource Divisions documents for GRTE in employing a two-part Thermopolis Shale for the GRTE–JODR area. Researchers need to pay attention to what configuration is in use in a given publication: the Muddy Sandstone Member and overlying black shale, where present, are variously assigned to the Thermopolis Shale, given their own formations, or assigned to the overlying Mowry Shale (Eicher 1960, Reeside and Cobban 1960). The Muddy Sandstone Member is occasionally given its own formation in the vicinity (Hale et al. 2004, Johnson 2008).

The Thermopolis Shale is a marine formation, with the rocks present in GRTE and JODR representing parts of a transgression-regression cycle (Condon 2000). Deposition was primarily under the northern arm of the Western Interior Seaway. The transgression that deposited the lower shale was eventually extensive enough that the northern and southern arms of the seaway connected (Eicher 1960). A regression followed during deposition of the Muddy Sandstone Member, and the two arms were separated, leaving only northern waters over the GRYN area (Druckenmiller 2002); authors have variously interpreted this member as having a basal unconformity (Druckenmiller 2002) or upper unconformity (Condon 2000). Deposition of the sandstone is associated with a delta (Vuke 1984), found to the east (Wulf 1962); various brackish shallow depositional settings are present (Eicher 1960). Deposition of the formation included volcanic ash (Vuke 1984). The age of the formation is earliest Late Cretaceous; the base of the Muddy Sandstone Member dates to around 98.5 Ma, and ammonites of the overlying shale indicate that it dates to between 98.74±0.59 and 98.54±0.70 Ma (Druckenmiller 2002).

The Thermopolis Shale is not known to be fossiliferous within GRTE or JODR, but it is fossiliferous in the vicinity. Love (1956a) reported that no fossils had been found in the lower shale member in the Jackson Hole area, but that foraminifera had been found to the east. The Muddy Sandstone Member has yielded foraminifera or spores, brachiopods, and fish and reptile bones east of GRTE (Love et al. 1948), and is fossiliferous at Mount Everts in YELL, to the north (Hale et al. 2004).

Palynomorphs have been found in the Thermopolis Shale in the Gros Ventre Mountains to the southeast (Schwab 1977).

Overall, macrofossils are rare in the Thermopolis Shale, but microfossils are common (Eicher 1958). Fossils attributed to the shaly parts of the formation (fossils limited to the upper shale here considered part of the Mowry Shale may be included) include radiolarians (Reeside and Cobban 1960), foraminifera, tintinnids (Eicher 1958, 1960), palynomorphs including dinoflagellates (Schwab 1977), sponges (Eicher 1958, 1960), bivalves, ammonites (Reeside and Cobban 1960), invertebrate burrows, trails, and castings (Eicher 1960), hybodont sharks, sawfish, rays, bony fish, turtles, marine crocodile relatives, and coprolites (Lash and Schmitt 2008). The Muddy Sandstone Member has yielded foraminifera, angiosperms (Eicher 1960), brachiopods, bivalves, asteroids (Wulf 1962), invertebrate traces (Tillman and Dresser 1976), and vertebrate remains such as teeth, spines, and bone fragments, representing cartilaginous and bony fish, turtles, and crocodile relatives (Eicher 1960, Wulf 1962, Kausch and Giffin 1993).

Sohare Formation (Upper Cretaceous)

The Sohare Formation is known only from the Jackson Hole area. In GRTE and the immediate vicinity to the east, it is composed of interbedded gray and brown sandstone and light and dark gray shale and siltstone, with some thin coal beds. It is up to 730 m (2,400 ft) thick, and has been mapped in the Elk Ranch Reservoir area of eastern GRTE (Love et al. 1992). This formation was identified in Love et al. (1948) and Love (1956a) as the coaly sequence and overlying lenticular sandstone and shale sequence (Love 1989b). The coaly sequence is only locally mappable, and intertongues with the sandstone and shale sequence (Love 1989b).

It is largely nonmarine (Love 1989b), deposited by a low-sinuosity fluvial system (Leier and Steidtmann 2009). Deposition occurred during parts of the Santonian and Campanian ages of the Late Cretaceous, between about 86 Ma and sometime before a tuff erupted at 73.1±0.7 Ma during deposition of the Meeteetse Formation (Leier and Steidtmann 2009). The upper contact with the Mesaverde Formation is gradational and placed arbitrarily (Love 1956a).

The Sohare Formation is not known to be fossiliferous in GRTE, but it is fossiliferous in the vicinity. The coaly sequence has yielded coal, plant fragments, and bivalves, while the lenticular sandstone and shale sequence has sparse coal, abundant well-preserved leaves of ferns, conifers, and angiosperms, and less abundant nonmarine bivalves and gastropods (Love et al. 1948, Love 1956a). Other fossils reported from the formation include pollen (Leier and Steidtmann 2009) and horsetail foliage (Love 1989b). The Sohare Formation is another part of the Jackson Hole coal field (Jones 1982, Glass and Jones 1991).

Mesaverde Formation (Upper Cretaceous)

The Mesaverde Formation is an exception to the rule of limited distribution mentioned in the Bacon Ridge Sandstone section, although it should be noted that the use of the Mesaverde name so far from Mesa Verde in southwestern Colorado is not universally supported (see the numerous cases of “Mesaverde” used in quotation marks in publications on Wyoming outcrops). In GRTE and the immediate vicinity, the Mesaverde Formation is composed mostly of white sandstone interbedded with gray shale, bentonite beds, and coal. In some areas, such as the vicinity of Elk Ranch Reservoir in GRTE,

there are also conglomerate beds up to 15 m (50 ft) thick (Love et al. 1992). The formation varies greatly in thickness in the Jackson Hole area, possibly due to Late Cretaceous erosion; it can be more than 300 m (980 ft) or barely 60 m (200 ft) thick (Love 1956a). It has been mapped in several areas between Two Ocean Lake and Eynon Draw in eastern GRTE (Love et al. 1992). To the southeast, in the Wind River Basin, it is divisible into a number of tongues and members as a result of its relationship with marine rocks (DeMar and Breithaupt 2006, Johnson 2008), but this has not been done in the Jackson Hole area because the marine rocks are not present.

The Mesaverde Formation of northwestern Wyoming represents part of the transition from marine to nonmarine deposition, and as such includes rocks deposited in a number of marine, marginal marine, and terrestrial settings (DeMar and Breithaupt 2006, Johnson 2008). The sea had left the Jackson Hole area and the coast was farther east, as evidenced by the complex relationship with the marine Cody and Lewis shales in the Bighorn (DeMar and Breithaupt 2006) and Wind River basins (Johnson 2008). In the Jackson Hole area, it is primarily a fluvial formation (Leier and Steidtmann 2009). The upper contact varies in Jackson Hole. If there is a conglomerate above it, there is a disconformity resulting from erosion during the Upper Cretaceous. Otherwise, it transitions into the overlying Meeteetse Formation (Love 1956a). The age of the Mesaverde Formation is constrained to some portion of the Campanian by the Sohare Formation, thought to extend into the Campanian, and a 73.1±0.7 Ma tuff low in the Meeteetse Formation (Leier and Steidtmann 2009).

As mentioned, the Mesaverde Formation name is used widely and not necessarily accurately. Therefore, the following discussion of fossils is limited to Jackson Hole and the immediate vicinity, including the Bighorn and Wind River basins. In Jackson Hole, fossils are limited to charophytes (Love 1956a), coal (Johnson et al. 1998), pollen, leaves (Leier and Steidtmann 2009), and mollusks (Love 1956a). The Mesaverde Formation is another part of the Jackson Hole coal field (Jones 1982), and some charophytes, plant fossils, and nonmarine mollusks have been found at Dry Cottonwood Creek, east of GRTE (Love 1956a). Fossils are not yet known from this unit within GRTE.

A larger assemblage is known from the Bighorn and Wind River basins, including coal (Johnson 2008), petrified wood (Lillegraven and McKenna 1986), logs, root traces, invertebrate burrows and bioturbation (Johnson 2008), bivalves, ammonites (DeMar and Breithaupt 2006), sharks, carpet sharks, angel sharks, rays, skates, ratfish, various ray-finned fish (Case 1987, DeMar and Breithaupt 2006), frogs, salamanders, turtles, champsosaurs, lizards, mosasaurs, snakes, polycotylid plesiosaurs, crocodile relatives, pterosaurs, small and large theropods, armored dinosaurs, horned dinosaurs, duckbilled dinosaurs, birds (DeMar and Breithaupt 2006), and early mammals including multituberculates, dryolestids, marsupials, “insectivores,” and other forms (Lillegraven and McKenna 1986, DeMar and Breithaupt 2006).

Pinyon Conglomerate (Upper Cretaceous–Paleocene)

The Pinyon Conglomerate of GRTE, JODR, and the immediate vicinity is a rusty brown formation composed of conglomerate in a sandstone matrix. It reaches a maximum of 1,160 m (3,800 ft) thick. Within GRTE, it is present around Emma Matilda Lake and Two Ocean Lake, and in a small area near Mount

Berry (Love et al. 1992). Within JODR, it is present in two areas in the central region of the parkway, and an area near the western boundary (Christiansen et al. 1978, Love et al. 1992). It is sometimes informally divided into a coal member and conglomerate member (Love 1956a). The coal member was originally described as basal (Love 1956a), but there are actually older rocks present in areas where the coal member is not found; it is basal in southeastern Jackson Hole, though (Love 1973a). Lindsey (1972) instead interpreted the formation as including a lower sandstone member (similar to the coal member) and intertonguing upper conglomerate member.

The Pinyon Conglomerate is a gravelly fluvial formation (Leier and Steidtmann 2009). The same source rocks, general depositional setting, and environmental conditions are thought to have held for both the underlying Harebell Formation and the Pinyon Conglomerate (Lindsey 1972, Love 1973a), except the marine influence had departed and volcanism decreased during deposition of the more recent Pinyon Conglomerate (Love 1973a). The Pinyon Conglomerate was previously thought to be Paleocene in age, based on fossils and stratigraphic relationships (Love 1956a), but the discovery of a tooth of the small horned dinosaur *Leptoceratops* in this formation establishes that part of it is latest Cretaceous in age (McKenna and Love 1970). A tuff dated to 67 Ma within the formation further supports the formation crossing period boundaries (Love 1990). The southern outcrops of the formation are entirely Paleocene in age (Love 1973a, 1990). The upper part of the formation dates to some part of the middle or late Paleocene, predating the late Paleocene fossils of the overlying Devils Basin Formation found outside of GRTE (Love 1989b).

The Pinyon Conglomerate is not known to be fossiliferous within GRTE or JODR, but it is fossiliferous in the vicinity. Paleocene pollen has been found in non-conglomeratic rocks in Two Ocean Lake Quadrangle (Love 1973b), fossils of the conifer *Metasequoia* and the angiosperm *Celastrus* has been reported from Whetstone Creek, east of GRTE (Love 1956a), and a bivalve, possible lizard scute, and *Leptoceratops* tooth were found on the east side of Pinyon Peak, northeast of GRTE (McKenna and Love 1970). Overall, the fossil assemblage of the Pinyon Conglomerate includes coal, pollen, wood, logs (Love 1973a), leaves of conifers and angiosperms, freshwater bivalves, freshwater and terrestrial gastropods (Love 1956a), a possible lizard scute, a *Leptoceratops* tooth, mammals, and reworked Paleozoic fossils (Love 1973a). Reworked materials include Madison Limestone and other limestones with fragments of foraminifera, corals, bryozoans, bivalves, and crinoids (Lindsey 1972). The coal member of the formation is part of the Jackson Hole coal field (Jones 1982). The Love Quarry site outside of GRTE, included in the Pinyon Conglomerate by McKenna (1980), is actually in the Devils Canyon Formation (Love 1989b).

Hominy Peak Formation (Lower–Middle Eocene)

The Hominy Peak Formation of GRTE, JODR, and the immediate vicinity is mostly composed of brown to dull green mudflow and volcanic breccias, conglomerate, and sandstone, with light gray tuff and claystone zones in the lower and upper parts of the formation. It can be as much as 660 m (2,000 ft) thick. Within GRTE, it has been mapped in several areas around Forellen Peak and Survey Peak, and north and east of Emma Matilda Lake and Two Ocean Lake (Love et al. 1992). Within JODR, it is present in a large area along the western boundary of the parkway (Christiansen et al.

1978, Love et al. 1992). Before it was named, it was known under various other names, such as "late basic breccia," "early basic breccia" (Love et al. 1978), or the Eocene basalt, andesite, and volcaniclastics mapped in the Whetstone Mountain Quadrangle (Love 1975). The formation was named from an area on the northwest end of the Tetons and along the southern boundary of YELL (Love et al. 1978). The eastern outcrops were not included in the formation at that time, but they were included in the formation by the time Love et al. (1992) was published. The lower and upper contacts of the formation are both disconformable (Love et al. 1978).

The formation originated as a combination of volcaniclastic sediments and volcanics, erupted during the first major volcanic activity of the Absaroka volcanic field. The actual volcanic source seems to have been southwest of Conant Basin, west of northern GRTE. Deposition occurred under a humid subtropical climate. The age of the formation is reasonably well-constrained to the early and middle Eocene; volcanic rocks in and near GRTE have been dated to 48.6±0.7 and 45.9±0.5 Ma, and the formation is intruded by igneous rocks that date to 40.5±2.6 Ma along the southern YELL boundary (Love et al. 1978).

The Hominy Peak Formation is not known to be fossiliferous within GRTE or JODR, but is fossiliferous in the immediate vicinity. Outside of the parks, it has yielded carbonized plant fragments, carbonized and silicified wood (including angiosperm wood), stumps, other plant debris, spores and pollen of clubmosses, spikemosses, ferns, conifers, and angiosperms, and reworked Madison Limestone rocks with corals and brachiopods (Love et al. 1978). Fossil trees are common in this formation (Love et al. 1992).

Unnamed Conglomerate (Upper Miocene)

The unnamed conglomerate is only found on the northeast side of Signal Mountain, within GRTE. It is a gray conglomerate, up to 370 m (1,200 ft) thick (Love et al. 1992). This unit was formerly part of the now-abandoned "Bivouac Formation," and was the lowest part, just above the Teewinot Formation and below the Conant Creek Tuff (Love 1989b). It is thought to be Late Miocene in age (Love et al. 1992). This conglomerate is not known to be fossiliferous (Love 1989b). Because it is partially composed of reworked Paleozoic and Mesozoic rocks (Love et al. 1992), its most likely fossils are reworked Paleozoic and Mesozoic fossils.

Conant Creek Tuff (Upper Miocene)

The Conant Creek Tuff of GRTE, JODR, and the immediate vicinity is composed primarily of gray, buff, and pale lavender tuff, with a black layer of obsidian near the base. It is up to 90 m (300 ft) thick (Love et al. 1992). Within GRTE, it is present east of Signal Mountain (Love et al. 1992). The rocks here were formerly included as part of the now-abandoned Bivouac Formation (Love 1989b). Within JODR, it has been mapped in two areas near the western boundary (Christiansen et al. 1978). The Conant Creek Tuff includes the tuff of Boone Creek as mapped by Love (1973b) and included in the GRI map; by the time of the GRTE map of Love et al. (1992), this unit was mapped as the Conant Creek Tuff. The basal contact, at least where the "tuff of Boone Creek" is concerned, is disconformable (Love 1973b).

The Conant Creek Tuff is predominantly a rhyolitic volcanic ash-flow tuff (Christiansen and Love 1978). There is some difference of opinion about its age. Most sources prefer a Late Miocene age (5.51±0.13 Ma [Lageson et al. 1999, Morgan et al. 2008]; 5.78±0.08 Ma [Christiansen and Love 1978]; 5.97±0.01 Ma

[Anders et al. 2009]), but publications by J. D. Love prefer an Early Pliocene age of 4.2±0.7 Ma based on a fission-track date (Love 1989b, Love et al. 1992). It is part of the Heise Volcanic Field, which was active between about 6.3 and 4.5 Ma (Morgan et al. 2008).

The Conant Creek Tuff appears to be unfossiliferous (Christiansen and Love 1978; Love 1989b). As an ash-fall unit, there is some potential for fossils to be present, especially at the base.

Yellowstone Group: Huckleberry Ridge Tuff (Lower Pleistocene)

The Huckleberry Ridge Tuff of GRTE, JODR, and the immediate vicinity is a gray to brown rhyolitic ash-flow tuff, with up to three members (Christiansen et al. 1978, Love et al. 1992). Within GRTE, it can be found in many areas of the extreme northwestern and north sections, east and northeast of Jackson Lake, south of Pilgrim Mountain, and on the north and east sides of Signal Mountain (Love et al. 1992). Within JODR, it is present in a large area along the western boundary (Christiansen et al. 1978, Love et al. 1992). The type section for the Huckleberry Ridge Tuff is at Flagg Ranch, within JODR (Christiansen 2001).

The three members that make up this volcanic unit represent substantial eruptions. Member A, at the base, is thought to have originally covered an area of 6,280 km^2 (2,420 mi^2) with a volume of at least 820 km^3 (200 mi^3). It probably was erupted from somewhere near the center of the Yellowstone Plateau. The overlying Member B is thought to have covered an area of 15,400 km^2 (5,950 mi^2) with a volume of 1,340 km^3 (320 mi^3). The source is thought to have been in the Big Bend Ridge area of Idaho, to the northwest. Member C, at the top, is thought to have covered an area of 3,690 km^2 (1,420 mi^2) with a volume of at least 290 km^3 (70 mi^3). Its source is interpreted as near the Red Mountains and the South Entrance of YELL. The first eruption probably triggered the second, which in turn triggered the third, with the sequence being almost simultaneous (Christiansen 2001). The series of eruptions occurred at about 2.059±0.004 Ma (Lanphere et al. 2002). After the eruptions, a broad area of southern and western YELL and adjoining areas of Idaho and Montana collapsed into a large caldera (Christiansen 2001).

The Huckleberry Ridge Tuff is not known to be fossiliferous within GRTE or JODR. The outcrop at Signal Mountain was unsuccessfully sampled for diatoms and pollen (Love 1989b). It is not known to be fossiliferous at this time.

Lewis Canyon Rhyolite (Middle Pleistocene)

The Lewis Canyon Rhyolite of JODR and the immediate vicinity is composed of rhyolitic lava flows, up to at least 180 m (600 ft) thick. It is one of the most widely-distributed units of JODR, present in much of the northern and central sections of the parkway (Christiansen et al. 1978, Love et al. 1992, NPS 2010). It is somewhat unusual, being more similar to rocks of the first cycle of Yellowstone Caldera eruptions than those of the third cycle, which it is closer to in age. It dates to about 0.853±0.007 Ma (Christiansen 2001). The upper contact with the Lava Creek Tuff is disconformable (Christiansen and Blank 1972). No fossils have been reported from the Lewis Canyon Rhyolite, but as a volcanic flow there is some possibility of finding fossils, such as charcoal and stumps.

Leidy Formation (Middle Pleistocene)

The Leidy Formation is found only in a few areas along the Gros Ventre River and its tributaries (Love 1994). In GRTE and its immediate vicinity, it is composed mostly of

brown, pink, and gray clay, with some gray sand, gravel, and conglomerate, up to 140 m (450 ft) thick. Within GRTE, it is only present in a small area along the eastern boundary just north of the Gros Ventre River (Love et al. 1992). It is interpreted as a combination of glacial till, fluvial gravel, and fine-grained lake deposits. The formation is associated with an ice-dammed lake, dammed at the mouth of Gros Ventre Canyon (Love 1994). Its age is uncertain, but it is thought to be younger than about 0.75 Ma, based on magnetic polarity and the lack of volcanic debris (Love et al. 1992). The Leidy Formation is not known to be fossiliferous within GRTE, but coaly debris and sparse leaf fragments have been found just east of the park at Devils Elbow. Pollen has also been found in the formation, mostly reworked from Upper Cretaceous rocks (Love 1994).

Lava Creek Tuff (Middle Pleistocene)

The Lava Creek Tuff of JODR and the immediate vicinity is composed of gray to brown rhyolitic ash flows, at least 30 m (100 ft) thick. It can be found in several areas in southern JODR, east and west of the Snake River (Love et al. 1992). It consists of two major ash flows, defined as unnamed members (Christiansen and Blank 1972, Christiansen 2001). The lower member covered approximately 3,240 km^2 (1,250 mi^2), with a volume estimated at 510 km^3 (120 mi^3), and the upper member covered approximately 7,300 km^2 (2,820 mi^2), with a volume of 490 km^3 (120 mi^3) (Christiansen 2001). The Lava Creek Tuff erupted at 0.639±0.002 Ma (Lanphere et al. 2002). It is not known to be fossiliferous, but like other tuffs, it may prove to be fossiliferous.

Park Collections

GRTE houses a small collection of fossils in the Colter Bay Museum. At the time of Tracy's (2003) visit, these included 14 catalog numbers: GRTE 2946-2949, various bones of the beaver *Dipoides stirtoni*; GRTE 4909 and 4939, brachiopods; GRTE 4915, a specimen confusingly listed as "Molluscs *Cephalopoda gryphaea;*" GRTE 4915, corals; GRTE 4916, mollusks; GRTE 4917, a magnolia leaf; GRTE 4919, unspecified fossil plants; GRTE 4921, trilobites; GRTE 4927, a horn coral; and GRTE 4920, ferns (GRTE Figure 6). Tracy (2003) added a larger collection of fossils from several formations, recovered in order to determine their taxonomic identities. They are almost entirely marine invertebrates except for a few trace fossils, a fish specimen, and several plant fossils from the Frontier Formation. The Gros Ventre Formation (2 specimens), Darby Formation (4 specimens), Madison Limestone (17 specimens), Phosphoria Formation (5 specimens), Sundance Formation (18 specimens), and Frontier Formation (5 specimens) are represented in this collection. Although her specimens are at GRTE, some documentation of her studies may also be at Georgia College & State University in Milledgeville, Georgia.



GRTE Figure 6. Invertebrate fossils in GRTE collections (VLS).

Several outside institutions also have fossils from GRTE or JODR. The largest collection is probably at the National Museum of Natural History (USNM; Washington, D.C.), especially with the transfer of some former USGS collections. For example, the various collections from the Amsden Formation project of Sando et al. (1975) were made as USGS localities, and the material was originally in the upper Paleozoic and foraminifera collections of the USGS in Washington, but inspection of the online USNM collections database shows these fossils in their collections. Other such former USGS collections now at the USNM include the Tensleep Formation foraminifera of Henbest (1956) and the Phosphoria interval collections of Sheldon (1963) and Yochelson and van Sickle (1968). Although the specimens have been transferred, the USGS would still have documentation relating to the field work. In addition, USGS–Denver may still have relevant Mesozoic fossils. The USNM collections also include the Yellowstone-area fossils described by Girty (1899) and Stanton (1899) from GRTE and JODR, the brachiopods described by Walcott (1901, 1902, 1912) from GRTE, the type of *Hesperosorex lovei* (see below) (Hibbard 1957), and various remains of the vole *Microtoscoptes disjunctus* (USNM 21383, 21825, and 21826) (Hibbard 1959). The Colter Formation fossils described by Barnosky (1986) are reposited at the Burke Museum of Natural History and Culture (UWBM; Seattle, WA).

It is unclear what institution or institutions house the microbial structures described in Fenton and Fenton (1939), because they did not designate type specimens in their text. Given the disposition of other species they named, the fossils could have been at the University of Cincinnati (UCM; Cincinnati, Ohio) or Princeton University (PU; Princeton, New

Jersey); the former would now be at the Cincinnati Museum Center (CMC), and the latter might now be at the Peabody Museum of Natural History at Yale (YPM; New Haven, Connecticut). The YPM collections database shows that at least some relevant material is now there, via Princeton. Specimens include YPM PB 159379 (*Aulophycus callosus*, formerly PU 26087), YPM PB 52085 (*Aulophycus callosus*, formerly PU 26087), YPM PB 44978 (*Aulophycus repens*, formerly PU 44978), YPM PB 35348 (*Collenia magna*, formerly PU 26057), YPM PB 44976 (*Tetonophycus blackwelderii*, formerly PU 26114), YPM PB 44977 (*Tetonophycus blackwelderii*, formerly PU 26098), YPM PB 46098 (*Tetonophycus blackwelderii*, formerly PU 26064), and YPM PB 44973 (*Tetonophycus blackwelderii*, formerly PU 26117). It is uncertain which (if any) of these specimens are types, and two species are unaccounted for (*Aulophycus parvus* and *Collenia spissa*), but these are at least GRTE specimens. The types of the two missing species may well be lost, given that they may not have been clearly marked as types, stromatolites are not necessarily impressive fossils or even immediately identifiable as fossils, and there has been an institution change to contend with. Per a collections document (available at http://www.docstoc.com/docs/115940564/Paleobot-Collections), the University of Michigan Museum of Paleontology's (Ann Arbor, Michigan) fossil collections include casts of four Fenton and Fenton taxa from GRTE: UMMP 18755 (*Aulophycus callosus*), UMMP 18756 (*Aulophycus prolificus*), UMMP 18758 (*Tetonophycus blackwelderii*), and UMMP 18761 (*Aulophycus repens*).

Thirteen taxa have been named from specimens collected within GRTE (six microbial structures, three brachiopods, two rodents, a shrew, and a pika) (GRTE Table 2), a bivalve has been named from a syntype series (multiple specimens serving as types) including a specimen from JODR (GRTE Table 3), and an echinoid and possibly a bivalve have been named from a locality that is within either GRTE or JODR (GRTE Table 4). The majority of these specimens were collected after GRTE was established; the exceptions are the three brachiopods from GRTE, the bivalve from JODR, and the echinoid of equivocal provenance.

GRTE Table 2. Type specimens from GRTE. The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column.

Taxon	Publication	Catalog Number	Provenance	Notes
Obolus tetonensis	Walcott 1901	USNM 35220 (syntype)	Gallatin Limestone, divide at the head of Jackson or Sheep Creek (USNM locality 4e)	Brachiopod
Acrotreta microscopica tetonensis	Walcott 1902	USNM 35280 (syntype)	Gallatin Limestone, divide at the head of Jackson or Sheep Creek (USNM locality 4e)	Brachiopod
Productus parviformis	Girty 1899	USNM 35166 and 35167 (syntypes)	Madison Limestone, south of Forellen Peak	Brachiopod
Hesperosorex lovei	Hibbard 1957	USNM 21384	Teewinot Formation, Kelly Road	Shrew
Oreolagus colteri	Barnosky 1986	UWBM 62698	Colter Formation, North Pilgrim 2 (UWBM loc. CO237)	Pika
Mojavemys magnumarcus	Barnosky 1986	UWBM 62641	Colter Formation, North Pilgrim 2 (UWBM loc. CO237)	Rodent
Lignimus transversus	Barnosky 1986	UWBM 62662	Colter Formation, North Pilgrim 2 (UWBM loc. CO237)	Rodent, now known as Parapliosaccomys transversus
Tetonophycus blackwelderii	Fenton and Fenton 1939	Unknown	Gallatin Limestone, divide at the head of Jackson or Sheep Creek	“Algal” trace fossil
Aulophycus callosus	Fenton and Fenton 1939	Unknown	Gallatin Limestone, divide at the head of Jackson or Sheep Creek	“Algal” trace fossil
Aulophycus parvus	Fenton and Fenton 1939	Unknown	Gallatin Limestone, divide at the head of Jackson or Sheep Creek	“Algal” trace fossil
Collenia spissa	Fenton and Fenton 1939	Unknown	Gallatin Limestone, divide at the head of Jackson or Sheep Creek	“Algal” trace fossil
Collenia magna	Fenton and Fenton 1939	Unknown	Gallatin Limestone, divide at the head of Jackson or Sheep Creek	“Algal” trace fossil
Aulophycus repens	Fenton and Fenton 1939	Unknown	Gros Ventre Formation, divide at the head of Jackson or Sheep Creek	“Algal” trace fossil

GRTE Table 3. Type specimens from JODR. The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column.

Taxon	Publication	Catalog Number	Provenance	Notes
Inoceramus acuteplicatus	Stanton 1899	At least one of syntypes USNM 28950, 28951, and 315993	Cody Shale?, near the mouth of Glade Creek (other syntype[s] from YELL)	Bivalve; preoccupied, renamed Inoceramus stantoni (Sokolov 1914)

GRTE Table 4. Type specimens from GRTE or JODR. The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column.

Taxon	Publication	Catalog Number	Provenance	Notes
Astarte meeki	Stanton 1899	Possibly at least one of a syntype series including USNM 28936 and 28937	Sundance Formation, north of Berry Creek (other syntype[s] from within and north of YELL)	Bivalve
Holectypus pealei	Clark (in Clark and Twitchell 1915)	USNM 31192	Sundance Formation, north of Berry Creek	Echinoid

Cultural Resource Contexts

Humans have a relatively long history in the Jackson Hole area, with a record going back to the end of the Pleistocene (Pierce et al. 2003). Hundreds of archeological sites were known in the Yellowstone–Jackson Hole area by 1980 (Wright 1980). Thus, there is the possibility of a long record of fossils in cultural resource contexts. Some caveats apply: it appears that it was several thousand years before humans had a substantial population in Jackson Hole (Wright 1980), which affects the temporal element; the size of Jackson Lake has varied over time, and the present incarnation doubtless is covering sites that were on the shore in the past; and it has been observed that human sites in Jackson Hole have little in the way of faunal remains, which has been used to suggest that various plant foods were preferred in the Jackson Hole area, with hunting done elsewhere in the vicinity (Wright 1980). As mentioned in the Upper Cenozoic section above, there are seven sites known in the Hermitage Point area of GRTE with faunal remains, all from approximately the past 1,600 years. These sites typically include at least *Bison* and/or cervids (deer and elk), and then often carnivorans (mustelids and bears, followed by canids and felids) and rodents, with rarer fish, birds, and, in the most recent sites, horses. Faunal remains from archeological sites in GRTE are described in Cannon (1991). An example of a fossil/cultural site in the vicinity with greater antiquity is the Helen Lookingbill Site (48FR308), 77 km (48 miles) east of GRTE. This site includes Paleo-Indian, Early Plains Archaic, and younger components, and has yielded bones of mountain sheep, deer, elk, and bison (Pinner 1979). A variety of fossiliferous formations found in the region are also known as sources of material for stone tools (Frison 1991). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Literature Cited

Adams, T., B. Breithaupt, J. Shinn, E. Southwell, and N. Matthews. 2004. The Sundance vertebrate ichnofaunal province: evidence for population structures of Bathonian dinosaurs from tracksites in the Bighorn Basin, Wyoming. *Journal of Vertebrate Paleontology* 24(supplement to 3):33A.

Agatston, R. S. 1952. Tensleep formation of the Big Horn Basin. Pages 44-48 *in* R. W. Spalding and J. S. Wold, editors. Southern Big Horn Basin, Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 7.

Anders, M. H., J. Saltzman, and S. R. Hemming. 2009. Neogene tephra correlations in eastern Idaho and Wyoming: implications for Yellowstone Hotspot-related volcanism and tectonic activity. *Geological Society of America Bulletin* 121(5-6):837-856.

Andersson, K. A. 1985. Permian trace fossils of western Wyoming and southwestern Montana: systematics and paleoenvironments. Abstracts with Programs. *Geological Society of America* 17(4):207.

Andrews, H. N., Jr. and C. S. Pearsall. 1941. On the flora of the Frontier Formation of southwestern Wyoming. *Annals of the Missouri Botanical Garden* 28(2):165-192.

Andrichuk, J. M. 1956. Devonian stratigraphy in northwestern Wyoming and adjoining areas. Pages 43-50 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Ash, S. R. and C. B. Read. 1976. North American species of *Tempskya* and their stratigraphic significance. U.S. Geological Survey, Reston, VA. Professional Paper 874. Available online at: http://pubs.er.usgs.gov/publication/pp874. Accessed February 2013.

Ash, S. R. and W. D. Tidwell. 1998. Plant megafossils from the Brushy Basin Member of the Morrison Formation near Montezuma Creek Trading Post, southeastern Utah. *Modern Geology* 22(1-4):321-340.

Aubrey, W. M. 1991. Geologic framework of Cretaceous and Tertiary rocks in the Southern Ute Indian Reservation and adjacent areas in the northern San Juan Basin, southwestern Colorado. Pages B1-B24 *in* Zech, R. S., editor. Geologic framework and stratigraphy of Cretaceous and Tertiary rocks of the Southern Ute Indian Reservation, southwestern Colorado. U.S. Geological Survey, Reston, VA. Professional Paper 1505-B,C. Available online at: http://pubs.er.usgs.gov/publication/pp1505BC Accessed March 2011.

Bachrach, R. 1956. Tensleep-Amsden sections of the Gros Ventre-Snake River area, northwestern Wyoming. Pages 64-65 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Baker, R. G. 1976. Late Quaternary vegetation history of the Yellowstone Lake Basin, Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 729-E. Available online at: http://pubs.er.usgs.gov/publication/pp729E. Accessed March 2013.

Baker, R. G. 1986. Sangamonian(?) and Wisconsinan paleoenvironments in Yellowstone National Park. *Geological Society of America Bulletin* 97(6):717-736.

Barker, K. S. 1984. Stratigraphy, petrography, and paleoenvironmental interpretation of Mississippian-Pennsylvanian Amsden Formation south of La Barge Guard Station, Salt River Range, western Wyoming. *AAPG Bulletin* 68(7):932.

Barnosky, A. D. 1984a. The Colter Formation: evidence for Miocene volcanism in Jackson Hole, Teton County, Wyoming. *Earth Science Bulletin* 17:49-97.

Barnosky, A. D. 1985. Late Blancan (Pliocene) microtine rodents from Jackson Hole, Wyoming: biostratigraphy and biogeography. *Journal of Vertebrate Paleontology* 5(3):255-271.

Barnosky, A. D. 1986. Arikareean, Hemingfordian, and Barstovian mammals from the Miocene Colter Formation, Jackson Hole, Teton County, Wyoming. *Bulletin of Carnegie Museum of Natural History* 26.

Barnosky, A. D. and W. J. LaBar. 1989. Mid-Miocene (Barstovian) environmental and tectonic setting near Yellowstone Park, Wyoming and Montana. *Geological Society of America Bulletin* 101(11):1448-1456.

Barnosky, C. W. 1984b. Late Miocene vegetational and climatic variations inferred from a pollen record in northwest Wyoming. *Science* 223(4631):49-51.

Beebee, R. A. and R. Cox. 1998. Dynamics of marine transgression onto a non-linear shoreline: the Middle Cambrian Flathead Sandstone, Clarks Fork Valley, Wyoming. *Mountain Geologist* 35(3):91-101.

Behnken, F. H., B. R. Wardlaw, and L. N. Stout. 1986. Conodont biostratigraphy of the Permian Meade Peak phosphatic shale member, Phosphoria Formation, southeastern Idaho. *Contributions to Geology* 24(2):169-190.

Behrendt, J. C., B. L. Tibbetts, W. E. Bonini, P. M. Lavin, J. D. Love, and J. C. Reed, Jr. 1968. A geophysical study in Grand Teton National Park and vicinity, Teton County, Wyoming: with sections on stratigraphy and structure and Precambrian rocks. U.S. Geological Survey, Washington, DC. Professional Paper 516-E. Available online at: http://pubs.er.usgs.gov/publication/pp516E or http://www.nps.gov/history/history/online_books/geology/publications/pp/516-E/index.htm. Accessed February 2013.

Bell, L. H. and L. T. Middleton. 1978. An introduction to the Cambrian Flathead Sandstone, Wind River basin, Wyoming. Pages 79-88 *in* R. G. Boyd, W. W. Boberg, and G. M. Olson, editors. Resources of the Wind River basin. Wyoming Geological Association, Casper, WY. Guidebook 30.

Bell, W. C. 1941. Cambrian Brachiopoda from Montana. *Journal of Paleontology* 15(3):193-255.

Bennett, S. C. 1989. A pteranodontid pterosaur from the Early Cretaceous of Peru, with comments on the relationships of Cretaceous pterosaurs. *Journal of Paleontology* 63(5):669-677.

Benson, A. L. 1966. Devonian stratigraphy of western Wyoming and adjacent areas. *Bulletin of the American Association of Petroleum Geologists* 50(12):2566-2603.

Berry, E. W. 1930. The flora of the Frontier Formation. Pages 129-135 *in* Shorter contributions to general geology, 1929. U.S. Geological Survey, Reston, VA. Professional Paper 158.

Black, C. C. 1968. Small mammals from the Colter Formation, Jackson Hole, Wyoming. Pages 10-12 *in* C. C. Black, M. C. McKenna, and P. Robinson, editors. Field conference guidebook for the high altitude and mountain basin deposits of Miocene age in Wyoming and Colorado. University of Colorado Museum, Boulder, CO.

Blackwell, W. H., W. D. Martin, and R. G. McWilliams. 1983. Algal remains in cryptalgal laminated carbonates of the upper Middle Cambrian of Northwest Wyoming. *American Journal of Botany* 70(5, Part 2):68.

Blake, D. B. 1981. The new Jurassic sea star genus *Eokainaster* and comments on life habits and the origins of the modern Asteroidea. *Journal of Paleontology* 55(1):33-46.

Blome, C. D. and D. L. Eicher. 1994. Radiolarian paleoceanography of the Upper Cretaceous Western Interior Seaway, southern Montana. Abstracts with Programs. *Geological Society of America* 26(7):A-159.

Bonem, R. M. 1972. Stratigraphic and faunal studies of the Pilgrim Formation in south-central Montana. Pages 11-17 *in* J. Lynn, C. Balster, and J. Warne, editors. Crazy Mountains Basin. Montana Geological Society, Billings, MT. Guidebook 21.

Boyd, D. W. 2010. Morphology and taphonomy of an exceptional trackway from the Flathead Sandstone (Middle Cambrian) of Wyoming. Contributions to Geology **45**(1):23-34.

Boyd, D. W. and H. T. Ore. 1963. A Wyoming specimen of *Dendrophycus*. *Contributions to Geology* 2(1):63-68.

Boyd, H. A. 1995. The Laramide Orogeny and associated lithostratigraphic units, southwestern Wyoming. Pages 313-341 *in* R. W. Jones, editor. Resources of southwestern Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 46.

Bradley, F. H. 1872. On the Quebec and Carboniferous rocks in the Teton Range. *American Journal of Science* 4:230-231.

Branson, E. B. 1947. Triassic (Chugwater) footprints from Wyoming. *Journal of Paleontology* 21(6):588-590.

Branson, E. B. and M. G. Mehl. 1932. Footprint records from the Paleozoic and Mesozoic of Missouri, Kansas and Wyoming. *Bulletin of the Geological Society of America* 43(2):383-398.

Bray, E. and K. F. Hirsch. 1998. Eggshell from the Upper Jurassic Morrison Formation. *Modern Geology* 23(1-4):219-240.

Breithaupt, B. H. 1985. Nonmammalian vertebrate faunas from the Late Cretaceous of Wyoming. Pages 159-175 *in* G. E. Nelson, editor. The Cretaceous geology of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 36.

Breithaupt, B. H., E. H. Southwell, T. L. Adams, and N. A. Matthews. 2001. Innovative documentation methodologies in the study of the most extensive dinosaur tracksite in Wyoming. Pages 113-122 *in* V. L. Santucci and L. McClelland, editors. Proceedings of the 6th fossil resource conference: 2001 a fossil odyssey. NPS Geological Resources Division, Denver, CO. Technical Report NRS/NRGRD/GRDTR-01/01. Available online at: http://www.nature.nps.gov/geology/paleontology/pub/fossil_conference_6/breithaupt_3.htm. Accessed June 2013.

Breithaupt, B. H., E. H. Southwell, T. Adams, and N. A. Matthews. 2006. The Red Gulch Dinosaur Tracksite: public participation in the conservation and management of a world-class paleontological site. Page 10 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 34.

Brenner, R. L. and D. K. Davies. 1973. Storm-generated coquinoid sandstone: genesis of high-energy marine sediments from the Upper Jurassic of Wyoming and Montana. *Geological Society of America Bulletin* 84(5):1685-1698.

Brenner, R. L. and D. K. Davies. 1974. Oxfordian sedimentation in Western Interior United States. *AAPG Bulletin* 58(3):407-428.

Breuninger, R. H. 2000. Zoned microbial reef complex in the Pilgrim Formation, Upper Cambrian age, western Montana. Abstracts with Programs. *Geological Society of America* 32(5):3.

Britt, B., D. Chure, G. Engelmann, R. Scheetz, and R. Hansen. 2010. Multi-taxic theropod bonebeds in an interdunal setting of the Early Jurassic eolian Nugget Sandstone, Utah. *Journal of Vertebrate Paleontology* 30(supplement to 5):65A.

Brown, B. and H. E. Vokes. 1944. Fossil imprints of unknown origin: II. Further information and a possible explanation. *American Journal of Science* 242:656-672.

Burford, A. E. 1985. Reptilian markings on the upper Mowry Shale, Emigrant Gap area, Natrona County, Wyoming. Pages 157-158 *in* G. E. Nelson, editor. The Cretaceous geology of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 36.

Burgess, J. D. 1971. Palynological interpretation of Frontier environments in central Wyoming. *Geoscience and Man* 3:69-82.

Burton, D., B. W. Greenhalgh, B. B. Britt, B. J. Kowallis, W. S. Elliott, Jr., and R. Barrick. 2006. New radiometric ages from the Cedar Mountain Formation, Utah and the Cloverly Formation, Wyoming: implications for contained dinosaur faunas. Abstracts with Programs. *Geological Society of America* 38(7):52.

Byers, C. W. and D. W. Larson. 1979. Paleoenvironments of Mowry Shale (Lower Cretaceous), western and central Wyoming. *AAPG Bulletin* 63(3):354-361.

Cannon, K. P. 1991. Faunal remains from Grand Teton National Park, Wyoming. Pages 265-301 *in* Jackson Lake archeological project: the 1987 and 1988

field work. Midwest Archeological Center Technical Report 7.

Carpenter, K. and J. I. Kirkland. 1998. Review of Lower and Middle Cretaceous ankylosaurs from North America. Pages 249-270 *in* S. G. Lucas, J. I. Kirkland, and J. W. Estep, editors. Lower and Middle Cretaceous terrestrial ecosystems. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 14.

Cartwright, A. M., T. P. Cleland, S. F. Derby, E. E. Ergas, H. I. Fay, K. M. Loughney, J. A. Riedel, M. K. Rocheford, C. L. Scott, and K. L. Skaggs. 2005. Aspects of the paleontology and stratigraphy of the Lower Triassic-Lower Cretaceous strata of the eastern Bighorn Basin, WY. Abstracts with Programs. *Geological Society of America* 37(7):302.

Case, G. R. 1987. A new selachian fauna from the late Campanian of Wyoming (Teapot Sandstone Member, Mesaverde Formation, Big Horn Basin). Palaeontographica. *Abteilung A: Palaeozoologie-Stratigraphie* 197(1-3):1-37.

Cather, S. M. 2003. Polyphase Laramide tectonism and sedimentation in the San Juan Basin, New Mexico. Pages 119-132 *in* S. G. Lucas, S. C. Semken, W. Berglof, and D. Ulmer-Scholle, editors. Geology of the Zuni Plateau. New Mexico Geological Society, Socorro, NM. Guidebook 54.

Cavaroc, V. V. and R. M. Flores. 1991. Red beds of the Triassic Chugwater Group, southwestern Powder River basin, Wyoming. U.S. Geological Survey, Reston, VA. Bulletin 1917-E. Available online at: http://pubs.er.usgs.gov/publication/b1917E. Accessed February 2013.

Chambers, M., H. Kimberly, B. B. Britt, D. J. Chure, G. F. Engelmann, and R. Scheetz. 2011. Preliminary taphonomic analysis of a coelophysoid theropod dinosaur bonebed in the Early Jurassic Nugget Sandstone of Utah. Abstracts with Programs. *Geological Society of America* 43(4):16.

Chen, X. and G. D. Webster. 1994. Sedimentology, tectonic control and evolution of a Lower Mississippian carbonate ramp with offshore bank, central Wyoming to eastern Idaho and northeastern Utah, U.S.A. Pages 557-587 *in* A. F. Embry, B. Beauchamp, and D. J. Glass, editors. Pangea: global environments and resources. Canadian Society of Petroleum Geologists, Calgary, Canada. Memoir 17.

Christiansen, R. L. 2001. The Quaternary and Pliocene Yellowstone Plateau volcanic field of Wyoming, Idaho, and Montana. U.S. Geological Survey, Reston, VA. Professional Paper 729-G. Available online at: http://pubs.usgs.gov/pp/pp729g/. Accessed March 2013.

Christiansen, R. L. and H. R. Blank, Jr. 1972. Volcanic stratigraphy of the Quaternary rhyolite plateau in Yellowstone National Park. U.S. Geological Survey, Washington, DC. Professional Paper 729-B. Available online at: http://pubs.er.usgs.gov/publication/pp729B. Accessed March 2013.

Christiansen, R. L. and J. D. Love. 1978. The Pliocene Conant Creek Tuff in the northern part of the Teton Range and Jackson Hole, Wyoming. U.S. Geological Survey, Reston, VA. Bulletin 1435-C. Available online at: http://pubs.er.usgs.gov/publication/b1435C. Accessed March 2013.

Christiansen, R. L., H. R. Blank, Jr., J. D. Love, and J. C. Reed, Jr. 1978. Geologic map of the Grassy Lake Reservoir Quadrangle, Yellowstone National Park and vicinity, Wyoming. U.S. Geological Survey, Reston, VA. Geologic Quadrangle Map 1459. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_10993.htm. Accessed March 2013.

Chure, D. J., R. Litwin, S. T. Hasiotis, E. Evanoff, and K. Carpenter. 2006. The fauna and flora of the Morrison Formation: 2006. Pages 233-249 *in* J. R. Foster and S. G. Lucas, editors. Paleontology and geology of the Upper Jurassic Morrison Formation. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 36.

Chure, D. J., G. F. Engelmann, B. B. Britt, and R. Scheetz. 2009. Interdune facies of the Lower Jurassic Glen Canyon Group sandstone and their paleontologic potential in and around Dinosaur National Monument, northeastern Utah. Abstracts with Programs. *Geological Society of America* 41(6):47.

Cicimurri, D. 2001. Fossil selachians from the Belle Fourche Shale (Cretaceous, Cenomanian), Black Hills region of South Dakota and Wyoming. *Mountain Geologist* 38(4):181-192.

Ciccimuri, D. J. 2004. Early Cenomanian (Late Cretaceous) elasmobranchs from the Mowry Shale, Fall River County, South Dakota. *The Mosasaur* 7:69-73.

Ciriacks, K. W. 1963. Permian and Eotriassic bivalves of the Middle Rockies. *Bulletin of the American Museum of Natural History* 125:1-100. Available online at: http://hdl.handle.net/2246/1222. Accessed March 2013.

Clark, B. E., P. M. Myrow, R. L. Ripperdan, R. L. Ethington, and J. Taylor. 2000. Cambro-Ordovician stratigraphy: north-central Wyoming. Abstracts with Programs. *Geological Society of America* 32(5):A-6.

Clark, N. D. L. and M. K. Brett-Surman. 2008. A comparison between dinosaur footprints from the Middle Jurassic of the Isle of Skye, Scotland, UK, and Shell, Wyoming, USA. *Scottish Journal of Geology* 44(2):139-150.

Clark, W. B. and M. W. Twitchell. 1915. The Mesozoic and Cenozoic Echinodermata of the United States. U.S. Geological Survey, Washington, D.C. Monograph 54.

Cloud, P. and J. E. Bever. 1973. Trace fossils from the Flathead Sandstone, Fremont County, Wyoming, compared with early Cambrian forms from California and Australia. *Journal of Paleontology* 47(5):883-885.

Cobban, W. A. 1951. Scaphitoid cephalopods of the Colorado group. U.S. Geological Survey, Washington, DC. Professional Paper 239. Available online at: http://pubs.er.usgs.gov/publication/pp239. Accessed March 2013.

Cobban, W. A. 1952. A new Upper Cretaceous ammonite genus from Wyoming and Utah. *Journal of Paleontology* 26(5):758-760.

Cobban, W. A. 1990. Ammonites and some characteristic bivalves from the Upper Cretaceous Frontier Formation, Natrona County, Wyoming. U.S. Geological Survey, Reston, VA. Bulletin 1917-B. Available online at:

http://pubs.er.usgs.gov/publication/b1917B. Accessed February 2013.

Cobban, W. A. 1995. Occurrences of the free-swimming Upper Cretaceous crinoids *Uintacrinus* and *Marsupites* in the Western Interior of the United States. Pages C1-C6 *in* Shorter contributions to the stratigraphy and geochronology of Upper Cretaceous rocks in the Western Interior of the United States. U.S. Geological Survey, Reston, VA. Bulletin 2113. Available online at: http://pubs.er.usgs.gov/publication/b2113. Accessed March 2013.

Cobban, W. A., C. E. Erdmann, B. R. Alto, and C. H. Clark. 1958. *Scaphites depressus* zone (Cretaceous) in northwestern Montana. *Bulletin of the American Association of Petroleum Geologists* 42(3):656-664.

Cobban, W. A., I. Walaszczyk, J. D. Obradovich, and K. C. McKinney. 2006. A USGS zonal table for the Upper Cretaceous Middle Cenomanian-Maastrichtian of the Western Interior of the United States based on ammonites, inoceramids, and radiometric ages. U.S. Geological Survey, Reston, VA. Open-File Report 2006-1250. Available online at: http://pubs.usgs.gov/of/2006/1250/. Accessed March 2013.

Colbert, E. H. 1943. A Miocene oreodont from Jackson Hole, Wyoming. *Journal of Paleontology* 17(3):298-304.

Colbert, E. H. 1961. The Triassic reptile, *Poposaurus*. Fieldiana. *Geology* 14(4):59-78. Available online at: http://www.biodiversitylibrary.org/item/25266. Accessed February 2013.

Condon, S. M. 2000. Stratigraphic framework of Lower and Upper Cretaceous rocks in central and eastern Montana. U.S. Geological Survey, Reston, VA. Digital Data Series 57. Available online at: http://pubs.er.usgs.gov/publication/ds57. Accessed February 2013.

Connely, M. and B. Talbot. 2005. Trace fossils in marine sediments of the Mowry Shale (Early Cretaceous) of Wyoming are possibly vertebrate in origin. *Journal of Vertebrate Paleontology* 25(supplement to 3):47A.

Conroy, J., M. A. Wilson, and C. M. Tang. 2002. Bored and encrusted carbonate cobbles and hardgrounds at the base of a regressive sequence (lower Sundance Formation, Middle Jurassic, eastern Wyoming). Abstracts with Programs. *Geological Society of America* 34(2):95.

Covington, S. and M. V. Ransmeier. 2005. Grand Teton National Park geologic resource evaluation scoping report. National Park Service, Geologic Resources Division, Denver, CO. Available online at: http://www.nature.nps.gov/geology/inventory/publications/s_summaries/GRTE_scoping_summary_08152005.pdf. Accessed March 2013.

Cox, E. R. 1974. Water resources of Grand Teton National Park, Wyoming. U.S. Geological Survey, Washington, DC. Open-File Report 74-1019. Available online at: http://pubs.er.usgs.gov/publication/ofr741019. Accessed March 2013.

Csonka, J. and K. V. Bulinski. 2010. The *Chondrites* ichnofossil: a comparative study. Abstracts with Programs. *Geological Society of America* 42(2):93.

Cygan, N. E. and F. L. Koucky. 1963. The Cambrian and Ordovician rocks of the east flank of the Big Horn Mountains, Wyoming. Pages 26-37 *in* G. C. Cooper, D. F. Cardinal, H. W. Lorenz, and J. R. Lynn, editors. Northern Powder River basin, Wyoming and Montana. Wyoming Geological Association and Billings Geological Society, Casper, WY. Joint Guidebook 1.

D'Emic, M. D. and B. Z. Foreman. 2012. The beginning of the sauropod dinosaur hiatus in North America: insights from the Lower Cretaceous Cloverly Formation of Wyoming. *Journal of Vertebrate Paleontology* 32(4):883-902.

Daley, R. L. and D. W. Boyd. 1996. The role of skeletal microstructure during selective silicification of brachiopods. *Journal of Sedimentary Research* 66(1):155-162.

Darton, N. H. 1904. Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range. *Geological Society of America Bulletin* 15:379-448.

Darton, N. H. 1906. Geology of the Bighorn Mountains. U.S. Geological Survey, Washington, DC. Professional Paper 51. Available online at: http://pubs.er.usgs.gov/publication/pp51. Accessed February 2013.

Davidson, W. R. 1987. Petrology and environmental interpretation of the synorogenic Bacon Ridge Formation, northwest Wyoming. Pages 207-216 *in* W. R. Miller, editor. The thrust belt revisited. Wyoming Geological Association, Casper, WY. Guidebook 38.

Davis, H. R., C. W. Byers, and L. M. Pratt. 1989. Depositional mechanisms and organic matter in Mowry Shale (Cretaceous), Wyoming. *AAPG Bulletin* 73(9):1103-1116.

Dawley, R. M., J. M. Zawiskie, and J. W. Cosgriff. 1979. A rauisuchid thecodont from the Upper Triassic Popo Agie Formation of Wyoming. *Journal of Paleontology* 53(6):1428-1431.

DeBoer, D. A. and L. T. Middleton. 1981. Paleoenvironmental and paleogeographic significance of Middle Cambrian algal buildups, Teton Range, Wyoming. Abstracts with Programs. *Geological Society of America* 13(4):194.

DeBoer, D. and L. Middleton. 1983. Sedimentology of a shallowing-upward sequence in Middle Cambrian carbonate-siliciclastic associations, western Wyoming. *AAPG Bulletin* 67(3):448-449.

DeCelles, P. G. 1986. Sedimentation in a tectonically partitioned, nonmarine foreland basin: the Lower Cretaceous Kootenai Formation, southwestern Montana. *Geological Society of America Bulletin* 97(8):911-931.

Deiss, C. F. 1936. Revision of type Cambrian formations and sections of Montana and Yellowstone National Park. *Geological Society of America Bulletin* 47(8):1257-1342.

Deiss, C. F. 1938. Cambrian formations and sections in part of Cordilleran Trough. *Geological Society of America Bulletin* 49(7):1067-1168.

DeMar, D. G., Jr. and B. H. Breithaupt. 2006. The nonmammalian vertebrate microfossil assemblages of the Mesaverde Formation

(Upper Cretaceous, Campanian) of the Wind River and Bighorn Basins, Wyoming. Pages 33-53 *in* S. G. Lucas and R. M. Sullivan, editors. Late Cretaceous vertebrates from the Western Interior. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 35.

Denison, R. H. 1951. Late Devonian fresh-water fishes from the western United States. *Fieldiana*: *Geology* 11(5). Available online at: http://archive.org/details/latedevonianfres115deni. Accessed March 2013.

Dodson, P., A. K. Behrensmeyer, R. T. Bakker, and J. S. McIntosh. 1980. Taphonomy and paleoecology of the dinosaur beds of the Jurassic Morrison Formation. *Paleobiology* 6(2):208-232.

Dong, X., P. C. J. Donoghue, and J. E. Repetski. 2005. Basal tissue structure in the earliest euconodonts: testing hypotheses of developmental plasticity in euconodont phylogeny. *Palaeontology* 48(2):411-421.

Dorf, E. and C. Lochman. 1940. Upper Cambrian formations in southern Montana. *Geological Society of America Bulletin* 51(4):541-556.

Driscoll, E. G. and G. B. Newton. 1969. A new species of the coral *Syringopora* from the Tensleep Formation (Pennsylvanian) of Montana. *Journal of Paleontology* 43(2):531-534.

Druckenmiller, P. S. 2002. Osteology of a new plesiosaur from the Lower Cretaceous (Albian) Thermopolis Shale of Montana. *Journal of Vertebrate Paleontology* 22(1):29-42.

Dubiel, R. F. 1992. Sedimentology and depositional history of the Upper Triassic Chinle Formation in the Uinta, Piceance, and Eagle basins, northwestern Colorado and northeastern Utah. U.S. Geological Survey, Reston, VA. Bulletin 1787-W. Available online at: http://pubs.er.usgs.gov/publication/b1787W. Accessed September 2011.

Dyman, T. S., W. J. Perry, Jr., D. J. Nichols, L. E . Davis, and J. C. Haley. 1989. Stratigraphy, petrology, and provenance of the Cenomanian to Turonian Frontier Formation near Lima, southwestern Montana. Pages 103-114 *in* D. E. French and R. F. Grabb, editors. Montana Geological Society 1989 field conference guidebook: Montana centennial edition: Geologic resources of Montana, Volume I. Montana Geological Society, Bozeman, MT. Field Conference 1989(1).

Edmund, R. W. 1951. The structure, geology, and physiography of the northern end of the Teton Range, Wyoming. Augustana Library, Rock Island, IL. Publication 23.

Eicher, D. L. 1958. The Thermopolis shale in eastern Wyoming. Pages 79-83 *in* J. Strickland, F. Byrne, and J. Barlow, editors. Powder River Basin. Wyoming Geological Association, Casper, WY. Guidebook 13.

Eicher, D. L. 1960. Stratigraphy and micropaleontology of the Thermopolis Shale. Peabody Museum of Natural History Bulletin 15. Available online at: http://peabody.yale.edu/sites/default/files/documents/scientific-publications/ypmB15_1960.pdf. Accessed February 2013.

Eicher, D. L. 1965. Foraminifera and biostratigraphy of the Graneros Shale. *Journal of Paleontology* 39(5):875-909.

Eicher, D. L. 1967. Foraminifera from Belle Fourche Shale and equivalents, Wyoming and Montana. *Journal of Paleontology* 41(1):167-188.

Elder, W. P. and J. I. Kirkland. 1993. Cretaceous paleogeography of the Colorado Plateau and adjacent areas. Pages 129-151 *in* M. Morales, editor. Aspects of Mesozoic geology and paleontology of the Colorado Plateau. Museum of Northern Arizona, Flagstaff, AZ. Bulletin 59.

Elder, W. P. and J. I. Kirkland. 1994. Cretaceous paleogeography of the southern Western Interior region. Pages 415-440 *in* M. V. Caputo, J. A. Peterson, and K. J. Franczyk, editors. Mesozoic system of the Rocky Mountain region, USA. Rocky Mountain Section, Society for Sedimentary Geology, Denver, CO.

Engelmann, G. F. and D. J. Chure. 2008. Vertebrate burrows in sandstones of the Lower Jurassic Glen Canyon Group in the vicinity of Dinosaur National Monument, Utah. Abstracts with Programs. *Geological Society of America* 40(1):45.

Engelmann, G. F., D. J. Chure, and A. R. Fiorillo. 2004. The implications of a dry climate for the paleoecology of the fauna of the Upper Jurassic Morrison Formation. *Sedimentary Geology* 167(3-4):297-308.

Engelmann, G. F., D. J. Chure, and B. Britt. 2009. Paleoecological information from paleontology and sedimentary geology of interdunal sediments of the early Jurassic Glen Canyon Group in and around Dinosaur National Monument (DNM) in northeastern Utah. Abstracts with Programs. *Geological Society of America* 41(7):163.

Engelmann, G. F., D. J. Chure, and D. B. Loope. 2010. An occurrence of remarkably abundant *Brasilichnium* tracks (Nugget Sandstone, early Jurassic, Dinosaur National Monument) and their environmental context. Abstracts with Programs. *Geological Society of America* 42(5):642.

Entzminger, D. J. 1979. Revision of Upper Cretaceous stratigraphy: Big Hole Mountains, Idaho. *Earth Science Bulletin* 12(4):15-24.

Faul, H. and W. A. Roberts. 1951. New fossil footprints from the Navajo(?) Sandstone of Colorado. *Journal of Paleontology* 25(3):266-274.

Feldmann, R. M. 1979. *Eryma foersteri*, a new species of lobster (Decapoda) from the Jurassic (Callovian) of North America. American Museum Novitates 2668.

Fenton, C. L. 1943. Pre-Cambrian and early Paleozoic algae. *American Midland Naturalist* 30(1):83-111.

Fenton, C. L. and M. A. Fenton. 1939. Pre-Cambrian and Paleozoic algae. *Geological Society of America Bulletin* 50(1):89-114.

Fisher, C. G. and W. W. Hay. 1999. Calcareous nannofossils as indicators of Mid-Cretaceous paleofertility along an ocean front, U. S. Western Interior. Pages 161-180 *in* E. Barrera and C. C. Johnson, editors. Evolution of the Cretaceous ocean-climate system. Geological Society of America, Boulder, CO. Special Paper 332.

Fisher, J. H. 1963. Tensleep Sandstone of the eastern Big Horn Mountains, Wyoming. Pages 54-60 *in* G. C. Cooper, D. F. Cardinal, H. W. Lorenz, and J. R. Lynn, editors. Northern Powder River basin, Wyoming and Montana. Wyoming Geological Association and Billings Geological Society, Casper, WY. Joint Guidebook 1.

Forster, C. A. 1984. The paleoecology of the ornithopod dinosaur *Tenontosaurus tilletti* from the Cloverly Formation, Big Horn Basin of Wyoming and Montana. *Mosasaur* 2:151-163.

Foster, J. R. 2003. Paleoecological analysis of the vertebrate fauna of the Morrison Formation (Upper Jurassic), Rocky Mountain region, U.S.A. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 23.

Foster, J. 2007. Jurassic West: the dinosaurs of the Morrison Formation and their world. Indiana University Press, Bloomington and Indianapolis, IN.

Fox, S. K., Jr. 1954. Cretaceous foraminifera from the Greenhorn, Carlile, and Cody formations, South Dakota, Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 254-E. Available online at: http://pubs.er.usgs.gov/publication/pp254E. Accessed March 2013.

Franczyk, K. J., T. D. Fouch, R. C. Johnson, C. M. Molenaar, and W. A. Cobban. 1992. Cretaceous and Tertiary paleogeographic reconstructions for the Uinta-Piceance Basin Study Area, Colorado and Utah. U.S. Geological Survey, Reston, VA. Bulletin 1787-Q. Available online at: http://pubs.er.usgs.gov/publication/b1787Q. Accessed September 2011.

Frison, G. C. 1991. Prehistoric hunters of the high plains (2nd edition). Academic Press, New York, NY.

Fritz, M. A. and B. F. Howell. 1955. An Upper Cambrian coral from Montana. *Journal of Paleontology* 29(1):181-183.

Frost, B. R., C. D. Frost, M. Cornia, K. R. Chamberlain, and R. Kirkwood. 2006. The Teton-Wind River domain: a 2.68-2.67 Ga active margin in the western Wyoming Province. *Canadian Journal of Earth Sciences* 43(10):1489-1510.

Frost, B. R., S. M. Swapp, and C. D. Frost. 2009. 2.685-2.671 Ga Himalayan-type orogeny in the northern Teton Range, Wyoming, USA. *Geochimica et Cosmochimica Acta* 73(13S):A399.

Frost, B. R., C. D. Frost, S. M. Swapp, and K. R. Chamberlain. 2011. Multiple terranes in the Teton Range, Wyoming: evidence for tectonic assembly at 2.68 and 2.62 Ga. Abstracts with Programs. *Geological Society of America* 43(5):435.

Fryxell, F. M. 1944. Jackson Hole National Monument, the geologic story. *National Parks Magazine* 18(76):19-25.

Gilmour, E. H. and R. C. Walker. 1986. Bryozoans from the Phosphoria Formation (Permian), southeastern Idaho. *Contributions to Geology* 24(2):191-209.

Girty, G. H. 1899. Devonian and Carboniferous fossils. Pages 479-599 *in* Geology of the Yellowstone national park. U.S. Geological Survey, Washington, D.C. Monograph 32. Available online at:

http://archive.org/details/geologyofyellows00hagu. Accessed March 2013.

Glass, G. B. and R. W. Jones. 1991. Coal fields and coal beds of Wyoming. Pages 133-167 *in* B. R. Frost and S. Roberts, editors. Mineral resources of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 42.

Good, J. M. and K. L. Pierce. 1996. Interpreting the landscapes of Grand Teton and Yellowstone national parks: recent and ongoing geology. Grand Teton Natural History Association, Moose, WY.

Gordon, M., Jr. 1966. Permian coleoid cephalopods from the Phosphoria Formation in Idaho and Montana. Pages B28-B35 *in* Geological Survey Research 1966, Chapter B. U.S. Geological Survey, Washington, DC. Professional Paper 550-B. Available online at: http://pubs.er.usgs.gov/publication/pp550B. Accessed February 2013.

Gordon, M., Jr. 1971. Primitive squid gladii from the Permian of Utah. Pages C34-C38 *in* Geological Survey Research 1971, Chapter C. U.S. Geological Survey Professional Paper 750-C. Available online at: http://pubs.er.usgs.gov/publication/pp750C. Accessed February 2013.

Gordon, M., Jr. 1975. Brachiopoda of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 858-D. Available online at: http://pubs.er.usgs.gov/publication/pp848D. Accessed February 2013.

Gordon, M., Jr. and J. Pojeta, Jr. 1975. Pelecypoda and Rostroconchia of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 848-E. Available online at: http://pubs.er.usgs.gov/publication/pp848E. Accessed February 2013.

Gordon, M., Jr. and E. L. Yochelson. 1975. Gastropoda, Cephalopoda, and Trilobita of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 848-F. Available online at: http://pubs.er.usgs.gov/publication/pp848F. Accessed February 2013.

Gorman, D. R. 1963. Stratigraphic-sedimentational aspects of the Amsden Formation, Big Horn Mountains, Wyoming. Pages 67-70 *in* G. C. Cooper, D. F. Cardinal, H. W. Lorenz, and J. R. Lynn, editors. Northern Powder River basin, Wyoming and Montana. Wyoming Geological Association and Billings Geological Society, Casper, WY. Joint Guidebook 1.

Gregson, J. D., D. Chure, and D. A. Sprinkel. 2010. Geology and paleontology of Dinosaur National Monument, Utah-Colorado. Pages 161-192 *in* D. A. Sprinkel, T. C. Chidsey, Jr., and P. B. Anderson, editors. Geology of Utah's parks and monuments (3rd edition). Utah Geological Association, Salt Lake City, UT. Publication 28.

Gutschick, R. C. 1966. Transitional Devonian to Mississippian environmental changes in western Montana. Pages 171-181 *in*

Symposium on cyclic sedimentation. Kansas Geological Survey, Lawrence, KS. Bulletin 169. Available online at: http://www.kgs.ku.edu/Publications/Bulletins/169/Gutschick/index.html. Accessed February 2013.

Gutschick, R. C. and R. Lamborn. 1975. *Bifungites*, trace fossils from Devonian-Mississippian rocks of Pennsylvania and Montana, U.S.A. *Palaeogeography, Palaeoclimatology, Palaeoecology* 18(3):193-212.

Gutschick, R. C., J. L. Weiner, and L. Young. 1961. Lower Mississippian arenaceous Foraminifera from Oklahoma, Texas, and Montana. *Journal of Paleontology* 35(6):1193-1221.

Gutschick, R. C., M. McLane, and J. Rodriguez. 1976. Summary of late Devonian-early Mississippian biostratigraphic framework in western Montana. Pages 91-124 *in* Guidebook of selected areas in southwestern Montana. Montana Bureau of Mines and Geology, Butte, MT. Special Publication 73.

Guyer, G. S., C. F. Vondra, and R. D. Cody. 1995. Paleoenvironments of the Jurassic Gypsum Spring Formation, Big Horn Basin, Wyoming. Abstracts with Programs. *Geological Society of America* 27(3):54-55.

Hadly, E. A. 1996. Influence of late-Holocene climate on northern Rocky Mountain mammals. *Quaternary Research* 46(3):298-310.

Hadly, E. A. 1999. Fidelity of terrestrial vertebrate fossils to a modern ecosystem. *Palaeogeography, Palaeoclimatology, Palaeoecology* 149(1-4):389-409.

Haiar, B. and R. Lupia. 2011. Paleobotany and paleoecology of localities from the Cretaceous Cloverly Formation, Bighorn Basin, Wyoming. Abstracts with Programs. *Geological Society of America* 43(5):312.

Hale, E. S., W. A. Cobban, T. S. Dyman, J. A. Fitzke, D. J. Nichols, K. W. Porter, and K. I. Takahashi. 2004. Stratigraphy and age of Cretaceous rocks at Mount Everts, Yellowstone National Park, Wyoming and Montana. Abstracts with Programs. *Geological Society of America* 36(5):73.

Hamblin, A. H., S. A. Bilbey, and J. E. Hall. 2000. Prehistoric animal tracks at Red Fleet State Park, northeastern Utah. Pages 569-578 *in* D. A. Sprinkel, T. C. Chidsey, Jr., and P. B. Anderson, editors. Geology of Utah's parks and monuments. Utah Geological Association, Salt Lake City, UT. Publication 28. Available online at: http://www.utahgeology.org/pub28_pdf_files/HamblinRedFleet.pdf. Accessed September 2011.

Hampel, A., R. Hetzel, and A. L. Densmore. 2007. Postglacial slip-rate increase on the Teton normal fault, northern Basin and Range Province, caused by melting of the Yellowstone ice cap and deglaciation of the Teton Range? *Geology* 35(12):1107-1110.

Harrington, C. D. 1985. A revision in the glacial history of Jackson Hole, Wyoming. *Mountain Geologist* 22(1):28-32.

Harris, J. D. and K. J. Lacovara. 2004. Enigmatic fossil footprints from the Sundance Formation (Upper Jurassic) of Bighorn Canyon National Recreation Area, Wyoming. *Ichnos* 11:151-166. Available online at:

http://cactus.dixie.edu/jharris/Sundance_Tracks.pdf. Accessed February 2013.

Harris, J. D., K. R. Johnson, J. Hicks, and L. Tauxe. 1996. Four-toed theropod footprints and a paleomagnetic age from the Whetstone Falls Member of the Harebell Formation (Upper Cretaceous: Maastrichtian), northwestern Wyoming. *Cretaceous Research* 17(4):381-401.

Harris, J. D. 1997. Four-toed theropod footprints and a paleomagnetic age from the Whetstone Falls Member of the Harebell Formation (Upper Cretaceous: Maastrichtian), northwestern Wyoming: a correction. *Cretaceous Research* 18(1):139.

Hasiotis, S. T. 2004. Reconnaissance of Upper Jurassic Morrison Formation ichnofossils, Rocky Mountain Region, USA: paleoenvironmental, stratigraphic, and paleoclimatic significance of terrestrial and freshwater ichnocoenoses. *Sedimentary Geology* 167(3-4):177-268.

Hawkins, B. J., P. M. Myrow, R. L. Ripperdan, and J. Taylor. 2001. Shoaling cycles in the Cambro-Ordovician Gallitan Formation: northern Wyoming and central Montana. Abstracts with Programs. *Geological Society of America* 33(5):13.

Henbest, L. G. 1956. Foraminifera and correlation of the Tensleep Sandstone of Pennsylvanian age in Wyoming. Pages 58-63 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Hendrix, M. S. and C. W. Byers. 2000. Stratigraphy and sedimentology of Permian strata, Uinta Mountains, Utah: allostratigraphic controls on the accumulation of economic phosphate. Pages 349-367 *in* C. R. Glenn, L. Prevot-Lucas, and J. Lucas, editors. Marine authigenesis: from global to microbial. Society for Sedimentary Geology Special Publication 66.

Herrick, E. M. and F. R. Schram. 1978. Malacostracan crustacean fauna from the Sundance Formation (Jurassic) of Wyoming. *American Museum Novitates* 2652. Available online at: http://hdl.handle.net/2246/2966. Accessed February 2013.

Hiatt, E. E. and D. A. Budd. 2001. Sedimentary phosphate formation in warm shallow waters: new insights into the palaeoceanography of the Permian Phosphoria Sea from analysis of phosphate oxygen isotopes. *Sedimentary Geology* 145(1-2):119-133.

Hibbard, C. W. 1957. Notes on late Cenozoic shrews. *Transactions of the Kansas Academy of Science* 60(4):327-337.

Hibbard, C. W. 1959. Late Cenozoic microtine rodents from Wyoming and Idaho. Papers of the Michigan Academy of Science, Arts, and Letters 44:3-39. Available online at: http://deepblue.lib.umich.edu/bitstream/handle/2027.42/48569/ID426.pdf?sequence=2. Accessed March 2013.

Hibbard, C. W. 1970. The Pliocene rodent *Microtoscoptes disjunctus* (Wilson) from Idaho and Wyoming. *Contributions from the Museum of Paleontology, The University of Michigan* 23(6):95-98. Available online at: http://hdl.handle.net/2027.42/48448. Accessed March 2013.

High, L. R., Jr. and M. D. Picard. 1965. Sedimentary petrology and origin of analcime-rich Pogo Agie Member, Chugwater (Triassic) Formation, west-central Wyoming. *Journal of Sedimentary Petrology* 35(1):49-70.

High, L. R., Jr. and M. D. Picard. 1967. Rock units and revised nomenclature, Chugwater Group (Triassic), western Wyoming. *Mountain Geologist* 4(2):73-81.

High, L. R., Jr. and M. D. Picard. 1969. Stratigraphic relations within upper Chugwater group (Triassic), Wyoming. *American Association of Petroleum Geologists Bulletin* 53(5):1091-1104.

Hill, C., W. Sutherland, and L. Tierney. 1976. Caves of Wyoming. Geological Survey of Wyoming, Laramie, WY. Bulletin 59.

Hill, R. L. 1987. Stratigraphy and depositional environments of the Frontier Formation along the Gros Ventre River, Teton County, Wyoming. Pages 355-356 *in* W. R. Miller, editor. The thrust belt revisited. Wyoming Geological Association, Casper, WY. Guidebook 38.

Hirsch, K. F. 1994. Upper Jurassic eggshells from the Western Interior of North America. Pages 137-150 *in* K. Carpenter, K. F. Hirsch, and J. R. Horner, editors. Dinosaur eggs and babies. Cambridge University Press, Cambridge, United Kingdom.

Hoare, R. D. and J. D. Burgess. 1960. Fauna from the Tensleep sandstone in Wyoming. *Journal of Paleontology* 34(4):711-716.

Holland, S. M. and M. E. Patzkowsky. 2009. The stratigraphic distribution of fossils in a tropical carbonate succession: Ordovician Bighorn Dolomite, Wyoming, USA. *Palaios* 24(5):303-317.

Holland, S. M. and M. E. Patzkowsky. 2012. Sequence architecture of the Bighorn Dolomite, Wyoming, USA: transition to the Late Ordovician icehouse. *Journal of Sedimentary Research* 82(8):599-615.

Horberg, C. L., R. W. Edmund, and F. M. Fryxell. 1955. Geomorphic and structural relations of Tertiary volcanics in the northern Teton Range and Jackson Hole, Wyoming. *Journal of Geology* 63(6):501-511.

Houlik, C. W., Jr. 1973. Interpretation of carbonate-detrital silicate transitions in the Carboniferous of western Wyoming. *American Association of Petroleum Geologists Bulletin* 57(3):498-509.

Howell, B. F. 1963. New Cambrian conchostracans from Wyoming and Newfoundland, brachiopods from Vermont, and worm, hydrozoan and problematicum from Newfoundland. *Journal of Paleontology* 37(1):264-267.

Hu, C.-h. 1970. The ontogenies of *Ponumia obscura* (Lochman), n.g., and of *Housia canadensis* (Walcott) (Trilobita) from the upper Cambrian of the Big Horn mountains, Wyoming. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series* 78:253-263.

Iddings, J. P. and W. H. Weed. 1899. Descriptive geology of the northern end of the Teton Range. Pages 149-164 *in* Geology of the Yellowstone national park. U.S. Geological Survey, Washington, D.C. Monograph 32. Available online at:

http://archive.org/details/geologyofyellows00hagu. Accessed March 2013.

Imlay, R. W. 1947. Marine Jurassic of Black Hills area, South Dakota and Wyoming. *Bulletin of the American Association of Petroleum Geologists* 31(2):227-273.

Imlay, R. W. 1953. Callovian (Jurassic) ammonites from the United States and Alaska: Part 1, Western Interior United States; Part 2, Alaska Peninsula and Cook Inlet regions. U.S. Geological Survey, Washington, DC. Professional Paper 249-A. Available online at: http://pubs.er.usgs.gov/publication/pp249A. Accessed February 2013.

Imlay, R. W. 1956a. Interpretations of the marine Jurassic fossil record at Lower Slide Lake, Teton County, Wyoming. Pages 70-71 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Imlay, R. W. 1956b. Marine Jurassic exposed in Bighorn Basin, Pryor Mountains, and northern Bighorn Mountains, Wyoming and Montana. *Bulletin of the American Association of Petroleum Geologists* 40(4):562-599.

Imlay, R. W. 1967. Twin Creek Limestone (Jurassic) in the Western Interior of the United States. U.S. Geological Survey, Washington, DC. Professional Paper 540. Available online at: http://pubs.er.usgs.gov/publication/pp540. Accessed March 2013.

Jacobs, K. and C. Whitlock. 2006. 2000 years of fire history from three sites in Grand Teton National Park. Program and Abstracts. *American Quaternary Association Conference* 19:97-98. Available online at: http://www.amqua.org/pastmeetings/2006_Meeting_Abstracts.pdf. Accessed March 2013.

Jacobs, K. and C. Whitlock. 2008. A 2000-year environmental history of Jackson Hole, Wyoming, inferred from lake-sediment records. *Western North American Naturalist* 68(3):350-364. Available online at: http://www.montana.edu/paleoecology/Jacobs&Whitlock_WNAN2008.pdf. Accessed May 2013.

Jacobson, S. R., B. R. Wardlaw, and J. D. Saxton. 1982. Acritarchs from the Phosphoria and Park City formations (Permian, northeastern Utah). *Journal of Paleontology* 56(2, Part 1):449-458.

Johnson, R. C. 2008. Detailed measured sections, cross sections, and paleogeographic reconstructions of the Upper Cretaceous and lower Tertiary nonmarine interval, Wind River Basin, Wyoming. U.S. Geological Survey, Reston, VA. Digital Data Series 69-J. Available online at: http://pubs.usgs.gov/dds/dds-069/dds-069-j/REPORTS/69_J_CH_10.pdf. Accessed March 2013.

Johnson, R. C. 2010. Detailed west to east cross section of Cretaceous and lower Tertiary rocks across the south part of the Bighorn Basin, Wyoming. U.S. Geological Survey, Reston, VA. Digital Data Series 69-V. Available online at: http://pubs.er.usgs.gov/publication/ds69V. Accessed February 2013.

Johnson, R. C., W. R. Keefer, C. W. Keighin, and T. M. Finn. 1998. Detailed outcrop studies of the upper part of the Upper

Cretaceous Cody Shale and the Upper Cretaceous Mesaverde, Meeteetse, and Lance Formations, Bighorn Basin, Wyoming. Pages 59-78 *in* W. R. Keefer and J. E. Goolsby, editors. Cretaceous and lower Tertiary rocks of the Bighorn Basin, Wyoming and Montana. Wyoming Geological Association, Casper, WY. Guidebook 49.

Jones, D. J. 1954. Non-marine Frontier microfauna, Coalville area, Utah. *Journal of Sedimentary Petrology* 24(2):140.

Jones, R. W. 1982. The Jackson Hole coal field. Pages 315-321 *in* S. G. Reid and D. J. Foote, editors. Geology of Yellowstone Park area. Wyoming Geological Association, Casper, WY. Guidebook 33.

Jud, N. A. 2011. Diversity of a Lower Cretaceous pre-angiosperm flora in the Cloverly Formation, WY. Abstracts with Programs. *Geological Society of America* 43(5):312.

Jud, N. A. and S. L. Wing. 2010. Angiosperms from the Early Cretaceous of Wyoming. Abstracts with Programs. *Geological Society of America* 42(5):482.

Kauffman, E. G. 1969. Evidence for sea-level origin of the upper Pinyon Conglomerate, northwestern Wyoming. Page 609 *in* Abstracts for 1968. Geological Society of America, Boulder, CO. Special Paper 121.

Kauffman, E. G. 1973. A brackish water biota from the upper Cretaceous Harebell Formation of northwestern Wyoming. *Journal of Paleontology* 47(3):436-445.

Kausch, T. K. and E. Giffin. 1993. Early Cretaceous vertebrates of the Muddy Sandstone, Big Horn Basin, Wyoming. *Journal of Vertebrate Paleontology* 13(supplement to 3):43A-44A.

KellerLynn, K. 2010. Grand Teton National Park and John D. Rockefeller, Jr. Memorial Parkway geologic resources inventory report. Natural Resource Report NPS/NRPC/GRD/NRR—2010/230. National Park Service, Denver, CO. Available online at: http://www.nature.nps.gov/geology/inventory/publications/reports/grte_gri_rpt_view.pdf . Accessed March 2013.

Kenworthy, J. P. and V. L. Santucci. 2006. A preliminary investigation of National Park Service paleontological resources in cultural resource contexts, Part 1: general overview. Pages 70-76 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 34. Available online at: http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed February 2013.

Kerr, D. R. and R. H. Dott, Jr. 1988. Eolian dune types preserved in the Tensleep Sandstone (Pennsylvanian-Permian), north-central Wyoming. *Sedimentary Geology* 56(1-4):383-402.

Klapper, G. 1966. Upper Devonian and Lower Mississippian conodont zones in Montana, Wyoming, and South Dakota. University of Kansas Paleontological Contributions 3. Available online at: http://hdl.handle.net/1808/3674. Accessed March 2013.

Knowlton, F. H. 1917. A fossil flora from the Frontier Formation of southwestern Wyoming. Pages 73-107 *in* Shorter contributions to general geology, 1917. U.S. Geological Survey, Reston, VA. Professional Paper 108.

Koch, A. L. and V. L. Santucci. 2003. Grand Teton National Park. Pages 9-13 *in* A. L. Koch and V. L. Santucci. Paleontological resource inventory and monitoring—Greater Yellowstone Network. TIC# D-1025. National Park Service, Denver, CO.

Koucky, F. L., Jr., N. E. Cygan, and F. H. T. Rhodes. 1961. Conodonts from the eastern flank of the central part of the Big Horn Mountains, Wyoming. *Journal of Paleontology* 35(4):877-879.

Koucky, F. L., F. H. T. Rhodes, and C. H. Hu. 1968. Upper Cambrian-Lower Ordovician conodont sequences of the Big Horn Mountains, Wyoming. Pages 123-124 *in* Abstracts for 1967. Geological Society of America, Boulder, CO. Special Paper 115.

Kulas, H. A. and R. L. Batten. 1997. Silicified gastropods from the Permian Phosphoria rock complex of Wyoming. *Contributions to Geology* 31(2):33-58.

Kvale, E. P. and C. F. Vondra. 1993. Effects of relative sea-level changes and local tectonics on a Lower Cretaceous fluvial to transitional marine sequence, Bighorn Basin, Wyoming, USA. Pages 383-399 *in* M. Marzo and C. Puigdefabregas, editors. Alluvial sedimentation. Blackwell, Oxford. Special Publication of the International Association of Sedimentologists 17.

Kvale, E. P., G. D. Johnson, D. L. Mickelson, K. Keller, L. C. Furer, and A. W. Archer. 2001. Middle Jurassic (Bajocian and Bathonian) dinosaur megatracksites, Bighorn Basin, Wyoming, U.S.A. *Palaios* 16(3):233-254.

Lageson, D. R., D. C. Adams, L. Morgan, K. L. Pierce, and R. B. Smith. 1999. Neogene-Quaternary tectonics and volcanism of southern Jackson Hole, Wyoming and southeastern Idaho. Pages 115-130 *in* Hughes, S. S. and G. D. Thackray, editors. Guidebook to the geology of eastern Idaho. Idaho Museum of Natural History, Pocatello, ID. Available online at: http://imnh.isu.edu/digitalatlas/geo/gsa/papers/gsac2p7.pdf. Accessed March 2013.

Landman, N. H. and W. A. Cobban. 2005. Ammonite markings on the seafloor of the Late Cretaceous Western Interior Seaway. Abstracts with Programs. *Geological Society of America* 37(7):443-444.

Lanphere, M. A., D. E. Champion, R. L. Christiansen, G. A. Izett, and J. D. Obradovich. 2002. Revised ages for tuffs of the Yellowstone Plateau volcanic field: assignment of the Huckleberry Ridge Tuff to a new geomagnetic polarity event. *Geological Society of America Bulletin* 114(5):559-568.

Lash, C. E. and J. G. Schmitt. 2008. Depositional environment and taphonomy of marine vertebrate biofacies in the Lower Cretaceous (Albian) Thermopolis Shale, south-central Montana. Abstracts with Programs. *Geological Society of America* 40(6):378.

Lebauer, L. R. 1964. Petrology of the Middle Cambrian Wolsey Shale of southwestern Montana. *Journal of Sedimentary Petrology* 34(3):503-511.

Leier, A. L. and J. R. Steidtmann. 2009. The Bacon Ridge Sandstone of northwestern Wyoming and its place within the larger-scale Late Cretaceous depositional history of the region. *Mountain Geologist* 46(2):51-70.

Leopold, E. B., G. Liu, J. D. Love, and D. W. Love. 2007. Plio-Pleistocene climatic transition and the lifting of the Teton Range, Wyoming. *Quaternary Research* 67(1):1-11.

Licciardi, J. M. and K. L. Pierce. 2008. Cosmogenic exposure-age chronologies of Pinedale and Bull Lake glaciations in greater Yellowstone and the Teton Range, USA. *Quaternary Science Reviews* 27(7-8):814-831.

Lillegraven, J. A. and M. C. McKenna. 1986. Fossil mammals from the "Mesaverde" Formation (Late Cretaceous, Judithian) of the Bighorn and Wind River basins, Wyoming, with definitions of Late Cretaceous North American land-mammal "ages." American Museum Novitates 2840. Available online at: http://hdl.handle.net/2246/3575. Accessed March 2013.

Lindsey, D. A. 1972. Sedimentary petrology and paleocurrents of the Harebell Formation, Pinyon Conglomerate, and associated coarse clastic deposits, northwestern Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 734-B. Available online at: http://pubs.er.usgs.gov/publication/pp734B. Accessed March 2013.

Lochman, C. 1950. Status of Dry Creek shale of central Montana. *Bulletin of the American Association of Petroleum Geologists* 34(11):2200-2222.

Lochman-Balk, C. 1956. The Cambrian of the Rocky Mountains and southwest deserts of the United States and adjoining Sonora province, Mexico. Pages 529-661 *in* J. Rodgers, editor. El Sistema Cambrico, su paleogeografia y el problema de su base. Symposium: Parte II, Australia, America. International Geological Congress, Mexico City, Mexico. Report 20.

Lochman, C. L. and D. Duncan. 1944. Early Upper Cambrian faunas of central Montana. Geological Society of America, Boulder, CO. Special Paper 54.

Lockley, M. 1990. Tracking the rise of dinosaurs in eastern Utah. *Canyon Legacy* 6:2-8.

Lockley, M. and A. P. Hunt. 1995. Dinosaur tracks and other fossil footprints of the western United States. Columbia University Press, New York, NY.

Lockley, M. G. and J. L. Wright. 2003. Pterosaur swim tracks and other ichnological evidence of behaviour and ecology. Pages 297-313 *in* E. Buffetaut and J. M. Mazin, editors. Evolution and palaeobiology of pterosaurs. Geological Society, London, United Kingdom. Special Publication 217.

Lockley, M. G., K. Conrad, M. Poquette, and A. Hamblin. 1992. Late Triassic vertebrate tracks in the Dinosaur National Monument area. Pages 383-391 *in* J. R. Wilson, editor. Field guide to geologic excursions in Utah and adjacent areas of Nevada, Idaho, and Wyoming. Utah Geological Survey, Salt

Lake City, UT. Miscellaneous Publication 92-3.

Loeblich, A. R., Jr. and H. N. Tappan. 1950. The type Redwater shale (Oxfordian) of South Dakota, Part 1 of North American Jurassic Foraminifera. *Journal of Paleontology* 24(1):39-60.

Lopez, D. A., S. W. Van DeLinder, M. L. Hendricks, G. S. Bayliss, and W. L. Ewert. 2007. The Tensleep play of south-central Montana, a part of the Permo-Pennsylvanian petroleum system of Montana and Wyoming. Montana Bureau of Mines and Geology, Butte, MT. Report of Investigations RI-18.

Love, C. M. 1977a. Geological influences on prehistoric populations of western Wyoming. Pages 15-29 *in* E. L. Heisey, D. E. Lawson, E. R. Norwood, P. H. Wach, and L. A. Hale, editors. Rocky Mountain Thrust Belt: geology and resources. Wyoming Geological Association, Casper, WY. Guidebook 29.

Love, J. D. 1939. Geology along the southern margin of the Absaroka Range, Wyoming. Geological Society of America, Boulder, CO. Special Paper 20.

Love, J. D. 1953. Tertiary stratigraphy of the Jackson Hole area, northwestern Wyoming. U.S. Geological Survey, Washington, DC. Oil and Gas Investigations Chart 27. Scale 1:2,400. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_5184.htm. Accessed March 2013.

Love, J. D. 1956a. Cretaceous and Tertiary stratigraphy of the Jackson Hole area, northwestern Wyoming. Pages 75-94 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Love, J. D. 1956b. New geologic formation names in Jackson Hole, Teton County, northwestern Wyoming. *Bulletin of the American Association of Petroleum Geologists* 40(8):1899-1914.

Love, J. D. 1956c. Summary of geologic history of Teton County, Wyoming, during Late Cretaceous, Tertiary, and Quaternary times. Pages 140-150 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Love, J. D. 1969. Late Cretaceous and Cenozoic sedimentation and tectonism, southern Yellowstone-Jackson Hole area, Wyoming. Pages 611-612 *in* Abstracts for 1968. Geological Society of America, Boulder, CO. Special Paper 121.

Love, J. D. 1973a. Harebell Formation (Upper Cretaceous) and Pinyon Conglomerate (uppermost Cretaceous and Paleocene), northwestern Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 734-A. Available online at: http://pubs.er.usgs.gov/publication/pp734A. Accessed March 2013.

Love, J. D. 1973b. Preliminary geologic map of the Two Ocean Lake Quadrangle, Teton County, Wyoming. U.S. Geological Survey, Washington, DC. Open-File Report 73-158. Scale 1:24,000. Available online at: http://pubs.er.usgs.gov/publication/ofr73158 . Accessed March 2013.

Love, J. D. 1975. Geologic map of Whetstone Mountain Quadrangle, Teton County, Wyo. U.S. Geological Survey, Washington, DC.

Open-File Report 75-138. Scale 1:24,000. Available online at: http://pubs.er.usgs.gov/publication/ofr75138 Accessed March 2013.

Love, J. D. 1977b. Summary of Upper Cretaceous and Cenozoic stratigraphy and of tectonic and glacial events in Jackson Hole, northwestern Wyoming. Pages 585-593 *in* E. L. Heisey, D. E. Lawson, E. R. Norwood, P. H. Wach, and L. A. Hale, editors. Rocky Mountain Thrust Belt: geology and resources. Wyoming Geological Association, Casper, WY. Guidebook 29.

Love, J. D. 1987. Teton mountain front, Wyoming. Pages 173-178 *in* S. S. Beus, editor. Rocky Mountain Section of the Geological Society of America. Geological Society of America, Boulder, CO. Centennial Field Guide 2.

Love, J. D., leader. 1989a. Sedimentation and tectonics of western North America: Volume 3, Yellowstone and Grand Teton national parks and the middle Rocky Mountains. Field trips for the 28th International Geological Congress. American Geophysical Union, Washington, DC. T328.

Love, J. D. 1989b. Names and descriptions of new and reclassified formations in northwestern Wyoming. U.S. Geological Survey, Reston, VA. Professional Paper 932-C. Available online at: http://pubs.er.usgs.gov/publication/pp932C. Accessed March 2013.

Love, J. D. 1990. Cretaceous rocks of Jackson Hole, northwestern Wyoming. *AAPG Bulletin* 74(8):1335.

Love, J. D. 1994. Leidy Formation: new name for a Pleistocene glacio-fluviatile-lacustrine sequence in northwestern Wyoming. U.S. Geological Survey, Reston, VA. Professional Paper 932-D. Available online at: http://pubs.er.usgs.gov/publication/pp932D. Accessed March 2013.

Love, J. D. and W. R. Keefer. 1969. Type locality of Darby Formation, western Wyoming. *American Association of Petroleum Geologists Bulletin* 53(1):167-170.

Love, J. D. and J. M. Love. 1980. Road log, Jackson to Dinwoody and return. Pages 283-317 *in* S. Hollis, editor. Stratigraphy of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 31.

Love, J. D. and J. C. Reed, Jr. 1968. Creation of the Teton landscape: the geologic story of Grand Teton National Park. Grand Teton Natural History Association, Moose, WY. Available online at: http://www.nps.gov/history/history/online_books/grte/grte_geology/index.htm. Accessed March 2013.

Love, J. D. and J. C. Reed, Jr. 1973. Preliminary geologic map of the Colter Bay Quadrangle, Teton County, Wyoming. U.S. Geological Survey, Washington, DC. Open-File Report 73-160. Scale 1:24,000. Available online at: http://pubs.er.usgs.gov/publication/ofr73160 Accessed March 2013.

Love, J. D. and J. C. Reed, Jr. 1975. Geologic map of Teton Village Quadrangle, Teton County, Wyo. U.S. Geological Survey, Washington, DC. Open-File Report 75-335. Scale 1:24,000. Available online at:

http://pubs.er.usgs.gov/publication/ofr75335 Accessed March 2013.

Love, J. D. and D. W. Taylor. 1962. Faulted Pleistocene strata near Jackson, northwestern Wyoming. Pages D136-D139 in Short papers in the geological and hydrological sciences. U.S. Geological Survey, Washington, DC. Professional Paper 450-D.

Love, J. D., H. R. Bergquist, and R. K. Hose. 1948. Stratigraphic sections of Jurassic and Cretaceous rocks in the Jackson Hole area, northwestern Wyoming. Geological Survey of Wyoming, Laramie, WY. Bulletin 40. Available online at: http://www.wsgs.uwyo.edu/public-info/onlinepubs/docs/B-40.pdf. Accessed March 2013.

Love, J. D., J. M. de la Montagne, G. M. Richmond, and J. M. Good. 1965. Relation of Quaternary tectonics and volcanism to glaciation, Part D. Pages 37-52 *in* Guidebook for Field Conference E, northern and middle Rocky Mountains–International Association for Quaternary Research, 7th Congress, U.S.A., 1965. Nebraska Academy of Sciences, Lincoln, NE.

Love, J. D., E. B. Leopold, and D. W. Love. 1978. Eocene rocks, fossils, and geologic history, Teton Range, northwestern Wyoming. U.S. Geological Survey, Reston, VA. Professional Paper 932-B. Available online at: http://pubs.er.usgs.gov/publication/pp932B. Accessed March 2013.

Love, J. D., J. M. Love, P. E. Flanagan, W. Neiler, and R. Near. 1990. Day 5: Jackson to Riverton, Wyoming. Pages 98-127 *in* J. L. de Vries and F. Crockett, editors. Field trip road logs, August 17-23. Wyoming Geological Association, Casper, WY. Field trips for Guidebook 41.

Love, J. D., J. C. Reed, and A. C. Christiansen. 1992. Geologic map of Grand Teton National Park, Teton County, Wyoming. U.S. Geological Survey, Reston, VA. Miscellaneous Investigations Series Map 2031. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_10095.htm. Accessed February 2013.

Love, J. D., L. A. Morgan, and W. C. McIntosh. 1997. The Teewinot Formation: evidence for late Miocene basin formation in response to volcanism, faulting, and uplift associated with the Yellowstone Hotspot? Abstracts with Programs. *Geological Society of America* 29(6):365.

Lovelace, D. M. 2011. Sedimentology and ichnology from the Early and Middle Triassic formations of the Chugwater Group, central Wyoming, USA. Abstracts with Programs. *Geological Society of America* 43(5):266.

Lovelace, D. M. and S. D. Lovelace. 2012. Paleoenvironments and paleoecology of a Lower Triassic invertebrate and vertebrate ichnoassemblage from the Red Peak Formation (Chugwater Group), central Wyoming. *Palaios* 27(9):636-657.

Lynch, E. A. 1998. Origin of a park-forest vegetation mosaic in the Wind River Range, Wyoming. *Ecology* 79(4):1320-1338.

Macomber, R. W. 1970. Articulate brachiopods from the upper Bighorn Formation (late Ordovician) of Wyoming. *Journal of Paleontology* 44(3):416-450.

Maione, S. J. 1971. Stratigraphy of the Frontier Sandstone Member of the Mancos Shale (Upper Cretaceous) on the south flank of the eastern Uinta Mountains, Utah and Colorado. *Earth Science Bulletin* 4(3):27-58.

Mamet, B. L. 1975. Carboniferous foraminifera and algae of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 848-B. Available online at: http://pubs.er.usgs.gov/publication/pp848B. Accessed February 2013.

Mankiewicz, D. and J. R. Steidtmann. 1979. Depositional environments and diagenesis of the Tensleep Sandstone, eastern Big Horn Basin, Wyoming. Pages 319-336 *in* P. A. Scholle and P. R. Schluger, editors. Aspects of diagenesis. Society of Economic Paleontologists and Mineralogists, Tulsa, OK. Special Publication 26.

Mapel, W. J. and M. H. Bergendahl. 1956. Gypsum Spring Formation, northwestern Black Hills, Wyoming and South Dakota. *Bulletin of the American Association of Petroleum Geologists* 40(1):84-93.

Marsh, O. C. 1895. The Reptilia of the *Baptanodon* beds. *American Journal of Science* 50(299):405-406.

Martin, W. D., J. H. Fischer, R. J. Keogh, and K. Moore. 1980. The petrology of the limestones in the upper Gros Ventre and Gallatin Limestone formations (Middle and Upper Cambrian), northwestern Wind River basin, Wyoming. Pages 37-51 *in* S. Hollis, editor. Stratigraphy of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 31.

Massare, J. A. and L.E. Dain. 1989. The marine reptiles of the Mowry Shale (Albian) of northeastern Wyoming. *Journal of Vertebrate Paleontology* 9(supplement to 3):32A.

Massare, J. A., E. A. Buchholtz, J. M. Kenney, and A.-M. Chomat. 2006. Vertebral morphology of *Ophthalmosaurus natans* (Reptilia: Ichthyosauria) from the Jurassic Sundance Formation of Wyoming. *Paludicola* 5:242-254.

Massare, J. A., W. R. Wahl, M. Ross, and M. V. Connely. In press. Palaeoecology of the marine reptiles of the Redwater Shale Member of the Sundance Formation (Jurassic of central Wyoming, USA. *Geological Magazine*.

Matthews, N., M. Wegweiser, and B. Breithaupt. 2003. Caught in Dante's inferno: studying dinosaur tracks near this side of Hell Quarry, Wyoming. *Journal of Vertebrate Paleontology* 23(supplement to 3):76A-77A.

Matthews, N. A., T. A. Noble, and B. H. Breithaupt. 2006. The application of photogrammetry, remote sensing and geographic information systems (GIS) to fossil resource management. Pages 119-131 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 34.

Maughan, E. K. 1964. The Goose Egg Formation in the Laramie Range and adjacent parts of southeastern Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 501-B:B53-B60.

Available online at: http://pubs.er.usgs.gov/publication/pp501B. Accessed February 2013.

Maughan, E. K. 1967. Eastern Wyoming, eastern Montana, and the Dakotas. U.S. Geological Survey, Washington, DC. Professional Paper 515-G. Available online at: http://pubs.usgs.gov/pp/0515/report.pdf. Accessed February 2013.

Maughan, E. K. 1987. Wind River canyon, Wyoming. Pages 191-196 *in* S. S. Beus, editor. Rocky Mountain Section of the Geological Society of America. Geological Society of America, Boulder, CO. Centennial Field Guide 2.

Maxwell, E. E. and B. P. Kear. 2010. Postcranial anatomy of *Platypterygius americanus* (Reptilia, Ichthyosauria) from the Cretaceous of Wyoming. *Journal of Vertebrate Paleontology* 30(4):1059-1068.

Maxwell, W. D. and J. R. Horner. 1994. Neonate dinosaurian remains and dinosaurian eggshell from the Cloverly Formation, Montana. *Journal of Vertebrate Paleontology* 14(1):143-146.

McKelvey, V. E., T. M. Cheney, E. R. Cressman, R. P. Sheldon, R. W. Swanson, and J. S. Williams. 1959. Geology of Permian rocks in the western phosphate field: the Phosphoria, Park City, and Shedhorn formations in the western phosphate field. U.S. Geological Survey, Washington, DC. Professional Paper 313-A. Available online at: http://pubs.er.usgs.gov/publication/pp313A. Accessed February 2013.

McKenna, M. C. 1980. Late Cretaceous and early Tertiary vertebrate paleontological reconnaissance, Togwotee Pass area, northwestern Wyoming. Pages 321-343 *in* L. L. Jacobs, editor. Aspects of vertebrate history: essays in honor of Edwin Harris Colbert. Museum of Northern Arizona Press, Flagstaff, AZ.

McKenna, M. C. and J. D. Love. 1970. Local stratigraphic and tectonic significance of *Leptoceratops*, a Cretaceous dinosaur in the Pinyon Conglomerate, northwestern Wyoming. Pages D55-D61 *in* Geological Survey research 1970, Chapter D. U.S. Geological Survey, Washington, DC. Professional Paper 700-D. Available online at: http://pubs.er.usgs.gov/publication/pp700D. Accessed March 2013.

Medville, D. M., J. C. Kampel, C. Plantz, and E. Werner. 1979. Solutional landforms on carbonates of the southern Teton Range, Wyoming. *NSS Bulletin* 41(3):70-79.

Mehl, M. G. 1915. *Poposaurus gracilis*, a new reptile from the Triassic of Wyoming. *Journal of Geology* 23(6):516-522.

Merewether, E. A. 1996. Stratigraphy and tectonic implications of Upper Cretaceous rocks in the Powder River basin, northeastern Wyoming and southeastern Montana. U.S. Geological Survey, Reston, VA. Bulletin 1917-T. Available online at: http://pubs.er.usgs.gov/publication/b1917T. Accessed February 2013.

Merewether, E. A. and W. A. Cobban. 2008. Outcrop descriptions and fossils from the Upper Cretaceous Frontier Formation, Wind River basin and adjacent areas, Wyoming. U.S. Geological Survey, Reston, VA. Digital Data Series 69-J. Available online at: http://pubs.usgs.gov/dds/dds-069/dds-

069-j/chapters.html. Accessed September 2011.

Merewether, E. A., W. A. Cobban, and E. T. Cavanaugh. 1979. Frontier Formation and equivalent rocks in eastern Wyoming. *Mountain Geologist* 16(3):67-102.

Merewether, E. A., P. D. Blackmon, and J. C. Webb. 1984. The Mid-Cretaceous Frontier Formation near the Moxa Arch, southwestern Wyoming. U.S. Geological Survey, Reston, VA. Professional Paper 1290. Available online at: http://pubs.er.usgs.gov/publication/pp1290. Accessed March 2013.

Merewether, E. A., W. A. Cobban, and R. W. Tillman. 2010. Outcrops, fossils, geophysical logs, and tectonic interpretations of the Upper Cretaceous Frontier Formation and contiguous strata in the Bighorn Basin, Wyoming and Montana. U.S. Geological Survey, Reston, VA. Scientific Investigations Report 2009-5256. Available online at: http://pubs.er.usgs.gov/publication/sir20095256. Accessed February 2013.

Merritt, Z. S. 1956. Upper Tertiary sedimentary rocks of the Alpine, Idaho-Wyoming area. Pages 117-119 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Mettes, K. J. and D. W. Boyd. 1985. The contact and boundary beds of the late Paleozoic Tensleep Sandstone and Phosphoria Formation in northwest Wyoming. Abstracts with Programs. *Geological Society of America* 17(4):256.

Meyer, G. A., L. P. Persico, and R. Levine. 2010. Beaver damming and discontinuity along streams in the greater Yellowstone ecosystem. Abstracts with Programs. *Geological Society of America* 42(5):519.

Mickelson, D. L., K. A. Mickelson, M. R. King, and P. Getty. 2006a. Jurassic dinosaur tracksites from the American West. Pages 138-140 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 34.

Mickelson, D. L., M. R. King, P. Getty, and K. A. Mickelson. 2006b. Subaqueous tetrapod swim tracks from the Middle Jurassic: Bighorn Canyon National Recreation Area (BCNRA), Wyoming, U.S.A. Page 26 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 34.

Miller, A. K. 1928. A new echinoid from the Sundance of west-central Wyoming. *American Journal of Science* 16(92):143-146.

Miller, A. K. and A. G. Unklesbay. 1943. A new asteroid from the Jurassic of central Wyoming. *Journal of Paleontology* 17(2):179-180.

Miller, B. M. 1936a. Cambrian stratigraphy of northwestern Wyoming. *Journal of Geology* 44(2, part 1):113-144.

Miller, B. M. 1936b. Cambrian trilobites from northwestern Wyoming. *Journal of Paleontology* 10(1):23-34.

Mirsky, A. 1962. Stratigraphy of non-marine Upper Jurassic and Lower Cretaceous rocks, southern Big Horn Mountains, Wyoming. *Bulletin of the American Association of Petroleum Geologists* 46(9):1653-1680.

Moberly, R. M., Jr. 1960. Morrison, Cloverly, and Sykes Mountain formations, northern Bighorn Basin, Wyoming and Montana. *Geological Society of America Bulletin* 71(8):1137-1176.

Moberly, R., Jr. 1962. Lower Cretaceous history of the Bighorn Basin, Wyoming, Pages 94-101 *in* R. L. Enyert and W. H. Curry, III, editors. Symposium on Early Cretaceous rocks of Wyoming and adjacent areas. Wyoming Geological Association, Casper, WY. Guidebook 17.

Molenaar, C. M. and B. W. Wilson. 1990. The Frontier Formation and associated rocks of northeastern Utah and northwestern Colorado. U.S. Geological Survey, Reston, VA. Bulletin 1787-M. Available online at: http://www.nps.gov/history/history/online_books/geology/publications/bul/1787-m/contents.htm. Accessed September 2011.

Moore, G. T. 1973. Lodgepole Limestone facies in southwestern Montana. *American Association of Petroleum Geologists Bulletin* 57(9):1703-1713.

Morgan, D. 1998. Paleoenvironmental interpretation of the Middle Cambrian Flathead Sandstone and Wolsey Shale, Clarks Fork region, Wyoming. *Keck Research Symposium in Geology* 11:275-278. Available online at: http://keckgeology.org/files/pdf/symvol/11th/Wyoming/morgan.pdf. Accessed February 2013.

Morgan, L. A., K. L. Pierce, and W. C. P. Shanks. 2008. Track of the Yellowstone Hotspot: young and ongoing geologic processes from the Snake River plain to the Yellowstone Plateau and Tetons. Geological Society of America, Boulder, CO. Pages 139-173 *in* R. G. Raynolds, editor. Roaming the Rocky Mountains and environs: geological field trips. Geological Society of America, Boulder, CO. Field Guide 10.

Moslow, T. F. and R. W. Tillman. 1986. Sedimentary facies and reservoir characteristics of Frontier Formation sandstones, southwestern Wyoming. Pages 271-295 *in* C. W. Spencer and R. F. Mast, editors. Geology of tight gas reservoirs. American Association of Petroleum Geologists, Tulsa, OK. AAPG Studies in Geology 24.

Myers, R. C. 1977. Stratigraphy of the Frontier Formation (Upper Cretaceous), Kemmerer area, Lincoln County, Wyoming. Pages 271-311 *in* E. L. Heisey, D. E. Lawson, E. R. Norwood, P. H. Wach, and L. A. Hale, editors. Rocky Mountain Thrust Belt: geology and resources. Wyoming Geological Association, Casper, WY. Guidebook 29.

Nace, R. L. 1939. A new ichthyosaur from the Upper Cretaceous Mowry Formation of Wyoming. *American Journal of Science* 237(9):673-686.

National Park Service. 1996. Grand Teton: John D. Rockefeller, Jr. Memorial Parkway: journey through the past, a geology tour. National Park Service, Washington, DC.

National Park Service, Geologic Resources Division. 2010. Digital geologic map of Grand Tetons National Park, John D. Rockefeller Jr. Memorial Parkway and vicinity, Wyoming (NPS, GRD, GRI, GRTE, GRTE digital map). National Park Service, Geologic Resources Division, Denver, CO. Scale 1:65,000. Available online at: https://irma.nps.gov/App/Reference/Profile?Code=2165235. Accessed March 2013.

Nydam, R. L. and R. L. Cifelli. 2002. Lizards from the lower Cretaceous (Aptian-Albian) Antlers and Cloverly formations. *Journal of Vertebrate Paleontology* 22(2):286-298.

O'Keefe, F. R. and H. P. Street. 2009. Osteology of the cryptocleidoid plesiosaur *Tatenectes laramiensis*, with comments on the taxonomic status of the Cimoliasauridae. *Journal of Vertebrate Paleontology* 29(1):48-57.

O'Keefe, F. R., H. P. Street, J. P. Cavigelli, J. J. Socha, and R. D. O'Keefe. 2009. A plesiosaur containing an ichthyosaur embryo as stomach contents from the Sundance Formation of the Bighorn Basin, WY. *Journal of Vertebrate Paleontology* 29(4):1306-1310.

Oboh-Ikuenobe, F. E., D. G. Benson, R. W. Scott, J. M. Holbrook, M. J. Evetts, and J. Erbacher. 2007. Re-evaluation of the Albian-Cenomanian boundary in the U.S. Western Interior based on dinoflagellate cysts. *Review of Palaeobotany and Palynology* 144(1-2):77-97.

Oreska, M. P. J., M. T. Carrano, and K. M. Dzikiewicz. 2013. Vertebrate paleontology of the Cloverly Formation (lower Cretaceous), I: faunal composition, biogeographic relationships, and sampling. *Journal of Vertebrate Paleontology* 33(2):264-292.

Ostrom, J. H. 1970. Stratigraphy and paleontology of the Cloverly Formation (lower Cretaceous) of the Bighorn Basin area, Wyoming and Montana. Peabody Museum of Natural History Bulletin 35. Available online at: http://peabody.yale.edu/sites/default/files/documents/scientific-publications/ypmB35_1970.pdf. Accessed February 2013.

Palmer, A. N., and M. V. Palmer. 1995. The Kaskaskia paleokarst of the northern Rocky Mountains and Black Hills, northwestern U.S.A. *Carbonates and Evaporites* 10(2):148-160.

Pampeyan, E. H., M. L. Schroeder, E. M. Schell, and E. R. Cressman. 1967. Geologic map of the Driggs Quadrangle, Bonneville and Teton counties, Idaho, and Teton County, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Field Studies Map 300. Scale 1:31,680. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_2722.htm. Accessed March 2013.

Parcell, W. C. and M. K. Williams. 2005. Mixed sediment deposition in a retro-arc foreland basin: lower Ellis Group (M. Jurassic), Wyoming and Montana, U.S.A. *Sedimentary Geology* 177(3-4):175-194.

Parrish, J. T., F. Peterson, and C. E. Turner. 2004. Jurassic "savannah:" plant taphonomy and climate of the Morrison Formation (Upper Jurassic, Western USA). *Sedimentary Geology* 167(3-4):137-162.

Paull, R. A. and R. K. Paull. 1987. Lower Triassic rocks within and adjacent to the thrust belt of Wyoming, Idaho, Utah. Pages 149-161 *in* W. R. Miller, editor. The thrust belt revisited. Wyoming Geological Association, Casper, WY. Guidebook 38.

Paull, R. A. and R. K. Paull. 1990. Persistent myth about the Lower Triassic Little Medicine Member of the Goose Egg Formation and the Lower Triassic Dinwoody Formation, central Wyoming. Pages 57-68 *in* R. W. Specht, editor. Wyoming sedimentation and tectonics. Wyoming Geological Association, Casper, WY. Guidebook 41.

Paull, R. A. and R. K. Paull. 1993. Stratigraphy of the Lower Triassic Dinwoody Formation in the Wind River basin area, Wyoming. Pages 31-47 *in* W. R. Keefer, W. J. Metzger, and L. H. Godwin, editors. Wyoming Geological Association special symposium on oil and gas and other resources of the Wind River basin, Wyoming. Wyoming Geological Association, Casper, WY.

Paull, R. A., R. K. Paull, and B. R. Kramer. 1989. Depositional history of Lower Triassic rocks in southwestern Montana and adjacent parts of Wyoming and Idaho. Pages 69-90 *in* D. E. French and R. F. Grabb, editors. Montana Geological Society 1989 field conference guidebook: Montana centennial edition: Geologic resources of Montana, Volume I. Montana Geological Society, Bozeman, MT. Field Conference 1989(1).

Paull, R. K. and R. A. Paull. 1983. Revision of type Lower Triassic Dinwoody Formation, Wyoming, and designation of principal reference section. *Contributions to Geology* 22(2):83-90.

Paull, R. K., R. A. Paull, and A. L. Anderson. 1985. Conodont biostratigraphy and depositional history of the Lower Triassic Dinwoody Formation in the Meade Plate, southeastern Idaho. Pages 55-66 *in* G. J. Kerns and R. L. Kerns, editors. Orogenic patterns and stratigraphy of north-central Utah and southeastern Idaho. Utah Geological Association, Salt Lake City, UT. Publication 14.

Peale, A. C. 1893. The Paleozoic section in the vicinity of Three Forks, Montana, with petrographic notes by G. P. Merrill. U.S. Geological Survey, Washington, DC. Bulletin 110. Available online at: http://pubs.er.usgs.gov/publication/b110. Accessed April 2013.

Peck, R. E. 1957. North American Mesozoic Charophyta. U.S. Geological Survey, Washington, DC. Professional Paper 294-A.

Persico, L. P. and G. A. Meyer. 2009. Holocene beaver damming, fluvial geomorphology, and climate in Yellowstone National Park, Wyoming. *Quaternary Research* 71(3):340-353.

Peterson, J. A. 1954. Jurassic Ostracoda from the “lower Sundance” and Rierdon formations, western interior United States. *Journal of Paleontology* 28(2):153-176.

Peterson, J. A. 1957a. Marine Jurassic of northern Rocky Mountains and Williston Basin. *Bulletin of the American Association of Petroleum Geologists* 41(3):399-440.

Peterson, J. A. 1957b. Gypsum Spring and Sundance formations, central Wyoming. Pages 47-54 *in* Southwest Wind River

basin. Wyoming Geological Association, Casper, WY. Guidebook 12.

Peterson, J. A. 1984. Permian stratigraphy, sedimentary facies, and petroleum geology, Wyoming and adjacent area. Pages 25-64 *in* J. Goolsby, editor. The Permian and Pennsylvanian geology of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 35.

Picard, M. D. 1966. Petrography of Red Peak Member, Chugwater Formation (Triassic), west-central Wyoming. *Journal of Sedimentary Petrology* 36(4):904-926.

Picard, M. D. 1967. Stratigraphy and depositional environments of the Red Peak Member of the Chugwater Formation (Triassic), west-central Wyoming. *Contributions to Geology* 6(1):39-67.

Picard, M. D. 1977. Petrology of the Jurassic Nugget Sandstone, northeast Utah and southwest Wyoming. Pages 239-258 *in* E. L. Heisey, D. E. Lawson, E. R. Norwood, P. H. Wach, and L. A. Hale, editors. Rocky Mountain Thrust Belt: geology and resources. Wyoming Geological Association, Casper, WY. Guidebook 29.

Picard, M. D. 1993. The early Mesozoic history of Wyoming. Pages 210-248 *in* A. W. Snoke, J. R. Steidtmann, and S. M. Roberts, editors. Geology of Wyoming. Wyoming State Geological Survey, Laramie, WY. Memoir 5.

Pierce, K. L. and J. M. Good. 1990. Quaternary geology of Jackson Hole, Wyoming. Pages 79-87 *in* S. Roberts, editor. Geologic field tours of western Wyoming and parts of adjacent Idaho, Montana, and Utah. Geological Survey of Wyoming, Laramie, WY. Public Information Circular 29.

Pierce, K. L. and J. D. Good. 1992. Field guide to the Quaternary geology of Jackson Hole, Wyoming. U.S. Geological Survey, Reston, VA. Open-File Report 92-504. Available online at: http://pubs.er.usgs.gov/publication/ofr92504 . Accessed March 2013.

Pierce, K. L., D. G. Despain, C. Whitlock, K. P. Cannon, G. Meyer, L. A. Morgan, and J. M. Licciardi. 2003. Quaternary geology and ecology of the greater Yellowstone area. Pages 313-344 *in* D. J. Easterbrook, editor. Quaternary geology of the United States: INQUA 2003 field guide volume. Desert Research Institute, Reno, NV.

Pierce, K. L., D. R. Muhs, M. A. Fosberg, S. A. Mahan, J. G. Rosenbaum, J. M. Licciardi, and M. J. Pavich. 2011. A loess-paleosol record of climate and glacial history over the past two glacial-interglacial cycles (approximately 150 ka), southern Jackson Hole, Wyoming. *Quaternary Research* 76(1):119-141.

Pinner, J. 1979. The Helen Lookingbill site: 48FR308. *Wyoming Archaeologist* 22(4):24-26. Available online at: http://www.wyomingarchaeology.org/thewyomingarchaeologist/19791970.html. Accessed March 2013.

Pipiringos, G. N. and R. W. Imlay. 1979. Lithology and subdivisions of the Jurassic Stump Formation in southeastern Idaho and adjoining areas. U.S. Geological Survey, Reston, VA. Professional Paper 1035-C. Available online at: http://pubs.er.usgs.gov/publication/pp1035C Accessed September 2011.

Ploynoi, M. and W. C. Parcell. 2005. Development of Middle Jurassic microbial buildups in Bighorn Basin, Wyoming. Abstracts with Programs. *Geological Society of America* 37(7):17.

Poole, F. G. and J. H. Stewart. 1964a. Chinle Formation and Glen Canyon Sandstone in northeastern Utah and northwestern Colorado. Pages D30-D39 *in* Geological Survey Research 1964, Chapter D. U.S. Geological Survey, Reston, VA. Professional Paper 501-D.

Poole, F. G. and J. H. Stewart. 1964b. Chinle Formation and Glen Canyon Sandstone in northeast Utah and northwest Colorado. Pages 93-104 *in* E. F. Sabatka, editor. Guidebook to the geology and mineral resources of the Uinta Basin, Utah's hydrocarbon storehouse. Intermountain Association of Petroleum Geologists, Salt Lake City, UT. Field Conference Guidebook 13.

Rautman, C. A. 1975. Sedimentology of the "Lower Sundance" Formation (upper Jurassic) Wyoming region. *Wyoming Geological Association Earth Science Bulletin* 8(4):1-16.

Reaugh, A. B. 1980. Cambrian acritarchs from the Gallatin, Gros Ventre and Death Canyon formations, Sublette Co., Wyoming. *Palynology* 4:248.

Reed, J. C., Jr. and J. D. Love. 1971. Preliminary geologic map of the Mount Bannon Quadrangle, Teton County, Wyoming. U.S. Geological Survey, Washington, DC. Open-File Report 71-233. Scale 1:24,000. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_8619.htm. Accessed March 2013.

Reed, J. C., Jr. and R. E. Zartman. 1973. Geochronology of Precambrian rocks of the Teton Range, Wyoming. *Geological Society of America Bulletin* 84(2):561-582.

Reeside, J. B., Jr. 1923. A new fauna from the Colorado Group of southern Montana. Pages 25-33 *in* Contributions to general geology, 1923. U.S. Geological Survey, Washington, DC. Professional Paper 132.

Reeside, J. B., Jr. 1927. Cephalopods from the lower part of the Cody Shale of Oregon Basin, Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 150-A. Available online at: http://pubs.er.usgs.gov/publication/pp150. Accessed March 2013.

Reeside, J. B., Jr., and W. A. Cobban. 1960. Studies of the Mowry shale (Cretaceous) and contemporary formations in the United States and Canada. U.S. Geological Survey, Washington, DC. Professional Paper 355. Available online at: http://pubs.er.usgs.gov/publication/pp355. Accessed February 2013.

Reeves, C. C., Jr. 1964. New Cambrian, Ordovician, Devonian, and Mississippian measured sections, west flank Teton Mountains, Wyoming. *Mountain Geologist* 1(4):213-225.

Resser, C. E. 1937. Third contribution to nomenclature of Cambrian trilobites. Smithsonian *Miscellaneous Collections* 95(22). Available online at: http://archive.org/details/smithsonianmisce951937smit. Accessed March 2013.

Richards, P. W. 1955. Geology of the Bighorn Canyon-Hardin area, Montana and Wyoming. U.S. Geological Survey,

Washington, DC. Bulletin 1026. Available online at: http://pubs.er.usgs.gov/publication/b1026. Accessed February 2013.

Richmond, G. M. 1973a. Surficial geologic map of the Huckleberry Mountain Quadrangle, Yellowstone National Park and adjoining area, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Geologic Investigations Map 639. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9417.htm. Accessed March 2013.

Richmond, G. M. 1973b. Surficial geologic map of the Grassy Lake Reservoir Quadrangle, Yellowstone National Park and adjoining area, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Geologic Investigations Map 644. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9422.htm. Accessed March 2013.

Richmond, G. M. 1986. Stratigraphy and chronology of glaciations in Yellowstone National Park. *Quaternary Science Reviews* 5:83-98.

Rieppel, O. 1998. *Corosaurus alcovensis* Case and the phylogenetic interrelationships of Triassic stem-group Sauropterygia. *Zoological Journal of the Linnean Society* 124(1):1-41.

Roberts, S. V. and D. W. Burbank. 1993. Uplift and thermal history of the Teton Range (northwestern Wyoming) defined by apatite fission-track dating. *Earth and Planetary Science Letters* 118(1-4):295-309.

Robison, S. F., M. E. Thompson, J. K. Huang, T. B. Thompson, A. R. Tedrow, and P. Barrett. 2011. Preliminary report of the first recorded Late Pleistocene mammal tracks from southeast Idaho and management implications. *Geology Studies* 49A:28.

Rodriguez, J. and R. C. Gutschick. 1968. *Productina*, *Cyrtina*, and *Dielasma* (Brachiopoda) from the Lodgepole Limestone (Mississippian) of southwestern Montana. *Journal of Paleontology* 42(4):1027-1032.

Ryer, T. A. 1977. Age of Frontier Formation in north-central Utah. *AAPG Bulletin* 61(1):112-116.

Saltzman, M. R. 1999. Upper Cambrian carbonate platform evolution, *Elvinia* and *Taenicephalus* zones (pterocephaliid-ptychaspid biomere boundary), northwestern Wyoming. *Journal of Sedimentary Research* 69(4):926-938.

Saltzman, M. R., J. P. Davidson, P. Holden, B. Runnegar, and K. C. Lohmann. 1995. Sea-level-driven changes in ocean chemistry at an Upper Cambrian extinction horizon. *Geology* 23(10):893-896.

Sandberg, C. A. 1965. Nomenclature and correlation of lithologic subdivisions of the Jefferson and Three Forks formations of southern Montana and northern Wyoming. U.S. Geological Survey, Washington, DC. Bulletin 1194-N:N1-N18. Available online at: http://pubs.er.usgs.gov/publication/b1194N. Accessed February 2013.

Sandberg, C. A. and G. Klapper. 1967. Stratigraphy, age, and paleotectonic significance of the Cottonwood Canyon Member of the Madison Limestone in Wyoming and Montana. U.S. Geological

Survey, Washington, DC. Bulletin 1251-B. Available online at: http://pubs.er.usgs.gov/publication/b1251B. Accessed February 2013.

Sando, W. J. 1960. Distribution of corals in the Madison Group and correlative strata in Montana, western Wyoming, and northeastern Utah. Pages B225-B227 *in* Short papers in the geological sciences: Geological Survey research 1960. U.S. Geological Survey, Washington, DC. Professional Paper 400-B. Available online at: http://pubs.er.usgs.gov/publication/pp400B. Accessed March 2013.

Sando, W. J. 1967. Madison Limestone (Mississippian), Wind River, Washakie, and Owl Creek Mountains, Wyoming. *American Association of Petroleum Geologists Bulletin* 51(4):529-557

Sando, W. J. 1968. A new member of the Madison Limestone (Mississippian) in Wyoming. *Geological Society of America Bulletin* 79(12):1855-1857.

Sando, W. J. 1972. Madison Group (Mississippian) and Amsden Formation (Mississippian and Pennsylvanian) in the Beartooth Mountains, northern Wyoming and southern Montana. Pages 57-63 *in* J. Lynn, C. Balster, and J. Warne, editors. Crazy Mountains Basin. Montana Geological Society, Billings, MT. Field Conference 21.

Sando, W. J. 1975a. Stratigraphic sections of the Madison Limestone and Amsden Formation, west flank of the Bighorn Basin, Wyoming. Pages 129-137 *in* F. A. Exum and G. R. George, editors. Geology and mineral resources of the Bighorn Basin. Wyoming Geological Association, Casper, WY. Guidebook 27.

Sando, W. J. 1975b. Coelenterata of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey Professional Paper 848-C. Available online at: http://pubs.er.usgs.gov/publication/pp848C. Accessed February 2013.

Sando, W. J. 1977. Stratigraphy of the Madison Group (Mississippian) in the northern part of the Wyoming-Idaho Overthrust Belt and adjacent areas. Pages 173-177 *in* E. L. Heisey, D. E. Lawson, E. R. Norwood, P. H. Wach, and L. A. Hale, editors. Rocky Mountain Thrust Belt: geology and resources. Wyoming Geological Association, Casper, WY. Guidebook 29.

Sando, W. J. 1988. Madison Limestone (Mississippian) paleokarst: a geologic synthesis. Pages 256-277 in N. P. James and P. W. Choquette, editors. Paleokarst. Springer-Verlag, New York, NY.

Sando, W. J. and J. T. Dutro, Jr. 1974. Type sections of Madison Group (Mississippian) and its subdivisions in Montana. U.S. Geological Survey, Washington, DC. Professional Paper 842. Available online at: http://pubs.er.usgs.gov/publication/pp842. Accessed February 2013.

Sando, W. J., M. Gordon, Jr., and J. T. Dutro, Jr. 1975. Stratigraphy and geologic history of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 848-A. Available online at: http://pubs.er.usgs.gov/publication/pp848A. Accessed February 2013.

Santiago-Blay, J. A., C. C. Labandeira, L. Pribyl, C. Hotton, and L. D. Martin. 2001. The Sundance insect fauna (Middle Jurassic) of northern Wyoming and southern Montana. Abstracts with Programs. *Geological Society of America* 33(6):266.

Santucci, V. L. and W. P. Wall. 1999. Paleontological resources at Grand Teton National Park, northwestern Wyoming. Pages 31-36 *in* H. J. Harlow and M. Harlow, editors. University of Wyoming–National Park Service Research Center, 22nd annual report 1998.

Santucci, V. L., J. Kenworthy, and R. Kerbo. 2001. An inventory of paleontological resources associated with National Park Service caves. NPS Geological Resources Division, Denver, CO. Technical Report NPS/NRGRD/GRDTR-01/02. TIC# D-2231. Available online at: http://www.nature.nps.gov/geology/paleontology/pub/cavepaleo.pdf. Accessed February 2013.

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring *in situ* paleontological resources. Pages 189-204 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, CO.

Schaeffer, B. and C. Patterson. 1984. Jurassic fishes from the western United States, with comments on Jurassic fish distribution. American Museum Novitates 2796. Available online at: http://hdl.handle.net/2246/5270. Accessed February 2013.

Schmitt, J. G. and D. W. Boyd. 1981. Patterns of silicification in Permian pelecypods and brachiopods from Wyoming. *Journal of Sedimentary Petrology* 51(4):1297-1308.

Schmude, D. C. 2000. Interplay of paleostructure, sedimentation and preservation of Middle Jurassic rocks, Big Horn Basin, Wyoming. *Mountain Geologist* 37(4):145-155.

Schroeder, M. L. 1972. Geologic map of the Rendezvous Peak Quadrangle, Teton County, Wyoming. U.S. Geological Survey, Washington, DC. Geologic Quadrangle Map 980. Scale 1:24,000. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_2279.htm. Accessed March 2013.

Schwab, K. W. 1977. Palynology of the lower Thermopolis and Cloverly formations (Albian), Gros Ventre Mountains, Wyoming. *Palynology* 1:176.

Schwimmer, D. R. 1975. Quantitative taxonomy and biostratigraphy of middle Cambrian trilobites from Montana and Wyoming. *Journal of the International Association for Mathematical Geology* 7(2):149-166.

Scott, R. W. and D. O. Asquith. 1972. Dendroid graptolites from the Bighorn Dolomite (Ordovician), southeastern Idaho. *Contributions to Geology* 11(2):73-82.

Scott, R. W., Holbrook, J. M. Evetts, and M. J. Oboh-Ikuenobe, F. E. 2001. Albian-Cenomanian depositional cycles transgressed from Chihuahua Trough to Western Interior. Pages 221-228 *in* S. G. Lucas and D. S. Ulmer-Scholle, editors. Geology of the Llano Estacado. Guidebook - New Mexico Geological Society 52. New

Mexico Geological Society, Socorro, NM. Guidebook 48.

Scott, R. W., F. E. Oboh-Ikuenobe, D. G. Benson, Jr., and J. M. Holbrook. 2009. Numerical age calibration of the Albian/Cenomanian boundary. *Stratigraphy* 6(1):17-32.

Shaw, A. B. 1954. The Cambrian and Ordovician of the Pryor Mountains, Montana, and northern Bighorn Mountains, Wyoming. Pages 32-37 *in* P. W. Richards, editor. Pryor Mountains-northern Bighorn Basin, Montana, September 9-11, 1954. Billings Geological Society, Billings, MT. Guidebook 5.

Shaw, A. B. 1962. Rhynchonellid brachiopods and a *Torynifer* from the Madison Group (Mississippian). *Journal of Paleontology* 36(4):630-637.

Shaw, A. B. and C. R. Deland. 1955. Cambrian of southwestern Wyoming. Pages 38-42 *in* Green River basin. Wyoming Geological Association, Casper, WY. Guidebook 10.

Sheldon, R. P. 1956. Stratigraphy of the Phosphoria Formation in the Jackson Hole region, Wyoming. Pages 66-69 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Sheldon, R. P. 1963. Physical stratigraphy and mineral resources of Permian rocks in western Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 313-B. Available online at: http://pubs.er.usgs.gov/publication/pp313B. Accessed March 2013.

Shin, J.-Y. 2003. Taxonomic diversity and microvertebrate faunal analysis of the Late Cretaceous Meeteetse Formation, northern Wyoming. *Journal of Vertebrate Paleontology* 23(supplement to 3):96A.

Simmons, S. P. and P. A. Scholle. 1990. Late Paleozoic uplift and sedimentation, northeast Bighorn Basin, Wyoming. Pages 39-55 *in* R. W. Specht, editor. Wyoming sedimentation and tectonics. Wyoming Geological Association, Casper, WY. Guidebook 41.

Smith, D. L. 1982. Waulsortian bioherms in the Paine Member of the Lodgepople Limestone (Kinderhookian) of Montana, U.S.A. Pages 51-64 *in* K. Bolton, H. R. Lane, and D. V. LeMone, editors. Symposium on the paleoenvironmental setting and distribution of the Waulsortian facies. El Paso Geological Society, El Paso, TX.

Smith, K. G. and D. A. Bradley. 1954. Radioactive fossil bones in Teton County, Wyoming. Geological Survey of Wyoming, Laramie, WY. Report of Investigations 4.

Smith, R. B. and L. J. Siegel. 2000. Windows into the Earth: the geologic story of Yellowstone and Grand Teton national parks. Oxford University Press, Oxford, United Kingdom.

Smith, R. B., J. O. D. Byrd, and D. D. Susong. 1993a. The Teton Fault, Wyoming: seismotectonics, Quaternary history, and earthquake hazards. Pages 628-667 *in* A. W. Snoke, J. R. Steidtmann, and S. M. Roberts, editors. Geology of Wyoming. Geological Survey of Wyoming, Laramie, WY. Memoir 5.

Smith, R. B., K. L. Pierce, and R. J. Wold. 1993b. Seismic surveys and Quaternary

history of Jackson Lake, Wyoming. Pages 668-693 *in* A. W. Snoke, J. R. Steidtmann, and S. M. Roberts, editors. Geology of Wyoming. Geological Survey of Wyoming, Laramie, WY. Memoir 5.

Smith, T. M. and S. L. Dorobek. 1993. Early Mississippian climate change: isotopic evidence from meteoric calcite. *Geophysical Monograph* 78:77-88.

Sohn, I. G. 1975. Mississippian Ostracoda of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 848-G. Available online at: http://pubs.er.usgs.gov/publication/pp848G. Accessed February 2013.

Sokolov, D. W. 1914. Kreideinoceramen des russischen Sachalin. *Mémoires du Comité géologique. N. Sér., Liv.* 83.

Specht, R. W. and R. L. Brenner. 1979. Storm-wave genesis of bioclastic carbonates in upper Jurassic epicontinental mudstones, east-central Wyoming. *Journal of Sedimentary Petrology* 49(4):1307-1321.

Sprinkel, D. A., B. J. Kowallis, and P. H. Jensen. 2011. Correlation and age of the Nugget Sandstone and Glen Canyon Group, Utah. Pages 131-149 *in* D. A. Sprinkel, W. A. Yonkee, and T. C. Chidsey, Jr., editors. Sevier thrust belt: northern and central Utah and adjacent areas. Utah Geological Association, Salt Lake City, UT. Publication 40.

Stamm, R. G. and B. R. Wardlaw. 2003. Conodont faunas of the late Middle Pennsylvanian (Desmoinesian) lower Kittanning cyclothem, U.S.A. Pages 95-121 *in* C. B. Cecil and N. T. Edgar, editors. Climate controls on stratigraphy. Society for Sedimentary Geology, Tulsa, OK. Special Publication 77.

Stanley, G. and R. Burke. 2000. The Mississippian Lodgepole Limestone (Madison Group), Little Belt Mountains, central Montana: lower Mississippian carbonate rocks and reef-like buildups. Pages 197-208 *in* S. Roberts and D. Winston, editors. Geologic field trips, western Montana and adjacent areas. Geological Society of America, Rocky Mountain Section, Boulder, CO. Guidebook 52.

Stanton, T. W. 1899. Mesozoic fossils. Pages 600-650 *in* Geology of the Yellowstone national park. U.S. Geological Survey, Washington, D.C. Monograph 32. Available online at: http://archive.org/details/geologyofyellows00hagu. Accessed March 2013.

Steele, T. E. and E. A. Hadly. 2002. Ecological differences between two late Holocene sites from Yellowstone National Park, Wyoming, USA. *Journal of Vertebrate Paleontology* 22(supplement to 3):111A.

Steventon, R. L. and J. E. Kutzbach. 1988. University of Wisconsin radiocarbon dates XXV. *Radiocarbon* 30(3):367-383.

Stewart, J. C. 1958. Geology of the Dryhead-Garvin Basin, Bighorn and Carbon counties, Montana. Montana Bureau of Mines and Geology, Butte, MT. Special Publication 17.

Stewart, J. D. and M. Hakel. 2006. Ichthyofauna of the Mowry Shale (early Cenomanian) of Wyoming. Pages 161-163

in S. G. Lucas, and R. M. Sullivan, editors. Late Cretaceous vertebrates from the Western Interior. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 35.

Stewart, J. D., S. A. Bilbey, D. J. Chure, and S. K. Madsen. 1994. Vertebrate fauna of the Mowry Shale (Cenomanian) in northeastern Utah. *Journal of Vertebrate Paleontology* 14(supplement to 3):47A.

Stone, R. and C. F. Vondra. 1972. Sediment dispersal patterns of oolitic calcarenite in the Sundance Formation (Jurassic), Wyoming. *Journal of Sedimentary Petrology* 42(1):227-229.

Storrs, G. W. 1991a. Dinosaur Hunt–the saga of a Yale expedition. *Discovery* 22(2):10-18.

Storrs, G. W. 1991b. Anatomy and relationships of *Corosaurus alcovensis* (Diapsida: Sauropterygia) and the Triassic Alcova Limestone of Wyoming. Bulletin of the Peabody Museum of Natural History Yale University 44. Available online at: http://www.peabody.yale.edu/sites/default/files/documents/scientific-publications/ypmB44_1991.pdf. Accessed June 2013.

Strickland, J. W. 1956. Mississippian stratigraphy, western Wyoming. Pages 51-57 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Strickland, L. E., R. S. Thompson, and K. H. Anderson. 2001. USGS/NOAA North American packrat midden database data dictionary. U.S. Geological Survey, Reston, VA. Open File Report 01-022. Available online at: http://pubs.er.usgs.gov/publication/ofr0122. Accessed March 2013.

Strömberg, C. A. E. and S. L. Wing. 2007. Niche breadth of Late Cretaceous plants inferred from patterns of distribution and abundance in the early Maastrichtian Big Cedar Ridge Tuff, Wyoming. Abstracts with Programs. *Geological Society of America* 39(6):167-168.

Sutton, J. F. and C. C. Black. 1972. Oligocene and Miocene deposits of Jackson Hole, Wyoming. Pages 73-79 *in* Field conference on Tertiary biostratigraphy of southern and western Wyoming. Adelphi University, Department of Biology, Garden City, New York.

Swain, F. M. 1998. Ostracoda from the Swift Formation (Upper Jurassic) of Montana and Wyoming. *Revista Espanola De Micropaleontologia* 30(1):139-158.

Swain, F. M., Jr. and J. A. Peterson. 1951. Ostracoda from the Upper Jurassic Redwater shale member of the Sundance Formation at the type locality in South Dakota. *Journal of Paleontology* 25(6):796-807.

Swain, F. M., Jr. and J. A. Peterson. 1952. Ostracodes from the upper part of the Sundance Formation of South Dakota, Wyoming, and southern Montana. U.S. Geological Survey, Washington, DC. Professional Paper 243-A. Available online at: http://pubs.er.usgs.gov/usgspubs/pp/pp243A Accessed February 2013.

Tang, C. M. 1997. Evolutionary paleoecology of Jurassic hard-substrate assemblages from the U. S. Western Interior. Abstracts with

Programs. *Geological Society of America* 29(6):107.

Taylor, D. W. 1956. Pliocene mollusks from Jackson Hole, Grand Valley, and Star Valley, Wyoming and Idaho. Wyoming Geological Association, Casper, WY. Pages 123-125 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Theriot, E. C., S. C. Fritz, C. Whitlock, and D. J. Conley. 2006. Late Quaternary rapid morphological evolution of an endemic diatom in Yellowstone Lake, Wyoming. *Paleobiology* 32(1):38-54.

Thom, W. T., Jr., G. M. Hall, C. H. Wegemann, and G. F. Mouton. 1935. Geology of Big Horn County and the Crow Indian Reservation, Montana, with special reference to the Water, Coal, Oil and Gas Resources. U.S. Geological Survey, Washington, DC. Bulletin 856. Available online at: http://pubs.er.usgs.gov/publication/b856. Accessed February 2013.

Thornburg, J. B. 1989. Depositional environments of the Tosi Chert Member of the Permian Phosphoria Formation in southwest Montana. Abstracts with Programs. *Geological Society of America* 21(6):A174-A175.

Tiller, C. C. and K. R. Kelts. 1994. Post-glacial environmental variability within large lake basins of the Yellowstone-Grand Teton region, WY, USA. Program and Abstracts. *American Quaternary Association Conference* 13:169.

Tillman, R. W. and H. Dresser. 1976. Subtidal trace fossils, Muddy and Frontier formations, Wyoming and Montana. *AAPG Bulletin* 60(4):727-728.

Tohill, B. and M. D. Picard. 1966. Stratigraphy and petrology of Crow Mountain Sandstone Member (Triassic), Chugwater Formation , northwestern Wyoming. *Bulletin of the American Association of Petroleum Geologists* 50(12):2547-2565.

Tracy, K. H. 2003. Grand Teton National Park Paleontological Survey. Thesis. Georgia College and State University. Milledgeville, GA.

Trumbull, C. B. and M. V. Connely. 2010. New ichnotaxa from the Mowry Shale of Wyoming may be vertebrate in origin. Abstracts with Programs. *Geological Society of America* 42(3):41-42.

Tschudy, R. H., B. D. Tschudy, S. Van Loenen, and G. Doher. 1980. Illustrations of plant microfossils from the Morrison Formation. I. Plant microfossils from the Brushy Basin Member. U.S. Geological Survey, Reston, VA. Open-File Report 81-35. Available online at: http://pubs.er.usgs.gov/publication/ofr8135. Accessed January 2012.

Tschudy, R. H., B. D. Tschudy, and S. Van Loenen. 1981. Illustrations of plant microfossils from the Morrison Formation. II. Plant microfossils from the Westwater Canyon Member. U.S. Geological Survey, Reston, VA. Open-File Report 81-1154. Available online at: http://pubs.er.usgs.gov/publication/ofr811154. Accessed January 2012.

Tschudy, R. H., B. D. Tschudy, and S. D. Van Loenen. 1988a. Illustrations of plant microfossils from the Morrison Formation.

III. Plant microfossils from the Recapture Member. U.S. Geological Survey, Reston, VA. Open-File Report 88-234. Available online at: http://pubs.er.usgs.gov/publication/ofr88234 Accessed January 2012.

Tschudy, R. H., B. D. Tschudy, and S. D. Van Loenen. 1988b. Illustrations of plant microfossils from the Morrison Formation. IV. Plant microfossils from the Salt Wash Member. U.S. Geological Survey, Reston, VA. Open-File Report 88-235. Available online at: http://pubs.er.usgs.gov/publication/ofr88235 Accessed January 2012.

Turner, C. E. and F. Peterson. 1999. Biostratigraphy of dinosaurs in the Upper Jurassic Morrison Formation of the Western Interior, U.S.A. Pages 77-114 *in* D. D. Gillette, editor. Vertebrate paleontology in Utah. Utah Geological Survey, Salt Lake City, UT. Miscellaneous Publication 99-1.

Turner, C. E. and F. Peterson. 2004. Reconstruction of the upper Jurassic Morrison Formation extinct ecosystem—a synthesis. *Sedimentary Geology* 167(3-4):309-355.

Tuttle, S. D. 1990. Grand Teton National Park. Pages 505-520 *in* A. G. Harris and E. Tuttle. Geology of National Parks (4th edition). Kendall/Hunt Publishing Company, Dubuque, IA.

Tweet, J. S., V. L. Santucci, and A. P. Hunt. 2012. An inventory of packrat (*Neotoma* spp.) middens in National Park Service areas. Pages 355-368 *in* A. P. Hunt, J. Milàn, S. G. Lucas, and J. A. Spielmann, editors. Vertebrate coprolites. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 57.

Tysdal, R. G. 1976. Paleozoic and Mesozoic stratigraphy of the northern part of the Ruby Range, southwestern Montana. U.S. Geological Survey, Washington, DC. Bulletin 1405-I. Available online at: http://pubs.er.usgs.gov/publication/b1405I. Accessed April 2013.

Tysdal, R. G., T. S. Dyman, D. J. Nichols, and W. A. Cobban. 1990. Correlation chart of Frontier Formation from Greenhorn Range, southwestern Montana, to Mount Everts in Yellowstone National Park, Wyoming. U.S. Geological Survey, Reston, VA. Miscellaneous Field Studies Map 2116. Available online at: http://pubs.er.usgs.gov/publication/mf2116. Accessed April 2013.

Ulrich, E. O. and G. A. Cooper. 1936. New genera and species of Ozarkian and Canadian brachiopods. *Journal of Paleontology* 10(7):616-631.

Upshaw, C. F. 1963. Occurrences of *Aequitriradites* in the upper Cretaceous of Wyoming. *Micropaleontology* 9(4):427-431.

Upshaw, C. F. 1964. Palynological zonation of the Upper Cretaceous Frontier Formation near Dubois, Wyoming. Pages 153-168 *in* Palynology in oil exploration—A symposium. Society of Economic Paleontologists and Mineralogists, Tulsa, OK. Special Publication 11.

Uygur, K. and M. D. Picard. 1985. Mesozoic stratigraphy of Uinta Basin, northeast Utah. Pages 21-37 *in* M. D. Picard, editor. Geology and energy resources, Uinta Basin

of Utah. Utah Geological Association Publication 12.

van Tuinen, M. and E. A. Hadly. 2003. Tracking avian abundance through the Medieval Warm Period and Little Ice Age. *Congress of the International Union for Quaternary Research* 16:100.

Verville, G. J. 1957. Wolfcampian fusulinids from the Tensleep sandstone in the Big Horn Mountains, Wyoming. *Journal of Paleontology* 31(2):349-352.

Verville, G. J., G. A. Sanderson, and B. D. Rea. 1970. Missourian fusulinids from the Tensleep sandstone, Bighorn mountains, Wyoming. *Journal of Paleontology* 44(3):478-479.

Vice, M. A. and J. E. Utgaard. 1989. Depositional environments in the Mission Canyon Limestone (Madison Group, Mississippian), northern Bighorn Basin region, Montana and Wyoming. Pages 55-64 *in* D. E. French and R. F. Grabb, editors. Montana Geological Society 1989 field conference guidebook: Montana centennial edition: Geologic resources of Montana, Volume I. Montana Geological Society, Bozeman, MT. Field Conference 1989(1).

Vuke, S. M. 1984. Depositional environments of the Early Cretaceous Western Interior seaway in southwestern Montana and the northern United States. Pages 127-144 *in* D. F. Stott and D. J. Glass, editors. The Mesozoic of middle North America. Canadian Society of Petroleum Geologists, Calgary, Canada. Memoir 9.

Wahl, W. R., Jr. 2004. A large specimen of the genus *Eryma* (Crustacea, Decopoda) from the latest Callovian of North America. Abstracts with Programs. *Geological Society of America* 36(5):363.

Wahl, W. R. 2005. A hybodont shark from the Redwater Shale Member, Sundance Formation (Jurassic), Natrona County, Wyoming. *Paludicola* 5(1):15-19.

Wahl, W. R., M. Ross, and J. A. Massare. 2007. Rediscovery of Wilbur Knight's *Megalneusaurus rex* site: new material from an old pit. *Paludicola* 6(2):94-104.

Walcott, C. D. 1901. Cambrian Brachiopoda: *Obolella*, subgenus *Glyptias*; *Bicia*; *Obolus*, subgenus *Westonia*; with descriptions of new species. *Proceedings of the United States National Museum* 23:669-695.

Walcott, C. D. 1902. Cambrian Brachiopoda: *Acrotreta*; *Linnarssonella*; *Obolus*; with descriptions of new species. *Proceedings of the United States National Museum* 25:577-612.

Walcott, C. D. 1912. Cambrian Brachiopoda. U.S. Geological Survey, Washington, D.C. Monograph 51. Available online at: http://archive.org/details/cambrianbrachiop00walc. Accessed March 2013.

Walton, K. A., B. M. Blake, Jr., B. E. Bodenbender, and T. M. Demko. 2007. Paleobotany of the Sykes Mountain Formation (Early Cretaceous), Bighorn Basin, Shell, Wyoming. Abstracts with Programs. *Geological Society of America* 39(3):10.

Wanless, H. R., R. L. Belknap, and H. Foster. 1955. Paleozoic and Mesozoic rocks of Gros Ventre, Teton, Hoback, and Snake River ranges, Wyoming. Geological Society of America, Boulder, CO. Memoir 63.

Wardlaw, B. R. and J. W. Collinson. 1986. Paleontology and deposition of the Phosphoria Formation. *Contributions to Geology* 24(2):107-142.

Wegweiser, M. D. 2006. Paleowildfire characteristics and behavior: diagenetic changes occurring in vascular bone during cremation by wildfire reveal ancient fire behavior. Pages 55-60 *in* S. G. Lucas and R. M. Sullivan, editors. Late Cretaceous vertebrates from the Western Interior. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 35.

Weigner, M. M. and P. Isaacson. 2012. Late Devonian shelly fossils from the Jefferson Formation, Grandview Canyon, east-central Idaho. Abstracts with Programs. *Geological Society of America* 44(7):88.

White, C. A. 1879. Note on *Endothyra ornata*. *Proceedings of the United States National Museum* 2:291. Available online at: http://archive.org/details/proceedingsofuni21879unit. Accessed March 2013.

Whitlock, C. 1992. Holocene vegetation and climate of Grand Teton National Park and vicinity. Pages 50-54 *in* K. L. Pierce and J. D. Good. Field guide to the Quaternary geology of Jackson Hole, Wyoming. U.S. Geological Survey, Reston, VA. Open-File Report 92-504. Available online at: http://pubs.er.usgs.gov/publication/ofr92504 Accessed March 2013.

Whitlock, C. 1993. Postglacial vegetation and climate of Grand Teton and southern Yellowstone national parks. *Ecological Monographs* 63(2):173-198.

Whitlock, C., S. Fritz, B. Bracht, L. Stevens, M. J. Power, W. Dean, and J. Rosenbaum. 2006. The last 2000 years in northern Yellowstone National Park based on multiproxy data from Crevice Lake. Program and Abstracts. *American Quaternary Association Conference* 19:168-169. Available online at: http://www.amqua.org/pastmeetings/2006_Meeting_Abstracts.pdf. Accessed March 2013.

Wilborn, B. 2006. Macrofloral assemblages of the Cloverly Formation, Bighorn Basin, Wyoming. Abstracts with Programs. *Geological Society of America* 38(1):29.

Williston, S. W. 1904. Notice of some new reptiles from the upper Trias of Wyoming. *Journal of Geology* 12(8):688-697.

Williston, S. W. 1905. A new armored dinosaur from the upper Cretaceous of Wyoming. *Science* 22(564):503-504.

Windolph, J. F., Jr., R. C. Warlow, and N. L. Hickling. 1986. Deposition of deltaic and intermontane Cretaceous and Tertiary coal-bearing strata in the Wind River basin, Wyoming. Pages 123-140 *in* P. C. Lyons and C. L. Rice, editors. Paleoenvironmental and tectonic controls in coal-forming basins of the United States. Geological Society of America, Boulder, CO. Special Paper 210.

Wing, S. L., L. J. Hickey, and C. C. Swisher. 1993. Implications of an exceptional fossil flora for Late Cretaceous vegetation. *Nature* 363(6427):342-344. Available online at: http://hdl.handle.net/10088/8828. Accessed June 2013.

Wing, S. L., C. E. Stromberg, L. J. Hickey, F. Tiver, B. Willis, R. J. Burnham, and A. K. Behrensmeyer. 2012. Floral and environmental gradients on a Late

Cretaceous landscape. *Ecological Monographs* 82(1):23-47. Available online at: http://hdl.handle.net/10088/18466. Accessed June 2013.

Wings, O. 2007. A review of gastrolith function with implications for fossil vertebrates and a revised classification. *Acta Palaeontologica Polonica* 52(1):1-16. Available online at: http://app.pan.pl/archive/published/app52/app52-001. Accessed May 2013.

Wings, O. 2009. A simulated bird gastric mill and its implications for fossil gastrolith authenticity. *Fossil Record* 12(1):91-97.

Winslow, N. S. and P. L. Heller. 1987. Evaluation of unconformities in upper Jurassic and lower Cretaceous nonmarine deposits, Bighorn Basin, Wyoming and Montana, U.S.A. *Sedimentary Geology* 53(3-4):181-202.

Witkind, I. J. 1969. Geology of the Tepee Creek Quadrangle, Montana-Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 609. Available online at: http://pubs.er.usgs.gov/publication/pp609. Accessed April 2013.

Wright, G. A. 1980. The archeological sequence and native American land use in Jackson Hole. Pages 13-16 *in* S. Hollis, editor. Stratigraphy of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 31.

Wright, R. P. 1974. Jurassic bivalves from Wyoming and South Dakota: a study of feeding relationships. *Journal of Paleontology* 48(3):425-433.

Wroblewski, A. F. J. and B. E. Gulas-Wroblewski. 2002. Tidal and brackish-water indicators in the Upper Cretaceous Judith River and Meeteetse Formations, northern Bighorn Basin, Wyoming. Abstracts with Programs. *Geological Society of America* 34(6):279.

Wulf, G. R. 1962. Lower Cretaceous Albian rocks in northern Great Plains. *Bulletin of the American Association of Petroleum Geologists* 46(8):1371-1415.

Yen, T.-C. 1949. Review of the lower Cretaceous fresh-water molluscan faunas of North America. *Journal of Paleontology* 23(5):465-470.

Yen, T.-C. 1951. Fresh-water mollusks of Cretaceous age from Montana and Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 233-A. Available online at: http://pubs.er.usgs.gov/publication/pp233A. Accessed February 2013.

Yen, T.-C. and J. B. Reeside, Jr. 1946. Fresh-water mollusks from the Morrison Formation (Jurassic) of Sublette County, Wyoming. *Journal of Paleontology* 20(1):52-58.

Yochelson, E. L. 1963. Paleoecology of the Permian Phosphoria Formation and related rocks. Pages B123-B124 *in* Geological Survey Research 1963. U.S. Geological Survey, Washington, DC. Professional Paper 475-B. Available online at: http://pubs.er.usgs.gov/publication/pp475B. Accessed April 2013.

Yochelson, E. L. and D. H. van Sickle. 1968. Biostratigraphy of the Phosphoria, Park City, and Shedhorn formations, with a section on fish. U.S. Geological Survey, Washington, DC. Professional Paper 313-D. Available online at:

http://pubs.er.usgs.gov/publication/pp313D. Accessed March 2013.

Young, K. P. 1951. Foraminifera and stratigraphy of the Frontier Formation (Upper Cretaceous), southern Montana. *Journal of Paleontology* 25(1):35-68.

Zaleha, M. J. 2006. Sevier orogenesis and nonmarine basin filling: implications of new stratigraphic correlations of Lower Cretaceous strata throughout Wyoming, USA. *Geological Society of America Bulletin* 118(7-8):886-896.

Zaleha, M. J. and S. A. Wiesemann. 2005. Hyperconcentrated flows and gastroliths: sedimentology of diamictites and wackes of the upper Cloverly Formation, Lower Cretaceous, Wyoming, U.S.A. *Journal of Sedimentary Research* 75(1):43-54.

Additional References

Adams, T. L. and B. H. Breithaupt. 2003. Middle Jurassic dinosaurs of northern Wyoming: evidence from the Yellow Brick Road Dinosaur Tracksite, Bighorn Basin, Wyoming. *Wyoming Geo-Notes* 78:39-46.

Anderson, E. 1974. A survey of the late Pleistocene and Holocene mammalian fauna of Wyoming. Pages 78-87 *in* M. V. Wilson, editor. Applied geology and archaeology: the Holocene history of Wyoming. Geological Survey of Wyoming, Laramie, WY. Report of Investigations 10.

Zartman, R. E. and J. C. Reed, Jr. 1998. Zircon geochronology of the Webb Canyon Gneiss and the Mount Owen Quartz Monzonite, Teton Range, Wyoming: significance to dating late Archean metamorphism in the Wyoming Craton. *Mountain Geologist* 35(2):71-77.

Zeller, E. J. 1957. Mississippian endothyroid foraminifera from the Cordilleran Geosyncline. *Journal of Paleontology* 31(4):679-704.

Zenger, D. H. 1992. Burrowing and dolomitization patterns in the Steamboat Point Member, Bighorn Dolomite (upper Ordovician), northwest Wyoming. *Contributions to Geology* 29(2):133-142.

Baker, R. G. 1983. Holocene vegetational history of the western United States. Pages 109-127 *in* H. E. Wright, Jr., editor. Late-Quaternary environments of the United States. Volume 2: the Holocene. University of Minnesota Press, Minneapolis, USA.

Betancourt, J. L., T. R. Van Devender, and P. S. Martin, editors. 1990. Packrat middens: the last 40,000 years of biotic change. University of Arizona Press, Tucson, AZ.

Blackwelder, E. 1918. New geological formations in western Wyoming. *Washington Academy of Sciences Journal* 8(13):417-426.

Bradley, C. C. 1956. The pre-Cambrian complex of Grand Teton National Park, Wyoming. Pages 34-42 *in* R. R. Berg and

J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Branson, E. B. and M. G. Mehl. 1929. Triassic amphibians from the Rocky Mountain region. *The University of Missouri Studies* 4:1-87.

Cannon, K. P. 2006. Prehistoric ecology of *Bison* in the greater Yellowstone ecosystem. Program and Abstracts. *American Quaternary Association Conference* 19:70-72. Available online at: http://www.amqua.org/pastmeetings/2006_Meeting_Abstracts.pdf. Accessed March 2013.

Cheney, T. M., R. P. Sheldon, R. G. Waring, and M. A. Warner. 1954. Stratigraphic sections of the Phosphoria Formation in Wyoming. U.S. Geological Survey, Washington, DC. Available online at: http://pubs.er.usgs.gov/publication/cir324. Accessed April 2013.

Doelger, N. M. 1987. The stratigraphy of the Nugget Sandstone. Pages 163-178 *in* W. R. Miller, editor. The thrust belt revisited. Wyoming Geological Association, Casper, WY. Guidebook 38.

Elias, S. A. 1996. The ice-age history of national parks in the Rocky Mountains. Smithsonian Institution Press, Washington, DC.

Ellwood, B. B. 1996. Geology and America's National Park areas. Prentice Hall, Upper Saddle River, NJ.

Foster, H. L. 1947. Paleozoic and Mesozoic stratigraphy of northern Gros Ventre Mountains and Mount Leidy Highlands, Teton County, Wyoming. *Bulletin of the American Association of Petroleum Geologists* 31(9):1537-1593.

Fournier, R. O., R. L. Christiansen, R. A. Hutchinson, and K. L. Pierce. 1994. A field-trip guide to Yellowstone National Park, Wyoming, Montana, and Idaho: volcanic, hydrothermal, and glacial activity in the region. U.S. Geological Survey, Reston, VA. Bulletin 2099. Available online at: http://pubs.er.usgs.gov/publication/b2099. Accessed March 2013.

Goodwin, J. H. and C. R. Schmit. 1974. Sedimentology and geochemistry of piston cores from Yellowstone and Jackson Lakes, Wyoming. Abstracts with Programs. *Geological Society of America* 6(7):760.

Hanna, R. L. and K. L. Verosub. 1989. A review of lacustrine paleomagnetic records from western North America: 0-40 000 years BP. *Physics of the Earth and Planetary Interiors* 56(1-2):76-95.

Hay, O. P. 1924. The Pleistocene of the middle region of North America and its vertebrated animals. Carnegie Institute of Washington Publication 322A.

Hay, O. P. 1927. The Pleistocene of the western region of North America and its vertebrated animals. Carnegie Institute of Washington Publication 322B.

Hill, C. L. 2007. Pleistocene mammals in the greater Yellowstone ecosystem. Northwest Geology **36**:151-166. Available online at: http://sspa.boisestate.edu/anthropology/files/2010/06/mammals-greater-yellowstone.pdf. Accessed May 2013.

Jacobs, K. M. 2007. Fire and vegetation history of the last 2000 years in Jackson Hole, Grand Teton National Park, Wyoming. Thesis. Montana State University, Bozeman, MT.

Kvale, E. P., D. L. Mickelson, S. T. Hasiotis, and G. D. Johnson. 2004. The history of dinosaur footprint discoveries in Wyoming with emphasis on the Bighorn Basin. *Ichnos* 11(1-2):3-9.

Love, J. D. 1961. Reconnaissance study of Quaternary faults in and south of Yellowstone National Park, Wyoming. *Geological Society of America Bulletin* 72(12):1749-1764.

Love, J. D. 1974. Geologic map of the south half of the Huckleberry Mountain Quadrangle, Teton County, Wyo. U.S. Geological Survey, Washington, DC. Open-File Report 74-54. Scale 1:24,000. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_15071.htm. Accessed April 2013.

Love, J. D. and J. M. de la Montagne. 1956. Pleistocene and Recent tilting of Jackson Hole, Teton County, Wyoming. Pages 169-178 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Love, J. D., J. C. Reed, Jr., and K. L. Pierce. 2003. Creation of the Teton landscape: a geologic chronicle of Jackson Hole and the Teton Range. Grand Teton Natural History Association, Moose, WY.

MacTavish, J. N. 1971. Faunal elements of part of the Lodgepole Formation, Madison Group (Mississippian), from Darby Canyon, Grand Teton Mountains, Wyoming. Dissertation. Case Western Reserve University, Cleveland, OH.

Mayor, A. 2005. Fossil legends of the first Americans. Princeton University Press, Princeton, NJ.

McCracken, H., W. W. Wedel, R. Edgar, J. Moss, H. E. Wright, W. Husted, and W. Mulloy. 1978. The Mummy Cave project in northwest Wyoming. Buffalo Bill Historical Center, Cody, WY.

Merewether, E. A. and W. A. Cobban. 1986. Biostratigraphic units and tectonism in the mid-Cretaceous foreland of Wyoming, Colorado, and adjoining areas. Pages 443-468 *in* J. A. Peterson, editor. Paleotectonics and sedimentation in the Rocky Mountain region, United States. American Association of Petroleum Geologists, Tulsa, OK. Memoir 41.

Olsen, S. J. 1971. Zooarchaeology: animal bones in archaeology and their interpretation. Addison-Wesley Publishing Company, New York, NY.

Pierce, K. L. and L. A. Morgan. 1992. The track of the Yellowstone hot spot: volcanism, faulting, and uplift. Pages 1-53 *in* P. K. Link, M. A. Kuntz, and L. B. Platt, editors. Regional geology of eastern Idaho and western Wyoming. Geological Society of America, Boulder, CO. Memoir 179.

Reed, J. C., Jr. 1963. Structure of Precambrian crystalline rocks in the northern part of Grand Teton National Park, Wyoming. Pages C1-C6 *in* Geological Survey research, 1963. U.S. Geological Survey, Washington, DC. Professional Paper 475-C.

Available online at: http://pubs.er.usgs.gov/publication/pp475C. Accessed March 2013.

Reed, J. C., Jr. 1973. Geology of the Precambrian rocks of the Teton Range, Wyoming. U.S. Geological Survey, Washington, DC. Open-File Report 73-230. Scale 1:62,500. Available online at: http://pubs.er.usgs.gov/publication/ofr73230. Accessed March 2013.

Ryan, D. C. 1981. Foraminiferal biostratigraphy and paleoecology of the Cody Shale, Upper Slide Lake, Jackson Hole, Wyoming. Thesis. University of Wyoming, Laramie, WY.

Sohn, I. G. 1956. Pliocene ostracodes from Jackson Hole, Wyoming. Pages 120-122 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Tidwell, W. D. 1975. Common fossil plants of western North America. Brigham Young University Press, Provo, UT.

Tonnsen, J. J. 1980. The Frontier Formation in northwestern Wyoming and adjacent areas. Pages 173-184 *in* S. Hollis, editor. Stratigraphy of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 31.

Tracy, K. H. 2003. Grand Teton National Park paleontological survey. *Georgia Journal of Science* 61(1):31.

Tracy, K. H, W. P. Wall, and V. L. Santucci. 2002. Grand Teton National Park paleontological survey. Abstracts with Programs. *Geological Society of America* 34(6):423.

Van Norman, K. J. and C. Whitlock. 1994. A postglacial pollen record from the southwestern Yellowstone National Park region. Program and Abstracts. *American Quaternary Association Conference* 13:174.

Zell, R. 1959. A Mississippian coral assemblage from Darby Canyon, Teton County, Wyoming. Thesis. University of Wyoming, Laramie, WY.

Data Sets

Grand Teton National Park Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Grand Teton National Park Collections
1929–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by GRTE staff; status: Active.

John D. Rockefeller, Jr. Memorial Parkway Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Grand Teton National Park & John D. Rockefeller, Jr. Memorial Parkway Digital Geologic Map
2010–present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Available online at: https://irma.nps.gov/App/Reference/Profile?Code=2165235.

Peabody Museum of Natural History (former Princeton University collections)
Late 1980s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by YPM staff; status: Active.

Princeton University
1930s–late 1980s. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by PU staff; status: Inactive.

U.S. Geological Survey
1940s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by USGS staff; status: Active or inactive (depends on the collection).

National Museum of Natural History (including former USGS specimens)
1929–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by USNM staff; status: Active.

Museum of Paleontology, University of Michigan
1930s?–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by UMMP staff; status: Active.

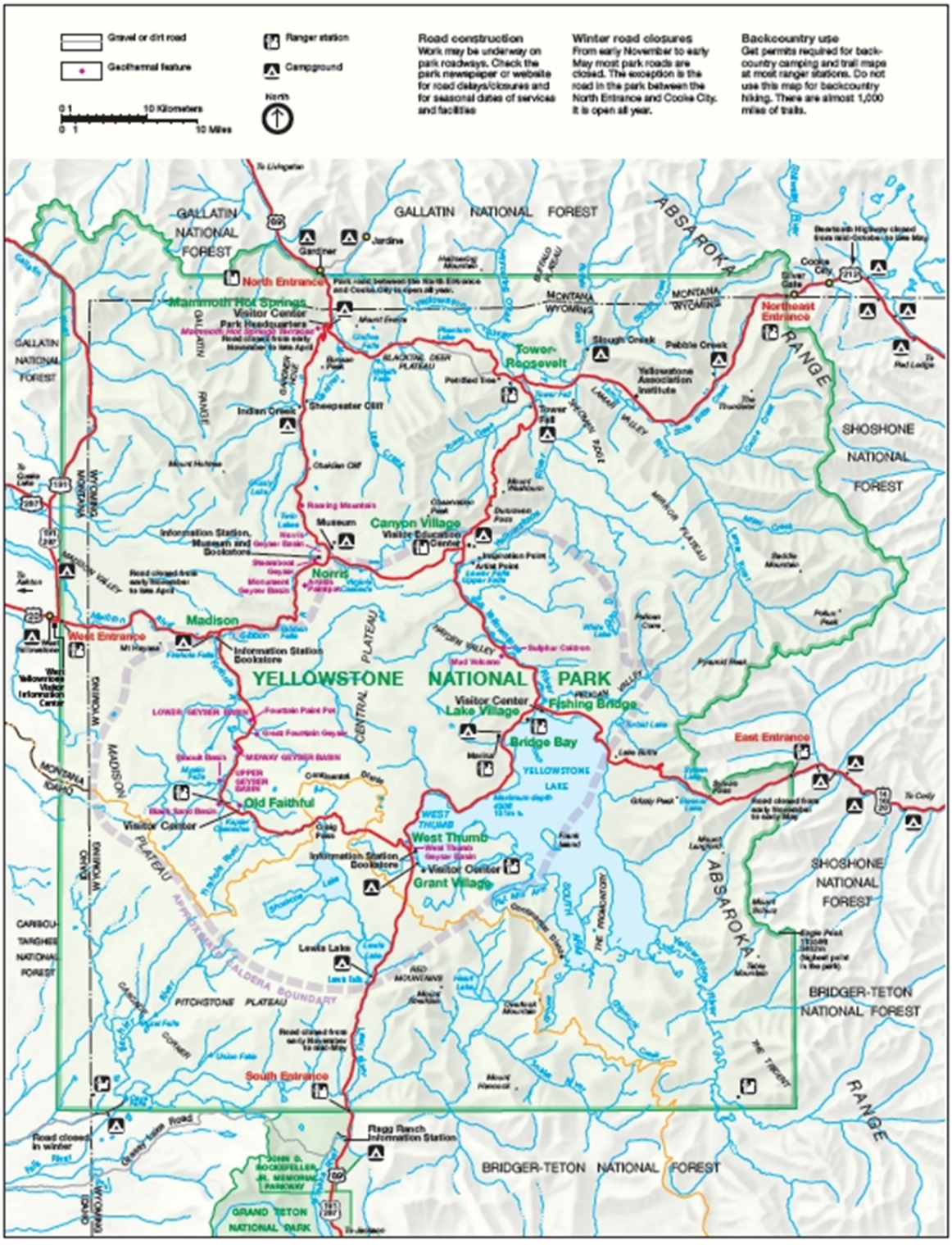
Burke Museum of Natural History and Culture
1980s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by UWBM staff; status: Active.

Yellowstone National Park

Yellowstone National Park (YELL) is the oldest national park of the United States, the second largest in the 48 contiguous states, and in the first rank of National Park Service (NPS) units in the public consciousness. It preserves a great variety of natural resources that have been shaped by glaciation and two extensive episodes of Cenozoic volcanism (see the appendix for a geologic time scale). The first episode, during the Eocene, is responsible for the "fossil forests" found in the northeastern and northwestern areas of the park (YELL Figure 1). The second episode occurred during the Quaternary and included three of the most voluminous volcanic eruptions known from North America, erupted in response to the presence of a hotspot which is still active today and feeding geothermal features. YELL was established March 1, 1872. The park's boundaries have changed several times: on May 26, 1926; March 1, 1929; April 19, 1930; and October 20, 1932. Today the park encompasses 898,317.43 ha (2,219,790.71 acres), all but 0.64 ha (1.58 acres) of which is federal (YELL Figure 2). It was designated a Biosphere Reserve in 1976 and a World Heritage Site September 6, 1978.



YELL Figure 1. Standing petrified fossil stumps at Specimen Ridge in YELL (see the cover for these stumps as they were circa 1890) (VLS).



YELL Figure 2. Geography of YELL (NPS).

Executive Summary

YELL is among the most fossiliferous units of the National Park Service. Fossils have been reported from YELL in the scientific literature since the 1870s. In paleontological circles, it is most renowned for abundant remains of Eocene plants, including large standing stumps and apparent “fossil forests,” but invertebrate and vertebrate fossils are also common. The exposed geology of YELL is dominated by the products of massive Pleistocene volcanic eruptions, but rocks of a variety of ages are also present, such as unfossiliferous Precambrian rocks, Cambrian and Ordovician formations, and a relatively complete sequence from the Late Devonian to the Eocene (see the appendix for a geologic time scale). After Pleistocene igneous rocks and Quaternary surficial deposits, Eocene igneous and associated sedimentary rocks are most common, mostly east of 110° 20’W and north of 44° 45’N. Older rocks are found near the northern and southern boundaries of the park. Those in the north are identified using Montana terminology, and those in the south are identified using Wyoming terminology (USGS 1972).

Fossils are known from many of the formations in YELL, and a half-dozen groupings can be considered particular highlights. Middle and Upper Cambrian rocks in northern YELL preserve a variety of early invertebrates with hard parts, such as hyoliths (enigmatic organisms with conical shells) and other enigmatic extinct forms, brachiopods (lamp shells), and trilobites, as well as stromatolites and other microbial structures, and invertebrate burrows and trails. The Mississippian-Permian rocks of the park feature a nearly completely different marine assemblage of foraminifera (protists that secrete “shells”), corals, bryozoans (moss animals), brachiopods, gastropods, trilobites, crinoids (sea lilies), and cartilaginous and bony fish. The Middle and lower Upper Jurassic rocks have yielded a third different marine assemblage, composed of corals, brachiopods, bivalves, ammonite and belemnite cephalopods, scaphopods (tusk shells), and crinoids. Upper Cretaceous rocks are marked by shifting marine and terrestrial deposition, reflected in the presence of bivalves, ammonites, gastropods, and fish scales and teeth in some beds, and spores, pollen, foliage, and other remains of a variety of land plants in other beds. Lower and Middle Eocene rocks preserve vast quantities of spores, pollen, foliage, petrified wood, and other remains of mosses, clubmosses, ferns, horsetails, conifers, and angiosperms that lived near chains of volcanoes. Finally, many sites of Quaternary age in the park have yielded fossils useful for paleoclimatological and paleoecological studies. These include diatoms, spores, pollen, and other microfossils from cores of lake sediment, and abundant bones of small vertebrates from caves.

YELL maintains a small collection of fossils (~65 specimens), and nearly a dozen outside institutions are thought to also have YELL fossils. The largest collection is at the National Museum of Natural History (USNM) in Washington, D.C., with other significant collections at Montana State University in Bozeman and the University of California at Berkeley’s Museum of Paleontology (UCMP). The holotype or name-bearing specimens of 175 fossil taxa came from YELL, the majority being either Paleozoic or Mesozoic marine invertebrates or Eocene plants. YELL also includes a number of examples of fossils with cultural contexts, mostly from archeological sites, but there is also petrified wood used as

building stone, and the possible description of YELL petrified forests in the tall tales of mountain men.

Although fossils from YELL have been studied since the 1870s, and have been featured in a landmark monograph published in 1899 and the first park-specific NPS paleontological inventory in 1998, the areal extent and diversity of bedrock units ensure that there are still scientifically important fossils yet to be found. Important issues facing fossil resource management at YELL include interpreting and protecting this vast resource, and continuing to promote scientific research. Research on Quaternary fossils is also important for park management in the face of climate change, and understanding human usage of the park area over the Holocene.

Paleontological Resource Management, Preliminary Recommendations

- Park staff should be encouraged to observe exposed sedimentary rocks and associated eroded deposits for fossil material while conducting their usual duties. To promote this, they should also 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, recreation area staff should take advantage of them, if funding and time permit. Any future study should be coordinated with the Yellowstone Center For Resources. Additional funding and staff will be required for future studies.

- Staff should photodocument 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 by artificially accelerated natural processes or direct human impacts. A Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring, with stumps on Specimen Ridge as one case study (Santucci et al. 2009).

- The petrified trees and stumps of YELL are of particular interest for inventorying and monitoring, because of their visibility and scientific value. The many historic photos of the fossils also offer a unique opportunity for monitoring, which could be used as the basis for a project. A compilation of historic photos which show petrified trees and standing stumps could be used to evaluate changes in the trees and stumps since the date of the historic photos by comparison to recent photos. 3D photogrammetric digital documentation of the stumps is recommended (B. Breithaupt, Bureau of Land Management, pers. comm., July 2013).

- Fossils found in a cultural context should be documented like other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to the Archeological Resources Protection Act [ARPA] or the Native American Graves Protection and Repatriation Act [NAGPRA]) and should be regarded as such until otherwise established. The Geologic Resources Division can coordinate additional documentation/research of such material.

- Theft and vandalism of paleontological resources are of long and ongoing concern; see for example Weed (1892), Sanborn (1951), Santucci (1998), Santucci et al. (2009), or Heasler and Jaworowski (2012) to follow the history of petrified wood theft. Formations and fossiliferous float found along popular trails and sightseeing locations are at the most risk of fossil theft and vandalism.

- Fossil packrat middens are typically found in dry caves and rockshelters, and resemble piles or mounds of plant material with a dark glossy coating of crystallized packrat urine. Fossil middens can provide important paleoecological information. If one is located, there are several midden researchers who may be contacted. The Geologic Resources Division maintains a list of active researchers and can facilitate

communication between the recreation area and these researchers. Contact the NPS Geologic Resources Division for technical assistance with paleontological resource management issues.

Geologic Background

YELL occupies a significant portion of northwestern Wyoming, in western Park and northern Teton counties. It also extends into eastern Fremont County, Idaho, and southern Gallatin and Park counties, Montana. The Absaroka Range dominates eastern YELL, the Gallatin Range occupies part of northwestern YELL, and the Teton Range is adjacent to the park on the south. Much of the rest of the park's land area belongs to a series of plateaus. Lakes are interspersed throughout. Southeastern YELL includes large Yellowstone Lake, flanked on the southwest by three smaller lakes, from northwest to southeast Shoshone Lake, Lewis Lake, and Heart Lake. Yellowstone River flows north through Yellowstone Lake, cutting the Grand Canyon of the Yellowstone within the central part of the park. Most of southern and southwestern YELL is in the Snake River drainage. National forests almost entirely surround the park. Gallatin National Forest borders it on the northwest and north, Shoshone National Forest borders it on the east, Bridger-Teton National Forest borders it on the southeast and south, and Caribou-Targhee National Forest borders it on the southwest and west. The only area that does not border a national forest is a small section of the southern boundary that shares the border with the John D. Rockefeller, Jr. Memorial Parkway (JODR), which forms a NPS corridor from YELL to Grand Teton National Park (GRTE). Bozeman, Montana is about 60 km (37 miles) north of YELL, Cody, Wyoming is about 74 km (46 miles) east of YELL, and Jackson, Wyoming is about 74 km (46 miles) south of YELL.

There has been no shortage of geological publications on YELL; for example, a GeoRef search using "Yellowstone National Park" as a search term returns 2,246 results, searching the Yellowstone Database (http://refbase.wsulibs.wsu.edu/yellowstone/index.php) for "geology" returns 3,019 results, and searching the same source with "paleontology" returns 320 results. Although a certain percentage of these results are doubtless irrelevant, even a partial accounting would result in a substantial list, and would still be incomplete. It is customary in these reports to provide such a list, but in this case it is more helpful to see to the references in context in the text. The foundational work for the paleontology of the park is in a series of papers produced by Hauge et al. (1899). The NPS Geologic Resources Division coordinated a Geologic Resource Inventory workshop for YELL in June 2005 (NPS 2005). A paleontological survey was prepared by Santucci (1998), and the fossils of the park were also described in the initial Greater Yellowstone Network (GRYN) paleontological resource inventory and summary (Koch and Santucci 2003).

The strata of YELL include very ancient rocks and a fairly complete record from the Cambrian to the earliest Cenozoic. Most outcrops derive from extensive volcanism during the Eocene and Quaternary. The oldest rocks are intrusive igneous and high-grade metamorphic Precambrian rocks found in the northwestern section of the park and on the southwest flank of the Beartooth Mountains, in approximately the eastern half of the northern margin of YELL (USGS 1972). The Precambrian of YELL is not particularly well known, but better-described rocks of this age in the Beartooth Mountains on the north and the Teton Range to the south bracket the park. YELL, along with GRTE and JODR, is found near the western edge of the Wyoming

Province, one of the ancient components of the core of the North American continent (Frost et al. 2006). The rocks in the Beartooth Mountains provide evidence for shuffled terranes (distinct continental blocks) in the Wyoming Province. Two related terranes, one composed of metamorphosed sedimentary rocks and present in YELL, the other composed of igneous rocks and found to the east, had formed in the same general area by 3.6 Ga (billion years ago) but were not juxtaposed until at least 2.75 Ga (Mogk et al. 1992). The early tectonic activity did not involve subduction, as seen in modern plate tectonics, but subduction appears to have been active by around 2.8 Ga (Mueller et al. 1985). The Precambrian rocks of the Teton Range also show early evidence for modern-style plate tectonics, with a Himalayan-like orogeny (mountain-building event) between approximately 2.685 and 2.671 Ga (Frost et al. 2009). The most recent interpretation, albeit still largely published in abstracts, proposes that two terranes are present north of Mount Moran, and a third is present to the south. The two northern terranes collided during the 2.685-2.671 Ga event, and the third arrived sometime between 2.625 and 2.615 Ga, during a period when other terranes were accreting along the "southern" margin of the Wyoming province (Frost et al. 2011). The Precambrian rocks of YELL are likely of comparable age to these ancient rocks (Ruppel 1972). They are followed by a major hiatus on the order of 2 billion years in duration.

The oldest recognizable sedimentary rocks are from the Middle Cambrian, over 500 million years ago. During the Middle Cambrian, a marine transgression (advance) arrived in the area from the west (Shaw 1954, Bell and Middleton 1978). The Cambrian sea, also known as the Sauk Sea, had several transgression-regression (marine retreat) cycles, beginning during deposition of the Flathead Sandstone and continuing into the Gallatin Formation and equivalents (Saltzman 1999). Sedimentary rocks were deposited in a variety of settings, at first above or below sea level along a coast (Bell and Middleton 1978, Beebe and Cox 1998), then becoming deeper marine (Beebe and Cox 1998), and then returning to coastal deposition (Martin et al. 1980, Clark et al. 2000). Deposition was occasionally interrupted, leaving disconformities within the Cambrian section (Miller 1936, Beebe and Cox 1998).

A depositional hiatus followed the Cambrian deposition until the Late Ordovician, represented by the Bighorn Dolomite. This unit was deposited under a shallow sea, when the modern GRYN area was near the equator (Holland and Patzowsky 2012). This was a time of transition from "greenhouse" to "icehouse" conditions, which is reflected by changes in the Bighorn Dolomite's cyclicity and the turnover of faunal assemblages (Holland and Patzowsky 2009, 2012). Another substantial hiatus followed, lasting until the Late Devonian. Devonian rocks are represented by the marine Darby Formation in southern YELL and the equivalent Jefferson and Three Forks formations in the north. The Darby Formation was deposited during a transgression (Andrichuk 1956) in a restricted basin (Wanless et al. 1955). The Jefferson Formation was deposited during a marine transgression from the west (Witkind 1969). Shallow and restricted marine deposition continued into the Three Forks Formation, which records a regression near the end of its deposition (Sandberg 1965).

The Upper Devonian formations are the first in a series of formations that present a mostly

complete stratigraphic column into the early Cenozoic. From the Late Devonian to the Jurassic, the general configuration featured a shallow sea which transgressed and regressed several times, arriving from what is now the west but would then have been more northwest. Episodic uplift occurred in the region from the late Paleozoic (Simmons and Scholle 1990) into the Triassic (Picard 1967).

The Madison Limestone or Group of the Mississippian is a marine unit deposited during a period of overall marine transgression (Gutschick et al. 1976). When the sea retreated and deposition ceased, the limestones of the Madison Limestone were exposed to the open air, forming a karst surface. An early generation of voids and caves formed. After the hiatus that led to the early erosion of the Madison Limestone, the shallow sea returned from the west, resulting in the primarily marine Amsden Formation (Sando 1988). Sea level fluctuated during deposition (Gorman 1963). The succeeding Quadrant Sandstone and Tensleep Sandstone were deposited in a regression, and record a change from shallow marine to coastal sand dune deposition (Mankiewicz and Steidtmann 1979, Saperstone and Ethridge 1984, Saperstone 1986, Kerr and Dott 1988, Lopez et al. 2007). The setting has been compared to the southeastern part of the Qatar Peninsula in the Persian Gulf (Mankiewicz and Steidtmann 1979). A dune system was moving south out of north-central Wyoming during deposition. At this time, the modern GRYN area was situated near 10°N (Kerr and Dott 1988).

By the Permian, the GRYN area had moved to about 20°N (Hiatt and Budd 2001). Another shallow warm sea inundated the land surface (Hiatt and Budd 2001), arriving from the west (Sheldon 1956). Two transgression-regression cycles moving from west to east produced a variety of lithologies now represented in the complex Phosphoria/Shedhorn stratigraphic interval (Sheldon 1956). At this time, the sea was bounded on the north by some ancient topographic highs, on the south by the Ancestral Rockies, on the east by evaporitic basins, and on the west by an island arc system (Hiatt and Budd 2001). Three more transgression-regression cycles occurred during the Triassic, with the sea spreading from west to east. The Dinwoody Formation, the oldest Triassic unit of YELL, was deposited during the first transgression (Paull and Paull 1993). Further marine fluctuations are represented in southern YELL by the overlying Chugwater Formation (Cavaroc and Flores 1991) and in northern YELL by the Woodside Formation and Thaynes(?) Formation (Paull et al. 1989). Deposition occurred under a warm arid climate (Maughan 1964, 1967, Picard 1966), with some volcanism (High and Picard 1965). After the Triassic sea retreated, there is a hiatus in the YELL rock column until the Middle Jurassic and the return of marine conditions. During the Middle and Late Jurassic, a marine body known as the Sundance Sea encroached on the GRYN area from the northwest, a volcanic archipelago was present on the west, the Ancestral Rockies were present on the south, and upland continental areas existed to the east (Harris and Lacovara 2004). Marine deposition is represented by the Gypsum Spring and Sundance formations in southern YELL and the Ellis Group in northern YELL. Several marine transgression-regression cycles occurred during this time (Kvale et al. 2001).

After the Sundance Sea retreated for the last time, terrestrial deposition took place in the form of the Morrison Formation. By the time of Morrison deposition, the region had moved

out of the low subtropical latitudes (Picard 1993) and humidity increased (Lockley and Wright 2003), supporting a great diversity of life. The Morrison Formation is interpreted as a semi-arid seasonal savanna-like setting (Engelmann et al. 2004, Hasiotis 2004, Turner and Peterson 2004). The overlying Cloverly/Kootenai interval of the Early Cretaceous is similar, and it can be difficult to differentiate the Morrison Formation from the younger rocks. The Cloverly and Kootenai formations are primarily fluvial and lacustrine sedimentary sequences with a substantial amount of sediment derived from volcanoes (volcaniclastics) (Moberly 1960, Condon 2000). Deposition occurred under a warm, seasonal climate, becoming more humid over time (Forster 1984). To the west, a mountain-building episode known as the Sevier Orogeny was active (DeCelles 1986). The upper part of the interval shows an increasing marine influence as a shallow continental sea known as the Western Interior Seaway or Cretaceous Interior Seaway began to encroach upon the area (Forster 1984, DeCelles 1986), from the north (Nydam and Cifelli 2002). The uppermost rocks of this complex interval are interpreted as shallow marine (Moberly 1960, Kvale and Vondra 1993).

The next sequence of Cretaceous rocks exposed at YELL, ranging in age from the late Early Cretaceous to the late Late Cretaceous, was deposited in the Western Interior Seaway system. The Seaway eventually extended from the Arctic to the Gulf of Mexico, bisecting North America (Elder and Kirkland 1993, 1994). Its waxings and wanings influenced the geology of numerous NPS units. Deep marine shales alternated with shallower marine sandstones as the sea transgressed and regressed (Eicher 1960, Condon 2000, Johnson 2010). Numerous bentonite beds in the section indicate that volcanoes to the west contributed significant amounts of ash to the sediment (Reeside and Cobban 1960). The last major marine formation in southern YELL is the Bacon Ridge Sandstone (Love 1956a) although a marine tongue advanced as far as the Two Ocean Lake area in GRTE during deposition of the Harebell Formation, several million years later (Kauffman 1973). In northern YELL, the last marine units are the Telegraph Creek Formation and Eagle Sandstone (Fraser et al. 1969, Dyman et al. 1997), partially equivalent to the Bacon Ridge Sandstone. Otherwise, coastal plain deposition dominated the rest of the Cretaceous (Lindsey 1972, Kauffman 1973, Johnson 2008). Near the end of the Cretaceous, deposition occurred within a large fluvial system bringing sediment from young uplifts and nearby volcanoes (Love 1973), under a warm humid climate in the vicinity of the receding sea (Lindsey 1972).

Throughout much of western North America, the final withdrawal of the Western Interior Seaway occurred concurrently with the beginning of a major mountain-building event known as the Laramide Orogeny (Cather 2003). This event took place from the Late Cretaceous to the Eocene and was responsible for much of the present form of the Rocky Mountains (Aubrey 1991). The dramatic changes brought about by the orogeny can be seen in the contact of the Harebell Formation and Pinyon Conglomerate: the two cannot have been separated by more than a few million years, yet the Harebell-Pinyon contact is an angular unconformity that is perpendicular in some locations (Love 1973). It appears that the nearby Washakie Range was uplifted, thrust to the west, and eroded down to its Paleozoic core during the

relatively brief hiatus between the two formations (Love 1990).

The first major volcanic activity of the area, from the Absaroka volcanic field, began during the Eocene. The rocks of the Absaroka Volcanic Supergroup derived from a field of stratovolcanoes (Smedes and Prostka 1972). These volcanoes were arranged in two subparallel northwest-southeast chains, each about 240 km (150 miles) long. One passed through YELL from near the northwestern corner to near the southeastern corner, and the other was approximately 30 to 50 km (20 to 30 miles) to the east (Chadwick 1970). The volcanic field was active between about 55 and 44 Ma (million years ago) (Harlan and Morgan 2010), with activity moving southeast over time (Fritz and Harrison 1985). The western belt is slightly older than the eastern belt (53 to 49 Ma versus 49 to 44 Ma, per Snoke 1993). The Absaroka Volcanic Supergroup occupies an area approximately 250 km by 95 km (160 miles by 60 miles), roughly 25,000 km^2 (10,000 $miles^2$), with a volume of 29,000 km^3 (7,000 mi^3) (King and Beikman 1978). The physiographic setting has been comparable to modern stratovolcanoes, such as Mount St. Helens or the volcanoes of Central America (Fritz 1982).

Most of the rest of the Cenozoic, approximately 40 million years, is not directly represented within YELL, but outcrops of various formations deposited during this hiatus are found in the vicinity (Love 1953, 1956b, 1989a, 1989b, Sutton and Black 1975, McKenna 1980, Barnosky 1984, Love et al. 1992, NPS 2010). Erosion occurred during the Early Miocene, followed by extension and subsidence to about 14.8 Ma. Uplift occurred until about the end of the Miocene in the vicinity of northern YELL, leading to tilting, erosion, and faster subsidence (Barnosky and LaBar 1989).

The most recent episode of volcanism in YELL is due to the activity of the Yellowstone Hotspot, responsible for some of the largest known volcanic events on Earth. The hotspot is first recognized as the source of the voluminous Columbia River Plateau flood basalts of approximately 16 Ma. Volcanic activity from this mantle plume has moved east-northeast as the North American continent has moved west-southwest; Craters of the Moon National Monument (CRMO) in central Idaho represents another eruptive phase. After the Columbia River eruptions, activity has been focused into smaller, caldera-producing eruptions. The hotspot entered the immediate vicinity of northwestern Wyoming between 7 and 4 Ma, creating the Heise volcanic field just to the west. Major eruptions from this field include those that produced the Blacktail Creek Tuff (6.62±0.4 Ma), the Walcott Tuff (6.27±0.04 Ma), the Conant Creek Tuff, which is found in GRTE and JODR (5.51±0.13 Ma), and the Kilgore Tuff (4.45±0.05 Ma). By about 2 Ma, the hotspot was beneath the Yellowstone Plateau. From here, it has produced three major calderas: the Huckleberry Ridge Caldera (Huckleberry Ridge Tuff) at about 2.05 Ma; the Henry's Fork Caldera (Mesa Falls Tuff) at about 1.3 Ma; and the Yellowstone Caldera (Lava Creek Tuff) at about 0.64 Ma (Morgan et al. 2008). A smaller, more localized volcanic source, the Jackson Hole volcanic field, was active to the south about 8 Ma (Lageson et al. 1999).

The Laramide Orogeny was not the end of major tectonic activity in northwestern Wyoming. The Yellowstone portion of the Washakies rose during the Oligocene. The

modern Gros Ventre-Teton system began stirring during the Pliocene, with the Gros Ventre Range rising first (Love 1969). The Teton Range is the result of extensional tectonics that caused some 6 to 9 km (4 to 6 miles) of vertical offset (Smith et al. 1993) through a combination of uplift and subsidence, raising the range and dropping Jackson Hole (Roberts and Burbank 1993). The feature responsible for this is the Teton Fault, which became active around 3±1 Ma (Anders et al. 2009). The appearance of the fault and movement on it may be related to the Yellowstone Hotspot, or to the Basin and Range extension that created the modern topography of the Great Basin (Smith et al. 1993). Aside from its volcanic and caldera-producing activity, the Yellowstone Hotspot is also responsible for more widespread tectonic deformation; its presence causes regional uplift, and as its surficial position has changed, a "bow wake" of deformation has trailed it (Pierce et al. 2007a). The uplift of the Yellowstone area promoted by the hotspot also made the area susceptible to glaciation (Pierce et al. 2007a), so in a bit of poetry the hotspot has led to both fire and ice. Earthquake activity has continued to the historic era, with one event greater than magnitude 7 (the Hebgen Lake earthquake of August 17, 1959) and seven other events between magnitudes 6 and 7 since recording began (Smith and Braile 1984).

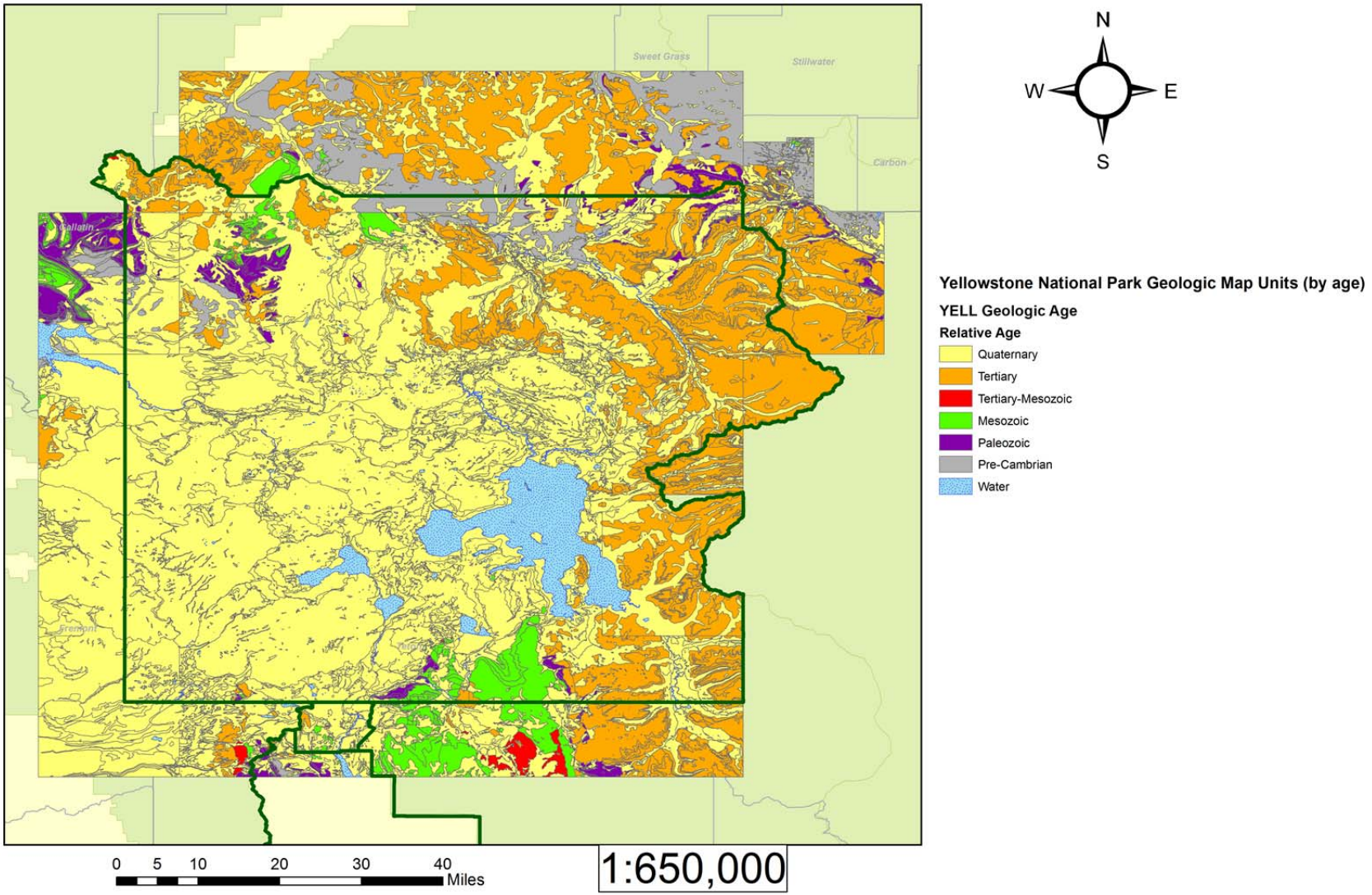
Glaciation in the YELL area has a long history, beginning perhaps in the Pliocene with what is known as the "ghost glaciation" in and around GRTE (Love 1989a; note that the Pliocene-Pleistocene boundary was moved back to 2.588 Ma in 2009, so many "Pliocene" events in older references are now considered Pleistocene in age). In YELL, glacial events possibly occurred between 5.89 and 2.01 Ma, and definitely occurred after 2.01 Ma (Richmond 1986). Traditionally, the glaciations of the park are known from oldest to youngest as the Buffalo, Bull Lake, and Pinedale glaciations (Richmond 1964), but the actual history is much more complex (Pierce 1979, Richmond 1986, 1987). The pre-Bull Lake glaciations are represented by scattered deposits (Pierce 1979). The Bull Lake and Pinedale events are well-supported. The Bull Lake glaciation reached its maximum and retreated between about 140,000 and 130,000 years ago (Licciardi and Pierce 2008, Pierce et al. 2011). The Pinedale glaciation, as the most recent extensive glaciation, is by far the best known. It took place between about 35,000 and 16,000 to 14,000 years ago (Hampel et al. 2007), reaching its maximum between roughly 19,000 and 16,000 years ago (Licciardi and Pierce 2008, Pierce et al. 2011). The age of the maximum varied by location, and is slightly younger in the YELL-GRTE area than the Wind River Mountains (for example, Licciardi and Pierce 2008). Ice, up to a kilometer (0.62 miles) thick, covered some 16,500 km^2 (6,300 mi^2) of the area, capping Yellowstone and the Teton Range (Hampel et al. 2007). Following this glacial advance, there has been tectonic rebound, mostly before 8,000 years ago (Hampel et al. 2007). The Holocene has seen three minor glacial advances in the high elevations of the park (Richmond 1969).

Following the Bull Lake glaciation, the area attained its warmest recent climate around 82,000 years ago. Tundra conditions existed between 70,000 and 50,000 years ago, followed by the Pinedale glaciation. Deglaciation occurred around 14,000 years ago (Baker 1986). Following the warming at the end of the Pleistocene, central and southern YELL appear to have entered a drier climate during the early Holocene, while

northern YELL entered a moister climate, due to changes in atmospheric circulation. These climates have equalized somewhat since the early Holocene, but the difference is still recognizable (Whitlock and Bartlein 1993, Pierce et al. 2003). Humans were present in the Yellowstone Lake area by sometime between 10,600 and 9,800 years ago (Pierce et al. 2007a). The park had sustained seasonal occupation by around 5,000 years ago, by people gathering resources at various elevations as different food resources became available. YELL may have served as a refugium during the harsher warm and dry conditions of the middle Holocene (Altithermal). There is some evidence that people largely abandoned YELL several hundred years ago, only returning in numbers around 1800 AD (Wright 1982).

Because YELL covers a large area, and pre-caldera stratigraphy is divided by the volcanic rocks that cover most of the central part of the park, the northern and southern portions of the park have distinct stratigraphic nomenclature (Ruppel 1972, Love and Keefer 1975, Santucci 1998). The southern portion uses the same names as the Teton-Jackson Hole region to the south (compare to the GRTE/JODR chapter of this inventory), and the northern portion uses Montana terminology. This leads to some redundancy. In particular, the Devonian, Pennsylvanian, Middle Jurassic, and Lower Cretaceous sections use different names for what are probably the same formations, and several Cambrian and Mississippian formations of the north are recognized as members in the south. In the latter cases, Cambrian units that can be described as members of the Gros Ventre Formation or Gallatin Limestone will be described separately because they are commonly described separately within YELL, and two Mississippian units (Lodgepole Limestone and Mission Canyon Limestone) will be included with the Madison Limestone/Group because it is common practice to map them undivided.

Pre-Cenozoic rock units exposed in northern YELL include the following, in ascending order (oldest to youngest): Precambrian basement (Archean, possibly also Paleoproterozoic and Mesoproterozoic); the Flathead Sandstone, Wolsey Shale, Meagher Limestone, and Park Shale (Middle Cambrian); the Pilgrim Limestone and Snowy Range Formation (Upper Cambrian); the Bighorn Dolomite (Upper Ordovician); the Jefferson and Three Forks formations (Upper Devonian); the Lodgepole and Mission Canyon limestones of the Madison Group (Lower–Middle Mississippian); the Amsden Formation (Upper Mississippian-Middle? Pennsylvanian); the Quadrant Sandstone (Middle Pennsylvanian); the Shedhorn Sandstone and associated rocks (Lower-Middle Permian); the Dinwoody, Woodside, and Thaynes(?) formations (Lower Triassic); the Sawtooth and Rierdon formations of the Ellis Group (Middle Jurassic); the Swift Formation of the Ellis Group (Middle-Upper Jurassic); the Morrison Formation (Upper Jurassic); the Kootenai Formation and Thermopolis Shale (Lower Cretaceous); the Mowry Shale, Frontier Formation, Cody Shale, Telegraph Creek Formation, Eagle Sandstone, Everts Formation, and Landslide Creek Formation (Upper Cretaceous); and unnamed igneous and associated sedimentary rocks (Upper Cretaceous or Paleocene) (YELL Figure 3, Table 1) (Ruppel 1972, USGS 1972).



YELL Figure 3. Schematic geological map of YELL; because of the many formations, units are grouped by age. Map graphic adapted from digital geologic map data available at the following URL:https://irma.nps.gov/App/Reference/Profile?Code=1044842.

YELL Table 1. Concise tabulation of pre-Cenozoic northern YELL stratigraphy, fossils, and depositional setting; details and references can be found in the text. High-grade metamorphic and intrusive igneous rocks are included here for completeness, but are not discussed in detail in the text because they are unfossiliferous.

Formation	Age	Fossils	Depositional Environment
Igneous and associated sedimentary rocks	Late Cretaceous or Paleocene	None to date; plant microfossils and macrofossils are most likely	Unknown, but terrestrial settings in the vicinity of volcanoes is likely
Unspecified Upper Cretaceous rocks on Mount Everts	Late Cretaceous	Fern and angiosperm leaves and dinosaurs eggshell	Unknown
Landslide Creek Formation	Late Cretaceous	Coal, twigs and other plant macrofossils, spores and pollen (of mosses, hornworts, clubmosses, ferns, plants from the group including ferns, lycopods, and relatives, and angiosperms)	Fluvial
Everts Formation	Late Cretaceous	Spores and pollen (of hornworts, ferns, caytoniacean pteridosperms, plants from the group including ferns, lycopods, and relatives, possible cycads, conifers, angiosperms, and unknown plants), plant macrofossils, and bivalves; probably the source of Knowlton's (1899) "Laramie Formation" conifer and angiosperm fossils from Mount Everts	Deltaic and associated settings
Eagle Sandstone	Late Cretaceous	Coal, unspecified plant fossils, and bivalves	Shallow marine to coastal terrestrial over time
Telegraph Creek Formation	Late Cretaceous	Dinoflagellates, spores, pollen, an angiosperm leaf, bivalves, ammonites, invertebrate burrows, and tortoise and unidentified vertebrate bones	Shoreface
Cody Shale	Late Cretaceous	Bivalves, cephalopods including ammonites, and gastropods	Open marine
Frontier Formation	Late Cretaceous	Coal, carbonaceous debris, palynomorphs (pertaining to acritarchs, dinoflagellates, chlorophyte algae, mosses, clubmosses, ferns, and conifers), bivalves, ammonites, gastropods, invertebrate burrows and trails, shark teeth, and fish teeth	Deltaic, nearshore, and more open marine
Mowry Shale	Late Cretaceous	Fish scales, teeth, and vertebrae, and an indeterminate small hollow bone	Open marine
Thermopolis Shale	Early Cretaceous	Dinoflagellates, pollen, spores, bivalves, gastropods, and invertebrate burrows	Marine, brackish coastal to open
Kootenai Formation	Early Cretaceous	Bivalves and gastropods	Fluvial, floodplain, and lacustrine settings; marine influence near top
Morrison Formation	Late Jurassic	Wood and fragments of a dinosaur bone	Fluvial, floodplain, and lacustrine settings
Swift Formation	Middle–Late Jurassic	Brachiopods, bivalves, belemnites, and abundant fossil fragments; this and the two underlying formations are the source of Stanton's (1899) collections of Jurassic brachiopods, bivalves, ammonites, belemnites, gastropods, and crinoids from northwestern YELL, but the exact stratigraphy is unknown	Shallow marine
Rierdon Formation	Middle Jurassic	Bivalves, ammonites, and belemnites	Shallow marine

YELL Table 1. Concise tabulation of pre-Cenozoic northern YELL stratigraphy, fossils, and depositional setting; details and references can be found in the text. High-grade metamorphic and intrusive igneous rocks are included here for completeness, but are not discussed in detail in the text because they are unfossiliferous (continued).

Formation	Age	Fossils	Depositional Environment
Sawtooth Formation	Middle Jurassic	Corals, bivalves, ammonites, and gastropods	Coastal terrestrial and restricted marine, lower and upper, and open marine middle
Thaynes(?) Formation	Early Triassic	None to date; marine invertebrates are most likely	Open to marginal marine
Woodside Formation	Early Triassic	None to date; fossils are very rare in this formation	Marginal marine
Dinwoody Formation	Early Triassic	Brachiopods	Shallow marine
Shedhorn Sandstone and associated rocks	Early–Middle Permian	Brachiopods and phosphatized fish bones	Coastal terrestrial to marine basins, changing multiple times
Quadrant Sandstone	Middle Pennsylvanian	Foraminifera, brachiopods, gastropods, and ostracodes	Shallow marine to coastal dunes over time
Amsden Formation	Late Mississippian–Middle? Pennsylvanian	None to date; diverse marine invertebrates are known from southern YELL	Beaches and offshore bars, followed by restricted and shallow marine
Mission Canyon Limestone	Early–Middle Mississippian	Foraminifera, corals, bryozoans, brachiopods, gastropods, trilobites, and crinoids, along with beds of fossil fragments; a tooth plate of a cartilaginous fish was found in this or the Lodgepole Limestone	Shallow marine
Lodgepole Limestone	Early–Middle Mississippian	Sponges, corals, bryozoans, brachiopods, rostroconchs, gastropods, trilobites, and crinoids, along with beds of fossil fragments	Shallow marine
Three Forks Formation	Late Devonian	Stromatoporoid sponges, corals, brachiopods, gastropods, and unspecified fossils	Restricted to shallow marine
Jefferson Formation	Late Devonian	Stromatoporoid sponges, corals, and gastropods	Dominantly shallow marine
Bighorn Dolomite	Late Ordovician	Receptaculitids (probably chlorophyte algae), bryozoans, brachiopods, orthoconic cephalopods (probably nautiloids), trilobites, and ostracodes	Shallow marine, open and restricted
Snowy Range Formation	Late Cambrian	Stromatolites, “algal” limestone, sponge spicules, hyoliths, brachiopods, helcionelloid mollusks, possible gastropods (*Scaevogyra*), trilobites, crinoids, invertebrate trails, and possible invertebrate egg cases; this and the Pilgrim Limestone are probably the sources of Walcott’s (1899, 1902, 1905) “Gallatin” brachiopods, gastropod-like forms, and trilobites	Shallow marine
Pilgrim Limestone	Late Cambrian	*Chancelloria*, hyoliths, brachiopods, trilobites, and conodonts	Shallow marine

YELL Table 1. Concise tabulation of pre-Cenozoic northern YELL stratigraphy, fossils, and depositional setting; details and references can be found in the text. High-grade metamorphic and intrusive igneous rocks are included here for completeness, but are not discussed in detail in the text because they are unfossiliferous (continued).

Formation	Age	Fossils	Depositional Environment
Park Shale	Middle Cambrian	Fossiliferous lenses; brachiopods are probably included, because it was once known as the "*Obolella* Shale"; this and the two underlying formations are probably the sources of Fitzke and Hale's (2003) sponge spicules, hyoliths, brachiopods, trilobites, crinoid calyx plate, and invertebrate trace fossils, and Walcott's (1897, 1899) "Flathead" possible archaeocyathid sponges, hyoliths, brachiopods, and trilobites	Tidal flats
Meagher Limestone	Middle Cambrian	Brachiopods and trilobites	Offshore marine
Wolsey Shale	Middle Cambrian	Invertebrate trace fossils	Tidal flats
Flathead Sandstone	Middle Cambrian	Brachiopods	Coastal sandstone
Precambrian "basement" rocks	Archean, possibly also Paleoproterozoic and Mesoproterozoic	Unfossiliferous	Not applicable

Pre-Cenozoic rock units exposed in southern YELL include the following, in ascending order: possibly the Gros Ventre Formation (Middle–Upper Cambrian); the Gallatin Limestone (Upper Cambrian); the Bighorn Dolomite (Upper Ordovician); the Darby Formation (Upper Devonian); the Madison Limestone (Lower–Middle Mississippian); the Amsden Formation (Upper Mississippian–Middle? Pennsylvanian); the Tensleep Sandstone (Middle–Upper Pennsylvanian); the Phosphoria Formation and associated rocks (Lower–Middle Permian); the Dinwoody Formation (Lower Triassic); the Chugwater Formation (Triassic); the Gypsum Spring Formation (Middle Jurassic); the Sundance Formation (Middle–Upper Jurassic); the Morrison(?) Formation (Upper Jurassic); the Cloverly Formation and Thermopolis Shale (Lower Cretaceous); the Mowry Shale, Frontier Formation, Cody Shale, Bacon Ridge Sandstone, and Harebell Formation (Upper Cretaceous); and the Pinyon Conglomerate (Upper Cretaceous–Paleocene) (YELL Figure 3, Table 2) (USGS 1972, Love and Keefer 1975).

Cenozoic rocks and sediments exposed in YELL include the following, from in ascending order: the Hominy Peak Formation and assorted intrusions and volcanic flows of the Absaroka Volcanic Group (Lower–Middle Eocene); the Cathedral Cliffs Formation, Sepulcher Formation, the Lamar River Formation, Mount Wallace Formation, and the Crescent Hill Basalt of the Absaroka Volcanic Supergroup (Lower Eocene); the Wapiti Formation, Trout Peak Trachyandesite, Langford Formation, and Two Ocean Formation of the Absaroka Volcanic Supergroup (Lower–Middle Eocene); the Wiggins Formation of the Absaroka Volcanic Supergroup (Middle Eocene); the gravel of Mount Everts and Heart Lake Conglomerate (Pliocene or Lower Pleistocene); numerous flows, tuffs, and intrusions of the Yellowstone Plateau volcanic field (Pleistocene); and a variety of Quaternary sedimentary rocks and deposits (Pleistocene-Holocene) (YELL Figure 3, Table 3) (USGS 1972, Christiansen et al. 1978).

Most of these formations are fossiliferous within YELL, and the rest, with the exception of the Precambrian metamorphic and igneous rocks and the various Cenozoic intrusive igneous bodies, have some potential for fossils, although it is very unlikely that fossils will be found in the extrusive igneous rocks, which represent lava flows (YELL Figure 4). The fossil record of YELL is one of the most diverse in the NPS (YELL Tables 1, 2, and 3). Fossils are particularly abundant in rocks of the Cambrian (early marine invertebrates), Mississippian–Permian (marine invertebrates), Middle Jurassic (marine invertebrates), Upper Cretaceous (marine and terrestrial fossils), Eocene (plants), and Quaternary (diatoms, spores and pollen, and small mammals), and the fossils of any one of those divisions would make YELL a fossil park of note.

YELL Table 2. Concise tabulation of pre-Cenozoic southern YELL stratigraphy, fossils, and depositional setting; details and references can be found in the text.

Formation	Age	Fossils	Depositional Environment
Pinyon Conglomerate	Late Cretaceous–Paleocene	None to date; palynomorphs and freshwater and terrestrial mollusks are most likely	Fluvial
Harebell Formation	Late Cretaceous	Coal, carbonaceous debris, pollen, angiosperm leaves, plant fragments, bivalves, and the tooth of a tyrannosaurid dinosaur	Fluvial coastal plain to marginal marine
Bacon Ridge Sandstone	Late Cretaceous	Coal, leaves, bivalves, gastropods, and worm tubes	Marginal marine to coastal terrestrial
Cody Shale	Late Cretaceous	Mollusks including bivalves and ammonites	Open marine
Frontier Formation	Late Cretaceous	Ammonites, bivalves, and probably coal	Deltaic, nearshore, and more open marine
Mowry Shale	Late Cretaceous	Fish scales, teeth, and vertebrae	Open marine
Thermopolis Shale	Early Cretaceous	Possible invertebrate traces	Marine, brackish coastal to open
Cloverly Formation	Early Cretaceous	Gastropods and ostracodes	Fluvial, floodplain, and lacustrine settings; marine influence near top
Morrison(?) Formation	Late Jurassic	Bivalves, gastropods, and possible charophytes and ostracodes	Fluvial, floodplain, and lacustrine settings
Sundance Formation	Middle–Late Jurassic	Lower Sundance: bivalves, ammonites, and fossil fragments Upper Sundance: bivalves, belemnites, scaphopods, and crinoids	Primarily shallow marine, occasional tidal flat episodes
Gypsum Spring Formation	Middle Jurassic	None to date; marine invertebrates are most likely	Coastal terrestrial and restricted marine, lower and upper, and open marine middle
Chugwater Formation	Triassic	Possible teeth or plates in the Popo Agie Member (Late Triassic)	Coastal terrestrial to nearshore marine, changing multiple times
Dinwoody Formation	Early Triassic	Brachiopods	Shallow marine
Phosphoria Formation and associated rocks	Early–Middle Permian	Sponge spicules, brachiopods, scaphopods and other mollusks, and bones and teeth of cartilaginous fish, ray-finned fish, and indeterminate fish	Coastal terrestrial to marine basins, changing multiple times
Tensleep Sandstone	Middle–Late Pennsylvanian	None to date; marine microfossils are most likely	Shallow marine to coastal dunes over time
Amsden Formation	Late Mississippian–Middle? Pennsylvanian	*Komia* (an “algae” or sponge), foraminifera, bryozoans, brachiopods, crinoids, and indeterminate echinoderms	Beaches and offshore bars, followed by restricted and shallow marine
Madison Limestone	Early–Middle Mississippian	Horn corals, colonial corals, and brachiopods, along with beds of fossil fragments	Shallow marine
Darby Formation	Late Devonian	None to date; marine invertebrates are most likely	Shallow marine
Bighorn Dolomite	Late Ordovician	Bryozoans, brachiopods, ostracodes, and crinoids	Shallow marine, open and restricted
Gallatin Limestone	Late Cambrian	None to date	Offshore marine
Gros Ventre Formation?	Middle–Late Cambrian	None to date	Offshore marine and tidal flats

YELL Table 3. Concise tabulation of YELL Cenozoic stratigraphy, fossils, and depositional setting; details and references can be found in the text. Intrusive igneous rocks are included here for completeness, but are not discussed in detail in the text because they are unfossiliferous.

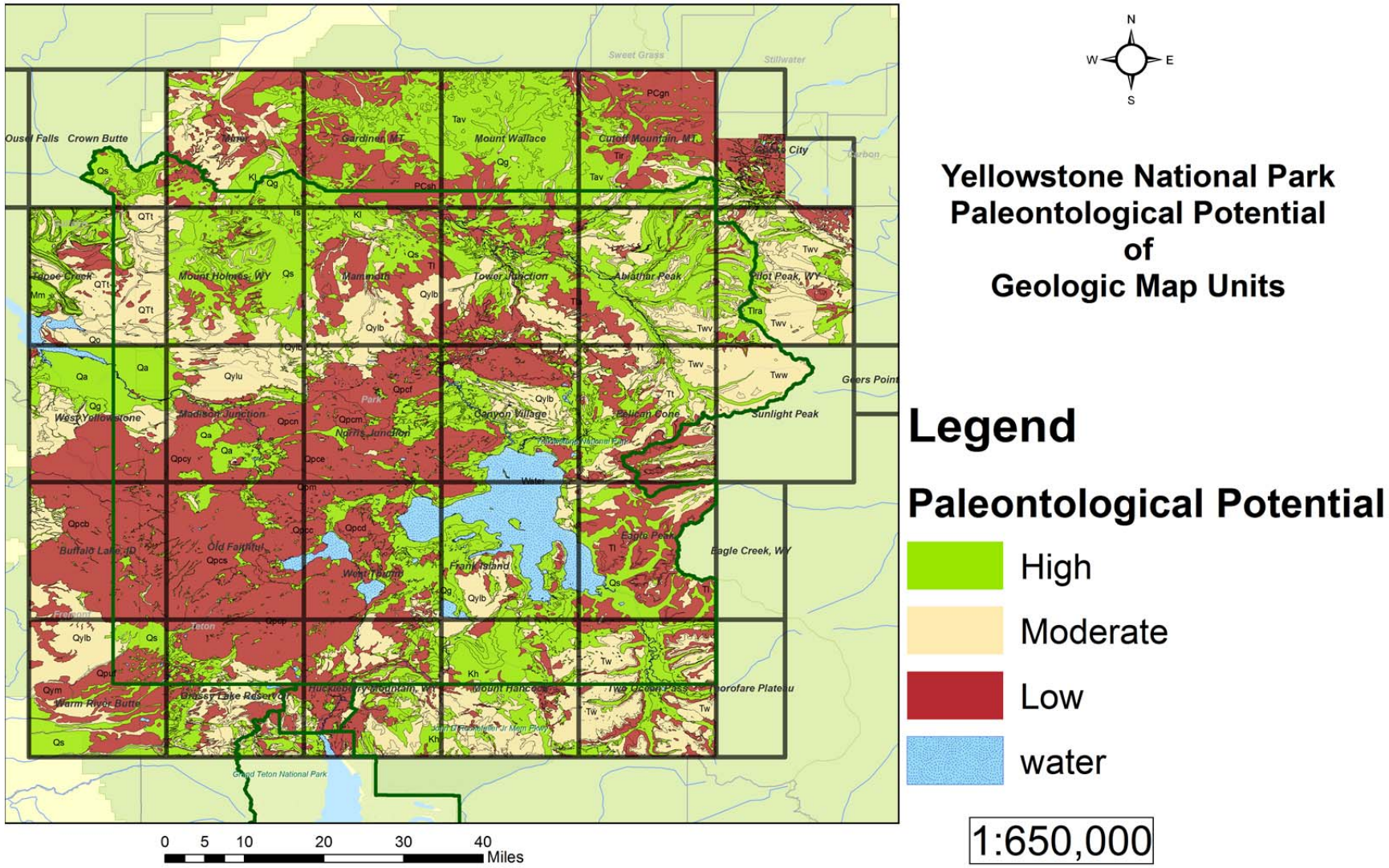
Formation	Age	Fossils	Depositional Environment
Quaternary rocks and sediments, non-Yellowstone Plateau volcanic field	Pleistocene-Holocene	Pleistocene lacustrine sites (Late, Middle, and Early Pleistocene): diatoms, charophyte and chlorophyte algae, peat, moss mats, plant macrofossils such as leaves and twigs (representing spikemosses, quillworts, ferns, conifers, and angiosperms), spores and pollen (representing spikemosses, quillworts, horsetails, ferns, gnetophytes, conifers, and angiosperms), indeterminate plant remains, freshwater bryozoans, and cladocerans Other Pleistocene: wood and fragmentary horse bones Postglacial (latest Pleistocene and Holocene) lacustrine sites: rhizopods, diatoms, peat and gyttja, charophyte and chlorophyte algae, charcoal, bark, wood, stumps, twigs, leaves, needles, and foliage (representing mosses, conifers, angiosperms), angiosperm seeds and fruits, other plant macrofossils, pollen and spores (representing mosses, spikemosses, quillworts, horsetails, ferns, gnetophytes, conifers, and angiosperms), indeterminate plant fossils, freshwater bryozoans, cladocerans, ostracodes, insect fossils such as caterpillar mandibles, unspecified shells, bioturbation, and reworked palynomorphs Hydrothermal deposits, mostly Holocene: microbes, microbial textures, diatoms, fungal molds, and a bird mold Late Holocene packrat sites: charcoal, wood, sticks, cones, other plant fragments, bones of fish, amphibians (including salamanders), reptiles, birds (including grebes, ducks, shorebirds, coots, grouse, and perching birds), and mammals (including shrews, various rodents, rabbits, pikas, bats, canids, felids, mustelids, bears, deer, elk, bighorn sheep, pronghorns, and bison), and packrat middens Holocene fossils from cultural contexts: beaver, mule deer, and other ungulates Other Holocene: plant fragments (some gnawed) associated with beaver ponds Unspecified Quaternary sediments: diatomites, moss mats, bison bones and reworked Eocene petrified wood	Fluvial, alluvial, glacial, hot spring, lacustrine, swamp, landslide, and other terrestrial settings

YELL Table 3. Concise tabulation of YELL Cenozoic stratigraphy, fossils, and depositional setting; details and references can be found in the text. Intrusive igneous rocks are included here for completeness, but are not discussed in detail in the text because they are unfossiliferous (continued).

Formation	Age	Fossils	Depositional Environment
Yellowstone Plateau volcanic field	Pleistocene; intrusions and flows of various ages	Conifer and angiosperm pollen	Ash falls, volcanic flows, and igneous bodies emplaced at depth or volcanic flows
Unnamed sedimentary rocks	Early Pleistocene or Pliocene	Spores and pollen of mosses, spikemosses, conifers, and angiosperms, and possibly logs and other plant macrofossils	Terrestrial deposition, probably fluvial and alluvial
Heart Lake Conglomerate	Early Pleistocene or Pliocene	Reworked Madison Limestone clasts with corals, crinoids, and other fossils	Terrestrial conglomerate and volcanic ash
Gravel of Mount Everts	Early Pleistocene or Pliocene	None to date; reworked petrified wood is most likely	Alluvial channel gravel
Wiggins Formation	Middle Eocene	None to date	Alluvial sediments and volcanic flows
Two Ocean Formation	Early–Middle Eocene	None to date; fossils are unlikely but not impossible	Alluvial sediments and volcanic flows
Langford Formation	Early–Middle Eocene	Fragments of petrified wood and logs, conifer cones, and leaves of the sycamore *Macginitiea*	Alluvial sediments and volcanic flows
Trout Peak Trachyandesite	Early–Middle Eocene	None to date; fossils are unlikely but not impossible	Volcanic flows and minor associated alluvial sediments and ash falls
Wapiti Formation	Early–Middle Eocene	None to date; petrified wood and fragmentary mammalian remains are most likely	Alluvial sediments and volcanic flows
Crescent Hill Basalt	Early Eocene	Unfossiliferous	Volcanic flows
Mount Wallace Formation	Early Eocene	None to date; fossils are unlikely but not impossible	Volcanic flows and associated alluvial sediments
Lamar River Formation	Early Eocene	Macrofossils including foliage, cones, and wood representing ferns, horsetails, conifers, and angiosperms; pollen and spores; and unidentifiable petrified wood and other plant remains	Fluvial, alluvial, mudflow, debris flow, lacustrine, and volcanic airfall deposition closely associated with volcanoes, and some volcanic flows
Sepulcher Formation	Early Eocene	Macrofossils including foliage, nuts, and wood representing ferns, horsetails, conifers, and angiosperms; spores and pollen representing mosses, clubmosses, ferns, conifers, angiosperms, and unknown plants; and unidentifiable petrified wood and other plant remains	Fluvial, alluvial, mudflow, debris flow, lacustrine, and volcanic airfall deposition closely associated with volcanoes, and some volcanic flows
Cathedral Cliffs Formation	Early Eocene	None to date; fossils are rare in this formation	Alluvial sediments closely associated with volcanoes
Unspecified sedimentary rocks of the Absaroka Volcanic Supergroup	Early-Middle Eocene	Carbonized and silicified wood, horsetails, and angiosperms	Alluvial sediments closely associated with volcanoes
Hominy Peak Formation	Early–Middle Eocene	None to date; plant macrofossils and palynomorphs are most likely	Volcanic flows and ash

YELL Table 3. Concise tabulation of YELL Cenozoic stratigraphy, fossils, and depositional setting; details and references can be found in the text. Intrusive igneous rocks are included here for completeness, but are not discussed in detail in the text because they are unfossiliferous (continued).

Formation	Age	Fossils	Depositional Environment
Assorted intrusions and volcanic flows of the Absaroka Volcanic Group	Eocene	Unfossiliferous	Igneous bodies emplaced at depth or volcanic flows



YELL Figure 4. Paleontological potential map for YELL. Green units have yielded fossils somewhere in the park, cream units are potentially fossiliferous, and red units have low fossil potential.

Sources of Paleontological Resources

The fossils of YELL present opportunities for education, interpretation, and scientific research in the park. The oldest formal report of fossils from the area may be Lesquereux (1872), based on material collected by members of the Hayden Survey. Lesquereux (1872, 1878) described plants from the "Laramie Formation" found at "the divide between the source of the Snake River and the southern shores of Yellowstone Lake;" Knowlton (1900) noted that what was thought to be the source of the Snake River is actually a small tributary. This nebulous area includes both Cretaceous and Cenozoic rocks, particularly the Upper Cretaceous Harebell Formation and the Eocene Wiggins Formation, and it is unclear at this time what formation(s) the plants belong to. Two obscure species were named from this area: the fern *Gymnogramma haydenii* (Lesquereux 1872) and the angiosperm *Geonomites schimperi* (Lesquereux 1878).

Holmes (1883) mentioned a number of fossil occurrences in YELL in passing. Provenance information for most of these fossils is limited to a general area and geologic time period. The finds include, in rough stratigraphic order and with some interpretation in brackets: brachiopods (lamp shells) and trilobites southeast of Mount Holmes [possibly a reference to Trilobite Point]; Carboniferous corals and brachiopods in the valley of Indian Creek [probable Madison Group locality]; Carboniferous brachiopods in a sandstone on the east slope of Mount Everts and in Blacktail Deer Creek [lithology suggests the Quadrant Sandstone or Shedhorn Sandstone]; Jurassic brachiopods in the Panther Creek area, Jurassic spiral shells [gastropods or ammonites?] at Electric Peak, and a limy-rich sandstone on Sepulcher Mountain with Jurassic brachiopods, bivalves, and crinoids (sea lilies) [probable Ellis Group localities]; coal found throughout at Mount Everts [Cretaceous]; sandy shales on the mountain with carbonaceous masses, impressions of deciduous leaves, and poorly preserved fruits, and coal shales and sandstones with numerous leaf impressions [Cretaceous]; a bed near the summit of the mountain with small bivalve and gastropod shells of latest Cretaceous or early Cenozoic age, with imperfect leaves found frequently in the same interval [Eagle Sandstone or Everts Formation?]; conifer and angiosperm leaves above the shell interval [Everts Formation?]; and an early description of the fossil forest at Amethyst Mountain [Lamar River Formation].

Stanton (1899) described brachiopods he interpreted as possibly Triassic in age from the summit of Quadrant Mountain. From the map by Iddings and Weed (1899), the rocks of this area were mapped as the Teton Formation, a now-abandoned unit regarded as a synonym of the Phosphoria/Shedhorn interval. Modern maps of the mountain show that the highest elevations are indeed mapped as the Phosphoria/Shedhorn interval, but a secondary prominence of comparable height on the north side also has undivided Triassic rocks, capped by a small area of Ellis Group rocks (Ruppel 1972). Stanton compared the specimens to a Jurassic species, so it seems most likely that they were found on the lower ridge in Ellis Group rocks.

Santucci (1998) mentioned the discovery of fern and angiosperm foliage and dinosaur eggshell from unspecified Cretaceous rocks on Mount Everts. Because practically the entire section on Mount Everts is Upper Cretaceous, the fossils are doubtless Late Cretaceous in

age. The most likely candidates are probably the Eagle Sandstone, Everts Formation, and Landslide Creek Formation, which are the most extensively mapped units on the mountain (Ruppel 1972).

Flathead Sandstone (Middle Cambrian)

The Flathead Sandstone is a sandstone formation found in Idaho, Montana, and Wyoming. It is exposed in the Gallatin Range and Buffalo Plateau areas of northern and northwestern YELL, where it ranges from 37 to 49 m (120 to 160 ft) thick, and is composed of gray to orange or pink quartzitic sandstone in relatively thin beds usually 1 m (3 ft) or less in thickness (Ruppel 1972). This unit does not crop out within southern YELL, but identifiable eroded float can be found in the area of the Fox Creek patrol cabin (Love and Keefer 1975). Early usage of the Flathead name as per Iddings and Weed (1899) in northwestern Wyoming included rocks now assigned to other formations. The former Flathead rocks are now assigned to the Wolsey Shale, Meagher Limestone (or Death Canyon), and Park Shale units (Miller 1936), either as members of the Gros Ventre Formation as seen in the Tetons (Love et al. 1992), or as their own formations, as seen in northern YELL (Ruppel 1972).

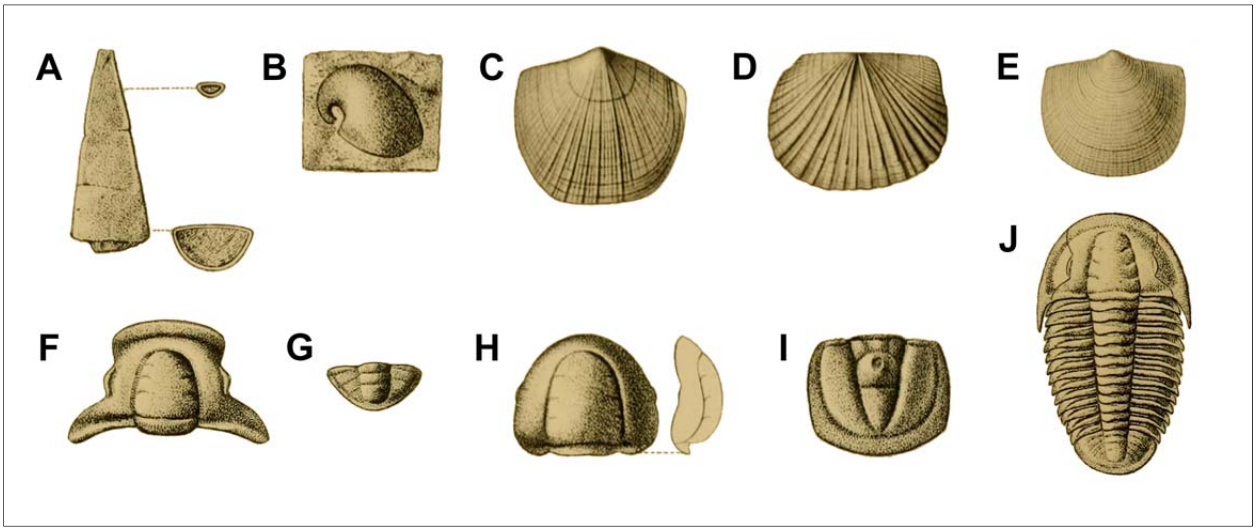
The Flathead Sandstone is thought to date to the Middle Cambrian (Wanless et al. 1955; Love et al. 1992). The formation becomes younger going west to east, because it was deposited during a marine transgression moving from west to east (Bell and Middleton 1978). It represents the first stage of the initial Cambrian transgression of the area. This transgression was not a simple advance, reflected by the presence of depositional hiatuses within the formation (Beebe and Cox 1998). The Flathead Sandstone is a coastal sandstone (Bell and Middleton 1978). Depositional environments include tidal areas, sand flats, beaches, coastal terraces (Bell and Middleton 1978), and fluvial settings (Beebe and Cox 1998).

The Flathead Sandstone overlies Precambrian rocks, with a significant unconformity (Reeves 1964). Although the unconformity represents the loss of billions of years, based on the age of the underlying rocks (Frost et al. 2006, 2011), the contact is even, indicating that the Precambrian rocks had been eroded to a level plain before deposition of the Flathead Sandstone (Wanless et al. 1955, Reeves 1964). The upper contact with the Wolsey Shale is gradational (Hanson 1960).

The Flathead Sandstone is sparsely fossiliferous, but is fossiliferous within YELL. Brachiopods have been found at Crowfoot Ridge (Montana Bureau of Mines and Geology locality 43-1) (Deiss 1936, Ruppel 1972). Overall, including areas outside of YELL, the fossil assemblage of the Flathead Sandstone includes brachiopods (Bell and Middleton 1978), trilobites (Hu 1970), bioturbation (disruption of sedimentary features by biological activity) (Morgan 1998), and burrows, tracks, and other invertebrate trace fossils (Cloud and Beyer 1973), including some unusual large tracks and trails (Boyd 2010). Invertebrate trails and burrows are the only common fossils (Bell and Middleton 1978). Walcott (1897, 1899) attributed a number of fossils to the Flathead Sandstone from YELL, but it is more likely that the majority are actually from the rocks now removed to other, younger formations. These include three species named from fossils found in the park: the archaeocyathid ?sponge *Haguia sphaerica* from below a saddle on a ridge between Pebble and Soda

creeks, on the north side of Soda Creek Butte (Walcott [1899]; the map in Ruppel [1972] shows Upper Cambrian but not Middle Cambrian rocks in this area, so it could be younger), and from the Crowfoot Ridge area the brachiopod *Lingulepis meeki* (Walcott 1897) and the trilobite *Ptychoparia penfieldi* (Walcott 1899). Walcott reported additional trilobites from the Soda Butte Creek site, and additional hyoliths (enigmatic conical forms), brachiopods, and trilobites from the Crowfoot Ridge area (Walcott 1899). Walcott's (1899) *Liostracus parvus*, a trilobite named from unspecified Middle Cambrian rocks on the south side of Pebble Creek, is probably in a similar situation. A selection of Cambrian fossils from YELL is pictured below (YELL Figure 5).

Fitzke and Hale (2003), in an abstract, reported on recent Middle Cambrian finds from Trilobite Point and Trilobite Mountain. They did not provide details on the stratigraphy, but the map in Ruppel (1972) indicates the presence of all four Middle Cambrian formations of northern YELL in that area. Because the Flathead Sandstone is sparsely fossiliferous, most or all of the finds are probably from the Wolsey Shale, Meagher Limestone, and Park Shale. The authors found sponge spicules, hyoliths, brachiopods, trilobites, a piece of a crinoid, and invertebrate trace fossils, from 11 localities.



YELL Figure 5. A selection of Cambrian fossils from YELL, taken from Walcott (1899). **A.** hyolith *Hyolithes primordialis*, flat side and two sections, "Flathead" Formation; **B.** gastropod-like *Platyceras primordialis*, cast of interior shell, "Gallatin" Formation near Soda Butte Creek; **C.** brachiopod *Billingsella coloradoensis*, ventral valve, "Gallatin" Formation of the Gallatin Range; **D.** brachiopod *Orthis*(?) *remnicha*, dorsal valve, "Gallatin" Formation; **E.** brachiopod *Iphidea* sp., "Gallatin" Formation; **F.** trilobite *Ptychoparia penfieldi*, central portion of head, "Flathead" Formation of Crowfoot Ridge; **G.** trilobite *Ptychoparia penfieldi*, pygidium (tail section), "Flathead" Formation of Crowfoot Ridge; **H.** trilobite *Arionellus levis*, central portion of head of type (USNM 35230) and side outline, "Gallatin" Formation of Crowfoot Ridge; **I.** trilobite *Agnostus interstrictus*, pygidium, "Flathead" Formation of the Gallatin Range; **J.** trilobite *Ptychoparia antiquata*, slightly restored, "Flathead" Formation.

Wolsey Shale (Middle Cambrian)

The Wolsey Shale probably has a similar distribution to the Flathead Sandstone in northern and northwestern YELL, but it does not form good outcrops. It primarily consists of greenish gray sandy shale in the park, with some interbeds of limy siltstone and sandstone and sandy limestone. Limestone becomes more prominent higher in the formation, and the contact with the overlying Meagher Limestone is gradational and placed arbitrarily (Ruppel 1972). The formation is 45 m (150 ft) thick at Crowfoot Ridge and thins going east. Early references to the Wolsey Shale in YELL, for example in Iddings and Weed (1899), call it the "Flathead Shale" unit of the Flathead Sandstone (Miller 1936). It is also known as the Wolsey Shale Member of the Gros Ventre Formation, for example in the Teton Range (Love et al. 1992), and is approximately equivalent to the lower shale member of the Gros Ventre Formation as used in the vicinity (Hanson 1960, Ruppel 1972). The Wolsey Shale was deposited during the Middle Cambrian (Ruppel 1972). It is interpreted as a tidal flat unit in the Tetons (Love and Reed 1968).

The Wolsey Shale is fossiliferous within YELL, having yielded invertebrate trails, including at Crowfoot Ridge (Montana Bureau of Mines and Geology locality 43-2) (Deiss 1936). Overall, the fossil assemblage of the Wolsey Shale includes hyoliths, brachiopods, trilobites (Deiss 1936), fossil hash (Lebauer 1964), bioturbation (Morgan 1998), and invertebrate burrows and trails (Lebauer 1964).

Meagher Limestone (Middle Cambrian)

The Meagher Limestone of the YELL region is a mottled gray limestone unit, noted as a cliff-forming formation. It thins substantially from west to east, being 135 m (450 ft) thick in the Madison Range west of the park, 118 m (388 ft) thick on Crowfoot Ridge, and 55 to 60 m (175 to 200 ft) thick on Buffalo Plateau and near Buffalo and Slough creeks. Like the other Middle Cambrian units, it is found in the Gallatin Range and Buffalo Plateau regions of the park. The upper part of the formation in the Gallatin Range within YELL has a unique sand- and lime-rich shale unit 3 m (10 ft) thick (Ruppel 1972). The upper contact with the Park Shale is intertonguing (Tysdal 1976). Early references to the Meagher Limestone in YELL, for example in Iddings and Weed (1899), call it the "Trilobite Limestone" unit of the Flathead Sandstone (Miller 1936). It becomes the Death Canyon Limestone Member of the Gros Ventre Formation elsewhere, and transitions to shale east of YELL (Hanson 1960). The Meagher Limestone is another Middle Cambrian unit (Ruppel 1972). Equivalent rocks in the Tetons are interpreted as having been deposited in offshore marine setting in clear water (Love and Reed 1968).

The Meagher Limestone is fossiliferous within YELL. Resser named three species of trilobites from the formation in the park: *Ehmania walcotti*, *Ehmania weedi* (Resser 1935), and *Zacanthoides weedi* (Resser 1937). At Crowfoot Ridge, Bell (1941) found brachiopods and Deiss (1936) found trilobites (Montana Bureau of Mines and Geology localities 43-3 and 43-3a), and brachiopods were found near the ridge at National Museum of Natural History (USNM) locality 302b (Bell 1941). The Meagher Limestone of the Tepee Creek Quadrangle, including part of western YELL, has brachiopods and trilobites (Witkind 1969). The fossil assemblage of the Meagher Limestone includes microbial structures, calcispheres (Lebauer 1965),

possible calcareous algae (Kauffman 1975), sponge spicules, hyoliths, brachiopods, trilobites, echinoderm plates (Lebauer 1965), undetermined conical fossils (Kauffman 1975), invertebrate burrows, and fecal pellets, with fossils concentrated in the lower part of the formation (Lebauer 1965).

Park Shale (Middle Cambrian)

The Park Shale of the YELL area is similar to the Wolsey Shale (Hanson 1960), and like it, is poorly exposed in the park (Ruppel 1972). It is mostly composed of grayish green shale and mudstone. Within the park, it is about 37 to 30 m (120 to 100 ft) thick (Ruppel 1972). The upper contact with the Pilgrim Limestone is conformable in the park (Ruppel 1972), but this may differ elsewhere; in the Ruby Range to the west of YELL, the upper contact may be unconformable (Tysdal 1976). Early references to the Park Shale in YELL, for example in Iddings and Weed (1899), call it the "*Obolella* [a brachiopod] Shale" unit of the Flathead Sandstone (Miller 1936). It is also known as the Park Shale Member of the Gros Ventre Formation, for example in the Teton Range (Love et al. 1992), and is approximately equivalent to the upper shale member of the Gros Ventre Formation as used in the vicinity (Hanson 1960). The Park Shale is the youngest Middle Cambrian unit of the area (Ruppel 1972), and the Middle–Late Cambrian boundary is probably near the Park Shale–Pilgrim Limestone contact (Hanson 1960). It is interpreted as a tidal flat unit in the Tetons (Love and Reed 1968), representing a relatively brief period of shoaling before further marine transgression (Witkind 1969)

The Park Shale is fossiliferous within YELL, but there is little specificity about its fossils. Fossiliferous lenses are present on Crowfoot Ridge (Montana Bureau of Mines and Geology locality 44-2) (Deiss 1936), and it includes rocks described as "limestone coquina" in YELL (Ruppel 1972), including in the Abiathar Peak quadrangle (Prostka et al. 1975a); "coquina" is usually reserved for a rock that is primarily composed of shell fragments, which implies the presence of fossils. The Park Shale of the Tepee Creek Quadrangle, including part of western YELL, has brachiopods and trilobites (Witkind 1969). The name first used for the Park Shale, the "*Obolella*" Shale, implies that brachiopods are a noteworthy component of the formation. Overall, the fossil assemblage of the Park Shale includes microbial mats, laminations, and filaments (Blackwell et al. 1983), microbial buildups (DeBoer and Middleton 1981), brachiopods (Bell 1941), trilobites (Schwimmer 1975), echinoderm fragments (Martin et al. 1980), and invertebrate burrows (Miller 1936).

Pilgrim Limestone (Upper Cambrian)

The Pilgrim Limestone is a cliff-forming light gay limestone unit that can be found across northern YELL. It consists of three divisions: "a lower unit of interbedded ribboned limestone, oolitic limestone, and less common limestone conglomerate and shale," "a middle unit of limestone pebble conglomerate," and "an upper unit of mottled oolitic limestone." Fossil fragments are noted in the lower and middle units. The upper unit represents Iddings and Weed's (1899) "mottled limestone" of the Gallatin Formation. The thickness of the formation in the park is at least 52 m (172 ft) (Ruppel 1972). It is sometimes denoted as the Pilgrim Limestone Member of the Gallatin Limestone (Miller 1936). The Maurice Formation, as used for example in Brown (1959), is a deprecated synonym of the Pilgrim Limestone (Lochman-Balk 1956). Another name sometimes used for

this interval is the Du Noir Limestone (Miller 1936). The Pilgrim Limestone dates to the Late Cambrian, and the contact with the overlying Snowy Range Formation is conformable within YELL (Ruppel 1972). Deposition occurred in a shallow marine setting (Lochman and Duncan 1944), under deeper water than the Park Shale (Witkind 1969).

The Pilgrim Limestone is fossiliferous within YELL, with an assemblage including the enigmatic *Chancelloria* (an extinct sponge-like animal), hyoliths, brachiopods, trilobites, and conodonts (extinct eel-like chordates). One of Walcott's (1899) trilobites, *Solenopleura? weedi*, is now attributed to the Pilgrim Limestone. Deiss (1936) reported brachiopods and trilobites from Crowfoot Ridge (Montana Bureau of Mines and Geology locality 44-1). Lochman and Duncan (1944), using the Maurice Formation name, further described the trilobites of the 44-1 locality, finding examples of the Cedaria and overlying *Crepicephalus* trilobite biozones and naming *Maryvillia aequa* and *Modocia yellowstonensis* from the site. Resser named three species of trilobites from the formation in the park: *Tricrepicephalus yellowstonensis* (Resser 1937), *Blountia polita* (Resser 1938), and *Semnocephalus minor* (Resser 1942a). Witkind (1969) reported fossils from two localities in western YELL within the Tepee Creek quadrangle: 3824-CO yielded *Chancelloria*, hyoliths, brachiopods, trilobites, and conodonts, and 3825-CO yielded Chancelloria, hyoliths, and trilobites. Ruppel (1972) noted that trilobite fragments are abundant in some beds of the lower unit, and that the middle unit is also fossiliferous. Abundant trilobite fragments are present at Three River Peak (Ruppel 1972). Finally, Koch and Santucci (2003) reported that Fitzke and Hale were preparing a report on brachiopod and trilobite hash from the formation at Trilobite Point.

Overall, the fossil assemblage of the Pilgrim Limestone includes various microbial structures, up to mounds and reefs in size (Breuninger 2000), calcareous algae (Lochman and Duncan 1944), possible corals (Fritz and Howell 1955), sponge spicules, chancellorids, hyoliths (Bonem 1972), enigmatic shelled *Hypseloconus* and *Kinsabia* (Lochman and Duncan 1944), brachiopods (Bonem 1972), monoplacophorans (cap-shelled mollusks) (Breuninger 2000), trilobite-like aglaspid arthropods (Lochman and Duncan 1944), trilobites, eocrinoids (early stalked echinoderms) (Bonem 1972), fragments of other echinoderms (Lochman and Duncan 1944), conodonts (Witkind 1969), and invertebrate burrows (Breuninger 2000).

Snowy Range Formation (Upper Cambrian)

The Snowy Range Formation is found in the northern boundary area of YELL. Up to three members can be distinguished in the park. At the base is the Dry Creek Shale Member, a shale unit 12 to 15 m (40 to 50 ft) thick. Above this is the Sage Limestone Member, and then locally the Grove Creek Limestone Member, recognized only at Three Rivers Peak in the park. The latter two units vary in thickness due to erosion during the Ordovician (Ruppel 1972). The rocks now classified as the Snowy Range Formation are historically entangled with Devonian rocks, which created substantial confusion in the literature. Briefly, the Dry Creek Shale was described by two authors from multiple sections which were thought to be Cambrian in age, but one of the descriptions relied on what were later shown to be Devonian rocks. An additional unit, the Yogo Formation, was introduced above the

Dry Creek Shale at the Devonian section and used as a Cambrian unit. The Devonian "Dry Creek Shale" and true "Yogo" are actually part of the Devonian Maywood Formation, a unit that is another story in its own right. When this was recognized, the Dry Creek Shale name was redefined to fit the Cambrian interval it had been intended for, and Cambrian rocks called the "Yogo" were named the Sage Limestone Member (Lochman 1950). Another formation name sometimes employed in YELL for the Snowy Range interval is the Open Door Formation, as used by Saltzman et al. (1995) and Saltzman (1998, 1999) for the rocks above the Dry Creek Shale Member. Saltzman et al. (1995) and Saltzman (1999) interpreted the two as representing different depositional environments, with the Open Door Formation as shoal environments and the Snowy Range Formation as basin deposits on a shelf, to the northeast of northwestern Wyoming. Deposition in YELL began in an "algal" reef and shoaling portion of the formation, followed by a lowstand and then deeper basinal and ramp deposition (Saltzman et al. 1995). Water depth was probably at the most a few tens of meters (Grant 1965, Myrow et al. 2004). The Snowy Range Formation is usually described as Late Cambrian in age (Ruppel 1972), but the Grove Creek Member may include the Cambrian–Ordovician boundary (McLaughlin 1998). The upper contact with the Bighorn Dolomite is disconformable (Ruppel 1972).

All three members of the Snowy Range Formation of YELL are fossiliferous, yielding an assemblage of stromatolites (layered sedimentary structures created by algae and microbes), "algal" limestone, sponge spicules, hyoliths, brachiopods, helcionelloid mollusks (extinct forms with coiled conical shells), possible gastropods, trilobites, crinoids, invertebrate trails, and possible invertebrate egg cases. At least 11 taxa have been named from fossils found in this formation in the park: the hyolith *Hyolithes gallatinensis* (Resser 1938); the brachiopods *Angulotreta vescula* (Grant 1965), *Billingsella perfecta pyriformis* (Bell 1941), *Dicellomus mosaica* (Bell 1941), *Billingsella radiata* (Bell 1941), *Billingsella exasperata* (Bell 1941), and *Ocnerorthis monticola* (Bell 1941); and the trilobites *Idahoia wyomingensis* (Resser 1937), *Taenicephalus holmesi* (Resser 1942b), *Taenicephalus speciosus* (Resser 1942b), and *Wilbernia walcotti* (Resser 1937).

Deiss (1936) and Bell (1941) both discussed fossils from Montana Bureau of Mines and Geology locality 44-2 on Crowfoot Ridge. This site is reported as the Dry Creek Shale, but because the thickness exceeds what is reported by Ruppel (1972), and because no units are differentiated above it, there is the possibility that the Sage Limestone Member is involved. Deiss (1936) reported the presence of brachiopods, trilobites, crinoids, and invertebrate trails. Bell (1941) reported on the site's brachiopods, and also discussed the brachiopods from several other "Dry Creek Shale" localities in the park, at the head of Deep Creek (USNM locality 4j), on Abiathar Mountain (USNM 62r), on Soda Butte Creek (USNM 151e), near Crowfoot Ridge (USNM 302b), in Gallatin Valley (USNM 302c), on the north side of Elk Pass (USNM 302f), and on the north slope of Crowfoot Ridge (USNM 302g). Aside from the above, which are reported from the Dry Creek Shale but might not be, trilobite fragments can be found in the Dry Creek Shale Member at Three Rivers Peak (Ruppel 1972).

The Sage Limestone Member of YELL is particularly fossiliferous, with some beds that can be described as coquinas. A basal layer with "algal" columns (*Collenia magna*) is present in the park in the Buffalo Plateau and other areas in the northeast, but is not present in the Gallatin Range in northwestern YELL. At Three Rivers Peak, the member includes abundant brachiopods as well as fossils of trilobites and the gastropod-like shelled organisms *Pelagiella* (a helcionelloid mollusk) and *Scaevogyra* (possibly a gastropod) (Ruppel 1972). At Crowfoot Ridge, Grant (1965) found sponge spicules, brachiopods, *Pelagiella*, trilobites, crinoids, and phosphatic balls that may be egg cases of the gastropod-like enigmatic animal *Sinuella*. Saltzman (1998, 1999) reported fossils from the Open Door Formation in YELL. Because the Dry Creek Shale was considered distinct in these publications, the reports probably correspond to the Sage Limestone Member. Saltzman (1998) reported trilobites from Crowfoot Ridge and Three Rivers Peak, and Saltzman (1999) reported brachiopods, trilobites, and invertebrate burrows from Three Rivers Peak. The trilobite assemblages possibly show evidence of two of the three Late Cambrian trilobite mass extinctions (Saltzman 1998). Finally, the Grove Creek Limestone Member includes "algal" limestone and fragments of brachiopods and trilobites at Three Rivers Peak (Ruppel 1972). In addition to the finds assigned to members, Witkind (1969), working in the Tepee Creek quadrangle, reported brachiopods and trilobites from the Snowy Range Formation at locality 3826-CO in YELL, and noted that this locality had the best assemblage in the quadrangle.

A variety of fossils have been described from the Snowy Range Formation over its entire depositional area. Fossils that have been attributed to the Dry Creek Shale Member include brachiopods, trilobites, crinoids, and invertebrate trails (Deiss 1936). Fossils from the Sage Limestone Member include stromatolites, sponge spicules, hyoliths, brachiopods, *Pelagiella*, the possible gastropod *Lytospira*, trilobites, crinoids, conodonts, and possible invertebrate egg cases (Grant 1965). Fossils from the Grove Creek Member include "algal" limestone, brachiopods, trilobites (Witkind 1969), bradoriid arthropods (extinct ostracode [seed shrimp]-like crustaceans) (Howell 1963), crinoids, graptolites (extinct colonial animals possibly related to the chordates) (Grant 1965), conodonts (McLaughlin 1998), and indeterminate fossils (Grant 1965). Fossils not previously listed, and described without assignment to member, include thrombolites (clotted microbial structures) (Myrow et al. 2012), conical spongiomorph algae (Brett et al. 1983), possible fragments of aglaspidan arthropods (Grant 1965), and echinoderms that may represent cystoids (extinct relatives of crinoids) (Lochman and Hu 1960) and echinoids (sea urchins) (Saltzman 1999)

Bighorn Dolomite (Upper Ordovician)

The Bighorn Dolomite is a widespread formation of the GRYN and vicinity. It is sometimes divisible into multiple members (Zenger 1992, Holland and Patzowsky 2012), but this has not been done at YELL. It is exposed in northern YELL (Ruppel 1972). In southern YELL, it has been mapped undivided with the Gallatin Formation in the Birch Hills (Christiansen et al. 1978), and eroded boulders that derived from the formation have been found in the area of the Fox Creek patrol cabin (Love and Keefer 1975). It is primarily composed of light brownish gray dolomite, thinner-bedded in the west than in the east. It ranges from 30 to 60 m (100 to 200 ft) thick

(Ruppel 1972). The upper contact with Devonian rocks is disconformable, with either the Darby Formation in the south (Wanless et al. 1955) or the Jefferson Formation in the north (Ruppel 1972), and there are also sometimes internal unconformities (Scott and Asquith 1972, Holland and Patzowsky 2012). Rocks assigned to the Maywood Formation in western YELL by Grant (1965) are more likely part of the Bighorn Dolomite (Witkind 1969).

The Bighorn Dolomite is a marine formation, dominated by open marine shallow subtidal deposits. The lower part of the formation is interpreted as representing primarily shallow subtidal marine deposition, becoming shallower near the top of the sequence. Above this, there is a restricted marine unit, and then a return to open marine conditions (Holland and Patzowsky 2012). Deposition occurred during the Late Ordovician, approximately 450 to 446 Ma (Holland and Patzowsky 2012).

The Bighorn Dolomite is fossiliferous within YELL, but not as fossiliferous as the preceding Cambrian units. An E&R report submitted by R. J. Ross, Jr. in 1957 reported poorly preserved fossils of a trilobite, an orthoconic (straight-shelled) cephalopod (probably a nautiloid), and a possible bryozoan (moss animal) from Meridian Peak. Ruppel (1972) reported receptaculitid corals (now classified as probable chlorophyte algae) from Three Rivers Peak. Finally, Santucci (1998) reported that bryozoans, brachiopods, ostracodes, and crinoids had been found in the park.

Overall, the fossil assemblage of the Bighorn Dolomite includes dasycladacean algae, stromatoporoid sponges, corals, bryozoans, brachiopods, bivalves, nautiloid cephalopods, gastropods, trilobites, ostracodes, crinoids (Holland and Patzowsky 2009, 2012), cystoids (Macomber 1970), graptolites (Scott and Asquith 1972), conodonts, general bioturbation, and invertebrate trace fossils including burrows (Holland and Patzowsky 2009, 2012).

Jefferson Formation (Upper Devonian)

The Jefferson Formation is exposed in the Gallatin Range and northeastern parts of YELL. The Jefferson Formation in the Gallatin Range section of the park is a brownish or grayish unit that includes two members or their equivalents: the unnamed shaly lower member and the overlying dolomitic Birdbear Member of Sandberg (1965). In northeastern YELL, the formation is pale brown to yellowish brown and composed of dolomite and dolomitic limestone. The formation thickens from west to east across the park, from 73 to 53 m (240 to 175 ft) thick. The contact with the overlying Three Forks Formation is conformable (Ruppel 1972). Early reports from the park gave the Jefferson Formation a Silurian age (Iddings and Weed 1899), but fossils indicate a Late Devonian age (Frasnian, approximately 383 to 372 Ma) (Weigner and Isaacson 2012).

The Jefferson Formation is a marine unit (Sandberg 1965), deposited during a marine transgression from the west (Witkind 1969). The deposition of the lower member of the Jefferson Formation occurred in a variety of settings, giving it a heterogeneous lithology (Sandberg 1965). A relative high called the Yellowstone Park Uplift was present in the YELL area during deposition, and was probably emergent for part of the deposition of the lower member (Mapel and Sandberg 1968).

The Jefferson Formation is not notably fossiliferous, but is fossiliferous within YELL. Iddings and Weed (1899) recognized gastropods in the formation at Crowfoot Ridge. Witkind (1969) reported a fossiliferous locality in the Tepee Creek quadrangle (locality 402), but did not explicitly identify what fossils were found there, except that the material includes at least one of the two forms of stromatoporoid sponges and four forms of corals that are present in the quadrangle. Benson (1966) found mat-like algae and corals in the lower member of the Jefferson Formation at Crowfoot Ridge. Ruppel (1972), describing a section at Three Rivers Peak, found stromatoporoid sponges and small horn corals near the base of the formation, and fossil fragments and stromatoporoids higher. Ruppel also mentioned two collections from the formation: locality USGS 7567-SD at the head of the Gallatin River Valley had stromatoporoid sponges and corals, and USGS 8141-SD at Crowfoot Ridge had corals.

The Jefferson Formation is found in several states and has multiple members, most of which are found elsewhere, so it was thought most useful to restrict the following accounting of fossils to the vicinity of YELL, and members present in the park. With these restrictions, the fossil assemblage of the Jefferson Formation includes stromatolites and other microbial structures (Benson 1966), foraminifera (amoeba-like protists that form "shells") (Dorobek and Smith 1989), plant debris, stromatoporoid sponges, corals, brachiopods (Benson 1966), gastropods, trilobites (Kindle 1908), crinoids (Dorobek and Smith 1989), conodonts (Benson 1966), bioturbation (Dorobek and Smith 1989), and fish remains (Benson 1966).

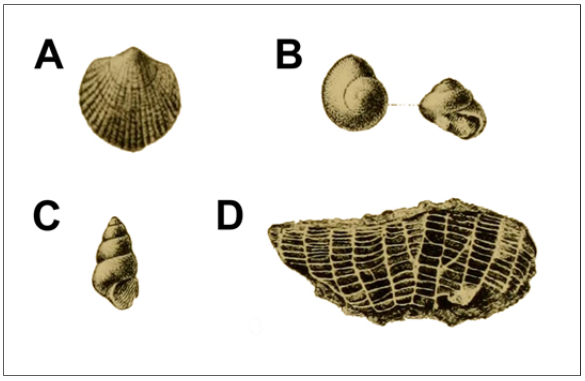
Three Forks Formation (Upper Devonian)

The Three Forks Formation, like the underlying Jefferson Formation, is found in the Gallatin Range and northeastern regions of YELL, and has different lithologies in the two areas. The Three Forks Formation of the Gallatin Range is thought to be equivalent to the Logan Gulch Member, and includes a 9 to 11 m (30 to 35 ft) thick interval of olive mudstone that weathers orange, and an overlying 14 to 15 m (45 to 50 ft) thick interval of gray dolomite. In the northeast part of the park, the formation is divisible into lower shale (15 m/50 ft thick), middle limestone (9 m/30 ft), and upper shale units (15 m/50 ft). The two lower units are thought to be equivalent to the Logan Gulch Member, and the upper unit is thought to be equivalent to the Trident Member. The upper contact with the Madison Group looks conformable, but is probably disconformable because of the absence of intervening units (Ruppel 1972).

The Three Forks Formation includes restricted marine and evaporite deposition near the bottom of the section (Logan Gulch Member), shallow open marine deposition in the middle (Trident Member), and regressive marginal marine deposition near the top, in rocks not present at YELL. A regression following the deposition of the middle portion gives an internal disconformity with the overlying rocks (Sandberg 1965). It dates to the Late Devonian; middle Famennian? fossils are present in the Logan Gulch Member (approximately 365 Ma) (Tysdal 1976).

The Three Forks Formation is fossiliferous within YELL. Three taxa have been named from the formation within YELL: the brachiopod *Athyris vittata* var. *triplicata* and the gastropods *Loxonema delicatum* and *Platystoma minutum* (Girty 1899). Girty

(1899) reported fossils from the Bighorn Pass and Antler Peak areas of the northwest corner and the Abiathar Peak and Soda Butte Creek areas of the northeast corner, including stromatoporoid sponges, horn and tabulate corals, brachiopods, and gastropods. Ruppel (1972) found fossiliferous limestone beds in the upper shale unit of the northeast region, and Prostka et al. (1975a) described the Trident equivalent as fossiliferous in the Abiathar Peak quadrangle. A selection of fossils from the Three Forks Formation of YELL is pictured in YELL Figure 6.



YELL Figure 6. A selection of fossils from the Three Forks Formation of YELL, taken from Girty (1899). **A.** brachiopod *Atrypa reticularia*, typical of YELL; **B.** gastropod *Platystoma minutum*, apical and lateral views of type specimen (USNM 34129), south side of Soda Butte Creek; **C.** gastropod *Loxonema delicatum*, type specimen (USNM 34127), south side of Soda Butte Creek; **D.** tabulate coral *Favosites* sp., north side of Soda Butte Creek.

The two members of the Three Forks Formation thought to be present at YELL are not especially fossiliferous. Over their entire depositional areas, the Logan Gulch Member has yielded brachiopods (Tysdal 1976) and the Trident Member has yielded algal filaments, bryozoans, brachiopods, bivalves, cephalopods, gastropods (Sartenaer and Sandberg 1974), crinoids (Webster and Fox 1986), conodonts, invertebrate trails, and fish bones (Sartenaer and Sandberg 1974).

Madison Limestone/Group (Lower–Middle Mississippian)

The Madison Limestone or Group is a widely distributed limestone unit in the GRYN and nearby areas. It is exposed in several areas of the park: in the Birch Hills (Christiansen et al. 1978), in the Two Ocean Plateau area, between the South Entrance and Yellowstone Lake (Love and Keefer 1975), in the northeast corner (particularly along Soda Butte Creek), isolated areas north of Blacktail Deer Plateau, and extensively in the northwest corner (Ruppel 1972). In southern YELL, the interval is known as the Madison Limestone, and is approximately 330 m (1,100 ft) thick. It consists of white, gray, and blue-gray limestone, and minor amounts of dolomite, shale, and chert, with abundant fossils (Love and Keefer 1975). In northern YELL, the interval is known as the Madison Group and includes two formations: the Lodgepole Limestone and overlying Mission Canyon Limestone. The Lodgepole Limestone is a limestone unit of pale brown, yellow, and gray beds, with some chert. It is noted for its thin beds, which are separated by thin partings of limy siltstone and silty limestone; this lithological variation produces ledges. In the northwest area of the park, it is about 150 m (485 ft) thick, but it becomes thicker to the east, reaching thicknesses of at least 170 to 185 m (550 to 600 ft) near the Northeast Entrance. The Mission Canyon Limestone is thick-bedded and lacks the thin partings of the Lodgepole Limestone, and thus forms prominent cliffs. It is mostly composed of gray limestone; a quarter of the formation is dolomite or dolomitic, and chert is also common. Dolomitic beds form prominent markers. It can be over 245 m (800 ft) thick in

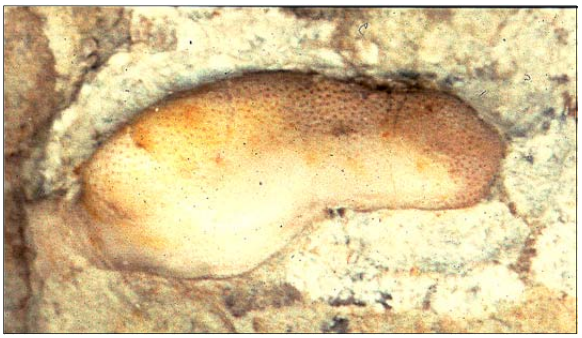
the park. Both formations have coarse-grained beds that are made up mostly of fossils (Ruppel 1972).

The rocks of the Madison Limestone are of marine origin, and record a marine transgression moving rapidly west to east (Gutschick et al. 1976). The Lodgepole Limestone is thought to represent more open marine conditions, and the Mission Canyon Limestone more restricted marine conditions (Sando 1977). Sea-level fluctuations during Mission Canyon time led to occasional periods of evaporitic conditions, but overall the sea was transgressing (Gutschick et al. 1976). The sea departed after deposition of the Mission Canyon Limestone, leading to subaerial exposure with large river systems cutting across the former marine deposits, and the formation of an early generation of voids and caves (Sando 1988). Karst and cave formation resumed more recently, and today most of the karst in the Tetons to the south is in the Mission Canyon Limestone, with some in the Lodgepole Limestone as well (Medville et al. 1979).

Deposition of the Madison Limestone occurred during the Mississippian. The Lodgepole Limestone is Kinderhookian to Osagean (348 to 340 Ma) in age (Stanley and Burke 2000) and the Mission Canyon Limestone is Osagean to early Meramecian (340 to approximately 335 Ma) in age (Smith and Dorobek 1993). There can be internal disconformities (Strickland 1956), and the upper contact with the Amsden Formation is disconformable in the area (Wanless et al. 1955, Ruppel 1972). The depositional hiatus is longer going eastward, reflecting the west to east transgression of the sea that deposited the overlying rocks (Palmer and Palmer 1995).

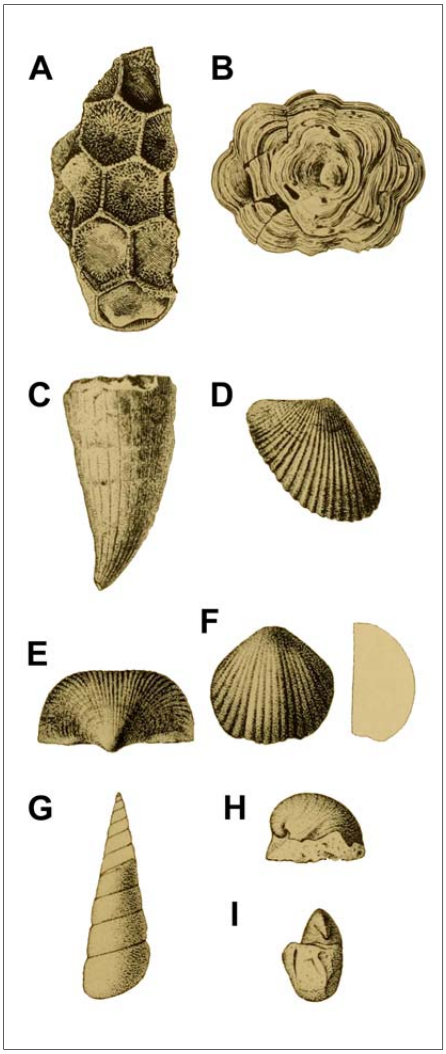
The Madison Limestone or Group is abundantly fossiliferous, and this is true in YELL. Fossils common in the Madison Limestone of southern YELL include horn corals, colonial corals, and brachiopods (Love and Keefer 1975). The fossils of the Madison Group in northern YELL have described in much greater detail. Both of its formations are abundantly fossiliferous, with some beds almost entirely made of fossils or fossil fragments. Common fossils in the Lodgepole Limestone in the park include corals, brachiopods, and crinoids, and common fossils in the Mission Canyon Limestone include corals and brachiopods. Girty (1899) provided a biostratigraphic assessment of the Madison Group in YELL based on Crowfoot Ridge; however, Ruppel (1972) noted that part of the Madison Group section from Crowfoot Ridge used by Iddings and Weed (1899) and Girty (1899) is repeated by a fault. Specifically, the Lodgepole Limestone appears to represent beds 24 through 28 and part of 31, and the Mission Canyon Limestone appears to represent beds 29, 30, part of 31, and 32. In hindsight, fossils described by Girty that can be attributed to the Lodgepole Limestone in YELL include sponges, corals, bryozoans, brachiopods, rostroconchs (extinct bivalved mollusks), gastropods, trilobites, and crinoids, and fossils attributable to the Mission Canyon Limestone include foraminifera, corals, bryozoans, brachiopods, gastropods, trilobites, and crinoids. Girty named a number of taxa from the Madison Group in the park, including the sponge *Holasterella wrighti* var. *americana*, the tabulate corals *Aulopora geometrica*, *Clisiophyllum teres*, *Menophyllum? excavatum*, *Syringopora aculeata*, and *Syringopora surcularia*, and the brachiopods *Camarotoechia herrickana*, *Cliothyris crassicardinalis* var. *nana*,

Liorhynchus haguei, *Martinia rostrata*, *Productella alifera*, *Productus gallatinensis*, *Productus parviformis*, *Seminula humilis*, *Seminula immatura*, *Spirifer centronatus* var. *semifurcatus*, and *Spirifer striatus* var. *madisonensis*. Additional collections of the same varieties of fossils are detailed in Witkind (1969) and Ruppel (1972). Vertebrates are also present; a tooth plate of a cochliodont, a type of cartilaginous fish, was found in the Madison Group in 1997 (Santucci 1998) (YELL Figure 7). In general, any exposure of the Madison Limestone or Group in YELL should be regarded as potentially fossiliferous. A selection of fossils from the Madison Limestone or Group in YELL is pictured in YELL Figure 8.



YELL Figure 7. A tooth of a cochliodont fish from near Pebble Creek, found in 1997 (VLS).

Overall, including areas outside of YELL, the Lodgepole Limestone has a fossil assemblage including possible microbial structures (Moore 1973), calcispheres (Gutschick et al. 1976), foraminifera (Gutschick et al. 1961), sponges (Gutschick 1966, Gutschick et al. 1976), conulatans (extinct coral relatives that formed pyramidal structures from rods) (Tysdal 1976), corals, bryozoans (Sando and Dutro 1974), brachiopods (Rodriguez and Gutschick 1968), microconchid tentaculitid ?mollusks (formerly identified as spirobid worm tubes; Witkind 1969), rostroconchs (Girty 1899), bivalves (Chen and Webster 1994), ammonites



YELL Figure 8. A selection of fossils from the Madison Limestone/Group of YELL, taken from Girty (1899). **A.** tabulate coral *Michelinia placenta*, view of cells, from west of Electric Peak; **B.** *Michelinia placenta*, lower surface, from between Gallatin River and Panther Creek; **C.** rugose coral *Menophyllum*(?) *excavatum*, from Crowfoot Ridge; **D.** rostroconch *Conocardium pulchellum*(?), from Crowfoot Ridge; **E.** brachiopod *Productus semireticulatus*, posterior view of ventral valve, Crowfoot Ridge; **F.** brachiopod *Camarotoechia* sp., dorsal valve, from south side of Soda Butte Creek; **G.** gastropod *Loxonoma*(?) sp., lateral view of internal cast; **H.** gastropod *Platyceras* form E, lateral view, from between Gallatin River and Panther Creek; **I.** gastropod *Platyceras* form E, posterior view, from between Gallatin River and Panther Creek.

(Stanley and Burke 2000), gastropods (Sando and Dutro 1974), trilobites (Stanley and Burke 2000), ostracodes, blastoids (sea buds), crinoids (Rodriguez and Gutschick 1968), echinoids (Smith 1982), holothurians (sea cucumbers), conodonts (Gutschick 1966; Gutschick et al. 1961), indeterminate spicules (needle-like skeletal structures), invertebrate burrows (Smith 1982), and fragmentary fish remains (Gutschick et al. 1961; Gutschick and Lamborn 1975). The Mission Canyon Limestone has yielded stromatolites, oncolites, calcispheres, foraminifera, "phylloid" algae, red algae, dasycladacean algae (Vice and Utgaard 1989), fragments of *Lepidodendron* and other land plants (Houlik 1973), sponges, corals, bryozoans, brachiopods, bivalves, gastropods, ostracodes, trilobites, crinoids, conodonts, and invertebrate pellets and burrows (Vice and Utgaard 1989).

Amsden Formation (Upper Mississippian–Middle? Pennsylvanian)

The Amsden Formation is a heterogeneous unit. It can be found in YELL in the Birch Hills area (Christiansen et al. 1978), in the Two Ocean Plateau area, between the South Entrance and Yellowstone Lake (Love and Keefer 1975), and in the northwest corner of the park (Ruppel 1972). The Amsden Formation was not recognized from YELL during the early geological work; instead, the Quadrant Sandstone was given the entire section between the Madison Group below and the Teton Formation (now in part the Shedhorn Sandstone) above. Later, once a distinct second unit had been recognized in the "Quadrant" interval, it was sometimes identified as the problematic Sacajawea Formation (Ruppel 1972). In YELL, the northern and southern outcrops of the Amsden Formation have distinct lithologies. The Amsden Formation of northern YELL is typically 6 to 15 m (20 to 50 ft) thick and includes a reddish or orange mudstone, siltstone, and shale unit with interbedded limy sandstone, and an overlying reddish limy to dolomitic siltstone unit. The contact with the overlying Quadrant Formation is disconformable (Ruppel 1972). In southern YELL, it can be 70 m (230 ft) thick and includes a tan, gray, or red sandstone unit at the base, known as the Darwin Sandstone Member, and an overlying shale and carbonate unit. The contact with the overlying Tensleep Sandstone is gradational (Love and Keefer 1975), and the two formations can be difficult to distinguish (Fisher 1963).

The Amsden Formation can be divided into several members depending on location, although the only formal member reported from YELL is the Darwin Sandstone Member, and that has only been reported from the southern part of the park (Love and Keefer 1975). The Darwin Sandstone Member is interpreted as mostly beach and offshore bar deposition following a marine transgression. Overlying members were typically deposited in shallow or restricted marine settings (Sando et al. 1975). The initial transgression proceeded from west to east, beginning in what is now western Wyoming (Sando 1988). This resulted in the Amsden Formation being time-transgressive, with older sediments at the base in the west than the east. The oldest sediments are found in western Wyoming, where the Mississippian–Pennsylvanian boundary (323 Ma) is high in the formation; in east–central Wyoming, this boundary is much lower (Gordon 1975). In YELL, fossils of early Atokan age (about 311 Ma) are present near the southern boundary of the park (Love and Keefer 1975).

The Amsden Formation is fossiliferous within YELL. Love and Keefer (1975) described a small collection of fossils from 300 m (1,000 ft) east of the junction of the Lewis and Snake rivers in southern YELL; organisms represented include *Komia* (an "algae" or sponge of uncertain relationships), foraminifera, bryozoans, brachiopods, crinoids, and indeterminate echinoderms, the latter four groups represented only by fragments. The formation is not known to be fossiliferous in northern YELL, although fossil fragments have been found north of the park in the southwestern corner of the Gardiner quadrant (Fraser et al. 1969), and foraminifera, corals, bryozoans, brachiopods, and gastropods probably of late Mississippian age are known from the Tepee Creek quadrangle, which includes part of northwestern YELL (Witkind 1969).

The Amsden Formation is sparsely fossiliferous, but has a distinctive assemblage. Fossil groups represented include foraminifera, marine algae including *Girvanella*, land plants (including calamitaceans, *Sphenopteris*, and *Lepidodendron*), the sponge *Chaetetes* (formerly identified as a hydrozoan, related to corals), conulatans, corals, bryozoans, brachiopods, rostroconchs, bivalves, cephalopods, gastropods, microconchid worm tubes formerly identified as *Spirorbis*, ostracodes, trilobites, blastoids, crinoids, echinoids, the possible worm *Cornulitella*, conodonts, invertebrate burrows, and fish (including cartilaginous and ray-finned fish) (Sando et al. 1975). Several groups were described in detail in a group of 1975 publications: foraminifera, algae, and other microfossils (Mamet 1975), corals and Chaetetes (Sando 1975a), brachiopods (Gordon 1975), bivalves and rostroconchs (Gordon and Pojeta 1975), ammonites, nautiloids, gastropods, and trilobites (Gordon and Yochelson 1975), and ostracodes (Sohn 1975). Representatives of all groups are generally found throughout the formation above the Darwin Sandstone Member, which is not known for its fossils. To date, there are only two reports of fossils in the Darwin Sandstone Member: Sando (1975b) reported foraminifera from the west flank of the Bighorn Basin, east of YELL, and Barker (1984) reported a brachiopod.

Quadrant Sandstone (Middle Pennsylvanian)

The Quadrant Sandstone of YELL is a light brown cliff-forming unit (Ruppel 1972). It can be divided into two units, as seen at Quadrant Mountain in the park: a lower dolomite member and an upper sandstone member (Saperstone 1986). The dolomite member includes sandy dolomite, algal dolomite, and sandstone. It is interpreted as representing tidal flats, like those seen today in subtidal to sabkha (salt flat)-dominated areas along the Persian Gulf. The sandstone member is composed of dune sandstones with interdune carbonates, and represents eolian coastal dunes. This dune field is part of the same dune system that deposited the Tensleep Sandstone (Saperstone and Ethridge 1984). The Quadrant Sandstone is found in the Blacktail Deer Plateau and the northwestern corner of the park, and is generally 90 to 100 m (300 to 325 ft) thick. As noted in the Amsden Formation section above, the Quadrant Sandstone of YELL originally included what is now recognized as the Amsden Formation (Scott 1935, Ruppel 1972). The upper contact with the Shedhorn Sandstone interval is disconformable (Ruppel 1972). The Quadrant Sandstone has proven difficult to date because fossils are rare, but fossils near the top of the

sandstone member at YELL give a Middle Pennsylvanian age (early Desmoinesian, approximately 308 Ma) (Verville et al. 1990).

The Quadrant Sandstone is not particularly fossiliferous, but it is fossiliferous within YELL. Fragmentary fossils were known to be present on Quadrant Mountain as long ago as 1918 (Condit 1918). The best-known fossils from the park are fusulinid foraminifera from Quadrant Mountain, described by Thompson and Scott (1941). Fragments of macrofossils are also found in the formation at Quadrant Mountain (Scott 1935, Thompson and Scott 1941). These include brachiopods, gastropods, and ostracodes (Scott 1935). The fossiliferous beds on Quadrant Mountain are in the sandstone member (Saperstone 1986). Elsewhere, outside of the park, the dolomite member has yielded rocks with algal or microbial laminations (Saperstone and Ethridge 1984), brachiopods, conodonts, and fossil fragments, and the sandstone member has yielded conodonts and invertebrate burrows (Saperstone 1986). Both members also have bioturbated beds (Saperstone 1986). On Cinnabar Mountain just north of the park, invertebrate burrows and bioturbation are present in the sandstone member (Saperstone 1986), and fossil debris is present in reworked Quadrant Sandstone rocks just below Permian rocks (Fraser et al. 1969).

Phosphoria Formation/Shedhorn Sandstone Interval (Lower–Middle Permian)

The Phosphoria Formation, Shedhorn Sandstone, and associated rocks make up a complex interval of intertonguing redbeds, marine shales and phosphatic shales, chert-rich beds, sandstones, and carbonates. Within YELL, the rocks were originally identified as part of the now-abandoned Teton Formation (Ruppel 1972). This interval is present in both northern and southern YELL, in the Birch Hills area (Christiansen et al. 1978), in the Two Ocean Plateau area, between the South Entrance and Yellowstone Lake (Love and Keefer 1975), and in the northwest corner of the park (Ruppel 1972). In northern YELL, the interval is about 35 m (115 ft) thick, and in southern YELL, the interval is perhaps 60 m (200 ft) thick (Love and Keefer 1975). Modern names that may be used in the YELL area at the formation level include the Park City, Phosphoria, and Shedhorn formations; the Park City name is usually applied to carbonate rocks and some of the sandstones, the Phosphoria name is applied to phosphatic, carbonaceous, and cherty rocks, and the Shedhorn Sandstone name is applied to other sandstones (Ciriacks 1963).

The Permian interval of YELL can be divided into smaller units (Cressman and Swanson 1960, Sheldon 1963, Yochelson and van Sickle 1968). There is general agreement that the basic framework is, in ascending order, a lower Shedhorn Sandstone member, the Retort Phosphatic Shale Member of the Phosphoria Formation, the Tosi Chert Member of the Phosphoria Formation, and an upper Shedhorn Sandstone member (Cressman and Swanson 1960, Sheldon 1963, Yochelson and van Sickle 1968). This sequence is found in both northern YELL, at Quadrant Mountain (Cressman and Swanson 1960), and in southern YELL, at Red Creek (Sheldon 1963). There may also be thin tongues or equivalents to the Grandeur Member of the Park City Formation and overlying Meade Peak Phosphatic Shale low in the interval (Cressman and Swanson 1960).

The Phosphoria/Shedhorn interval was deposited in and around a shallow, broad,

warm sea (Hiatt and Budd 2001). Two large transgression-regression cycles occurred during deposition, with the sea transgressing from west to east (Sheldon 1956). The maximum transgressions are represented by the Meade Peak and Retort phosphatic shale members (Wardlaw and Collinson 1986). The Park City Formation is interpreted as representing mudflat and marine shelf settings, the Phosphoria Formation is interpreted as deeper marine basins, and the Shedhorn Sandstone is interpreted as sands deposited on or near beaches (Yochelson 1963). The interval dates to the Leonardian and Guadalupian ages of the Early and Middle Permian (between 280 and 260.4 Ma) (Hiatt and Budd 2001). The upper contact with the Dinwoody Formation is disconformable (Paull and Paull 1990), but the hiatus is shorter in the west, nearer YELL, than in the east (Hiatt and Budd 2001). Internal disconformities are also present depending on location, between the Grandeur and overlying Meade Peak members and the Franson (not present at YELL) and Retort members (Hiatt and Budd 2001).

The Phosphoria/Shedhorn interval is fossiliferous within YELL. Phosphatized fish bones are common throughout (Ruppel 1972). Condit (1918) reported the presence of fish bones in sandstones and brachiopod fragments in a thin phosphate bed near the base of the interval on Quadrant Mountain, which implies the Shedhorn Sandstone and a tongue of the Phosphoria Formation, respectively. Sheldon (1963) and Yochelson and van Sickle (1968) discussed fossils from the interval on Red Creek in southern YELL. Most of the fossils are from the Shedhorn members, but the Tosi Chert Member yielded sponge spicules (Sheldon 1963). Yochelson and van Sickle (1968) reported four USGS collections of fossils from the lower Shedhorn Sandstone and one collection from the upper Shedhorn Sandstone. The lower Shedhorn Sandstone yielded scaphopods (tusk shells) and other mollusks, and bones and teeth of cartilaginous fish, ray-finned fish, and indeterminate fish. The upper Shedhorn Sandstone yielded brachiopods.

In general, over its entire depositional area, the Phosphoria interval has an assemblage of abundant but low-diversity brachiopods and mollusks. Sponges, corals, brachiopods, trilobites, crinoids, and fish are less-common components (Kulas and Batten 1997). Park City Formation fossil assemblages are dominated by brachiopods, with bryozoans and bivalves also common. Phosphoria Formation fossil assemblages include abundant sponge spicules as well as brachiopods and mollusks, particularly cephalopods. Finally, the Shedhorn Sandstone fossil assemblage is mostly made up of large bivalves, scaphopods, and resistant fish remains (Yochelson 1963). Fossils have been reported from each of the various members relevant to YELL:

The Grandeur Member of the Park City Formation has yielded foraminifera (McKelvey et al. 1959), sponges, solitary corals, conulatans, bryozoans, brachiopods, bivalves, straight nautiloids, gastropods, scaphopods, trilobites, crinoids (Yochelson and van Sickle 1968), conodonts (Behnken et al. 1986), and bones and teeth of cartilaginous and ray-finned fish (Yochelson and van Sickle 1968);

The Meade Peak Phosphatic Shale Member of the Phosphoria Formation has yielded acritarchs (organic microfossils that cannot be classified as anything else) (Jacobson et al. 1982), foraminifera (McKelvey et al. 1959),

sponges (Hendrix and Byers 2000), conulatans, bryozoans, brachiopods, bivalves, ammonites, belemnites (Yochelson and van Sickle 1968), nautiloids (McKelvey et al. 1959), other cephalopods (Gordon 1966, 1971, Yochelson and van Sickle 1968), gastropods, ostracodes, crinoids (Yochelson and van Sickle 1968), invertebrate burrows and general bioturbation (Hendrix and Byers 2000), conodonts (Behnken et al. 1986), and bones and teeth of fish (McKelvey et al. 1959, Yochelson and van Sickle 1968);

The Retort Phosphatic Shale Member of the Phosphoria Formation has yielded brachiopods, bivalves (McKelvey et al. 1959), aulacocerids (relatives of belemnite cephalopods) (Gordon 1966), gastropods (McKelvey et al. 1959), conodonts (Behnken et al. 1986), and bones and teeth of cartilaginous fish, ray-finned fish, and indeterminate fish (Yochelson and van Sickle 1968);

The Tosi Chert Member of the Phosphoria Formation has yielded sponge spicules (Sheldon 1963), bryozoans, brachiopods, bivalves, echinoids (McKelvey et al. 1959), conodonts (Behnken et al. 1986), and invertebrate burrows and general bioturbation (Thornburg 1989).

Finally, the Shedhorn Sandstone has yielded sponge spicules (Sheldon 1963), bryozoans, brachiopods, bivalves, gastropods, scaphopods (Yochelson and van Sickle 1968), invertebrate traces (Andersson 1985), and bones and teeth of cartilaginous fish, ray-finned fish, and indeterminate fish (Yochelson and van Sickle 1968).

Dinwoody Formation

The Dinwoody Formation, like some of the preceeding formations, varies in lithology from northern to southern YELL. In northern YELL, it may only be present only south of Fawn Pass, where it is up to 15 m (50 ft) thick and composed of light gray limestone that weathers brownish (Ruppel 1972). It is occasionally identified on Quadrant Mountain as well (Paull et al. 1989). In southern YELL, it is present in the Birch Hills area (Christiansen et al. 1978), in the Two Ocean Plateau area, and between the South Entrance and Yellowstone Lake (Love and Keefer 1975). In this part of the park, it is perhaps 60 m (200 ft) thick, and is primarily composed of greenish-gray siltstone and shale (Love and Keefer 1975). The distribution of the formation indicates that it thins going northeast across the park (Kummel 1960), and it appears to have been eroded before deposition of the overlying Woodside Formation in parts of the park (Ruppel 1972), instead of having the typical gradational contact.

The Dinwoody Formation is a marine unit, deposited on a shallow, locally restricted shelf during a transgression-regression cycle (Paull and Paull 1993). The transgression arrived from the west and spread rapidly over the level erosional surface (Paull and Paull 1993), followed by a drawn-out and fluctuating regression (Picard 1993). Distinct basinal, outer shelf, inner shelf, and redbed facies are present. Inner shelf facies are succeeded by redbed facies at YELL (Paull et al. 1985). The formation dates to the Griesbachian age of the Early Triassic (approximately 252 to 251 Ma) (Paull and Paull 1993). The contact with the overlying Chugwater Formation, present in southern YELL, is vertically and laterally transitional (Paull and Paull 1993), and has been plotted differently by different authors (Paull and Paull 1983, 1993). In areas like northern YELL where the Woodside and

Thaynes formations are present instead of the Chugwater Formation, the relationship is more complex. The contact with the Woodside Formation is laterally and vertically gradational, and the contact with the Thaynes Formation is vertically gradational (Paull and Paull 1987).

The Dinwoody Formation is fossiliferous within YELL. Brachiopods were found in the formation a little less than 5 km (3 miles) north of the South Entrance (Love and Keefer 1975), as well as on Quadrant Mountain in northwestern YELL (Condit 1918). Additionally, brachiopods and bivalves are found in the Tepee Creek quadrangle, which includes part of northwestern YELL (Witkind 1969). Fossils from the Dinwoody Formation over its entire depositional area are not notably abundant (Paull and Paull 1983), but include brachiopods, bivalves, ammonites, gastropods, scaphopods, "serpulid" worm tubes (these are often misidentified), crinoids, echinoids, ophiuroids (brittle stars), conodonts, bioturbation (Paull et al. 1985), invertebrate burrows and trails, and fish (Paull and Paull 1987). Bivalves, gastropods, and "serpulids" are known from the inner shelf facies present in the YELL area (Paull et al. 1985).

Chugwater Formation (Triassic)

The Chugwater Formation of YELL is only present in the southern part of the park, in the Birch Hills (Christiansen et al. 1978), in the Two Ocean Plateau area, and between the South Entrance and Yellowstone Lake (Love and Keefer 1975). It is a distinctive bright red unit, reaching thicknesses of nearly 300 m (1,000 ft). It can be divided into four members, in ascending order the Red Peak, Alcova Limestone, Crow Mountain Sandstone, and Popo Agie members. The Red Peak Member accounts for the bulk of the formation in the park. It is a brick-red siltstone unit up to roughly 240 m (800 ft) thick. The Alcova Limestone Member is a thin gray or tan limestone unit, only 3 m (10 ft) thick. The Crow Mountain Sandstone Member is a red and green siltstone, sandstone, and shale unit between 12 and 21 m (40 and 70 ft) thick. Finally, the Popo Agie Member at the top is a variegated unit composed of sandstone, siltstone, conglomerate, and shale, 20 to 30 m (70 to 100 ft) thick (Love and Keefer 1975).

The various members of the Chugwater Formation are distinctive but the contacts can be difficult to place (High and Picard 1967, Love and Keefer 1975). Picard's publications presented the Alcova Limestone as within the Crow Mountain interval, but other authors have preferred to include "Crow Mountain" rocks below the Alcova Limestone in the Red Peak Member or Formation (Cavaroc and Flores 1991, Lovelace and Lovelace 2012). The Red Peak (Picard 1967), Crow Mountain Sandstone (Tohill and Picard 1966), and Popo Agie members (High and Picard 1965) can each be further subdivided. The Chugwater Formation is sometimes raised to a group; in these cases, the members become formations.

The Chugwater Formation is interpreted as the result of both marine and terrestrial deposition near a coast (Cavaroc and Flores 1991). This is a similar depositional setting to the partly contemporaneous Moenkopi Formation exposed in many NPS units of the Colorado Plateau. The Chugwater Formation grades into fully marine beds going westward (Stewart 1958). The climate was semi-arid to arid, at least during deposition of the lower part of the formation (Picard 1966). The various interpretations of the depositional environment differ in the relative contributions of marine

and terrestrial deposition preferred by a given author, and will vary by study area. The Red Peak Member is variously interpreted as alternating nearshore marine and tidal flat deposition (Picard 1967), fluvial, deltaic, and nearshore marine deposition (Cavaroc and Flores 1991), and fluvial and lacustrine deposition becoming marine higher in the section (Lovelace and Lovelace 2012). The Alcova Limestone Member is usually interpreted as a marine incursion from the west (High and Picard 1969, Cavaroc and Flores 1991), although some authors have suggested a lacustrine origin (Cartwright et al. 2005, Lovelace 2011). There may have been marine evaporation near the top, as shown by local gypsum beds (Picard 1967). The Crow Mountain Sandstone Member encompasses the regression of the marine body responsible for the Alcova Limestone Member, transitioning from shallow nearshore marine deposition to tidal and beach deposition over time (Tohill and Picard 1966, Cavaroc and Flores 1991). The Popo Agie Member is a fluvial and lacustrine unit (High and Picard 1965, 1969), with a volcanic source for some sediments (High and Picard 1965).

The Chugwater Formation spans much of the Triassic (High and Picard 1969, Cavaroc and Flores 1991), but there is an internal disconformity between the Crow Mountain Sandstone and Popo Agie members that eliminates part of the Middle and Late Triassic (Tohill and Picard 1966). This may be the regional disconformity seen for example between the Moenkopi and Chinle formations (High and Picard 1969). Some older sources report it as Permian to Triassic in age (Richards 1955), but this includes older rocks now assigned to other formations. Dating has been hindered by the generally sparse fossils, particularly the absence of biostratigraphically useful fossils (Picard 1993). The upper contact of the Chugwater Formation with the Gypsum Spring Formation is disconformable (Love and Keefer 1975).

The Chugwater Formation of YELL appears to be fossiliferous. Love and Keefer (1975) reported amber-colored possible plates or teeth low in the Popo Agie Member on the northeast side of the Snake River 1,200 m (4,000 ft) southeast of the mouth of Red Creek. Bone fragments and a vertebra have been found in the Popo Agie Member just south of the park on Huckleberry Ridge. Over its entire depositional area, the Chugwater Formation has a restricted fossil assemblage, but each of the four members discussed above is fossiliferous. The Red Peak Member has yielded root traces, a bivalve, conchostracans (clam shrimp), invertebrate burrows, invertebrate tracks, fish scales, and tracks of turtle-like reptiles, lepidosaurs (lizards and relatives), enigmatic cheirotheres (terrestrial reptiles probably distantly related to crocodiles), and dinosauromorphs (dinosaurs and relatives), with most finds from central Wyoming (Lovelace and Lovelace 2012). Apparent plant molds were later shown to be inorganic (Boyd and Ore 1963). The Alcova Limestone Member has stromatolites (Lovelace 2011), plates from phylloid algae, bivalves, gastropods (Picard 1993), ostracodes (Branson 1947), and the marine reptile Corosaurus, an early relative of plesiosaurs (Storrs 1991, Rieppel 1998). The Crow Mountain Sandstone Member has only invertebrate burrows (Tohill and Picard 1966). Finally, the Popo Agie Member has probably the best-known fossils of the Chugwater Formation, and certainly the best-known vertebrates, which were first described near the turn of the 20th century (Williston 1904). Its fossil assemblage includes horsetails,

cycadophytes (cycads and relatives), plant fragments, freshwater bivalves (High and Picard 1965), invertebrate burrows (Picard 1993), lungfish, metoposaur amphibians, therapsids ("mammal-like reptiles"), phytosaurs (crocodile-like aquatic reptiles) (High and Picard 1965), early relatives of crocodilians (High and Picard 1965, Dawley et al. 1979) which in some cases were mistakenly thought to be dinosaurs (Mehl 1915, Colbert 1961, High and Picard 1965), and reptile tracks (Lockley 1990). Darton (1906) reported bivalves, gastropods, and ostracodes in a limestone in the upper Chugwater Formation of the Bighorn Mountains, but this may be a reference to the modern Gypsum Spring Formation, which was removed from the Chugwater Formation.

Sundance Formation (Middle–Upper Jurassic)

The Sundance Formation of YELL and the immediate vicinity is divisible into lower and upper sections. The lower Sundance Formation is a fossiliferous unit composed of gray and brown shale, siltstone, and limestone, 105 to 120 m (350 to 400 ft) thick. The overlying upper Sundance Formation is a gray and brown unit mostly composed of sandstone, with some limestone and shale, 20 to 25 m (70 to 85 ft) thick. The two units and the underlying Gypsum Spring Formation (see below under "Potential Sources of Paleontological Resources") are mapped undivided in the YELL area, and can be found between Heart Lake and the South Entrance in the park (Love and Keefer 1975). The Sundance Formation is sometimes divided into a number of members, but this has not been formally done in YELL. The lower and upper Sundance are roughly equivalent to the Rierdon and Swift formations as used in Montana, respectively, and are separated by the J-3 regional disconformity (Kvale et al. 2001). The lower Sundance includes strata that are equivalent to, from oldest to youngest, the Canyon Springs Sandstone, Stockade Beaver Shale, Hulett Sandstone, and Lak members of the Sundance Formation, and the upper Sundance includes equivalents of the Pine Butte and Redwater Shale members (Imlay 1953, Kvale et al. 2001, Mickelson et al. 2006a).

The Sundance Formation is primarily a marine unit, deposited by the Sundance Sea, a shallow continental marine body that encroached from the northwest (Harris and Lacovara 2004). The various members track the extent of the sea. In ascending order, the Canyon Springs Sandstone Member has been interpreted broadly as representing littoral marine deposition, the Stockade Beaver Shale as a brackish lagoon, the Hulett Sandstone Member as littoral, the Lak Member as a hypersaline lagoon, the Pine Butte Member as littoral, the Redwater Shale Member as an open marine shelf, and the Windy Hill Member as littoral (Wright 1974). The presence of terrestrial tracks shows some periods of subaerial exposure during the deposition of both the lower (Kvale et al. 2001, Mickelson et al. 2006a) and upper Sundance Formation (Harris and Lacovara 2004). Tidal flats facing the sea on the southwest were sometimes present in the Bighorn Basin during deposition of the early part of the lower Sundance Formation, under a climate that was at least seasonally arid (Mickelson et al. 2006a). It appears that one large transgression-regression cycle with three smaller subcycles occurred during deposition of the lower part of the formation, and one or two occurred during deposition of the upper part. The lower Sundance cycle is separated from the upper Sundance cycle or cycles by

the J-3 unconformity mentioned above, and another regional unconformity (J-4) marks the division of the two potential Upper Sundance cycles (Kvale et al. 2001). Deposition of the Sundance Formation occurred during the Middle and Late Jurassic, from the Bathonian to the Oxfordian ages (between 168 and 157 Ma) (Kvale et al. 2001, Mickelson et al. 2006a), albeit with significant internal hiatuses (Kvale et al. 2001). The upper contact with the possible Morrison Formation in southern YELL is abrupt but not obviously erosional (Love and Keefer 1975), so it may or may not be conformable.

The Sundance Formation is fossiliferous within YELL, although not all of the fossils attributed to the Sundance Formation in the park over time are actually from the Sundance Formation. For example, fossils described from northwestern YELL as deriving from the Sundance Formation by Crickmay (1936) are now regarded as coming from the Rierdon and Swift formations (Ruppel 1972). The rule of thumb is if the locality is in southern YELL, the Sundance Formation name should be used, but if the locality is in northern YELL, it is in either the Rierdon or Swift formations. The lower Sundance Formation of southern YELL has yielded bivalves, ammonites, and fossil fragments from several localities, and the upper Sundance Formation has yielded bivalves, belemnites, scaphopods, and crinoids. Just south of the park, the lower Sundance Formation also has gastropods, crinoids, and possible microfossils, and the upper Sundance Formation also has brachiopods and possible sponges (Love and Keefer 1975). Imlay's (1953) description of Callovian ammonites included a specimen from the lower Sundance Formation in southern YELL.

Overall, rocks from the lower Sundance Formation (Canyon Springs Sandstone to Lak members) have yielded a variety of marine fossils, mostly from the Stockade Beaver Shale Member. The assemblage includes foraminifera (Loeblich and Tappan 1950), dinoflagellates (a type of algae that moves using flagella), other microfossils, corals, bryozoans (Kvale et al. 2001), brachiopods, bivalves, ammonites, belemnites (Imlay 1947), gastropods (Breithaupt et al. 2001), worm tubes (Imlay 1956), ostracodes (Peterson 1954a, Wright 1974, Swain 1998) and other crustaceans (Herrick and Schram 1978, Feldmann 1979), asteroids (sea stars) (Miller and Unklesbay 1943), crinoids (Imlay 1947), echinoids (Imlay 1956), general bioturbation (Rautman 1975), marine invertebrate trace fossils such as borings (Tang 1997, Conroy et al. 2002) and fecal pellets (Stone and Vondra 1972), hybodont sharks, several types of early bony fish (Schaeffer and Patterson 1984), and dinosaur tracks (Kvale et al. 2001, Breithaupt et al. 2001, 2006, Adams et al. 2004, Matthews et al. 2006).

Fossils from the upper Sundance Formation across its depositional area are best known from the Redwater Shale Member, which has a very diverse fossil assemblage. Plants are represented by wood (Brenner and Davies 1974, Pipiringos and Imlay 1979). Invertebrates are abundant, and marine vertebrates are occasionally found (O'Keefe and Street 2009). The invertebrate fossil assemblage of the Redwater Member includes foraminifera (Loeblich and Tappan 1950), brachiopods (Brenner and Davies 1973), bivalves, ammonites, belemnites (Imlay 1947), gastropods, scaphopods (Specht and Brenner 1979), the lobster-like decapod crustacean *Eryma* (Wahl 2004), ostracodes

(Swain and Peterson 1951, 1952), asteroids (Blake 1981), crinoids, echinoids, polychaete worm tubes, and other invertebrate trace fossils (Specht and Brenner 1979). Vertebrates reported from the member include hybodont sharks (Wahl 2005), a more derived shark (Massare et al. in press), the ichthyosaur (dolphin-like marine reptile) *Opthalmosaurus* (formerly known as *Baptanodon*) (Massare et al. 2006), plesiosaurs *Megalneusaurus* (Wahl et al. 2007), *Pantosaurus* (O'Keefe et al. 2009), and *Tatenectes* (O'Keefe and Street 2009), a purported crocodylomorph (Marsh 1895), indeterminate reptile bones (Specht and Brenner 1979), and unusual reptile tracks (Harris and Lacovara 2004). Ichthyosaurs are the most common large reptiles, and belemnites appear to have been a major food source (Massare et al. in press).

Finally, there are some reports of fossil material from an unspecified or undetermined member or portion of the Sundance Formation. Most notable among these are pollen of conifers and other gymnosperms, and insect fossils, including hemipterans (true bugs), beetles, and caddisfly larvae (Santiago-Blay et al. 2001).

Ellis Group: Sawtooth Formation (Middle Jurassic)

The Sawtooth Formation is a different facies of the same depositional system that produced the Gypsum Spring Formation, as seen in southern YELL, southern Bighorn Canyon National Recreation Area (BICA), and GRTE, and the Piper Formation, as seen in northern BICA (Nordquist 1955, Parcell and Williams 2005). Within YELL, it is mapped undivided with the rest of the Ellis Group (the overlying Rierdon and Swift formations) in isolated bodies scattered throughout the northwestern part of the park (Ruppel 1972). It has a threefold division, much like the Gypsum Spring and Piper formations (Parcell and Williams 2005). In YELL, the lower part of the formation is composed of grayish red and grayish green siltstone, mudstone, and shale, 6 to 9 m (20 to 30 ft) thick; the middle part of the formation is composed of darker gray fossiliferous limestone with some dark shale, 18 to 23 m (60 to 75 ft) thick; and the upper part of the formation is composed of red siltstone, mudstone, and shale, 8 to 12 m (25 to 40 ft) thick. The upper contact with the Rierdon Formation is considered conformable (Ruppel 1972).

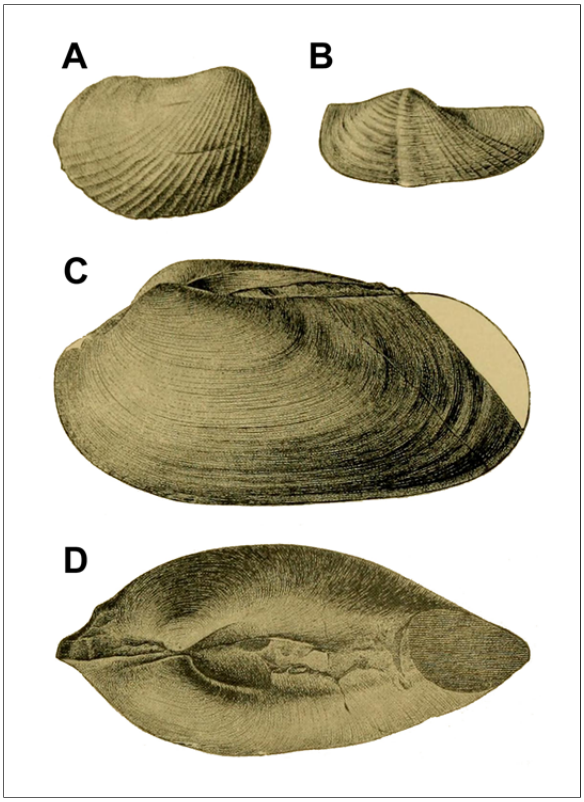
The Sawtooth Formation was deposited under shallow and marginal marine conditions. The lower portion represents one transgression-regression cycle and the middle and upper represent a second, leading to a brief depositional hiatus between the lower and middle units. The transgression of the lower unit was less extensive than the later transgression, and only restricted marine to sabkha deposition resulted. Open marine to sabkha deposition occurred during the second transgression-regression cycle (Parcell and Williams 2005). The climate are semi-arid to seasonally arid (Davies 1983). Nearby volcanic activity is represented by bentonites in the middle part of the formation (Cobban 1945). The Sawtooth Formation dates primarily to the Bajocian of the Middle Jurassic (Parcell and Williams 2005), approximately 170 to 168 Ma.

The Sawtooth Formation is fossiliferous within YELL. Crickmay (1936) described Middle and Upper Jurassic rocks from Fawn Pass and Fan Creek Pass in northwestern YELL. He used the Sundance Formation name for most of the rocks; Ruppel (1972) identified his Yb through Yj beds as the Sawtooth

Formation. At Fan Creek Pass, Crickmay found bivalves, ammonites, and gastropods in what is now recognized as the Sawtooth Formation. Ruppel (1972) reported another collection from the middle limestone on Quadrant Mountain with corals and bivalves. Stanton's (1899) bivalve *Anatina (Cercomya) punctata* is from the Piper Formation on Gray Mountain according to Imlay (1967), which equates to the Sawtooth Formation. The formation is abundantly fossiliferous west of YELL in the Tepee Creek quadrangle, producing bivalves, ammonites, and echinoids (Witkind 1969).

In addition to *Anatina* (*Cercomya*) *punctata*, Stanton (1899) described a variety of fossils from undivided Jurassic rocks in northwestern YELL and named seven other bivalve taxa apparently based at least in part from specimens found in YELL (the text is not explicit about designating type specimens or type localities, leaving sometimes the unsatisfactory condition of syntype series from more than one state): *Astarte meeki*, *Camptonectes bellistriatus* var. *distans*, *Cyprina? cinnabarensis*, *Homomya gallatinensis*, *Pholadomya inaequiplicata*, *Tancredia? knowltoni*, and *Thracia weedi*. The fossil assemblage includes brachiopods, bivalves, ammonites, belemnites, gastropods, and crinoids. The species are typical of the Ellis Group and doubtless came from it, but their exact stratigraphic disposition is not known. A selection of bivalves from the Ellis Group of YELL are pictured in YELL Figure 9.

Overall, the fossil assemblage of the Sawtooth Formation includes foraminifera (Davies 1983), corals (Ruppel 1972), possible brachiopods (Davies 1983), bivalves, ammonites, belemnites, gastropods,



YELL Figure 9. Bivalves from the Ellis Group of YELL, taken from Stanton (1899). **A.** *Pholadomya inaequiplacata*, right valve of the type specimen USNM 28956, from the divide between Fawn Creek and the Gallatin River; **B.** *Anatina (Cercomya) punctata*, left valve of the type specimen USNM 28945 (partially restored), from a ridge south of Gray Mountain; **C.** and **D.** *Homomya gallatinensis*, two views of the type specimen USNM 28942 (an internal cast), from the divide between Fawn Creek and the Gallatin River.

scaphopods (Cobban 1945), ostracodes (Davies 1983), crinoids (Cobban 1945), and echinoids (Witkind 1969), and some beds are bioturbated (Davies 1983).

Ellis Group: Rierdon Formation (Middle Jurassic)

The Rierdon Formation of YELL is composed of red or gray limy shale, mudstone, and siltstone, with some limestone, and is 12 to 18 m (40 to 60 ft) thick (Ruppel 1972). It is roughly equivalent to the lower Sundance

Formation (Imlay 1956, Kvale et al. 2001), and sometimes members of the Sundance Formation are extended from Wyoming into the Rierdon Formation (Imlay 1954, for reference, he extended the Hulett, Stockade Beaver, and Canyon Springs members). The upper contact with the Swift Formation is disconformable (Stewart 1958, Swain 1998), representing the regional J-3 unconformity (Kvale et al. 2001).

The Rierdon Formation is a marine formation, including a transgression-regression cycle (Parcell and Williams 2005). The Sheridan Arch extending east-west through north-central Wyoming and southeast Montana divided deposition (Peterson 1954b). Deposition occurred during the latter part of the Middle Jurassic, probably including some part of the late Bathonian (Swain 1998) and early Callovian ages (Imlay 1956), roughly 167 to 165 Ma.

The Rierdon Formation is fossiliferous within YELL. It is present in Crickmay's (1936) sections, albeit as the "middle Sundance Formation;" Ruppel (1972) identified his Yk and Yl beds as the Rierdon Formation. At Fawn Pass, Crickmay found bivalves in the Rierdon Formation, and at Fan Creek Pass, he found bivalves, ammonites, and belemnites. Ruppel (1972) noted that it is not as fossiliferous as the Sawtooth Formation in the park. Imlay (1953) found Callovian-age ammonites in this formation in northwestern YELL. The overall fossil assemblage of the Rierdon Formation over its entire depositional area includes foraminifera (Lalicker 1950), bryozoans (Imlay 1956), brachiopods, bivalves, ammonites (Imlay 1953, 1954, 1956), belemnites (Cobban 1945), nautiloids (Kummel 1954a), gastropods (Imlay 1954, 1956), ostracodes (Peterson 1954a, 1954b; Sherrington and Lord 1975, Lord and Sherrington 1976), crinoids, echinoids (Imlay 1954, 1956), and fish (Lopez 2000).

Ellis Group: Swift Formation (Middle–Upper Jurassic)

The Swift Formation of YELL is a yellowish brown to olive-gray unit primarily composed of limy sandstone and sandy limestone, 5 to 18 m (15 to 60 ft) thick. Fossil fragments are common throughout, and some beds can be described as coquinas (Ruppel 1972). The Swift Formation, preferred in Montana, is roughly equivalent to the upper Sundance Formation as used in Wyoming and the Black Hills, and the Stump Formation as used in eastern Idaho and western Wyoming (Brenner and Davies 1974). The upper contact with the Morrison Formation is conformable (Ruppel 1972), but can appear abrupt (Imlay 1956).

The Swift Formation is a marine unit. There is at least one and possibly two transgression-regression cycles in the Swift–upper Sundance interval, with the two possible cycles divided by an internal disconformity (Kvale et al. 2001). Deposition occurred between the late Callovian age of the Middle Jurassic and the late Oxfordian or early Kimmeridgian of the Late Jurassic (Swain 1998), between approximately 164 and 157 Ma.

The Swift Formation is fossiliferous within YELL. As noted by Ruppel (1972), fossil fragments are abundant. The formation is present in Crickmay's (1936) sections as the "upper Sundance Formation;" Ruppel (1972) identified his Ym beds as the Swift Formation. At Fawn Pass, Crickmay found brachiopods in the Swift Formation, and at Fan Creek Pass, he found bivalves and belemnites. Just west of the park, in the Hebgen Lake area, there is a fossiliferous shallow marine storm lag deposit

with dinoflagellates, coal, plant fragments, ginkgo pollen, bivalves, ammonites, gastropods, fish teeth, and bones (Sablock and Sablock 1988); similar deposits may eventually be found in YELL.

Overall, including areas outside of YELL, the fossil assemblage of the Swift Formation includes dinoflagellates (a type of algae that moves using flagella), coal, plant fragments (Sablock and Sablock 1988), wood (Cobban 1945), wood bored by invertebrates (Porter 1989), pollen from ginkgoes and other plants (Sablock and Sablock 1988), bivalves, ammonites (Cobban 1945, Sablock and Sablock 1988), belemnites (Cobban 1945), gastropods (Sablock and Sablock 1988), ostracodes (Swain and Peterson 1952, Peterson 1954b, Lord and Sherrington 1976, Swain 1998), possible worm tubes (Cobban 1945), invertebrate burrows (Cobban 1945, Meyers et al. 1992), and fish teeth (Cobban 1945, Sablock and Sablock 1988).

Morrison Formation (Upper Jurassic)

In both northern and southern YELL there are rocks that may represent the Upper Jurassic Morrison Formation. In northern YELL, the correlation is considered secure. Here it is a slope-forming variegated unit of shale, mudstone, siltstone, and lesser amounts of limestone and sandstone, up to about 60 m (200 ft) thick. The lower part is predominantly shale and mudstone with a few limestone beds, the upper part is mostly siltstone and sandstone, and the uppermost part is shale and mudstone with sandstone and a little limestone. Scattered outcrops are present in the northwestern part of the park (Ruppel 1972). Iddings and Weed (1899) probably included the modern Morrison Formation with the Kootenai Formation and lower Thermopolis Shale in their Dakota Formation, although exact correlation of a given bed in the 1899 sections to a modern equivalent is not feasible (Ruppel 1972). In southern YELL, the correlation is less secure: it is described as "Morrison(?)" and mapped undivided with the Cloverly Formation. The two are mapped in several areas in a general line between Heart Lake and the South Entrance. The Morrison and lower Cloverly formations here are 140 to 150 m (465 to 500 ft) thick and composed of shale, claystone, siltstone, and sandstone (Love and Keefer 1975). The Morrison Formation is often divisible into several members, although this has not been formally done in northwestern Wyoming.

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 about 155 and 148 Ma (Foster 2007). The contact with the overlying Cloverly Formation is placed arbitrarily in the Teton Range (Wanless et al. 1955), and is a point of contention elsewhere, where the two formations are better known (Moberly [1960]; see discussion in the BICA chapter of this inventory). The upper contact in northern YELL with the Kootenai Formation is unconformable, and is marked a conglomerate bed that is probably equivalent to the Pryor Conglomerate Member of the Cloverly/Kootenai interval (Ruppel 1972).

The Morrison Formation is fossiliferous within YELL. Ruppel (1972) reported that fragments of a dinosaur limb bone were found at the head of Stellaria Creek northwest of Fawn Pass, along with abundant fossil wood.

In southern YELL, northwest of Basin Creek Lake, bivalves, gastropods, and possible charophyte algae and ostracodes have been found in a limestone bed near the base of undivided Cloverly/Morrison(?) unit (Love and Keefer 1975); based on position, it is here assigned to the Morrison(?) part of the interval. The nearest localities with identifiable vertebrate remains are at Paint Creek in Park County, Wyoming, about 50 km (30 miles) east of YELL, and at a site known as the Strickland Creek Quarry slightly more than 50 km north of YELL outside of Livingston. The Paint Creek site has yielded fossils of the sauropod dinosaur *Camarasaurus*, and the Strickland Creek Quarry has yielded material of turtles, the theropod dinosaur *Allosaurus*, the sauropod dinosaur *Diplodocus*, and an unidentified sauropod (Foster 2003).

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, lizards, possible snakes, the lizard-like aquatic reptile *Cteniogenys*, terrestrial crocodylomorphs, *Goniopholis* (closely related to the ancestry of modern crocodilians) and other extinct crocodylomorphs, 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 like *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).

Cloverly Formation (Lower Cretaceous)

The Cloverly Formation of YELL is mapped with the Morrison(?) Formation, as noted above. The bulk of the formation has not been differentiated from the Morrison(?) Formation, but there is a distinct upper sandstone unit, 30 to 45 m (100 to 150 ft) thick. This upper unit is regarded as representing the widespread informal "rusty beds" of the formation; early descriptions of this sandstone unit in YELL assigned it to the Precambrian as part of the now-abandoned "Sheridan Quartzite." The contact with the overlying Thermopolis Shale is sharp and distinct, but conformable (Love and Keefer 1975). The Cloverly Formation is sometimes divisible into multiple members, but named members have not been designated in YELL. Equivalent Lower Cretaceous rocks in northern YELL are known as the Kootenai Formation, following usage in Montana.

The definition of the Cloverly Formation has varied widely over time. Both the upper and lower contacts have proven difficult to establish (Moberly 1960). The upper contact has been controversial because of a pair of units, the "rusty beds" and an underlying unit known in the Bighorn Basin, the Greybull Sandstone (but see for example Wilson [1934], which uses the Greybull name at Cinnabar Mountain). These two units have variously been included in the Cloverly Formation and equivalent Kootenai Formation, given their own formation (the Sykes Mountain Formation of Moberly [1960]), included in the overlying Thermopolis Shale, or distributed separately (Moberly 1960). It is not entirely clear how the Geologic Resources Division documents for YELL deal with the "rusty beds," being composite documents drawn from preexisting maps, but it appears that in southern YELL they are included with the Cloverly Formation and in northern YELL they are included in the Thermopolis Shale; this dichotomy can be seen in Ruppel (1972) and Love and Keefer (1975). For convenience, they will be dealt with only in this section, and at any rate they do not appear to be fossiliferous within YELL. Note that the vertebrate paleontology literature frequently employs the Sykes Mountain Formation name.

The Cloverly Formation has proven difficult to date (Oreska et al. 2013). Traditionally, it has been regarded as Aptian and Albian in age (125 to 100.5 Ma), but its base may be older (Winslow and Heller 1983). Recent interpretations suggest that there is a significant disconformity within the formation (Zaleha and Wiesemann 2005, Zaleha 2006), which could account for this. Recent dates from the Cloverly Formation include 108.5±0.2 Ma (Burton et al. 2006) and 104.4 Ma (D'Emic and Foreman 2012), placing at least part of it in the middle Albian age. The contact of the Greybull/"rusty" interval with the rest of the Cloverly Formation has been variously described as conformable (D'Emic and Foreman 2012) or unconformable (Kvale and Vondra 1993, Zaleha and Wiesemann 2005, Zaleha 2006). The upper contact of the Greybull/"rusty" interval with the Thermopolis Shale is transitional (Moberly 1960), which is one reason why it is sometimes assigned to that formation (Witkind 1969).

The Cloverly Formation was deposited under a warm, seasonal climate, becoming more humid over time as the Western Interior Seaway approached. Deposition began under an arid to semi-arid climate, with droughts. Later, a savannah environment appeared (Forster 1984). A substantial part of the sediment is of volcanic origin (Moberly 1960, 1962). The lower part of the lower Cloverly Formation is interpreted as having been deposited in playas (ephemeral lakes) and streams (Moberly 1960, Kvale and Vondra 1993). Higher in the lower Cloverly Formation, fluvial deposition predominated (Moberly 1960). Floodplains appeared as the seaway approached (D'Emic and Foreman 2012), advancing from the north (Nydam and Cifelli 2002). The Greybull/"rusty" interval was deposited during the transition to the full marine conditions of the overlying rocks (Zaleha and Wiesemann 2005, D'Emic and Foreman 2012). The "rusty beds" are shallow marine in origin (Moberly 1960, Kvale and Vondra 1993).

The Cloverly Formation is fossiliferous within YELL. Ostracodes of Early Cretaceous age have been found in the undivided Cloverly/Morrison(?) unit on Huckleberry Ridge, and gastropods are present in limestone a short distance below the rusty beds. Ostracodes are also present in a zone of limestone nodules at a site just south of YELL and east of JODR, roughly 5 km (3 miles) east of YELL's South Entrance (Love 1956b).

Overall, the Cloverly Formation below the contested Greybull/"rusty" interval has a substantial fossil assemblage, and is best known for its dinosaurs. Until recently, identifiable plant remains were sparse in the Cloverly Formation, and plants were only represented by charophyte algae (Peck 1957), coal and coalified wood (Mirsky 1962), petrified wood (Moberly 1960), leaf and needle fragments (Darton 1904, 1906), spores and pollen (Mirsky 1962), and root traces (Zaleha and Wiesemann 2005). Recently, a paleoflora was discovered in the Bighorn Basin, including spores, pollen, ferns, cycadophytes, conifers, and angiosperms, the latter only present near the top of the formation (Wilborn 2006, Jud and Wing 2010, Haiar and Lupia 2011, Jud 2011). Invertebrates are represented by bivalves, gastropods (Reeside 1923, Yen 1949, 1951), caddisfly casings (Jud 2011), shell fragments (Thom et al. 1935), crayfish gastroliths ("stomach stones") (Oreska et al. 2013), and burrows (Zaleha and Wiesemann 2005). Vertebrates are enumerated in Oreska et al. (2013), which also includes a discussion of their stratigraphic distribution within the formation. The following list is drawn from this publication, with annotations as needed. Vertebrates found in the Cloverly Formation include hybodont sharks, rays, several types of ray-finned fish, the lungfish Ceratodus, extinct salamander-like albanerpetontid amphibians, salamanders, frogs, several types of turtles and tortoises, lizards, representatives of four lineages of crocodile relatives, theropod dinosaurs including large *Acrocanthosaurus* and small *Deinonychus*, *Microvenator*, and an unnamed "ostrich-mimic," possible birds, sauropod dinosaurs including *Rugocaudia* and the giant *Sauroposeidon*, the armored dinosaurs *Sauropelta* and *Tatankacephalus*, an early horned dinosaur, the small ornithopod dinosaur *Zephyrosaurus*, the common large ornithopod *Tenontosaurus*, the triconodont mammals *Corviconodon* and *Gobiconodon*, several forms of multituberculate mammals, a symmetrodont mammal, additional unnamed early mammals, and dinosaur eggshells

(Maxwell and Horner 1994). Rounded isolated stones are often identified as dinosaur gastroliths, but this identification cannot be established for certain (Wings 2007, 2009), and they may be ordinary stones moved by special flow conditions (Zaleha and Wiesemann 2005). Finally, reworked Paleozoic clasts have been found in the formation; some have foraminifera, sponge spicules, bryozoans, brachiopods, gastropods, and echinoderms (Zaleha and Wiesemann 2005).

The Greybull/"rusty" interval, sometimes known as the Sykes Mountain Formation, has a small fossil assemblage. The "rusty beds" have yielded plant fossils (Darton 1904), stem impressions (Love et al. 1948), freshwater bivalves and gastropods (Love 1956b), and invertebrate traces (Love et al. 1948). References to fossils that could be from either unit, or the Sykes Mountain Formation, include tintinnids (protozoans with protein-based shells), carbonaceous debris, peat (Eicher 1960), petrified wood, leaves of ferns, fern-like plants, conifers, and angiosperms (Walton et al. 2007), bivalves (Kvale and Vondra 1993), possible casts of bivalves and gastropods (Eicher 1960), thin shell interbeds (Ostrom 1970), invertebrate trails and burrows (Eicher 1960, Moberly 1960, Kvale and Vondra 1993), invertebrate castings (feces), and fish teeth and fragments, most of which are known from the Bighorn Basin (Eicher 1960).

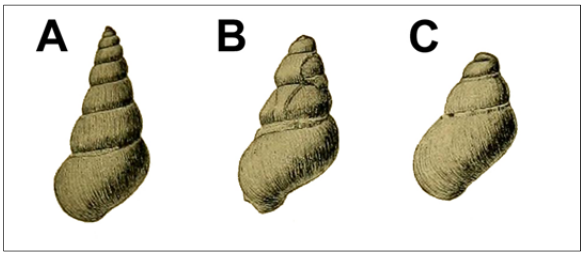
Kootenai Formation (Lower Cretaceous)

The Kootenai Formation, as mentioned above, is essentially the same interval as the Cloverly Formation; northern YELL's outcrops are mapped using the Montana terminology. Older references may use the Cloverly name in this interval, for instance Wilson (1934) and Fraser et al. (1969), which both reported the Cloverly Formation on Cinnabar Mountain just north of the park. In YELL, it is present in the northwestern section of the park, where it is informally divided into three parts: a basal conglomerate and sandstone unit, 6 to 15 m (20 to 50 ft) thick, thought to represent the Pryor Conglomerate as found elsewhere in Montana and Wyoming at the base of the Cloverly/Kootenai interval; a middle gray and red unit of shale, mudstone, and lesser amounts of limestone and sandstone; and 6 to 9 m (20 to 30 ft) of gray limestone at the top of the formation with abundant to pervasive molds of gastropod shells, known as the "gastropod limestone." The upper contact with the Thermopolis Shale (which in northern YELL includes the "rusty beds") appears to be conformable. Overall, the formation is 76 to 90 m (250 to 300 ft) thick in the park (Ruppel 1972).

The Kootenai Formation is a combination of fluvial and lacustrine deposits (DeCelles 1986, Condon 2000). Large paleochannels and valleys have been found in the formation, at least some of which are distributaries around lacustrine systems (Hopkins 1985). As with the Cloverly Formation, a marine influence appears at the top (James 1980a, DeCelles 1986).

The Kootenai Formation is fossiliferous within YELL. The existence of the "gastropod limestone" was noted by Stanton (1899). He reported bivalves and gastropods in this bed, and named three gastropod species (*Goniobasis? pealei* [YELL Figure 10A], *Goniobasis? increbescens* [YELL Figure 10B], and *Amnicola? cretacea* [YELL Figure 10C]). The types of the latter two were collected from Fawn Creek, but the syntypes of the first were more broadly distributed. He

did not report fossils from the rest of the "Dakota(?) Formation" (Stanton 1899). Ostracodes have also been recovered from the "gastropod limestone," on Cinnabar Mountain north of YELL (Fraser et al. 1969).



YELL Figure 10. Gastropods of the Kootenai Formation in the YELL area, taken from Stanton (1899). **A.** *Goniobasis? pealei*; **B.** *Goniobasis? increbescens*; **C.** *Amnicola? cretacea*.

The Kootenai Formation below the Greybull/"rusty" interval is primarily known for its paleobotanical record. Plants represented in the Kootenai Formation include charophytes (Peck 1941, 1957), mosses (Brown and Robison 1972, 1974), liverworts (Brown and Robison 1976, LaPasha and Miller 1985), hornworts, quillworts, horsetails, ferns, seed ferns (LaPasha and Miller 1985), cycads (Horner 1989), cycadeoids (LaPasha and Miller 1985), ginkgoes (Brown 1975), conifers (LaPasha 1977, Miller and LaPasha 1984), and unclassified plants (Brown 1972, LaPasha and Miller 1985). Plants are often found in coal seams (Horner 1989). In addition to plants, many other groups are represented, including algal or microbial limestone (Holm et al. 1977), dinoflagellates (Hopkins 1985), bivalves, gastropods (Yen 1949, 1951, James 1980a), ostracodes (Peck 1941, Yen 1951), general bioturbation (DeCelles 1986), hybodont sharks, holostean fish (Horner 1989), the turtle Naomichelys (Joyce et al. 2011), the herbivorous sphenodontian Toxolophosaurus (Olson 1960, Throckmorton et al. 1981), crocodile relatives (Horner 1989), and indeterminate dinosaurs (Weishampel et al. 2004).

Thermopolis Shale (Upper Cretaceous)

The Thermopolis Shale is found in both northwestern and southern YELL, but differs structurally between the two areas. In northwestern YELL, the formation has three parts: a brown to gray lower sandstone member with some interbedded shale and siltstone, 23 to 30 m (75 to 100 ft) thick; a middle dark shale member with some thin sandstone beds, 90 m (300 ft); and an upper sandstone member, predominantly grayish and including some shale and mudstone, up to 30 m (100 ft) thick (Ruppel 1972). The lower member can be identified with the "rusty beds" mentioned in the Cloverly Formation section, and the upper member can be identified with the Muddy Sandstone (Witkind 1969). In southern YELL, the Thermopolis Shale includes two or three members: a lower dark shale member; the Muddy Sandstone Member; and occasionally an upper dark shale member. It is difficult to distinguish the upper shale member from the overlying Mowry Shale, and the two are usually lumped together for descriptive purposes. The lower shale member is on the order of 50 m (170 ft) thick, and the Muddy Sandstone Member is up to 30 m (100 ft) thick (Love and Keefer 1975). There is some historic variation in the nomenclature for these rocks. In northern YELL, the Thermopolis Shale above the "rusty beds" was probably included in Iddings and Weed's (1899) Colorado Formation, along with the overlying Mowry Shale and Frontier Sandstone (Ruppel 1972). Furthermore, the Muddy Sandstone Member was the other part of the presumed "Precambrian" "Sheridan Quartzite" mentioned in the Cloverly Formation section (Love and Keefer 1975). Additionally, the Muddy Sandstone Member

is sometimes given its own formation in the area (Love 1950, Vuke 1984, Dyman et al. 1990, Hale et al. 2004). Historically, the definitions of the Thermopolis Shale, Mowry Shale, and overlying Frontier Formation have varied, because of the lack of obvious disconformities or changes in lithology (Reeside and Cobban 1960). The upper contact with the Mowry Shale is conformable in both northwestern (Ruppel 1972) and southern YELL (Love and Keefer 1975).

The Thermopolis Shale is generally a marine formation. Deposition was primarily under the northern arm of the Western Interior Seaway. The transgression that deposited the lower shale was eventually extensive enough that the northern and southern arms of the seaway connected (Eicher 1960). A regression followed during deposition of the Muddy Sandstone Member, and the two arms were separated, leaving only northern waters over the GRYN area (Druckenmiller 2002); authors have variously interpreted this member as having a basal unconformity (Druckenmiller 2002) or upper unconformity (Condon 2000). In the vicinity of northern YELL, the Muddy Sandstone is associated with a delta, and includes some terrestrial deposits (Vuke 1984). Deposition of the formation included volcanic ash (Vuke 1984). The age of the formation is earliest Late Cretaceous; the base of the Muddy Sandstone Member dates to around 98.5 Ma, and ammonites of the overlying shale indicate that it dates to between 98.74±0.59 and 98.54±0.70 Ma (Druckenmiller 2002).

The Thermopolis Shale is fossiliferous within YELL. Stanton (1899) reported a small quantity of fossils from the Colorado Formation in YELL. One of them, a bivalve (*Ostrea anomioides*), was found near the base of the formation on the north side of Fan Creek; this is probably the modern Thermopolis Shale. In northwestern YELL, bivalves are present in the Muddy Shale Member (Ruppel 1972). Love and Keefer (1975) reported that the Thermopolis Shale was not fossiliferous in southern YELL, but noted the presence of “fucoidal” markings in beds about 2 km (1 miles) south-southeast of Basin Creek Lake, which suggests that invertebrate trace fossils are present. An unpublished report by Elaine Hale and others on the Cretaceous rocks of Mount Everts documented the presence of dinoflagellates, pollen, spores, and invertebrate burrows in the lower Thermopolis Shale and bivalves and gastropods in the Muddy Sandstone Member (Koch and Santucci 2003). Nearby, but outside of YELL, plant fossils have been found in the formation on Cinnabar Mountain (Wilson 1934), and the lower shale and Muddy Sandstone members both have carbonaceous flecks and invertebrate traces in the Gardiner area (Fraser et al. 1969).

Overall, macrofossils are rare in the Thermopolis Shale, but microfossils are common (Eicher 1958). Fossils attributed to the shaly parts of the formation (which may include fossils limited to the upper shale here considered part of the Mowry Shale) include radiolarians (another type of “shelled” protist) (Reeside and Cobban 1960), foraminifera, tintinnids (Eicher 1958, 1960), palynomorphs including dinoflagellates (Schwab 1977), sponges (Eicher 1958, 1960), bivalves, ammonites (Reeside and Cobban 1960), invertebrate burrows, trails, and castings (Eicher 1960), hybodont sharks, sawfish, rays, bony fish, turtles, marine crocodile relatives, and coprolites (Lash and Schmitt 2008). The Muddy Sandstone Member has yielded foraminifera, angiosperms (Eicher 1960),

brachiopods, bivalves, asteroids (Wulf 1962), invertebrate traces (Tillman and Dresser 1976), and vertebrate remains such as teeth, spines, and bone fragments, representing cartilaginous and bony fish, turtles, and crocodile relatives (Eicher 1960, Wulf 1962, Kausch and Giffin 1993). The fossils of the Greybull/"rusty" interval are enumerated under the Cloverly Formation section above.

Mowry Shale (Upper Cretaceous)

Like the Thermopolis Shale, the Mowry Shale is found in both northwestern and southern YELL. In northern YELL, it is a medium or dark gray mudstone and shale unit about 90 m (300 ft) thick, with a few sandstone and bentonite beds, and some beds in the upper part of the formation with abundant fish scales. The upper contact with the Frontier Formation is conformable (Ruppel 1972). On Mount Everts, the contact is gradational, which makes the thicknesses of the two formations vary by author (Tysdal et al. 1990). The Mowry Shale of the southern YELL area is significantly thicker, with one mostly complete section a few km or miles south of YELL of 180 m (600 ft), but lithologically it is about the same, a dark unit of shale, claystone, and sandstone with fish scales. The upper contact is conformable here as well (Love and Keefer 1975).

The age of the Mowry Shale is frequently given as late Early Cretaceous in older reports, but advances in radiometric dating and refinement of the Cretaceous time scale have allowed a more precise placement. Recent works have tended to bracket the formation with a pair of bentonite beds dated within the early Late Cretaceous. They are the Arrow Creek Bentonite, dated to 98.52±0.41 Ma, and the Clay Spur Bentonite, dated to 97.17±0.69 Ma (Scott et al. 2009). The base of the formation is probably slightly older in the Jackson Hole area, depending on the presence and assignment of "upper Thermopolis black shale," which has ammonites indicating that it dates to between 98.74±0.59 and 98.54±0.70 Ma (Druckenmiller 2002).

The Mowry Shale is typically an offshore marine formation (Merewether 1996), deposited within the Western Interior Seaway (Franczyk et al. 1992). If the "upper black shale of the Thermopolis Shale" is included, then there are two transgressions represented, one for the "black shale" (Eicher 1960), and one for the rest of the Mowry Shale. The sea arrived from the north-northwest, transgressing from what is now Alberta and Saskatchewan (Wulf 1962). In Wyoming, it spread west to east (Byers and Larson 1979). It is uncertain if the northern part of the Seaway system, which included the GRYN, was connected to the southern part during the deposition of the Mowry Shale; they were not connected during deposition of the "black shale" (Eicher 1960), but they may have been connected near the end of deposition (Eicher 1965). Coastal plain environments appear in this formation in the Bozeman area and in the Madison and Gallatin ranges northwest of YELL (Vuke 1984). Volcanoes west of the seaway, perhaps in what is now Idaho, contributed to the rocks of the formation (Reeside and Cobban 1960).

The Mowry Formation is fossiliferous within YELL. Fish scales are present in northwestern YELL (Fraser et al. 1969, Ruppel 1972) and just south of the park (Love and Keefer 1975), and are probably present in southern YELL as well. Koch and Santucci (2003) also reported fish teeth and vertebrae. One of the authors of this document (VLS) reports observing abundant fish scales in the Mowry Shale at the

base of Mount Everts, as well as a small hollow bone potentially representing a pterosaur or bird. The Mowry Shale over its entire depositional area has a small but growing fossil assemblage. Non-animal organisms are represented by foraminifera, radiolarians, dinoflagellates, spores, pollen (Oboh-Ilkuenobe et al. 2007), coal (Uyger and Picard 1985), tree ferns (Ash and Read 1976), angiosperm leaves (Stewart et al. 1994), and other plant remains (Uyger and Picard 1985). Invertebrates include bryozoans (Maione 1971), bivalves (Reeside and Cobban 1960), and ammonites (Maione 1971, Molenaar and Wilson 1990); they are also represented by impressions of cephalopods (Brown and Vokes 1944, Connely and Talbot 2005), burrows, and local bioturbation (Davis et al. 1989, Merewether et al. 2010). The bottom sediments often show little evidence of burrowing animals, indicating anaerobic bottom waters (Byers and Larson 1979). Vertebrates are represented by sharks and other cartilaginous fish (Hamblin et al. 2000, Cicimurri 2004, Gregson et al. 2010), ray-finned fish (Hamblin et al. 2000, Stewart and Hakel 2006), the ichthyosaur *Platypterygius* (Nace 1939, Massare and Dain 1989, Maxwell and Kear 2010), a long-necked elasmosaurid plesiosaur, a short-necked plesiosaur, a crocodylomorph (Massare and Dain 1989), a pterosaur (Bennett 1989), and possible vertebrate trace fossils (Burford 1985, Connely and Talbot 2005, Trumbull and Connely 2010). Fish scales and bone fragments are abundant (Maione 1971, the "upper black shale of the Thermopolis shale," if it is indeed present and included in the Mowry Shale, include foraminifera, radiolarians (Eicher 1960), the tree fern *Tempskya* (Ash and Read 1976), bivalves, ammonites, crabs, ray-finned fish scales, turtle shell fragments (Eicher 1960), and the plesiosaur *Edgarosaurus* (Druckenmiller 2002).

Frontier Formation (Upper Cretaceous)

The Frontier Formation can be found in northwestern and southern YELL. Although it has been divided into a variety of members depending on location, members have not been formally designated in YELL. The Frontier Formation of northwestern YELL is marked by disagreement about the structure of the formation. Various publications (Fraser et al. 1969, Ruppel 1972, Tysdal et al. 1990, Tysdal 1991) note that regionally, between obvious Mowry Shale and Cody Shale rocks, there are two dominantly sandstone units sandwiching a shale unit. On Cinnabar Mountain, the sandstone–shale–sandstone succession is assigned to the Frontier Formation (Fraser et al. 1969, Tysdal et al. 1990). The lower sandstone unit thins south and is poorly developed at Mount Everts. Ruppel (1972) described the Frontier Formation of Mount Everts as a single sandstone bed, which he interpreted as the same as the lower sandstone unit, and assigned the middle shale and upper sandstone to the Cody Shale as the basal shale and middle sandstone members of that formation. Tysdal et al. (1990) disagreed with this in apparently every detail. Their Frontier Formation of Mount Everts seems to be only the upper sandstone (Ruppel's middle sandstone member of the Cody Shale), and the middle shale and poorly developed lower sandstone are assigned to the Mowry Shale because they did not find the lower sandstone to be distinct enough to be useful for mapping, and without a lower sandstone the middle shale cannot be distinguished from the Mowry Shale. To further confuse matters, the text can be read to imply that Tysdal and others did not think that

Ruppel's lower sandstone was actually the lower sandstone: Ruppel (1972:28) stated that "the sandstone mapped in the northern part of Yellowstone National Park is correlative with the lower sandstone member of the Frontier in the Gardiner area as mapped by Fraser and others (1969)." We disagree with this interpretation, and with Ruppel's statement (1972:29) that "the middle shale and upper sandstone of Fraser and others (1969) are really part of the Cody Shale" (Tysdal et al. 1990). This is difficult to understand. Tysdal and others and Ruppel clearly both recognize a sandstone–shale–sandstone succession, although they disagree on the formations. If Ruppel's Frontier Formation is not the basal sandstone assigned to the Mowry Shale by Tysdal and others, what can it be? It makes no sense for it to be the upper sandstone, because that leaves Ruppel's basal shale and middle sandstone members of the Cody Shale unaccounted for. Could Ruppel have accidentally described the upper sandstone intending to describe the lower sandstone? This also appears to be unlikely, because Ruppel included a stratigraphic section from Mount Everts with both the Frontier Formation and his "lower Cody Shale." Thicknesses do not help, either, because Ruppel's Frontier Formation is 15 to 30 m (50 to 100 ft) thick and his middle Cody Shale is 15 m (50 ft) thick, and Tysdal et al.'s Frontier Formation is 56.5 m (185 ft) thick. It is just as likely that Tysdal et al. made a mistake calling the correlation of Ruppel's Frontier Formation into question. Reconciling these results is beyond the scope of this document, although it appears that Ruppel's version of the Cody Shale has not been followed by other authors. To ensure that reports of fossils are not omitted because of disagreements over nomenclature, YELL fossil occurrences from both conceptions of the formation will be included.

The Frontier Formation of southern YELL is 240 to 270 m (800 to 900 ft) thick and is mostly composed of sandstone and shale, with some beds of bentonite and porcellanite (impure chert), and sparse coal, most common in the lower part. It takes on a ledgey appearance due to the interspersed sandstone beds (Love and Keefer 1975).

As can be gathered from the preceding discussion, the Frontier Formation is stratigraphically complex (Merewether et al. 1979). It includes a number of internal hiatuses (Merewether et al. 1979, 2010). Thus, the duration of deposition varies between areas. At Mount Everts, the Frontier Formation includes two intervals of slightly different age, based on fossils (Tysdal et al. 1990, Merewether et al. 2010). There is a lower, Cenomanian interval predating 95.73±0.51 Ma and an upper, Turonian interval dating to 93.48±0.58 and 92.46±0.58 Ma, followed by a hiatus lasting until about 88.55±0.59 Ma, when deposition of the Cody Shale began. At Upper Slide Lake, south of YELL and east of GRTE, the Frontier Formation includes roughly equivalent Cenomanian and Turonian intervals, as well as an interval in the Coniacian predating the Cody Shale (Merewether et al. 2010). These intervals are not named, but the lowest interval occupies the same time frame as the Belle Fourche Member of greater Wyoming, the Turonian interval occupies the Emigrant Gap Member zone (Merewether et al. 2010), and the Coniacian interval occupies the Wall Creek Member zone (Johnson 2008). In places like Mount Everts where there is a depositional hiatus between the Frontier and Cody formations, the contact can seem

conformable on visual inspection but is actually disconformable (paraconformable) (Tysdal et al. 1990), while in places where there is a Coniacian interval of the Frontier Formation, the contact with the Cody Shale is gradational and arbitrary (Love et al. 1948).

The Frontier Formation is primarily a marine unit (Love and Reed 1973), but also has deltaic and fluvial beds in the area (Leier and Steidtmann 2009). Unlike the underlying Mowry Formation, the northern and southern parts of the Western Interior Seaway were connected during Frontier Formation deposition (Scott et al. 2001). A series of deltas formed on the western side of the seaway (Burgess 1971, Ryer 1977). The Mount Everts section is interpreted as shoreface and locally upper offshore in setting, in a prodelta area (Tysdal et al. 1990), and the Frontier Formation of the Madison Range was primarily deposited on and around deltas (Tysdal 1991).

The Frontier Formation is fossiliferous in YELL, although care should be taken to be aware of which stratigraphic interpretation of the formation is in use in a given report. Ruppel (1972) reported invertebrate burrows and trails and fish teeth in the Frontier Formation and the bivalve *Inoceramus* in his "middle sandstone member of the Cody Shale." Love and Keefer (1975) discussed bivalves and ammonites from a site east of the mouth of Red Creek in southern YELL. Tysdal et al. (1990) described fossils in both the Cenomanian and Turonian intervals of the formation at Mount Everts. The older portion includes marine and terrestrial palynomorphs pertaining to acritarchs, dinoflagellates, chlorophyte algae, mosses, clubmosses, ferns, and conifers (USGS Paleobotany locality D6799-A, B). The younger portion has bivalves, ammonites, gastropods, and shark teeth (USGS Mesozoic locality D11921). Coal, carbonaceous debris, and invertebrate burrows are found throughout the formation in northern YELL (Tysdal et al. 1990). Near but not within the park, similar fossils have been found at Lincoln Mountain and near Big Sky in the Madison Range (Tysdal 1991), fish scales have been found at Cinnabar Mountain (Wilson 1934), and fern fronds have been found just south of YELL (Love and Keefer 1975). Porcellanite beds are noted as sources of leaves in the area (Love and Keefer 1975).

Overall, the Frontier Formation includes diverse fossils, befitting its transitional coastal origin; note, though, that because of the formation's stratigraphic complexity and variability, at least some of these reports may not be relevant to YELL. Palynomorphs and inorganic microfossils include acritarchs (Merewether 1996), microspheres (Upshaw 1963), calcareous nannofossils (Fisher and Hay 1999), foraminifera (Young 1951, Eicher 1967, Molenaar and Wilson 1990), radiolarians (Blome and Eicher 1994), chlorophyte algae (Tysdal et al. 1990), charophyte algae (Jones 1954), dinoflagellates and other microplankton, spores, and pollen (Upshaw 1964, Tysdal et al. 1990). The formation has a significant floral assemblage, first collected by the explorer John C. Frémont from southwestern Wyoming in 1843. It includes horsetails, ferns, cycadophytes, conifers, and monocot and dicot angiosperms (Knowlton 1917, Berry 1930, Andrews and Pearsall 1941). Coal and wood are common (Uygur and Picard 1985, Moslow and Tillman 1986, Merewether et al. 2010), and root traces have also been found (Moslow and Tillman 1986). Invertebrates are represented by corals (Merewether 1996), bryozoans (Merewether and Cobban 2008), brachiopods (Merewether

et al. 2010), bivalves, ammonites (Young 1951, Upshaw 1964, Merewether et al. 1984, Merewether and Cobban 2008), nautiloids (Cobban 1990), gastropods (Young 1951, Upshaw 1964, Merewether et al. 1984, Merewether and Cobban 2008), worm tubes (Merewether and Cobban 2008), nonmarine ostracodes (Jones 1954), crabs (Merewether and Cobban 2008), echinoids (Upshaw 1964, Merewether and Cobban 2008), and trace fossils, including invertebrate burrows (Merewether et al. 1979, Molenaar and Wilson 1990), and general bioturbation (Maione 1971). Vertebrates are represented by sharks, rays, gars, pycnodont fish (Breithaupt 1985), coelacanths (Cicimurri 2001), turtles (Breithaupt 1985), the ichthyosaur *Platypterygius* (Maxwell and Kear 2010), long-necked and short-necked plesiosaurs (Cicimurri 2001), squamates (lizards and snakes) (Breithaupt 1985), crocodile relatives (Williston 1905), pterosaurs (Cicimurri 2001), and dinosaurs (Breithaupt 1985), including washed-in skeletons of the armored dinosaurs *Nodosaurus* and *Stegopelta* (Carpenter and Kirkland 1998). Reworked Paleozoic clasts with fossils including corals, bryozoans, brachiopods, crinoids, and conodonts have also been found (Dyman et al. 1989).

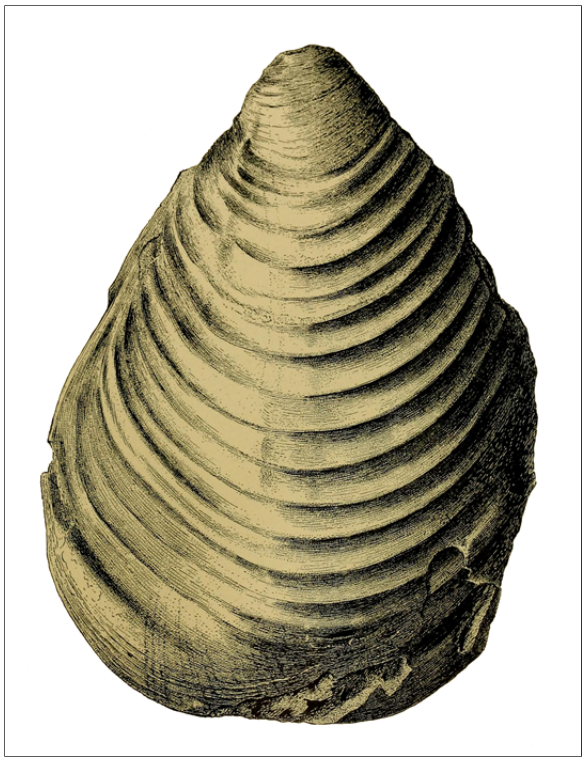
Cody Shale (Upper Cretaceous)

The Cody Shale is the youngest Mesozoic formation to be known from both northwestern and southern YELL. Issues involving the stratigraphy of the Cody Shale in northwestern YELL have already been discussed above in the Frontier Formation section. With the omission of Ruppel's (1972) basal shale and middle sandstone members as more likely the Frontier Formation, the Cody Shale of northwestern YELL is a medium to dark gray mudstone and shale unit that grades into the overlying Telegraph Creek Formation. It is approximately 240 m (800 ft) thick, although it seems thicker on Electric Peak because of numerous intruded sills (Ruppel 1972). In northwestern YELL, the Cody Shale, Telegraph Creek Formation, and part of the Eagle Sandstone probably made up Iddings and Weed's (1899) Montana Formation (Ruppel 1972). In southern YELL, it is substantially thicker, on the order of 530 m (1,730 ft), and is composed mostly of blue-grey shale with some sandstone (Love and Keefer 1975). The upper contact with the Bacon Ridge Sandstone is probably transitional in the area (Love 1956b), but is marked by a sharp lithological change in sandstone deposition in southern YELL (Love and Keefer 1975).

The Cody Shale is an offshore marine formation (Lillegraven and McKenna 1986, Leier and Steidtmann 2009). It was deposited during a marine transgression with smaller regressive cycles. Volcanism occurred during deposition, contributing to the rocks (Windolph et al. 1986). The base of the formation dates to around 88.55±0.59 Ma in the vicinity of YELL, in the middle Coniacian (Merewether et al. 2010), based on the presence of the ammonite *Scaphites ventricosus*. Although the upper part of the formation can be as young as Campanian (83.6 to 72.1 Ma) (Johnson 2008), this is in areas where the Bacon Ridge and Telegraph Creek formations are not present. The Bacon Ridge Sandstone is equivalent in part to the Cody Shale (Davidson 1987), and in the Jackson Hole area has yielded the ammonite *Scaphites ventricosus* var. *stantoni* (now assigned to S. depressus) (Love 1956b). The *Scaphites depressus* zone is the next youngest zone, spanning the early Coniacian and including a date of 87.14±0.39 Ma (Cobban et al. 2006). This indicates a relatively short

duration for the Cody Shale in southern YELL. In northern YELL, the formation persists longer, into the early Santonian (Tysdal and Nichols 1991); the Santonian began approximately 86.3 Ma.

The Cody Shale is fossiliferous within YELL. Stanton (1899) reported the bivalves *Inoceramus umbonatus* and *I. acuteplicatus* (YELL Figure 11) and the ammonites *Scaphites asper* and *S. ventricosus* from the upper Colorado Formation on the north bank of the Snake River near the mouth of Sickle Creek. Cobban et al. (1958) identified the source of the YELL syntype of the species as the Cody Shale. *I. acuteplicatus*, named by Stanton (1899), was later renamed *I. stantoni* because *acuteplicatus* was preoccupied (Sokolov 1914). The bivalve *Corbula subtrigonalis* and an ammonite fragment possibly from *Scaphites ventricosus* are known from black shales on Electric Peak in northwestern YELL (Stanton 1899). Much of Electric Peak is Cody Shale (Ruppel 1972), so these fossils likely derive from the Cody Shale as well. Cobban et al. (1958) also reported finding the ammonite *Phlycticrioceras oregonense* in the formation on Mount Everts. Other fossils from the Cody Shale on Mount Everts were described in Fox (1939), an unpublished dissertation. Another unpublished report, by Hale and others, found the formation's fauna on Mount Everts to include bivalves, cephalopods, and gastropods (Koch and Santucci 2003). Love and Keefer (1975) reported unspecified marine mollusks from the Cody Shale near Outlet Lake in southern YELL. Just north of YELL, bivalves and ammonites have been found on Cinnabar Mountain (Fraser et al. 1969).



YELL Figure 11. The YELL syntype of *Inoceramus acuteplicatus* (now *I. stantoni*), taken from Stanton (1899).

Overall, the fossil record of the Cody Shale includes marine palynomorphs (Entzminger 1979), foraminifera, bivalves, ammonites (Love 1956b), belemnites (Fox 1954), nautiloids (Reeside 1927a), serpulid worm tubes (Reeside 1927a), ostracodes (Love 1956b), barnacles (Reeside 1927a), crinoids (Cobban 1995), invertebrate trace fossils including burrows (Merewether et al. 2010) and strike marks of ammonite shells on the seafloor (Landman and Cobban 2005), and shark teeth (Fox 1954).

Bacon Ridge Sandstone (Upper Cretaceous)

The Bacon Ridge Sandstone is found in several areas of southern YELL between Yellowstone Lake and the boundary, mostly in a belt bent along the Wolverine Anticline between Big Game Ridge on the west and

Chicken Ridge on the east. It is composed mostly of light gray to tan or brown sandstone, with some finer-grained rocks. The thickness varies greatly due to erosion that preceded the deposition of the overlying Harebell Formation, and ranges from less than 150 m (500 ft) to more than 520 m (1,700 ft). The formation was formerly identified on Mount Everts in northwestern YELL, but the rocks are now assigned to the Telegraph Creek Formation and overlying Eagle Sandstone, which are similar to the Bacon Ridge Sandstone (Love and Keefer 1975).

The Bacon Ridge Sandstone is a marine formation, deposited during the last extensive Cretaceous marine transgression of the northwestern corner of Wyoming. At the time, the region was near the western shore of the seaway (Love 1956a). Depositional settings of this marginal marine formation include shorefaces, lagoons, rivers, and tidal channels. A long-lived river system feeding a major fan may have passed through Jackson Hole (Leier and Steidtmann 2009). The lower part of the formation has more of a marine influence, and the upper part is more terrestrial. Local uplift resulted in regression, overcoming a rising sea level. Volcanoes to the west in what is now Idaho contributed sediment (Davidson 1987). As discussed above in the Cody Shale section, the formation has yielded the ammonite *Scaphites depressus* var. *stantoni* (Love 1956b), indicating an early Coniacian age circa 87.14±0.39 Ma (Cobban et al. 2006) for part. Deposition continued into the following Santonian age (86.3 to 83.6 Ma) (Love 1990; Leier and Steidtmann 2009).

The Bacon Ridge Sandstone is fossiliferous within YELL. Blank et al. (1974), working in the Frank Island quadrangle of the park, reported it had abundant brackish and marine fossils. Love and Keefer (1975) mentioned several fossil occurrences in the southern part of the park. West of Barlow Peak, bivalves are found at several horizons. Bivalves and gastropods (some collected for the USGS) and leaf-producing sandstone were found about 5 km (3 miles) east-southeast of the mouth of Red Creek. Another, more substantial collection was made a little more 1 km (about 4,000 ft) southeast of the junction of the Snake and Heart rivers, where bivalves, gastropods, and worm tubes were found (Love and Keefer 1975). The Bacon Ridge Sandstone is part of the Jackson Hole coal field, mostly found outside of YELL but extending a short distance into it. It has not been mined in the park. It is the most productive of the various formations in the field (Jones 1982).

Overall, the fossil assemblage of the Bacon Ridge Sandstone includes foraminifera (Davidson 1987), marine palynomorphs (Entzminger 1979), coal, plant fragments, carbonized wood, petrified wood and stumps (Love et al. 1948), root traces (Davidson 1987), bivalves, ammonites, gastropods, shark teeth, reptile bones, indeterminate fragments (Love et al. 1948), invertebrate trails and burrows (Davidson 1987), and bioturbation (Leier and Steidtmann 2009). Marine microfossils and mollusks are more common low in the formation, while coal and other plant remains are more common higher up (Davidson 1987).

Harebell Formation (Upper Cretaceous)

The Harebell Formation is one of the most widely exposed pre-Cenozoic formations of YELL. It is present in the southern part of the park. It is a tuffaceous and heterogeneous formation that includes gray, greenish, and brown sandstone and siltstone, green, yellow, and black shale and claystone, carbonaceous

beds, and coal beds. It reaches thicknesses of 2,700 m (9,000 ft) in the park. The Harebell Formation is similar to the Landslide Creek Formation of northwestern YELL. Rocks assigned to the Landslide Creek Formation on Mount Everts and in the vicinity were once identified as the Harebell Formation, and it is possible that the Landslide Creek Formation is a northern extension of the lower Harebell Formation (Love and Keefer 1975).

Before it was named, the Harebell Formation was known in the literature as a white sandstone sequence and overlying conglomeratic sandstone sequence (Love et al. 1948). The two facies have been designated the Whetstone Falls and overlying Bobcat members. They have a gradational contact (Harris et al. 1996). The YELL outcrops of the formation are limited to the lower sandstone facies (Whetstone Falls Member) (Lindsey 1972). The upper contact of the Harebell Formation with the Pinyon Conglomerate is an angular unconformity; the angle of unconformity can be perpendicular (Love 1973). In YELL, the two are not found in contact, the small outcrops of Pinyon Conglomerate resting directly on older Mesozoic rocks (Love and Keefer 975). The Harebell Formation is lithologically very similar to the Pinyon Conglomerate, and the two have frequently been confused (Love 1973). The Harebell Formation is predominantly olive drab in color and more indurated, has abundant volcanic debris but little coal, and has some marine influence. The Pinyon Conglomerate is light gray to light brown and less indurated, has much less volcanic debris, has coal, and has no marine influence (Love 1973).

The Harebell Formation was deposited in a coastal plain to marginal marine setting, near sea level (Kauffman 1973). This formation and the overlying Pinyon Conglomerate were deposited predominantly on subsiding alluvial fans near highlands rising rapidly to the north and west. The predominant paleocurrent was east-northeast (Lindsey 1972). Sediment arrived from the Targhee Uplift to the west and from volcanoes to the north and northwest, with large rivers flowing from the uplift (Love 1973). The climate is thought to have been warm and humid, not too distant from the sea (Lindsey 1972). Marine tongues advanced twice during its deposition (Harris et al. 1996). At least once a marine tongue reached near YELL, as shown by brackish-water or marine fossils found north of Two Ocean Lake in GRTE in an estuarine setting (Kauffman 1973). The sea approached from the southeast (Love 1973). The formation dates to some part of the Maastrichtian age of the Late Cretaceous (72.1 to 66.0 Ma) (Harris et al. 1996).

The Harebell Formation is fossiliferous within YELL. Coal, carbonaceous debris, collections of pollen (USGS D3877-A and C), *Trapa*-like leaves (water chestnut), plant fragments, bivalves, and the tooth of a tyrannosaurid dinosaur (“Deinodontidae”) have been found in the park (Love 1973, Love and Keefer 1975, see Love [1973] for approximate locations and a detailed stratigraphic section, repeated in Love and Keefer 1975–the relevant units are Units 2 through 47 of the Harebell Formation). In the vicinity, Knowlton (1899) described ferns, conifers, and angiosperms from the “Laramie Formation” just south of YELL, north of Pinyon Peak in the valley of Wolverine Creek, and named several, including the ferns *Asplenium haguei* and *Onoclea minima*, and the angiosperm *Paliurus minimus*. Going by Love and Keefer (1975) and Love et al.

(1992), these plants are most likely from the Harebell Formation, although the Pinyon Conglomerate could also be involved.

Overall, the Harebell Formation fossil assemblage includes marine acritarchs and dinoflagellates (Love 1973), hystrichosphaerids (a type of cyst), unspecified spores (Kauffman 1973), charophytes, chlorophytes, pollen (Love 1973), coal, carbonized plant fragments, petrified conifer wood, pond weed seeds (Love et al. 1948), leaves of ferns, ginkgoes, possible cycadophytes, conifers, and angiosperms (Love 1956c), angiosperm fruits and nuts, soil fungus (Kauffman 1973), bivalves, gastropods, ostracodes (Love 1973), invertebrate traces (Harris et al. 1996), bones and teeth of bowfins, salamanders, crocodiles, dinosaurs (including tyrannosaurids, duckbills, and horned dinosaurs), and possible mammals (Love 1973), dinosaur tracks (Harris et al. 1996), and reworked fossils of the tree fern *Tempskya* and Paleozoic fusulinids (Love et al. 1948). Fossils from the Whetstone Falls Member include charophytes, coal, pond weed seeds, leaves of ferns, conifers, and angiosperms, bivalves, gastropods, ostracodes (Love et al. 1948), invertebrate traces, and dinosaur tracks (Harris et al. 1996).

Telegraph Creek Formation (Upper Cretaceous)

The Telegraph Creek Formation is found on Electric Peak and Mount Everts in YELL. It is primarily composed of gray limy sandstone, with some interbedded mudstone and shale. It is approximately 90 m (300 ft) thick and grades into the overlying Eagle Sandstone (Ruppel 1972). The Telegraph Creek Formation was deposited under shallow marine conditions (Cobban 1955). It is a shoreface formation, and records part of a regression (Dyman et al. 1997). There is a deltaic influence in the Madison Range (Dyman et al. 1997), and in the Billings area the formation is interpreted as shelf floor sand in advance of an eastward-moving shelf-bar sand body (Hansen 1989).

The formation can be dated to the late Santonian on the basis of ammonites; the ammonite *Desmoscaphites bassleri* is typical (Cobban 1950). There is a date of 84.30±0.34 Ma low in the *D. bassleri* ammonite zone (Cobban et al. 2006). Farther north in Montana, the formation extends into the *Scaphites hippocrepis* I zone of the Early Campanian (Shurr and Rice 1986), predating 81.86±0.55 Ma (Cobban et al. 2006), but it is not clear if the formation lasted that long in the YELL area. It may be slightly older in the YELL area (Tysdal and Nichols 1991). Because it represents part of a coastal complex, it can be assumed that its age will vary slightly from place to place.

The Telegraph Creek Formation is fossiliferous within YELL. On Mount Everts, dinoflagellates, spores, pollen (Koch and Santucci 2003), a willow-like leaf (Santucci 1998), bivalves, ammonites, invertebrate burrows, and the remains of a tortoise and an unidentified vertebrate first thought to be a plesiosaur have been found (Koch and Santucci 2003). It does not have a notably diverse fossil assemblage. Other fossils known from the formation, but so far only found outside of YELL include calcareous nannofossils (Bralower et al. 1995), carbonized wood (Cobban 1955), nautiloids (Reeside 1927b), crinoids (Cobban 1995), and invertebrate burrows (Tysdal 2000).

Eagle Sandstone (Upper Cretaceous)

The Eagle Sandstone is found on Mount Everts and caps Electric Peak in YELL. It is a cliff-forming unit composed primarily of gray sandstone, with some carbonaceous shale and coal. The formation is approximately 240 m (800 ft) thick. The basal 50 m (160 ft) of the formation is designated the Virgelle Sandstone Member; it differs from the unnamed upper part of the formation by lacking shale and coal (Ruppel 1972). The upper contact of the Eagle Sandstone with the Everts Formation is interpreted as disconformable in YELL (Ruppel 1972), but is reported to be gradational just to the north in the Gardiner area (Fraser et al. 1969). In northern YELL, the upper Eagle Sandstone, as well as the Everts Formation and Landslide Creek Formation, were probably part of Iddings and Weed's (1899) Laramie Formation (Ruppel 1972). This should not be confused with the Laramie Formation as used by Lesquereux (1872, 1878) in southern YELL.

The Eagle Sandstone of the YELL area is a mixed marine and terrestrial formation, deposited during an overall regression. Lower rocks are more marine, and upper rocks include brackish-water fossils and coal swamp deposition (Fraser et al. 1969). The Virgelle Sandstone Member has been interpreted as a coastal and interdeltaic sand unit (Shurr and Rice 1986). Fossils indicate an early Campanian age for the Eagle Sandstone in at least some areas, such as north-central Montana, where the *Scaphites hippocrepis* II zone and some younger Baculites zones are present (Shurr and Rice 1986); these zones are bracketed by dates of 81.86±0.36 and 80.58±0.55 Ma (Cobban et al. 2006). However, the formation is another time-transgressive unit, and the age becomes younger going from west to east. The top of the formation in the Gardiner area may be older than the base of the formation in central Montana (Fraser et al. 1969).

The Eagle Sandstone is fossiliferous within YELL. There is some coal above the Virgelle Sandstone Member (Ruppel 1972). Coal is present in the formation about 160 m (520 ft) south of the 45°N parallel and slightly more than 1 km (about 0.7 miles) east of the Gardner River, and coal and plant fossils have been found in the upper member 2.1 km (1.3 miles) north-northeast of Mammoth (Fraser et al. 1969). Finally, bivalves have been reported from Mount Everts (Koch and Santucci 2003).

Overall, including areas outside of YELL, the Eagle Sandstone has a limited fossil assemblage. The Virgelle Sandstone Member is mostly unfossiliferous (Sahni 1972). Fossils found in the Eagle Sandstone include dinoflagellates (Braman 2001), coal, spores, pollen, plant fossils (Fraser et al. 1969), petrified wood (Miller and Youngquist 1946), bored wood (Hansen 1989), rootlets or root traces (Tysdal 2000), bivalves, ammonites (Cobban 1955), belemnites (Miller and Youngquist 1946), nautiloids (Reeside 1927b), invertebrate burrows and general bioturbation (Spangler et al. 2011), and microvertebrate remains of sharks, fish, turtles, lizards, crocodile relatives, dinosaurs, and several types of early mammals, including multituberculates, marsupials, and eutherians (Davis and Davies 2005). Reworked shells can also be found (Fraser et al. 1969). The tyrannosaurid dinosaur *"Ornithomimus" grandis* (Marsh 1890) is often ascribed to the Eagle Sandstone, but it may be from the Judith River Formation instead (Sahni 1972).

Everts Formation (Upper Cretaceous)

The Everts Formation is found on Mount Everts in YELL, where it is a gray tuff-rich and lime-rich sandstone with some interbedded shale, mudstone, and siltstone. It is up to 370 m (1,200 ft thick). The upper contact with the overlying Landslide Creek Formation is probably disconformable (Ruppel 1972). Some older publications date it to the Santonian (Dyman et al. 1990, Tysdal and Nichols 1991), but an ash bed in the formation just north of YELL has been dated to 77.81 Ma (Hale et al. 2004), in the Campanian of the Late Cretaceous. The formation is interpreted as a delta, with lagoonal, marsh, fluvial, floodplain, shallow marine, and possibly beach deposition; unsurprisingly, it is extremely variable in terms of lithology (Fraser et al. 1969).

The Everts Formation is fossiliferous within YELL, having yielded spores, pollen, plant macrofossils, and bivalves. A diverse palynomorph assemblage has been described from the upper part of the formation at Mount Everts (USGS PB collections D6800 A-E). Hornworts, ferns, caytoniacean pteridosperms, plants from the group including ferns, lycopods, and relatives, possible cycads, conifers, angiosperms, and unknown plants are represented in the spores and pollen (Tysdal and Nichols 1991). Bivalves have also been reported from Mount Everts (Koch and Santucci 2003). Fraser et al. (1969) reported unspecified shallow marine fossils from the mountain, which are probably either bivalves or gastropods. Plant fossils have been found about 1.3 km (0.8 miles) east of Eagle Nest Rock, and bivalves are present about 0.5 km (0.3 miles) south of an island in the Yellowstone River on the 8/9 E section line (extrapolated), including in two coquinas near the top (Fraser et al. 1969). Knowlton (1899) described angiosperms and conifers from the "Laramie Formation" near the summit of the west end of Mount Everts, and named one species, the angiosperm *Phragmites falcata*. From the map in Ruppel (1972), the highest parts of Mount Everts are composed of the Everts Formation and volcanic rocks (Huckleberry Ridge Tuff per USGS [1972]), with the Eagle Sandstone making up a significant part of the western slope below the Everts Formation. The Everts Formation is the most likely source for these fossils. Overall, the only fossils known from the Everts Formation not yet reported from YELL are coal and gastropods (Fraser et al. 1969).

Landslide Creek Formation (Upper Cretaceous)

The Landslide Creek Formation is the youngest Cretaceous unit in northwestern YELL. It is present on Mount Everts in YELL, where it is a greenish-gray sandstone and conglomerate unit with fragments of andesitic volcanic rocks. It is generally concealed by glacial debris. No formal formations overlie it in the park (Ruppel 1972). As noted in the Harebell Formation section, the Landslide Creek Formation is quite similar to the Harebell Formation of southern YELL, and may represent a northern extension (Love and Keefer 1975). Its rocks were sometimes included as the lower part of the now-abandoned Reese Formation, or mapped as the Judith River Formation (Fraser et al. 1969). The Landslide Creek Formation is primarily fluvial, with some volcanic input (Fraser et al. 1969). It dates to the Campanian and possibly Maastrichtian ages of the Late Cretaceous (Tysdal and Nichols 1991, Hale et al. 2004), between 83.6 and 66.0 Ma.

The Landslide Creek Formation is fossiliferous within YELL. Like the

underlying Everts Formation, there is a diverse palynoflora known from Mount Everts (USGS PB collections D6800 F-G). Plants represented by pollen and spores include mosses, hornworts, clubmosses, ferns, plants from the group including ferns, lycopods, and relatives, and angiosperms (Tysdal and Nichols 1991). Additionally, coal and plant fossils including twigs have been found about 1.3 km (0.8 miles) east of Eagle Nest Rock (Fraser et al. 1969). Another fossil site is just east of YELL between Highway 89 and Little Trail Creek, where carbonaceous plant debris, plant fossils, and rare dinosaur bone fragments have been found (Fraser et al. 1969). The fossil assemblage of the Landslide Creek Formation is represented entirely by these collections from in and around YELL, and includes coal, palynomorphs, plant debris, and dinosaur bone fragments. Plant debris is common, and can make up beds, while dinosaur bone fragments are only present locally (Fraser et al. 1969).

Unspecified Sedimentary Rocks of the Absaroka Volcanic Supergroup (Lower–Middle Eocene)

The sedimentary fraction of the Absaroka Volcanic Supergroup hosts abundant paleobotanical fossils, best known from the Sepulcher and Lamar River formations, but also present throughout. William Fritz (City University of New York interim president and professor of geology) noted that "fossil leaves and wood occur in various formations of the overlying Sunlight and Thorofare Creek groups throughout the eastern and northeastern parts of the Park," but have not been formally collected or described (pers. comm., July 2013).

Lesquereux (1872) reported plant fossils including horsetails and angiosperm foliage from rocks associated with basalts near Yellowstone Lake. Knowlton (1899) later named *Equisetum lesquereuxii* from this "site." Mapping indicates that the Langford Formation and Trout Peak Trachyandesite are both present in that area (USGS 1972); either could conceivably be the source, but the Langford Formation seems more likely because it is more fossiliferous.

There is a report of carbonized and silicified wood from below the Crescent Hill Basalt between the headwaters of Glade Creek and Oxbow Creek in northern YELL (Howard 1937). This report predates the organization of the Absaroka Volcanic Supergroup and its constituent units by Smedes and Prostka (1972), so it is unclear what formation they may pertain to, although the Lamar River and Sepulcher formations are both present in the area (USGS 1972) and would satisfy the stratigraphic position.

Koch and Santucci (2003) mentioned a report (Hendrix 2003) on fossil plant material exposed during a road construction project between Sylvan Pass and the East Entrance. "Poorly preserved wood casts and wood debris" were found in debris flow deposits in this area. USGS (1972) shows that the primary unit of this area is the Trout Peak Trachyandesite, with the Langford Formation present in the west near Sylvan Pass; either formation, or both, could be the source.

Washburn Group: Sepulcher Formation (Lower Eocene)

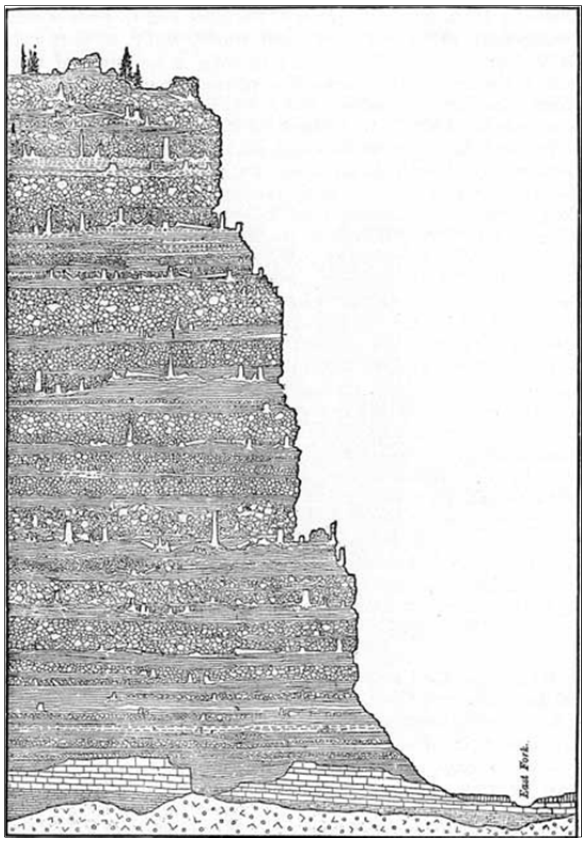
The Sepulcher Formation is one of two formations that preserve the majority of the famous "fossil forests" of YELL and the vicinity, the other being the Lamar River Formation. The Sepulcher Formation is found in northern and northwestern YELL as far east

as Specimen Ridge (USGS 1972), and is informally associated with the Gallatin Range (for example. the “Gallatin Fossil Forest”). Its rocks were mostly included in the “early acid breccia” of early reports. The Sepulcher Formation is part of the first phase of activity in the Absaroka volcanic field, and was deposited directly on an eroded landscape with relief of more than 150 m (500 ft). This contributes to its notably variable thickness, which can be less than 300 m (1,000 ft) or more than 900 m (3,000 ft), as seen at Sepulcher Mountain. In some locations, such as at Oxbow Creek, it is even thinner, roughly 150 m (500 ft) thick, but this is a special case because there is an internal disconformity. Like the other units of the Absaroka Volcanic Supergroup that are not primarily volcanic flows, the Sepulcher Formation is a combination of volcaniclastic sedimentary rocks (also known as the alluvial facies), rocks from or immediately adjacent to volcanic centers (the vent facies), and occasional volcanic flows. It is mostly light-colored, unlike the darker but similar Lamar River Formation, and typically transitions to a greater proportion of vent facies rocks higher in a given section and closer to the source volcanoes in the Gallatin Range (Smedes and Prostka 1972, Fritz 1982). Essentially, the two formations represent the interfingering of debris from different volcanic sources (Fritz 1980a, 1982)

The Sepulcher Formation can include several distinct units, depending on location. The base of the formation locally includes a prominent conglomerate, previously known as the Crandall(?) Conglomerate based on a mistaken correlation. The lower part of the formation includes lava flows known as the Elk Creek Basalt Member, which is also found in the Lamar River Formation. This member is up to 90 m (300 ft) thick and includes two to four basalt flows, sometimes separated by minor amounts of volcaniclastic sediments. Above the Elk Creek Basalt Member is rhyodacite tuff known as the Lost Creek Tuff Member, identified in older reports as “trachytic rhyolite.” This member is up to 300 m (1,000 ft) thick but thins rapidly and pinches out within YELL. At its thickest, it can include three tuffs. The Elk Creek Basalt and Lost Creek Tuff members were once thought to be late Cenozoic in age due a miscorrelation of the basalt, but are now known to belong to the Absaroka Volcanic Supergroup. Additionally, portions of the basal conglomerate and the Lost Creek Tuff Member once made up the upper part of the now-abandoned Reese Formation. Two more units are present in northwestern YELL above the tuff: the light-colored Daly Creek Member and overlying dark gray Fortress Mountain Member. The Sepulcher Formation is closely related to the Lamar River Formation, and the two units frequently have interfingering or gradational contacts with the exception of the Washburn Range, where there is a local angular unconformity representing a short hiatus. The upper contact with rocks of the Sunlight Group varies; the contact with the Crescent Hill Basalt is intertonguing, and the contact with the Mount Wallace Formation, which may be the same as the Crescent Hill Basalt, is depicted as conformable; other units have a disconformable contact. The Sepulcher Formation dates to the late Early Eocene; the Lost Creek Tuff Member has been dated to 49.2±1.5 Ma, and the overlying Mount Wallace Formation is beneath a tuff dated to 48.0±1.3 Ma (Smedes and Prostka 1972). The Sepulcher Formation is now known to be roughly the same age as the Lamar River Formation, but in some older works the rocks

of the “early acid breccia” were thought to be as old as the Cretaceous (Young 1940), due to a mistaken correlation with the Fort Union Formation (now known to be Paleocene, but sometimes thought to be Cretaceous) (Dorf 1939). The Sepulcher Formation fossils are also sometimes depicted as slightly older than the Lamar River Formation fossils (Dorf 1939).

As discussed in the Geologic Background, the Sepulcher Formation and the rest of the Absaroka Volcanic Supergroup derive from two belts of stratovolcanoes that crossed YELL (Chadwick 1970). The original interpretation of the fossil forests of the Sepulcher and Lamar River formations emphasized airfall of volcanic debris as the major mechanism for burying multiple successive horizons of *in-situ* forests (YELL Figure 12) (Holmes 1879, 1883, Weed 1892, Knowlton 1898a, 1914, Mitchell 1926, Young 1940, Sanborn 1951, Dorf 1960, 1964). This left an oddity: many horizons included a mix of temperate and tropical plants, which was interpreted as evidence that the Eocene plants had different environmental tolerances than would be expected based on modern relatives (Fritz 1980a, 1982). The prevailing model was challenged during the 1970s and 1980s. The more modern model for the fossil plants of the Sepulcher and Lamar River formations, as developed in Fritz (1980a, 1982, 1986) and Yuretich (1984), is that the formations are complex alluvial systems situated near volcanoes, with braided and meandering rivers, lakes, and frequent mudflows and debris flows. Temperate trees growing at high elevations around the volcanoes were sometimes transported to lower elevations by mudflows and fluvial processes. In some cases, they were transported into lakes. In other cases, forests were killed where they



YELL Figure 12. Idealized column of Specimen Ridge (Lamar River Formation) following the traditional interpretation of stacked fossil forests. From Knowlton (1914), in turn modified after Holmes (1879, 1883).

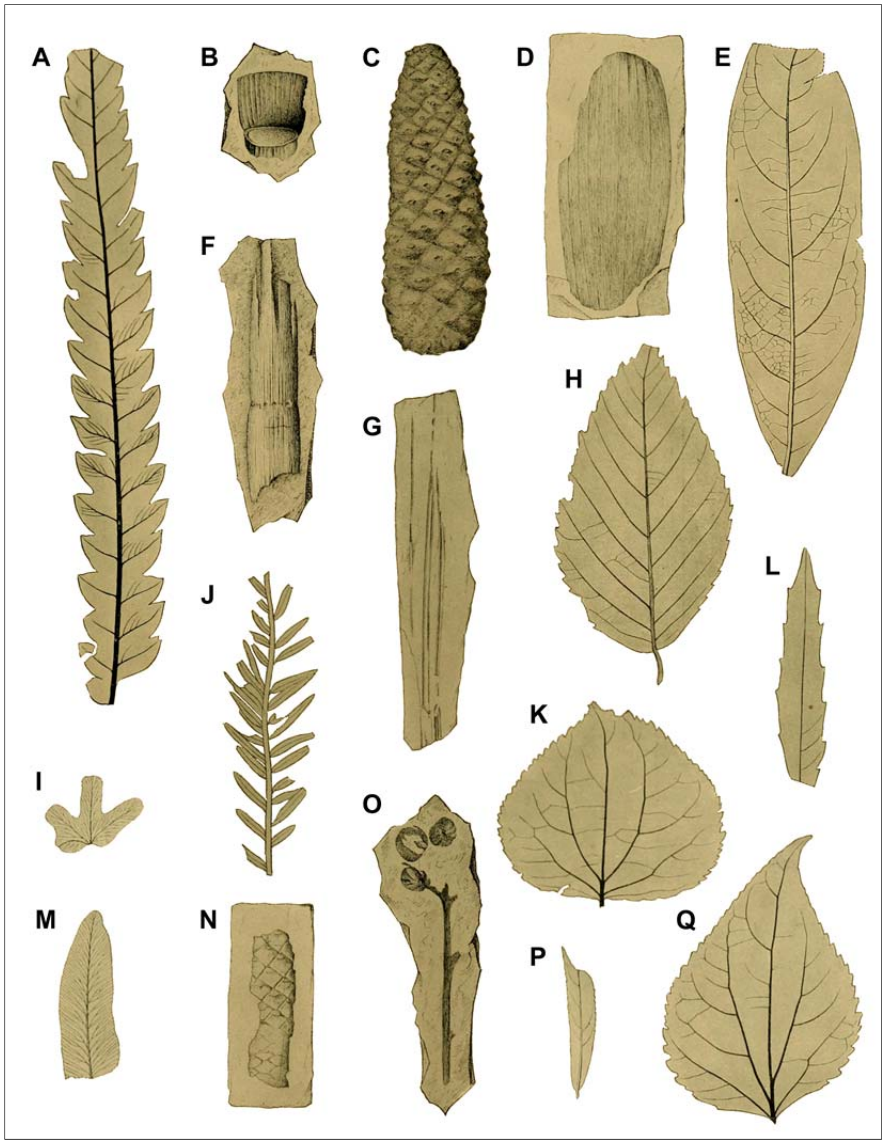
stood by mudflows or rising lake waters. Airfall debris was only a minor part of burial. Instead of large intact fossil forests in layer-cake succession, there are smaller “fragments” of *in situ* forests, as seen on Specimen Ridge and Amethyst Mountain, and concentrations of transported logs, as described by Yuretich in Fritz and Yuretich (1984). Dorf (1960) interpreted the climate of the Sepulcher and Lamar River formations as warm temperate to subtropical with rainfall of 130 to 150 cm (50 to 60 in), similar to the modern southeastern or south-central United States, but this is not necessarily accurate following the reevaluation of the depositional model. More recently, Wiemann et al. (1999) interpreted

wood from the Lamar River and Sepulcher formations to suggest mean annual temperatures of 23.4°C (74.1°F) or 17.7°C (63.9°F), depending on method, while leaves suggested 10.9 to 10.5°C (51.6 to 50.9°F).

It is somewhat misleading to describe the fossils of the Sepulcher Formation separately from the Lamar River Formation; the formations were approximately contemporaneous and were deposited by the same processes. They are occasionally confused; for example, Wiemann et al. (1999) listed Specimen Ridge and Amethyst Mountain as Sepulcher Formation sites. They will be kept separate here, based on precedent going back to the "early acid breccia" and "early basic breccia" of the late 19th century.

The Sepulcher Formation is very fossiliferous within YELL, with foliage, wood, and palynomorphs representing mosses, clubmosses, ferns, horsetails, conifers, and angiosperms. 47 plant taxa appear to have been named from specimens found in this formation in the park, including a handful of taxa with syntype series also incorporating material from the Lamar River Formation. Fossil trees and forests are common in the Fortress Mountain Member; Smedes and Prostka (1972) referred to the presence of at least 30 fossil forest horizons in that unit, although as discussed above the "fossil forest" phenomenon is a combination of *in situ* forests and transported material. Fossils are not limited to the Fortress Mountain Member: plant fragments have been found in a thin shale within the basal conglomerate at the mouth of Hellroaring Creek in YELL (Smedes and Prostka 1972); charred wood is common in the Lost Creek Tuff Member, and charred logs are locally present (Smedes and Prostka 1972); and the same kinds of fossils found in the Fortress Mountain Member are found throughout the Daly Creek Member (Fisk 1976). Aside from the publications discussed below, Sepulcher Formation plant fossils from YELL are discussed in many other publications, including Knowlton (1896), Conard (1930), Fisk and DeBord (1974a), Fritz (1982), Chadwick and Yamamoto (1984), Wheeler (1995), Wiemann et al. (1999), and Stefos and Jorstad (2002). A selection of paleobotanical fossils from the Sepulcher and Lamar River formations is pictured in YELL Figure 13.

Areas where the Sepulcher Formation is especially fossiliferous in YELL include Specimen Creek in northwestern YELL (not to be confused with Specimen Ridge of the Lamar River Formation) and near Yancey's Ranch in north-central YELL (Fritz 1982). Fossils were first described from outcrops in north-central YELL, and later "fossil forests" were found in the Gallatin Range within and near northwestern YELL. The first fossil described from the formation in the park may be the nut *Carpolithes osseus*, named and described by Lesquereux (1873) from a site near the mouth of Elk Creek. The conifer wood taxa *Cupressinoxylon eutreton* and *Pityoxylon fallax* described by Felix (1896) were probably named from the Sepulcher Formation, being described from the Yancey's–Lost Lake area. Knowlton (1899) described plant fossils from 13 general localities, divided between three floras which he called the "Fort Union," "Intermediate," and "Lamar Flora". The sites are: (1) Yellowstone River, half a mile below mouth of Elk Creek; (2) Yellowstone River, 1 mile below Elk Creek, opposite Hellroaring Creek; (3) northeast side of Crescent Hill; (4) Crescent Hill, above (west) Yanceys; (5) peak west of Dunraven on Carnelian Creek;



YELL Figure 13. A selection of plant fossils from the Sepulcher and Lamar River formations (and the Langford Formation, XC) of YELL, taken from Knowlton (1899). **A.** foliage of the fern *Asplenium magnum*, from the Yellowstone river below Elk Creek; **B.** stem of the horsetail *Equisetum deciduum*, from the Yellowstone River below Elk Creek; **C.** cone of conifer *Pinus premurrayana*, from east of Yellowstone Lake; **D.** petal of *Magnolia? pollardi* (described as an angiosperm, possibly a cycad), from fossil Forest Ridge; **E.** foliage of the angiosperm *Juglans laurifolia*, from Yancey's Fossil Forest; **F.** stem of the horsetail *Equisetum canaliculatum*, from Specimen Ridge; **G.** needles of the conifer *Pinus iddingsi*, from west of Dunraven; **H.** foliage of the angiosperm *Betula iddingsi*, from the Yellowstone River below Elk Creek; **I.** foliage of the fern *Lygodium kaulfussi*, from the Lamar River between Cache and Calfee creeks; **J.** foliage of the conifer *Taxites olriki?*, from above the mouth of Hellroaring Creek; **K.** foliage of the angiosperm *Populus glandulifera*, from the Yellowstone River below Elk Creek; **L.** foliage of the angiosperm *Myrica scotti*, from the Yellowstone River below Elk Creek; **M.** foliage of the fern *Osmunda affinis*, from a hill above Lost Creek; **N.** cone of the conifer *Pinus gracilistrobus*, from Fossil Forest (Amethyst Mountain); **O.** cones of the conifer *Sequoia* sp., from Fossil Forest (Amethyst Mountain); **P.** foliage of the angiosperm *Myrica lamarensis*, from the Lamar River between Cache and Calfee creeks; **Q.** foliage of the angiosperm *Populus daphnogenoides*, from the Yellowstone River below Elk Creek.

(6) (head of) Tower Creek; (7) Fossil Forest and vicinity, 1 mile south of Yanceys; (8) hill south of Yanceys; (9) hill above (north) of Lost Creek; (10) Specimen Ridge, near Crystal Creek; (11) Fossil Forest or Fossil Forest Ridge [Amethyst Mountain]; (12) cliff

west of Fossil Forest, near Chalcedony Creek; and (13) Lamar River, between Cache and Calfee creeks. The first six are assigned to the "Fort Union," 7 through 10 are "Intermediate," and 11 through 13 represent his "Lamar Flora." A reasonable first-order assumption is that the "Fort Union" is the Sepulcher Formation and "Lamar Flora" is the Lamar River Formation, but it is not quite that simple. Per inspection of USGS (1972), sites 1, 2, 4, 7, 8, 9, and probably 3 are in the Sepulcher Formation, and sites 10, 11, 12, 13, and probably 5 and 6 are in the Lamar River Formation. Fossils in Knowlton (1899) from sites that can be attributed to the Sepulcher Formation include foliage of ferns, horsetails, and conifers, and angiosperm foliage and wood (the species *Magnolia? pollardi* is sometimes listed as a possible cycad, *Zamites? pollardi*, following Dorf 1960).

The Gallatin fossil forest area is found in northwestern YELL and adjacent areas of the Gallatin Range outside of the park (Young 1940, Andrews and Lenz 1946, Fisk 1976). It has historically been poorly known and is difficult to reach (Sanborn 1951). There are two major areas of exposures: Ramshorn Peak outside of YELL and Big Horn Peak in YELL, which includes the Specimen Creek sites on the southern flank. Good outcrops can also be found in the vicinity of the headwaters of Daly Creek on the park boundary (Fisk 1976). Knowlton (1914) briefly mentioned the fossil forest area, which at that was not known to extend into YELL. Andrews (1939) made the first description of fossils from Specimen Creek in northwestern YELL, reporting conifer wood and foliage. Wheeler et al. (1977) described angiosperm wood from the Gallatin fossil forests in northwestern YELL. DeBord (1979) described palynomorphs from Specimen Creek, recording over 130 forms representing mosses, clubmosses, ferns, conifers, angiosperms, and unknown plants. Other fossils from the Gallatin fossil sites include fern and angiosperm foliage and pine cones (Young 1940), but these are not necessarily known from within YELL. Conifers are historically the best-known fossils from the Gallatin fossil forests (Fisk 1976). The wood sometimes appears to be bored by insects (Young 1940), but apparent bored wood at Amethyst Mountain is actually the result of differential mineralization: some wood cells were replaced by calcite instead of silica, and later were preferentially eroded (Fisk and Fritz 1984). The same process may have occurred in the Gallatin fossil forests. Mineralization of the petrified wood in the Sepulcher and Lamar River formations involved the filling of cell cavities with minerals, preserving the durable and relatively inert cell walls (Dorf 1960).

The fossil assemblage of the Sepulcher Formation within YELL is characteristic of the formation in general. Interestingly, no vertebrates or invertebrates are known (Fisk 1976).

Washburn Group: Lamar River Formation (Lower Eocene)

The Lamar River Formation contains the "fossil forests" of northeastern YELL, well-represented at Amethyst Mountain and Specimen Ridge. It is mostly exposed from Specimen Ridge east to the park border and Miller Creek north to the park border, with a

second area mapped around Mount Washburn and Dunraven Peak (USGS 1972). It is composed of brown volcaniclastic rocks, andesitic lava flows, and uncommon basaltic flows. It represents the lower two-thirds of the former "early basic breccia," the rest of the historic unit being taken by the slightly darker Wapiti Formation (under "Potential Sources of Paleontological Resources"). It can be more than 980 m (3,200 ft) thick in the Washburn Range, but is more typically 150 to 670 m (500 to 2,200 ft) thick, thinning away from the source vents. The upper contact with the Langford Formation or Wapiti Formation is disconformable, and can have up to 300 m (1,000 ft) of relief. The Elk Creek Basalt Member, previously discussed in the Sepulcher Formation section, also appears in the Lamar River Formation, where individual basalt flows are separated by much greater thicknesses of sedimentary rocks (Smedes and Prostka 1972).

The Lamar River Formation was deposited much like the Sepulcher Formation, by a combination of mudflows, debris flows, rivers, lakes, and volcanic airfall and flows (Fritz 1980a, 1982, 1986, Yuretich 1984). The most noticeable difference is that the Lamar River Formation was deposited between the two belts of Absaroka Volcanic Supergroup stratovolcanoes (Fritz 1980a, 1982), unlike the Sepulcher Formation, which is associated with only the western belt. Mount Washburn is interpreted as the remains of one of the volcanoes that produced the Lamar River Formation (Smedes and Prostka 1972). The age of the formation is approximately the same as the Sepulcher Formation, to slightly younger.

The Lamar River Formation, like the Sepulcher Formation, is extremely fossiliferous within YELL, with foliage, wood, palynomorphs, and other remains representing ferns, horsetails, conifers, and angiosperms. Most references deal with material either from Specimen Ridge or Amethyst Mountain. 69 plant taxa appear to have been named from specimens found in this formation in the park, including a handful of taxa with syntype series also incorporating material from the Sepulcher Formation. Roughly 200 plant taxa are known from the formation (Fritz 1980b); the taxonomy of the plant macrofossils is detailed most recently in Dorf (1960).

The first new species that can be definitely attributed to Lamar River Formation rocks from YELL are *Plataninium haydeni*, *Quercinium knowltoni*, and *Rhamnacinium radiatum*, angiosperm wood taxa named by Felix (1896) from specimens found on Amethyst Mountain. The first synoptic account of the fossil plants of the Lamar River Formation is Knowlton (1899). As discussed above in the Sepulcher Formation section, sites 10, 11, 12, 13, and probably 5 and 6 are in the Lamar River Formation. These sites are: (5) peak west of Dunraven on Carnelian Creek; (6) (head of) Tower Creek; (10) Specimen Ridge [not to be confused with Specimen Creek], near Crystal Creek; (11) Fossil Forest or Fossil Forest Ridge [Amethyst Mountain]; (12) cliff west of Fossil Forest, near Chalcedony Creek; and (13) Lamar River, between Cache and Calfee creeks. Fossils in Knowlton (1899) from sites that can be attributed to the Lamar River Formation include foliage of ferns and horsetails, and wood and foliage of conifers and angiosperms (the species *Magnolia? pollardi* is sometimes listed as a possible cycad, *Zamites? pollardi*, following Dorf [1960]). Additional wood taxa from Amethyst Mountain and Specimen Ridge

were described by Platen (1908), Beyer (1954), and Wheeler et al. (1977, 1978). Some wood has been described as having been bored by insect larvae (Brues 1936), but more recent investigation indicates that the bored appearance is the result of differential mineralization and erosion (Fisk and Fritz 1984). The most abundant plants are sycamores, walnuts, magnolias, chestnuts, oaks, redwoods, maples, and dogwoods (Dorf 1960, 1964). In terms of diversity, angiosperms represent about three quarters of the roughly 100 taxa known from macrofossils like leaves or wood, with conifers, ferns, and other nonflowering plants taking up the remaining quarter (Dorf 1964). Conglomeratic beds have the most logs, stumps, and wood. Rocks near the source volcanoes are dominated by temperate conifers, while those farther away have mixed temperate and tropical plants (Fritz 1982). Pollen and spores are also known from the formation within YELL (Fisk and DeBord 1974b).

The Lamar River Formation's fossil forest region occupies an extensive area, on the order of hundreds or perhaps thousands of square miles (W. Fritz, pers. comm., July 2013); the segments on Specimen Ridge and Amethyst Mountain alone have been described as occupying more than 50 km^2 (20 $miles^2$) in YELL (Dorf 1960). Early works described the tree and log specimens as up to 3 m (10 ft) in diameter and 15 m (50 ft) long (Weed 1892). Until the 1980s, the Lamar River Formation was thought to include 27 or more distinct successive fossil forests (Dorf 1964; Fritz 1982), existing over a total time span of perhaps 20,000 years (Dorf 1964). More recent work following the mudslide/fluvial/lacustrine model indicates perhaps 9 to 12 true stump levels, at least on Specimen Ridge (Yuretich 1984). At least one interval of contemporary trees has been described from tree rings signatures (Ammons et al. 1987). Santucci et al. (2009) used historic photos of stumps on Specimen Ridge as an example of a method for monitoring site conditions over time. Other publications that discuss Lamar River Formation fossils from YELL include Holmes (1883), Knowlton (1896, 1898a), Platen (1909), Chaney (1926), Conard (1930), Beyer (1950), Sanborn (1951), Brown (1961), Prostka et al. (1975a, 1975b), Fisk and DeBord (1974a), Fritz and Fisk (1977, 1978, 1979), Fisk et al. (1978), Fritz (1979), Hamilton (1982), Fritz and Harrison (1985), Wing (1987), Wheeler (1993, 1995), Wing and Greenwood (1993), Wiemann et al. (1999), and Collinson (2002). A selection of paleobotanical fossils from the Lamar River and Sepulcher formations is pictured in YELL Figure 13.

The fossil assemblage of the Lamar River Formation within YELL is characteristic of the formation in general. Again, as with the Sepulcher Formation, no vertebrates or invertebrates are known.

Thorofare Group: Langford Formation (Lower–Middle Eocene)

The Langford Formation is a light-colored unit composed of alluvial volcaniclastic sedimentary rocks and andesitic lava flows, up to 600 m (2,000 ft) thick. It includes some rocks formerly mapped as the "late acid breccia" and "late basic breccia." Several dark tongues of volcanic conglomerate and breccia, on the order of 180 m (600 ft) thick, are known as the Promontory Member. The upper contact of the formation with the overlying Two Ocean Formation is disconformable (Smedes and Prostka 1972). It dates to approximately the Early-Middle Eocene boundary, being bracketed by the Pacific

Creek Tuff Member of the Trout Peak Trachyandesite (48.0±1.3 Ma) below and the Two Ocean Formation (47.9±1.3 Ma) above (Smedes et al. 1989) (both formations are discussed below under "Potential Sources of Paleontological Resources").

The Langford Formation is fossiliferous within YELL. Knowlton (1899) named the conifer *Pinus premurrayana* (YELL Figure 13C) from a cone found east of Yellowstone Lake; Axelrod (1986) reported that this species is probably from the Langford Formation. Love and Keefer (1975) reported that fragments of petrified wood and logs are common in most exposures of the formation. Santucci (1998) reported that leaves of the sycamore *Macginitiea* were found during construction on the East Entrance road. Additionally, reworked Paleozoic rocks are present in the formation (Love and Keefer 1975), which indicates that reworked fossils may be found. Over its entire depositional area, the Langford Formation's fossil assemblage is similar to what is found in YELL, and its fossils are not particularly well-known. A locality at Emerald Lake, about 6.8 km (4.2 miles) south of YELL, was attributed to the Wiggins Formation by Love et al. (1976), but is now attributed to the Langford Formation (Barnosky 1984). Wood and leaves were found at this site (Love et al. 1976).

Heart Lake Conglomerate (Lower Pleistocene or Pliocene)

The Heart Lake Conglomerate is a very localized unit which outcrops only in two areas on the east and south slopes of Mount Sheridan and in an area south of the Basin Creek canyon. It is mostly conglomeratic, with the majority of the clasts from the Madison Limestone, but also has tuffaceous sandstone and claystone. The formation can be 23 to 40 m (75 to 130 ft) thick. The upper contact with an overlying tuff of the Yellowstone Group may be transitional, at least locally (Love and Keefer 1975). It derives from the erosion of a local uplift (the Basin Creek Uplift) during the Pliocene or Pleistocene (Love and Keefer 1969). The Heart Lake Conglomerate is fossiliferous within YELL, although all of its fossils are reworked. As noted, it is mostly made up of Madison Limestone clasts, and some of them are fossiliferous, bearing corals, crinoids, and other fossils. Pollen has been found in the overlying tuff, so it might be present in the Heart Lake Conglomerate as well (Love and Keefer 1969).

Unnamed Sedimentary Rocks (Lower Pleistocene or Pliocene)

There are a variety of local sedimentary rock units above the Absaroka Volcanic Supergroup. Many of them are undescribed or even unrecognized as distinct. Richmond et al. (1978) reported on two widely separated hitherto-unsuspected sedimentary rock units. Both were mapped as Sepulcher Formation rocks on USGS (1972), and both have produced spores and pollen. Locality TJ-1, south of Dunraven Peak near a small dam, consists of greenish gray or brown conglomerate, sandstone, and siltstone. A siltstone bed yielded pollen and spores of mosses, conifers, and angiosperms. Some coalifed logs and plant material had also been reported from this locality in a dissertation (Shultz 1962), but could not be found by Richmond et al. (1978), possibly due to slumping. True Eocene angiosperm leaf fossils were found about 0.3 km (0.2 miles) to the southwest. Locality TJ-2, near Petrified Tree, consists of buff siltstone and greenish gray to buff sandstone. Siltstone here yielded spores and pollen of mosses, spikemosses, conifers, and angiosperms. The two localities lack rock

fragments from the Yellowstone Plateau volcanic field, and their pollen profiles differ strongly from the Eocene rocks. The rocks at TJ-1 are thought to correlate to a gravel unit found beneath the Junction Butte Basalt (Richmond et al. 1978), a volcanic flow with an age of 2.16±0.04 Ma (Christiansen 2001). The rocks at TJ-2 are similar to the gravel at Mount Everts, below the Huckleberry Ridge Tuff (Richmond et al. 1978), which erupted at about 2.059±0.004 Ma (Lanphere et al. 2002). The two localities are probably similar in age, and their pollen content is similar to the modern, suggesting a similar climatic regime (Richmond et al. 1978). Richmond et al. (1978) proposed a latest Pliocene age, but the Pliocene–Pleistocene boundary has been revised to 2.588 Ma from much younger dates, which translates to a probable Early Pleistocene age. These fossils are also briefly mentioned in Richmond (1986).

Yellowstone Plateau Volcanic Field Rocks (including Yellowstone Group) (Pleistocene)

The rocks of the Yellowstone Plateau volcanic field encompasses the numerous volcanic flows, tuffs, and igneous intrusions associated with the Yellowstone Hotspot within and around YELL, mostly between about 2.15 Ma and 70,000 years ago. As such, the rocks are only marginally fossiliferous, and unlikely to produce abundant fossils. Thus, although the Yellowstone Plateau volcanic field is extremely important to YELL and the Greater Yellowstone Network in general, it is not as relevant for a paleontological resources report, and the following discussion is brief and mostly devoted to chronology. There are also some sedimentary rocks associated with and interspersed within the rocks of the Yellowstone Plateau volcanic field (Christiansen and Blank 1972), but for convenience they are excluded from this section, which is therefore limited to the various igneous rocks.

The rocks of the Yellowstone Plateau volcanic field are described extensively in Boyd (1961), Christiansen and Blank (1972), Christiansen (2001), and Morgan et al. (2008). They are divisible into three caldera-forming volcanic cycles. Each cycle included a significant volcanic tuff unit produced by the caldera-forming eruption(s) and associated igneous flows; the three tuffs are grouped together as the Yellowstone Group, but not the flows. Two of the cycles, the first and the third, are represented by rocks within YELL. The second, which produced the Henry's Fork Caldera and Mesa Falls Tuff, occurred mostly west of the park at about 1.3 Ma (Christiansen 2001, Morgan et al. 2008).

The first cycle produced the Huckleberry Ridge Caldera and Huckleberry Ridge Tuff (Morgan et al. 2008), along with several smaller units including the Junction Butte Basalt (2.16±0.04 to 2.01±0.05 Ma), Rhyolite of Snake River Butte (1.99±0.02 Ma), and some of the Big Bend Ridge Rhyolite (1.82±0.01 Ma) (Christiansen 2001). The Huckleberry Ridge Tuff includes three members, each representing massive volcanic eruptions. Member A, at the base, is thought to have originally covered an area of 6,280 km^2 (2,420 mi^2) with a volume of at least 820 km^3 (200 mi^3). It probably was erupted from somewhere near the center of the Yellowstone Plateau. The overlying Member B is thought to have covered an area of 15,400 km^2 (5,950 mi^2) with a volume of 1,340 km^3 (320 mi^3). The source is thought to have been in the Big Bend Ridge area of Idaho. Member C, at the top, is thought to have covered an area of 3,690 km^2 (1,420 mi^2) with a volume of at

least 290 km^3 (70 mi^3). Its source is interpreted as near the Red Mountains and the South Entrance of YELL. The first eruption probably triggered the second, which in turn triggered the third, with the sequence being almost simultaneous (Christiansen 2001). The series of eruptions occurred at about 2.059±0.004 Ma (Lanphere et al. 2002). Associated with these eruptions, a broad area of southern and western YELL and adjoining areas of Idaho and Montana collapsed into a large caldera (Christiansen 2001).

The third cycle produced the Yellowstone Caldera and Lava Creek Tuff (Christiansen 2001, Morgan et al. 2008), and a number of other units. Preceding the Lava Creek Tuff are the Lewis Canyon Rhyolite (0.853±0.007 Ma) and most of the Mount Jackson Rhyolite (various events, 1.22±0.01 to 0.609±0.006 Ma). The Lava Creek Tuff consists of two major ash flows, defined as unnamed members (Christiansen and Blank 1972, Christiansen 2001). The lower member covered approximately 3,240 km^2 (1,250 mi^2), with a volume estimated at 510 km^3 (120 mi^3), and the upper member covered approximately 7,300 km^2 (2,820 mi^2), with a volume of 490 km^3 (120 mi^3) (Christiansen 2001). The Lava Creek Tuff erupted at 0.639±0.002 Ma (Lanphere et al. 2002). Following the main eruption, there have been numerous smaller eruptions consolidated as the Plateau Rhyolite (0.481±0.008 to 0.071±0.002 Ma) and a number of local basalts (between 0.64 and 0.11 Ma) (Christiansen 2001).

The rocks of the Yellowstone Plateau volcanic field is fossiliferous within YELL. A tuff just above the Heart Lake Conglomerate near the Basin Creek canyon has yielded conifer and angiosperm pollen (Love and Keefer 1969). The younger tuff of Uncle Toms Trail, part of the Upper Basin Member at the base of the Plateau Rhyolite (Christiansen 2001), has pollen thought to represent a warm closed pine forest from a time before the Bull Lake glaciation (Richmond 1987). The major tuffs are not known to be fossiliferous, but may prove to be fossiliferous; macrofossils would most likely be found at the base of tuff units, buried by the ashfall. Tuffs are more likely to have fossils than the volcanic flows, which elsewhere occasionally produce tree casts, and the only fossils that might be found in intrusive units would be fossils in fragments of host rock that have been incorporated into the intrusive body.

Quaternary Rocks and Sediments (Pleistocene–Holocene)

YELL has substantial areas covered by unconsolidated Quaternary sediments, representing diverse environments and depositional processes including alluvial, colluvial, floodplain, fluvial, glacial, hot spring, landslide, lacustrine, loess, swamp, and talus deposits (Pierce 1973a, 1973b, 1974a, 1974b, Richmond 1973a, 1973b, 1973c, 1973d, 1974, 1977, Richmond and Pierce 1971a, 1971b, 1972, Richmond and Waldrop 1972, 1975, Waldrop 1975a, 1975b, Waldrop and Pierce 1975, Love et al. 2007). The Quaternary sediments of YELL are extensively fossiliferous. Many lakes, ponds, and former bodies of water have yielded records of diatoms (a type of algae with cell walls of silica) and pollen from various times during the Pleistocene and Holocene. Caves include packrat middens with thousands of bones. Reworked petrified wood from the Eocene is found throughout, and there are even a few rare megafaunal finds, some associated with cultural resources. Quaternary fossils have been known from YELL since the 1890s, when fragmentary bones were

recovered from the Tower Falls area and identified by the paleontologist O. C. Marsh as representing a “Pliocene” horse (described in more detail below). This age assessment suggested a Pliocene age for overlying basalts (Hague et al. 1896). With the advantage of radiometric dating, and taking into account revised dates for the geologic time scale, this age estimate for the Yellowstone Plateau volcanic field is more or less accurate.

Common Quaternary fossils of northern Wyoming and southern Montana include bones of large mammals and fossil material useful for paleoecological and paleoclimatological studies, such as pollen and packrat middens. Faunmap (http://www.ucmp.berkeley.edu/faunmap/index.html) and the Neotoma database (http://www.neotomadb.org/) show about 30 Quaternary fossil sites of both types within approximately 100 km (60 miles) of YELL, as well as a handful of sites with historic or slightly older (to about 400 AD) faunal remains, mostly from the Hermitage Point area of GRTE (48TE111, 48TE114, 48TE1090, 48TE1099, 48TE1102, 48TE1107, and Gull Island). Most of the fossil localities in and around YELL are paleoecological sites.

YELL Quaternary Diatom and Pollen Sites

The palynomorph and diatom record of YELL is outstanding. “Late Pliocene” [=modern Early Pleistocene] to Late Pleistocene lake sediments in the park frequently have palynomorphs and occasionally plant macrofossils (Baker 1980). Sites are scattered throughout the park, and typically yield at least some of the following: diatoms, algae, charcoal, wood, other plant macrofossils, spores and pollen of mosses, spikemosses, quillworts, horsetails, ferns, conifers, and angiosperms, fragments of freshwater bryozoans, and cladocerans (water fleas). Interglacial and postglacial sites are known; postglacial sites are discussed first, in alphabetical order.

Research began in earnest in the late 1960s, with the first prominent published site being the “15-foot lagoon site,” so named because the sediments are in an abandoned lagoon of Yellowstone Lake that was 15 feet above lake level when sampled (Baker 1969). The site later became known as Buckbean Fen, and should not be confused with other stranded lagoon sites (Baker 1976). It was initially described as including upper and lower pollen zones, with a date of 11,550± 50 radiocarbon years before present (14,200 to 12,630 calendar years before present) near the base of the upper zone (Baker 1970a, 1970b); note that radiocarbon dates are not the same as calendar dates, and that radiocarbon years require calibration to yield calendar years. Dates here were calibrated using Calib 6.0 (http://calib.qub.ac.uk/calib/) where appropriate. Further research has identified several transitions, from cold moist conditions and flora before about 13,000 radiocarbon years before present, followed by warming and drying to a maximum around 5,000 radiocarbon years before present, followed by a cooler and moister climate (Baker 1976). Cores from the site have produced a diverse fossil assemblage, including rhizopods (general amoeba-like protists), diatoms, peat, charophyte and chlorophyte algae, conifer needles, juniper bracts, leaves of mosses and willows, angiosperm seeds and fruits, pollen and spores of mosses, spikemosses, horsetails, ferns, conifers, and angiosperms, indeterminate plant fossils, freshwater bryozoans, and cladocerans. Fossils from 15-ft Lagoon/Buckbean Fen are also mentioned in Baker (1980), Elias (1988), Whitlock et al.

(1991), Whitlock (1993), and Whitlock and Bartlein (1993).

Blacktail Pond in northern YELL has a record beginning shortly after deglaciation, around 14,000 radiocarbon years before present. A core from this site contained charophyte algae, peat, conifer and angiosperm pollen, and spores. It shows a transition from tundra to parkland to a spruce-pine forest shortly after deglaciation, then warming leading to a Douglas fir parkland for most of the middle and late Holocene, with cooler and moister conditions toward the top of the core (Gennett and Baker 1986). Charcoal, wood, twigs, and fragments of aquatic zooplankton or insect chitin have also been found in pond sediments (Huerta et al. 2009). Blacktail Pond is also mentioned in Gennett (1981), Wright (1982), Elias (1988), Whitlock et al. (1991), Whitlock (1993), Whitlock and Bartlein (1993), Huerta (2008), and Krause and Whitlock (2013).

Crevice Lake is known for its diatoms, which have been used to study local climate change (Whitlock et al. 2006, 2008, Bracht et al. 2008). The record at this site goes back to approximately 2,550 years ago (Bracht et al. 2008). A variety of other fossils are also present, including charophyte algae, charcoal, bark, conifer needles, pollen, ostracodes, and unspecified shells (Whitlock et al. 2008, 2012). Crevice Lake is also mentioned in Huerta et al. (2009).

Cub Creek Pond on the east side of YELL, east of Yellowstone Lake, was first described by Waddington and Wright (1970). The fossil record at this site goes back to at least 14,360±400 radiocarbon years before present (18,520 to 16,790 calendar years before present), and includes chlorophyte algae and spores and pollen of quillworts, horsetails, ferns, conifers, angiosperms, and unidentified plants. The fossils indicate a treeline 500 m (1,600 ft) lower 11,600 radiocarbon years ago, followed by the warmer and drier Altithermal, and then a reversal of conditions around 4,500 radiocarbon years ago (Waddington and Wright 1974). This site was also discussed in Wright (1976), Baker (1976, 1983), Whitlock et al. (1991), Whitlock (1993), and Whitlock and Bartlein (1993).

Cygnet Lake Fen is a site in central YELL, with sediments at least as old as 14,490±700 radiocarbon years before present (18,990 to 15,530 calendar years before present). Spores and pollen of horsetails, ferns, conifers, and angiosperms were found here (Whitlock 1993). It is also mentioned in Whitlock and Bartlein (1993), Millspaugh et al. (2000), Pierce et al. (2003), and Huerta et al. (2009), the latter three publications discussing its fire record as seen through charcoal.

Gardners (or Gardiners) Hole, also known as Swan Lake or Swan Lake Flats, is a pollen organic sediment site in north-central YELL. It has a record going back to 13,530±130 radiocarbon years before present (16,980 to 16,030 calendar years before present) (Bender et al. 1971), featuring late glacial angiosperm and conifer pollen. It has been mentioned in Baker (1970b, 1983), Pierce (1970), and Whitlock et al. (1991).

Baker (1976) sampled several sites in the vicinity of Buckbean Fen and the Southeast Arm of Yellowstone Lake. The most productive of these sites was Lilypad Pond (the “40-ft lagoon”), which appears to be comparable in age to Buckbean Fen and yielded diatoms, charophyte algae, moss leaves, conifer needles, angiosperm fruits and seeds, pollen, indeterminate plant remains, and

cladocerans. Other cores were taken from abandoned lagoons at 8 and 27 m (25 and 90 ft), and Trail Creek Pond (Baker 1976), which has deposits as old as 7,215±70 radiocarbon years before present (8,180 to 7,930 years before present) (Pierce et al. 2007b).

Mariposa Lake in southeastern YELL has sediments dated as far back as 10,570±110 radiocarbon years before present (12,680 to 12,120 calendar years before present) (Steventon and Kutzbach 1987). Conifer and angiosperm macrofossils and pollen have been found in the sediments (Whitlock 1993), which also include significant amounts of gyttja (organic muck) (Steventon and Kutzbach 1987). The site is also discussed in Steventon and Kutzbach (1988) and Whitlock and Bartlein (1993).

Slough Creek Pond (or Lake) in north-central YELL has been mentioned several times in publically available literature (Whitlock 1993, Whitlock and Bartlein 1993, Pierce et al. 2003, Huerta et al. 2009). It is another conifer and angiosperm pollen site (Whitlock and Bartlein 1993), with some spruce wood as old as 11,725±140 radiocarbon years before present (13,850 to 13,300 calendar years before present) (Whitlock 1993). Charcoal is also present (Pierce et al. 2003, Huerta et al. 2009).

Yellowstone Lake itself has fossiliferous sediments, as illustrated by Theriot et al. (2006). This publication, concerning the evolution of the extant diatom Stephanodiscus yellowstonensis, reported on a core from the central part of the lake extending to at least 13,110 calendar years before present. Aside from diatoms, this core also contained wood, seeds, and the usual conifer and angiosperm pollen. This part of the park appears to have been warmest and driest during the Holocene between about 10,000 and 5,000 years ago (Theriot et al. 2006). Shorter cores mentioned by Goodwin and Schmit (1974) yielded seed cases and fragments of leaves and twigs in addition to diatoms. Postglacial diatoms have also been recovered from Lewis Lake, and cores from both lakes show evidence of bioturbation (Tiller and Kelts 1994).

Love et al. (2007) and Pierce et al. (2007b) described a number of fossiliferous sedimentary sequences associated with various stages of Yellowstone Lake, ranging in age from perhaps as old as the Early Pleistocene to the Holocene. Love et al. (2007) divided the rocks and sediments into several sequences of various ages. The Turbid Lake sequence is interpreted as Pleistocene in age, and contains twigs, leaf fragments, and other plant fossils. A unit named the Yellowstone Falls sequence by Love et al. (2007) was first reported by Howard (1937), who noted the presence of tiny plant fragments in Quaternary clay on the east rim of the Grand Canyon of the Yellowstone between the Upper and Lower Falls and fossil algae (perhaps diatoms?) from the Chittenden Bridge area. Love et al. (2007) described a larger fossil assemblage, including diatoms, chlorophyte algae, plant macrofossils including pondweed leaves and carbonized fragments, and spores and pollen from spikemosses, conifers, and angiosperms. The fossils may date to the Early or Middle Pleistocene (Love et al. 2007). Diatomite (rocks or sedimentary deposits made of diatoms) is also present in the Upper Falls area (Richmond 1987). Other publications that discuss the Falls sediments include Richmond (1986) and (1987). Diatoms have been found in the Hayden Valley sequence, which is Pleistocene in age but probably not older than the Middle or Late Pleistocene. The Alum

Creek sequence has yielded some fragments of carbonized wood, and is perhaps of Late Pleistocene age. The Mudkettle Sequence includes Pleistocene diatoms, chlorophyte algae, and spores and pollen of gnetophytes, conifers, and angiosperms, probably not older than Middle or Late Pleistocene. Probable Late Pleistocene diatoms have been found in the Astringent Creek Sand. The Pelican Valley sequence has yielded diatoms, various plant macrofossils such as twigs, rushes, blossoms, seeds, and fragments, a tree stump dated to 7,550±350 radiocarbon years before present (9,150 to 7,680 calendar years before present), spores and pollen of spikemosses, ferns, gnetophytes, conifers, and angiosperms, and reworked palynomorphs. Deposits in Gibbon Canyon include diatoms, mats of rushes, twigs, and stems, with plant material dated to 9,440±300 radiocarbon years before present (11,640 to 9,890 calendar years before present). Finally, sediments at Bannock Ford include diatoms, wood fragments, and plant debris, dated to 3,750±300 radiocarbon years before present (4,880 to 3,360 calendar years before present) (Love et al. 2007). Pierce et al. (2007b) reported on various Holocene sediments associated with the lake, which they used to describe the recent chronology of changes of the Yellowstone caldera. The majority of fossils they mentioned were charcoal, wood, pine needles, and other plant fragments used for radiocarbon dating, but they also noted the presence of latest Pleistocene caterpillar mandibles (11,400±90 radiocarbon years before present, or 13,800 to 13,040 calendar years before present) and early Holocene insects from Indian Pond Creek, and late Holocene insects in the West Thumb area (Pierce et al. 2007b).

Although most of the published pollen sites are postglacial, some near the mouth of the upper Yellowstone River are substantially older. Three sites along Beaverdam Creek near the southeastern tip of Yellowstone Lake preserve pollen from before the end of the Pinedale glaciation. Site EP-8 has peat, chlorophyte algae, and pollen and spores of spikemosses, horsetails, ferns, conifers, and angiosperms. Wood predating the effective range for radiocarbon dating is present 500 m (1,600 ft) downstream of this site (Baker and Richmond 1978). The site is thought to be slightly younger than 70,000 years, and contains fossils from a cold interstadial (nonglacial phase during a glacial period), with tundra conditions interrupted by a period of spruce-fir-pine parkland (Baker 1980). Site EP-6 is at least 127,000 years old (Baker 1986). This site has charophyte algae, spores and pollen of spikemosses, quillworts, horsetails, ferns, gnetophytes, conifers, and angiosperms, macrofossils of quillworts, ferns, conifers, and angiosperms, indeterminate plant remains, and cladocerans (Baker 1986), and is interpreted as representing a warm or dry climate during an interglacial (Baker 1980). Site EP-5 is slightly younger, with charophytes, spores and pollen of spikemosses, quillworts, ferns, conifers, and angiosperms, macrofossils of spikemosses, quillworts, conifers, and angiosperms, bryozoan fragments, and cladocerans (Baker 1986). To the southeast, at the confluence of Mountain Creek (Monument Creek in older maps) and the Yellowstone River, is the Yellowstone and Mountain site, with spores and pollen of spikemosses, conifers, and angiosperms. It is not dated but its fossil content appears to be comparable to EP-8 (Baker 1986).

Richmond (1986, 1987) described various fossils, mostly pollen, as they related to the park's glacial and climate history throughout

the Pleistocene. Aside from the pre-Yellowstone Plateau volcanic field pollen described under "Unnamed sedimentary rocks," the Beaverdam Creek pollen sites, and the Yellowstone Falls sites, these include: plant macrofossils showing tundra affiliation in lacustrine sediments at Bumpus Butte predating 1.56 Ma; warm interval pollen from Cascade Creek predating the Lava Creek Tuff of approximately 639,000 years ago; pollen from sediment at Flat Mountain Arm, showing a climate changing from cold to warm to cold, predating a volcanic flow dated to ca. 174,000 years ago; cold climate pollen from north of Rock Point, less than 153,000 years old; pollen from the Chittenden Bridge area, going from warm to cold after the Hayden Valley flow of 102±4 ka (thousand years ago; date after Christiansen [2001]); temperate pollen at Paintpot Hill, less than 90,000 years old; warm climate pollen from the Upper Falls Rest Area, probably close to 80,000 to 77,000 years old; and lacustrine silt from along Solution Creek that has fossils of diatoms and bryophyte [probably moss] mats, including one dated to 54,400±550 years before present. The Solution Creek site was also discussed by Richmond and Bradbury (1982), who reported that diatoms and conifer and angiosperm pollen were also present. The site appears to belong to the early stages of an interstadial, with tundra giving way to a bog (Richmond and Bradbury 1982).

Many pollen sites have been found in the vicinity of YELL as well. Given the detail supplied above for the YELL sites, it would be superfluous to discuss the sites outside of YELL at length. Postglacial sites in the immediate vicinity include Hedrick Pond near the Snake River Overlook in GRTE (Whitlock 1992, 1993), and Divide Lake, Emerald Lake, Fallback Lake, and Lily Lake and Fen in Bridger-Teton National Forest south of YELL (Whitlock 1993). Older fossils, approximately 82,000 years old, have been described from Grassy Lake Reservoir just south of YELL and west of JODR (Baker 1986).

Other Quaternary Fossils from YELL

Another type of paleoecological fossil known from YELL is packrat middens. Packrat middens are collections of plant material and food waste constructed by packrats (*Neotoma* spp.) and cemented by their viscous urine. They can be well-preserved in dry caves, and illustrate the environment of the builder's foraging range. Middens are important tools for reconstructing the ecology and climate of the late Pleistocene and Holocene of the southwestern United States (Strickland et al. 2001). Lamar Cave in YELL preserves abundant late Holocene (approximately 3,200 calendar years before present to the present) fossils collected by packrats. They include charcoal, wood, sticks, cones, other plant fragments, mollusks, and bones of fish, amphibians, reptiles, birds, and mammals (Hadly 1996, 1999). Amphibians from the site include salamanders (McMenamin and Hadly 2012). Birds from the site include grebes, ducks, shorebirds, coots, grouse, and perching birds (van Tuinen and Hadly 2003). The mammal assemblage includes over 10,000 bones of shrews, various rodents, rabbits, pikas, bats, canids, felids, mustelids (weasels and relatives), bears, deer, elk, bighorn sheep, pronghorns, and bison, with bones collected by packrats from carnivore scat, raptor pellets, and corpses (Hadly 1996). The fossils of Lamar Cave have been used to study how amphibians (McMenamin and Hadly 2012) and small mammals respond to climate change (Hadly 1990, Barnosky 1994, Hadly et al. 1998a, 1998b, 2001, Kohn 1998, O'Keefe et al. 2001, Barnosky et al. 2003, McGill et al.

2005), and how the site's assemblage compares to the modern fauna (Barnosky 1992, Hadly 1999). Other publications mentioning fossils from Lamar Cave include Hadly and van Tuinen (2002). Waterfall Locality along Soda Butte Creek in northeastern YELL, 24 km (15 miles) northeast of Lamar Cave, is another late Holocene packrat midden site, with approximately 3,000 bones of rodents, rabbits, and pikas from roughly the same time frame as Lamar Cave (Steele and Hadly 2002, 2003). Lamar Cave preserves a xeric grassland fauna, whereas the Waterfall Locality has mesic forest mammals (Steele and Hadly 2002). The YELL midden sites are unusual in that the focus of attention is vertebrate fossils, not plant fossils. Other caves and rockshelters in the park may yield packrat middens and other fossils. For example, faunal remains may also be present in a sinkhole on Mammoth Terrace (Santucci 1998), and bison bones have been found in McCartney's Cave (Santucci et al. 2001). Kenneth Pierce (USGS geologist emeritus, pers. comm., May 2013) reported seeing a packrat midden on the travertine bench above Gardiner and north of Bear Creek, just outside of YELL. Santucci et al. (2001) provided a review of fossils in National Park Service caves, and Tweet et al. (2012) provided a review of National Park Service midden sites. Both included discussion of Lamar Cave.

Fossils of large Quaternary mammals are rare in YELL, but are occasionally found. In terms of publication history, one of the most-discussed fossils of YELL is O. C. Marsh's "Pliocene horse," which has a habit of frequent anecdotal appearances. First mentioned in Hague et al. (1896), the find consists of fragmentary horse bones from stream gravels (Howard 1937), found below the upper basalt at Tower Falls (Jones and Field 1929). Per Hague et al. (1896), the fossils were found just north of Tower Creek in the Grand Canyon of the Yellowstone, indicating a site on the west side of the Yellowstone River. Unfortunately, the bones appear to be lost; a search of the National Museum of Natural History and the Peabody Museum of Natural History failed to locate the horse bones (Brown 1961). The horse would today be considered Pleistocene in age. Santucci (1998) mentioned another Pleistocene horse, represented by a partial lower jaw collected by O. T. Lewis in 1939. It is assigned to *Equus niobrarensis* and is reposited at the Peabody Museum as YPM VPPU 14673 (former Princeton University specimen). Some follow-up may be necessary, because according to the museum records, the locality is in Yellowstone County, Montana, which would be outside of YELL. There are also several reports of bison specimens from the park. These include: a skull from Rainbow Hot Spring identified as *B. occidentalis*, now possibly lost (Santucci 1998); a bison skull *in situ* in a dune sand cap on the west side of Stevenson Island (Santucci 1998); and bison remains of unspecified age from McCartney's Cave (Santucci et al. 2001). This latter report may be the same as one of two collections from the cave, a pre-1982 collection that was apparently discarded, and a 1982 collection dated to approximately 100 years before present. Bison in the region are further discussed in Cannon (2006). At least 15 bison jump and trap sites have been found in the upper Yellowstone Valley outside of YELL, with a few more to the west, dating to the past 2,000 years (Davis and Zeier 1978). A purported mammoth fossil site in the park turned out to be travertine (Santucci 1998).

Mammal bones are occasionally found with Holocene archeological sites in the park. Examples of these include: a butchered mule deer from Swan Lake Flat, nearly 3,000 years old; a former game trap at Rustic Falls; and another game site along the Gardner River with beaver and ungulate remains dating to between 1,450 and 1,250 years before present (Wright 1982). Similar sites are found throughout the GRYN. The best-known paleontological/archeological site in the area is Mummy Cave, about 20 km (12 miles) east of YELL (McCracken et al. 1978, Husted and Edgar 2002). Mummy Cave has been inhabited intermittently for the past 9,000 years (Husted and Edgar 2002). Charcoal, pollen (Wedel et al. 1968), a shell fragment (Husted and Edgar 2002), and the bones of a variety of birds (including ducks, geese, owls, probable grouse, ravens, and unknown perching birds) and mammals (including shrews, rodents, rabbits, bats, bobcats or lynx, foxes and other canids, mustelids, bears, mountain sheep, deer, bison, and indeterminate ungulates) (Harris 1978, Husted and Edgar 2002) have been found along with bone and antler tools, shell and bone beads, wood tools, petrified wood tools (Husted and Edgar 2002), bone pipes, leather straps, vegetable fiber cording, wood trimmings, inorganic artifacts, and the namesake natural mummy, the desiccated remains of a man (Wedel et al. 1968).

The nearest substantial Pleistocene megafauna site in the vicinity is Palisades Reservoir, about 90 km (55 miles) south of YELL just over the state line in Idaho. This site has bones of mammoths, mastodons, horses, camels or llamas, bighorn sheep, mountain goats, musk oxen, bison, and other megafauna, and tracks of proboscideans, horses, camels, bison or musk oxen, and possibly other ungulates (Robison et al. 2011). Pleistocene mammals have also been found in the Centennial Valley west of YELL (Hill 2007). The best-known site from this area is the Merrell site, on the west side of Lima Reservoir nearly 100 km (60 miles) west of YELL. The Merrell site has yielded bony fish, frogs, trumpeter swans, various rodents, the “scimitar cat” Homotherium, coyotes, wolves, bears, Columbian mammoths, horses, camels, pronghorns, deer and other cervids, and bison (Dundas 2007). The fossils of the Centennial Valley have been found in five stratigraphic units, as well as loose on the reservoir shore. The oldest fossils are older than 52,800 radiocarbon years before present (Hill 2007).

The hydrothermal deposits of the park occasionally include some biological remains. Some travertine at Mammoth Hot Springs preserves evidence of microbial activity, as noted by Bargar (1978), who included a photo illustrating microbial texture in travertine from Pinyon Terrace. The travertine of Mammoth Hot Springs is only about 8,000 years old at most (Pierce et al. 1991, Veysey et al. 2008), but other travertine in the park is older (Pierce et al. 1991, Sturchio et al. 1994). For example, some Terrace Mountain travertine dates to 400±30 ka (Pierce et al. 1991). Microbial activity is an important part of the modern travertine system of YELL, with different microbial communities for different modes of travertine deposition (Fouke et al. 2000, Fouke 2011), and doubtless was important in the past as well. Some caution is advised: for example, modern inorganic “stromatoloids” that closely resemble stromatolites are forming in YELL (Oehler 1972). Hydrothermal silica “spires” in Yellowstone Lake that are thought to be up to 11,000 years old incorporate microbes and diatoms (Love et al. 2007, Shanks et al. 2007), and microbes can be preserved in sinter

deposits, a process currently active in YELL (Farmer et al. 1997). Channing et al. (2005) described a body mold of a bird (an American Coot) found in sinter at Mammoth Hot Springs. The mold is perhaps as old as the Late Pleistocene, and preserves fine details of the bird's external surfaces, including feather structures. Microscopic microbial and fungal molds are associated with the mold of the bird, and microbial action probably helped to preserve it. Other fossils may also be found; Sturchio et al. (1994) included a photograph of plant casts from travertine found north of Gardiner, just outside of YELL.

There are also a number of fossils from YELL and the vicinity that do not fit into the above sections. Fragmentary plant remains are known from several locations. Reports include wood associated with the Bull Lake glaciation from unspecified locations (Richmond 1969), wood in lacustrine sediments older than perhaps 45,000 years ago in the vicinity of the southeast arm of Yellowstone Lake (Baker 1976), charcoal in the Bear Creek area south of Turbid Lake dated to 8,410±40 radiocarbon years before present (9,520 to 9,400 calendar years before present) (Pierce et al. 2007b; also reported by Love et al. [2007]), and a site known as the Powerline fossil locality near Le Hardy Rapids which has leaf impressions and silicified fragments of sedges, dating to before 7,280 years before present (Santucci 1998). Diatomite and moss mats dating to approximately the Pleistocene–Holocene boundary have been found at Mary Bay, and undated diatomites and moss mats are found on the windward side of Dot Island and possibly Stevenson Island (Santucci 1998). Eocene petrified wood is known to be reworked into Quaternary fluvial and glacial deposits in YELL (Conard 1930). Finally, Persico (2006), Persico and Meyer (2009), and Meyer et al. (2010) reported on the history of beaver dams in GRTE and YELL. Although the wood from dams often decays, the presence of a dam creates geomorphic changes in its immediate surroundings. The most obvious sign of a former dam is the presence of a berm across a valley. Gnawed stumps have been found in the vicinity of some dams, and the deposits of ponds behind dams often contain fragments of plants, sometimes gnawed by beavers. Beaver pond deposits from throughout the Holocene, mostly the past 4,000 years, have been identified in YELL (Persico and Meyer 2009).

One type of fossil resource found in the vicinity but not yet reported from YELL are mollusks. Some mollusks have been found in GRTE and the vicinity in lacustrine deposits, such as the gastropods found in marl in a glacial kettle (K. Pierce, pers. comm., May 2013) about 3 km (2 miles) south of Signal Mountain in GRTE (Love 1956b). These are perhaps related to mollusks from a 9,000-year-old marl near the Cunningham Cabin turnout (Love and Love 1980). Terrestrial snails have been found in loess, such as gastropods from the area of the Fish Hatchery just outside of GRTE (Love and Love 1980). These specimens date to 19,000±600 radiocarbon years before present (24,200 to 21,310 calendar years before present) per Love (1989b).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within YELL. However, they are known to preserve fossils elsewhere (except for some of the volcaniclastic units, which are included because similar units are fossiliferous), and future field investigations within the parks may locate fossils in one or more of them.

Gros Ventre Formation (Middle–Upper Cambrian)

The Gros Ventre Formation is included for completeness. It is widely exposed south of YELL in the Teton Range, but it is not clear if it is exposed at the surface within YELL. USGS (1972) mapped a small area of southwestern YELL in the Birch Hills as undivided Bighorn(?) Dolomite, Gallatin Formation, and Gros Ventre Formation, but a more recent and more detailed map (Christiansen et al. 1978) mapped it as undivided Bighorn Dolomite and Gallatin Formation. This leaves the presence of this formation questionable. However, although the formation itself may not be present at the surface in YELL, its constituent members are described as formations in northern YELL. Therefore, its presence or absence can be seen as more of a matter of semantics than geology. Because the description of this interval in YELL has been in terms of the constituent members as formations, the relevant information is reported in those sections, and this section will be used for a brief overview.

The Gros Ventre Formation is the oldest formation in the Teton Range with significant fossils. It is divisible into three members in GRTE and its immediate vicinity. In ascending order, they are the Wolsey Shale, Death Canyon Limestone or Meagher Limestone, and Park Shale members. The Wolsey Shale Member is a soft green or gray shale unit that grades out of the underlying Flathead Sandstone. The Death Canyon Limestone Member is a cliff-forming unit primarily composed of blue to dark gray limestone with a middle interval of shale. Finally, the Park Shale Member is composed of olive green shale and thin beds of distinctive “flat pebble” conglomerate. Microbial or “algal” structures are common in the lower part (Love et al. 1992).

The rocks of the Gros Ventre Formation were formerly included in the Flathead Sandstone. Early reports, such as Peale (1893) and Iddings and Weed (1899), described a much thicker multi-unit “Flathead Quartzite,” which included rocks now assigned to the Gros Ventre Formation. Specifically, Peale’s “Flathead Shale” is now recognized as the Wolsey Shale Member/Formation, the “Trilobite Limestone” is equivalent to the Meagher Limestone Member/Formation, and the “*Obolella* [a type of brachiopod] Shale” is now the Park Shale Member/Formation (Miller 1936). The Death Canyon Limestone name is sometimes used for the Meagher Limestone in the Tetons (Wanless et al. 1955); Love and Keefer (1975) used the Death Canyon name to identify some eroded boulders within YELL in the area of the Fox Creek patrol cabin. The Gros Ventre Formation is an offshore mud and carbonate formation (Beebe and Cox 1998). The lower and upper shale units were deposited on tidal flats, and the middle limestone member was deposited farther offshore in clear water (Love and Reed 1968). The upper contact of the formation with the Gallatin Formation is sometimes disconformable (Miller 1936). The Gros Ventre Formation is thought to span the Middle and Late Cambrian, with the boundary

within the Park Shale Member (Wanless et al. 1955).

A variety of fossils are known from the various units of the Gros Ventre Formation in and around northwestern Wyoming. The assemblages from the Wolsey Shale, Meagher Limestone, and Park Shale are described in the relevant formation sections. To date, the Gros Ventre Formation *per se* has not been reported as fossiliferous within YELL, but the eroded Death Canyon Limestone Member rocks may prove fossiliferous. The fossil assemblage of the Death Canyon Limestone Member includes acritarchs (Reaugh 1980), stromatolites (DeBoer and Middleton 1983), microbial buildups (DeBoer and Middleton 1981), brachiopods (Walcott 1912, Bell 1941), trilobites, burrows (Miller 1936), and bioturbation (Love et al. 1992, Tracy 2003). Fossils described from the Gros Ventre Formation without further subdivision include acritarchs (Reaugh 1980), trilobites (Beebe and Cox 1998), bradoriid arthropods (Howell 1963), conodonts (Koucky et al. 1961, 1968, Dong et al. 2005), invertebrate burrows (Csonka and Bulinski 2010), and material described as belonging to heterostracan fish (early jawless fish) (Cygan and Koucky 1963; the age of the fossils indicates either a stratigraphic or taxonomic misidentification).

Gallatin Limestone (Upper Cambrian)

The Gallatin Limestone is in a similar situation to the Gros Ventre Formation within YELL. It is mapped undivided with the Bighorn Dolomite in the Birch Hills (Christiansen et al. 1978), which leaves open the possibility that the outcrop is all Bighorn Dolomite, or somewhat less likely, that it is all Gallatin Limestone. Eroded material that can be ascribed to the Gallatin Limestone has been identified within YELL in the area of the Fox Creek patrol cabin (Love and Keefer 1975). As the Gros Ventre Formation is related to the Middle Cambrian units of northern YELL, so too the Gallatin Limestone is related to the Upper Cambrian units, although in its case through a rather more complicated nomenclature. The Gallatin Formation as described by Peale (1893) and Iddings and Weed (1899) contained the three units that make up the bulk of the modern Pilgrim Limestone and Snowy Range Formation, but names and allocations have varied. The Gallatin Formation itself has sometimes been called the Boysen Formation in northwestern Wyoming (Wanless et al. 1955). Miller (1936), using a Gallatin Formation framework, reported that Peale's (1893) basal "mottled limestone" of northwestern Wyoming is the Pilgrim Limestone Member, the Dry Creek Shale is the Dry Creek Shale Member, and the "pebbly limestone" is the Yogo Member as previously in use, but then introduced a new set of terminology in northwestern Wyoming, substituting the Du Noir Limestone for the Pilgrim Limestone and preferring not to give names to the overlying shale and limestone members (Miller 1936). The Yogo Limestone name was later found to be the result of a mistaken interpretation, and the interval identified as such in northwestern Wyoming is now the Sage pebble conglomerate member of the Snowy Range Formation (Lochman 1950). The three units are recognized today as the Pilgrim Limestone and the Dry Creek Shale and overlying Sage members of the Snowy Range Formation.

The Gallatin Limestone *per se* is not well-known from within YELL. To the south, in the Tetons, it is mostly composed of dark limestone, with some "flat-pebble" conglomerate in the lower section and green shale beds in the middle of the formation

(Love et al. 1992). It dates to the Late Cambrian (Wanless et al. 1955), although it has sometimes been suggested that the formation and its equivalents at the top of the Cambrian section extend into the Ordovician (Cygan and Koucky 1963). It was deposited offshore, in perhaps 30 to 60 m (100 to 200 ft) of water, with occasional storm events (Love and Reed 1968). Depositional environments include lagoons, tidal flats, and shoals (Martin et al. 1980). Shoal environments were replaced by deeper water deposition over time in the YELL area (Saltzman et al. 1995). The upper contact with the Bighorn Dolomite is disconformable (Wanless et al. 1955), and there may be a disconformity within the formation in northwestern Wyoming (Miller 1936).

The Gallatin Formation is not known to be fossiliferous within YELL; fossils identified as from the Gallatin Formation by Walcott (1899, 1902, 1905) would today be described as from the Pilgrim or Snowy Range formations. These include brachiopods from the Crowfoot Ridge area, the shell of an animal described as a gastropod (*Platyceras primordalis*, more likely one of several superficially gastropod-like extinct shelled animals) from Soda Butte Creek (Walcott 1899), and three taxa named from the park: the brachiopods *Orthis* (*Plectorthis*) *iddingsi* (Walcott 1905) and *Obolus* (*Lingulella*) *desideratus* (Walcott 1902) and the trilobite *Arionellus levis* (Walcott 1899) of the Crowfoot Ridge area. Fossils described as unspecified Upper Cambrian, including brachiopods from the Elk Pass area (Walcott 1899) and the brachiopod *Syntrophia abnormis* from the head of Deep Creek (Walcott 1905), also doubtless pertain to the Pilgrim or Snowy Range formations.

A number of fossils have been found in the Gallatin Formation of GRTE and the Teton Range, but they come from units that are here described in the Pilgrim and Snowy Range sections. Fossils described from the Gallatin Formation, without further subdivision, include microbial structures such as thrombolites (Hawkins et al. 2001), stromatolites, and laminations (Martin et al. 1980), acritarchs (Reaugh 1980), sponges, brachiopods, trilobites (Okulitch and Bell 1955), echinoderm fragments (Martin et al. 1980), conodonts (Koucky et al. 1968, Clark et al. 2000), and invertebrate burrows (Miller 1936).

Darby Formation (Upper Devonian)

The Darby Formation is something of a "name of convenience," originally intended for areas where the two most widespread Devonian formations of Wyoming, the Jefferson Limestone and overlying Three Forks Shale, cannot be mapped (Benson 1966). It has been mapped in two areas of southern YELL, near the Fox Creek patrol cabin (Love and Keefer 1975) and in the Birch Hills (Christiansen et al. 1978). In the Fox Creek area, 15 m (50 ft) of yellow and red shale and brown dolomite are exposed, representing the upper Darby Formation; its true thickness is estimated at 75 m (250 ft) in this area. It may correlate to the Logan Gulch Member of the Three Forks Formation (Love and Keefer 1975).

A marine unit, the Darby Formation is interpreted as having been deposited in a restricted basin under a climate humid enough to prevent significant evaporite deposition (Wanless et al. 1955). Deposition occurred during a marine transgression that moved to the east and southeast, reaching the maximum transgression during deposition of the Three Forks Shale equivalent (Andrichuk 1956). The

upper contact with the Madison Formation is disconformable, and it appears that more of the upper part of the Darby Formation is eroded going north and east in northwestern Wyoming (Wanless et al. 1955). Fossils in the Jefferson Formation indicate that at least the lower part of the Darby Formation has a Late Devonian age (Frasnian, approximately 383 to 372 Ma) (Weigner and Isaacson 2012).

The Darby Formation is not known to be fossiliferous within YELL (Love and Keefer 1975, Santucci 1998). Overall, the fossil record of the Darby Formation includes stromatolites (Tracy 2003), corals, bryozoans, brachiopods (Reeves 1964), ostracodes, crinoids (Andrichuk 1956), the ostracoderm jawless fish *Bothriolepis*, and lobe-finned fish (Denison 1951).

Tensleep Sandstone (Middle–Upper Pennsylvanian)

The Tensleep Sandstone of YELL is a white, gray, or buff sandstone with some thin carbonate beds, up to 115 m (380 ft) thick. It is a prominent cliff-forming unit elsewhere, but tends to form tree-covered bluffs and ledges in the park. This formation can be found in the Birch Hills area (Christiansen et al. 1978), in the Two Ocean Plateau area, and between the South Entrance and Yellowstone Lake (Love and Keefer 1975). Historically, it has been interpreted as marine, but more recent interpretations have suggested more terrestrial deposition, with a combination of marine beds and eolian sandstone (Mankiewicz and Steidtmann 1979, Kerr and Dott 1988, Lopez et al. 2007).

The Tensleep Sandstone spans at least the middle and late Pennsylvanian, possibly into the early Permian. Fossils ranging from Desmoinesian (308 to 306.5 Ma) (Driscoll and Newton 1969; Stamm and Wardlaw 2003) to Missourian (306.5 to 305 Ma) (Verville et al. 1970) to possibly Wolfcampian (299 to 294.5 Ma) (Fisher 1963) have been recovered from the Bighorn Mountains to the east. The nature of the upper contact with Permian rocks is uncertain within YELL, but conglomeratic beds are present at the base of the overlying rocks (Love and Keefer 1975). This is similar to the nature of the contact in the GRTE area to the south, where the contact is disconformable (Wanless et al. 1955).

The Tensleep Sandstone is not known to be fossiliferous within YELL (Love and Keefer 1975), and it is not known for its fossils. Overall, the fossil assemblage of the Tensleep Sandstone includes microbial mats (Mankiewicz and Steidtmann 1979), foraminifera (Verville 1957; Verville et al. 1970), the sponge *Chaetetes* (Agatston 1952), sponge spicules (Richards 1955), corals (Driscoll and Newton 1969), brachiopods (Darton 1906; Driscoll and Newton 1969; Mankiewicz and Steidtmann 1979), bivalves (Mankiewicz and Steidtmann 1979), gastropods (Darton 1906), scaphopods, trilobites (Hoare and Burgess 1960), crinoids (Agatston 1952, Mankiewicz and Steidtmann 1979), conodonts (Stamm and Wardlaw 2003), general bioturbation, invertebrate burrows, organic borings of plant or invertebrate origin (Mankiewicz and Steidtmann 1979), and tetrapod footprints, named *Steganoposaurus belli* and originally identified as amphibian (Branson and Mehl 1932), but now thought to be reptilian (Lockley and Hunt 1995).

Woodside Formation (Lower Triassic)

The Woodside Formation is present in northwestern YELL, where it is a grayish red to reddish brown unit composed of shale,

mudstone, siltstone, and sandstone, 23 to 30 m (75 to 100 ft) thick. The contact with the overlying Thaynes(?) Formation is conformable (Ruppel 1972). The Woodside Formation is a marginal marine unit deposited during a marine regression. It dates to the early Early Triassic (Dienerian) (Paull et al. 1989), approximately 250.4 to 249.7 Ma. It is not known to be fossiliferous within YELL, and is very sparsely fossiliferous overall. Reports include bivalves near the top of the formation in the Fort Hall area of southeastern Idaho (Mansfield 1916, 1920).

Thaynes(?) Formation (Lower Triassic)

The Thaynes Formation is a widespread marine unit, exposed from eastern Nevada to southwestern Montana. Rocks thought to pertain to this formation are present in northwestern YELL, in the Fawn Creek and Fawn Pass areas. The interval is 5 to 15 m (15 to 50 ft) thick and composed of lime-rich gray sandstone that forms a ledge. It probably was present over a wider area, but was partially eroded before deposition of Jurassic rocks (Ruppel 1972). The Thaynes Formation is sometimes divided into a number of members depending on location (Kummel 1943, 1954b, Picard et al. 1969, Massare and Callaway 1994), but this has not been done in YELL. Recent work in southern Utah has advocated raising the Thaynes Formation to a group and incorporating several other dominantly marine units (Lucas et al. 2007). The Thaynes Formation was deposited during the Early Triassic (the Smithian and Spathian ages, approximately 250 to 245 Ma) (Solien 1979, Solien et al. 1979). Deposition occurred during a rapid marine transgression (Paull et al. 1989). Depositional environments in the formation ranged from open marine to tidal flat settings, with shallower environments appearing over time (James 1980b).

Unsurprisingly for a unit of such limited distribution, no fossils have been found in the Thaynes(?) Formation of YELL (Ruppel 1972). Elsewhere outside of the park, the fossil assemblage of the Thaynes Formation is dominated by shelled marine invertebrates, particularly mollusks (Schubert and Bottjer 1995). Algae, microbes, and other unicellular organisms are represented by organic mounds (Picard et al. 1969), microbial limestone, stromatolites (James 1980b), wrinkle structures (Pruss et al. 2004), and foraminifera. Invertebrates are represented by sponges, brachiopods, bivalves, cephalopods (including ammonites and nautiloids), gastropods, ostracodes (Picard et al. 1969, Solien 1979, Solien et al. 1979, James 1980b), lobster-like crustaceans (Schram 1971), crinoids, echinoids, ophiuroids, conodonts, and trace fossils, including resting traces of asteroids (Picard et al. 1969, Solien 1979, Solien et al. 1979, James 1980b). Vertebrates are represented by sharks (Schroeder 1968, Mutter et al. 2005), bony fish (Stephenson 1965), the ichthyosaur *Cymbospondylus* (Massare and Callaway 1994), and bone fragments (Kummel 1954b).

Gypsum Spring Formation (Middle Jurassic)

The Gypsum Spring Formation of southern YELL and the immediate vicinity is a gray, white, and red unit composed of gypsum, dolomite, limestone, siltstone, and claystone, although usually the gypsum has been leached out. The formation is generally 8 to 15 m (25 to 50 ft) thick. It can be found between Heart Lake and the South Entrance in YELL (Love and Keefer 1975). Both the lower and upper contacts of the formation are disconformable, and represent the regional J-1 (lower) and J-2 (upper) unconformities (Kvale et al. 2001). It was first described as a member of the

Chugwater Formation (Love 1939, High and Picard 1967), and it is sometimes used as a member of the Twin Creek Limestone in the YELL area (Espach and Royse 1960, Imlay 1967). The Gypsum Spring Formation is dated to the Middle Jurassic, and is usually assigned at least in part to the Bajocian (170 to 168 Ma) (Kvale et al. 2001, Mickelson et al. 2006a).

Typically, the Gypsum Spring Formation can be split into distinct lower, middle, and upper parts. Generally the lower part of the formation is composed of red gypsum, claystone, and siltstone, the middle is composed of marine limestone, dolomite, and claystone, and the upper part is similar to the lower part, except with less gypsum (Picard 1993). Such a pattern can be seen in YELL (Love and Keefer 1975). This division becomes less clear going east, where the middle section disappears (Mapel and Bergendahl 1956). This is because the middle section was deposited under open marine conditions, and the seaway was not as extensive in northeastern Wyoming as in other areas (Peterson 1957a). Deposition occurred during two transgression-regression cycles, with the lower unit representing one cycle and the middle and upper representing a second, more extensive cycle (Parcell and Williams 2005). The lower and upper portions are interpreted as representing lagoonal, intertidal, and supratidal settings adjacent to an open marine shelf to the west, and the middle is interpreted as marine deposition under normal conditions (not hypersaline or brackish, not anoxic, etc.) (Wright 1974). The formation becomes more limestone-rich to the west, eventually grading into a marine formation (Picard 1993). The climate was seasonally arid (Clark and Brett-Surman 2008).

The Gypsum Spring Formation is not known to be fossiliferous within YELL at this time (Love and Keefer 1975). As a whole, the Gypsum Spring Formation is only notably fossiliferous in the middle section. The middle part of the formation has yielded stromatolites (Kvale et al. 2001), microbial reefs and other microbial structures, blue-green algae, coralline red algae, green algae, foraminifera, sponges, corals, bryozoans (Ploynoi and Parcell 2005), ammonites (Kvale et al. 2001), bivalves, gastropods, ostracodes (Peterson 1957b), crabs, shrimp (Guyer et al. 1995), crinoids, echinoids (Imlay 1967), invertebrate trace fossils (Kvale et al. 2001), reptile swim traces (Mickelson et al. 2006a, 2006b) and locally abundant dinosaur tracks (Kvale et al. 2001, Clark and Brett-Surman 2008). Most of these fossils are known from the Bighorn Basin to the east (Imlay 1956, Guyer et al. 1995, Kvale et al. 2001, Ploynoi and Parcell 2005, Mickelson et al. 2006a, 2006b, Clark and Brett-Surman 2008), or the Wind River Basin to the southeast (Peck 1957, Peterson 1957b).

Pinyon Conglomerate (Upper Cretaceous–Paleocene)

The Pinyon Conglomerate is mapped in a few small areas on the east and south sides of Mount Sheridan, west and southwest of Heart Lake. The outcrops consist of green to brown quartzite conglomerate, up to 140 m (450 ft) thick (Love and Keefer 1975). It is sometimes informally divided into a coal member and conglomerate member (Love 1956b). The coal member was originally described as basal (Love 1956b), but there are actually older rocks present in areas where the coal member is not found (Love 1973). Lindsey (1972) instead interpreted the formation as including a lower sandstone member (similar to the coal member) and intertonguing upper

conglomerate member. The small outcrops in south-central YELL have not been assigned to a member (Lindsey 1972).

The Pinyon Conglomerate is a gravelly fluvial formation (Leier and Steidtmann 2009). The same source rocks, general depositional setting, and environmental conditions are thought to have held for both the underlying Harebell Formation and the Pinyon Conglomerate (Lindsey 1972, Love 1973), except the marine influence had departed and volcanism decreased during deposition of the more recent Pinyon Conglomerate (Love 1973). The Pinyon Conglomerate was previously thought to be Paleocene in age, based on fossils and stratigraphic relationships (Love 1956b), but the discovery of a tooth of the small horned dinosaur *Leptoceratops* in this formation establishes that part of it is latest Cretaceous in age (McKenna and Love 1970). A tuff dated to 67 Ma within the formation further supports the formation crossing period boundaries (Love 1990). The southern outcrops of the formation are entirely Paleocene in age (Love 1973, 1990). The upper part of the formation dates to some part of the middle or late Paleocene, predating the late Paleocene fossils of an overlying formation found outside of YELL (Love 1989b).

The Pinyon Conglomerate is not known to be fossiliferous within YELL, and the small exposures reduce the likelihood of fossils being found. The best-known nearby fossil locality is on the east side of Pinyon Peak, a little less than 8 km (5 miles) south of YELL, where a bivalve, possible lizard scute, and *Leptoceratops* tooth were found (McKenna and Love 1970). Overall, the fossil assemblage of the Pinyon Conglomerate includes coal, pollen, wood, logs (Love 1973), leaves of conifers and angiosperms, freshwater bivalves, freshwater and terrestrial gastropods (Love 1956b), a possible lizard scute, a *Leptoceratops* tooth, mammals, and reworked Paleozoic fossils (Love 1973). Reworked materials include Madison Limestone and other limestones with fragments of foraminifera, corals, bryozoans, bivalves, and crinoids (Lindsey 1972). The Love Quarry site outside of GRTE, included in the Pinyon Conglomerate by McKenna (1980), is actually in the Devils Canyon Formation (Love 1989b).

Volcanic Rocks (Upper Cretaceous or Paleocene)

A small area in the extreme northwestern corner of YELL has been mapped as Upper Cretaceous or Paleocene volcanic rocks, including “basalt lava flows, andesitic tuff, and epiclastic sandstone, siltstone, and claystone” (USGS 1972). This unit has seemingly never been described anywhere else, but the presence of sedimentary rocks suggests that it is potentially fossiliferous. Other Cretaceous rocks in the area have produced spores, pollen, and plant debris, which offers a guide to what may be found.

Hominy Peak Formation (Lower–Middle Eocene)

An area in the Birch Hills of YELL identified as andesitic volcaniclastic rocks of the Absaroka Volcanic Supergroup in USGS (1972) was later identified by Christiansen et al. (1978) and Love et al. (1978) as the Hominy Peak Formation. In this area, the formation is up to about 600 m (2,000 ft) thick, and is composed of brown and green andesitic mudflow breccia, vent breccia, conglomerate, and sandstone, with tuff and claystone zones near the top and bottom of the formation (Christiansen et al. 1978).

The Hominy Peak Formation originated as a combination of volcaniclastic sediments and volcanics, erupted during the first major volcanic activity of the Absaroka volcanic field. The actual volcanic source seems to have been southwest of Conant Basin, south of western YELL. Deposition occurred under a humid subtropical climate. The age of the formation is reasonably well-constrained to the early and middle Eocene; volcanic rocks in and near GRTE have been dated to 48.6±0.7 and 45.9±0.5 Ma, and the formation is intruded by igneous rocks that date to 40.5±2.6 Ma along the southern YELL boundary (Love et al. 1978).

The Hominy Peak Formation is not known to be fossiliferous within YELL, but is fossiliferous in the immediate vicinity and stands a reasonable chance of proving fossiliferous in YELL. Outside of the park, it has yielded carbonized plant fragments, carbonized and silicified wood (including angiosperm wood), stumps, other plant debris, spores and pollen of clubmosses, spikemosses, ferns, conifers, and angiosperms, and reworked Madison Limestone rocks with corals and brachiopods (Love et al. 1978). Fossil trees are common (Love et al. 1992).

Washburn Group: Cathedral Cliffs Formation (Lower Eocene)

The Cathedral Cliffs Formation is mapped in a few areas of extreme northeastern YELL near Soda Butte and Pebble creeks and the Northeast Entrance (USGS 1972). It represents part of the “early acid breccia” of early workers, also subsumed in the Sepulcher Formation. The Sepulcher Formation is stratigraphically equivalent to it in northwestern YELL, but the two have different volcanic sources, and are separated by the lower Lamar River Formation. The Cathedral Cliffs Formation is composed of light-colored volcaniclastic sandstones, breccias, and conglomerates, and tuffs. It is 150 m (500 ft) thick east of the park and thickens to the northwest as it approaches a line of volcanic vents. The bulk of the formation is outside of YELL, and the portion within it is the result of tongues extending into the lower Lamar River Formation. It is alluvial in nature, and dates to the late Early or early Middle Eocene (Smedes and Prostka 1972); Early Eocene is more likely, based on stratigraphic relationships.

The Cathedral Cliffs Formation does not appear to fossiliferous within YELL, and in fact it is not clear how fossiliferous the formation is at all. Pierce (1963) and Smedes and Prostka (1972) reported the existence of plant collections, including ferns, angiosperms, and unidentified plants (Pierce 1963). According to Nelson and Pierce (1968), though, these fossils, from the Wapiti Quadrangle outside of YELL, are actually from the younger Wapiti Formation. Freshwater bivalves have also been reported from the formation (Pierce 1963), and do not appear to have been reassigned.

Sunlight Group: Mount Wallace Formation (Lower Eocene)

The Mount Wallace Formation has been mapped in eastern and northwestern YELL (USGS 1972). It is mostly composed of volcanic flows and alluvial volcaniclastic sedimentary rocks, up to 900 m (3,000 ft) thick. It is mostly exposed north of YELL, where a welded ash-flow sheet known as the Slough Creek Tuff Member is found in the middle. The lower part of the formation disappears going south, and the Slough Creek Tuff Member is at the base in the park. Volcanic flows succeed the tuff member. The

formation was originally mapped as “basic andesite breccia and flows.” It intertongues with the overlying Wapiti Formation and Trout Peak Trachyandesite. Deposition occurred just before the Early-Middle Eocene boundary of 47.8 Ma; the Mount Wallace Formation is cut by a 47.7±1.5 Ma intrusive unit, and is lower than the 48.0±1.3 Ma Pacific Creek Tuff Member of the Trout Peak Trachyandesite (Smedes and Prostka 1972). The Slough Creek Tuff Member was formerly mapped as a “trachytic rhyolite flow” and may date to between 49.2 and 48.0 Ma (Hickenlooper and Gutman 1982). The Crescent Hill Basalt, otherwise not discussed here because it is composed entirely of basalt flows, may be an outlier of the Mount Wallace Formation (Smedes and Prostka 1972). Fossils are not yet known from the Mount Wallace formation (Smedes and Prostka 1972).

Sunlight Group: Wapiti Formation (Middle Eocene)

The Wapiti Formation represents roughly the upper third of the former “early basic breccia” of YELL. It is composed of volcaniclastic sedimentary rocks and interlayered lava flows (Smedes and Prostka 1972). The formation is known for its variable lithology (Nelson and Pierce 1968). In east-central YELL, it is mostly represented by vent facies, from the immediate vicinity of the actual volcanoes, but going to the northeast the rocks are more alluvial in nature (Smedes and Prostka 1972). Volcanic breccias are interpreted as mudflows (Nelson and Pierce 1968). It has been mapped in large areas of northeastern YELL, mostly east and northeast of the Lamar River (USGS 1972). The formation can be as much as 1,500 m (5,000 ft) thick. The upper contact with the Trout Peak Trachyandesite can be interfingering or disconformable; outside of the park, it interfingers with the Langford Formation (Smedes and Prostka 1972). East and southeast of YELL, lava flows in the middle of the formation have been named the Jim Mountain Member (Nelson and Pierce 1968). Fossil mammals indicate a Bridgerian age, perhaps Bridger B (Eaton 1982); the Bridgerian is thought to date to between 50.3 and 46.2 Ma, which is appropriate considering the dates of associated volcanic rocks.

In older works, the Wapiti Formation is interpreted as equivalent to a formation called the Pitchfork Formation (Nelson and Pierce 1968, Smedes and Prostka 1972). More recently, the Pitchfork Formation has been abandoned, and the volcanic rocks and coarser sediments have been assigned to the Wapiti Formation, with the rest given to the Aycross Formation, another lateral equivalent (Decker 1990).

The Wapiti Formation is not known to be fossiliferous within YELL, but it may prove to be fossiliferous. The Wapiti Formation fossil assemblage includes plants such as ferns, horsetails, and angiosperms (Dorf 1939, Pierce 1963; in the Wapiti Formation per Nelson and Pierce [1968]), petrified wood (Nelson and Pierce 1968), and mammals, including taeniodonts and other cimolestans (extinct early mammals), primates, rodents, extinct carnivorous viverravids, hyposodont condylarths, brontotheres (Bown 1982), and horses (Eaton 1982). Petrified wood can be found scattered throughout (Nelson and Pierce 1968), and is probably the most likely type of fossils to be found in YELL.

Sunlight Group: Trout Peak Trachyandesite (Lower–Middle Eocene)

The Trout Peak Trachyandesite is one of the Absaroka Volcanic Supergroup units dominated by lava flows; volcaniclastic

sedimentary rocks are a minor component (Nelson and Pierce 1968, Smedes and Prostka 1972). Outcrops of the Trout Peak Trachyandesite can be found scattered through much of eastern YELL, mostly east of an imaginary line running north-south through the south arm of Yellowstone Lake (USGS 1972). In YELL, it is generally 240 to 370 m (800 to 1,200 ft) thick. Older works mapped it as "early basalt flows." The upper part of the formation sometimes includes a pale brown or yellowish welded tuff known as the Pacific Creek Tuff Member, which can be up to 90 m (300 ft) thick. This tuff has been dated to 48.0±1.3 Ma. The upper contact with the Langford Formation is conformable to interfingering (Smedes and Prostka 1972). Fossils are not known from the Trout Peak Trachyandesite at this time; they are unlikely, but the presence of sedimentary rocks and the abundant fossils in other Absaroka Volcanic Supergroup rocks mean they should not be ruled out *a priori*.

Thorofare Group: Two Ocean Formation (Lower–Middle Eocene)

The Two Ocean Formation is a dark-colored unit primarily composed of coarse andesitic volcaniclastic sedimentary rocks (Smedes and Prostka 1972), with some andesitic lava flows (USGS 1972). It has been mapped in several areas of southeastern YELL (USGS 1972). The upper contact with the Wiggins Formation is disconformable. Because both the lower and upper contacts are disconformable, its thickness varies and it is locally absent in its depositional area; its maximum thickness is greater than 600 m (2,000 ft). It can be readily distinguished from the Langford and Wiggins formations by its dark color. Early reports identified it as "late basic breccia" and, locally "late basalt sheets." It is primarily alluvial, with some vent-facies volcanic rocks and water-deposited tuff as well (Smedes and Prostka 1972). It dates to 47.9±1.3 Ma (Smedes et al. 1989). Fossils have not yet been reported from this formation.

Thorofare Group: Wiggins Formation (Middle Eocene)

The Wiggins Formation of YELL is not particularly complicated, but it has proven to be significantly problematic outside of the park. Within YELL and in the immediate vicinity, it is a "light-colored sequence of coarse andesitic volcaniclastic strata" and a few dark lava flows ("late basalt flows" of older reports). The formation is at least 900 m (3,000 ft) thick. Deposition occurred via similar means as the other Absaroka Volcanic Supergroup units, as a combination of mudflows, fluvial systems, ashfalls, and volcanic flows. It probably derives from several volcanic vents, including one thought to have been where Yellowstone Lake is now (Smedes and Prostka 1972). The volcanic centers moved south-southeast over time (Decker 1990). It is mapped in a large area of southeastern YELL, mostly south of Yellowstone Lake (USGS 1972). The Wiggins Formation can be divided into multiple units in some locations (Sundell et al. 1984, Eaton 1985), but this has not been done at YELL.

The age of the Wiggins Formation was long controversial due to misidentified conglomerates and misdated rocks. In brief, the age had been based in part on stratigraphic relationships at Beaver Divide in central Wyoming: in this area, it was thought that a conglomerate above the White River Formation was the basal Wiggins Formation, but the conglomerate in question doesn't belong to the Wiggins Formation, which is actually below the White River Formation (Emry 1975). The formations and their fossils

were confused, and the Wiggins Formation was given contradictory Uintan (Middle Eocene) and Chadronian (Late Eocene) ages (Prothero and Sanchez 2004). The fossils of the formation are now regarded as late Uintan (Prothero and Sanchez 2004), from between about 42.5 and 40 Ma, while radiometric dates associated with the formation range from between about 47.1 to 43.1 Ma (Bown 1982).

The Wiggins Formation is not known to be fossiliferous within YELL. Outside of the park, it has yielded diatoms (Emry 1975), charcoal, petrified wood and stumps, fossils of conifers and angiosperms (Love 1939), gastropods (Emry 1975), and bones and teeth of hedgehogs, primates and relatives, rodents, miacids, hyopsodont condylarths, brontotheres, horses, tapirs, amynodonts (rhino relatives), agriochoeres (oreodont relatives), dichobunid artiodactyls (Eaton 1980, 1985), and protoceratid artiodactyls (Prothero and Sanchez 2004). “Fossil forests” of petrified stumps and logs, mostly of subtropical trees like magnolias, are found in the formation in the Stratified Primitive area about 65 km (40 miles) southeast of YELL (Ketner et al. 1966).

The fossil assemblage of the Wiggins Formation has proven complicated as well, even beyond the misattributions in the Beaver Divide area. As noted in the Langford Formation section, there is a plant fossil site in the Emerald Lake area formerly attributed to the Wiggins Formation, but now attributed to the Langford Formation (Barnosky 1984). Furthermore, vertebrates from the area (Mink Creek) were formerly attributed to the Wiggins Formation (Brown 1961, Rohrer and Obradovich 1969) but are now attributed to the White River Formation (McKenna 1980, Mader 2009). Additionally, the Blue Point marker bed, found outside of YELL, was previously regarded as a fossiliferous part of the Wiggins Formation (Rohrer and Obradovich 1969, Sundell and Eaton 1982), but is no longer included in the formation (Eaton 1982, Decker 1990).

Gravel of Mount Everts (Lower Pleistocene or Pliocene)

The gravel of Mount Everts is an “alluvial channel gravel about 2 m [7 ft] thick, composed almost entirely of debris of the Absaroka Volcanic Supergroup,” found beneath the Huckleberry Ridge Tuff (Christiansen and Blank 1972). It is here described separately from the Yellowstone Plateau volcanic field rocks, because it has been included as a separate unit in the GRI map, but could also be considered with those rocks, as done in Christiansen and Blank (1972). It is not known to be fossiliferous, but could conceivably have reworked Eocene petrified wood because it derives from Absaroka Volcanic Supergroup rocks.

Park Collections

At the time of Santucci (1998), YELL's fossil collections were divided among four collections: "museum storage in the Albright Visitor Center basement; a warehouse in Gardiner (Building 2009); interpretive collections throughout the park; and collections made by Wayne Hamilton in the Physical Sciences trailer." According to Colleen Curry (YELL supervisory museum curator, pers. comm., July 2013), these collections have been consolidated to the park's new (2005) Heritage and Research Center facility in Gardiner, Montana, with the exception of interpretative collections. The specimens are mostly from the park, but there are a few specimens collected from the vicinity as well. They include petrified wood, leaves, a limb cast, a hickory nut impression, corals, brachiopods, mollusks including bivalves, ammonites, and gastropods, a dragonfly wing cast, echinoderms, a fish scale, and bones of dinosaurs and horses.

At least a handful of external institutions have fossils from YELL. The easiest to trace are type specimens, fossils that were used to name taxa. Taxa named by Lesquereux (1872, 1878), Walcott (1897, 1899, 1902, 1905), Knowlton (1898b, 1899), Girty (1899), Stanton (1899), and Resser (1935, 1937, 1938, 1942a, 1942b) have their type specimens in the National Museum of Natural History (USNM; Washington, D.C.). Read's (1933) taxa are in the paleobotany collections of the University of California at Berkeley's Museum of Paleontology (UCMP; Berkeley, California). Taxa named by Bell (1941) and Duncan (in Lochman and Duncan 1944) are in the collections of Montana State University (MSU, MSUM; Bozeman, Montana). Wood taxa named by Beyer (1954) were originally in the University of Cincinnati Museum collections (CINC; Cincinnati, Ohio), but are now reposited in the Cincinnati Museum Center. One of the slides was sent to the museum of Ohio University (Athens, Ohio). More recently, Joshua Miller of the University of Cincinnati has made collections of Quaternary ungulate bones from the park. 61 YELL catalog numbers have been assigned to this material, currently at the university (C. Curry, pers. comm., July 2013). Most of this material is probably essentially modern. Grant's (1965) brachiopod type from YELL is in the University of Texas system; the individual institution was not specified, but the flagship University of Texas at Austin is most likely. Wood taxa named by Wheeler et al. (1977, 1978) were in the U.S. Geological Survey's Fossil Wood Collection, but are now at the USNM. The present disposition of the specimens described by Felix (1896) and Platen (1908) is unknown; it can be assumed that at one point there were specimens in a German institution. Other repositories include: the Botany Department of Washington University (St. Louis, Missouri) (Andrews 1939); the University of Montana's Museum of the Department of Geology (Missoula, Montana) (Fritz 1980b); and the Peabody Museum of Natural History (YPM; New Haven, Connecticut) from a former Princeton University specimen (PU; Princeton, New Jersey) (Santucci 1998). The Museum of the Rockies (MOR; Bozeman, Montana) formerly had fossils from YELL, but has returned them (C. Curry, pers. comm., July 2013). The core used in Theriot et al. (2006) was stored for a time at the University of Minnesota Limnological Research Center (Minneapolis, Minnesota). The Permian fossils described in Yochelson and van Sickle (1968) and the Cretaceous fossils described by Tysdal et al.

(1990) and Tysdal and Nichols (1991) were USGS collections, but are probably now at the USNM with most USGS collections. USGS–Denver still retains some YELL fossils, though (YELL Figure 14), and the USGS also holds documentation pertaining to YELL projects conducted under their auspices. The core used in Gennett and Baker (1986) is a USGS core.



YELL Figure 14. YELL fossils in the collections of USGS–Denver (VLS).

One hundred seventy-five taxa have been named from specimens collected within YELL, including holotypes (single name-bearing specimens) and syntypes (series of name-bearing specimens). It is probable that all of the fossils were collected after the park was established, with the possible exception of some of Lesquereux's specimens. Taxa named from YELL include 85 angiosperms, 17 conifers, 8 ferns, 4 horsetails, an unidentified plant, a possible archaeocyathid (possibly a sponge), 9 bivalves, 22 brachiopods, 5 gastropods, a hyolith, a sponge, 5 tabulate corals, and 16 trilobites. 28 of the species are from Cambrian rocks, 3 are from the Devonian, 17 are from the Mississippian, 8 are from the Jurassic, 7 are from the Cretaceous, and 112 are from the Eocene. A table of type specimens from YELL (YELL Table 4) is included below. Not all of the taxa are considered valid today, and others have not been referenced since their original description. Because of the complexities and vagaries of taxonomy, only the original name of a taxon is supplied; new names required by preoccupation are included in the Notes column.

YELL Table 4. Type specimens from YELL. The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column.

Taxon	Publication	Catalog Number	Provenance	Notes
Billingsella exasperata	Bell 1941	Syntypes MSU T1172a-d	Snowy Range Formation, Crowfoot Ridge	Brachiopod
Billingsella perfecta pyriformis	Bell 1941	MSU T1180a	Snowy Range Formation, Crowfoot Ridge	Brachiopod
Billingsella radiata	Bell 1941	Syntypes MSU T1171a-f	Snowy Range Formation, Crowfoot Ridge	Brachiopod
Dicellomus mosaica	Bell 1941	MSU T1202a	Snowy Range Formation, Crowfoot Ridge	Brachiopod
Ocnerorthis monticola	Bell 1941	Syntypes MSU T1174a-f	Snowy Range Formation, Crowfoot Ridge	Brachiopod
Abies lapidea	Beyer 1954	CINC B-788 with slides	Lamar River Formation, Specimen Ridge	Conifer (Pinaceae)
Fagus grandiporosa	Beyer 1954	CINC B-807 with slides	Lamar River Formation, Specimen Ridge	Angiosperm (Fagaceae)
Libocedrus decurrenoides	Beyer 1954	CINC B-718 with slides	Lamar River Formation, Specimen Ridge	Conifer (Cupressaceae)
Piceoxylon laricinoides	Beyer 1954	CINC B-714 with slides	Lamar River Formation, Specimen Ridge	Conifer (Pinaceae)
Pinus pseudotsugoides	Beyer 1954	CINC B-725	Lamar River Formation, Specimen Ridge	Conifer (Pinaceae)
Quercus rubida	Beyer 1954	CINC B-229 with slides (at Ohio University Museum) and B-824a	Lamar River Formation, Specimen Ridge	Angiosperm (Fagaceae)
Thuja xantholitica	Beyer 1954	CINC B-782 with slides	Lamar River Formation, Specimen Ridge	Conifer (Cupressaceae)
Maryvillia aequa	Duncan (in Lochman and Duncan 1944)	MSUM T1549	Pilgrim Limestone, Crowfoot Ridge	Trilobite
Modocia yellowstonensis	Duncan (in Lochman and Duncan 1944)	MSUM T1560	Pilgrim Limestone, Crowfoot Ridge	Trilobite
Cupressinoxylon eutreton	Felix 1896	Unknown	Sepulcher Formation, Yancey's Forest below Lost Lake	Conifer
Pityoxylon fallax	Felix 1896	Unknown	Sepulcher Formation, Yancey's Forest below Lost Lake	Conifer
Plataninium haydeni	Felix 1896	Unknown	Lamar River Formation, Amethyst Mountain	Angiosperm
Quercinium knowltoni	Felix 1896	Unknown	Lamar River Formation, Amethyst Mountain	Angiosperm
Rhamnacinium radiatum	Felix 1896	Unknown	Lamar River Formation, Amethyst Mountain	Angiosperm
Athyris vittata var. *triplicata*	Girty 1899	USNM 34127	Three Forks Formation, south side of Soda Butte Creek, northwest of Abiathar Peak	Brachiopod
Aulopora geometrica	Girty 1899	USNM 35162	Madison Group, Bighorn Pass	Tabulate coral

YELL Table 4. Type specimens from YELL. The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column (continued).

Taxon	Publication	Catalog Number	Provenance	Notes
Camarotoechia herrickana	Girty 1899	Material including syntypes USNM 35174 and 35175	Madison Group, Crowfoot Ridge and near Bighorn Pass	Brachiopod
Cliothyris crassicardinalis var. *nana*	Girty 1899	Material including syntypes USNM 35198.A	Madison Group, Crowfoot Ridge	Brachiopod
Clisiophyllum teres	Girty 1899	Material including syntype USNM 35159	Madison Group, Three Fork Peak	Tabulate coral
Holasterella wrighti var. *americana*	Girty 1899	Material including syntype USNM 35200	Madison Group, near Bighorn Pass	Sponge
Liorhynchus haguei	Girty 1899	USNM 35178	Madison Group, Crowfoot Ridge	Brachiopod
Loxonema delicatum	Girty 1899	USNM 34127	Three Forks Formation, south side of Soda Butte Creek, northeast of Abiathar Peak	Gastropod
Martinia rostrata	Girty 1899	Material including syntypes USNM 35186.A-C	Madison Group, various YELL locations	Brachiopod
Menophyllum? *excavatum*	Girty 1899	Material including syntype USNM 35158	Madison Group, Crowfoot Ridge	Tabulate coral
Platystoma minutum	Girty 1899	USNM 34129	Three Forks Formation, south side of Soda Butte Creek, northeast of Abiathar Peak	Gastropod
Productella alifera	Girty 1899	Material including syntypes USNM 35171.A-C	Madison Group, south side of Soda Butte Creek northwest of Abiathar Peak	Brachiopod
Productus gallatinensis	Girty 1899	Material including syntypes USNM 35168 and 35169	Madison Group, Crowfoot Ridge and near Bighorn Pass	Brachiopod
Productus parviformis	Girty 1899	One of syntypes USNM 35166 and 35167	Madison Group, Crowfoot Ridge (other syntype from GRTE)	Brachiopod
Seminula humilis	Girty 1899	Material including syntypes USNM 35194.A and B	Madison Group, Crowfoot Ridge	Brachiopod
Seminula immatura	Girty 1899	Material including syntypes USNM 35195.A and B	Madison Group, west of Antler Peak	Brachiopod
Spirifer centronatus var. *semifurcatus*	Girty 1899	USNM 35185	Madison Group, Crowfoot Ridge	Brachiopod
Spirifer striatus var. *madisonensis*	Girty 1899	USNM 35184	Madison Group, Crowfoot Ridge	Brachiopod
Syringopora aculeata	Girty 1899	USNM 35161	Madison Group, Crowfoot Ridge	Tabulate coral
Syringopora surcularia	Girty 1899	USNM 35160	Madison Group, Crowfoot Ridge	Tabulate coral

YELL Table 4. Type specimens from YELL. The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column (continued).

Taxon	Publication	Catalog Number	Provenance	Notes
Angulotreta vescula	Grant 1965	University of Texas 12210b	Snowy Range Formation, Crowfoot Ridge	Brachiopod
Equisetum lesquereuxii	Knowlton 1898b	USNM 41	Unspecified Eocene, near Yellowstone Lake	Horsetail
Acacia lamarensis	Knowlton 1899	USNM 4413	Lamar River Formation, east bank of the Lamar River between Cache and Calfee creeks	Angiosperm (Fabaceae)
Acacia macrosperma	Knowlton 1899	USNM 4483	Lamar River Formation, Fossil Forest Ridge Bed 7 [Amethyst Mountain]	Angiosperm (Fabaceae)
Acacia wardii	Knowlton 1899	USNM 4412	Lamar River Formation, Fossil Forest Ridge Bed 4 [Amethyst Mountain]	Angiosperm (Fabaceae)
Acer vivarium	Knowlton 1899	USNM 4407	Lamar River Formation, Fossil Forest Ridge Bed 3 [Amethyst Mountain]	Angiosperm (Aceraceae)
Aralia serrulata	Knowlton 1899	USNM 4341	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Araliaceae)
Aralia wrightii	Knowlton 1899	USNM 4411	Lamar River Formation, Fossil Forest Ridge [Amethyst Mountain]	Angiosperm (Araliaceae)
Arctostaphylos elliptica	Knowlton 1899	USNM 4485	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Ericaceae)
Artocarpus? *quercoides*	Knowlton 1899	USNM 4409	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Moraceae)
Asplenium iddingsi	Knowlton 1899	Syntypes USNM 4728 and 5071	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Fern
Asplenium magnum	Knowlton 1899	Syntypes USNM 5036, 5070, 5087, 5088, and 5096	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Fern
Asplenium remotidens	Knowlton 1899	USNM 5067	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Fern
Betula iddingsi	Knowlton 1899	Syntypes USNM 4350, 4353, 5086, and 5164	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek and Bed 2 on a hill above Lost Creek	Angiosperm (Betulaceae)
Carpites pedunculatus	Knowlton 1899	USNM 4480	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Oleaceae)
Castanea pulchella	Knowlton 1899	Syntypes USNM 5080-5085	Lamar River / Sepulcher formations, 1/2 mile below the mouth of Elk Creek, Fossil Forest Ridge Bed 7 [Amethyst Mountain], and Junction Butte Fossil Forest	Angiosperm (Fagaceae)

YELL Table 4. Type specimens from YELL. The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column (continued).

Taxon	Publication	Catalog Number	Provenance	Notes
Celastrus culveri	Knowlton 1899	Syntypes USNM 4345 and 5140	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Celastraceae)
Celastrus ellipticus	Knowlton 1899	USNM 4390	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Celastraceae); preoccupied, renamed *Celastrus knowltoni* (Wonnacott 1955)
Celastrus inaequalis	Knowlton 1899	USNM 4397	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Celastraceae)
Cissus haguei	Knowlton 1899	USNM 4357	Lamar River Formation, Fossil Forest middle stratum [Amethyst Mountain]	Angiosperm (Vitaceae)
Cornus wrightii	Knowlton 1899	USNM 4424	Lamar River Formation, Fossil Forest [Amethyst Mountain]	Angiosperm (Cornaceae)
Credneria? pachyphylla	Knowlton 1899	Syntypes USNM 4352 and 5129	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Credneriaceae)
Cypericites giganteus	Knowlton 1899	USNM 5066	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Cyperaceae)
Devallia? montana	Knowlton 1899	USNM 4366	Lamar River Formation, Fossil Forest Ridge Bed 3 [Amethyst Mountain]	Fern
Diospyros haguei	Knowlton 1899	USNM 4393	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Ebenaceae)
Diospyros lamarensis	Knowlton 1899	Syntypes USNM 4348 and 4378	Lamar River Formation, east bank of the Lamar River between Cache and Calfee creeks	Angiosperm (Ebenaceae)
Dryopteris weedii	Knowlton 1899	Syntypes USNM 4389 and 5135	Sepulcher Formation, vicinity of the mouth of Hellroaring Creek	Fern
Dryopteris xantholithense	Knowlton 1899	USNM 5072	Lamar River Formation, Fossil Forest Ridge Bed 6 [Amethyst Mountain]	Fern
Dryopyllum longipetiolatum	Knowlton 1899	Syntypes USNM 4318, 4379, and 4380	Lamar River Formation, Fossil Forest Ridge Bed 7 [Amethyst Mountain]	Angiosperm (Fagaceae)
Equisetum canaliculatum	Knowlton 1899	Syntypes USNM 5094, 5105, and 5223	Lamar River / Sepulcher formations, several YELL localities	Horsetail
Equisetum deciduum	Knowlton 1899	USNM 5075	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Horsetail
Equisetum haguei	Knowlton 1899	Syntypes USNM 5061 and 5139	Sepulcher Formation, southeast end of hill north of Lost Creek, Bed 5	Horsetail

YELL Table 4. Type specimens from YELL. The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column (continued).

Taxon	Publication	Catalog Number	Provenance	Notes
Fagus undulata	Knowlton 1899	Syntypes USNM 5126, 5138, and 5185	Sepulcher Formation, along the Yellowstone River between Elk and Hellroaring creeks	Angiosperm (Fagaceae)
Ficus deformata	Knowlton 1899	USNM 4377	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Moraceae)
Ficus densifolia	Knowlton 1899	Syntypes USNM 4331, 4400, 4410, and 4489	Lamar River / Sepulcher formations, several localities in YELL	Angiosperm (Moraceae)
Ficus haguei	Knowlton 1899	USNM 4493	Lamar River Formation, Fossil Forest Ridge [Amethyst Mountain]	Angiosperm (Moraceae)
Fraxinus wrightii	Knowlton 1899	USNM 4358	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Oleaceae)
Grewiopsis? aldersoni	Knowlton 1899	Unknown	Lamar River Formation, Specimen Ridge	Angiosperm (Tiliaceae)
Hicoria crescentia	Knowlton 1899	USNM 4395	Lamar River / Sepulcher formations, northeast side of Crescent Hill or Fossil Forest Ridge Bed 6 [Amethyst Mountain]	Angiosperm (Juglandaceae)
Hicoria culveri	Knowlton 1899	USNM 4344	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Juglandaceae)
Juglans crescentia	Knowlton 1899	Unknown	Lamar River / Sepulcher formations, northeast side of Crescent Hill or Fossil Forest Ridge Bed 6 [Amethyst Mountain]	Angiosperm (Juglandaceae)
Juglans laurifolia	Knowlton 1899	Syntypes USNM 4325 and 5127	Lamar River Formation, including Yancey's Forest	Angiosperm (Juglandaceae)
Laurinoxylon pulchrum	Knowlton 1899	Unknown	Lamar River Formation, head of Crystal Creek on Specimen Ridge	Angiosperm
Laurus montana	Knowlton 1899	Syntypes USNM 4394 and 5186	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Lauraceae)
Laurus perdita	Knowlton 1899	Syntypes USNM 4404, 4478, 5093, 5220, and 5222	Sepulcher Formation, hill above Yancey's and vicinity	Angiosperm (Lauraceae)
Leguminosites lamarensis	Knowlton 1899	USNM 4391	Lamar River Formation, east bank of the Lamar River between Cache and Calfee creeks	Angiosperm (Fabaceae)
Litsea cuneata	Knowlton 1899	Syntypes USNM 4354, 4372, and 5132	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Lauraceae)
Magnolia culveri	Knowlton 1899	USNM 4401	Lamar River Formation, east bank of the Lamar River between Cache and Calfee creeks	Angiosperm (Magnoliaceae)

YELL Table 4. Type specimens from YELL. The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column (continued).

Taxon	Publication	Catalog Number	Provenance	Notes
Magnolia microphylla	Knowlton 1899	USNM 4481	Lamar River Formation, Fossil Forest Ridge Bed 3 [Amethyst Mountain]	Angiosperm (Magnoliaceae)
Magnolia spectabilis	Knowlton 1899	Syntypes USNM 4470, 4471, 4473, 4475, and 4490	Lamar River Formation, Fossil Forest Ridge Bed 3 [Amethyst Mountain]	Angiosperm (Magnoliaceae)
Magnolia? *pollardi*	Knowlton 1899	Syntypes USNM 5122 and 5123	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Magnoliaceae)
Malapoenna lamarensis	Knowlton 1899	Syntypes USNM 4355, 4356, and 4492	Lamar River / Sepulcher formations, east bank of the Lamar River between Cache and Calfee creeks, and 1/2 mile below the mouth of Elk Creek	Angiosperm (Lauraceae)
Myrica lamarensis	Knowlton 1899	USNM 4469	Lamar River Formation, east bank of the Lamar River between Cache and Calfee creeks	Angiosperm (Myricaceae)
Myrica wardii	Knowlton 1899	Syntypes USNM 4487 and 5216	Lamar River Formation, Fossil Forest Ridge Bed 5 [Amethyst Mountain]	Angiosperm (Myricaceae)
Phragmites falcata	Knowlton 1899	USNM 5104	Everts Formation, near summit of west end of Mount Everts	Angiosperm (Poaceae)
Phragmites? *latissima*	Knowlton 1899	USNM 4497	Sepulcher Formation, northeast side of Crescent Hill	Angiosperm (Poaceae)
Phyllites crassifolia	Knowlton 1899	Syntypes USNM 4305 and 4309	Lamar River Formation, Fossil Forest Ridge [Amethyst Mountain]	Angiosperm (Oleaceae)
Pinus gracilistrobus	Knowlton 1899	USNM 5091	Lamar River Formation, Fossil Forest Ridge Bed 7 [Amethyst Mountain]	Conifer
Pinus iddingsi	Knowlton 1899	USNM 4427	Lamar River Formation?, near peak west of Dunraven on Carnelian Creek	Conifer
Pinus macrolepis	Knowlton 1899	USNM 5157	Lamar River Formation, cliff west of Fossil Forest Ridge [Amethyst Mountain]	Conifer
Pinus premurrayana	Knowlton 1899	USNM 222760	Langford Formation, east of Yellowstone Lake	Conifer
Pinus wardii	Knowlton 1899	Syntypes USNM 5144 and 5152	Lamar River Formation, Fossil Forest Ridge Bed 4 [Amethyst Mountain]	Conifer
Pityoxylon aldersoni	Knowlton 1899	USNM 30868	Sepulcher Formation, head of Crystal Creek	Conifer
Pityoxylon amethystinum	Knowlton 1899	USNM 30869	Lamar River Formation, head of Crystal Creek	Conifer

YELL Table 4. Type specimens from YELL. The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column (continued).

Taxon	Publication	Catalog Number	Provenance	Notes
Platanus montana	Knowlton 1899	Syntypes USNM 4360 and 5131	Sepulcher Formation, east slope of hill 3/4 mile south of Yancey's	Angiosperm (Platanaceae)
Populus xantholithensis	Knowlton 1899	Syntypes USNM 4338 and 4339	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Salicaceae)
Populus? *vivaria*	Knowlton 1899	Unknown	Lamar River Formation, west end of Fossil Forest Ridge [Amethyst Mountain]	Angiosperm (Salicaceae)
Pterospermites haguei	Knowlton 1899	USNM 4370	Lamar River Formation, Fossil Forest Ridge [Amethyst Mountain]	Angiosperm (Sterculiaceae)
Quercinium lamarense	Knowlton 1899	USNM 30874	Lamar River Formation, Specimen Ridge	Angiosperm
Quercus culveri	Knowlton 1899	USNM 4381	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Fagaceae)
Quercus grossidentata	Knowlton 1899	Syntypes USNM 4361, 5165, and 5166	Lamar River Formation, Fossil Forest Ridge Bed 5 [Amethyst Mountain]	Angiosperm (Fagaceae)
Quercus hesperia	Knowlton 1899	Unknown	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Fagaceae)
Quercus weedii	Knowlton 1899	Syntypes USNM 4281 and 4402	Lamar River Formation, Fossil Forest Ridge Bed 6 [Amethyst Mountain]	Angiosperm (Fagaceae)
Quercus yanceyi	Knowlton 1899	USNM 4374	Sepulcher Formation, Yancey's Forest	Angiosperm (Fagaceae)
Quercus? *magnifolia*	Knowlton 1899	USNM 4376	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Angiosperm (Fagaceae)
Sapindus grandifolioloides	Knowlton 1899	Unknown	Sepulcher Formation, a hill north of Lost Creek	Angiosperm (Sapindaceae)
Sapindus wardii	Knowlton 1899	Syntypes USNM 4364 and 5068	Lamar River / Sepulcher formations, Fossil Forest Ridge Bed 5 [Amethyst Mountain] and 1/2 mile below the mouth of Elk Creek	Angiosperm (Sapindaceae)
Sequoia magnifica	Knowlton 1899	USNM 30837	Lamar River Formation, Specimen Ridge or Fossil Forest [Amethyst Mountain]	Conifer
Smilax lamarensis	Knowlton 1899	Syntypes USNM 4436, 5134, and 5162	Lamar River Formation, east bank of the Lamar River between Cache and Calfee creeks and Fossil Forest Ridge Bed 6 [Amethyst Mountain]	Angiosperm (Smilacaceae)
Woodwardia preareolata	Knowlton 1899	Unknown	Sepulcher Formation, northeast side of Crescent Hill	Fern

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Taxon	Publication	Catalog Number	Provenance	Notes
Gymnogramma haydenii	Lesquereux 1872	USNM 29	"Laramie" Formation, divide between the "source of the Snake River" and the southern shore of Yellowstone Lake	Fern
Carpolithes osseus	Lesquereux 1873	Missing	Sepulcher Formation, 1/2 mile below the mouth of Elk Creek	Plant
Aralia notata	Lesquereux 1878	USNM 332 and 332a	Sepulcher Formation, Elk Creek near the Yellowstone River	Angiosperm (Araliaceae)
Geonomites schimperi	Lesquereux 1878	USNM 104	"Laramie" Formation, divide between the "source of the Snake River" and the southern shore of Yellowstone Lake	Angiosperm (Arecaceae)
Elaeodendroxylon polymorphum	Platen 1908	Unknown	Lamar River Formation, Amethyst Mountain	Angiosperm
Plataninium knowltoni	Platen 1908	Unknown	Lamar River Formation, Amethyst Mountain	Angiosperm
Pruninium gummosum	Platen 1908	Unknown	Lamar River Formation, Amethyst Mountain	Angiosperm
Cupressinoxylon lamarense	Read 1933	UCMP Paleobotany 1281	Sepulcher Formation, Yancey Forest	Conifer
Pinus baumani	Read 1933	UCMP Paleobotany 1278	Lamar River Formation, Fossil Forest on Specimen Ridge	Conifer
Ehmania walcotti	Resser 1935	Material including syntype USNM 90667	Meagher Limestone, Crowfoot Ridge (USNM loc. 151d)	Trilobite
Ehmania weedi	Resser 1935	USNM 35234	Meagher Limestone, Crowfoot Ridge (USNM loc. 151d)	Trilobite
Idahoia wyomingensis	Resser 1937	USNM 35225	Snowy Range Formation, Soda Butte Creek (USNM loc. 151e)	Trilobite
Tricrepicephalus yellowstonensis	Resser 1937	USNM 61523	Pilgrim Limestone, between Pebble and Soda Butte creeks (USNM locality 151b)	Trilobite
Wilbernia walcotti	Resser 1937	USNM 35227	Snowy Range Formation, Soda Butte Creek	Trilobite
Zacanthoides weedi	Resser 1937	USNM 94345	Meagher Limestone Crowfoot Ridge (USNM 151d)	Trilobite
Blountia polita	Resser 1938	USNM 96488	Pilgrim Limestone, between Pebble and Soda Butte creeks (USNM loc. 151b)	Trilobite
Hyolithes gallatinensis	Resser 1938	USNM 35218-A	Snowy Range Formation, Crowfoot Ridge (USNM loc. 151c)	Hyolith

YELL Table 4. Type specimens from YELL. The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column (continued).

Taxon	Publication	Catalog Number	Provenance	Notes
Semnocephalus minor	Resser 1942a	USNM 102322	Pilgrim Limestone, Crowfoot Ridge	Trilobite
Taeinocephalus holmesi	Resser 1942b	USNM 9595	Snowy Range Formation, Gallatin Valley (USNM loc. 66x)	Trilobite
Taeinocephalus speciosus	Resser 1942b	USNM 108831a	Snowy Range Formation, Abiathar Peak (USNM loc. 62r)	Trilobite
Amnicola? cretacea	Stanton 1899	USNM 28949	Kootenai Formation, Fawn Creek	Gastropod
Anatina (*Cercomya*) *punctata*	Stanton 1899	USNM 28945	Sawtooth Formation, south slope of ridge south of Gray Mountain (USGS Mesozoic loc. 1131)	Bivalve
Astarte meeki	Stanton 1899	Material including syntypes USNM 28936 and 28937	Ellis Group, several localities in YELL (other syntype[s] from Cinnabar Mountain outside of YELL)	Bivalve
Camptonectes bellistriatus var. *distans*	Stanton 1899	Material including syntype USNM 28933	Ellis Group, near the source of the Gardiner River	Bivalve
Cyprina? cinnabarensis	Stanton 1899	Material including syntypes USNM 28939 and 30648, at least one of which is from YELL	Ellis Group, several localities in northern YELL (other syntype[s] from Cinnabar Mountain outside of YELL)	Bivalve
Goniobasis? increbescens	Stanton 1899	USNM 28948	Kootenai Formation, Fawn Creek	Gastropod
Goniobasis? pealei	Stanton 1899	Material including syntype USNM 28947	Kootenai Formation, northwestern YELL (other syntype[s] from Three Forks Valley outside of YELL)	Gastropod
Homomya gallatinensis	Stanton 1899	USNM 28942	Ellis Group, divide between Fawn Creek and Gallatin Valley	Bivalve
Inoceramus acuteplicatus	Stanton 1899	At least one of syntypes USNM 28950, 28951, and 315993	Cody Shale, 1/4 mile above the mouth of Sickle Creek on the Snake River (other syntype[s] from JODR)	Bivalve; preoccupied, renamed *Inoceramus stantoni* (Sokolov 1914)
Pholadomya inaequiplicata	Stanton 1899	USNM 28956	Ellis Group, divide between Fawn Creek and Gallatin Valley	Bivalve
Tancredia? knowltoni	Stanton 1899	USNM 28938	Ellis Group, north side of road near Sentinel Butte (now Clagett Butte)	Bivalve
Thracia weedi	Stanton 1899	Material including syntypes USNM 28943 and 28944	Ellis Group, stream bed west of Little Quadrant Mountain and saddle in ridge west of south head of Gardiner River	Bivalve

YELL Table 4. Type specimens from YELL. The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column (continued).

Taxon	Publication	Catalog Number	Provenance	Notes
Lingulepis meeki	Walcott 1897	Syntypes USNM 35206.A and B	"Flathead" Formation, Crowfoot Ridge (USNM loc. 302b)	Brachiopod
Arionellus levis	Walcott 1899	USNM 35230	"Gallatin" Formation, Crowfoot Ridge	Trilobite
Haguia sphaerica	Walcott 1899	Material including syntype USNM 35224	"Flathead" Formation, north side of Soda Butte Creek	Archaeocyathid? (possible sponge)
Liostracus parvus	Walcott 1899	USNM 35233	Unspecified Cambrian, in bluff on the south side of Pebble Creek north of saddle to Soda Butte Creek	Trilobite
Ptychoparia penfieldi	Walcott 1899	USNM 35231	"Flathead" Formation, Crowfoot Ridge	Trilobite
Solenopleura? *weedi*	Walcott 1899	USNM 35236	Pilgrim Limestone, Crowfoot Ridge	Trilobite
Obolus (*Lingulella*) *desideratus*	Walcott 1902	Material including syntypes USNM 27311.A-C, 33867.A-B, and 35207.A	"Gallatin" Formation, Crowfoot Ridge (USNM loc. 302l) (other syntype[s] from outside of YELL)	Brachiopod
Orthis (*Plectorthis*) *iddingsi*	Walcott 1905	Material including syntype USNM 52340	"Gallatin" Formation, south side of the Gallatin Valley	Brachiopod
Syntrophia abnormis	Walcott 1905	Material including syntypes USNM 52462.A-K	Unspecified Cambrian, head of Deep Creek (USNM loc. 4j)	Brachiopod
Alnus latissima	Wheeler et al. 1977	USNM 458726 (was USGS Fossil Wood Collection D-2089-13)	Sepulcher Formation, Gallatin Fossil Forest in YELL (USGS Paleobotany loc. 2089)	Angiosperm (Betulaceae)
Carpinus absarokensis	Wheeler et al. 1977	USNM 458280 (was USGS Fossil Wood Collection D-2054B-32)	Lamar River Formation, Specimen Ridge (USGS Paleobotany loc. D2054B)	Angiosperm (Betulaceae)
Carpinus saximontana	Wheeler et al. 1977	USNM 458277 (was USGS Fossil Wood Collection D-2089-16)	Sepulcher Formation, Gallatin Fossil Forest in YELL (USGS Paleobotany loc. 2089)	Angiosperm (Betulaceae)
Magnoliaceoxylon wetmorei	Wheeler et al. 1977	USNM 458287 (was USSG Fossil Wood Collection D-2089-20)	Sepulcher Formation, Gallatin Fossil Forest in YELL (USGS Paleobotany loc. 2089)	Angiosperm (Magnoliaceae)
Ulminium eocenicum	Wheeler et al. 1977	USNM 458286 (was USGS Fossil Wood Collection D-2054B-38)	Lamar River Formation, Specimen Ridge (USGS Paleobotany loc. D2054B)	Angiosperm (Lauraceae)
Ulminium parenchymatosum	Wheeler et al. 1977	USNM 458285 (was USGS Fossil Wood Collection D-2054B-40)	Lamar River Formation, Specimen Ridge (USGS Paleobotany loc. D2054B)	Angiosperm (Lauraceae)

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Taxon	Publication	Catalog Number	Provenance	Notes
Ulminium porosum	Wheeler et al. 1977	USNM 458281 (was USGS Fossil Wood Collection D-2054A-24)	Lamar River Formation, Amethyst Mountain (USGS Paleobotany loc. D2054A)	Angiosperm (Lauraceae)
Cyrilloxylon eocenicum	Wheeler et al. 1978	USNM 458297 (was USGS Fossil Wood Collection D-2054B-28)	Lamar River Formation, Specimen Ridge (USGS Paleobotany loc. D2054B)	Angiosperm (Cyrillaceae)
Myrica absarokensis	Wheeler et al. 1978	USNM 458313 (was USGS Fossil Wood Collection D-2054B-11)	Lamar River Formation, Specimen Ridge (USGS Paleobotany loc. D2054B)	Angiosperm (Myricaceae)
Nyssa saximontana	Wheeler et al. 1978	USNM 458318 (was USGS Fossil Wood Collection D-2054B-41)	Lamar River Formation, Specimen Ridge (USGS Paleobotany loc. D2054B)	Angiosperm (Nyssaceae)
Pterocaryoxlon knowltonii	Wheeler et al. 1978	USNM 458312 (was USGS Fossil Wood Collection D-2054B-37)	Lamar River Formation, Specimen Ridge (USGS Paleobotany loc. D2054B)	Angiosperm (Juglandaceae)
Quercinium amethystianum	Wheeler et al. 1978	USNM 458299 (was USGS Fossil Wood Collection D-2054A-11)	Lamar River Formation, Amethyst Mountain (USGS Paleobotany loc. D2054A)	Angiosperm (Fagaceae)
Rhus crystallifera	Wheeler et al. 1978	USNM 458296 (was USGS Fossil Wood Collection D-2054A-14)	Lamar River Formation, Amethyst Mountain (USGS Paleobotany loc. D2054A)	Angiosperm (Anacardiaceae)
Turpinia lamarense	Wheeler et al. 1978	USNM 458320 (was USGS Fossil Wood Collection D-2054B-24)	Lamar River Formation, Specimen Ridge (USGS Paleobotany loc. D2054B)	Angiosperm (Staphyleaceae)
Zelkovoxylon occidentale	Wheeler et al. 1978	USNM 458321 (was USGS Fossil Wood Collection D-2054B-26)	Lamar River Formation, Specimen Ridge (USGS Paleobotany loc. D2054B)	Angiosperm (Ulmaceae)

Cultural Resource Contexts

Humans have been present in the vicinity of YELL since the end of the Pleistocene (Pierce et al. 2003), and hundreds of archeological sites were known in the Yellowstone-Jackson Hole area by 1980 (Wright 1980). Thus, it is unsurprising that there are many examples of paleontological resources having cultural resource contexts. Several Holocene vertebrate sites in and around YELL with cultural associations were mentioned in the Quaternary section.

The abundant petrified wood of YELL and the vicinity has been used in several ways by humans. Petrified wood was used for tools and points, with examples found at Mummy Cave (Husted and Edgar 2002). Within YELL, about 1% of all stone tools discovered are made of petrified wood. Raw material sources are often important sites in their own right. A petrified wood quarry site is located near the Sky Rim Trail on the park's northwestern boundary. Fossil wood is also found just north of the park boundary at Ram's Horn Lake (S. Peterson, pers. comm., July 2013). More recently, the cabin foundation in Yancy's Hole (1880s) was partially made of petrified wood (S. Peterson, YELL park archeologist, pers. comm., July 2013), and petrified wood was used in the construction of the Roosevelt Lodge, where it can be seen in the foundation (Santucci 1998).

A number of fossiliferous formations are also known as sources of material for stone tools (Frison 1991). An example of a tool material that may contain fossils is Knife River flint (Davis and Zeier 1978). This occasionally fossiliferous rock is sourced from the nearby Northern Great Plains Network, including the vicinity of Knife River Indian Villages National Historic Site (KNRI) in North Dakota.

Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts, including an amusing anecdote involving YELL. Depending on one's opinion of the veracity of mountain men and their biographers, the fossil forests of YELL are the subject of a classic "tall tale" supposedly related by Jim Bridger, who upon hearing of the wonders of what eventually became Petrified Forest National Park, replied "O, that's peetrifaction. Come with me to Yellowstone next summer, and I'll show you peetrifed trees a-growing, with peetrified birds on 'em a-signing peetrified songs." Whether or not he actually said this, or if it springs from an older tall tale by a different mountain man, Bridger did visit the YELL area (Kenworthy and Santucci 2006).

References Cited

Adams, T., B. Breithaupt, J. Shinn, E. Southwell, and N. Matthews. 2004. The Sundance vertebrate ichnofaunal province: evidence for population structures of Bathonian dinosaurs from tracksites in the Bighorn Basin, Wyoming. *Journal of Vertebrate Paleontology* 24(supplement to 3):33A.

Agatston, R. S. 1952. Tensleep formation of the Big Horn Basin. Pages 44-48 *in* R. W. Spalding and J. S. Wold, editors. Southern Big Horn Basin, Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 7.

Ammons, R., W. J. Fritz, R. B. Ammons, and A. Ammons. 1987. Cross-identification of ring signatures in Eocene trees (*Sequoia magnifica*) from the Specimen Ridge locality of the Yellowstone fossil forests. *Palaeogeography, Palaeoclimatology, Palaeoecology* 60(1-2):97-108.

Anders, M. H., J. Saltzman, and S. R. Hemming. 2009. Neogene tephra correlations in eastern Idaho and Wyoming: implications for Yellowstone Hotspot-related volcanism and tectonic activity. *Geological Society of America Bulletin* 121(5-6):837-856.

Andersson, K. A. 1985. Permian trace fossils of western Wyoming and southwestern Montana: systematics and paleoenvironments. Abstracts with Programs. *Geological Society of America* 17(4):207.

Andrews, H. N. 1939. Notes on the fossil flora of Yellowstone National Park with particular reference to the Gallatin region. *American Midland Naturalist* 21(2):454-460.

Andrews, H. N., Jr. and L. W. Lenz. 1946. The Gallatin Fossil Forest. *Annals of the Missouri Botanical Garden* 33(3):309-313.

Andrews, H. N., Jr. and C. S. Pearsall. 1941. On the flora of the Frontier Formation of southwestern Wyoming. *Annals of the Missouri Botanical Garden* 28(2):165-192.

Andrichuk, J. M. 1956. Devonian stratigraphy in northwestern Wyoming and adjoining areas. Pages 43-50 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Ash, S. R. and C. B. Read. 1976. North American species of *Tempskya* and their stratigraphic significance. U.S. Geological Survey, Reston, VA. Professional Paper 874. Available online at: http://pubs.er.usgs.gov/publication/pp874. Accessed February 2013.

Ash, S. R. and W. D. Tidwell. 1998. Plant megafossils from the Brushy Basin Member of the Morrison Formation near Montezuma Creek Trading Post, southeastern Utah. *Modern Geology* 22(1-4):321-340.

Aubrey, W. M. 1991. Geologic framework of Cretaceous and Tertiary rocks in the Southern Ute Indian Reservation and adjacent areas in the northern San Juan Basin, southwestern Colorado. Pages B1-B24 *in* R. S. Zech, editor. Geologic framework and stratigraphy of Cretaceous

and Tertiary rocks of the Southern Ute Indian Reservation, southwestern Colorado. U.S. Geological Survey, Reston, VA. Professional Paper 1505-B,C. Online. Available online at: http://pubs.er.usgs.gov/publication/pp1505BC. Accessed March 2011.

Axelrod, D. I. 1986. Cenozoic history of some western American pines. *Annals of the Missouri Botanical Garden* 73(3):565-641.

Baker, R. G. 1969. Pollen and seed diagrams from an abandoned lagoon on the southeast arm of Yellowstone Lake, Wyoming. Abstracts with Programs. *Geological Society of America* 1(5):4-5.

Baker, R. G. 1970a. Pollen sequence from late Quaternary sediments in Yellowstone Park. *Science* 168(3938):1449-1450.

Baker, R. G. 1970b. Late-Quaternary vegetation history in Yellowstone Park. Program and Abstracts. *American Quaternary Association. Conference* 1:4-5.

Baker, R. G. 1976. Late Quaternary vegetation history of the Yellowstone Lake Basin, Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 729-E. Available online at: http://pubs.er.usgs.gov/publication/pp729E. Accessed March 2013.

Baker, R. G. 1980. Interglacial and interstadial environments in Yellowstone National Park. Pages 361-375 *in* W. C. Mahaney, editor. Quaternary paleoclimate. Geo Abstracts, Norwich, United Kingdom.

Baker, R. G. 1983. Holocene vegetational history of the western United States. Pages 109-127 *in* H. E. Wright, Jr., editor. Late-Quaternary environments of the United States. Volume 2: the Holocene. University of Minnesota Press, Minneapolis, USA.

Baker, R. G. 1986. Sangamonian(?) and Wisconsinan paleoenvironments in Yellowstone National Park. *Geological Society of America Bulletin* 97(6):717-736.

Baker, R. G. and G. M. Richmond. 1978. Geology, palynology, and climatic significance of two pre-Pinedale lake sediment sequences in and near Yellowstone National Park. *Quaternary Research* 10(2):226-240.

Bargar, K. E. 1978. Geology and thermal history of Mammoth Hot Springs, Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington DC. Bulletin 1444. Available online at: http://www.nps.gov/history/history/online_books/geology/publications/bul/1444/index.htm. Accessed April 2013.

Barker, K. S. 1984. Stratigraphy, petrography, and paleoenvironmental interpretation of Mississippian-Pennsylvanian Amsden Formation south of La Barge Guard Station, Salt River Range, western Wyoming. *AAPG Bulletin* 68(7):932.

Barnosky, A. D. 1984. The Colter Formation: evidence for Miocene volcanism in Jackson Hole, Teton County, Wyoming. *Earth Science Bulletin* 17:49-97.

Barnosky, A. D. and W. J. LaBar. 1989. Mid-Miocene (Barstovian) environmental and tectonic setting near Yellowstone Park, Wyoming and Montana. *Geological*

Society of America Bulletin 101(11):1448-1456.

Barnosky, A. D., E. A. Hadly, and C. J. Bell. 2003. Mammalian response to global warming on varied temporal scales. *Journal of Mammalogy* 84(2):354-368.

Barnosky, E. A. 1992. A positive role for taphonomy and time-averaging as illustrated by mammalian fossils from Lamar Cave, Yellowstone National Park, WY. Abstracts with Program - *Geological Society of America* 24(6):2.

Barnosky, E. H. 1994. Does climate induce change in morphologic variation within species? *Journal of Vertebrate Paleontology* 14(supplement to 3):16A.

Beebee, R. A. and R. Cox. 1998. Dynamics of marine transgression onto a non-linear shoreline: the Middle Cambrian Flathead Sandstone, Clarks Fork Valley, Wyoming. *Mountain Geologist* 35(3):91-101.

Behnken, F. H., B. R. Wardlaw, and L. N. Stout. 1986. Conodont biostratigraphy of the Permian Meade Peak phosphatic shale member, Phosphoria Formation, southeastern Idaho. *Contributions to Geology* 24(2):169-190.

Bell, L. H. and L. T. Middleton. 1978. An introduction to the Cambrian Flathead Sandstone, Wind River basin, Wyoming. Pages 79-88 *in* R. G. Boyd, W. W. Boberg, and G. M. Olson, editors. Resources of the Wind River basin. Wyoming Geological Association, Casper, WY. Guidebook 30.

Bell, W. C. 1941. Cambrian Brachiopoda from Montana. *Journal of Paleontology* 15(3):193-255.

Bender, M. M., R. A. Bryson, and D. A. Baerreis. 1971. University of Wisconsin radiocarbon dates IX. *Radiocarbon* 13(2):475-486.

Bennett, S. C. 1989. A pteranodontid pterosaur from the Early Cretaceous of Peru, with comments on the relationships of Cretaceous pterosaurs. *Journal of Paleontology* 63(5):669-677.

Benson, A. L. 1966. Devonian stratigraphy of western Wyoming and adjacent areas. *Bulletin of the American Association of Petroleum Geologists* 50(12):2566-2603.

Berry, E. W. 1930. The flora of the Frontier Formation. Pages 129-135 *in* Shorter contributions to general geology, 1929. U.S. Geological Survey, Reston, VA. Professional Paper 158.

Beyer, A. F. 1950. Additions to the fossil flora of Specimen Ridge, Yellowstone National Park, Wyoming. *American Journal of Botany* 37(8):672.

Beyer, A. F. 1954. Some petrified woods from the Specimen Ridge area of Yellowstone National Park. *American Midland Naturalist* 51(2):553-567.

Blackwell, W. H., W. D. Martin, and R. G. McWilliams. 1983. Algal remains in cryptalgal laminated carbonates of the upper Middle Cambrian of Northwest Wyoming. *American Journal of Botany* 70(5, Part 2):68.

Blake, D. B. 1981. The new Jurassic sea star genus *Eokainaster* and comments on life habits and the origins of the modern Asteroidea. *Journal of Paleontology* 55(1):33-46.

Blank, H. R., Jr., H. J. Prostka, W. R. Keefer, and R. L. Christiansen. 1974. Geologic map of the Frank Island Quadrangle, Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington, DC. Geologic Quadrangle Map 1209. Scale 1:62,500. Online. Available online at: http://pubs.er.usgs.gov/publication/gq1209 Accessed April 2013.

Blome, C. D. and D. L. Eicher. 1994. Radiolarian paleoceanography of the Upper Cretaceous Western Interior Seaway, southern Montana. Abstracts with Programs. *Geological Society of America* 26(7):A-159.

Bonem, R. M. 1972. Stratigraphic and faunal studies of the Pilgrim Formation in south-central Montana. Pages 11-17 *in* J. Lynn, C. Balster, and J. Warne, editors. Crazy Mountains Basin. Montana Geological Society, Billings, MT. Guidebook 21.

Bown, T. M. 1982. Geology, paleontology, and correlation of Eocene volcaniclastic rocks, southeast Absaroka Range, Hot Springs County, Wyoming. U.S. Geological Survey, Reston, VA. Professional Paper 1201-A. Available online at: http://pubs.er.usgs.gov/publication/pp1201A . Accessed April 2013.

Boyd, D. W. 2010. Morphology and taphonomy of an exceptional trackway from the Flathead Sandstone (Middle Cambrian) of Wyoming. *Contributions to Geology* 45(1):23-34.

Boyd, D. W. and H. T. Ore. 1963. A Wyoming specimen of *Dendrophycus*. *Contributions to Geology* 2(1):63-68.

Bracht, B. B., J. R. Stone, and S. C. Fritz. 2008. A diatom record of late Holocene climate variation in the northern range of Yellowstone National Park, USA. *Quaternary International* 188(1):149-155.

Bralower, T. J., R. M. Leckie, W. V. Sliter, and H. R. Thierstein. 1995. An integrated Cretaceous microfossil biostratigraphy. Pages 65-79 *in* W. A. Berggren, D. V. Kent, M.-P. Aubry, and J. Hardenbol, editors. Geochronology, time scales and global stratigraphic correlation. Society for Sedimentary Geology, Tulsa, OK. Special Publication 54.

Braman, D. R. 2001. Terrestrial palynomorphs of the upper Santonian-?lowest Campanian Milk River Formation, southern Alberta, Canada. *Palynology* 25:57-107.

Branson, E. B. 1947. Triassic (Chugwater) footprints from Wyoming. *Journal of Paleontology* 21(6):588-590.

Branson, E. B. and M. G. Mehl. 1932. Footprint records from the Paleozoic and Mesozoic of Missouri, Kansas and Wyoming. *Bulletin of the Geological Society of America* 43(2):383-398.

Bray, E. and K. F. Hirsch. 1998. Eggshell from the Upper Jurassic Morrison Formation. *Modern Geology* 23(1-4):219-240.

Breithaupt, B. H. 1985. Nonmammalian vertebrate faunas from the Late Cretaceous of Wyoming. Pages 159-175 *in* G. E. Nelson, editor. The Cretaceous geology of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 36.

Breithaupt, B. H., E. H. Southwell, T. L. Adams, and N. A. Matthews. 2001. Innovative documentation methodologies in the study of the most extensive dinosaur tracksite in Wyoming. Pages 113-122 *in* V. L. Santucci, and L. McClelland, editors. Proceedings of the 6th fossil resource conference: 2001 a fossil odyssey. NPS Geological Resources Division, Denver, CO. Technical Report NRS/NRGRD/GRDTR-01/01. Available online at: http://www.nature.nps.gov/geology/paleontology/pub/fossil_conference_6/breithaupt_3.htm. Accessed June 2013.

Breithaupt, B. H., E. H. Southwell, T. Adams, and N. A. Matthews. 2006. The Red Gulch Dinosaur Tracksite: public participation in the conservation and management of a world-class paleontological site. Page 10 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 34.

Brenner, R. L. and D. K. Davies. 1973. Storm-generated coquinoid sandstone: genesis of high-energy marine sediments from the Upper Jurassic of Wyoming and Montana. *Geological Society of America Bulletin* 84(5):1685-1698.

Brenner, R. L. and D. K. Davies. 1974. Oxfordian sedimentation in Western Interior United States. *AAPG Bulletin* 58(3):407-428.

Brett, C. E., W. D. Liddell, and K. L. Derstler. 1983. Late Cambrian hardground communities from Montana and Wyoming. Abstracts with Programs. *Geological Society of America* 15(5):408.

Breuninger, R. H. 2000. Zoned microbial reef complex in the Pilgrim Formation, Upper Cambrian age, western Montana. Abstracts with Programs. *Geological Society of America* 32(5):3.

Brown, B. and H. E. Vokes. 1944. Fossil imprints of unknown origin: II. Further information and a possible explanation. *American Journal of Science* 242:656-672.

Brown, C. W. 1959. Diagenesis of Late Cambrian ooelitic limestone, Maurice Formation, Montana and Wyoming. *Journal of Sedimentary Petrology* 29(2):260-266.

Brown, C. W. 1961. Cenozoic stratigraphy and structural geology, northeast Yellowstone National Park, Wyoming and Montana. *Geological Society of America Bulletin* 72(8):1173-1193.

Brown, J. T. 1972. *Sagenopteris* from the Kootenai Formation (Early Cretaceous) of Montana. *American Journal of Botany* 59(6, Part 2):659.

Brown, J. T. 1975. Upper Jurassic and lower Cretaceous ginkgophytes from Montana. *Journal of Paleontology* 49(4):724-730.

Brown, J. T. and C. R. Robison. 1972. A moss gametophyte from the Kootenai Formation (Lower Cretaceous) of Montana. American *Journal of Botany* 59(6, Part 2):659-660.

Brown, J. T. and C. R. Robison. 1974. *Diettertia montanensis*, gen. et sp. nov., a fossil moss from the lower Cretaceous

Kootenai Formation of Montana. *Botanical Gazette* 135(3):170-173.

Brown, J. T. and C. R. Robison. 1976. Observations on the structure of *Marchantiolites blairmorensis* (Berry) n. comb. from the lower Cretaceous of Montana, U.S.A. *Journal of Paleontology* 50(2):309-311.

Brues, C. T. 1936. Evidences of insect activity preserved in fossil wood. *Journal of Paleontology* 10(7):637-643.

Burford, A. E. 1985. Reptilian markings on the upper Mowry Shale, Emigrant Gap area, Natrona County, Wyoming. Pages 157-158 *in* G. E. Nelson, editor. The Cretaceous geology of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 36.

Burgess, J. D. 1971. Palynological interpretation of Frontier environments in central Wyoming. *Geoscience and Man* 3:69-82.

Burton, D., B. W. Greenhalgh, B. B. Britt, B. J. Kowallis, W. S. Elliott, Jr., and R. Barrick. 2006. New radiometric ages from the Cedar Mountain Formation, Utah and the Cloverly Formation, Wyoming: implications for contained dinosaur faunas. Abstracts with Programs. *Geological Society of America* 38(7):52.

Byers, C. W. and D. W. Larson. 1979. Paleoenvironments of Mowry Shale (Lower Cretaceous), western and central Wyoming. *AAPG Bulletin* 63(3):354-361.

Cannon, K. P. 2006. Prehistoric ecology of *Bison* in the greater Yellowstone ecosystem. Program and Abstracts. *American Quaternary Association Conference* 19:70-72. Available online at: http://www.amqua.org/publications/abstracts/amqua2006-abstracts.pdf. Accessed April 2013.

Carpenter, K. and J. I. Kirkland. 1998. Review of Lower and Middle Cretaceous ankylosaurs from North America. Pages 249-270 *in* S. G. Lucas, J. I. Kirkland, and J. W. Estep, editors. Lower and Middle Cretaceous terrestrial ecosystems. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 14.

Cartwright, A. M., T. P. Cleland, S. F. Derby, E. E. Ergas, H. I. Fay, K. M. Loughney, J. A. Riedel, M. K. Rocheford, C. L. Scott, and K. L. Skaggs. 2005. Aspects of the paleontology and stratigraphy of the Lower Triassic-Lower Cretaceous strata of the eastern Bighorn Basin, WY. Abstracts with Programs. *Geological Society of America* 37(7):302.

Cather, S. M. 2003. Polyphase Laramide tectonism and sedimentation in the San Juan Basin, New Mexico. Pages 119-132 *in* S. G. Lucas, S. C. Semken, W. Berglof, and D. Ulmer-Scholle, editors. Geology of the Zuni Plateau. New Mexico Geological Society, Socorro, NM. Guidebook 54.

Cavaroc, V. V. and R. M. Flores. 1991. Red beds of the Triassic Chugwater Group, southwestern Powder River basin, Wyoming. U.S. Geological Survey, Reston, VA. Bulletin 1917-E. Available online at: http://pubs.er.usgs.gov/publication/b1917E. Accessed February 2013.

Chadwick, A. V. and T. Yamamoto. 1984. A paleoecological analysis of the petrified trees in the Specimen Creek area of

Yellowstone National Park, Montana, U.S.A. *Palaeogeography, Palaeoclimatology, Palaeoecology* 45(1):39-48.

Chadwick, R. A. 1970. Belts of eruptive centers in the Absaroka–Gallatin Volcanic Province, Wyoming–Montana. *Geological Society of America Bulletin* 81(1):267-274.

Chaney, R. W. 1926. Palaeontology. *Carnegie Institution of Washington Year Book* 25:399-402.

Channing, A., M. H. Schweitzer, J. R. Horner, and Terry McEneaney. 2005. A silicified bird from Quaternary hot spring deposits. *Proceedings: Biological Sciences* 272(1566):905-911.

Chen, X. and G. D. Webster. 1994. Sedimentology, tectonic control and evolution of a Lower Mississippian carbonate ramp with offshore bank, central Wyoming to eastern Idaho and northeastern Utah, U.S.A. Pages 557-587 *in* A. F. Embry, B. Beauchamp, and D. J. Glass, editors. Pangea: global environments and resources. Canadian Society of Petroleum Geologists, Calgary, Canada. Memoir 17.

Christiansen, R. L. 2001. The Quaternary and Pliocene Yellowstone Plateau volcanic field of Wyoming, Idaho, and Montana. U.S. Geological Survey, Reston, VA. Professional Paper 729-G. Available online at: http://pubs.usgs.gov/pp/pp729g/. Accessed March 2013.

Christiansen, R. L. and H. R. Blank, Jr. 1972. Volcanic stratigraphy of the Quaternary Rhyolite Plateau in Yellowstone National Park. U.S. Geological Survey, Washington, DC. Professional Paper 729-B. Available online at: http://pubs.er.usgs.gov/publication/pp729B or http://www.nps.gov/history/history/online_books/geology/publications/pp/729-B/index.htm. Accessed April 2013.

Christiansen, R. L., H. R. Blank, Jr., J. D. Love, and J. C. Reed, Jr. 1978. Geologic map of the Grassy Lake Reservoir Quadrangle, Yellowstone National Park and vicinity, Wyoming. U.S. Geological Survey, Reston, VA. Geologic Quadrangle Map 1459. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_10993.htm. Accessed March 2013.

Chure, D. J., R. Litwin, S. T. Hasiotis, E. Evanoff, and K. Carpenter. 2006. The fauna and flora of the Morrison Formation: 2006. Pages 233-249 *in* J. R. Foster, and S. G. Lucas, editors. Paleontology and geology of the Upper Jurassic Morrison Formation. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 36.

Cicimurri, D. 2001. Fossil selachians from the Belle Fourche Shale (Cretaceous, Cenomanian), Black Hills region of South Dakota and Wyoming. *Mountain Geologist* 38(4):181-192.

Ciccimuri, D. J. 2004. Early Cenomanian (Late Cretaceous) elasmobranchs from the Mowry Shale, Fall River County, South Dakota. *The Mosasaur* 7:69-73.

Ciriacks, K. W. 1963. Permian and Eotriassic bivalves of the Middle Rockies. *Bulletin of the American Museum of Natural History*

125:1-100. Available online at: http://hdl.handle.net/2246/1222. Accessed March 2013.

Clark, B. E., P. M. Myrow, R. L. Ripperdan, R. L. Ethington, and J. Taylor. 2000. Cambro-Ordovician stratigraphy: north-central Wyoming. Abstracts with Programs. *Geological Society of America* 32(5):A-6.

Clark, N. D. L. and M. K. Brett-Surman. 2008. A comparison between dinosaur footprints from the Middle Jurassic of the Isle of Skye, Scotland, UK, and Shell, Wyoming, USA. *Scottish Journal of Geology* 44(2):139-150.

Cloud, P. and J. E. Bever. 1973. Trace fossils from the Flathead Sandstone, Fremont County, Wyoming, compared with early Cambrian forms from California and Australia. *Journal of Paleontology* 47(5):883-885.

Cobban, W. A. 1945. Marine Jurassic formations of Sweetgrass arch, Montana. *Bulletin of the American Association of Petroleum Geologists* 29(9):1262-1303.

Cobban, W. A. 1950. Telegraph Creek Formation of Sweetgrass arch, northcentral Montana. *Bulletin of the American Association of Petroleum Geologists* 34(9):1899-1900.

Cobban, W. A. 1955. Cretaceous rocks of northwestern Montana. Sweetgrass Arch—Disturbed Belt, Montana. Pages 107-119 *in* P. J. Lewis, editor. Billings Geological Society, Billings, MT. Guidebook 6.

Cobban, W. A. 1990. Ammonites and some characteristic bivalves from the Upper Cretaceous Frontier Formation, Natrona County, Wyoming. U.S. Geological Survey, Reston, VA. Bulletin 1917-B. Available online at: http://pubs.er.usgs.gov/publication/b1917B. Accessed February 2013.

Cobban, W. A. 1995. Occurrences of the free-swimming Upper Cretaceous crinoids *Uintacrinus* and *Marsupites* in the Western Interior of the United States. Pages C1-C6 *in* Shorter contributions to the stratigraphy and geochronology of Upper Cretaceous rocks in the Western Interior of the United States. U.S. Geological Survey, Reston, VA. Bulletin 2113. Available online at: http://pubs.er.usgs.gov/publication/b2113. Accessed March 2013.

Cobban, W. A., C. E. Erdmann, B. R. Alto, and C. H. Clark. 1958. *Scaphites depressus* zone (Cretaceous) in northwestern Montana. *Bulletin of the American Association of Petroleum Geologists* 42(3):656-664.

Cobban, W. A., I. Walaszczyk, J. D. Obradovich, and K. C. McKinney. 2006. A USGS zonal table for the Upper Cretaceous Middle Cenomanian-Maastrichtian of the Western Interior of the United States based on ammonites, inoceramids, and radiometric ages. U.S. Geological Survey, Reston, VA. Open-File Report 2006-1250. Available online at: http://pubs.usgs.gov/of/2006/1250/. Accessed March 2013.

Colbert, E. H. 1961. The Triassic reptile, *Poposaurus*. Fieldiana. *Geology* 14(4):59-78. Available online at: http://www.biodiversitylibrary.org/item/25266. Accessed February 2013.

Collinson, M. E. 2002. The ecology of Cainozoic ferns. *Review of Palaeobotany and Palynology* 119(1-2):51-68.

Conard, H. S. 1930. A *Pityoxylon* from Yellowstone National Park. *American Journal of Botany* 17(6):547-553.

Condit, D. D. 1918. Relations of late Paleozoic and early Mesozoic formations of southwestern Montana and adjacent parts of Wyoming. Pages 111-121 in Shorter contributions to general geology, 1918. U.S. Geological Survey, Washington, DC. Professional Paper 120. Available online at: http://pubs.er.usgs.gov/publication/pp120. Accessed April 2013.

Condon, S. M. 2000. Stratigraphic framework of Lower and Upper Cretaceous rocks in central and eastern Montana. U.S. Geological Survey, Reston, VA. Digital Data Series 57. Available online at: http://pubs.er.usgs.gov/publication/ds57. Accessed February 2013.

Connely, M. and B. Talbot. 2005. Trace fossils in marine sediments of the Mowry Shale (Early Cretaceous) of Wyoming are possibly vertebrate in origin. *Journal of Vertebrate Paleontology* 25(supplement to 3):47A.

Conroy, J., M. A. Wilson, and C. M. Tang. 2002. Bored and encrusted carbonate cobbles and hardgrounds at the base of a regressive sequence (lower Sundance Formation, Middle Jurassic, eastern Wyoming). Abstracts with Programs. *Geological Society of America* 34(2):95.

Cressman, E. R. and R. W. Swanson. 1960. Permian rocks in the Madison, Gravelly, and Centennial Ranges, Montana. Pages 226-232 *in* D. E. Campau and H. W. Anisgard, editors. West Yellowstone—Earthquake area. Billings Geological Society, Billings, MT. Guidebook 11.

Crickmay, C. H. 1936. Study in the Jurassic of Wyoming. *Geological Society of America Bulletin* 47(4):541-564.

Csonka, J. and K. V. Bulinski. 2010. The *Chondrites* ichnofossil: a comparative study. Abstracts with Programs. *Geological Society of America* 42(2):93.

Cygan, N. E. and F. L. Koucky. 1963. The Cambrian and Ordovician rocks of the east flank of the Big Horn Mountains, Wyoming. Pages 26-37 *in* G. C. Cooper, D. F. Cardinal, H. W. Lorenz, and J. R. Lynn, editors. Northern Powder River basin, Wyoming and Montana. Wyoming Geological Association and Billings Geological Society, Casper, WY. Joint Guidebook 1.

D'Emic, M. D. and B. Z. Foreman. 2012. The beginning of the sauropod dinosaur hiatus in North America: insights from the Lower Cretaceous Cloverly Formation of Wyoming. *Journal of Vertebrate Paleontology* 32(4):883-902.

Darton, N. H. 1904. Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range. *Geological Society of America Bulletin* 15:379-448.

Darton, N. H. 1906. Geology of the Bighorn Mountains. U.S. Geological Survey, Washington, DC. Professional Paper 51. Available online at:

http://pubs.er.usgs.gov/publication/pp51. Accessed February 2013.

Davidson, W. R. 1987. Petrology and environmental interpretation of the synorogenic Bacon Ridge Formation, northwest Wyoming. Pages 207-216 *in* W. R. Miller, editor. The thrust belt revisited. Wyoming Geological Association, Casper, WY. Guidebook 38.

Davies, G. R. 1983. Sedimentology of the Middle Jurassic Sawtooth Formation of southern Alberta. Pages 11-26 *in* J. R. McLean and G. E. Reinson, editors. Sedimentology of selected Mesozoic clastic sequences. Canadian Society of Petroleum Geologists, Calgary, Canada.

Davis, B. and K. Davies. 2005. First vertebrate fossils from the Eagle Formation (upper Santonian), north central Montana. *Journal of Vertebrate Paleontology* 25(supplement to 3):50A.

Davis, H. R., C. W. Byers, and L. M. Pratt. 1989. Depositional mechanisms and organic matter in Mowry Shale (Cretaceous), Wyoming. *AAPG Bulletin* 73(9):1103-1116.

Davis, L. B. and C. D. Zeier. 1978. Multi-phase Late period bison procurement at the Antonsen site, southwestern Montana. *Plains Anthropologist* 82(2):222-235.

Dawley, R. M., J. M. Zawiskie, and J. W. Cosgriff. 1979. A rauisuchid thecodont from the Upper Triassic Popo Agie Formation of Wyoming. *Journal of Paleontology* 53(6):1428-1431.

DeBoer, D. A. and L. T. Middleton. 1981. Paleoenvironmental and paleogeographic significance of Middle Cambrian algal buildups, Teton Range, Wyoming. Abstracts with Programs. *Geological Society of America* 13(4):194.

DeBoer, D. and L. Middleton. 1983. Sedimentology of a shallowing-upward sequence in Middle Cambrian carbonate-siliciclastic associations, western Wyoming. *AAPG Bulletin* 67(3):448-449.

DeBord, P. L. 1979. Palynology of the Gallatin Mountain “Fossil Forest” of Yellowstone National Park, Montana: Preliminary Report. Pages 159-164 *in* R. Linn, editor. Proceedings of the First Conference on Scientific Research in the National Parks. U.S. Department of Interior. National Park Service Transactions and Proceedings Series **5**(1).

DeCelles, P. G. 1986. Sedimentation in a tectonically partitioned, nonmarine foreland basin: the Lower Cretaceous Kootenai Formation, southwestern Montana. *Geological Society of America Bulletin* 97(8):911-931.

Decker, P. L. 1990. Style and mechanics of liquefaction-related deformation, lower Absaroka Volcanic Supergroup (Eocene), Wyoming. Geological Society of America, Boulder, CO. Special Paper 240.

Deiss, C. F. 1936. Revision of type Cambrian formations and sections of Montana and Yellowstone National Park. *Geological Society of America Bulletin* 47(8):1257-1342.

Denison, R. H. 1951. Late Devonian fresh-water fishes from the western United States. Fieldiana: *Geology* 11(5). Available online at:

http://archive.org/details/latedevonianfres115deni. Accessed March 2013.

Dodson, P., A. K. Behrensmeyer, R. T. Bakker, and J. S. McIntosh. 1980. Taphonomy and paleoecology of the dinosaur beds of the Jurassic Morrison Formation. *Paleobiology* 6(2):208-232.

Dong, X., P. C. J. Donoghue, and J. E. Repetski. 2005. Basal tissue structure in the earliest euconodonts: testing hypotheses of developmental plasticity in euconodont phylogeny. *Palaeontology* 48(2):411-421.

Dorf, E. 1939. Middle Eocene flora from the volcanic rocks of the Absaroka Range, Park County, Wyoming. *Geological Society of America Bulletin* 50(12, part 2):1906-1907.

Dorf, E. 1960. Tertiary fossil forests of Yellowstone National Park Wyoming. Pages 253-260 *in* D. E. Campau and H. W. Anisgard, editors. West Yellowstone—Earthquake area. Billings Geological Society, Billings, MT. Guidebook 11.

Dorf, E. 1964. The petrified forests of Yellowstone Park. *Scientific American* 210(4):106-112.

Dorobek, S. L. and T. M. Smith. 1989. Cyclic sedimentation and dolomitization history of the Devonian Jefferson Formation, southwestern Montana. Pages 31-46 *in* D. E. French and R. F. Grabb, editors. Montana Geological Society 1989 field conference guidebook: Montana centennial edition: Geologic resources of Montana, Volume I. Montana Geological Society, Bozeman, MT. Field Conference 1989(1).

Driscoll, E. G. and G. B. Newton. 1969. A new species of the coral *Syringopora* from the Tensleep Formation (Pennsylvanian) of Montana. *Journal of Paleontology* 43(2):531-534.

Druckenmiller, P. S. 2002. Osteology of a new plesiosaur from the Lower Cretaceous (Albian) Thermopolis Shale of Montana. *Journal of Vertebrate Paleontology* 22(1):29-42.

Dundas, R. G. 2007. The late Pleistocene vertebrate fauna from the Merrell locality, Beaverhead County, Montana. Abstracts with Programs. *Geological Society of America* 39(6):77.

Dyman, T. S., W. J. Perry, Jr., D. J. Nichols, L. E . Davis, and J. C. Haley. 1989. Stratigraphy, petrology, and provenance of the Cenomanian to Turonian Frontier Formation near Lima, southwestern Montana. Pages 103-114 *in* D. E. French and R. F. Grabb, editors. Montana Geological Society 1989 field conference guidebook: Montana centennial edition: Geologic resources of Montana, Volume I. Montana Geological Society, Bozeman, MT. Field Conference 1989(1).

Dyman, T. S., P. G. DeCelles, J. C. Haley, D. J. Nichols, R. C. Pearson, W. J. Perry, Jr., R. G. Tysdal, and R. K. Schwartz. 1990. Cretaceous rocks of southwestern Montana. *AAPG Bulletin* 74(8):1322.

Dyman, T. S., R. G. Tysdal, W. J. Perry, Jr., J. D. Obradovich, J. C. Haley, and D. J. Nichols. 1997. Correlation of Upper Cretaceous strata from Lima Peaks area to Madison Range, southwestern Montana and southeastern Idaho, USA. *Cretaceous Research* 18(6):751-766.

Eaton, J. G. 1980. Preliminary report on paleontological exploration of the southeastern Absaroka Range, Wyoming. *Papers on Paleontology* 24:139-142.

Eaton, J. G. 1982. Paleontology and correlation of Eocene volcanic rocks in the Carter Mountain area, Park County, southeastern Absaroka Range, Wyoming. *Contributions to Geology* 21(2):153-194.

Eaton, J. G. 1985. Paleontology and correlation of the Eocene Tepee Trail and Wiggins formations in the north fork of Owl Creek area, southeastern Absaroka Range, Hot Springs County, Wyoming. *Journal of Vertebrate Paleontology* 5(4):345-370.

Eicher, D. L. 1958. The Thermopolis shale in eastern Wyoming. Pages 79-83 *in* J. Strickland, F. Byrne, and J. Barlow, editors. Powder River Basin. Wyoming Geological Association, Casper, WY. Guidebook 13.

Eicher, D. L. 1960. Stratigraphy and micropaleontology of the Thermopolis Shale. Peabody Museum of Natural History Bulletin 15. Available online at: http://peabody.yale.edu/sites/default/files/documents/scientific-publications/ypmB15_1960.pdf. Accessed February 2013.

Eicher, D. L. 1965. Foraminifera and biostratigraphy of the Graneros Shale. *Journal of Paleontology* 39(5):875-909.

Eicher, D. L. 1967. Foraminifera from Belle Fourche Shale and equivalents, Wyoming and Montana. *Journal of Paleontology* 41(1):167-188.

Elder, W. P. and J. I. Kirkland. 1993. Cretaceous paleogeography of the Colorado Plateau and adjacent areas. Pages 129-151 *in* M. Morales, editor. Aspects of Mesozoic geology and paleontology of the Colorado Plateau. Museum of Northern Arizona, Flagstaff, AZ. Bulletin 59.

Elder, W. P. and J. I. Kirkland. 1994. Cretaceous paleogeography of the southern Western Interior region. Pages 415-440 *in* M. V. Caputo, J. A. Peterson, and K. J. Franczyk, editors. Mesozoic system of the Rocky Mountain region, USA. Rocky Mountain Section, Society for Sedimentary Geology, Denver, CO.

Elias, S. A. 1988. Late Pleistocene paleoenvironmental studies from the Rocky Mountain region: a comparison of pollen and insect fossil records. *Geoarchaeology* 3(2):147-153.

Emry, R. J. 1975. Revised Tertiary stratigraphy and paleontology of the western Beaver Divide, Fremont County, Wyoming. Smithsonian Contributions to Paleobiology 25. Available online at: http://www.sil.si.edu/eresources/silpurl.cfm?purl=1288303. Accessed March 2013.

Engelmann, G. F., D. J. Chure, and A. R. Fiorillo. 2004. The implications of a dry climate for the paleoecology of the fauna of the Upper Jurassic Morrison Formation. *Sedimentary Geology* 167(3-4):297-308.

Entzminger, D. J. 1979. Revision of Upper Cretaceous stratigraphy: Big Hole Mountains, Idaho. *Earth Science Bulletin* 12(4):15-24.

Espach, R. H., Jr. and F. Royse, Jr. 1960. Stratigraphic variations in the eastern Big Hole Mountains, Teton and Bonneville counties, Idaho. Pages 61-71 *in* D. P. McGookey and D. N. Miller, editors. Overthrust belt of southwestern Wyoming and adjacent areas. Wyoming Geological Association, Casper, WY. Guidebook 15.

Farmer, J. D., S. L. Cady, D. J. Des Marais, and M. Walter. 1997. Fossilization processes in modern thermal springs: clues for assessing the biogenicity of ancient hydrothermal deposits. Pages 30-31 *in* Conference on early Mars; geologic and hydrologic evolution, physical and chemical environments, and the implications for life. Lunar and Planetary Institute, Houston, TX. LPI Contribution 916. Available online at: http://www.lpi.usra.edu/meetings/earlymars/pdf/3031.pdf. Accessed April 2013.

Feldmann, R. M. 1979. *Eryma foersteri*, a new species of lobster (Decapoda) from the Jurassic (Callovian) of North America. *American Museum Novitates* 2668.

Felix, J. 1896. Untersuchungen über fossile Hölzer. *V. Stück. Zeitschrift der Deutschen Geologischen Gesellschaft* 48:249-260.

Fisher, C. G. and W. W. Hay. 1999. Calcareous nannofossils as indicators of Mid-Cretaceous paleofertility along an ocean front, U. S. Western Interior. Pages 161-180 *in* E. Barrera and C. C. Johnson, editors. Evolution of the Cretaceous ocean-climate system. Geological Society of America, Boulder, CO. Special Paper 332.

Fisher, J. H. 1963. Tensleep Sandstone of the eastern Big Horn Mountains, Wyoming. Pages 54-60 *in* G. C. Cooper, D. F. Cardinal, H. W. Lorenz, and J. R. Lynn, editors. Northern Powder River basin, Wyoming and Montana. Wyoming Geological Association and Billings Geological Society, Casper, WY. Joint Guidebook 1.

Fisk, L. H. 1976. The Gallatin "petrified forest": a review. Pages 53-72 *in* Guidebook: The Tobacco Root Geological Society 1976 field conference. Montana Bureau of Mines and Geology, Butte, MT. Special Publication 73.

Fisk, L. H. and P. DeBord. 1974a. Plant microfossils from the Yellowstone fossil forests: preliminary report. Abstracts with Programs. *Geological Society of America* 6(5):441-442.

Fisk, L. H. and P. DeBord. 1974b. Palynology of the "Fossil Forest" of Yellowstone National Park, Wyoming. *American Journal of Botany* 61(supplement to 5):15-16.

Fisk, L. H. and W. J. Fritz. 1984. Pseudoborings in petrified wood from the Yellowstone "fossil forests." *Journal of Paleontology* 58(1):58-62.

Fisk, L. H., M. R. Aguirre, and W. J. Fritz. 1978. Additional conifers from the Eocene Amethyst Mountain "fossil forest", Yellowstone National Park, Wyoming. Abstracts with Programs. *Geological Society of America* 10(5):216.

Fitzke, J. A. and E. Hale. 2003. Paleontologic inventory of Mount Holmes and Trilobite Point, Yellowstone National Park. Abstracts with Programs. *Geological Society of America* 35(6):501.

Forster, C. A. 1984. The paleoecology of the ornithopod dinosaur *Tenontosaurus tilletti* from the Cloverly Formation, Big Horn Basin of Wyoming and Montana. *Mosasaur* 2:151-163.

Foster, J. R. 2003. Paleoecological analysis of the vertebrate fauna of the Morrison Formation (Upper Jurassic), Rocky Mountain region, U.S.A. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 23.

Foster, J. 2007. Jurassic West: the dinosaurs of the Morrison Formation and their world. Indiana University Press, Bloomington and Indianapolis, IN.

Fouke, B. W. 2011. Hot-spring Systems Geobiology: abiotic and biotic influences on travertine formation at Mammoth Hot Springs, Yellowstone National Park, USA. *Sedimentology* 58:170-219.

Fouke, B. W., J. D. Farmer, D. J. Des Marais, L. Pratt, N. C. Sturchio, P. C. Burns, and M. K. Discipulo. 2000. Depositional facies and aqueous-solid geochemistry of travertine-depositing hot springs (Angel Terrace, Mammoth Hot Springs, Yellowstone National Park, U.S.A.). *Journal Of Sedimentary Research* 70(3):565-585.

Fox, S. K. 1939. Stratigraphy and micropaleontology of the Cody Shale in southern Montana and northern Wyoming. Dissertation. Princeton University, Princeton, NJ.

Fox, S. K., Jr. 1954. Cretaceous foraminifera from the Greenhorn, Carlile, and Cody formations, South Dakota, Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 254-E. Available online at: http://pubs.er.usgs.gov/publication/pp254E. Accessed March 2013.

Franczyk, K. J., T. D. Fouch, R. C. Johnson, C. M. Molenaar, and W. A. Cobban. 1992. Cretaceous and Tertiary paleogeographic reconstructions for the Uinta-Piceance Basin Study Area, Colorado and Utah. U.S. Geological Survey, Reston, VA. Bulletin 1787-Q. Available online at: http://pubs.er.usgs.gov/publication/b1787Q. Accessed September 2011.

Fraser, G. D., H. A. Waldrop, and H. J. Hyden. 1969. Geology of the Gardiner area, Park County, Montana. U.S. Geological Survey, Washington, DC. Bulletin 1277. Available online at: http://pubs.er.usgs.gov/publication/b1277. Accessed April 2013.

Frison, G. C. 1991. Prehistoric hunters of the high plains (2nd edition). Academic Press, New York, NY.

Fritz, M. A. and B. F. Howell. 1955. An Upper Cambrian coral from Montana. *Journal of Paleontology* 29(1):181-183.

Fritz, W. J. 1979. Depositional environment of the Yellowstone fossil forests as related to Eocene plant diversity. Abstracts with Programs. *Geological Society of America* 11(7):428.

Fritz, W. J. 1980a. Reinterpretation of the depositional environment of the Yellowstone “fossil forests.” *Geology* 8(7):309-313.

Fritz, W. J. 1980b. Stratigraphic framework of the Lamar River Formation in

Yellowstone National Park. *Northwest Geology* 9:1-18.

Fritz, W. J. 1982. Geology of the Lamar River Formation, northeast Yellowstone National Park. Pages 73-101 *in* S. G. Reid and D. J. Foote, editors. Geology of Yellowstone Park area. Wyoming Geological Association, Casper, WY. Guidebook 33.

Fritz, W. J. 1986. Plant taphonomy in areas of explosive volcanism in land plants: notes for a short course. *Studies in Geology* 15:1-9.

Fritz, W. J. and L. H. Fisk. 1977. Paleoecology of some Eocene fossil woods from Yellowstone National Park. Abstracts with Programs. *Geological Society of America* 9(6):723-724.

Fritz, W. J. and L. H. Fisk. 1978. Eocene petrified woods from one unit of the Amethyst Mountain "Fossil Forest." *Northwest Geology* 7:10-19.

Fritz, W. J. and L. H. Fisk. 1979. Paleoecology of petrified wood from the Amethyst Mountain "Fossil Forests," Yellowstone National Park, Wyoming. Pages 743-749 *in* R. Linn, editor. Proceedings of the First Conference on Scientific Research in the National Parks. U.S. Department of Interior. National Park Service Transactions and Proceedings Series 5(2).

Fritz, W. J. and S. Harrison. 1985. Early Tertiary volcaniclastic deposits of the northern Rocky Mountains. Pages 383-402 *in* R. M. Flores and S. S. Kaplan, editors. Cenozoic paleogeography of the west-central United States. Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Denver, CO.

Fritz, W. J. and R. F. Yuretich. 1984. Comment and reply on "Yellowstone fossil forests: new evidence for burial in place." *Geology* 12(10):638-639.

Frost, B. R., C. D. Frost, M. Cornia, K. R. Chamberlain, and R. Kirkwood. 2006. The Teton-Wind River domain: a 2.68-2.67 Ga active margin in the western Wyoming Province. *Canadian Journal of Earth Sciences* 43(10):1489-1510.

Frost, B. R., S. M. Swapp, and C. D. Frost. 2009. 2.685-2.671 Ga Himalayan-type orogeny in the northern Teton Range, Wyoming, USA. *Geochimica et Cosmochimica Acta* 73(13S):A399.

Frost, B. R., C. D. Frost, S. M. Swapp, and K. R. Chamberlain. 2011. Multiple terranes in the Teton Range, Wyoming: evidence for tectonic assembly at 2.68 and 2.62 Ga. Abstracts with Programs. *Geological Society of America* 43(5):435.

Gennett, J. A. 1981. A late Pinedale and Holocene pollen sequence from Blacktail Pond, Yellowstone Park, Wyoming. Abstracts with Programs. *Geological Society of America* 13(4):198.

Gennett, J. A. and R. G. Baker. 1986. A late Quaternary pollen sequence from Blacktail Pond, Yellowstone National Park, Wyoming, U.S.A. *Palynology* 10:61-71.

Girty, G. H. 1899. Devonian and Carboniferous fossils. Pages 479-599 *in* Geology of the Yellowstone national park. U.S. Geological Survey, Washington, DC. Monograph 32. Available online at:

http://archive.org/details/geologyofyellows00hagu. Accessed March 2013.

Goodwin, J. H. and C. R. Schmit. 1974. Sedimentology and geochemistry of piston cores from Yellowstone and Jackson Lakes, Wyoming. Abstracts with Programs. *Geological Society of America* 6(7):760.

Gordon, M., Jr. 1966. Permian coleoid cephalopods from the Phosphoria Formation in Idaho and Montana. Pages B28-B35 *in* Geological Survey Research 1966, Chapter B. U.S. Geological Survey, Washington, DC. Professional Paper 550-B. Available online at: http://pubs.er.usgs.gov/publication/pp550B. Accessed February 2013.

Gordon, M., Jr. 1971. Primitive squid gladii from the Permian of Utah. Pages C34-C38 *in* Geological Survey Research 1971, Chapter C. U.S. Geological Survey Professional Paper 750-C. Available online at: http://pubs.er.usgs.gov/publication/pp750C. Accessed February 2013.

Gordon, M., Jr. 1975. Brachiopoda of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 858-D. Available online at: http://pubs.er.usgs.gov/publication/pp848D. Accessed February 2013.

Gordon, M., Jr. and J. Pojeta, Jr. 1975. Pelecypoda and Rostroconchia of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 848-E. Available online at: http://pubs.er.usgs.gov/publication/pp848E. Accessed February 2013.

Gordon, M., Jr. and E. L. Yochelson. 1975. Gastropoda, Cephalopoda, and Trilobita of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 848-F. Available online at: http://pubs.er.usgs.gov/publication/pp848F Accessed February 2013.

Gorman, D. R. 1963. Stratigraphic-sedimentational aspects of the Amsden Formation, Big Horn Mountains, Wyoming. Pages 67-70 *in* G. C. Cooper, D. F. Cardinal, H. W. Lorenz, and J. R. Lynn, editors. Northern Powder River basin, Wyoming and Montana. Wyoming Geological Association and Billings Geological Society, Casper, WY. Joint Guidebook 1.

Grant, R. E. 1965. Faunas and stratigraphy of the Snowy Range Formation (Upper Cambrian) in southwestern Montana and northwestern Wyoming. Geological Society of America, Boulder, CO. Memoir 96.

Gregson, J. D., D. Chure, and D. A. Sprinkel. 2010. Geology and paleontology of Dinosaur National Monument, Utah-Colorado. Pages 161-192 *in* D. A. Sprinkel, T. C. Chidsey, Jr., and P. B. Anderson, editors. Geology of Utah's parks and monuments (3rd edition). Utah Geological Association, Salt Lake City, UT. Publication 28.

Gutschick, R. C. 1966. Transitional Devonian to Mississippian environmental changes in

western Montana. Pages 171-181 *in* Symposium on cyclic sedimentation. Kansas Geological Survey, Lawrence, KS. Bulletin 169. Available online at: http://www.kgs.ku.edu/Publications/Bulletins/169/Gutschick/index.html. Accessed February 2013.

Gutschick, R. C. and R. Lamborn. 1975. *Bifungites*, trace fossils from Devonian-Mississippian rocks of Pennsylvania and Montana, U.S.A. *Palaeogeography, Palaeoclimatology, Palaeoecology* 18(3):193-212.

Gutschick, R. C., J. L. Weiner, and L. Young. 1961. Lower Mississippian arenaceous Foraminifera from Oklahoma, Texas, and Montana. *Journal of Paleontology* 35(6):1193-1221.

Gutschick, R. C., M. McLane, and J. Rodriguez. 1976. Summary of late Devonian-early Mississippian biostratigraphic framework in western Montana. Pages 91-124 *in* Guidebook of selected areas in southwestern Montana. Montana Bureau of Mines and Geology, Butte, MT. Special Publication 73.

Guyer, G. S., C. F. Vondra, and R. D. Cody. 1995. Paleoenvironments of the Jurassic Gypsum Spring Formation, Big Horn Basin, Wyoming. Abstracts with Programs. *Geological Society of America* 27(3):54-55.

Hadly, E. A. 1990. A late Holocene record of mammalian community dynamics in Yellowstone National Park. *Journal of Vertebrate Paleontology* 10(supplement to 3):26A.

Hadly, E. A. 1996. Influence of late-Holocene climate on northern Rocky Mountain mammals. *Quaternary Research* 46(3):298-310.

Hadly, E. A. 1999. Fidelity of terrestrial vertebrate fossils to a modern ecosystem. *Palaeogeography, Palaeoclimatology, Palaeoecology* 149(1-4):389-409.

Hadly, E. A. and M. van Tuinen. 2002. Late Holocene abundance patterns of grebes and waterfowl from Lamar Cave, Yellowstone National Park, Wyoming. *Journal of Vertebrate Paleontology* 22(supplement to 3):61A-62A.

Hadly, E. A., M. H. Kohn, J. A. Leonard, and R. K. Wayne. 1998a. A genetic record of population isolation in pocket gophers during Holocene climatic change. *Proceedings of the National Academy of Sciences of the United States of America* 95(12):6893-6896.

Hadly, E. A., M. H. Kohn, and R. K. Wayne. 1998b. A genetic record of population isolation in pocket gophers (*Thomomys talpoides*) during Holocene climatic change. *Journal of Vertebrate Paleontology* 18(supplement to 3):47A.

Hadly, E. A., C. J. Conroy, and J. M. Zinck. 2001. Genetic variation of montane voles: the present is not a key to the past. *Journal of Vertebrate Paleontology* 21(supplement to 3):58A.

Hague, A., W. H. Weed, and J. P. Iddings. 1896. Yellowstone National Park folio, Wyoming. U.S. Geological Survey, Washington, DC. Folio of the Geologic Atlas 30. Available online at:

http://pubs.er.usgs.gov/publication/gf30. Accessed April 2013.

Hague, A., J. P. Iddings, W. H. Weed, C. D. Walcott, G. H. Girty, T. W. Stanton, and F. H. Knowlton. 1899. Geology of the Yellowstone National Park. Part II. Descriptive geology, petrography, and paleontology. U.S. Geological Survey, Washington, DC. Monograph 32.

Haiar, B. and R. Lupia. 2011. Paleobotany and paleoecology of localities from the Cretaceous Cloverly Formation, Bighorn Basin, Wyoming. Abstracts with Programs. *Geological Society of America* 43(5):312.

Hale, E. S., W. A. Cobban, T. S. Dyman, J. A. Fitzke, D. J. Nichols, K. W. Porter, and K. I. Takahashi. 2004. Stratigraphy and age of Cretaceous rocks at Mount Everts, Yellowstone National Park, Wyoming and Montana. Abstracts with Programs. *Geological Society of America* 36(5):73.

Hamblin, A. H., S. A. Bilbey, and J. E. Hall. 2000. Prehistoric animal tracks at Red Fleet State Park, northeastern Utah. Pages 569-578 *in* D. A. Sprinkel, T. C. Chidsey, Jr., and P. B. Anderson, editors. Geology of Utah's parks and monuments. Utah Geological Association, Salt Lake City, UT. Publication 28. Available online at: http://www.utahgeology.org/pub28_pdf_files/HamblinRedFleet.pdf. Accessed September 2011.

Hamilton, W. L. 1982. Geological investigations in Yellowstone Park, 1976-1981. Pages 19-26 *in* S. G. Reid and D. J. Foote, editors. Geology of Yellowstone Park area. Wyoming Geological Association, Casper, WY. Guidebook 33.

Hampel, A., R. Hetzel, and A. L. Densmore. 2007. Postglacial slip-rate increase on the Teton normal fault, northern Basin and Range Province, caused by melting of the Yellowstone ice cap and deglaciation of the Teton Range? *Geology* 35(12):1107-1110.

Hansen, W. B. 1989. Reexamination of Cretaceous (Campanian) Eagle Sandstone at Billings, Montana: sequence stratigraphic approach. *International Geological Congress, Abstracts* 28(2):2-25.

Hanson, A. M. 1960. Cambrian of the Madison River valley area. Pages 207-212 *in* D. E. Campau and H. W. Anisgard, editors. West Yellowstone—Earthquake area. Billings Geological Society, Billings, MT. Guidebook 11.

Harlan, S. S. and L. A. Morgan. 2010. Paleomagnetic results from Tertiary volcanic strata and intrusions, Absaroka volcanic supergroup, Yellowstone National Park and vicinity: contributions to the North American apparent polar wander path. *Tectonophysics* 485(1-4):245-259.

Harris, A. H. 1978. The Mummy Cave tetrapods. Pages 146-151 in H. McCracken, W. Wedel, R. Edgar, J. Moss, H. E. Wright, W. Husted, and W. Mulloy. The Mummy Cave project in northwest Wyoming. Buffalo Bill Historical Center, Cody, WY. Available online at: http://www.utep.edu/leb/curators/mummycave.pdf. Accessed April 2013.

Harris, J. D. and K. J. Lacovara. 2004. Enigmatic fossil footprints from the Sundance Formation (Upper Jurassic) of

Bighorn Canyon National Recreation Area, Wyoming. *Ichnos* 11:151-166. Available online at: http://cactus.dixie.edu/jharris/Sundance_Tracks.pdf. Accessed February 2013.

Harris, J. D., K. R. Johnson, J. Hicks, and L. Tauxe. 1996. Four-toed theropod footprints and a paleomagnetic age from the Whetstone Falls Member of the Harebell Formation (Upper Cretaceous: Maastrichtian), northwestern Wyoming. *Cretaceous Research* 17(4):381-401.

Hasiotis, S. T. 2004. Reconnaissance of Upper Jurassic Morrison Formation ichnofossils, Rocky Mountain Region, USA: paleoenvironmental, stratigraphic, and paleoclimatic significance of terrestrial and freshwater ichnocoenoses. *Sedimentary Geology* 167(3-4):177-268.

Hawkins, B. J., P. M. Myrow, R. L. Ripperdan, and J. Taylor. 2001. Shoaling cycles in the Cambro-Ordovician Gallitan Formation: northern Wyoming and central Montana. Abstracts with Programs. *Geological Society of America* 33(5):13.

Heasler, H. and C. Jaworowski. 2012. Natural resource damage at Petrified Tree, Yellowstone National Park. Unpublished National Park Service report. On file at YELL.

Hendrix, M. S. 2003. Report and recommendations for paleontological and geological resources affected by road widening between Sylvan Pass and the East Entrance, Yellowstone National Park. Department of Geology, University of Montana, Missoula, MT.

Hendrix, M. S. and C. W. Byers. 2000. Stratigraphy and sedimentology of Permian strata, Uinta Mountains, Utah: allostratigraphic controls on the accumulation of economic phosphate. Pages 349-367 *in* C. R. Glenn, L. Prevot-Lucas, and J. Lucas, editors. Marine authigenesis: from global to microbial. Society for Sedimentary Geology Special Publication 66.

Herrick, E. M. and F. R. Schram. 1978. Malacostracan crustacean fauna from the Sundance Formation (Jurassic) of Wyoming. American Museum Novitates 2652. Available online at: http://hdl.handle.net/2246/2966. Accessed February 2013.

Hiatt, E. E. and D. A. Budd. 2001. Sedimentary phosphate formation in warm shallow waters: new insights into the palaeoceanography of the Permian Phosphoria Sea from analysis of phosphate oxygen isotopes. *Sedimentary Geology* 145(1-2):119-133.

Hickenlooper, J. W., Jr. and J. T. Gutmann. 1982. Geology of the Slough Creek Tuff, northern Absaroka volcanic field, Park County, Montana. Pages 55-63 *in* S. G. Reid and D. J. Foote, editors. Geology of Yellowstone Park area. Wyoming Geological Association, Casper, WY. Guidebook 33.

High, L. R., Jr. and M. D. Picard. 1965. Sedimentary petrology and origin of analcime-rich Pogo Agie Member, Chugwater (Triassic) Formation, west-central Wyoming. *Journal of Sedimentary Petrology* 35(1):49-70.

High, L. R., Jr. and M. D. Picard. 1967. Rock units and revised nomenclature, Chugwater Group (Triassic), western Wyoming. *Mountain Geologist* 4(2):73-81.

High, L. R., Jr. and M. D. Picard. 1969. Stratigraphic relations within upper Chugwater group (Triassic), Wyoming. *American Association of Petroleum Geologists Bulletin* 53(5):1091-1104.

Hill, C. L. 2007. Pleistocene mammals in the greater Yellowstone ecosystem. *Northwest Geology* 36:151-166. Available online at: http://sspa.boisestate.edu/anthropology/files/2010/06/mammals-greater-yellowstone.pdf. Accessed May 2013.

Hirsch, K. F. 1994. Upper Jurassic eggshells from the Western Interior of North America. Pages 137-150 *in* K. Carpenter, K. F. Hirsch, and J. R. Horner, editors. Dinosaur eggs and babies. Cambridge University Press, Cambridge, United Kingdom.

Hoare, R. D. and J. D. Burgess. 1960. Fauna from the Tensleep sandstone in Wyoming. *Journal of Paleontology* 34(4):711-716.

Holland, S. M. and M. E. Patzkowsky. 2009. The stratigraphic distribution of fossils in a tropical carbonate succession: Ordovician Bighorn Dolomite, Wyoming, USA. *Palaios* 24(5):303-317.

Holland, S. M. and M. E. Patzkowsky. 2012. Sequence architecture of the Bighorn Dolomite, Wyoming, USA: transition to the Late Ordovician icehouse. *Journal of Sedimentary Research* 82(8):599-615.

Holm, M. R., W. C. James, and L. J. Suttner. 1977. Comparison of the Peterson and Draney limestones, Idaho and Wyoming, and the calcareous members of the Kootenai Formation, western Montana. Pages 259-270 *in* E. L. Heisey, D. E. Lawson, E. R. Norwood, P. H. Wach, and L. A. Hale, editors. Rocky Mountain Thrust Belt: geology and resources. Wyoming Geological Association, Casper, WY. Guidebook 29.

Holmes, W. H. 1879. Fossil forests of the volcanic Tertiary formations of the Yellowstone National Park. United States Geological and Geographical Survey of the Territories. Government Printing Office, Washington, DC. Bulletin **5**:125-132. Available online at: http://archive.org/details/bulletinuniteds00haydgoog. Accessed April 2013.

Holmes, W. H. 1883. Report on the geology of the Yellowstone National Park. *United States Geological and Geographical Survey Annual Report* 12(part 2):1-57. Available online at: http://archive.org/details/annualreport1st1122geol. Accessed April 2013.

Hopkins, J. C. 1985. Channel-fill deposits formed by aggradation in deeply scoured, superimposed distributaries of the lower Kootenai Formation (Cretaceous). *Journal of Sedimentary Petrology* 55(1):42-52.

Horner, J. R. 1989. The Mesozoic terrestrial ecosystems of Montana. Pages 153-162 *in* D. E. French and R. F. Grabb, editors. Montana Geological Society 1989 field conference guidebook: Montana centennial edition: Geologic resources of Montana, Volume I. Montana Geological Society, Bozeman, MT. Field Conference 1989(1).

Houlik, C. W., Jr. 1973. Interpretation of carbonate-detrital silicate transitions in the Carboniferous of western Wyoming. *American Association of Petroleum Geologists Bulletin* 57(3):498-509.

Howard, A. D. 1937. History of the Grand Canyon of the Yellowstone. Geological Society of America, Boulder, CO. Special Paper 6.

Howell, B. F. 1963. New Cambrian conchostracans from Wyoming and Newfoundland, brachiopods from Vermont, and worm, hydrozoan and problematicum from Newfoundland. *Journal of Paleontology* 37(1):264-267.

Hu, C.-h. 1970. The ontogenies of *Ponumia obscura* (Lochman), n.g., and of *Housia canadensis* (Walcott) (Trilobita) from the upper Cambrian of the Big Horn mountains, Wyoming. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series* 78:253-263.

Huerta, M. A. 2008. Postglacial vegetation, fire, and climate history of Blacktail Pond, northern Yellowstone National Park, WY. Thesis. Montana State University, Bozeman, MT. Available online at: http://etd.lib.montana.edu/etd/view/item/684. Accessed May 2013.

Huerta, M. A., C. Whitlock, and J. Yale. 2009. Holocene vegetation–fire–climate linkages in northern Yellowstone National Park, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology* 271:170-181.

Husted, W. M. and R. Edgar. 2002. The archeology of Mummy Cave, Wyoming: an introduction to Shoshonean prehistory. Midwest Archeological Center, Lincoln NE. Midwest Archeological Center Special Report 4 and Southeast Archeological Center Technical Report 9. Available online at: http://www.nps.gov/history/mwac/publications/pdf/spec4.pdf. Accessed May 2013.

Iddings, J. P. and W. H. Weed. 1899. Descriptive geology of the Gallatin Mountains. Pages 1-59 *in* Geology of the Yellowstone national park. U.S. Geological Survey, Washington, DC. Monograph 32. Available online at: http://archive.org/details/geologyofyellows00hagu. Accessed March 2013.

Imlay, R. W. 1947. Marine Jurassic of Black Hills area, South Dakota and Wyoming. *Bulletin of the American Association of Petroleum Geologists* 31(2):227-273.

Imlay, R. W. 1953. Callovian (Jurassic) ammonites from the United States and Alaska: Part 1, Western Interior United States: Part 2, Alaska Peninsula and Cook Inlet regions. U.S. Geological Survey, Washington, DC. Professional Paper 249-A. Available online at: http://pubs.er.usgs.gov/publication/pp249A. Accessed February 2013.

Imlay, R. W. 1954. Marine Jurassic formations in the Pryor Mountains and north Bighorn Mountains, Montana. Pages 54-65 *in* P. W. Richards, editor. Pryor Mountains-northern Bighorn Basin, Montana, September 9-11, 1954. Billings Geological Society, Billings, MT. Guidebook 5.

Imlay, R. W. 1956. Marine Jurassic exposed in Bighorn Basin, Pryor Mountains, and northern Bighorn Mountains, Wyoming

and Montana. *Bulletin of the American Association of Petroleum Geologists* 40(4):562-599.

Imlay, R. W. 1967. Twin Creek Limestone (Jurassic) in the Western Interior of the United States. U.S. Geological Survey, Washington, DC. Professional Paper 540. Available online at: http://pubs.er.usgs.gov/publication/pp540. Accessed March 2013.

Jacobson, S. R., B. R. Wardlaw, and J. D. Saxton. 1982. Acritarchs from the Phosphoria and Park City formations (Permian, northeastern Utah). *Journal of Paleontology* 56(2, Part 1):449-458.

James, B. H. 1980b. Paleoenvironments of the Lower Triassic Thaynes Formation near Diamond Fork in Spanish Fork Canyon, Utah County, Utah. *Geology Studies* 27(1):81-100.

James, W. C. 1980a. Limestone channel storm complex (Lower Cretaceous), Elkhorn Mountains, Montana. *Journal of Sedimentary Petrology* 50(2):447-455.

Johnson, R. C. 2008. Detailed measured sections, cross sections, and paleogeographic reconstructions of the Upper Cretaceous and lower Tertiary nonmarine interval, Wind River Basin, Wyoming. U.S. Geological Survey, Reston, VA. Digital Data Series 69-J. Available online at: http://pubs.usgs.gov/dds/dds-069/dds-069-j/REPORTS/69_J_CH_10.pdf. Accessed March 2013.

Johnson, R. C. 2010. Detailed west to east cross section of Cretaceous and lower Tertiary rocks across the south part of the Bighorn Basin, Wyoming. U.S. Geological Survey, Reston, VA. Digital Data Series 69-V. Available online at: http://pubs.er.usgs.gov/publication/ds69V. Accessed February 2013.

Jones, D. J. 1954. Non-marine Frontier microfauna, Coalville area, Utah. *Journal of Sedimentary Petrology* 24(2):140.

Jones, R. W. 1982. The Jackson Hole coal field. Pages 315-321 *in* S. G. Reid and D. J. Foote, editors. Geology of Yellowstone Park area. Wyoming Geological Association, Casper, WY. Guidebook 33.

Jones, O. T. and R. M. Field. 1929. The resurrection of the Grand Canyon of the Yellowstone. *American Journal of Science* 17(99):260-278.

Joyce, W. G., S. D. Chapman, R. T. J. Moody, and C. A. Walker. 2011. The skull of the solemydid turtle *Helochelydra nopcsai* from the Early Cretaceous of the Isle of Wight (UK) and a review of Solemydidae. Pages 75-97 *in* P. M. Barrett and A. R. Milner, editors. Studies on fossil tetrapods. Palaeontological Association, London, United Kingdom. Special Papers in Palaeontology 86.

Jud, N. A. 2011. Diversity of a Lower Cretaceous pre-angiosperm flora in the Cloverly Formation, WY. Abstracts with Programs. *Geological Society of America* 43(5):312.

Jud, N. A. and S. L. Wing. 2010. Angiosperms from the Early Cretaceous of Wyoming. Abstracts with Programs. *Geological Society of America* 42(5):482.

Kauffman, E. G. 1969. Evidence for sea-level origin of the upper Pinyon Conglomerate,

northwestern Wyoming. Page 609 *in* Abstracts for 1968. Geological Society of America, Boulder, CO. Special Paper 121.

Kauffman, E. G. 1973. A brackish water biota from the upper Cretaceous Harebell Formation of northwestern Wyoming. *Journal of Paleontology* 47(3):436-445.

Kauffman, M. E. 1975. Paleoecologic significance of "*Girvanella*", a calcareous fossil alga? from the Cambrian of Montana. Page 16 *in* International Symposium on Fossil Algae: program and abstracts. Institute of Palaeontology, Erlangen, Germany. Available online at: http://web.ku.edu/~ifaa/pdf/Erlangen_1975_abstracts.pdf. Accessed February 2013.

Kausch, T. K. and E. Giffin. 1993. Early Cretaceous vertebrates of the Muddy Sandstone, Big Horn Basin, Wyoming. *Journal of Vertebrate Paleontology* 13(supplement to 3):43A-44A.

Kenworthy, J. P. and V. L. Santucci. 2006. A preliminary investigation of National Park Service paleontological resources in cultural resource contexts, Part 1: general overview. Pages 70-76 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 34. Available online at: http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed February 2013.

Kerr, D. R. and R. H. Dott, Jr. 1988. Eolian dune types preserved in the Tensleep Sandstone (Pennsylvanian-Permian), north-central Wyoming. *Sedimentary Geology* 56(1-4):383-402.

Ketner, K. B., W. R. Keefer, F. S. Fisher, D. L. Smith, and R. G. Raabe. 1966. Mineral resources of the Stratified Primitive Area, Wyoming. U.S. Geological Survey, Washington, DC. Bulletin 1230-E. Available online at: http://pubs.er.usgs.gov/publication/b1230E. Accessed April 2013.

Kindle, E. M. 1908. The fauna and stratigraphy of the Jefferson limestone in the northern Rocky Mountain region. *Bulletins of American Paleontology* 4(20). Available online at: http://www.biodiversitylibrary.org/page/30374890. Accessed February 2013.

King, P. B. and H. M. Beikman. 1978. The Cenozoic rocks; a discussion to accompany the geologic map of the United States. U.S. Geological Survey, Washington, DC. Professional Paper 904. Available online at: http://pubs.er.usgs.gov/publication/pp904. Accessed April 2013.

Knowlton, F. H. 1896. The Tertiary floras of the Yellowstone National Park. *American Journal of Science* 2(7):51-58.

Knowlton, F. H. 1898a. The standing fossil forests of the Yellowstone National Park. *Plant World* 1:53-55.

Knowlton, F. H. 1898b. A catalogue of the Cretaceous and Tertiary plants of North America. U.S. Geological Survey, Washington, DC. Bulletin 152. Available online at: http://pubs.er.usgs.gov/publication/b152. Accessed May 2013.

Knowlton, F. H. 1899. Fossil flora. Pages 651-882 *in* Geology of the Yellowstone national park. U.S. Geological Survey, Washington, DC. Monograph 32. Available online at: http://archive.org/details/geologyofyellows00hagu. Accessed March 2013.

Knowlton, F. H. 1900. Flora of the Montana Formation. U.S. Geological Survey, Washington, DC. Bulletin 163. Available online at: http://pubs.er.usgs.gov/publication/b163. Accessed April 2013.

Knowlton, F. H. 1914. Fossil forests of the Yellowstone National Park. Government Printing Office, Washington, DC. Available online at: http://www.nps.gov/history/history/online_books/yell/knowlton/index.htm. Accessed April 2013.

Knowlton, F. H. 1917. A fossil flora from the Frontier Formation of southwestern Wyoming. Pages 73-107 *in* Shorter contributions to general geology, 1917. U.S. Geological Survey, Reston, VA. Professional Paper 108.

Koch, A. L. and V. L. Santucci. 2003. Grand Teton National Park. Pages 14-23 *in* A. L. Koch and V. L. Santucci. Paleontological resource inventory and monitoring—Greater Yellowstone Network. TIC# D-1025. National Park Service, Denver, CO.

Kohn, M. 1998. A genetic record of pocket gophers during Holocene climatic change as revealed by ancient DNA. *Paleobios* 18(supplement to 3):4. Available online at: http://docubase.berkeley.edu/cgi-bin/pl_dochome?query_src=pl_search&collection=PaleoBios+Archive+Public&id=124. Accessed April 2013.

Koucky, F. L., Jr., N. E. Cygan, and F. H. T. Rhodes. 1961. Conodonts from the eastern flank of the central part of the Big Horn Mountains, Wyoming. *Journal of Paleontology* 35(4):877-879.

Koucky, F. L., F. H. T. Rhodes, and C. H. Hu. 1968. Upper Cambrian-Lower Ordovician conodont sequences of the Big Horn Mountains, Wyoming. Pages 123-124 *in* Abstracts for 1967. Geological Society of America, Boulder, CO. Special Paper 115.

Krause, T. R. and C. Whitlock. 2013. Climate and vegetation change during the late-glacial/early Holocene transition inferred from multiple proxy records from Blacktail Pond, Yellowstone National Park, USA. *Quaternary Research* 79(3):391-402.

Kulas, H. A. and R. L. Batten. 1997. Silicified gastropods from the Permian Phosphoria rock complex of Wyoming. *Contributions to Geology* 31(2):33-58.

Kummel, B., Jr. 1943. The Thaynes Formation, Bear Lake Valley, Idaho. *American Journal of Science* 241(5):316-332.

Kummel, B. 1954a. Jurassic nautiloids from western North America. *Journal of Paleontology* 28(3):320-324.

Kummel, B. 1954b. Triassic stratigraphy of southeastern Idaho and adjacent areas. Pages 165-194 *in* Shorter contributions to general geology, 1953. U.S. Geological Survey, Reston, VA. Professional Paper 254. Available online at:

http://pubs.er.usgs.gov/publication/pp254H. Accessed May 2013.

Kummel, B. 1960. The Triassic of southwestern Montana. Pages 233-238 *in* D. E. Campau and H. W. Anisgard, editors. West Yellowstone—Earthquake area. Billings Geological Society, Billings, MT. Guidebook 11.

Kvale, E. P. and C. F. Vondra. 1993. Effects of relative sea-level changes and local tectonics on a Lower Cretaceous fluvial to transitional marine sequence, Bighorn Basin, Wyoming, USA. Pages 383-399 *in* M. Marzo and C. Puigdefabregas, editors. Alluvial sedimentation. Blackwell, Oxford. *Special Publication of the International Association of Sedimentologists* 17.

Kvale, E. P., G. D. Johnson, D. L. Mickelson, K. Keller, L. C. Furer, and A. W. Archer. 2001. Middle Jurassic (Bajocian and Bathonian) dinosaur megatracksites, Bighorn Basin, Wyoming, U.S.A. *Palaios* 16(3):233-254.

Lageson, D. R., D. C. Adams, L. Morgan, K. L. Pierce, and R. B. Smith. 1999. Neogene-Quaternary tectonics and volcanism of southern Jackson Hole, Wyoming and southeastern Idaho. Pages 115-130 *in* S. S. Hughes and G. D. Thackray, editors. Guidebook to the geology of eastern Idaho. Idaho Museum of Natural History, Pocatello, ID. Online. Available online at: http://imnh.isu.edu/digitalatlas/geo/gsa/papers/gsac2p7.pdf. Accessed March 2013.

Lalicker, C. G. 1950. Foraminifera of the Ellis group, Jurassic, at the type locality. *University of Kansas Paleontological Contributions* 5(2). Available online at: http://kuscholarworks.ku.edu/dspace/handle/1808/3779. Accessed February 2013.

Landman, N. H. and W. A. Cobban. 2005. Ammonite markings on the seafloor of the Late Cretaceous Western Interior Seaway. Abstracts with Programs. *Geological Society of America* 37(7):443-444.

Lanphere, M. A., D. E. Champion, R. L. Christiansen, G. A. Izett, and J. D. Obradovich. 2002. Revised ages for tuffs of the Yellowstone Plateau volcanic field: assignment of the Huckleberry Ridge Tuff to a new geomagnetic polarity event. *Geological Society of America Bulletin* 114(5):559-568.

LaPasha, C. A. 1977. Comparison of compressed foliage from two sites in the Kootenai Formation of Great Falls, Montana. Abstracts with Programs. *Geological Society of America* 9(6):741-742.

LaPasha, C. A. and C. N. Miller, Jr. 1985. Flora of the Early Cretaceous Kootenai Formation in Montana: bryophytes and tracheophytes excluding conifers. *Palaeontographica. Abteilung B: Palaeophytologie* 196(4-6):111-145.

Lash, C. E. and J. G. Schmitt. 2008. Depositional environment and taphonomy of marine vertebrate biofacies in the Lower Cretaceous (Albian) Thermopolis Shale, south-central Montana. Abstracts with Programs. *Geological Society of America* 40(6):378.

Lebauer, L. R. 1964. Petrology of the Middle Cambrian Wolsey Shale of southwestern

Montana. *Journal of Sedimentary Petrology* 34(3):503-511.

Lebauer, L. R. 1965. Genesis and environment of deposition of the Meagher Formation in southwestern Montana. *Journal of Sedimentary Petrology* 35(2):428-447.

Leier, A. L. and J. R. Steidtmann. 2009. The Bacon Ridge Sandstone of northwestern Wyoming and its place within the larger-scale Late Cretaceous depositional history of the region. *Mountain Geologist* 46(2):51-70.

Lesquereux, L. 1872. Fossil flora. Pages 283-318 *in* F. V. Hayden, Preliminary report of the United States Geological Survey of Montana and portions of adjacent territories, being a fifth annual report of progress. Department of the Interior, Washington, DC.

Lesquereux, L. 1873. Lignitic formation and fossil flora. *Annual Report of the United States Geological Survey of the Territories* 6:315-427.

Lesquereux, L. 1878. Contributions to the fossil flora of the western territories. Part II. The Tertiary flora. Report of the United States Geological Survey of the Territories. Department of the Interior, Washington, DC.

Licciardi, J. M. and K. L. Pierce. 2008. Cosmogenic exposure-age chronologies of Pinedale and Bull Lake glaciations in greater Yellowstone and the Teton Range, USA. *Quaternary Science Reviews* 27(7-8):814-831.

Lillegraven, J. A. and M. C. McKenna. 1986. Fossil mammals from the "Mesaverde" Formation (Late Cretaceous, Judithian) of the Bighorn and Wind River basins, Wyoming, with definitions of Late Cretaceous North American land-mammal "ages." *American Museum Novitates* 2840. Available online at: http://hdl.handle.net/2246/3575. Accessed March 2013.

Lindsey, D. A. 1972. Sedimentary petrology and paleocurrents of the Harebell Formation, Pinyon Conglomerate, and associated coarse clastic deposits, northwestern Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 734-B. Available online at: http://pubs.er.usgs.gov/publication/pp734B. Accessed March 2013.

Lochman, C. 1950. Status of Dry Creek shale of central Montana. *Bulletin of the American Association of Petroleum Geologists* 34(11):2200-2222.

Lochman-Balk, C. 1956. The Cambrian of the Rocky Mountains and southwest deserts of the United States and adjoining Sonora province, Mexico. Pages 529-661 *in* J. Rodgers, editor. El Sistema Cambrico, su paleogeografia y el problema de su base. Symposium: Parte II, Australia, America. International Geological Congress, Mexico City, Mexico. Report 20.

Lochman, C. L. and D. Duncan. 1944. Early Upper Cambrian faunas of central Montana. Geological Society of America, Boulder, CO. *Special Paper* 54.

Lochman, C. and C. H. Hu. 1960. Upper Cambrian faunas from the northwest Wind River Mountains, Wyoming. Part I. *Journal of Paleontology* 34(5):793-834.

Lockley, M. 1990. Tracking the rise of dinosaurs in eastern Utah. *Canyon Legacy* 6:2-8.

Lockley, M. and A. P. Hunt. 1995. Dinosaur tracks and other fossil footprints of the western United States. Columbia University Press, New York, NY.

Lockley, M. G. and J. L. Wright. 2003. Pterosaur swim tracks and other ichnological evidence of behaviour and ecology. Pages 297-313 *in* E. Buffetaut and J.-M. Mazin, editors. Evolution and palaeobiology of pterosaurs. Geological Society, London, United Kingdom. *Special Publication* 217.

Loeblich, A. R., Jr. and H. N. Tappan. 1950. The type Redwater shale (Oxfordian) of South Dakota, Part 1 of North American Jurassic Foraminifera. *Journal of Paleontology* 24(1):39-60.

Lopez, D. A. 2000. Geologic map of the Bridger 30' x 60' Quadrangle, Montana. Montana Bureau of Mines and Geology, Butte, MT. Geologic Map 58. Scale 1:100,000.

Lopez, D. A., S. W. Van DeLinder, M. L. Hendricks, G. S. Bayliss, and W. L. Ewert. 2007. The Tensleep play of south-central Montana, a part of the Permo-Pennsylvanian petroleum system of Montana and Wyoming. Montana Bureau of Mines and Geology, Butte, MT. Report of Investigations RI-18.

Lord, A. and P. F. Sherrington. 1976. Ostracods from the Rierdon Formation (Jurassic) of Montana. *Bulletin of Canadian Petroleum Geology* 24(2):305-309.

Love, J. D. 1939. Geology along the southern margin of the Absaroka Range, Wyoming. Geological Society of America, Boulder, CO. Special Paper 20.

Love, J. D. 1950. Upper Cretaceous section from southwestern Wyoming to Yellowstone National Park. Page 48 *in* Southwest Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 5.

Love, J. D. 1953. Tertiary stratigraphy of the Jackson Hole area, northwestern Wyoming. U.S. Geological Survey, Washington, DC. Oil and Gas Investigations Chart 27. Scale 1:2,400. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_5184.htm. Accessed March 2013.

Love, J. D. 1956a. Summary of geologic history of Teton County, Wyoming, during Late Cretaceous, Tertiary, and Quaternary times. Pages 140-150 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Love, J. D. 1956b. Cretaceous and Tertiary stratigraphy of the Jackson Hole area, northwestern Wyoming. Pages 75-94 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Love, J. D. 1956c. New geologic formation names in Jackson Hole, Teton County, northwestern Wyoming. *Bulletin of the American Association of Petroleum Geologists* 40(8):1899-1914.

Love, J. D. 1969. Late Cretaceous and Cenozoic sedimentation and tectonism,

southern Yellowstone-Jackson Hole area, Wyoming. Pages 611-612 *in* Abstracts for 1968. Geological Society of America, Boulder, CO. *Special Paper* 121.

Love, J. D. 1973. Harebell Formation (Upper Cretaceous) and Pinyon Conglomerate (uppermost Cretaceous and Paleocene), northwestern Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 734-A. Available online at: http://pubs.er.usgs.gov/publication/pp734A. Accessed March 2013.

Love, J. D., leader. 1989a. Sedimentation and tectonics of western North America: Volume 3, Yellowstone and Grand Teton national parks and the middle Rocky Mountains. Field trips for the 28th International Geological Congress. American Geophysical Union, Washington, DC. T328.

Love, J. D. 1989b. Names and descriptions of new and reclassified formations in northwestern Wyoming. U.S. Geological Survey, Reston, VA. Professional Paper 932-C. Available online at: http://pubs.er.usgs.gov/publication/pp932C. Accessed March 2013.

Love, J. D. 1990. Cretaceous rocks of Jackson Hole, northwestern Wyoming. *AAPG Bulletin* 74(8):1335.

Love, J. D. and W. R. Keefer. 1969. Basin Creek uplift and Heart Lake Conglomerate, southern Yellowstone National Park, Wyoming. Pages D122-D130 *in* Geological Survey research 1969, Chapter D. U.S. Geological Survey, Washington, DC. Professional Paper 650-D. Available online at: http://pubs.er.usgs.gov/publication/pp650D. Accessed April 2013.

Love, J. D. and W. R. Keefer. 1975. Geology of sedimentary rocks in southern Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 729-D. Scale 1:62,500. Available online at: http://pubs.er.usgs.gov/publication/pp729D. Accessed April 2013.

Love, J. D. and J. M. Love. 1980. Road log, Jackson to Dinwoody and return. Pages 283-317 *in* S. Hollis, editor. Stratigraphy of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 31.

Love, J. D. and J. C. Reed, Jr. 1968. Creation of the Teton landscape: the geologic story of Grand Teton National Park. Grand Teton Natural History Association, Moose, WY. Available online at: http://www.nps.gov/history/history/online_books/grte/grte_geology/index.htm. Accessed March 2013.

Love, J. D. and J. C. Reed, Jr. 1973. Preliminary geologic map of the Colter Bay Quadrangle, Teton County, Wyoming. U.S. Geological Survey, Washington, DC. Open-File Report 73-160. Scale 1:24,000. Available online at: http://pubs.er.usgs.gov/publication/ofr73160. Accessed March 2013.

Love, J. D., H. R. Bergquist, and R. K. Hose. 1948. Stratigraphic sections of Jurassic and Cretaceous rocks in the Jackson Hole area, northwestern Wyoming. Geological Survey of Wyoming, Laramie, WY. Bulletin 40. Available online at: http://www.wsgs.uwyo.edu/public-

info/onlinepubs/docs/B-40.pdf. Accessed March 2013.

Love, J. D., M. C. McKenna, and M. R. Dawson. 1976. Eocene, Oligocene, and Miocene rocks and vertebrate fossils at the Emerald Lake locality, 3 miles south of Yellowstone National Park, Wyoming. U.S. Geological Survey, Reston, VA. Professional Paper 932-A. Available online at: http://pubs.er.usgs.gov/publication/pp932A. Accessed March 2013.

Love, J. D., E. B. Leopold, and D. W. Love. 1978. Eocene rocks, fossils, and geologic history, Teton Range, northwestern Wyoming. U.S. Geological Survey, Reston, VA. Professional Paper 932-B. Available online at: http://pubs.er.usgs.gov/publication/pp932B. Accessed March 2013.

Love, J. D., J. C. Reed, and A. C. Christiansen. 1992. Geologic map of Grand Teton National Park, Teton County, Wyoming. U.S. Geological Survey, Reston, VA. Miscellaneous Investigations Series Map 2031. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_10095.htm. Accessed February 2013.

Love, J. D., J. M. Good, and D. G. Browne. 2007. Reconnaissance study of Pleistocene lake and fluvial deposits in and near ancestral Yellowstone Lake, Wyoming. Pages 53-90 *in* Morgan, L. A., editor. Integrated geoscience studies in the greater Yellowstone area: volcanic, tectonic, and hydrothermal processes in the Yellowstone geoecosystem. U.S. Geological Survey, Reston, VA. Professional Paper 1717. Available online at: http://pubs.er.usgs.gov/publication/pp1717 Accessed April 2013.

Lovelace, D. M. 2011. Sedimentology and ichnology from the Early and Middle Triassic formations of the Chugwater Group, central Wyoming, USA. Abstracts with Programs. *Geological Society of America* 43(5):266.

Lovelace, D. M. and S. D. Lovelace. 2012. Paleoenvironments and paleoecology of a Lower Triassic invertebrate and vertebrate ichnoassemblage from the Red Peak Formation (Chugwater Group), central Wyoming. *Palaios* 27(9):636-657.

Lucas, S. G., K. Krainer, and A. R. C. Milner. 2007. The type section and age of the Timpoweap Member and stratigraphic nomenclature of the Triassic Moenkopi Group in southwestern Utah. Pages 109-117 *in* Lucas, S. G. and J. A. Spielmann, editors. Triassic of the American West. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 40. Available online at: http://paleo.cortland.edu/globaltriassic/Bull40/12-Lucas%20et%20al.%20(Timpoweap).pdf. Accessed March 2011.

Macomber, R. W. 1970. Articulate brachiopods from the upper Bighorn Formation (late Ordovician) of Wyoming. *Journal of Paleontology* 44(3):416-450.

Mader, B. J. 2009. Details of the cranial anatomy of a primitive diplacodont brontothere, cf. Protitanotherium, from the Wiggins Formation of Wyoming (Mammalia, Perissodactyla,

Brontotheriidae). *Journal of Vertebrate Paleontology* 29(4):1224-1232.

Maione, S. J. 1971. Stratigraphy of the Frontier Sandstone Member of the Mancos Shale (Upper Cretaceous) on the south flank of the eastern Uinta Mountains, Utah and Colorado. *Earth Science Bulletin* 4(3):27-58.

Mamet, B. L. 1975. Carboniferous foraminifera and algae of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 848-B. Available online at: http://pubs.er.usgs.gov/publication/pp848B. Accessed February 2013.

Mankiewicz, D. and J. R. Steidtmann. 1979. Depositional environments and diagenesis of the Tensleep Sandstone, eastern Big Horn Basin, Wyoming. Pages 319-336 *in* P. A. Scholle and P. R. Schluger, editors. Aspects of diagenesis. Society of Economic Paleontologists and Mineralogists, Tulsa, OK. Special Publication 26.

Mansfield, G. R. 1916. Subdivisions of the Thaynes limestone and Nugget sandstone, Mesozoic, in the Fort Hall Indian Reservation, Idaho. *Washington Academy of Sciences Journal* 6(2):31-42.

Mansfield, G. R. 1920. Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho. U.S. Geological Survey, Reston, VA. Bulletin 713.

Mapel, W. J. and M. H. Bergendahl. 1956. Gypsum Spring Formation, northwestern Black Hills, Wyoming and South Dakota. *Bulletin of the American Association of Petroleum Geologists* 40(1):84-93.

Mapel, W. J. and C. A. Sandberg. 1968. Devonian paleotectonics in east-central Idaho and southwestern Montana. Pages D115-D125 *in* Geological Survey research 1968, Chapter D. U.S. Geological Survey, Washington, DC. Professional Paper 600-D. Available online at: http://pubs.er.usgs.gov/publication/pp600D. Accessed April 2013.

Marsh, O. C. 1890. Description of new dinosaurian reptiles. *American Journal of Science* (3rd series) 39:81-86. Available online at: http://marsh.dinodb.com/marsh/Marsh%201890%20-%20Description%20of%20new%20dinosaurian%20reptiles.pdf. Accessed April 2013.

Marsh, O. C. 1895. The Reptilia of the *Baptanodon* beds. *American Journal of Science* 50(299):405-406.

Martin, W. D., J. H. Fischer, R. J. Keogh, and K. Moore. 1980. The petrology of the limestones in the upper Gros Ventre and Gallatin Limestone formations (Middle and Upper Cambrian), northwestern Wind River basin, Wyoming. Pages 37-51 *in* S. Hollis, editor. Stratigraphy of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 31.

Massare, J. A. and J. M. Callaway. 1994. *Cymbospondylus* (Ichthyosauria: Shastasauridae) from the Lower Triassic Thaynes Formation of southeastern Idaho. *Journal of Vertebrate Paleontology* 14(1):139-141.

Massare, J. A. and L.E. Dain. 1989. The marine reptiles of the Mowry Shale (Albian) of northeastern Wyoming. *Journal of Vertebrate Paleontology* 9(supplement to 3):32A.

Massare, J. A., E. A. Buchholtz, J. M. Kenney, and A.-M. Chomat. 2006. Vertebral morphology of *Ophthalmosaurus natans* (Reptilia: Ichthyosauria) from the Jurassic Sundance Formation of Wyoming. *Paludicola* 5:242-254.

Massare, J. A., W. R. Wahl, M. Ross, and M. V. Connely. In press. Palaeoecology of the marine reptiles of the Redwater Shale Member of the Sundance Formation (Jurassic of central Wyoming, USA. *Geological Magazine*.

Matthews, N. A., T. A. Noble, and B. H. Breithaupt. 2006. The application of photogrammetry, remote sensing and geographic information systems (GIS) to fossil resource management. Pages 119-131 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 34.

Maughan, E. K. 1964. The Goose Egg Formation in the Laramie Range and adjacent parts of southeastern Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 501-B:B53-B60. Available online at: http://pubs.er.usgs.gov/publication/pp501B. Accessed February 2013.

Maughan, E. K. 1967. Eastern Wyoming, eastern Montana, and the Dakotas. U.S. Geological Survey, Washington, DC. Professional Paper 515-G. Available online at: http://pubs.usgs.gov/pp/0515/report.pdf. Accessed February 2013.

Maxwell, E. E. and B. P. Kear. 2010. Postcranial anatomy of *Platypterygius americanus* (Reptilia, Ichthyosauria) from the Cretaceous of Wyoming. *Journal of Vertebrate Paleontology* 30(4):1059-1068.

Maxwell, W. D. and J. R. Horner. 1994. Neonate dinosaurian remains and dinosaurian eggshell from the Cloverly Formation, Montana. *Journal of Vertebrate Paleontology* 14(1):143-146.

McCracken, H., W. Wedel, R. Edgar, J. Moss, H. E. Wright, W. Husted, and W. Mulloy. 1978. The Mummy Cave project in northwest Wyoming. Buffalo Bill Historical Center, Cody, WY.

McGill, B. J., E. A. Hadly, and B. A. Maurer. 2005. Community inertia of Quaternary small mammal assemblages in North America. *Proceedings of the National Academy of Sciences of the United States of America* 102(46):16701-16706.

McKelvey, V. E., T. M. Cheney, E. R. Cressman, R. P. Sheldon, R. W. Swanson, and J. S. Williams. 1959. Geology of Permian rocks in the western phosphate field: the Phosphoria, Park City, and Shedhorn formations in the western phosphate field. U.S. Geological Survey, Washington, DC. Professional Paper 313-A. Available online at: http://pubs.er.usgs.gov/publication/pp313A. Accessed February 2013.

McKenna, M. C. 1980. Late Cretaceous and early Tertiary vertebrate paleontological reconnaissance, Togwotee Pass area, northwestern Wyoming. Pages 321-343 *in* L. L. Jacobs, editor. Aspects of vertebrate history: essays in honor of Edwin Harris Colbert. Museum of Northern Arizona Press, Flagstaff, AZ.

McKenna, M. C. and J. D. Love. 1970. Local stratigraphic and tectonic significance of *Leptoceratops*, a Cretaceous dinosaur in the Pinyon Conglomerate, northwestern Wyoming. Pages D55-D61 *in* Geological Survey research 1970, Chapter D. U.S. Geological Survey, Washington, DC. Professional Paper 700-D. Available online at: http://pubs.er.usgs.gov/publication/pp700D. Accessed March 2013.

McLaughlin, M. C. 1998. Conodont biostratigraphy and chemostratigraphy of the Grove Creek Member of the Snowy Range Formation, northwestern Wyoming and southwestern Montana. *Keck Research Symposium in Geology* 11:279-282. Available online at: http://keckgeology.org/files/pdf/symvol/11th/Wyoming/mclaughlin.pdf. Accessed April 2013.

McMenamin, S. K. and E. A. Hadly. 2012. Ancient DNA assessment of tiger salamander population in Yellowstone National Park. Plos One E32763. Available online at: http://www.plosone.org/article/info:doi/10.1371/journal.pone.0032763. Accessed April 2013.

Medville, D. M., J. C. Kampel, C. Plantz, and E. Werner. 1979. Solutional landforms on carbonates of the southern Teton Range, Wyoming. *NSS Bulletin* 41(3):70-79.

Mehl, M. G. 1915. *Poposaurus gracilis*, a new reptile from the Triassic of Wyoming. *Journal of Geology* 23(6):516-522.

Merewether, E. A. 1996. Stratigraphy and tectonic implications of Upper Cretaceous rocks in the Powder River basin, northeastern Wyoming and southeastern Montana. U.S. Geological Survey, Reston, VA. Bulletin 1917-T. Available online at: http://pubs.er.usgs.gov/publication/b1917T. Accessed February 2013.

Merewether, E. A. and W. A. Cobban. 2008. Outcrop descriptions and fossils from the Upper Cretaceous Frontier Formation, Wind River basin and adjacent areas, Wyoming. U.S. Geological Survey, Reston, VA. Digital Data Series 69-J. Available online at: http://pubs.usgs.gov/dds/dds-069/dds-069-j/chapters.html. Accessed September 2011.

Merewether, E. A., W. A. Cobban, and E. T. Cavanaugh. 1979. Frontier Formation and equivalent rocks in eastern Wyoming. *Mountain Geologist* 16(3):67-102.

Merewether, E. A., P. D. Blackmon, and J. C. Webb. 1984. The Mid-Cretaceous Frontier Formation near the Moxa Arch, southwestern Wyoming. U.S. Geological Survey, Reston, VA. Professional Paper 1290. Available online at: http://pubs.er.usgs.gov/publication/pp1290 Accessed March 2013.

Merewether, E. A., W. A. Cobban, and R. W. Tillman. 2010. Outcrops, fossils, geophysical logs, and tectonic

interpretations of the Upper Cretaceous Frontier Formation and contiguous strata in the Bighorn Basin, Wyoming and Montana. U.S. Geological Survey, Reston, VA. Scientific Investigations Report 2009-5256. Available online at: http://pubs.er.usgs.gov/publication/sir20095256. Accessed February 2013.

Meyer, G. A., L. P. Persico, and R. Levine. 2010. Beaver damming and discontinuity along streams in the greater Yellowstone ecosystem. Abstracts with Programs. *Geological Society of America* 42(5):519.

Meyers, J. H., C. M. Graves, P. J. O'Malley, and R. K. Schwartz. 1992. Environments of deposition in the Late Jurassic marine to nonmarine transition, Swift and Morrison formations, southwestern Montana. Pages 47-48 *in* SEPM 1992 theme meeting; Mesozoic of the Western Interior; abstracts. Society for Sedimentary Geology, Tulsa, OK.

Mickelson, D. L., K. A. Mickelson, M. R. King, and P. Getty. 2006a. Jurassic dinosaur tracksites from the American West. Pages 138-140 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 34.

Mickelson, D. L., M. R. King, P. Getty, and K. A. Mickelson. 2006b. Subaqueous tetrapod swim tracks from the Middle Jurassic: Bighorn Canyon National Recreation Area (BCNRA), Wyoming, U.S.A. Page 26 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 34.

Miller, A. K. and A. G. Unklesbay. 1943. A new asteroid from the Jurassic of central Wyoming. *Journal of Paleontology* 17(2):179-180.

Miller, A. K. and W. L. Youngquist. 1946. A giant ammonite from the Cretaceous of Montana. *Journal of Paleontology* 20(5):479-484.

Miller, B. M. 1936. Cambrian stratigraphy of northwestern Wyoming. *Journal of Geology* 44(2, part 1):113-144.

Miller, C. N., Jr. and C. A. LaPasha. 1984. Flora of the Early Cretaceous Kootenai Formation in Montana, conifers. *Palaeontographica. Abteilung B: Palaeophytologie* 193(1-4):1-17.

Millspaugh, S. H., C. Whitlock, and P. J. Bartlein. 2000. Variations in fire frequency and climate over the past 17000 yr in central Yellowstone National Park. *Geology* 28(3):211-214.

Mirsky, A. 1962. Stratigraphy of non-marine Upper Jurassic and Lower Cretaceous rocks, southern Big Horn Mountains, Wyoming. *Bulletin of the American Association of Petroleum Geologists* 46(9):1653-1680.

Mitchell, G. E. 1926. The standing stone forests of Wyoming. *Scientific American* 134:98-99.

Moberly, R. M., Jr. 1960. Morrison, Cloverly, and Sykes Mountain formations, northern Bighorn Basin, Wyoming and Montana.

Geological Society of America Bulletin 71(8):1137-1176.

Moberly, R., Jr. 1962. Lower Cretaceous history of the Bighorn Basin, Wyoming, Pages 94-101 *in* R. L. Enyert and W. H. Curry, III, editors. Symposium on Early Cretaceous rocks of Wyoming and adjacent areas. Wyoming Geological Association, Casper, WY. Guidebook 17.

Mogk, D. W., P. A. Mueller, and J. L. Wooden. 1992. The nature of Archean terrane boundaries: an example from the northern Wyoming Province. *Precambrian Research* 55(1-4):155-168.

Molenaar, C. M. and B. W. Wilson. 1990. The Frontier Formation and associated rocks of northeastern Utah and northwestern Colorado. U.S. Geological Survey, Reston, VA. Bulletin 1787-M. Available online at: http://www.nps.gov/history/history/online_books/geology/publications/bul/1787-m/contents.htm. Accessed September 2011.

Moore, G. T. 1973. Lodgepole Limestone facies in southwestern Montana. *American Association of Petroleum Geologists Bulletin* 57(9):1703-1713.

Morgan, D. 1998. Paleoenvironmental interpretation of the Middle Cambrian Flathead Sandstone and Wolsey Shale, Clarks Fork region, Wyoming. *Keck Research Symposium in Geology* 11:275-278. Available online at: http://keckgeology.org/files/pdf/symvol/11th/Wyoming/morgan.pdf. Accessed February 2013.

Morgan, L. A., K. L. Pierce, and W. C. P. Shanks. 2008. Track of the Yellowstone Hotspot: young and ongoing geologic processes from the Snake River plain to the Yellowstone Plateau and Tetons. Geological Society of America, Boulder, CO. Pages 139-173 *in* R. G. Raynolds, editor. Roaming the Rocky Mountains and environs: geological field trips. Geological Society of America, Boulder, CO. Field Guide 10.

Moslow, T. F. and R. W. Tillman. 1986. Sedimentary facies and reservoir characteristics of Frontier Formation sandstones, southwestern Wyoming. Pages 271-295 *in* C. W. Spencer and R. F. Mast, editors. Geology of tight gas reservoirs. American Association of Petroleum Geologists, Tulsa, OK. *AAPG Studies in Geology* 24.

Mueller, P. A., J. L. Wooden, D. J. H., and D. R. Bowes. 1985. Archean crustal evolution of the eastern Beartooth Mountains, Montana and Wyoming. Pages 9-20 *in* G. K. Czamanske and M. L. Zientek, editors. The Stillwater Complex, Montana: geology and guide. State of Montana Bureau of Mines and Geology, Butte, MT. *Special Publication* 92.

Mutter, R. J. and H. Rieber. 2005. *Pyknotylacanthus spathianus* gen. et sp. nov., a new ctenacanthoid from the Early Triassic of Bear Lake (Idaho, USA). *Revista Brasileira de Paleontologia* 8(2):139-148. Available online at: http://www.sbpbrasil.org/revista/edicoes/8_2/8%282%29mutter.pdf. Accessed August 2011.

Myrow, P. M., L. Tice, B. Archuleta, B. Clark, J. F. Taylor, and R. L. Ripperdan. 2004.

Flat-pebble conglomerate: its multiple origins and relationship to metre-scale depositional cycles. *Sedimentology* 51(5):973-996.

Myrow, P. M., J. F. Taylor, A. C. Runkel, and R. L. Ripperdan. 2012. Mixed siliciclastic-carbonate upward-deepening cycles of the Upper Cambrian inner detrital belt of Laurentia. *Journal of Sedimentary Research* 82(4):216-231.

Nace, R. L. 1939. A new ichthyosaur from the Upper Cretaceous Mowry Formation of Wyoming. *American Journal of Science* 237(9):673-686.

National Park Service. 2005. Geologic resource evaluation scoping summary, Yellowstone National Park. National Park Service, Geologic Resources Division, Denver, CO. Available online at: http://nature.nps.gov/geology/inventory/publications/s_summaries/YELL_scoping_summary_20051103.pdf. Accessed April 2013.

National Park Service, Geologic Resources Division. 2010. Digital geologic map of Grand Tetons National Park, John D. Rockefeller Jr. Memorial Parkway and vicinity, Wyoming (NPS, GRD, GRI, GRTE, GRTE digital map). National Park Service, Geologic Resources Division, Denver, CO. Scale 1:65,000. Available online at: https://irma.nps.gov/App/Reference/Profile?Code=2165235. Accessed March 2013.

Nelson, W. H. and W. G. Pierce. 1968. Wapiti Formation and Trout Peak Trachyandesite, northwestern Wyoming. U.S. Geological Survey, Washington, DC. Bulletin 1254-H. Available online at: http://pubs.er.usgs.gov/publication/b1254H. Accessed April 2013.

Nordquist, J. W. 1955. Pre-Rierdon Jurassic stratigraphy in northern Montana and Williston Basin. Pages 96-106 *in* P. J. Lewis, editor. Sweetgrass Arch—Disturbed Belt, Montana. Billings Geological Society, Billings, MT. Guidebook 6.

Nydam, R. L. and R. L. Cifelli. 2002. Lizards from the lower Cretaceous (Aptian-Albian) Antlers and Cloverly formations. *Journal of Vertebrate Paleontology* 22(2):286-298.

O'Keefe, F. R. and H. P. Street. 2009. Osteology of the cryptocleidoid plesiosaur *Tatenectes laramiensis*, with comments on the taxonomic status of the Cimoliasauridae. *Journal of Vertebrate Paleontology* 29(1):48-57.

O'Keefe, K. B., E. A. Hadly, and J. M. Zinck. 2001. Evolutionary and ecological response of *Spermophilus armatus* to climate change during the late Holocene. *Journal of Vertebrate Paleontology* 21(supplement to 3):85A.

O'Keefe, F. R., H. P. Street, J. P. Cavigelli, J. J. Socha, and R. D. O'Keefe. 2009. A plesiosaur containing an ichthyosaur embryo as stomach contents from the Sundance Formation of the Bighorn Basin, WY. *Journal of Vertebrate Paleontology* 29(4):1306-1310.

Oboh-Ikuenobe, F. E., D. G. Benson, R. W. Scott, J. M. Holbrook, M. J. Evetts, and J. Erbacher. 2007. Re-evaluation of the Albian-Cenomanian boundary in the U.S. Western Interior based on dinoflagellate

cysts. *Review of Palaeobotany and Palynology* 144(1-2):77-97.

Oehler, J. H. 1972. “Stromatoloids” from Yellowstone Park, Wyoming. Abstracts with Programs. *Geological Society of America* 4(3):212-213.

Okulitch, V. J. and W. G. Bell. 1955. *Gallatinospongia*, a new siliceous sponge from the Upper Cambrian of Wyoming. *Journal of Paleontology* 29(3):460-461.

Olson, E. C. 1960. A trilophosaurid reptile from the Kootenai Formation (Lower Cretaceous). *Journal of Paleontology* 34(3):551-555.

Oreska, M. P. J., M. T. Carrano, and K. M. Dzikiewicz. 2013. Vertebrate paleontology of the Cloverly Formation (Lower Cretaceous), I: faunal composition, biogeographic relationships, and sampling. *Journal of Vertebrate Paleontology* 33(2):264-292.

Ostrom, J. H. 1970. Stratigraphy and paleontology of the Cloverly Formation (lower Cretaceous) of the Bighorn Basin area, Wyoming and Montana. Peabody Museum of Natural History Bulletin 35. Available online at: http://peabody.yale.edu/sites/default/files/documents/scientific-publications/ypmB35_1970.pdf. Accessed February 2013.

Palmer, A. N., and M. V. Palmer. 1995. The Kaskaskia paleokarst of the northern Rocky Mountains and Black Hills, northwestern U.S.A. *Carbonates and Evaporites* 10(2):148-160.

Parcell, W. C. and M. K. Williams. 2005. Mixed sediment deposition in a retro-arc foreland basin: lower Ellis Group (M. Jurassic), Wyoming and Montana, U.S.A. *Sedimentary Geology* 177(3-4):175-194.

Parrish, J. T., F. Peterson, and C. E. Turner. 2004. Jurassic “savannah:” plant taphonomy and climate of the Morrison Formation (Upper Jurassic, Western USA). *Sedimentary Geology* 167(3-4):137-162.

Paull, R. A. and R. K. Paull. 1987. Lower Triassic rocks within and adjacent to the thrust belt of Wyoming, Idaho, Utah. Pages 149-161 *in* W. R. Miller, editor. The thrust belt revisited. Wyoming Geological Association, Casper, WY. Guidebook 38.

Paull, R. A. and R. K. Paull. 1990. Persistent myth about the Lower Triassic Little Medicine Member of the Goose Egg Formation and the Lower Triassic Dinwoody Formation, central Wyoming. Pages 57-68 *in* R. W. Specht, editor. Wyoming sedimentation and tectonics. Wyoming Geological Association, Casper, WY. Guidebook 41.

Paull, R. A. and R. K. Paull. 1993. Stratigraphy of the Lower Triassic Dinwoody Formation in the Wind River basin area, Wyoming. Pages 31-47 *in* W. R. Keefer, W. J. Metzger, and L. H. Godwin, editors. Wyoming Geological Association special symposium on oil and gas and other resources of the Wind River basin, Wyoming. Wyoming Geological Association, Casper, WY.

Paull, R. K. and R. A. Paull. 1983. Revision of type Lower Triassic Dinwoody Formation, Wyoming, and designation of principal reference section. *Contributions to Geology* 22(2):83-90.

Paull, R. A., R. K. Paull, and B. R. Kramer. 1989. Depositional history of Lower Triassic rocks in southwestern Montana and adjacent parts of Wyoming and Idaho. Pages 69-90 *in* D. E. French and R. F. Grabb, editors. Montana Geological Society 1989 field conference guidebook: Montana centennial edition: Geologic resources of Montana, Volume I. Montana Geological Society, Bozeman, MT. Field Conference 1989(1).

Paull, R. K., R. A. Paull, and A. L. Anderson. 1985. Conodont biostratigraphy and depositional history of the Lower Triassic Dinwoody Formation in the Meade Plate, southeastern Idaho. Pages 55-66 *in* G. J. Kerns and R. L. Kerns, editors. Orogenic patterns and stratigraphy of north-central Utah and southeastern Idaho. Utah Geological Association, Salt Lake City, UT. Publication 14.

Peale, A. C. 1893. The Paleozoic section in the vicinity of Three Forks, Montana, with petrographic notes by G. P. Merrill. U.S. Geological Survey, Washington, DC. Bulletin 110. Available online at: http://pubs.er.usgs.gov/publication/b110. Accessed April 2013.

Peck, R. E. 1941. Lower Cretaceous Rocky Mountain nonmarine microfossils. *Journal of Paleontology* 15(3):285-304.

Peck, R. E. 1957. North American Mesozoic Charophyta. U.S. Geological Survey, Washington, DC. Professional Paper 294-A.

Persico, L. P. 2006. Beaver, climate, and fluvial geomorphic change in Yellowstone National Park, Wyoming USA. Thesis. University of New Mexico, Albuquerque, NM.

Persico, L. P. and G. A. Meyer. 2009. Holocene beaver damming, fluvial geomorphology, and climate in Yellowstone National Park, Wyoming. *Quaternary Research* 71(3):340-353.

Peterson, J. A. 1954a. Jurassic Ostracoda from the “lower Sundance” and Rierdon formations, western interior United States. *Journal of Paleontology* 28(2):153-176.

Peterson, J. A. 1954b. Distribution of marine Upper Jurassic ostracodes, Western Interior United States. *Journal of Sedimentary Petrology* 24(2):141-142.

Peterson, J. A. 1957a. Marine Jurassic of northern Rocky Mountains and Williston Basin. *Bulletin of the American Association of Petroleum Geologists* 41(3):399-440.

Peterson, J. A. 1957b. Gypsum Spring and Sundance formations, central Wyoming. Pages 47-54 *in* Southwest Wind River basin. Wyoming Geological Association, Casper, WY. Guidebook 12.

Picard, M. D. 1966. Petrography of Red Peak Member, Chugwater Formation (Triassic), west-central Wyoming. *Journal of Sedimentary Petrology* 36(4):904-926.

Picard, M. D. 1967. Stratigraphy and depositional environments of the Red Peak Member of the Chugwater Formation (Triassic), west-central Wyoming. *Contributions to Geology* 6(1):39-67.

Picard, M. D. 1993. The early Mesozoic history of Wyoming. Pages 210-248 *in* A. W. Snoke, J. R. Steidtmann, and S. M.

Roberts, editors. Geology of Wyoming. Wyoming State Geological Survey, Laramie, WY. Memoir 5.

Picard, M. D., R. Aadland, and L. R. High, Jr. 1969. Correlation and stratigraphy of Triassic Red Peak and Thaynes formations, western Wyoming and adjacent Idaho. *American Association of Petroleum Geologists Bulletin* 53(11):2274-2289.

Pierce, K. L. 1970. Glaciation of northern Yellowstone Park. Program and Abstracts. *American Quaternary Association Conference* 1:105-106.

Pierce, K. L. 1973a. Surficial geologic map of the Mount Holmes quadrangle and parts of the Tepee Creek, Crown Butte, and Miner quadrangles, Yellowstone National Park, Wyoming and Montana. U.S. Geological Survey, Washington, DC. Miscellaneous Geologic Investigations Map 640. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9418.htm. Accessed April 2013.

Pierce, K. L. 1973b. Surficial geologic map of the Mammoth quadrangle and part of the Gardiner quadrangle, Yellowstone National Park, Wyoming and Montana. U.S. Geological Survey, Washington, DC. Miscellaneous Geologic Investigations Map 641. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9419.htm. Accessed April 2013.

Pierce, K. L. 1974a. Surficial geologic map of the Abiathar Peak and parts of adjacent quadrangles, Yellowstone National Park, Wyoming and Montana. U.S. Geological Survey, Washington, DC. Miscellaneous Investigations Series Map 646. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9424.htm. Accessed April 2013.

Pierce, K. L. 1974b. Surficial geologic map of the Tower Junction quadrangle and part of the Mount Wallace quadrangle, Yellowstone National Park and adjoining area, Wyoming and Montana. U.S. Geological Survey, Washington, DC. Miscellaneous Investigations Series Map 647. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9425.htm. Accessed April 2013.

Pierce, K. L. 1979. History and dynamics of glaciation in the northern Yellowstone National Park area. U.S. Geological Survey, Washington, DC. Professional Paper 729-F. Available online at: http://pubs.er.usgs.gov/publication/pp729F Accessed April 2013.

Pierce, K. L., K. D. Adams, and N. C. Sturchio. 1991. Geologic setting of the Corwin Springs Known Geothermal Resource Area Mammoth Hot Springs Area in and adjacent to Yellowstone National Park. Pages C1-C37 *in* M. L. Sorey, editor. Effects of potential geothermal development in the Corwin Springs Known Geothermal Resource Area, Montana, on the thermal features of Yellowstone National Park. U.S. Geological Survey, Reston, VA. Water Resources Investigations Report 91-4052. Available online at: http://pubs.er.usgs.gov/publication/wri914052. Accessed May 2013.

Pierce, K. L., D. G. Despain, C. Whitlock, K. P. Cannon, G. Meyer, L. A. Morgan, and J. M. Licciardi. 2003. Quaternary geology

and ecology of the greater Yellowstone area. Pages 313-344 *in* D. J. Easterbrook, editor. Quaternary geology of the United States: INQUA 2003 field guide volume. Desert Research Institute, Reno, NV.

Pierce, K. L., D. G. Despain, L. A. Morgan, and J. M. Good. 2007a. The Yellowstone Hotspot, greater Yellowstone ecosystem, and human geography. Pages 1-39 *in* L. A. Morgan, editor. Integrated geoscience studies in the greater Yellowstone area; volcanic, tectonic, and hydrothermal processes in the Yellowstone geoecosystem. U.S. Geological Survey, Reston, VA. Professional Paper 1717. Available online at: http://pubs.er.usgs.gov/publication/pp1717 Accessed April 2013.

Pierce, K. L., K. P. Cannon, G. A. Meyer, M. J. Trebesch, and R. D. Watts. 2007b. Postglacial inflation-deflation cycles, tilting, and faulting in the Yellowstone caldera based on Yellowstone Lake shorelines. Pages 127-168 *in* L. A. Morgan, editor. Integrated geoscience studies in the greater Yellowstone area; volcanic, tectonic, and hydrothermal processes in the Yellowstone geoecosystem. U.S. Geological Survey, Reston, VA. Professional Paper 1717. Available online at: http://pubs.er.usgs.gov/publication/pp1717 Accessed May 2013.

Pierce, K. L., D. R. Muhs, M. A. Fosberg, S. A. Mahan, J. G. Rosenbaum, J. M. Licciardi, and M. J. Pavich. 2011. A loess-paleosol record of climate and glacial history over the past two glacial-interglacial cycles (approximately 150 ka), southern Jackson Hole, Wyoming. *Quaternary Research* 76(1):119-141.

Pierce, W. G. 1963. Cathedral Cliffs Formation, the early acid breccia unit of northwestern Wyoming. *Geological Society of America Bulletin* 74(1):9-22.

Pipiringos, G. N. and R. W. Imlay. 1979. Lithology and subdivisions of the Jurassic Stump Formation in southeastern Idaho and adjoining areas. U.S. Geological Survey, Reston, VA. Professional Paper 1035-C. Available online at: http://pubs.er.usgs.gov/publication/pp1035C Accessed September 2011.

Platen, P. 1908. Untersuchungen fossiler Hölzer aus dem Westen der Vereinigten Staaten von Nordamerika. *Sitzungsberichte der Naturforschende Gesellschaft zu Leipzig* 34:1-155.

Platen, P. 1909. Die fossilen Wälder am Amethyst-Mount im Yellowstone-Nationalpark und die mikroskopische Untersuchung ihrer Hölzer. *Prometheus* 20:241-246.

Ploynoi, M. and W. C. Parcell. 2005. Development of Middle Jurassic microbial buildups in Bighorn Basin, Wyoming. Abstracts with Programs. *Geological Society of America* 37(7):17.

Porter, K. W. 1989. Marine Jurassic rocks of western Montana: new considerations, Pages 91-102 *in* D. E. French and R. F. Grabb, editors. Montana Geological Society 1989 field conference guidebook: Montana centennial edition: Geologic resources of Montana, Volume I. Montana Geological Society, Bozeman, MT. Field Conference 1989(1).

Prostka, H. J., E. T. Ruppel, and R. L. Christiansen. 1975a. Geologic map of the Abiathar Peak Quadrangle, Yellowstone National Park, Wyoming and Montana. U.S. Geological Survey, Washington, DC. Geologic Quadrangle Map 1244. Scale 1:62,500. Available online at: http://pubs.er.usgs.gov/publication/gq1244 Accessed April 2013.

Prostka, H. J., H. W. Smedes, and R. L. Christiansen. 1975b. Geologic map of the Pelican Cone Quadrangle, Yellowstone National Park and vicinity, Wyoming. U.S. Geological Survey, Washington, DC. Geologic Quadrangle Map 1243. Scale 1:62,500. Available online at: http://pubs.er.usgs.gov/publication/gq1243 Accessed April 2013.

Prothero, D. R. and F. Sanchez. 2004. Magnetic stratigraphy of the middle to upper Eocene section at Beaver Divide, Fremont County, central Wyoming. Pages 151-154 *in* S. G. Lucas, K. E. Zeigler, and P. E. Kondrashov, editors. Paleogene mammals. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 26.

Pruss, S., M. Fraiser, and D. J. Bottjer. 2004. Proliferation of Early Triassic wrinkle structures: implications for environmental stress following the end-Permian mass extinction. *Geology* 32(5):461-464.

Rautman, C. A. 1975. Sedimentology of the "Lower Sundance" Formation (Upper Jurassic) Wyoming region. *Wyoming Geological Association Earth Science Bulletin* 8(4):1-16.

Read, C. B. 1933. Fossil floras of Yellowstone National Park. Part I. Coniferous woods of Lamar River flora. *Carnegie Institution of Washington Publication* 416:1-19.

Reaugh, A. B. 1980. Cambrian acritarchs from the Gallatin, Gros Ventre and Death Canyon formations, Sublette Co., Wyoming. *Palynology* 4:248.

Reeside, J. B., Jr. 1923. A new fauna from the Colorado Group of southern Montana. Pages 25-33 *in* Contributions to general geology, 1923. U.S. Geological Survey, Washington, DC. Professional Paper 132.

Reeside, J. B., Jr. 1927a. Cephalopods from the lower part of the Cody Shale of Oregon Basin, Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 150-A. Available online at: http://pubs.er.usgs.gov/publication/pp150. Accessed March 2013.

Reeside, J. B., Jr. 1927b. The cephalopods of the Eagle Sandstone and related formations in the Western Interior of the United States. U.S. Geological Survey, Washington, DC. Professional Paper 151.

Reeside, J. B., Jr., and W. A. Cobban. 1960. Studies of the Mowry shale (Cretaceous) and contemporary formations in the United States and Canada. U.S. Geological Survey, Washington, DC. Professional Paper 355. Available online at: http://pubs.er.usgs.gov/publication/pp355. Accessed February 2013.

Reeves, C. C., Jr. 1964. New Cambrian, Ordovician, Devonian, and Mississippian measured sections, west flank Teton Mountains, Wyoming. *Mountain Geologist* 1(4):213-225.

Resser, C. E. 1935. Nomenclature of some Cambrian trilobites. *Smithsonian Miscellaneous Collections* 93(5):1-46.

Resser, C. E. 1937. Third contribution to nomenclature of Cambrian trilobites. *Smithsonian Miscellaneous Collections* 95(22).

Resser, C. E. 1938. Fourth contribution to nomenclature of Cambrian fossils. *Smithsonian Miscellaneous Collections* 97(10).

Resser, C. E. 1942a. Fifth contribution to nomenclature of Cambrian fossils. *Smithsonian Miscellaneous Collections* 101(15).

Resser, C. E. 1942b. New Upper Cambrian trilobites. *Smithsonian Miscellaneous Collections* 103(5).

Richards, P. W. 1955. Geology of the Bighorn Canyon-Hardin area, Montana and Wyoming. U.S. Geological Survey, Washington, DC. Bulletin 1026. Available online at: http://pubs.er.usgs.gov/publication/b1026. Accessed February 2013.

Richmond, G. M. 1964. Glacial geology of the West Yellowstone Basin and adjacent parts of Yellowstone National Park. Pages 223-236 *in* The Hebgen Lake, Montana, earthquake of August 17, 1959. U.S. Geological Survey, Washington, DC. Professional Paper 435. Available online at: http://pubs.er.usgs.gov/publication/pp435. Accessed April 2013.

Richmond, G. M. 1969. Development and stagnation of the last Pleistocene icecap in the Yellowstone Lake Basin, Yellowstone National Park, USA. *Eiszeitalter und Gegenwart* 20:196-203.

Richmond, G. M. 1973a. Surficial geologic map of the Huckleberry Mountain quadrangle, Yellowstone National Park and adjoining area, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Geologic Investigations Map 639. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9417.htm. Accessed April 2013.

Richmond, G. M. 1973b. Surficial geologic map of the West Thumb quadrangle, Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Geologic Investigations Map 643. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9421.htm. Accessed April 2013.

Richmond, G. M. 1973c. Surficial geologic map of the Grassy Lake Reservoir quadrangle, Yellowstone National Park and adjoining area, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Geologic Investigations Map 644. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9422.htm. Accessed April 2013.

Richmond, G. M. 1973d. Surficial geologic map of the Warm Butte quadrangle, Yellowstone National Park and adjoining area, Idaho and Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Geologic Investigations Map 645. Scale 1:62,500. Available online at:

http://ngmdb.usgs.gov/Prodesc/proddesc_9423.htm. Accessed April 2013.

Richmond, G. M. 1974. Surficial geologic map of the Frank Island quadrangle, Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Investigations Series Map 642. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9420.htm. Accessed April 2013.

Richmond, G. M. 1977. Surficial geologic map of the Canyon Village quadrangle, Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Investigations Series Map 652. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9430.htm. Accessed April 2013.

Richmond, G. M. 1986. Stratigraphy and chronology of glaciations in Yellowstone National Park. *Quaternary Science Reviews* 5:83-98.

Richmond, G. M. 1987. Geology and evolution of the Grand Canyon of the Yellowstone, Yellowstone National Park, Wyoming. Pages 155-160 *in* S. S. Beus, editor. Rocky Mountain Section of the Geological Society of America. Geological Society of America, Boulder, CO. Centennial Field Guide 2.

Richmond, G. M. and J. P. Bradbury. 1982. Environmental amelioration at beginning of early/middle Wisconsin interstadial about 54,000 B.P. in Yellowstone National Park. Program and Abstracts. *American Quaternary Association Conference* 7:156.

Richmond, G. M. and K. L. Pierce. 1971a. Surficial geologic map of the Two Ocean Pass quadrangle, Yellowstone National Park and adjoining area, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Geologic Investigations Map 635. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9413.htm. Accessed April 2013.

Richmond, G. M. and K. L. Pierce. 1971b. Surficial geologic map of the Mount Hancock quadrangle, Yellowstone National Park and adjoining area, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Geologic Investigations Map 636. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9414.htm. Accessed April 2013.

Richmond, G. M. and K. L. Pierce. 1972. Surficial geologic map of the Eagle Peak quadrangle, Yellowstone National Park and adjoining area, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Geologic Investigations Map 637. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9415.htm. Accessed April 2013.

Richmond, G. M. and H. A. Waldrop. 1972. Surficial geologic map of the Pelican Cone quadrangle, Yellowstone National Park and adjoining area, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Geologic Investigations Map 638. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9416.htm. Accessed April 2013.

Richmond, G. M. and H. A. Waldrop. 1975. Surficial geologic map of the Norris Junction quadrangle, Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Investigations Series Map 650. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9428.htm. Accessed April 2013.

Richmond, G. M., W. Mullenders, and M. Coremans. 1978. Climatic implications of two pollen analyses from newly recognized rocks of latest Pliocene age in the Washburn Range, Yellowstone National Park, Wyoming. U.S. Geological Survey, Reston, VA. Bulletin 1455. Available online at: http://pubs.er.usgs.gov/publication/b1455. Accessed March 2013.

Rieppel, O. 1998. *Corosaurus alcovensis* Case and the phylogenetic interrelationships of Triassic stem-group Sauropterygia. *Zoological Journal of the Linnean Society* 124(1):1-41.

Roberts, S. V. and D. W. Burbank. 1993. Uplift and thermal history of the Teton Range (northwestern Wyoming) defined by apatite fission-track dating. *Earth and Planetary Science Letters* 118(1-4):295-309.

Robison, S. F., M. E. Thompson, J. K. Huang, T. B. Thompson, A. R. Tedrow, and P. Barrett. 2011. Preliminary report of the first recorded Late Pleistocene mammal tracks from southeast Idaho and management implications. *Geology Studies* 49A:28.

Rodriguez, J. and R. C. Gutschick. 1968. *Productina*, *Cyrtina*, and *Dielasma* (Brachiopoda) from the Lodgepole Limestone (Mississippian) of southwestern Montana. *Journal of Paleontology* 42(4):1027-1032.

Rohrer, W. L. and J. D. Obradovich. 1969. Age and stratigraphic relations of the Tepee Trail and Wiggins formations, northwestern Wyoming. U.S. Pages B57-B62 *in* Geological Survey research 1969, Chapter B. Geological Survey, Washington, DC. Professional Paper 650-B. Available online at: http://pubs.er.usgs.gov/publication/pp650B. Accessed April 2013.

Ruppel, E. T. 1972. Geology of pre-Tertiary rocks in the northern part of Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 729-A. Scale 1:62,500. Available online at: http://pubs.er.usgs.gov/publication/pp729A. Accessed April 2013.

Ryer, T. A. 1977. Age of Frontier Formation in north-central Utah. *AAPG Bulletin* 61(1):112-116.

Sablock, J. M. and P. E. Sablock. 1988. A new fossil locality in southwestern Montana, Late Jurassic Swift Formation. Abstracts with Programs. *Geological Society of America* 20(6):466.

Sahni, A. 1972. The vertebrate fauna of the Judith River Formation, Montana. *Bulletin of the American Museum of Natural History* 147:321-412. Available online at: http://hdl.handle.net/2246/1099. Accessed April 2013.

Saltzman, M. R. 1998. Trilobite mass extinction event at the boundary of the

Elvinia and *Taenicephalus* biozones, Yellowstone National Park. Pages 154-157 *in* V. L. Santucci and L. McClelland, editors. National Park Service Paleontological Research 3. NPS Technical Report NPS/NRGRD/GRDTR-98/01. Available online at: http://www.nature.nps.gov/geology/paleontology/pub/grd3_3/yell1.htm. Accessed April 2013.

Saltzman, M. R. 1999. Upper Cambrian carbonate platform evolution, *Elvinia* and *Taenicephalus* zones (pterocephaliid-ptychaspid biomere boundary), northwestern Wyoming. *Journal of Sedimentary Research* 69(4):926-938.

Saltzman, M. R., J. P. Davidson, P. Holden, B. Runnegar, and K. C. Lohmann. 1995. Sea-level-driven changes in ocean chemistry at an Upper Cambrian extinction horizon. *Geology* 23(10):893-896.

Sanborn, W. B. 1951. Groves of stone: fossil forests of the Yellowstone region. *Pacific Discovery* 4(3):18-25.

Sandberg, C. A. 1965. Nomenclature and correlation of lithologic subdivisions of the Jefferson and Three Forks formations of southern Montana and northern Wyoming. U.S. Geological Survey, Washington, DC. Bulletin 1194-N:N1-N18. Available online at: http://pubs.er.usgs.gov/publication/b1194N. Accessed February 2013.

Sando, W. J. 1975a. Stratigraphic sections of the Madison Limestone and Amsden Formation, west flank of the Bighorn Basin, Wyoming. Pages 129-137 *in* F. A. Exum and G. R. George, editors. Geology and mineral resources of the Bighorn Basin. Wyoming Geological Association, Casper, WY. Guidebook 27.

Sando, W. J. 1975b. Coelenterata of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey Professional Paper 848-C. Available online at: http://pubs.er.usgs.gov/publication/pp848C. Accessed February 2013.

Sando, W. J. 1977. Stratigraphy of the Madison Group (Mississippian) in the northern part of the Wyoming-Idaho Overthrust Belt and adjacent areas. Pages 173-177 *in* E. L. Heisey, D. E. Lawson, E. R. Norwood, P. H. Wach, and L. A. Hale, editors. Rocky Mountain Thrust Belt: geology and resources. Wyoming Geological Association, Casper, WY. Guidebook 29.

Sando, W. J. 1988. Madison Limestone (Mississippian) paleokarst: a geologic synthesis. Pages 256-277 *in* N. P. James and P. W. Choquette, editors. Paleokarst. Springer-Verlag, New York, NY.

Sando, W. J. and J. T. Dutro, Jr. 1974. Type sections of Madison Group (Mississippian) and its subdivisions in Montana. U.S. Geological Survey, Washington, DC. Professional Paper 842. Available online at: http://pubs.er.usgs.gov/publication/pp842. Accessed February 2013.

Sando, W. J., M. Gordon, Jr., and J. T. Dutro, Jr. 1975. Stratigraphy and geologic history of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 848-A. Available online at:

http://pubs.er.usgs.gov/publication/pp848A. Accessed February 2013.

Santiago-Blay, J. A., C. C. Labandeira, L. Pribyl, C. Hotton, and L. D. Martin. 2001. The Sundance insect fauna (Middle Jurassic) of northern Wyoming and southern Montana. Abstracts with Programs. *Geological Society of America* 33(6):266.

Santucci, V. L. 1998. The Yellowstone paleontological survey. Yellowstone Center for Resources, National Park Service, Yellowstone National Park, WY. YCR-NR-91-1.

Santucci, V. L., J. Kenworthy, and R. Kerbo. 2001. An inventory of paleontological resources associated with National Park Service caves. NPS Geological Resources Division, Denver, CO. Technical Report NPS/NRGRD/GRDTR-01/02. TIC# D-2231. Available online at: http://www.nature.nps.gov/geology/paleontology/pub/cavepaleo.pdf. Accessed February 2013.

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring *in situ* paleontological resources. Pages 189-204 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, CO.

Saperstone, H. I. 1986. Description of measured sections of the Pennsylvanian Quadrant Sandstone, Beaverhead, Madison, and Park counties, southwestern Montana. U.S. Geological Survey, Reston, VA. Open-File Report 86-182. Available online at: http://pubs.er.usgs.gov/publication/ofr86182. Accessed April 2013.

Saperstone, H. I. and F. G. Ethridge. 1984. Origin and paleotectonic setting of the Pennsylvanian Quadrant Sandstone, southwestern Montana. Pages 309-331 *in* J. Goolsby and D. Morton, editors. The Permian and Pennsylvanian geology of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 35.

Sartenaer, P. and C. A. Sandberg. 1974. New North American species of upper Famennian rhynchonellid genus *Megalopterorhynchus* from Lost River Range, Idaho. *Journal of Paleontology* 48(4):756-765.

Schaeffer, B. and C. Patterson. 1984. Jurassic fishes from the western United States, with comments on Jurassic fish distribution. American Museum Novitates 2796. Available online at: http://hdl.handle.net/2246/5270. Accessed February 2013.

Schmude, D. C. 2000. Interplay of paleostructure, sedimentation and preservation of Middle Jurassic rocks, Big Horn Basin, Wyoming. *Mountain Geologist* 37(4):145-155.

Schram, F. R. 1971. *Litogaster turnbullensis* (sp. nov.): a lower Triassic glypheid decapod crustacean from Idaho. *Journal of Paleontology* 45(3):534-537.

Schroeder, M. L. 1968. Lower Triassic foraminifera from the Thaynes Formation in southeastern Idaho and western Wyoming. *Micropaleontology* 14(1):73-82.

Schubert, J. K. and D. J. Bottjer. 1995. Aftermath of the Permian-Triassic mass extinction event: paleoecology of Lower

Triassic carbonates in the Western USA. *Palaeogeography, Palaeoclimatology, Palaeoecology* 116(1-2):1-39.

Schwab, K. W. 1977. Palynology of the lower Thermopolis and Cloverly formations (Albian), Gros Ventre Mountains, Wyoming. *Palynology* 1:176.

Schwimmer, D. R. 1975. Quantitative taxonomy and biostratigraphy of middle Cambrian trilobites from Montana and Wyoming. *Journal of the International Association for Mathematical Geology* 7(2):149-166.

Scott, H. W. 1935. Some Carboniferous stratigraphy in Montana and northwestern Wyoming. *Journal of Geology* 43(8, part 2):1011-1032.

Scott, R. W. and D. O. Asquith. 1972. Dendroid graptolites from the Bighorn Dolomite (Ordovician), southeastern Idaho. *Contributions to Geology* 11(2):73-82.

Scott, R. W., Holbrook, J. M. Evetts, and M. J. Oboh-Ikuenobe, F. E. 2001. Albian-Cenomanian depositional cycles transgressed from Chihuahua Trough to Western Interior. Pages 221-228 *in* S. G. Lucas and D. S. Ulmer-Scholle, editors. Geology of the Llano Estacado. Guidebook - New Mexico Geological Society 52. New Mexico Geological Society, Socorro, NM. Guidebook 48.

Scott, R. W., F. E. Oboh-Ikuenobe, D. G. Benson, Jr., and J. M. Holbrook. 2009. Numerical age calibration of the Albian/Cenomanian boundary. *Stratigraphy* 6(1):17-32.

Shanks, W. C., III, J. C. Alt, and L. A. Morgan. 2007. Geochemistry of sublacustrine hydrothermal deposits in Yellowstone Lake—hydrothermal reactions, stable-isotope systematics, sinter deposition, and spire formation. Pages 205-234 *in* L. A. Morgan, editor. Integrated geoscience studies in the greater Yellowstone area: volcanic, tectonic, and hydrothermal processes in the Yellowstone geoecosystem. U.S. Geological Survey, Reston, VA. Professional Paper 1717. Available online at: http://pubs.er.usgs.gov/publication/pp1717 Accessed April 2013.

Shaw, A. B. 1954. The Cambrian and Ordovician of the Pryor Mountains, Montana, and northern Bighorn Mountains, Wyoming. Pages 32-37 *in* P. W. Richards, editor. Pryor Mountains-northern Bighorn Basin, Montana, September 9-11, 1954. Billings Geological Society, Billings, MT. Guidebook 5.

Sheldon, R. P. 1956. Stratigraphy of the Phosphoria Formation in the Jackson Hole region, Wyoming. Pages 66-69 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Sheldon, R. P. 1963. Physical stratigraphy and mineral resources of Permian rocks in western Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 313-B. Available online at: http://pubs.er.usgs.gov/publication/pp313B. Accessed March 2013.

Sherrington, P. F. and A. Lord. 1975. On *Lophocythere* (*Neurocythere*) *minuta*

(Peterson). *Stereo-Atlas of Ostracod Shells* 2(4).

Shultz, C. H. 1962. Petrology of Mt. Washburn, Yellowstone National Park, Wyoming. Dissertation. Ohio State University, Columbus, OH.

Shurr, G. W. and D. D. Rice. 1986. Paleotectonic controls on deposition of the Niobrara Formation, Eagle Sandstone, and equivalent rocks (Upper Cretaceous), Montana and South Dakota. Pages 193-211 *in* J. A. Peterson, editor. Paleotectonics and sedimentation in the Rocky Mountain region, United States. American Association of Petroleum Geologists, Tulsa, OK. Memoir 41.

Simmons, S. P. and P. A. Scholle. 1990. Late Paleozoic uplift and sedimentation, northeast Bighorn Basin, Wyoming. Pages 39-55 *in* R. W. Specht, editor. Wyoming sedimentation and tectonics. Wyoming Geological Association, Casper, WY. Guidebook 41.

Smedes, H. W. and H. J. Prostka. 1972. Stratigraphic framework of the Absaroka Volcanic Supergroup in the Yellowstone National Park region. U.S. Geological Survey, Washington, DC. Professional Paper 729-C. Available online at: http://pubs.er.usgs.gov/publication/pp729C. Accessed April 2013.

Smedes, H. W., J. W. M'Gonigle, and H. J. Prostka. 1989. Geologic map of the Two Ocean Pass Quadrangle, Yellowstone National Park and vicinity, Wyoming. U.S. Geological Survey, Reston, VA. Geologic Quadrangle Map 1667. Scale 1:62,500. Available online at: http://pubs.er.usgs.gov/publication/gq1667 Accessed April 2013.

Smith, D. L. 1982. Waulsortian bioherms in the Paine Member of the Lodgepople Limestone (Kinderhookian) of Montana, U.S.A. Pages 51-64 *in* K. Bolton, H. R. Lane, and D. V. LeMone, editors. Symposium on the paleoenvironmental setting and distribution of the Waulsortian facies. El Paso Geological Society, El Paso, TX.

Smith, R. B. and L. W. Braile. 1984. Crustal structure and evolution of an explosive silicic volcanic system at Yellowstone National Park. Pages 96-109 *in* Explosive volcanism: inception, evolution, and hazards. National Academy Press, Washington, DC. Studies in geophysics.

Smith, T. M. and S. L. Dorobek. 1993. Early Mississippian climate change: isotopic evidence from meteoric calcite. *Geophysical Monograph* 78:77-88.

Smith, R. B., J. O. D. Byrd, and D. D. Susong. 1993. The Teton Fault, Wyoming: seismotectonics, Quaternary history, and earthquake hazards. Pages 628-667 *in* A. W. Snoke, J. R. Steidtmann, and S. M. Roberts, editors. Geology of Wyoming. Geological Survey of Wyoming, Laramie, WY. Memoir 5.

Snoke, A. W. 1993. Geologic history of Wyoming within the tectonic framework of the North American Cordillera. Pages 2-56 *in* A. W. Snoke, J. R. Steidtmann, and S. M. Roberts, editors. Geology of Wyoming. Geological Survey of Wyoming, Laramie, WY. Memoir 5.

Sohn, I. G. 1975. Mississippian Ostracoda of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 848-G. Available online at: http://pubs.er.usgs.gov/publication/pp848G. Accessed February 2013.

Sokolov, D. W. 1914. Kreideinoceramen des russischen Sachalin. *Mémoires du Comité géologique. N. Sér., Liv.* 83.

Solien, M. A. 1979. Conodont biostratigraphy of the Lower Triassic Thaynes Formation, Utah. *Journal of Paleontology* 53(2):276-306.

Solien, M. A., W. A. Morgan, and D. L. Clark. 1979. Structure and stratigraphy of a Lower Triassic conodont locality, Salt Lake City, Utah. *Geology Studies* 26(3):165-177.

Spangler, E., J. Hauer, J. Staub, M. H. Hofmann, and M. S. Hendrix. 2011. Deltaic sandstones in the Upper Cretaceous Eagle Formation: south central Montana. Abstracts. AAPG Meeting, Rocky Mountain Section 2011:unpaginated. Available online at: http://www.searchanddiscovery.com/abstracts/pdf/2011/rocky/abstracts/ndx_spangler.pdf. Accessed March 2013.

Specht, R. W. and R. L. Brenner. 1979. Storm-wave genesis of bioclastic carbonates in Upper Jurassic epicontinental mudstones, east-central Wyoming. *Journal of Sedimentary Petrology* 49(4):1307-1321.

Stamm, R. G. and B. R. Wardlaw. 2003. Conodont faunas of the late Middle Pennsylvanian (Desmoinesian) lower Kittanning cyclothem, U.S.A. Pages 95-121 *in* C. B. Cecil and N. T. Edgar, editors. Climate controls on stratigraphy. Society for Sedimentary Geology, Tulsa, OK. Special Publication 77.

Stanley, G. and R. Burke. 2000. The Mississippian Lodgepole Limestone (Madison Group), Little Belt Mountains, central Montana: lower Mississippian carbonate rocks and reef-like buildups. Pages 197-208 *in* S. Roberts and D. Winston, editors. Geologic field trips, western Montana and adjacent areas. Geological Society of America, Rocky Mountain Section, Boulder, CO. Guidebook 52.

Stanton, T. W. 1899. Mesozoic fossils. Pages 600-650 *in* Geology of the Yellowstone national park. U.S. Geological Survey, Washington, DC. Monograph 32. Available online at: http://archive.org/details/geologyofyellows00hagu. Accessed March 2013.

Steele, T. E. and E. A. Hadly. 2002. Ecological differences between two late Holocene sites from Yellowstone National Park, Wyoming, USA. *Journal of Vertebrate Paleontology* 22(supplement to 3):111A.

Steele, T. and E. Hadly. 2003. Paleoecology of small mammals from Waterfall Locality, Yellowstone National Park, Wyoming. *Journal of Vertebrate Paleontology* 23(supplement to 3):100A-101A.

Stefos, M. M. and R. B. Jorstad. 2002. An initial investigation of Eocene pollen from northern Yellowstone National Park,

Wyoming, USA. Abstracts with Programs. *Geological Society of America* 34(2):87.

Stephenson, G. R. 1965. New lower Triassic locality in southeastern Idaho. Page 348 *in* Abstracts for 1964. Geological Society of America, Boulder, CO. *Special Paper* 82.

Steventon, R. L. and J. E. Kutzbach. 1987. University of Wisconsin radiocarbon dates XXIV. *Radiocarbon* 29(3):397-415.

Steventon, R. L. and J. E. Kutzbach. 1988. University of Wisconsin radiocarbon dates XXV. *Radiocarbon* 30(3):367-383.

Stewart, J. C. 1958. Geology of the Dryhead-Garvin Basin, Bighorn and Carbon counties, Montana. Montana Bureau of Mines and Geology, Butte, MT. *Special Publication* 17.

Stewart, J. D. and M. Hakel. 2006. Ichthyofauna of the Mowry Shale (early Cenomanian) of Wyoming. Pages 161-163 *in* S. G. Lucas and R. M. Sullivan, editors. Late Cretaceous vertebrates from the Western Interior. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 35.

Stewart, J. D., S. A. Bilbey, D. J. Chure, and S. K. Madsen. 1994. Vertebrate fauna of the Mowry Shale (Cenomanian) in northeastern Utah. *Journal of Vertebrate Paleontology* 14(supplement to 3):47A.

Stone, R. and C. F. Vondra. 1972. Sediment dispersal patterns of oolitic calcarenite in the Sundance Formation (Jurassic), Wyoming. *Journal of Sedimentary Petrology* 42(1):227-229.

Storrs, G. W. 1991. Anatomy and relationships of *Corosaurus alcovensis* (Diapsida: Sauropterygia) and the Triassic Alcova Limestone of Wyoming. Bulletin of the Peabody Museum of Natural History Yale University 44. Available online at: http://www.peabody.yale.edu/sites/default/files/documents/scientific-publications/ypmB44_1991.pdf. Accessed June 2013.

Strickland, J. W. 1956. Mississippian stratigraphy, western Wyoming. Pages 51-57 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Strickland, L. E., R. S. Thompson, and K. H. Anderson. 2001. USGS/NOAA North American packrat midden database data dictionary. U.S. Geological Survey, Reston, VA. Open File Report 01-022. Available online at: http://pubs.er.usgs.gov/publication/ofr0122. Accessed March 2013.

Sturchio, N. C., K. L. Pierce, M. T. Murrell, and M. L. Sorey. 1994. Uranium-series ages of travertines and timing of the last glaciation in the northern Yellowstone area, Wyoming–Montana. *Quaternary Research* 41(3):265-277.

Sundell, K. A. and J. G. Eaton. 1982. Stratigraphic relations within the southeastern Absaroka volcanic sequence, northwestern Wyoming. Pages 65-71 *in* S. G. Reid and D. J. Foote, editors. Geology of Yellowstone Park area. Wyoming Geological Association, Casper, WY. Guidebook 33.

Sundell, K. A., P. N. Shive, and J. G. Eaton. 1984. Measured sections, magnetic

polarity and biostratigraphy of the Eocene Wiggins, Tepee Trail and Aycross formations within the southeastern Absaroka Range, Wyoming. *Earth Science Bulletin* 17:1-48.

Sutton, J. F. and C. C. Black. 1972. Oligocene and Miocene deposits of Jackson Hole, Wyoming. Pages 73-79 *in* Field conference on Tertiary biostratigraphy of southern and western Wyoming. Adelphi University, Department of Biology, Garden City, New York.

Swain, F. M. 1998. Ostracoda from the Swift Formation (Upper Jurassic) of Montana and Wyoming. *Revista Espanola De Micropaleontologia* 30(1):139-158.

Swain, F. M., Jr. and J. A. Peterson. 1951. Ostracoda from the Upper Jurassic Redwater shale member of the Sundance Formation at the type locality in South Dakota. *Journal of Paleontology* 25(6):796-807.

Swain, F. M., Jr. and J. A. Peterson. 1952. Ostracodes from the upper part of the Sundance Formation of South Dakota, Wyoming, and southern Montana. U.S. Geological Survey, Washington, DC. Professional Paper 243-A. Available online at: http://pubs.er.usgs.gov/usgspubs/pp/pp243A Accessed February 2013.

Tang, C. M. 1997. Evolutionary paleoecology of Jurassic hard-substrate assemblages from the U. S. Western Interior. Abstracts with Programs. *Geological Society of America* 29(6):107.

Theriot, E. C., S. C. Fritz, C. Whitlock, and D. J. Conley. 2006. Late Quaternary rapid morphological evolution of an endemic diatom in Yellowstone Lake, Wyoming. *Paleobiology* 32(1):38-54.

Thom, W. T., Jr., G. M. Hall, C. H. Wegemann, and G. F. Mouton. 1935. Geology of Big Horn County and the Crow Indian Reservation, Montana, with special reference to the Water, Coal, Oil and Gas Resources. U.S. Geological Survey, Washington, DC. Bulletin 856. Available online at: http://pubs.er.usgs.gov/publication/b856. Accessed February 2013.

Thompson, M. L. and H. W. Scott. 1941. Fusulinids from the type sections of the lower Pennsylvanian Quadrant Formation. *Journal of Paleontology* 15(4):349-353.

Thornburg, J. B. 1989. Depositional environments of the Tosi Chert Member of the Permian Phosphoria Formation in southwest Montana. Abstracts with Programs. *Geological Society of America* 21(6):A174-A175.

Throckmorton, G. S., J. A. Hopson, and P. Parks. 1981. A redescription of *Toxolophosaurus cloudi* Olson, a Lower Cretaceous herbivorous sphenodontid reptile. *Journal of Paleontology* 55(3):586-597.

Tiller, C. C. and K. R. Kelts. 1994. Post-glacial environmental variability within large lake basins of the Yellowstone-Grand Teton region, WY, USA. Program and Abstracts. *American Quaternary Association Conference* 13:169.

Tillman, R. W. and H. Dresser. 1976. Subtidal trace fossils, Muddy and Frontier

formations, Wyoming and Montana. *AAPG Bulletin* 60(4):727-728.

Tohill, B. and M. D. Picard. 1966. Stratigraphy and petrology of Crow Mountain Sandstone Member (Triassic), Chugwater Formation , northwestern Wyoming. *Bulletin of the American Association of Petroleum Geologists* 50(12):2547-2565.

Tracy, K. H. 2003. Grand Teton National Park Paleontological Survey. Thesis. Georgia College and State University. Milledgeville, GA.

Trumbull, C. B. and M. V. Connely. 2010. New ichnotaxa from the Mowry Shale of Wyoming may be vertebrate in origin. Abstracts with Programs. *Geological Society of America* 42(3):41-42.

Tschudy, R. H., B. D. Tschudy, S. Van Loenen, and G. Doher. 1980. Illustrations of plant microfossils from the Morrison Formation. I. Plant microfossils from the Brushy Basin Member. U.S. Geological Survey, Reston, VA. Open-File Report 81-35. Available online at: http://pubs.er.usgs.gov/publication/ofr8135. Accessed January 2012.

Tschudy, R. H., B. D. Tschudy, and S. Van Loenen. 1981. Illustrations of plant microfossils from the Morrison Formation. II. Plant microfossils from the Westwater Canyon Member. U.S. Geological Survey, Reston, VA. Open-File Report 81-1154. Available online at: http://pubs.er.usgs.gov/publication/ofr811154. Accessed January 2012.

Tschudy, R. H., B. D. Tschudy, and S. D. Van Loenen. 1988a. Illustrations of plant microfossils from the Morrison Formation. III. Plant microfossils from the Recapture Member. U.S. Geological Survey, Reston, VA. Open-File Report 88-234. Available online at: http://pubs.er.usgs.gov/publication/ofr88234. Accessed January 2012.

Tschudy, R. H., B. D. Tschudy, and S. D. Van Loenen. 1988b. Illustrations of plant microfossils from the Morrison Formation. IV. Plant microfossils from the Salt Wash Member. U.S. Geological Survey, Reston, VA. Open-File Report 88-235. Available online at: http://pubs.er.usgs.gov/publication/ofr88235. Accessed January 2012.

Turner, C. E. and F. Peterson. 2004. Reconstruction of the Upper Jurassic Morrison Formation extinct ecosystem—a synthesis. *Sedimentary Geology* 167(3-4):309-355.

Tweet, J. S., V. L. Santucci, and A. P. Hunt. 2012. An inventory of packrat (*Neotoma* spp.) middens in National Park Service areas. Pages 355-368 *in* A. P. Hunt, J. Milàn, S. G. Lucas, and J. A. Spielmann, editors. Vertebrate coprolites. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 57.

Tysdal, R. G. 1976. Paleozoic and Mesozoic stratigraphy of the northern part of the Ruby Range, southwestern Montana. U.S. Geological Survey, Washington, DC. Bulletin 1405-I. Available online at: http://pubs.er.usgs.gov/publication/b1405I Accessed April 2013.

Tysdal, R. G. 1991. Depositional environments for strata of composite section of Frontier Formation, Madison

Range, southwestern Montana. U.S. Geological Survey, Reston, VA. Bulletin 1949. Available online at: http://pubs.er.usgs.gov/publication/b1949. Accessed April 2013.

Tysdal, R. G. 2000. Revision of Cretaceous Slim Sam Formation, Elkhorn Mountains area, Montana. Pages B1-B8 *in* Tysdal, R. G. Revision of middle Proterozoic Yellowjacket Formation, central Idaho, and revision of Cretaceous Slim Sam Formation, Elkhorn Mountains area, Montana. U.S. Geological Survey, Reston, VA. Professional Paper 1601-A, B. Available online at: http://pubs.er.usgs.gov/publication/pp1601AB. Accessed April 2013.

Tysdal, R. G. and D. J. Nichols. 1991. Biostratigraphic correlation of Santonian and Campanian formations in the northwestern part of Yellowstone National Park, and the Madison Range and Livingston area of southwestern Montana. Pages 11-19 *in* T. S. Dyman, J. C. Haley, W. J. Perry, Jr., R. G. Tysdal, D. J. Nichols, and W. A. Cobban. Contributions to Late Cretaceous stratigraphy and paleontology, western Montana. U.S. Geological Survey, Reston, VA. Bulletin 1962. Available online at: http://pubs.er.usgs.gov/publication/b1962. Accessed April 2013.

Tysdal, R. G., T. S. Dyman, D. J. Nichols, and W. A. Cobban. 1990. Correlation chart of Frontier Formation from Greenhorn Range, southwestern Montana, to Mount Everts in Yellowstone National Park, Wyoming. U.S. Geological Survey, Reston, VA. Miscellaneous Field Studies Map 2116. Available online at: http://pubs.er.usgs.gov/publication/mf2116. Accessed April 2013.

Upshaw, C. F. 1963. Occurrences of *Aequitriradites* in the Upper Cretaceous of Wyoming. *Micropaleontology* 9(4):427-431.

Upshaw, C. F. 1964. Palynological zonation of the Upper Cretaceous Frontier Formation near Dubois, Wyoming. Pages 153-168 *in* Palynology in oil exploration—A symposium. Society of Economic Paleontologists and Mineralogists, Tulsa, OK. Special Publication 11.

U.S. Geological Survey. 1972. Geologic map of Yellowstone National Park. U.S. Geological Survey, Washington, DC. Scale 1:125,000. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9475.htm. Accessed April 2013.

Uygur, K. and M. D. Picard. 1985. Mesozoic stratigraphy of Uinta Basin, northeast Utah. Pages 21-37 *in* M. D. Picard, editor. Geology and energy resources, Uinta Basin of Utah. Utah Geological Association Publication 12.

van Tuinen, M. and E. A. Hadly. 2003. Tracking avian abundance through the Medieval Warm Period and Little Ice Age. *Congress of the International Union for Quaternary Research* 16:100.

Verville, G. J. 1957. Wolfcampian fusulinids from the Tensleep sandstone in the Big Horn Mountains, Wyoming. *Journal of Paleontology* 31(2):349-352.

Verville, G. J., G. A. Sanderson, and B. D. Rea. 1970. Missourian fusulinids from the Tensleep sandstone, Bighorn mountains,

Wyoming. *Journal of Paleontology* 44(3):478-479.

Verville, G. J., G. A. Sanderson, J. F. Baesemann, and G. L. Hampton, III. 1990. Pennsylvanian fusulinids from the Beaverhead Mountains, Morrison Lake area, Beaverhead County, Montana. *Mountain Geologist* 27(2):47-55.

Veysey, J., II, B. W. Fouke, M. T. Kandianis, T. J. Schickel, R. W. Johnson, and N. Goldenfeld. 2008. Reconstruction of water temperature, pH, and flux of ancient hot springs from travertine depositional facies. *Journal of Sedimentary Research* 78(2):69-76.

Vice, M. A. and J. E. Utgaard. 1989. Depositional environments in the Mission Canyon Limestone (Madison Group, Mississippian), northern Bighorn Basin region, Montana and Wyoming. Pages 55-64 *in* D. E. French and R. F. Grabb, editors. Montana Geological Society 1989 field conference guidebook: Montana centennial edition: Geologic resources of Montana, Volume I. Montana Geological Society, Bozeman, MT. Field Conference 1989(1).

Vuke, S. M. 1984. Depositional environments of the Early Cretaceous Western Interior seaway in southwestern Montana and the northern United States. Pages 127-144 *in* D. F. Stott and D. J. Glass, editors. The Mesozoic of middle North America. Canadian Society of Petroleum Geologists, Calgary, Canada. Memoir 9.

Waddington, J. C. B. and H. E. Wright, Jr. 1970. Late-Quaternary vegetational changes on the east side of Yellowstone Park, Wyoming. Program and Abstracts. *American Quaternary Association Conference* 1:139-140.

Waddington, J. C. B. and H. E. Wright, Jr. 1974. Late Quaternary vegetational changes on the east side of Yellowstone Park, Wyoming. *Quaternary Research* 4(2):175-184.

Wahl, W. R., Jr. 2004. A large specimen of the genus *Eryma* (Crustacea, Decopoda) from the latest Callovian of North America. Abstracts with Programs. *Geological Society of America* 36(5):363.

Wahl, W. R. 2005. A hybodont shark from the Redwater Shale Member, Sundance Formation (Jurassic), Natrona County, Wyoming. *Paludicola* 5(1):15-19.

Wahl, W. R., M. Ross, and J. A. Massare. 2007. Rediscovery of Wilbur Knight's *Megalneusaurus rex* site: new material from an old pit. *Paludicola* 6(2):94-104.

Walcott, C. D. 1897. Note on the genus *Lingulepis*. *American Journal of Science* (4th series)3:404-405.

Walcott, C. D. 1899. Cambrian fossils. Pages 440-478 *in* Geology of the Yellowstone national park. U.S. Geological Survey, Washington, DC. Monograph 32. Available online at: http://archive.org/details/geologyofyellows00hagu. Accessed March 2013.

Walcott, C. D. 1902. Cambrian Brachiopoda: *Acrotreta*; *Linnarssonella*; *Obolus*; with descriptions of new species. *U.S. National Museum Proceedings* 25:577-612.

Walcott, C. D. 1905. Cambrian Brachiopoda, with descriptions of new genera and

species. *U.S. National Museum Proceedings* 28:227-337.

Walcott, C. D. 1912. Cambrian Brachiopoda. U.S. Geological Survey, Washington, D.C. Monograph 51. Available online at: http://archive.org/details/cambrianbrachiop00walc. Accessed March 2013.

Waldrop, H. A. 1975a. Surficial geologic map of the West Yellowstone quadrangle, Yellowstone National Park and adjoining area, Montana, Wyoming, and Idaho. U.S. Geological Survey, Washington, DC. Miscellaneous Investigations Series Map 648. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9426.htm. Accessed April 2013.

Waldrop, H. A. 1975b. Surficial geologic map of the Old Faithful quadrangle, Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Investigations Series Map 649. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9427.htm. Accessed April 2013.

Waldrop, H. A. and K. L. Pierce. 1975. Surficial geologic map of the Madison Junction quadrangle, Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Investigations Series Map 651. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_9429.htm. Accessed April 2013.

Walton, K. A., B. M. Blake, Jr., B. E. Bodenbender, and T. M. Demko. 2007. Paleobotany of the Sykes Mountain Formation (Early Cretaceous), Bighorn Basin, Shell, Wyoming. Abstracts with Programs. *Geological Society of America* 39(3):10.

Wanless, H. R., R. L. Belknap, and H. Foster. 1955. Paleozoic and Mesozoic rocks of Gros Ventre, Teton, Hoback, and Snake River ranges, Wyoming. Geological Society of America, Boulder, CO. Memoir 63.

Wardlaw, B. R. and J. W. Collinson. 1986. Paleontology and deposition of the Phosphoria Formation. *Contributions to Geology* 24(2):107-142.

Webster, G. D. and S. E. Fox. 1986. A new Devonian species of flexible crinoid from the Lost River Range, east-central Idaho. *Journal of Paleontology* 60(2):405-410.

Wedel, W. R., W. M. Husted, and J. H. Moss. 1968. Mummy Cave: prehistoric record from Rocky Mountains of Wyoming. *Science* 160(3824):184-186.

Weed, W. H. 1892. The fossil forests of the Yellowstone. *School of Mines Quarterly* 13:230-236.

Weigner, M. M. and P. Isaacson. 2012. Late Devonian shelly fossils from the Jefferson Formation, Grandview Canyon, east-central Idaho. Abstracts with Programs. *Geological Society of America* 44(7):88.

Weishampel, D. B., P. M. Barrett, R. A. Coria, J. Le Loueff, Xu X., Zhao X., A. Sahni, E. M. P. Gomani, and C. N. Noto. 2004. Dinosaur distribution. Pages 517-606 *in* D. B. Weishampel, P. Dodson, and H. Osmólska, editors. The Dinosauria (2nd edition). University of California Press, Berkeley, CA.

Wheeler, E. 1993. Fossil dicotyledonous woods of Yellowstone National Park, Wyoming. Pages 113-116 *in* V. Santucci, editor. National Park Service Paleontological Research Technical Report NPS/NRPEFO/NRTR-93/11.

Wheeler, E. 1995. Systematic and ecologic significance of fossil hardwoods: examples from Big Bend National Park, Yellowstone National Park, and Florissant Fossil Beds National Monument. Pages 191-200 *in* V. Santucci and L. McClelland, editors. National Park Service Paleontological Research Technical Report. NPS/NRPO/NRTR-95/16. Available online at: http://www.nature.nps.gov/geology/paleontology/pub/grd2/gsa23.htm. Accessed April 2013.

Wheeler, E. F., R. A. Scott, and E. S. Barghoorn. 1977. Fossil dicotyledonous woods from Yellowstone National Park. I. *Journal of the Arnold Arboretum* 58:280-306. Available online at: http://www.biodiversitylibrary.org/item/41082. Accessed March 2013.

Wheeler, E. F., R. A. Scott, and E. S. Barghoorn. 1978. Fossil dicotyledonous woods from Yellowstone National Park. II. *Journal of the Arnold Arboretum* 59:1-28. Available online at: http://www.biodiversitylibrary.org/item/33622. Accessed March 2013.

Whitlock, C. 1992. Holocene vegetation and climate of Grand Teton National Park and vicinity. Pages 50-54 *in* K. L. Pierce and J. D. Good. Field guide to the Quaternary geology of Jackson Hole, Wyoming. U.S. Geological Survey, Reston, VA. Open-File Report 92-504. Available online at: http://pubs.er.usgs.gov/publication/ofr92504. Accessed March 2013.

Whitlock, C. 1993. Postglacial vegetation and climate of Grand Teton and southern Yellowstone national parks. *Ecological Monographs* 63(2):173-198.

Whitlock, C. and P. J. Bartlein. 1993. Spatial variations of Holocene climatic change in the Yellowstone region. *Quaternary Research* 39(2):231-238.

Whitlock, C., S. C. Fritz, and D. R. Engstrom. 1991. A prehistoric perspective on the northern range. Pages 289-305 *in* R. B. Keiter and M. S. Boyce, editors. The greater Yellowstone ecosystem: redefining America's wilderness heritage. Yale University Press, New Haven, CT.

Whitlock, C., S. Fritz, B. Bracht, L. Stevens, M. J. Power, W. Dean, and J. Rosenbaum. 2006. The last 2000 years in northern Yellowstone National Park based on multiproxy data from Crevice Lake. Program and Abstracts. *American Quaternary Association Conference* 19:168-169. Available online at: http://www.amqua.org/pastmeetings/2006_Meeting_Abstracts.pdf. Accessed March 2013.

Whitlock, C., W. Dean, J. Rosenbaum, L. R. Stevens, S. C. Fritz, B. B. Bracht, and M. Power. 2008. A 2650-year-long record of environmental change from northern Yellowstone National Park based on a comparison of multiple proxy data. *Quaternary International* 188(1):126-138.

Whitlock, C., W. E. Dean, S. C. Fritz, L. R. Stevens, J. R. Stone, M. J. Power, B. B. Bracht-Flyr, J. R. Rosenbaum, K. L.

Pierce, and B. B. Bracht-Flyr. 2012. Holocene seasonal variability inferred from multiple proxy records from Crevice Lake, Yellowstone National Park, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology* 331-332:90-103.

Wiemann, M. C., S. R. Manchester, and E. A. Wheeler. 1999. Paleotemperature estimation from dicotyledonous wood anatomical characters. *Palaios* 14(5):459-474.

Wilborn, B. 2006. Macrofloral assemblages of the Cloverly Formation, Bighorn Basin, Wyoming. Abstracts with Programs. *Geological Society of America* 38(1):29.

Williston, S. W. 1904. Notice of some new reptiles from the Upper Trias of Wyoming. *Journal of Geology* 12(8):688-697.

Williston, S. W. 1905. A new armored dinosaur from the Upper Cretaceous of Wyoming. *Science* 22(564):503-504.

Wilson, C. W., Jr. 1934. Section of Paleozoic and Mesozoic rocks measured at Cinnabar Mountain, Park County, Montana, and at Mount Everts, Yellowstone National Park, Wyoming. *Bulletin of the American Association of Petroleum Geologists* 18(3):368-379.

Windolph, J. F., Jr., R. C. Warlow, and N. L. Hickling. 1986. Deposition of deltaic and intermontane Cretaceous and Tertiary coal-bearing strata in the Wind River basin, Wyoming. Pages 123-140 *in* P. C. Lyons and C. L. Rice, editors. Paleoenvironmental and tectonic controls in coal-forming basins of the United States. Geological Society of America, Boulder, CO. Special Paper 210.

Wing, S. L. 1987. Eocene and Oligocene floras and vegetation of the Rocky Mountains. *Annals of the Missouri Botanical Garden* 74(4):748-784.

Wing, S. L. and D. R. Greenwood. 1993. Fossils and fossil climate: the case for equable continental interiors in the Eocene. *Philosophical Transactions of the Royal Society* B 341(1297):243-252.

Wings, O. 2007. A review of gastrolith function with implications for fossil vertebrates and a revised classification. *Acta Palaeontologica Polonica* 52(1):1-16. Available online at: http://app.pan.pl/archive/published/app52/app52-001. Accessed May 2013.

Wings, O. 2009. A simulated bird gastric mill and its implications for fossil gastrolith authenticity. *Fossil Record* 12(1):91-97.

Winslow, N. S. and P. L. Heller. 1987. Evaluation of unconformities in Upper Jurassic and Lower Cretaceous nonmarine deposits, Bighorn Basin, Wyoming and Montana, U.S.A. *Sedimentary Geology* 53(3-4):181-202.

Witkind, I. J. 1969. Geology of the Tepee Creek Quadrangle, Montana-Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 609. Available online at: http://pubs.er.usgs.gov/publication/pp609. Accessed April 2013.

Wonnacott, F. M. 1955. Celastraceae. Pars 29 of Jongmans, W., editor. Fossilium Catalogus. II: Plantae. A. Sijhoff Den Haag, the Netherlands.

Wright, G. A. 1980. The archeological sequence and native American land use in Jackson Hole. Pages 13-16 *in* S. Hollis, editor. Stratigraphy of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 31.

Wright, G. A. 1982. Archeological research in Yellowstone National Park. Pages 11-14 *in* S. G. Reid and D. J. Foote, editors. Geology of Yellowstone Park area. Wyoming Geological Association, Casper, WY. Guidebook 33.

Wright, H. E., Jr. 1976. The dynamic nature of Holocene vegetation: a problem in paleoclimatology, biogeography, and stratigraphic nomenclature. *Quaternary Research* 6(4):581-596.

Wright, R. P. 1974. Jurassic bivalves from Wyoming and South Dakota: a study of feeding relationships. *Journal of Paleontology* 48(3):425-433.

Wulf, G. R. 1962. Lower Cretaceous Albian rocks in northern Great Plains. *Bulletin of the American Association of Petroleum Geologists* 46(8):1371-1415.

Yen, T.-C. 1949. Review of the lower Cretaceous fresh-water molluscan faunas of North America. *Journal of Paleontology* 23(5):465-470.

Yen, T.-C. 1951. Fresh-water mollusks of Cretaceous age from Montana and Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 233-A. Available online at: http://pubs.er.usgs.gov/publication/pp233A. Accessed February 2013.

Yochelson, E. L. 1963. Paleoecology of the Permian Phosphoria Formation and related rocks. Pages B123-B124 *in* Geological Survey Research 1963. U.S. Geological Survey, Washington, DC. Professional Paper 475-B. Available online at: http://pubs.er.usgs.gov/publication/pp475B. Accessed April 2013.

Yochelson, E. L. and D. H. van Sickle. 1968. Biostratigraphy of the Phosphoria, Park City, and Shedhorn formations, with a section on fish. U.S. Geological Survey, Washington, DC. Professional Paper 313-D. Available online at: http://pubs.er.usgs.gov/publication/pp313D. Accessed March 2013.

Young, K. P. 1951. Foraminifera and stratigraphy of the Frontier Formation (Upper Cretaceous), southern Montana. *Journal of Paleontology* 25(1):35-68.

Young, P. A. 1940. Gallatin Petrified Forest. *Bulletin of the Torrey Botanical Club* 67(2):121-123.

Yuretich, R. F. 1984. Yellowstone fossil forests: new evidence for burial in place. *Geology* 12(3):159-162.

Zaleha, M. J. 2006. Sevier orogenesis and nonmarine basin filling: implications of new stratigraphic correlations of Lower Cretaceous strata throughout Wyoming, USA. *Geological Society of America Bulletin* 118(7-8):886-896.

Zaleha, M. J. and S. A. Wiesemann. 2005. Hyperconcentrated flows and gastroliths: sedimentology of diamictites and wackes of the upper Cloverly Formation, Lower Cretaceous, Wyoming, U.S.A. *Journal of Sedimentary Research* 75(1):43-54.

Zenger, D. H. 1992. Burrowing and dolomitization patterns in the Steamboat

Point Member, Bighorn Dolomite (Upper Ordovician), northwest Wyoming. *Contributions to Geology* 29(2):133-142.

Additional References

Allen, E.T. and A. L. Day. 1935. Hot Springs of the Yellowstone National Park. Carnegie Institution of Washington Publication 466.

Adams, T. L. and B. H. Breithaupt. 2003. Middle Jurassic dinosaurs of northern Wyoming: evidence from the Yellow Brick Road Dinosaur Tracksite, Bighorn Basin, Wyoming. *Wyoming Geo-Notes* 78:39-46.

Agenbroad, L. D. 1984. New world mammoth distribution. Pages 90-112 *in* P. S. Martin and R. G. Klein, editors. Quaternary extinction: a prehistoric revolution. University of Arizona Press, Tucson, Arizona, USA.

Amidon, L. 1997. Paleoclimate study of Eocene fossil woods and associated paleosols from the Gallatin Petrified Forest, Gallatin National Forest, SW Montana. Thesis. University of Montana, Missoula, MT.

Amidon, L. J., M. S. Hendrix, and R. Lenegan. 1996. Dendroclimatologic analyses of the Gallatin petrified forest (middle Eocene), southwest Montana: a record of altitude-related microclimate in the Yellowstone region? Abstracts with Programs. *Geological Society of America* 28(7):A-294.

Anderson, E. 1974. A survey of the late Pleistocene and Holocene mammalian fauna of Wyoming. Pages 78-87 *in* M. V. Wilson, editor. Applied geology and archaeology: the Holocene history of Wyoming. Geological Survey of Wyoming, Laramie, WY. Report of Investigations 10.

Andersson, K. A. and J. A. Sauvagnat. 1998. Large columnar structures hiding *Skolithos grandis* n. isp. in Permian strata western U.S.A. *Ichnos* 6(3):167-182.

Baker, R. G. 1969. Pollen and plant macrofossils from late Pinedale (later Pleistocene) and Recent sediments in an abandoned lagoon of Yellowstone lake, Wyoming. Dissertation. University of Colorado at Boulder, Boulder, CO.

Baker, R. G. 1983. Holocene vegetational history of the western United States. Pages 109-127 *in* H. E. Wright, Jr., editor. Late-Quaternary environments of the United States. Volume 2: the Holocene. University of Minnesota Press, Minneapolis, USA.

Betancourt, J. L., T. R. Van Devender, and P. S. Martin, editors. 1990. Packrat middens: the last 40,000 years of biotic change. University of Arizona Press, Tucson, AZ.

Beutner, E. C. and G. P. Gerbi. 2005. Catastrophic emplacement of the Heart Mountain block slide, Wyoming and Montana, USA. *Geological Society of America Bulletin* 117(5-6):724-735.

Blackwelder, E. 1918. New geological formations in western Wyoming. *Washington Academy of Sciences Journal* 8(13):417-426.

Bracht, B. B. 2007. A diatom record of late-Holocene climate variability in the Northern Rocky Mountains. Thesis. University of Nebraska at Lincoln, Lincoln, NE.

Branson, E. B. and M. G. Mehl. 1929. Triassic amphibians from the Rocky Mountain region. *The University of Missouri Studies* 4:1-87.

Cannon, K. P. 1991. Faunal remains from Grand Teton National Park, Wyoming. Pages 265-301 *in* Jackson Lake archeological project: the 1987 and 1988 field work. Midwest Archeological Center Technical Report 7.

Cannon, K. P. 2006. Prehistoric ecology of *Bison* in the greater Yellowstone ecosystem. Program and Abstracts. *American Quaternary Association Conference* 19:70-72. Available online at: http://www.amqua.org/pastmeetings/2006_Meeting_Abstracts.pdf. Accessed March 2013.

Cheney, T. M., R. P. Sheldon, R. G. Waring, and M. A. Warner. 1954. Stratigraphic sections of the Phosphoria Formation in Wyoming. U.S. Geological Survey, Washington, DC. Available online at: http://pubs.er.usgs.gov/publication/cir324. Accessed April 2013.

Christiansen, R. L. 1974. Geologic map of the West Thumb Quadrangle, Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington, DC. Geologic Quadrangle Map 1191. Scale 1:62,500. Available online at: http://pubs.er.usgs.gov/publication/gq1191 Accessed April 2013.

Christiansen, R. L. 1975. Geologic map of the Norris Junction Quadrangle, Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington, DC. Geologic Quadrangle Map 1193. Scale 1:62,500. Available online at: http://pubs.er.usgs.gov/publication/gq1193 Accessed April 2013.

Christiansen, R. L. 1989. The Yellowstone Plateau-Island Park region. Pages 14-37 *in* K. L. Ruebelmann. Volcanism and plutonism of western North America: Volume 2, Snake River plain-Yellowstone volcanic province. Field trips for the 28th International Geological Congress. American Geophysical Union, Washington, DC. T305.

Christiansen, R. L. and H. R. Blank, Jr. 1974. Geologic map of the Old Faithful Quadrangle, Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington, DC. Geologic Quadrangle Map 1189. Scale 1:62,500. Available online at: http://pubs.er.usgs.gov/publication/gq1189 Accessed April 2013.

Christiansen, R. L. and H. R. Blank, Jr. 1974. Geologic map of the Madison Junction Quadrangle, Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington, DC. Geologic Quadrangle Map 1190. Scale 1:62,500. Available online at: http://pubs.er.usgs.gov/publication/gq1190 Accessed April 2013.

Christiansen, R. L. and H. R. Blank, Jr. 1975. Geologic map of the Canyon Village Quadrangle, Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington, DC. Geologic Quadrangle Map 1192. Scale 1:62,500. Available online at: http://pubs.er.usgs.gov/publication/gq1192 Accessed April 2013.

Christiansen, R. L., J. D. Obradovich, and H. R. Blank, Jr. 1969. Late Cenozoic volcanic stratigraphy of the Yellowstone Park region: a preliminary report. Pages 591-592 *in* Abstracts for 1968. Geological Society of America, Boulder CO. Special Paper 121.

Christiansen, R. L., J. B. Lowenstern, R. B. Smith, H. Heasler, L. A. Morgan, M. Nathenson, L. G. Mastin, L. J. P. Muffler, and J. E. Robinson. 2007. Preliminary assessment of volcanic and hydrothermal hazards in Yellowstone National Park and vicinity. U.S. Geological Survey, Reston, VA. Open-File Report 2007-1071. Available online at: http://pubs.usgs.gov/of/2007/1071/. Accessed June 2013.

Cobban, W. A. 1955. Some guide fossils from the Colorado shale and Telegraph Creek Formation, northwestern Montana. Pages 198-207 *in* P. J. Lewis, editor. Sweetgrass Arch—Disturbed Belt, Montana. Billings Geological Society, Billings, MT. Guidebook 6.

Condit, D. D., E. H. Finch, and J. T. Pardee. 1928. Phosphate rock in the Three-Forks–Yellowstone Park region, Montana. Pages 147-209 in Contribution to economic geology (short papers and preliminary reports), 1927. Part I. Metals and nonmetals except fuels. U.S. Geological Survey, Washington, DC. Available online at: http://pubs.er.usgs.gov/publication/b795G. Accessed April 2013.

Cooley, J. T., J. G. Schmitt, and J. R. Horner. 1992. Fluvial systems of the Upper Jurassic Morrison Formation, Gallatin and Beartooth ranges, southwest Montana. Page 20 *in* SEPM 1992 theme meeting: Mesozoic of the Western Interior: abstracts. Society for Sedimentary Geology, Tulsa, OK.

Dana, E. S. and G. B. Grinnell. 1876. Geological report. Pages 93-137 *in* W. Ludlow. 1876. Report of a reconnaissance from Carroll, Montana Territory, on the Upper Missouri to the Yellowstone National Park and return, made in the summer of 1875 by William Ludlow. Government Printing Office, Washington, DC. Available online at: http://archive.org/details/reportofreconnai00uni. Accessed April 2013.

Deiss, C. F. 1938. Cambrian formations and sections in part of Cordilleran Trough. *Geological Society of America Bulletin* 49(7):1067-1168.

Denson, N. M. 1939. Trilobites from the Park Shale of Montana and Yellowstone National Park. Thesis. University of Montana, Missoula, MT.

Dorf, E. 1974. Early Tertiary fossil forests of Yellowstone Park. Pages 108-111 *in* B. Voight and M. A. Voight, editors. Rock mechanics, the American northwest. Pennsylvania State University, University Park, PA.

Dorf, E. 1980. Petrified forests of Yellowstone. U.S. Government Printing Office, Washington, DC. Available online at: http://archive.org/details/petrifiedforests00nati. Accessed April 2013.

Duncan, D. C. 1937. Upper Cambrian trilobites from Montana and Yellowstone National Park. Thesis. University of Montana, Missoula, MT.

Dundas, R. G. 1990. The Merrell locality: a late Pleistocene fauna from southwestern Montana. Abstracts with Programs. *Geological Society of America* 22(6):8-9.

Dundas, R. G. 1992. A scimitar cat (*Homotherium serum*) from the late Pleistocene Merrell locality, southwestern Montana. *Paleobios* 14(1):9-12. Available online at: http://docubase.berkeley.edu/cgi-bin/pl_dochome?query_src=pl_search&collection=PaleoBios+Archive+Public&id=59. Accessed April 2013.

Elias, S. A. 1996. The ice-age history of national parks in the Rocky Mountains. Smithsonian Institution Press, Washington, DC.

Elias, S. A. 1997. Reconstructing Yellowstone's climate history. *Yellowstone Science* 5(4):2-8. Available online at: http://www.greateryellowstonescience.org/sites/default/files/references/YS_5_4_Elias.pdf. Accessed May 2013.

Ellwood, B. B. 1996. Geology and America's National Park areas. Prentice Hall, Upper Saddle River, NJ.

Fisk, L. H. 1976. Palynology of the Amethyst Mountain "Fossil Forest," Yellowstone National Park, Wyoming. Dissertation. Loma Linda University, Loma Linda, CA.

Fisk, L. H. and M. R. Aguirre. 1981. An Eocene liverwort from the Lamar River Flora, Yellowstone National Park, Wyoming. Botanical Society of America, St. Louis, MO. *Miscellaneous Series Publication* 160:44.

Foster, H. L. 1947. Paleozoic and Mesozoic stratigraphy of northern Gros Ventre Mountains and Mount Leidy Highlands, Teton County, Wyoming. *Bulletin of the American Association of Petroleum Geologists* 31(9):1537-1593.

Fournier, R. O., R. L. Christiansen, R. A. Hutchinson, and K. L. Pierce. 1994. A field-trip guide to Yellowstone National Park, Wyoming, Montana, and Idaho: volcanic, hydrothermal, and glacial activity in the region. U.S. Geological Survey, Reston, VA. Bulletin 2099. Available online at: http://pubs.er.usgs.gov/publication/b2099. Accessed March 2013.

Fritz, W. J. 1977. Paleoecology of petrified woods from the Amethyst Mountain "Fossil Forest" Yellowstone National Park, Wyoming. Dissertation. Walla Walla College, College Park, WA.

Fritz, W. J. and J. W. Sears. 1993. Tectonics of the Yellowstone hotspot wake in southwestern Montana. *Geology* 21(5):427-430.

Gansecki, C. A., G. A. Mahood, and M. O. McWilliams. 1996. $^{40}Ar/^{39}Ar$ geochronology of rhyolites erupted

following collapse of the Yellowstone Caldera, Yellowstone Plateau volcanic field: implications for crustal contamination. *Earth and Planetary Science Letters* 142(1-2):91-108.

Gansecki, C. A., G. A. Mahood, and M. McWilliams. 1998. New ages for the climactic eruptions at Yellowstone: single-crystal $^{40}Ar/^{39}Ar$ dating identifies contamination. *Geology* 26(4):343-346.

Gennett, J. A. 1977. Palynology and paleoecology of sediments from Blacktail Pond, northern Yellowstone Park, Wyoming. Thesis. University of Iowa, Iowa City, IA.

Good, J. M. and K. L. Pierce. 1996. Interpreting the landscapes of Grand Teton and Yellowstone national parks: recent and ongoing geology. Grand Teton Natural History Association, Moose, WY.

Goodwin, J. H. and C. R. Schmit. 1974. Sedimentology and geochemistry of piston cores from Yellowstone and Jackson Lakes, Wyoming. Abstracts with Programs. *Geological Society of America* 6(7):760.

Hadly, E. 1990. Late Holocene mammalian fauna of Lamar Cave and its implications for ecosystem dynamics in Yellowstone National Park, Wyoming. Thesis. Northern Arizona University, Flagstaff, AZ.

Hague, A., J. P. Iddings, W. H. Weed, C. D. Walcott, G. H. Girty, T. W. Stanton, and F. H. Knowlton. 1899. Descriptive geology, petrology, petrography, and paleontology. Pages 1-23 in Part II of Geology of the Yellowstone national park. U.S. Geological Survey, Washington, DC. Monograph 32. Available online at: http://archive.org/details/geologyofyellows00hagu. Accessed March 2013.

Hall, W. B. 1960. Multiple glaciation in the Madison and Gallatin Ranges, southwestern Montana. Pages 191-199 *in* D. E. Campau and H. W. Anisgard, editors. West Yellowstone—Earthquake area. Billings Geological Society, Billings, MT. Guidebook 11.

Hanna, R. L. and K. L. Verosub. 1989. A review of lacustrine paleomagnetic records from western North America: 0-40 000 years BP. *Physics of the Earth and Planetary Interiors* 56(1-2):76-95.

Harlan, S. S. and L. A. Morgan. 2006. Paleomagnetic and rock magnetic properties of Tertiary volcanic and intrusive rocks of the Eocene Absaroka Volcanic Supergroup, northeastern Yellowstone National Park. Abstracts with Programs. *Geological Society of America* 38(7):352.

Hay, O. P. 1924. The Pleistocene of the middle region of North America and its vertebrated animals. Carnegie Institute of Washington Publication 322A.

Hay, O. P. 1927. The Pleistocene of the western region of North America and its vertebrated animals. Carnegie Institute of Washington Publication 322B.

Hayden, F. V. 1876. The Yellowstone Park and the mountain regions of portions of Idaho, Nevada, Colorado, and Utah. Louis Prang, Boston, MA.

Haynes, C. V., Jr., D. C. Grey, and A. Long. 1971. Arizona radiocarbon dates VIII.

Radiocarbon 13(1):1-18. Available online at: https://journals.uair.arizona.edu/index.php/radiocarbon/article/view/267/272. Accessed April 2013.

Henbest, L. G. 1956. Foraminifera and correlation of the Tensleep Sandstone of Pennsylvanian age in Wyoming. Pages 58-63 *in* R. R. Berg and J. W. Strickland, editors. Jackson Hole. Wyoming Geological Association, Casper, WY. Guidebook 11.

Hill, C. L. 2002. The last full glacial to interglacial transition in the lower Yellowstone Valley, northern Great Plains. Program and Abstracts. *American Quaternary Association Conference* 17:67.

Hill, C. L. 2006. Late Pleistocene (Rancholabrean) fauna in the greater Yellowstone ecosystem: geology and paleobiology. Program and Abstracts. *American Quaternary Association Conference* 19:95-96. Available online at: http://www.amqua.org/publications/abstracts/amqua2006-abstracts.pdf. Accessed April 2013.

Hill, C. L. 2006. Stratigraphic and geochronologic contexts of mammoth (*Mammuthus*) and other Pleistocene fauna, upper Missouri Basin (northern Great Plains and Rocky Mountains), U.S.A. *Quaternary International* 142-143:87-106.

Horberg, C. L., R. W. Edmund, and F. M. Fryxell. 1955. Geomorphic and structural relations of Tertiary volcanics in the northern Teton Range and Jackson Hole, Wyoming. *Journal of Geology* 63(6):501-511.

Howard, A. D. 1936. The deposits of Hayden Valley, in Yellowstone National Park. *Science* 83(2143):80.

Imlay, R. W. 1948. Characteristic marine fossils from the western interior of the United States. U.S. Geological Survey, Washington, DC. Professional Paper 214B. Available online at: http://pubs.er.usgs.gov/publication/pp214B. Accessed April 2013.

Kellogg, K. S. and V. S. Williams. 2000. Geologic map of the Ennis 30' x 60' quadrangle, Madison and Gallatin counties, Montana, and Park County, Wyoming. U.S. Geological Survey, Reston, VA. Geologic Investigations Series 2690. Scale 1:100,000. Available online at: http://pubs.usgs.gov/imap/i-2690/. Accessed April 2013.

Koch, R. D., D. W. Ramsey, and R. L. Christiansen. 2011. Database for the Quaternary and Pliocene Yellowstone Plateau volcanic field of Wyoming, Idaho, and Montana. U.S. Geological Survey, Reston, VA. Data Series DS-551. Available online at: http://pubs.usgs.gov/ds/551/. Accessed March 2013.

Kummel, B. 1960. The Triassic of southwestern Montana. Pages 233-238 *in* D. E. Campau and H. W. Anisgard, editors. West Yellowstone—Earthquake area. Billings Geological Society, Billings, MT. Guidebook 11.

Kvale, E. P., D. L. Mickelson, S. T. Hasiotis, and G. D. Johnson. 2004. The history of dinosaur footprint discoveries in Wyoming with emphasis on the Bighorn Basin. *Ichnos* 11(1-2):3-9.

Leopold, E. B., G. Liu, J. D. Love, and D. W. Love. 2007. Plio-Pleistocene climatic transition and the lifting of the Teton Range, Wyoming. *Quaternary Research* 67(1):1-11.

Love, J. D. 1953. Tertiary stratigraphy of the Jackson Hole area, northwestern Wyoming. U.S. Geological Survey, Washington, DC. Oil and Gas Investigations Chart 27. Scale 1:2,400. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_5184.htm. Accessed March 2013.

Love, J. D. 1961. Reconnaissance study of Quaternary faults in and south of Yellowstone National Park, Wyoming. *Geological Society of America Bulletin* 72(12):1749-1764.

Love, J. D. 1974. Geologic map of the south half of the Huckleberry Mountain Quadrangle, Teton County, Wyo. U.S. Geological Survey, Washington, DC. Open-File Report 74-54. Scale 1:24,000. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_15071.htm. Accessed April 2013.

Love, J. D. and W. R. Keefer. 1969. Type locality of Darby Formation, western Wyoming. *American Association of Petroleum Geologists Bulletin* 53(1):167-170.

Love, J. D., J. M. de la Montagne, G. M. Richmond, and J. M. Good. 1965. Relation of Quaternary tectonics and volcanism to glaciation, Part D. Pages 37-52 *in* Guidebook for Field Conference E, northern and middle Rocky Mountains – International Association for Quaternary Research, 7th Congress, U.S.A., 1965. Nebraska Academy of Sciences, Lincoln, NE.

Love, J. D., J. C. Reed, Jr., and K. L. Pierce. 2003. Creation of the Teton landscape: a geologic chronicle of Jackson Hole and the Teton Range. Grand Teton Natural History Association, Moose, WY.

Lynch, E. A. 1998. Origin of a park-forest vegetation mosaic in the Wind River Range, Wyoming. *Ecology* 79(4):1320-1338.

MacTavish, J. N. 1971. Faunal elements of part of the Lodgepole Formation, Madison Group (Mississippian), from Darby Canyon, Grand Teton Mountains, Wyoming. Dissertation. Case Western Reserve University, Cleveland, OH.

Malinky, J. M. 1988. Early Paleozoic hyolitha from North America: reexamination of Walcott's and Resser's type specimens. *Journal of Paleontology* 62(2):218-233.

Mayor, A. 2005. Fossil legends of the first Americans. Princeton University Press, Princeton, NJ.

McCracken, H., W. W. Wedel, R. Edgar, J. Moss, H. E. Wright, W. Husted, and W. Mulloy. 1978. The Mummy Cave project in northwest Wyoming. Buffalo Bill Historical Center, Cody, WY.

Merewether, E. A. and W. A. Cobban. 1986. Biostratigraphic units and tectonism in the mid-Cretaceous foreland of Wyoming, Colorado, and adjoining areas. Pages 443-468 *in* J. A. Peterson, editor. Paleotectonics and sedimentation in the Rocky Mountain region, United States. American Association of Petroleum Geologists, Tulsa, OK. Memoir 41.

Miller, B. M. 1936b. Cambrian trilobites from northwestern Wyoming. *Journal of Paleontology* 10(1):23-34.

Millspaugh, S. H. and C. Whitlock. 1995. A 750-year fire history based on lake sediment records in central Yellowstone National Park, USA. *Holocene* 5(3):283-292.

Montagne, J. and R. A. Chadwick. 1982. Cenozoic history of the Yellowstone Valley between Yellowstone Park and Livingston, Montana. Pages 31-51 *in* S. G. Reid and D. J. Foote, editors. Geology of Yellowstone Park area. Wyoming Geological Association, Casper, WY. Guidebook 33.

Nowatzyk, G. 1983. Archaeological investigations at the Cremer site (24SW264). *Archaeology in Montana* 24(2):59-91.

O'Neill, J. M. and R. L. Christiansen. 2004. Geologic map of the Hebgen Lake Quadrangle, Beaverhead, Madison, and Gallatin Counties, Montana, Park and Teton Counties, Wyoming, and Clark and Fremont Counties, Idaho. U.S. Geological Survey, Reston, VA. Scientific Investigations Map 2816. Scale 1:100,000. Available online at: http://pubs.usgs.gov/sim/2004/2816/. Accessed April 2013.

Obradovich, J. D. 1992. Geochronology of the late Cenozoic volcanism of Yellowstone National Park and adjoining areas, Wyoming and Idaho. U.S. Geological Survey, Reston, VA. Open-File Report 92-408. Available online at: http://pubs.er.usgs.gov/publication/ofr92408. Accessed April 2013.

Olsen, S. J. 1971. Zooarchaeology: animal bones in archaeology and their interpretation. Addison-Wesley Publishing Company, New York, NY.

Parsons, W. H. 1974. Volcanic rocks of the Absaroka-Yellowstone region. Pages 94-101 *in* B. Voight and M. A. Voight, editors. Rock mechanics, the American northwest. Pennsylvania State University, University Park, PA.

Patton, J. L. 1995. Evolution, ecology, and taphonomy of late-Holocene mammals from Lamar Cave, Yellowstone National Park, Wyoming, USA. Dissertation. University of California at Berkeley, Berkeley, CA.

Payenberg, T. H. D., A. D. Miall, and D. R. Braman. 2001. Sequence stratigraphy of the Milk River Formation in southern Alberta and Eagle Formation in northern Montana. *CSPG Annual Convention* 2001:022-1. Available online at: http://www.cspg.org/documents/Conventions/Archives/Annual/2001/11-022.pdf. Accessed April 2013.

Pierce, K. L. 1982. History and dynamics of glaciation in the northern Yellowstone National Park area. Pages 27-29 *in* S. G. Reid and D. J. Foote, editors. Geology of Yellowstone Park area. Wyoming Geological Association, Casper, WY. Guidebook 33.

Pierce, K. L. and L. A. Morgan. 1992. The track of the Yellowstone hot spot: volcanism, faulting, and uplift. Pages 1-53 *in* P. K. Link, M. A. Kuntz, and L. B. Platt, editors. Regional geology of eastern Idaho and western Wyoming. Geological

Society of America, Boulder, CO. Memoir 179.

Pierce, K. L., K. P. Cannon, G. A. Meyer, M. J. Trebesch, and R. Watts. 2002. Post–glacial inflation–deflation cycles, tilting, and faulting in the Yellowstone caldera based on Yellowstone Lake shorelines. U.S. Geological Survey, Reston, VA. Open–File Report 02-142. Available online at: http://pubs.er.usgs.gov/publication/ofr02142. Accessed May 2013.

Pierce, W. G., compiler. 1997. Geologic map of the Cody 1° x 2° quadrangle, northwestern Wyoming. U.S. Geological Survey, Reston, VA. Miscellaneous Investigations Series 2500. Scale 1:250,000. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_13047.htm. Accessed April 2013.

Pierce, W. G., W. H. Nelson, and H. J. Prostka. 1973. Geologic maps of the Pilot Peak Quadrangle, Park County, Wyoming. U.S. Geological Survey, Washington, DC. Miscellaneous Investigations Series 816. Scale 1:62,500. Available online at: http://ngmdb.usgs.gov/Prodesc/proddesc_13015.htm. Accessed April 2013.

Pinner, J. 1979. The Helen Lookingbill site: 48FR308. *Wyoming Archaeologist* 22(4):24-26. Available online at: http://www.wyomingarchaeology.org/thewyomingarchaeologist/19791970.html. Accessed March 2013.

Pitt, A. M., C. S. Weaver, and W. Spence. 1979. The Yellowstone Park earthquake of June 30, 1975. *Bulletin of the Seismological Society of America* 69(1):187-205.

Pritchard, C. J. and P. B. Larson. 2012. Genesis of the post-caldera eastern Upper Basin Member rhyolites, Yellowstone, WY: from volcanic stratigraphy, geochemistry, and radiogenic isotope modeling. *Contributions to Mineralogy and Petrology* 164(2):205-228.

Prostka, H. J., H. R. Blank, Jr., R. L. Christiansen, and E. T. Ruppel. 1975. Geologic map of the Tower Junction Quadrangle, Yellowstone National Park, Wyoming and Montana. U.S. Geological Survey, Washington, DC. Geologic Quadrangle Map 1247. Scale 1:62,500. Available online at: http://pubs.er.usgs.gov/publication/gq1247 Accessed April 2013.

Pursell, V. 1985. The petrology and diagenesis of Pleistocene and Recent travertines from Gardiner, Montana, and Yellowstone National Park, Wyoming. Thesis. University of Texas at Austin, Austin, TX.

Read, C. B. 1933. Fossil floras of Yellowstone National Park. Part I. Coniferous woods of Lamar River flora. Fossil floras of Yellowstone National Park and southeastern Oregon. *Carnegie Institution of Washington Publication* 416:1-19.

Reed, J. C., Jr. 1963. Structure of Precambrian crystalline rocks in the northern part of Grand Teton National Park, Wyoming. Pages C1-C6 *in* Geological Survey research, 1963. U.S. Geological Survey, Washington, DC. Professional Paper 475-C. Available online at: http://pubs.er.usgs.gov/publication/pp475C. Accessed March 2013.

Reed, J. C., Jr. 1973. Geology of the Precambrian rocks of the Teton Range, Wyoming. U.S. Geological Survey, Washington, DC. Open-File Report 73-230. Scale 1:62,500. Available online at: http://pubs.er.usgs.gov/publication/ofr73230. Accessed March 2013.

Retallack, G. and W. J. Fritz. 1981. Comment and reply on "Reinterpretation of the depositional environment of the Yellowstone fossil forests." *Geology* 9(2):52-54.

Richmond, G. M., R. G. Baker, J. P. Bradbury, and W. Mullenders, investigators. 1980. Records of past climates in lake sediments from Yellowstone Park area. Pages 221-222 *in* Geological Survey Research 1980. U.S. Geological Survey, Reston, VA. Professional Paper 1175. Available online at: http://pubs.er.usgs.gov/publication/pp1175 Accessed April 2013.

Sandberg, C. A. and G. Klapper. 1967. Stratigraphy, age, and paleotectonic significance of the Cottonwood Canyon Member of the Madison Limestone in Wyoming and Montana. U.S. Geological Survey, Washington, DC. Bulletin 1251-B. Available online at: http://pubs.er.usgs.gov/publication/b1251B. Accessed February 2013.

Smith, R. B. and L. J. Siegel. 2000. Windows into the Earth: the geologic story of Yellowstone and Grand Teton national parks. Oxford University Press, Oxford, United Kingdom.

Sorey, M. L., editor. 1991. Effects of potential geothermal development in the Corwin Springs Known Geothermal Resource Area, Montana, on the thermal features of Yellowstone National Park. U.S. Geological Survey, Reston, VA. Water Resources Investigations Report 91-4052. Available online at: http://pubs.er.usgs.gov/publication/wri914052. Accessed May 2013.

Sturchio, N. C., M. T. Murrell, K. L. Pierce, and M. L. Sorey. 1992. Yellowstone travertines: U-series ages and isotope ratios (C, O, Sr, U). Pages 1427-1430 *in* Y. K. Kharaka and M. D. Maest, editors. Water–rock interaction. Balkema, Rotterdam, Netherlands.

Tidwell, W. D. 1975. Common fossil plants of western North America. Brigham Young University Press, Provo, UT.

Tiller, C. C. 1995. Postglacial sediment stratigraphy of large lakes in greater Yellowstone: scenarios of tectonic and climatic forcing. Thesis. University of Minnesota, Minneapolis, MN.

Tonnsen, J. J. 1980. The Frontier Formation in northwestern Wyoming and adjacent areas. Pages 173-184 *in* S. Hollis, editor. Stratigraphy of Wyoming. Wyoming Geological Association, Casper, WY. Guidebook 31.

Turner, C. E. and F. Peterson. 1999. Biostratigraphy of dinosaurs in the Upper Jurassic Morrison Formation of the Western Interior, U.S.A. Pages 77-114 *in* D. D. Gillette, editor. Vertebrate paleontology in Utah. Utah Geological Survey, Salt Lake City, UT. Miscellaneous Publication 99-1.

Tuttle, S. D. 1990. Yellowstone National Park. Pages 480-500 *in* A. G. Harris and E.

Tuttle. Geology of National Parks (4th edition). Kendall/Hunt Publishing Company, Dubuque, IA.

Van Norman, K. J. and C. Whitlock. 1994. A postglacial pollen record from the southwestern Yellowstone National Park region. Program and Abstracts. *American Quaternary Association Conference* 13:174.

White, C. A. 1879. Note on *Endothyra ornata*. *Proceedings of the United States National Museum* 2:291. Available online at: http://archive.org/details/proceedingsofuni21879unit. Accessed March 2013.

White, D. E., R. O. Fournier, L. P. J. Muffler, and A. H. Truesdell. 1975. Physical results of research drilling in thermal areas of Yellowstone National Park, Wyoming. U.S. Geological Survey, Washington, DC. Professional Paper 892. Available online at: http://pubs.er.usgs.gov/publication/pp892. Accessed June 2013.

Whitfield, R. P. 1876. Descriptions of new species of fossils. Pages 139-145 *in* W. Ludlow. 1876. Report of a reconnaissance from Carroll, Montana Territory, on the Upper Missouri to the Yellowstone National Park and return, made in the summer of 1875 by William Ludlow. Government Printing Office, Washington, DC. Available online at: http://archive.org/details/reportofreconnai00uni. Accessed April 2013.

Witkind, I. J., J. B. Hadley, and W. H. Nelson. 1964. Pre-Tertiary stratigraphy and structure of the Hebgen Lake area. Pages 199-207 in The Hebgen Lake, Montana, earthquake of August 17, 1959. U.S. Geological Survey, Washington, DC. Professional Paper 435. Available online at: http://pubs.er.usgs.gov/publication/pp435. Accessed April 2013.

Wooton, K. M. and T. L. Spell. 2007. Latest Yellowstone volcanism: Roaring Mountain rhyolites, Yellowstone volcanic field, Wyoming. Abstracts with Programs. *Geological Society of America* 39(6):393.

Yamamoto, T. and A. V. Chadwick. 1982. Identification of fossil wood from the Specimen Creek area of the Gallatin Petrified Forest, Yellowstone National Park. Part I. Gymnosperms. *Journal San-iku Gakuin J C.* 10:25-42.

Yamamoto, T. and A. V. Chadwick. 1983. Identification of fossil wood from the Specimen Creek area of the Gallatin Petrified Forest, Yellowstone National Park. Part II. Angiosperms. *Journal San-iku Gakuin J C.* 11:49-66.

Yochelson, E. L., T. M. Cheney, D. van Sickle, and D. H. Dunkle. 1961. Permian outcrops in western Duchesne County, Utah. *Bulletin of the American Association of Petroleum Geologists* 45(1):107-108.

Yuretich, R. F. and W. J. Fritz. 1981. Comment and reply on “Reinterpretation of the depositional environment of the Yellowstone ‘fossil forests’: Stumps transported and deposited upright by Mount St. Helens mud flows.” *Geology* 9(4):146-147.

Zartman, R. E. and J. C. Reed, Jr. 1998. Zircon geochronology of the Webb Canyon Gneiss and the Mount Owen Quartz Monzonite, Teton Range,

Wyoming: significance to dating late Archean metamorphism in the Wyoming Craton. *Mountain Geologist* 35(2):71-77.

Zell, R. 1959. A Mississippian coral assemblage from Darby Canyon, Teton County, Wyoming. Thesis. University of Wyoming, Laramie, WY.

Data Sets

Yellowstone National Park Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Yellowstone National Park Collections
1872–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by YELL staff; status: Active.

Yellowstone National Park Digital Geologic Map
2007–present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online. https://irma.nps.gov/App/Reference/Profile?Code=1044842.

Cincinnati Museum Center, collections of the University of Cincinnati Museum
Early 1950s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by CMC staff; status: Active.

Montana State University
Early 1940s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by MSU staff; status: Active.

Museum of the Rockies
Uncertain. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by MOR staff; status: Inactive.

Ohio University
Early 1950s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by OU staff; status: Active.

Peabody Museum of Natural History (former Princeton University collections)
Late 1980s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by YPM staff; status: Active.

Princeton University
1930s?–late 1980s. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by PU staff; status: Inactive.

U.S. Geological Survey
1940s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by USGS staff; status: Active or inactive (depends on the collection).

National Museum of Natural History (including former USGS specimens)
1872–present. (museum specimens; associated specimen notes; collection records; maps;

etc.). Originated by USNM staff; status: Active.

University of California Museum of Paleontology
Early 1930s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by UCMP staff; status: Active.

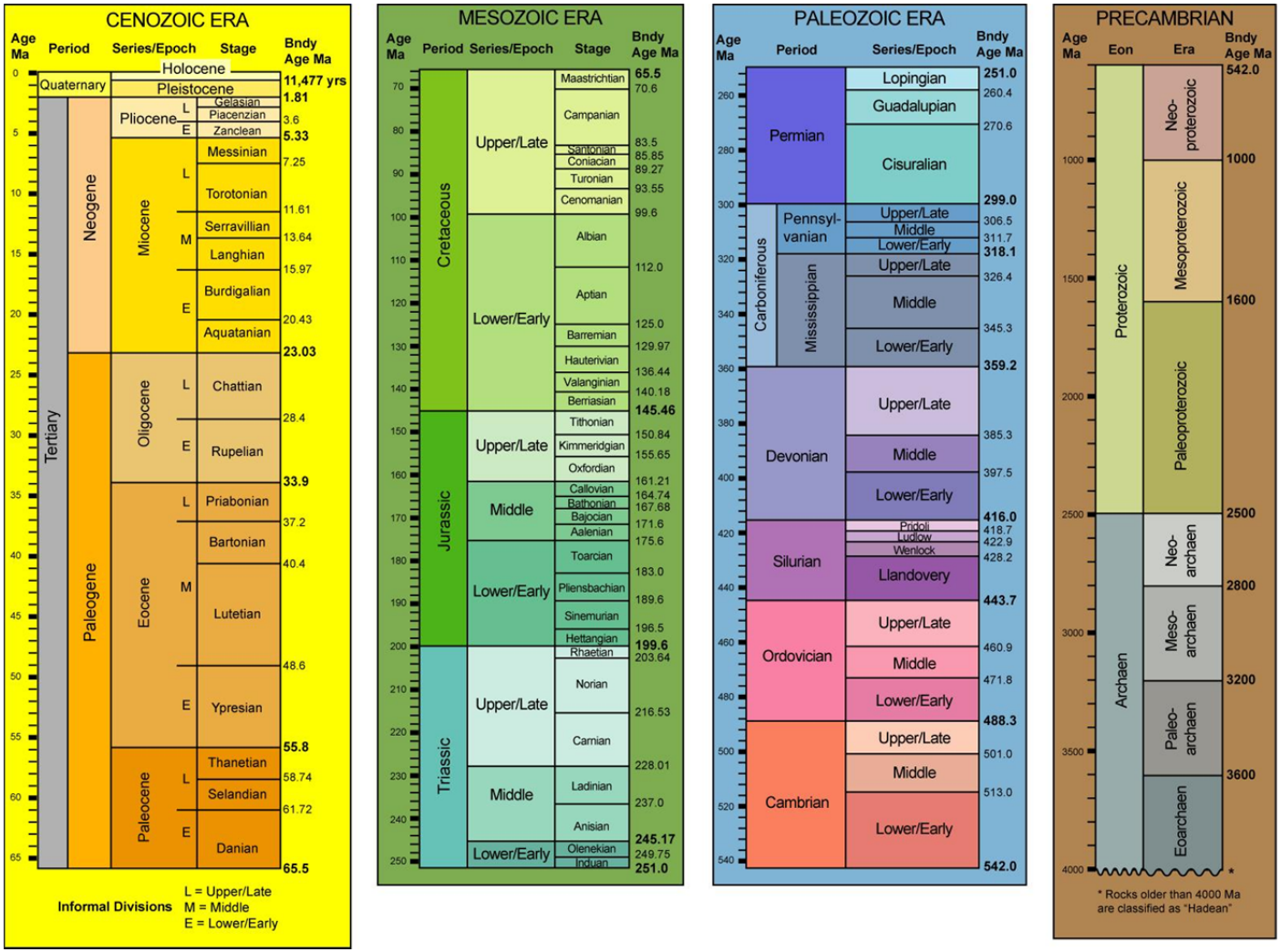
University of Cincinnati
2000s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by Joshua Miller; status: Active.

University of Montana
Late 1970s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by UM staff; status: Active.

University of Texas system
1960s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by UT staff; status: Active.

Washington University in St. Louis
1930s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by Washington University botany department staff; status: Active.

Appendix: 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 (www.geosociety.org/science/timescale/timescl.pdf). Dates and additional information from 2004 International Commission on Stratigraphy (www.stratigraphy.org/gssp.htm) and USGS Fact Sheet 2007-3015 (http://pubs.usgs.gov/fs/2007/3015/).

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

NPS 101/122152, 136/122152, 642/122152, 617/122152, August 2013

National Park Service
U.S. Department of the Interior

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