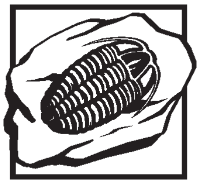


Chapter 3: Fossils of the Northwest Central US

Fossils (from the Latin word *fossilis*, meaning "dug up") are the remains or traces of organisms that lived in the geologic past (older than the last 10,000 years), now preserved in the Earth's **crust**. Most organisms never become fossils, but instead decompose after death, and any hard parts are broken into tiny fragments. In order to become fossilized, an organism must be buried quickly before it is destroyed by weathering, is decomposed, or is eaten by other organisms. This is why fossils are found almost exclusively in sediment and **sedimentary rocks**. **Igneous rocks**, which form from cooling **magma** or **lava**, and **metamorphic rocks**, which have been altered by **heat** and pressure, are unlikely to contain fossils (but may, under special circumstances).

Since rapid burial in sediment is important for the formation of fossils, most fossils form in marine environments, where sediments are more likely to accumulate. Fossils come in many types. Those that consist of an actual part of an organism, such as a bone, shell, or leaf, are known as **body fossils**; those that record the actions of organisms, such as footprints and burrows, are called **trace fossils**. Body fossils may be preserved in a number of ways. These include preservation of the original **mineral** skeleton of an organism, mineral **replacement** (chemical replacement of the material making up a shell by a more

Lagerstätten

The "soft" tissues of an organism, such as skin, muscles, and internal organs, are typically not preserved as fossils. Exceptions to this rule occur when conditions favor rapid burial and mineralization or very slow decay. The absence of oxygen and limited disruption of the sediment by burrowing are both important for limiting decay in those deposits where soft tissues are preserved. The Northwest Central States contain numerous examples of such exceptional preservation, also called lagerstätten, including the Miocene Clarkia fossil beds in northern Idaho, the Bear Gulch Beds of central Montana, the Florissant fossil beds of Colorado, the Agate bone beds of Nebraska, and the Eocene Green River Formation of Utah, Colorado, and Wyoming.

crust • *the uppermost, rigid outer layer of the Earth, composed of tectonic plates.*

sedimentary rock • *rock formed through the accumulation and consolidation of grains of broken rock, crystals, skeletal fragments, and organic matter.*

magma • *molten rock located below the surface of the Earth.*

lava • *molten rock located on the Earth's surface.*

metamorphic rocks • *rocks formed by the recrystallization and realignment of minerals in pre-existing sedimentary, igneous, and metamorphic rocks when exposed to high enough temperature and/or pressure.*

mineral • *a naturally occurring solid with a specific chemical composition and crystalline structure.*

CHAPTER AUTHORS

Warren D. Allmon
Dana S. Friend

3

Fossils

Overview

clay • *the common name for a number of very fine-grained, earthy materials that become plastic (flow or change shape) when wet.*

filter feeder • *an animal that feeds by passing water through a filtering structure that traps food.*

intertidal • *areas that are above water during low tide and below water during high tide.*

crystal form • *a physical property of minerals, describing the shape of the mineral's crystal structure.*

Discovering Ancient Environments

The kinds of animals and plants living in a particular place depend on the local environment. The fossil record preserves not only fossil organisms, but also evidence of what their environments were like. By studying the geological and biological information recorded in a rock that contains a fossil, scientists can determine some aspects of the paleoenvironment.

Grain size and composition of the rock **can tell us what type of sediment surface the animal lived on, what the water flow was like, or whether it was transported in a current. Grain size also tells us about the clarity of the water. Fine-grained rocks such as shales are made of tiny particles of silt or** ***clay*** **that easily remain suspended in water. Thus, a fossil found in shale might have lived in muddy or very quiet water.** ***Filter-feeding*** **organisms, such as clams or corals, are not usually found in muddy water because the suspended sediment can clog their filters.**

Sedimentary structures**, such as asymmetrical ripples and** ***cross-beds*****, can indicate that the organism lived in moving water. Mud cracks or symmetrical ripples are characteristic of shoreline or** ***intertidal*** **environments.**

Broken shells or concentrated layers of shells **may indicate transportation and accumulation by waves or currents.**

Color of the rock **may indicate the amount of oxygen in the water. If there is not enough oxygen in the water, organic material (carbon) in sediments will not decompose, and the rock formed will be dark gray or black in color.**

stable mineral), **recrystallization** (replacement by a different **crystal form** of the same chemical compound), **permineralization** (filling of empty spaces in a bone or shell by minerals), and molds and casts, which show impressions of the exterior or interior of a shell. **Chemical fossils** are chemicals produced by an organism that leave behind an identifiable trace in the geologic record, and it is these fossils that provide some of the oldest evidence for life on Earth.

Paleontologists use fossils as a record of the history of life. Fossilized organisms are also extremely useful for understanding the ancient environment that existed when they were alive. The study of the relationships of fossil organisms to one another and their environment is called **paleoecology**.

Fossils

3

Fossils are also the most important tool for dating the rocks in which they are preserved. Because species only exist for a certain amount of time before going **extinct**, their fossils only occur in rocks of a certain age. The relative age of such fossils is determined by their order in the stacks of layered rocks that make up the **stratigraphic** record (older rocks are on the bottom and younger rocks on the top—a principle called **superposition**). Such fossils are known as **index fossils.** The most useful index fossils are abundant, widely distributed, easy to recognize, and occur only during a narrow time span. This use of fossils to determine relative age in geology is called **biostratigraphy**.

Index fossils **are used to determine the age of many deposits that cannot be dated radiometrically. This practice is called biostratigraphy. An ideal index fossil lived during a short period of time, was geographically and environmentally widespread, and is easy to identify. Some of the most useful index fossils are hard-shelled organisms that were once part of the marine plankton.**

Ancient Biodiversity

Since life began on Earth more than 3.7 billion years ago, it has continuously become more abundant and diverse. It wasn't until the beginning of the **Cambrian** period, around 541 million years ago, that *complex life*—living things with cells that are differentiated for different tasks—became predominant. The diversity of life has, in general, increased through time since then. Measurements of the number of different kinds of organisms—for example, estimating the number of species alive at a given time—attempt to describe Earth's **biodiversity**. With a few significant exceptions, the rate at which new species evolve is significantly greater than the rate of extinction.

Most species have a lifespan of several million years; rarely do species exist longer than 10 million years. The extinction of a species is a normal event in the history of life. There are, however, intervals of time during which extinction rates are unusually high, in some cases at a rate of 10 or 100 times the normal pace. These intervals are known as **mass extinctions**. There were five particularly devastating mass extinctions in geologic history (*Figure 3.1*), and these specific mass extinction events have helped to shape life through time. Unfortunately, this is not just a phenomenon of the past—it is estimated that the extinction rate on Earth right now may be as much as 1000 times higher than normal, due mostly to human activity, and that we are currently experiencing a sixth mass extinction event.

Different fossils are found in different regions because of the presence of rocks deposited at different times and in a variety of environments. The availability of fossils from a given time period depends both on the deposition of sedimentary rocks and the preservation of these rocks through time.

Overview

extinction • *the end of species or other taxonomic groups, marked by death of the last living individual.*

stratigraphy • *the branch of geology specifically concerned with the arrangement and age of rock units.*

Cambrian • *a geologic time period lasting from 541 to 485 million years ago.*

biodiversity • *the number of kinds of organisms at any given time and place.*

3 Fossils

Overview

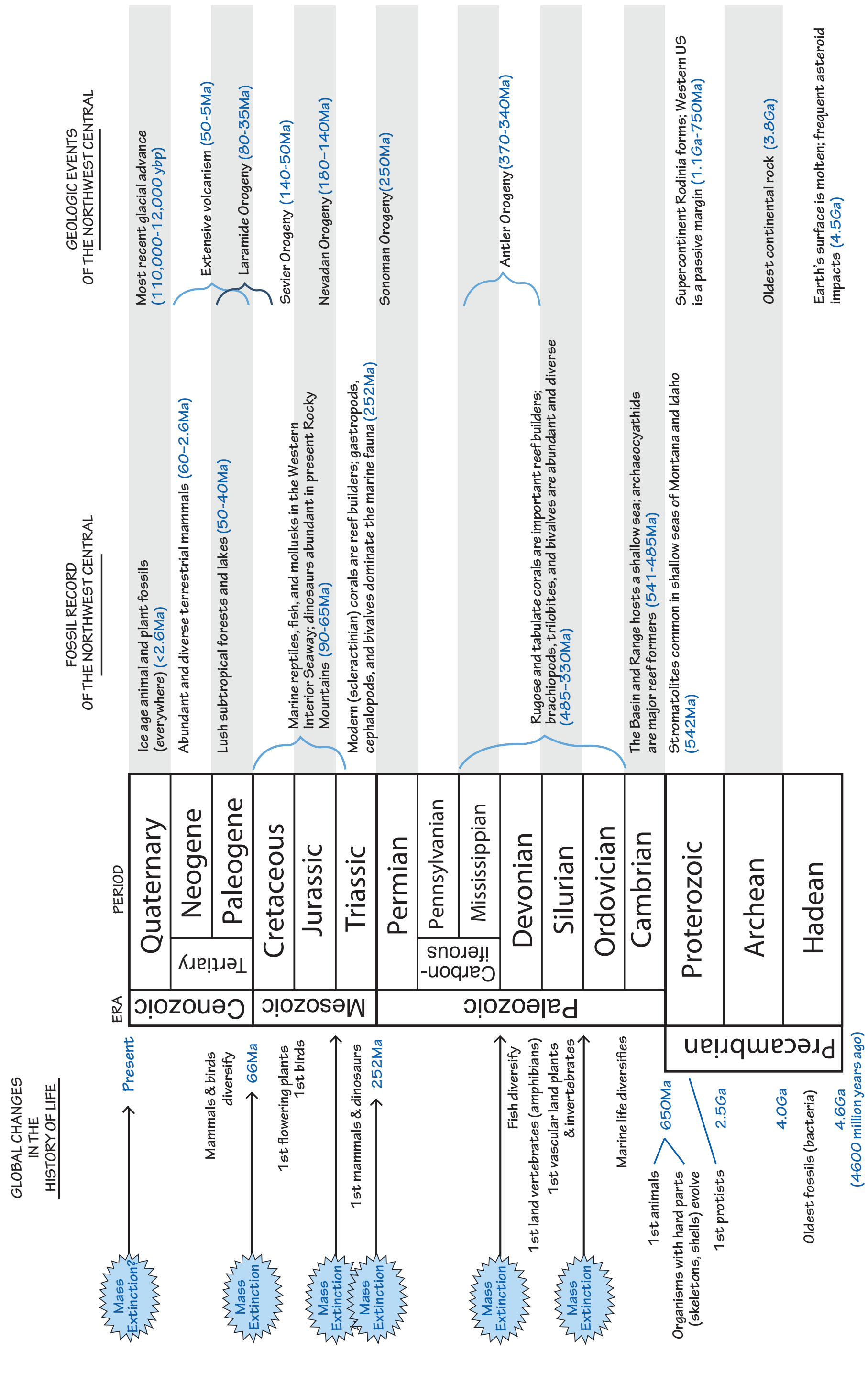


Figure 3.1: The history of life in relation to global and regional geological events and the fossil record of the Northwest Central US (Time scale is not to scale).

Fossils 3

Region 1

Fossils of the Northwest Central US

The rocks of the Northwest Central United States contain abundant and spectacular fossils, and preserve an excellent fossil record of many aspects and intervals in the history of life (*see Figure 3.1*). Indeed, this area contains some of the most spectacular fossil deposits in the world, and in many places, fossils are almost everywhere. In the remainder of this chapter, we will highlight the major types of fossils present in most of the geologic periods represented by rocks in each state. The references at the end of the chapter should be consulted for details, especially for identifying particular fossils you might find.

Fossils of the Central Lowland
Region 1

The Central Lowland region composes the middle part of the North American continent, centered on the Mississippi River Valley. This region as a whole includes abundant and extensive fossils from the early **Paleozoic** (for example, in Ohio, Iowa, and Wisconsin), demonstrating that the area was covered by a warm, shallow sea during much of this time.

The portion of the Central Lowland region represented in the Northwest Central States—eastern Nebraska, eastern South Dakota, and eastern North Dakota—has very few Paleozoic rocks at the surface. The majority of fossils found in this region are from the **Cretaceous** period, which is the youngest bedrock in the area, although younger **Quaternary** sediments also yield fossils (*see, for example, Figure 3.50*). Cores drilled from the subsurface in eastern parts of the Dakotas, however, have yielded marine fossils of early and middle Paleozoic age similar to those found elsewhere in the region (*Figure 3.2*), revealing that these areas were also covered by the same warm, shallow sea. Fossils and other subsurface information indicate that coral **reefs** were well developed in what is now North Dakota during parts of the **Silurian** and **Devonian**.

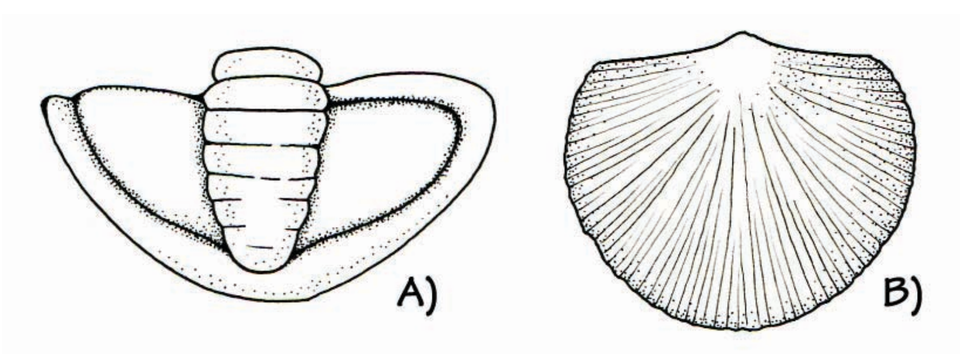


Figure 3.2: Cambrian trilobite and brachiopod found in cores from the Dakotas and Montana. A) Trilobite pygidium (tail), Lloydia valmyensis. *B) Brachiopod,* Nanorthis perilla. *Both fossils are about 5 millimeters (0.25 inches) wide.*

Paleozoic • *a geologic time interval that extends from 541 to 252 million years ago.*

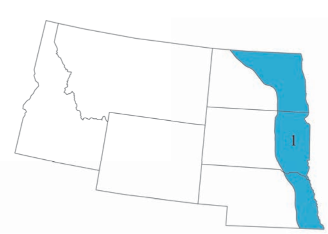
Cretaceous • *a geologic time period spanning from 144 to 66 million years ago.*

Quaternary • *a geologic time period that extends from 2.6 million years ago to the present.*

reef • *a feature lying beneath the surface of the water, which is a buildup of sediment or other material built by organisms, and which has positive relief from the sea floor.*

Silurian • *a geologic time period spanning from 443 to 419 million years ago.*

Devonian • *a geologic time period spanning from 419 to 359 million years ago.*



3 Fossils

Region 1

Pennsylvanian rocks outcrop in easternmost Nebraska (in Cass, Otoe, and Sarpy counties), and contain a diversity of marine fossils, including **foraminifera**, **brachiopods**, **bryozoans**, **cephalopods**, **crinoids**, **gastropods**, **bivalves**, **trilobites**, corals, and the teeth of early **sharks** (*Figures 3.3–3.12*). The Beil Limestone, for example, is a rock layer containing abundant corals; it occurs in Cass County, Nebraska, and also extends into Mills and Montgomery counties in Iowa, Holt County in Missouri, and Doniphan, Atchison, Greenwood, and Douglas counties in Kansas (*Figure 3.13*).

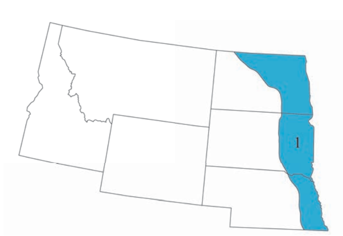
Pennsylvanian • *a subperiod of the Carboniferous, spanning from 323 to 299 million years ago.*

foraminifera • *a class of aquatic protists that possess a calcareous or siliceous exoskeleton.*

bryozoan • *a marine or freshwater colonial invertebrate animal characterized by an encrusting or branching calcareous skeleton from which multiple individuals (zooids) extend from small pores to filter-feed using crowns of tentacles (lophophores).*

cephalopod • *a marine invertebrate animal characterized by a prominent head, arms and tentacles with suckers, and jet propulsion.*

crinoid • *a marine invertebrate animal characterized by a head (calyx) with a mouth surrounded by feeding arms.*



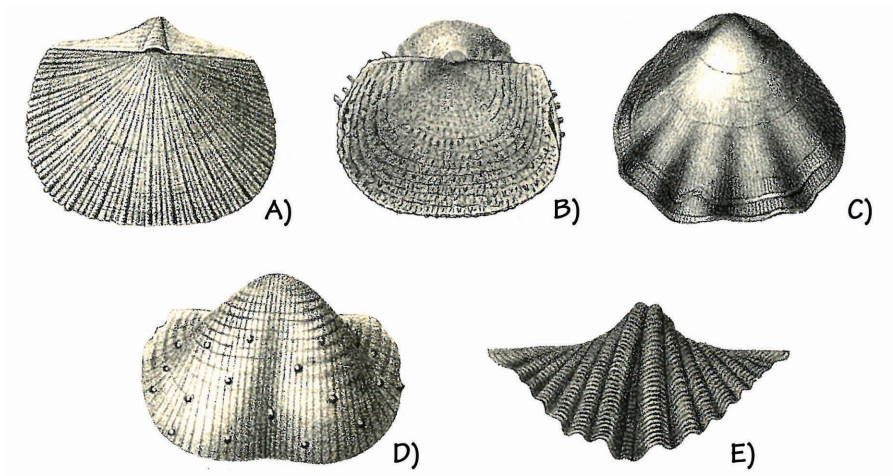


Figure 3.3: Pennsylvanian brachiopods from eastern Nebraska. A) Hemipronites crassus. *B)* Parajuresania nebrascensis. *C)* Syntrilasma hemiplicata. *D)* "Productus" costatus. *E)* Punctospirifer kentuckensis. *All specimens are 3–4 centimeters (1.25–1.5 inches) wide.*

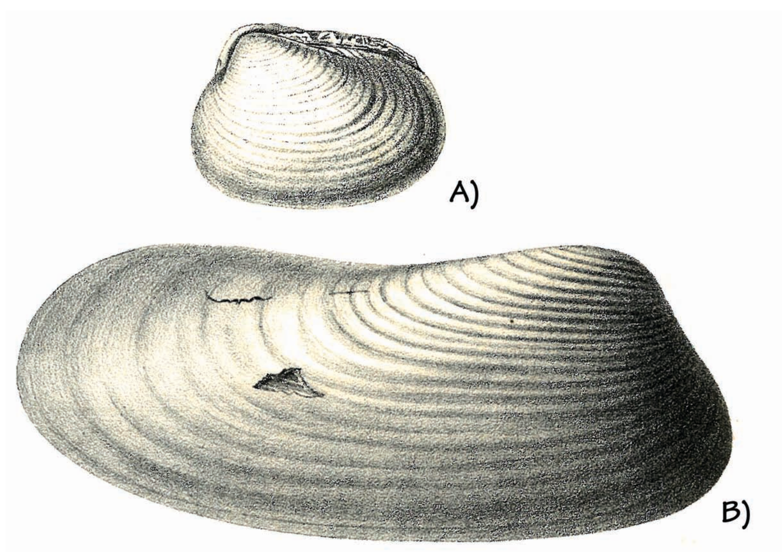
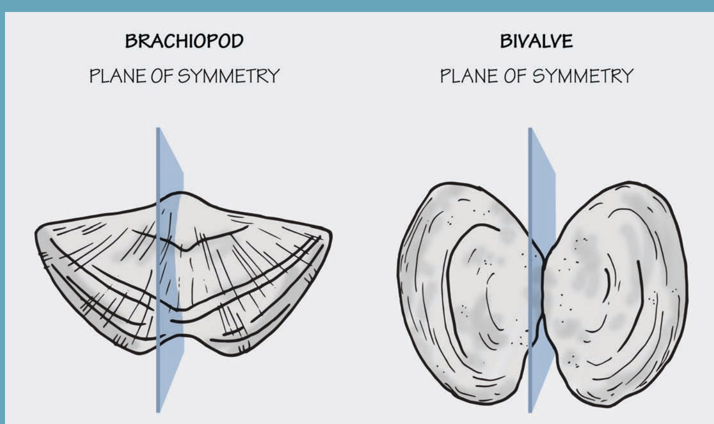


Figure 3.4: Pennsylvanian bivalves from eastern Nebraska. A) Allorisma subcuneata*, about 3 centimeters (1.25 inches) wide. B)* Edmondia aspinwallensis*, about 9 centimeters (3.5 inches) wide.*

Region 1

Brachiopods

Brachiopods are filter-feeding animals that have two shells and are superficially similar to bivalves (such as clams). Instead of being mirror images between shells (symmetrical like your hands), brachiopod shells are mirror images across each shell (symmetrical like your face). Internally, brachiopods are substantially different from bivalves, with a lophophore (filter-feeding organ made of thousands of tiny tentacles), and a small and simple gut and other organs. Bivalves, in contrast, have a fleshier body and collect their food with large gills.



The difference between the shells of a typical brachiopod (left) and a typical bivalve mollusk (right). Most brachiopods have a plane of symmetry across the valves (shells), whereas most bivalves have a plane of symmetry between the valves.

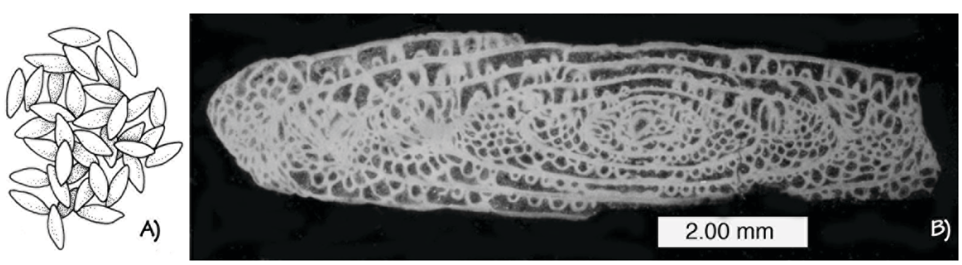


Figure 3.5: Single-celled fusulinid foraminifera from the Permian. A) A cluster of the shells, about the size and shape of large rice grains. B) Photograph of a cross-section through a single fusulinid, as seen through a microscope. Fusulinids can be a major component of carbonate rocks, composing up to 70% of some limestones in eastern Nebraska.

gastropod • *a marine, freshwater, or terrestrial invertebrate animal characterized by a single, coiled, calcareous shell, a muscular foot for gliding, and internal asymmetry caused by torsion.*

bivalve • *a marine or freshwater invertebrate animal characterized by right and left calcareous shells (valves) joined by a hinge.*

trilobite • *an extinct marine invertebrate animal characterized by a three-part body and a chitinous exoskeleton divided longitudinally into three lobes.*

shark • *a large fish characterized by a cartilaginous skeleton and five to seven gill slits on the side of the head.*

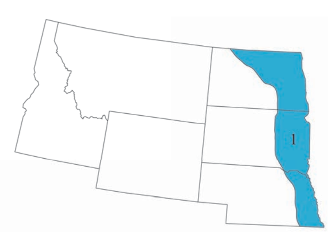


Figure 3.6: Pennsylvanian bryozoan from eastern Nebraska. Fenestella *sp., about 4 centimeters (1.5 inches) wide.*

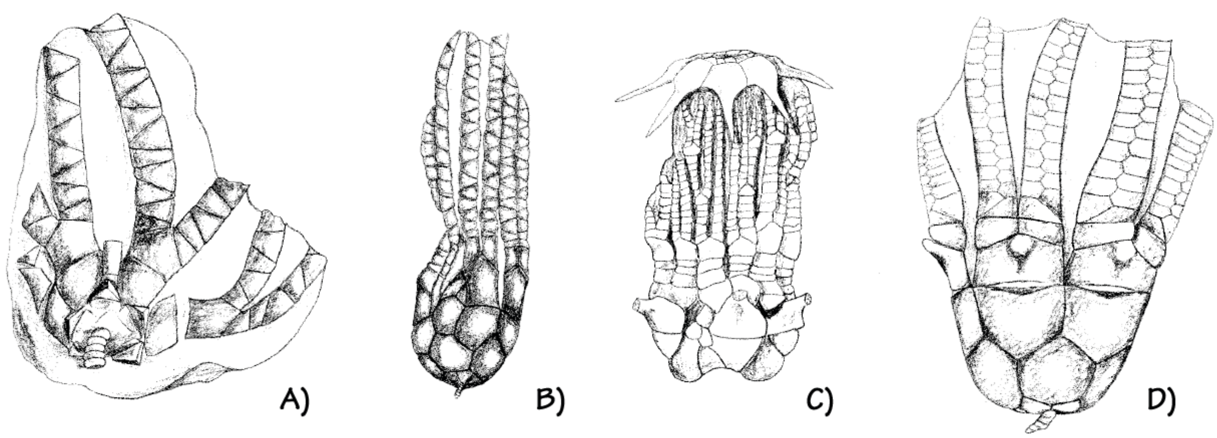


Figure 3.7: Pennsylvanian crinoid crowns from eastern Nebraska. A) Stellarocrinus. *B)* Apographiocrinus. *C)* Stenopeerinus. *D)* Exaetocrinus. *All specimens are about 4–5 centimeters (1.75–2 inches) tall.*

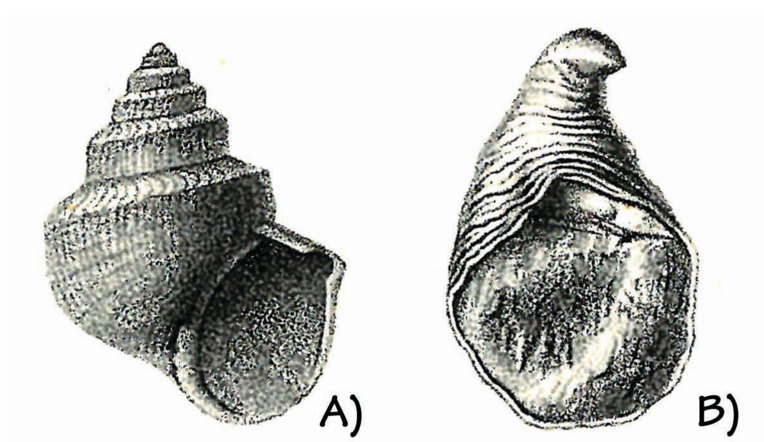
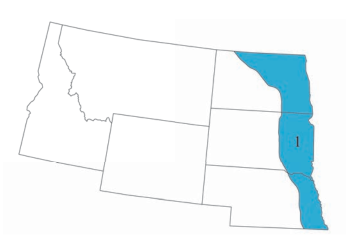


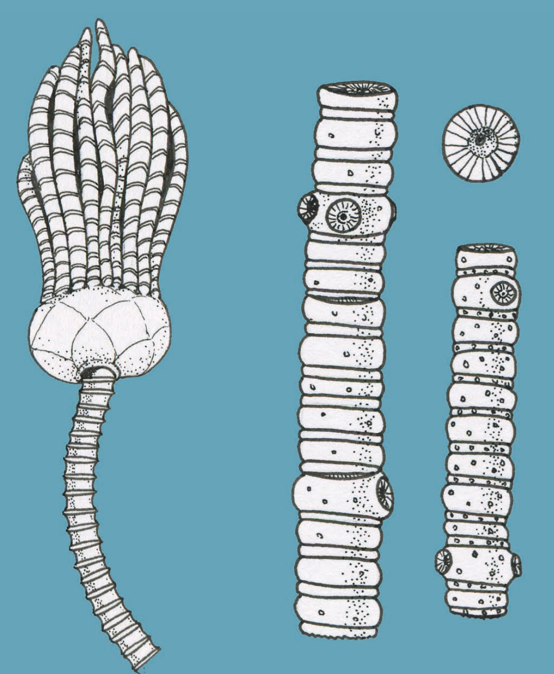
Figure 3.8: Pennsylvanian gastropods from eastern Nebraska. A) Hypselentoma perhumerosa, *about 2 centimeters (0.8 inches) tall. B)* Platyceras nebrascensis, *about 3 centimeters (1.25 inches) tall.*



Region 1

Crinoids

Crinoids are *echinoderms*, related to sea urchins and sea stars. These invertebrate animals feed by using their arms to filter food out of the water. Most are attached to the sediment by a stalk that ends in a root-like structure called the holdfast—however, some forms are free floating. Crinoid fossils are most commonly found as "columnals," pieces of the stalk that hold the head (*calyx*) above the surface. The calyx and the holdfast are only occasionally preserved as fossils.



Crown and stem, about 15 centimeters (6 inches) long.

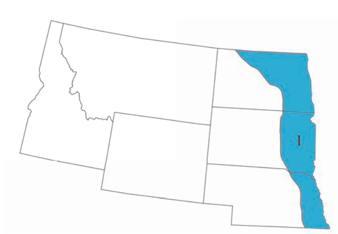
Stem fragments.

The northeastern corner of North Dakota (Pembina County) contains the Central Lowland's only **Jurassic** bedrock. By that time, a shallow sea had flooded the region again, and fossil marine gastropods, bivalves, and crinoids are found in the state's Jurassic deposits. Cretaceous rocks occurring in the Central Lowland, as well as the few **Cenozoic** deposits that extend into northeastern Nebraska, are identical to those found in the Great Plains region and will be discussed in detail in the next section.

echinoderm • *a member of the Phylum Echinodermata, which includes starfish, sea urchins, and crinoids.*

Jurassic • *the geologic time period lasting from 201 to 145 million years ago.*

Cenozoic • *the geologic time period spanning from 66 million years ago to the present.*



3 Fossils

Region 1

Cephalopods

Cephalopods, such as squid, octopods, nautiloids, ammonoids, and belemnites, are mollusks with tentacles and beak-shaped mouths for catching prey. Some cephalopods such as belemnites and living cuttlefish have internal shells, while others have straight or coiled shells, such as those of ammonoids or nautiloids. Still other cephalopods, such as the octopus, have no shell. The mass extinction at the end of the Cretaceous (famous for eliminating the non-avian dinosaurs), also eliminated belemnites and ammonoids, which had been extremely diverse during the Mesozoic.

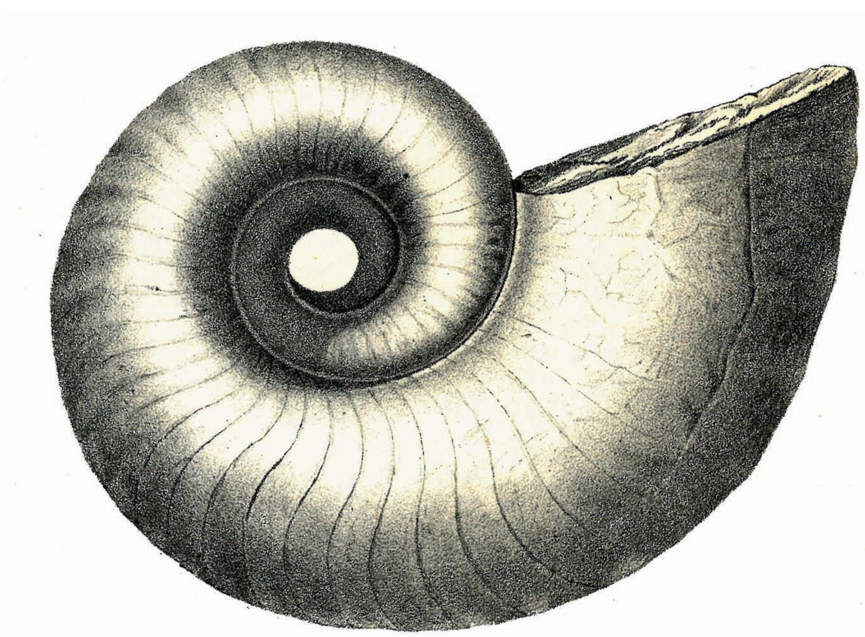
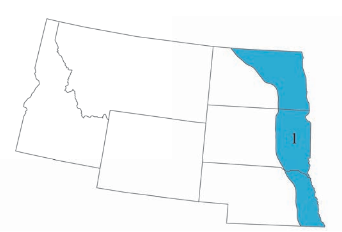


Figure 3.9: Pennsylvanian nautiloid cephalopod from eastern Nebraska, Titanoceras ponderosus, *about 15 centimeters (6 inches) in diameter.*



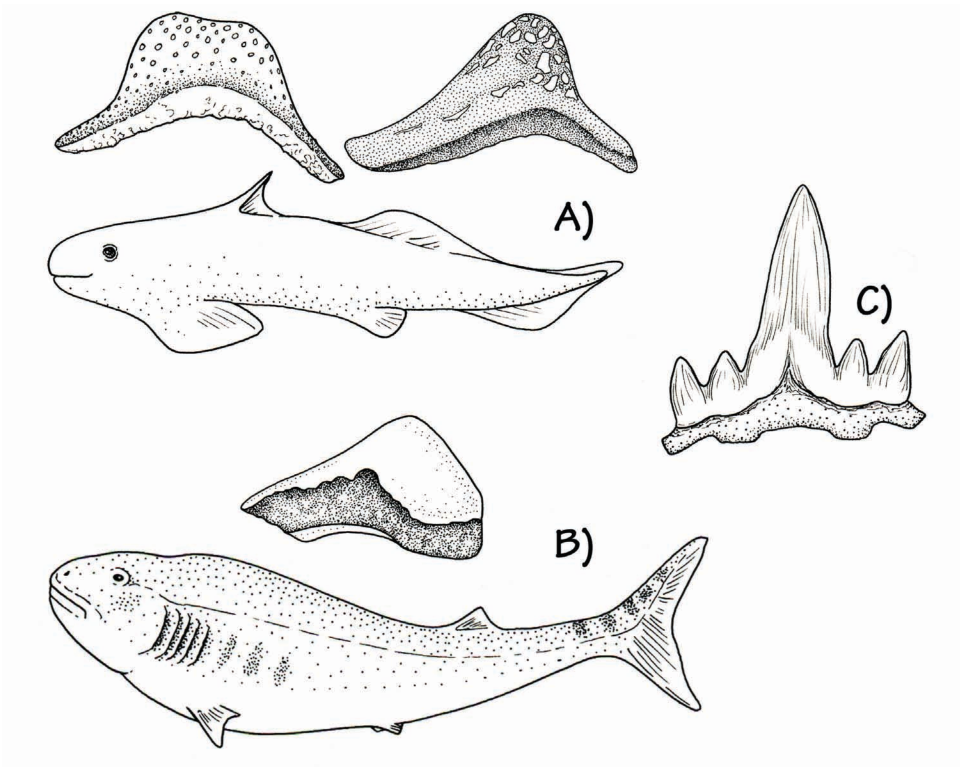


Figure 3.10: Early sharks from the Pennsylvanian of Nebraska. A) Helodus simplex, teeth and restoration. Teeth about 2 centimeters (0.8 inches) wide; body about 30 centimeters (1 foot) long. B) Orodus sp., tooth and restoration. Tooth about 1 centimeter (0.4 inches) wide; body about 1 meter (3 feet) long. C) Cladodus occidentalis, tooth, about 1.5 centimeters (0.5 inches) tall.

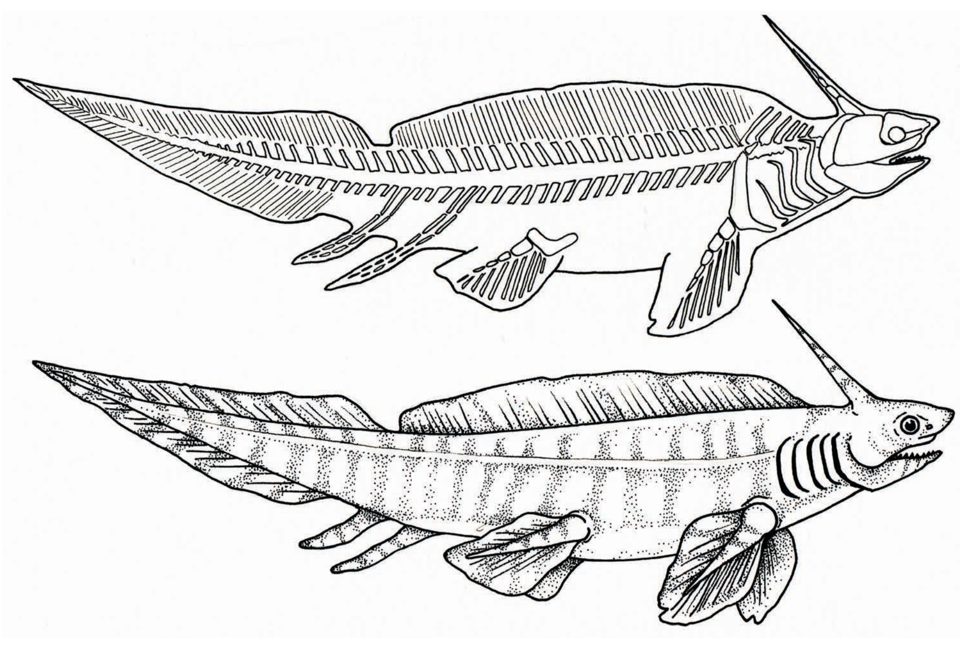
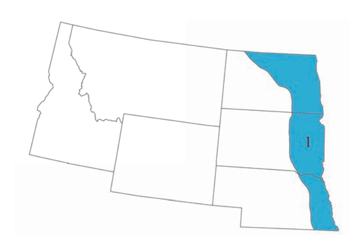


Figure 3.11: Skeleton and restoration of Xenacanthus. Xenacanths were freshwater sharks that lived during the Pennsylvanian and Permian periods. Body about 30 centimeters (1 foot) long.



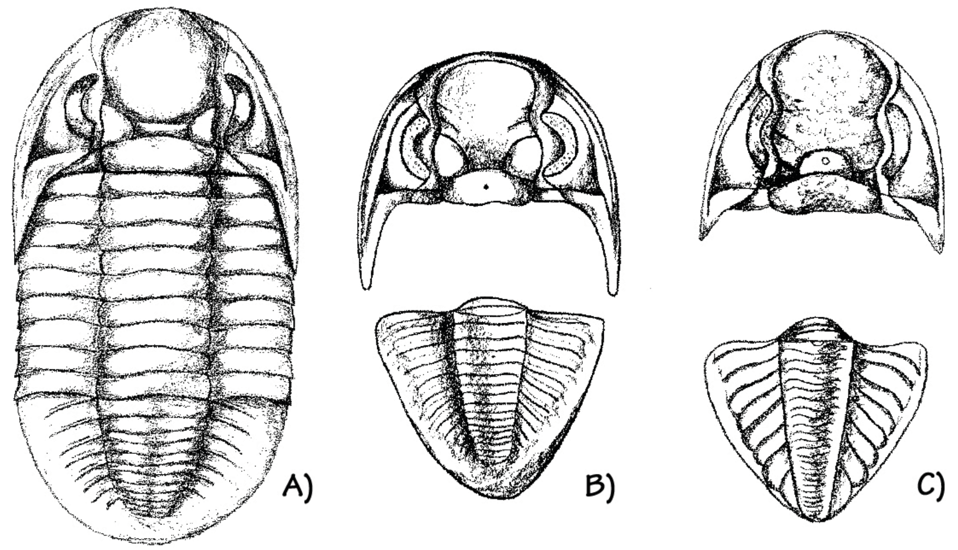


Figure 3.12: Pennsylvanian trilobites from eastern Nebraska. A) Ditomopyge*, about 2 centimeters (0.8 inches) long. B)* Ameura *cephalon (head) and pygidium (tail), each about 1 centimeter (0.4 inches) in maximum width. C)* Anisopyge *cephalon (head) and pygidium (tail), each about 1 centimeter (0.4 inches) in maximum width.*

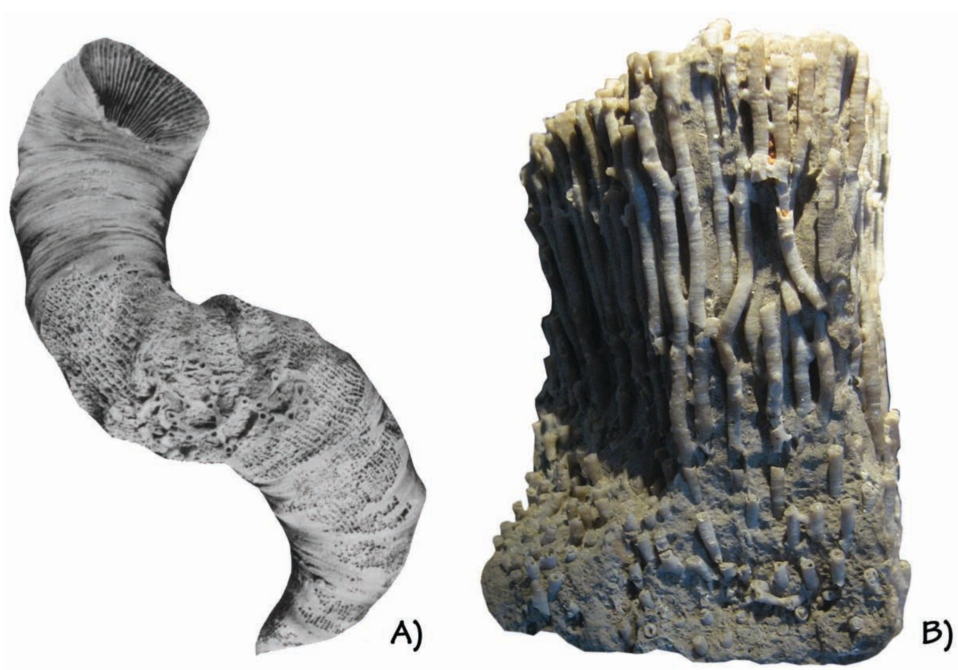
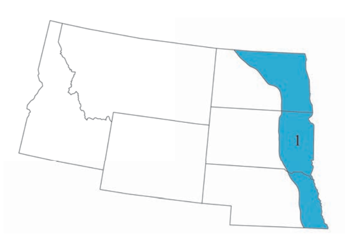


Figure 3.13: Common corals of the Beil Limestone. A) Solitary rugose ("horn") coral, Caninia torquata*, Upper Pennsylvanian. Specimen about 14 centimeters (4.5 inches) long. B) Colonial tabulate coral,* Syringopora *sp. Specimen is about 6 centimeters (2.3 inches) tall.*



Trilobites

Trilobites are iconic Paleozoic fossils, but were more common in the Cambrian and Ordovician than in later periods. They were arthropods, and had well-defined head, tail, and thoracic (leg-bearing) segments. Most had large compound eyes, often with lenses that are visible to the naked eye. In life, they had antennae like many other arthropods, but since these were not mineralized, they only fossilize under exceptional circumstances. Many could roll up for protection, and several species also had large spines.

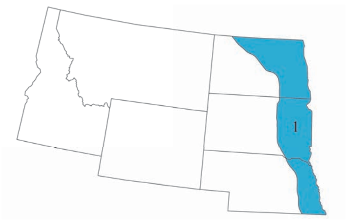
Corals

Corals are *sessile* relatives of jellyfish and sea anemones. They possess stinging tentacles, which they use to feed on small planktonic prey. Each group of coral possesses distinctly shaped "cups" that hold individual animals, or polyps. Colonial corals live in colonies of hundreds or even thousands of individuals that are attached to one another. Solitary coral lives independently, as a single isolated polyp.

Rugose corals were both colonial and solitary (solitary forms are often called "horn corals"). Tabulate corals were exclusively colonial and produced a variety of shapes, including sheetlike and chainlike forms. These corals receive their name from the table-like horizontal partitions within their chambers. Both rugose and tabulate corals went extinct at the end of the *Permian*. Modern corals—scleractinians—appeared in the Triassic, and include both solitary and colonial species. Many scleractinian corals have photosynthetic symbiotic algae in their tissues, called zooxanthellae. This algae provides nutrition to the coral polyps, helping them to grow more rapidly.

sessile • *unable to move, as in an organism that is permanently attached to its substrate.*

Permian • *the geologic time period lasting from 299 to 252 million years ago.*



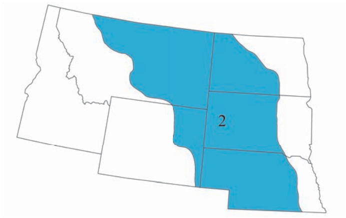
Region 2

uplift • *upward movement of the crust due to compression, subduction, or mountain building.*

erosion • *the transport of weathered materials.*

Precambrian • *a geologic time period that spans from the formation of Earth (4.6 billion years ago) to the beginning of the Cambrian (541 million years ago).*

sandstone • *sedimentary rock formed by cementing together grains of sand.*



Fossils of the Great Plains
Region 2

Paleozoic rocks occur at the surface in the Great Plains only because of tectonic forces that have **uplifted** the younger rocks and caused them to **erode**, exposing the older rocks beneath. The Black Hills of western South Dakota are a particularly striking example of this phenomenon. The center of the Black Hills consists of **Precambrian** igneous rocks, surrounded by a rim of Paleozoic sedimentary rocks. The oldest sedimentary rock formation in the Black Hills is the Deadwood Formation, a layer of late Cambrian **sandstone** that outcrops around the town of Deadwood. The Deadwood Formation contains abundant marine fossils, including trilobites, brachiopods, trace fossils (burrows) (*Figure 3.14*), and bony plates from one of the oldest known armored fishes (*Anatolepsis*). Cambrian trilobites and brachiopods are also known from rocks in central Montana (*see Figure 3.2*).

See Chapter 4: Topography for more information about the formation of the Black Hills.

Figure 3.14: Skolithos *burrows from the Deadwood Formation, Deadwood, South Dakota. Rocks containing abundant* Skolithos *are sometimes called "pipe rock." The organism that made these burrows is unknown, but their shape suggests a worm-like creature that lived in vertical burrows.*

The **Ordovician** Whitewood and **Mississippian** Pahasapa **limestones** overlie the Deadwood, forming concentric rings farther from the core of the Black Hills. These younger layers also contain abundant and diverse marine fossils, including corals, snails, and cephalopods (*Figure 3.15*). Mississippian-aged rocks in this part of the Great Plains are correlated—determined to be the same age—mostly by using tiny fossils called **conodonts** as index fossils. Mississippian-aged rocks in North Dakota include the Bakken Shale, which is an important **oil**-producing layer. The oil comes from the altered remains of organisms that lived in a shallow sea.

See Chapter 6: Energy to learn more about oil shales and petroleum resources throughout the Northwest Central.

Figure 3.15: Fossils from the Ordovician Whitewood and Mississippian Pahasapa Formations of South Dakota. A) Tabulate coral, Favosites, *Pahasapa Formation. Specimen is about 27 centimeters (10.5 inches) long. B) Cephalopod,* Cyclendoceras annulatus, *Whitewood Formation. Specimen is about 79 centimeters (31 inches) long.*

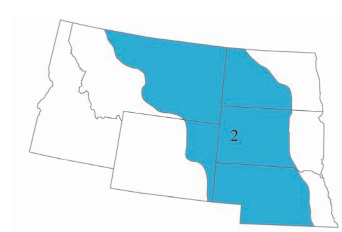
Ordovician • *a geologic time period spanning from 485 to 443 million years ago.*

Mississippian • *a subperiod of the Carboniferous, spanning from 359 to 323 million years ago.*

limestone • *a sedimentary rock composed of calcium carbonate ($CaCO_3$).*

conodont • *an extinct, eel-shaped animal classified in the class Conodonta and thought to be related to primitive chordates.*

oil • *See petroleum: a naturally occurring, flammable liquid found in geologic formations beneath the Earth's surface and consisting primarily of hydrocarbons*

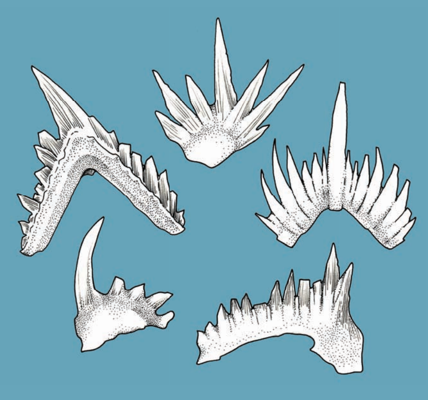


arthropod • *an invertebrate animal, belonging to the Phylum Arthropoda, and posessing an external skeleton (exoskeleton), body segments, and jointed appendages.*

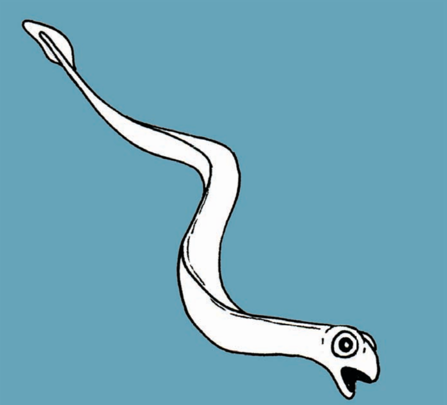
sponge • *a marine invertebrate belonging to the Phylum Porifera, and characterized by a soft shape with many pores and channels for water flow.*

Conodonts

Conodonts are tiny, tooth-shaped microfossils (0.2–5 millimeters long), found in Cambrian- through Triassic-aged marine rocks. They have long been among the most important index fossils in these rocks, allowing the latter to be dated through biostratigraphy. For many years, paleontologists did not know what kind of animal they belonged to, but in 1983 the discovery of a whole conodont animal in Scotland revealed that they belonged to small, fish-like animals that were distant relatives of bony fish.



Isolated conodont elements (Silurian).



Restoration of a live conodont animal. Length 2–4 centimeters (1–2 inches).

The Mississippian Bear Gulch Beds of central Montana reveal a rare preservational "window" into the marine life of this time. The Bear Gulch Beds consist of layers of fine-grained limestone (similar to the Jurassic Solnhofen limestone in Germany that preserves many spectacular fossils, including *Archaeopteryx*, the oldest known bird). These rocks are exposed at the surface only because of the Potter Creek Dome, an uplifted outcrop located about 30 kilometers (18.6 miles) northeast of the Big Snowy Mountains in Fergus County, Montana. Bear Gulch preserves one of the most diverse fossil fish assemblages in the world (*Figure 3.16*), as well as fossils of many beautifully-preserved soft-bodied organisms, including **arthropods**, snails (gastropods), sea stars, nautiloid cephalopods, brachiopods, **sponges**, worms, and algae (*Figure 3.17*).

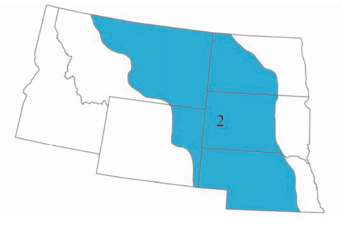


Figure 3.16: The small shark Falcatus falcatus. *A) Well-preserved specimen from the Mississippian Bear Gulch Beds. B) Life restoration.* Falcatus *reached 25–30 centimeters (10–12 inches) as an adult, and is the most abundant shark preserved in the Bear Gulch Beds. A peculiar feature is the dorsal spine on the top of some individuals, interpreted to be mature males; it may have been used during mating.*

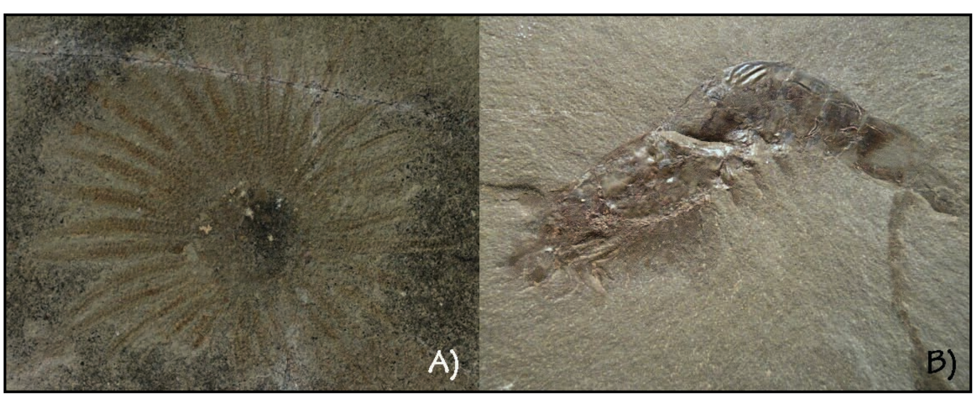
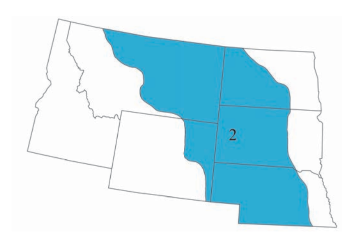


Figure 3.17: Invertebrates from the Bear Gulch Formation, Montana. A) Lepidasterella*, a starfish, 10.5 centimeters (4 inches) in diameter. B)* Aenigmacaris*, a shrimp, 10.2 centimeters (4 inches) long.*



3 Fossils

Region 2

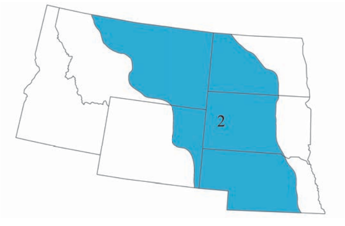
shale • *a dark, fine-grained, laminated sedimentary rock formed by the compression of successive layers of silt- and clay-rich sediment.*

delta • *a typically wedge-shaped deposit formed as sediment is eroded from mountains and transported by streams across lower elevations.*

silt • *fine granular sediment most commonly composed of quartz and feldspar crystals.*

floodplain • *the land around a river that is prone to flooding.*

dinosaur • *a member of a group of terrestrial reptiles with a common ancestor and thus certain anatomical similarities, including long ankle bones and erect limbs.*



In yet another concentric band even farther from the core of the Black Hills, fossiliferous early Jurassic-aged rocks outcrop in in eastern Wyoming, eastern Montana, and western South Dakota. These Jurassic sediments eroded from the highlands to the north and west, and record several cycles of sea level rise and fall across the region. These limestones, sandstones, and **shales** are rich in fossil cephalopods, oysters, and other marine invertebrates (*Figure 3.18*).

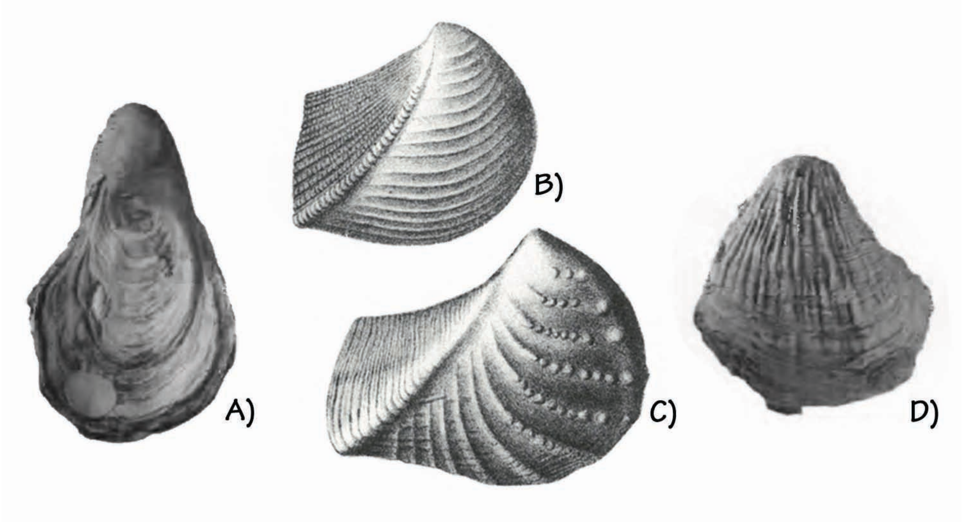


Figure 3.18: Jurassic bivalves of the Western Interior Seaway. A) Gryphaea nebrascensis. *B) and C)* Trigonia *sp. D)* Gryphaea impressimarginata. *All specimens about 5–8 centimeters (2–3 inches) in maximum width.*

Bivalves

Clams and their relatives, such as mussels, scallops, and oysters, are mollusks possessing a pair of typically symmetrical shells. Most are filter feeders, collecting food with their gills. Bivalves are among the most important marine fossils of the Pacific margin. Paleozoic bivalves typically lived on the surface of the sediment ("epifaunally"), but in the Mesozoic they evolved the ability to burrow more deeply into the sediment and live "infaunally." This innovation led to the rapid evolution of a large number of groups present in today's ocean.

By the late Jurassic, the shallow sea had begun to retreat to the east, and marine deposits of the middle Jurassic were replaced by **deltas** and freshwater deposits. The Morrison Formation is a layer of late Jurassic-aged rock exposed across a wide swath of the Rocky Mountains and Great Plains (*Figure 3.19*) The **silty** sediments of the Morrison were deposited by eastward-flowing rivers sweeping across broad, swampy **floodplains**, and contain extraordinary accumulations of **dinosaur** bones, as well as fossils of land plants including **conifers**, **cycads**, and **ginkgoes**, and also fish, frogs, lizards, crocodiles, turtles, and small mammals. The Morrison Formation's abundant dinosaurs include some of the most famous, such as *Apatosaurus*, *Stegosaurus, Allosaurus, Diplodocus, Camarasaurus* and many more (*Figure 3.20*).

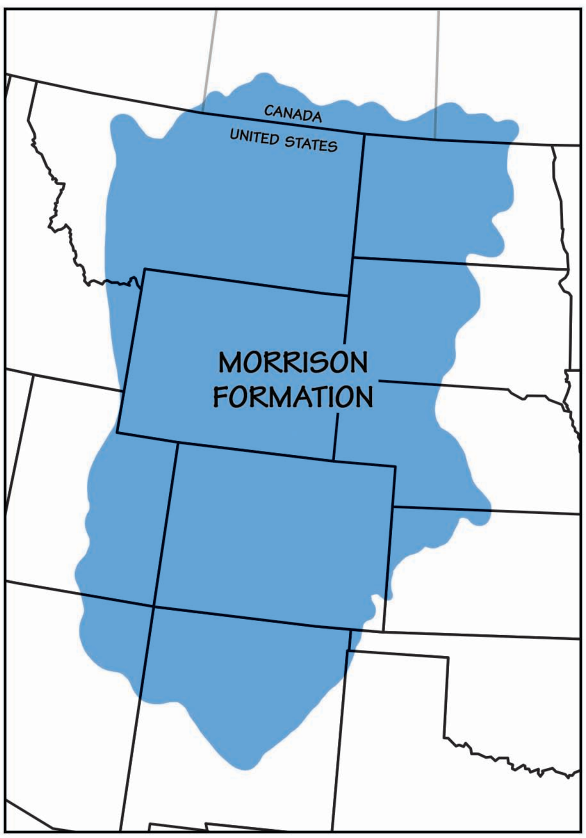


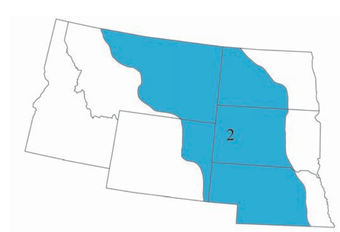
Figure 3.19: Geographic extent of the Jurassic-aged Morrison Formation.

In the Cretaceous, global sea levels rose, spreading shallow epicontinental seas over much of the continent. The Western Interior Seaway stretched across the center of North America from the Gulf of Mexico to the Arctic Ocean, and from the foot of the still-forming Rocky Mountains to as far east as Iowa. It covered most of the Dakotas and Nebraska, as well as eastern Montana, east-central Wyoming, and eastern Colorado. An abundance of aquatic life thrived there for tens of millions of years, and most of the bedrock in those states is of Cretaceous age. Over the course of the Cretaceous, the shores of this seaway

conifer • *a woody plant bearing cones that contain its seeds.*

cycad • *a palm-like, terrestrial seed plant (tree) characterized by a woody trunk, a crown of stiff evergreen leaves, seeds without protective coatings, and no flowers.*

ginkgo • *a terrestrial tree belonging to the plant division Ginkgophyta, and characterized by broad fan-shaped leaves, large seeds without protective coatings, and no flowers.*



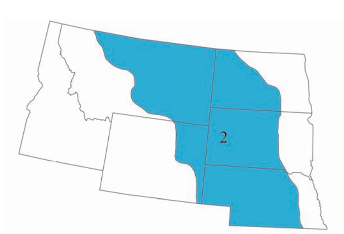
Region 2

chalk • *a soft, fine-grained, easily pulverized, white-to-grayish variety of limestone, composed of the shells of minute planktonic single-celled algae.*

carbonate rocks • *rocks formed by accumulation of calcium carbonate, often made of the skeletons of aquatic organisms.*

coccolithophore • *a marine phytoplankton with a skeleton made up of microscopic calcareous disks or rings, and forming much of the content of chalk rocks.*

inland sea • *a shallow sea covering the central area of a continent during periods of high sea level.*



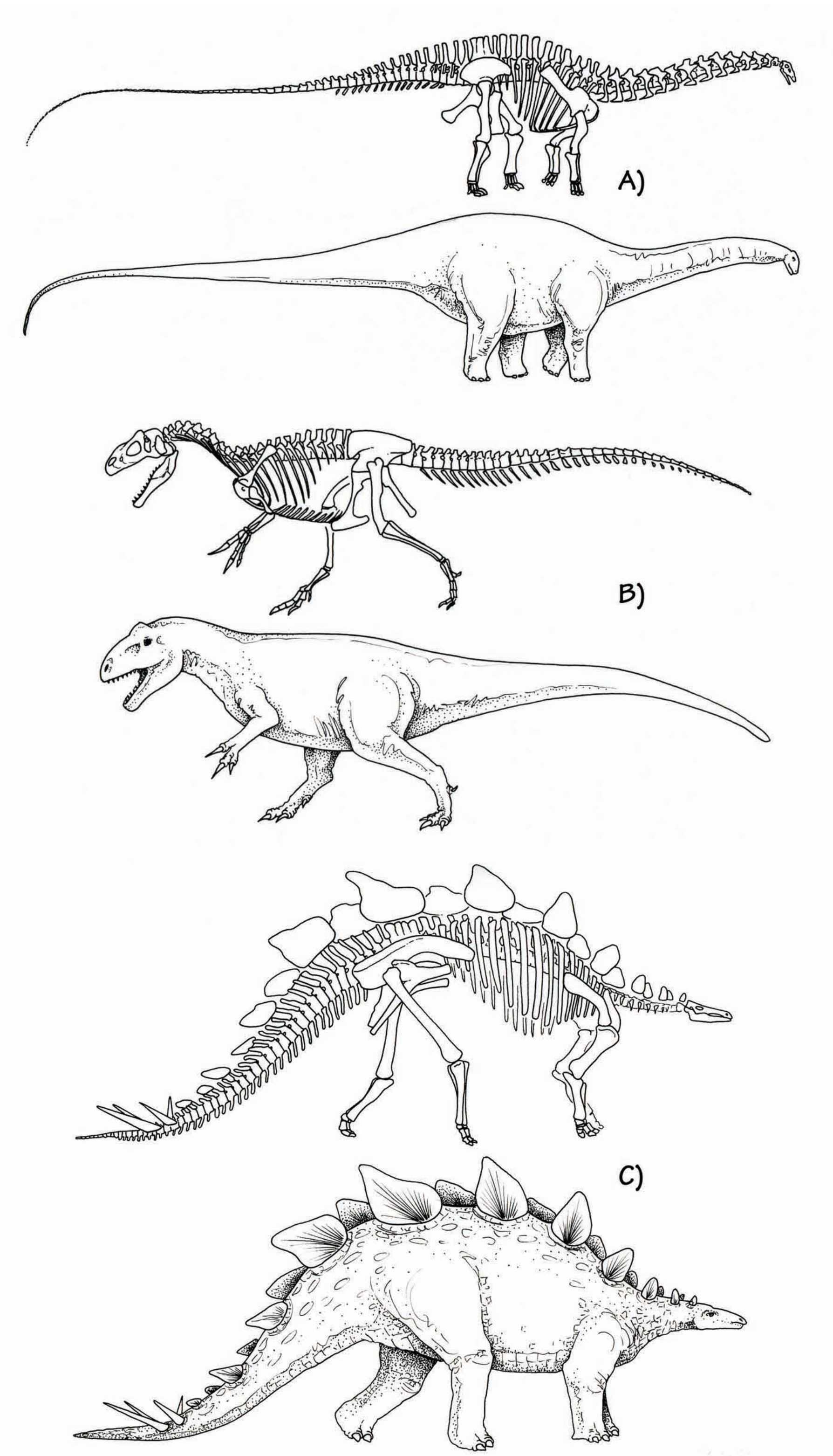


Figure 3.20: Some common and familiar dinosaurs from the Morrison Formation. A) Apatosaurus *(about 23 meters [75 feet] long), skeleton and restoration; B)* Allosaurus*, (about 8.5 meters [28 feet] long), skeleton and restoration; C)* Stegosaurus *(about 9 meters [30 feet] long), skeleton and restoration.*

swept back and forth, resulting in the deposition of alternating layers of marine and terrestrial rocks. Deeper waters toward the center of the Seaway led to the deposition of **chalk**—a **carbonate rock** made up primarily of the shells of microscopic marine algae, called **coccolithophores** (*Figure 3.21*). Today, such sediments accumulate mainly in the deep sea; during the Cretaceous, when sea levels were much higher than today, chalk accumulated throughout the extensive shallow **inland seas**. The Cretaceous period is in fact named for the abundance of chalk that accumulated during this time. (The Latin word for chalk is *creta*.) The Western Interior Seaway was also home to huge marine reptiles, including **plesiosaurs**, **mosasaurs**, and turtles (*Figures 3.22–3.24*), which are frequently found as fossils in Cretaceous rocks in Nebraska and the Dakotas, as well as bony fish, sharks, and sea birds (*Figure 3.25*).

See Chapter 1: Geologic History to learn more about the Western Interior Seaway and other North American inland seas throughout geologic time.

plesiosaur • *a member of a group of extinct long-necked Mesozoic marine reptiles.*

mosasaur • *an extinct, carnivorous, marine vertebrate reptile characterized by a streamlined body for swimming, a powerful fluked tail, and reduced, paddle-like limbs.*

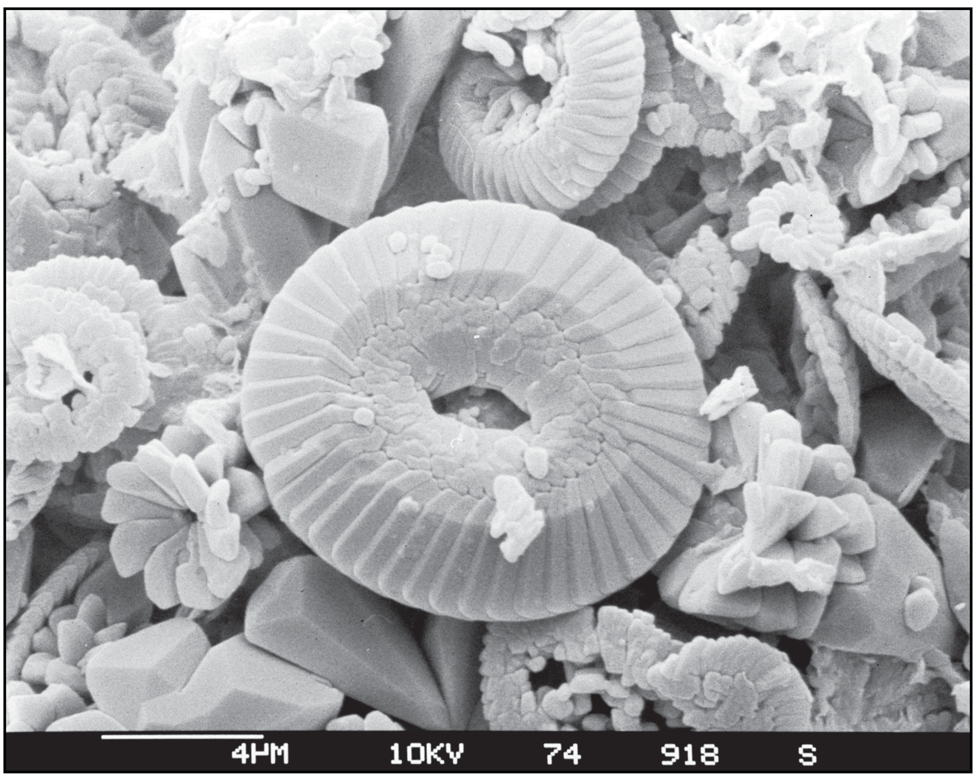
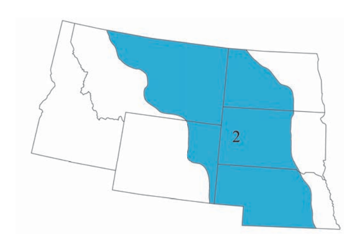


Figure 3.21: A microscopic view of chalk, showing that it is composed almost completely of the shells of protists called coccolithophores. Scale bar = 4 nanometers (4 x 10^{-9} meters; about 0.0000001575 inches).



Mesozoic • *a geologic time period that spans from 252 to 66 million years ago.*

rugose coral • *an extinct group of corals that were prevalent from the Ordovician through the Permian.*

tabulate coral • *an extinct form of colonial coral that often formed honeycomb-shaped colonies of hexagonal cells.*

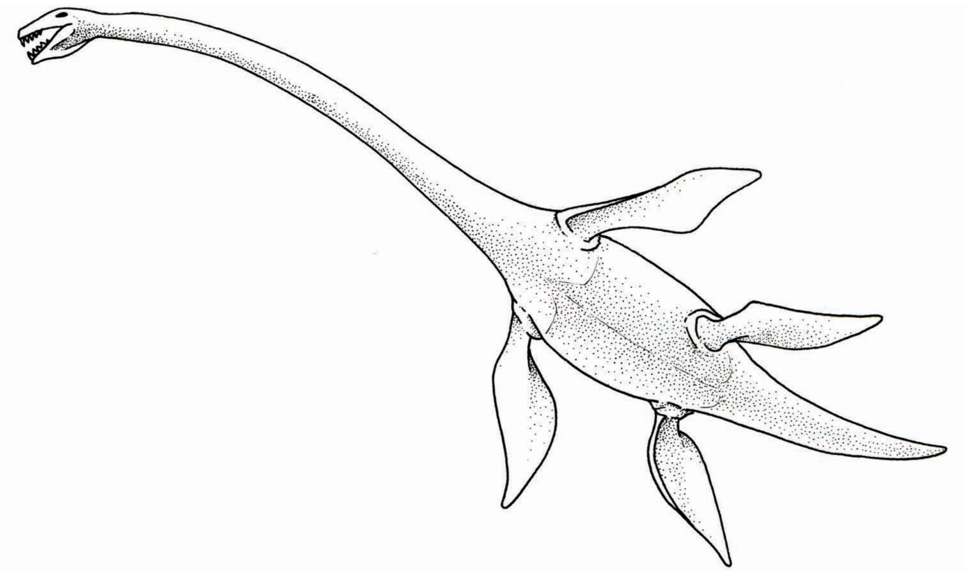


Figure 3.22: Restoration of Elasmosaurus, *a large plesiosaur from Nebraska. About 14 meters (46 feet) long.*

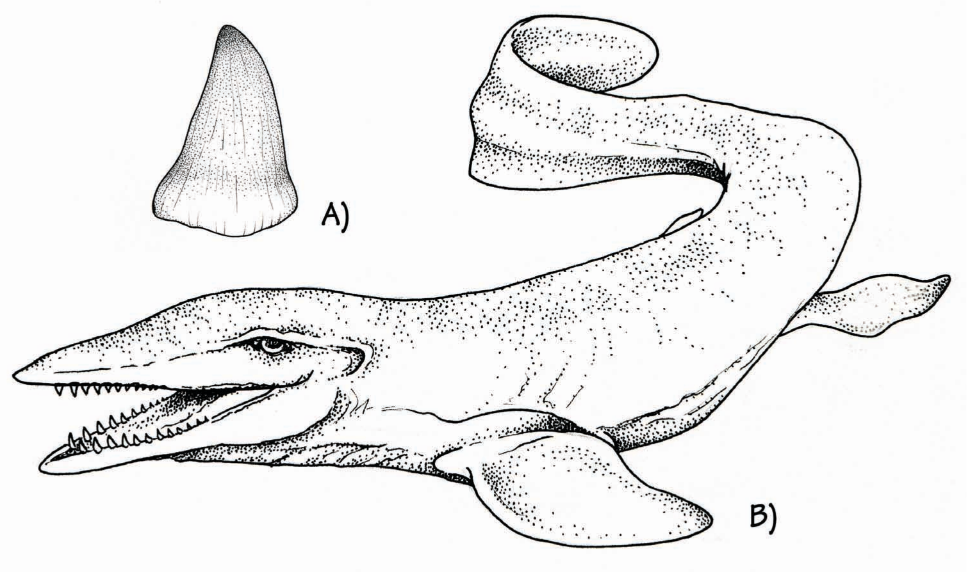
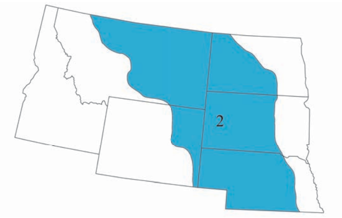


Figure 3.23: A) Mosasaur tooth, about 5 centimeters (2 inches) long. B) Restoration of the Cretaceous mosasaur Tylosaurus. *About 15 meters (50 feet) long.*



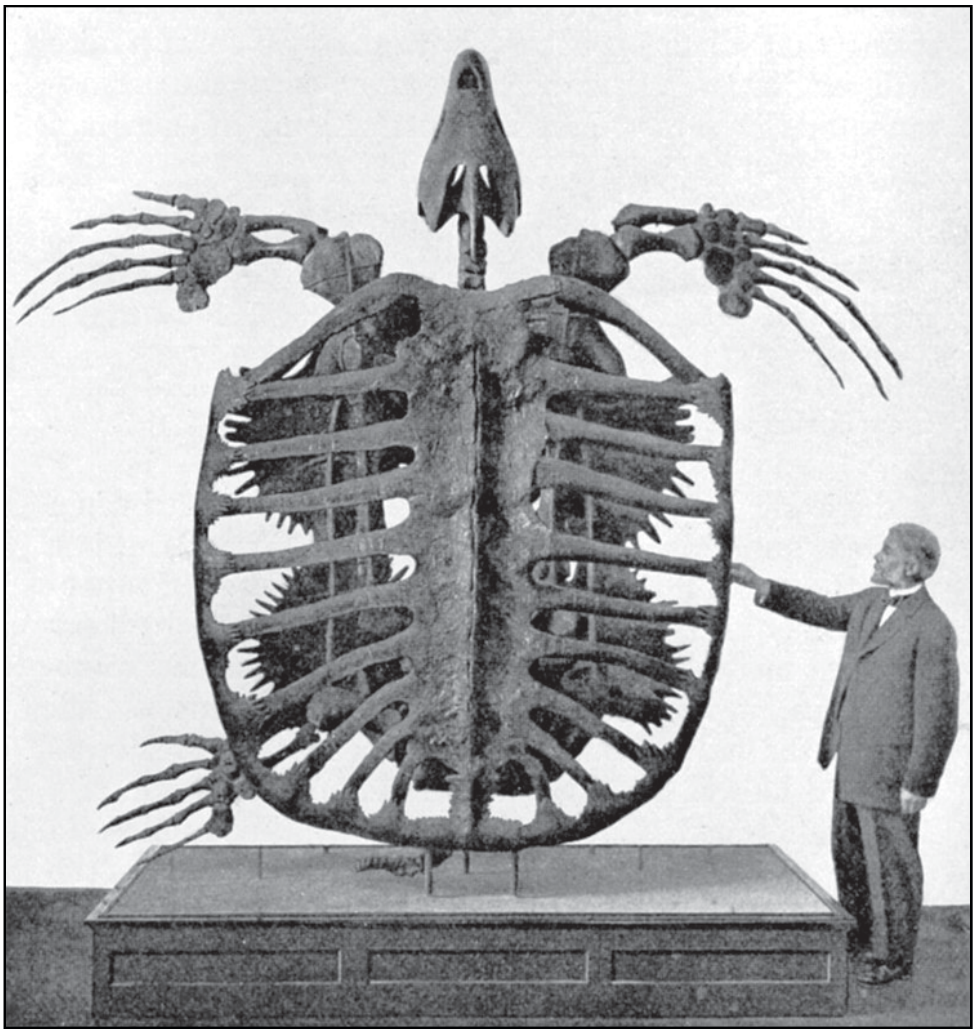


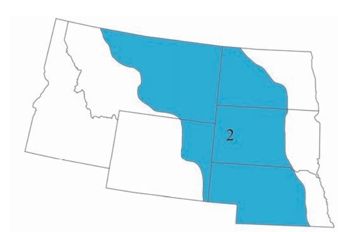
Figure 3.24: The giant marine turtle Archelon ischyros, approximately 4 meters (13 feet) long. The skeleton in this photograph is the type specimen for the species, housed in the Yale Peabody Museum.

scleractinian coral *• a colonial or solitary marine invertebrate animal characterized by an encrusting calcareous skeleton enclosing polyps that capture prey with small tentacles equipped with stinging cells (nematocysts).*

rudists *• an extinct group of box- or tube-shaped bivalves that arose during the Jurassic.*

ammonoid *• a member of a group of extinct cephalopods belonging to the Phylum Mollusca, and posessing a spiraling, tightly coiled shell characterized by ridges, or septa.*

Marine invertebrates in these **Mesozoic** seas were very different from those that had filled the seas of the Paleozoic. **Rugose** and **tabulate corals** were replaced by **scleractinians—**modern corals (*Figure 3.26*). Brachiopods declined dramatically in abundance and diversity at the end of the Paleozoic, their ecological niches being filled in many cases by bivalves. In the Cretaceous, two bizarre groups of clams were particularly abundant: **rudists** formed reefs, while inoceramids lived on flat parts of the sea floor (*Figures 3.27–3.28*). *Inoceramus* was a large, usually flat, thick-shelled bivalve with tightly interlocking shells. The largest species could reach diameters of up to 1.5 meters (5 feet)! Inoceramids were relatives of living oysters—among today's most common and well-known bivalves that cement themselves to the bottom—and were diverse and abundant during the Cretaceous. **Ammonoids** also became



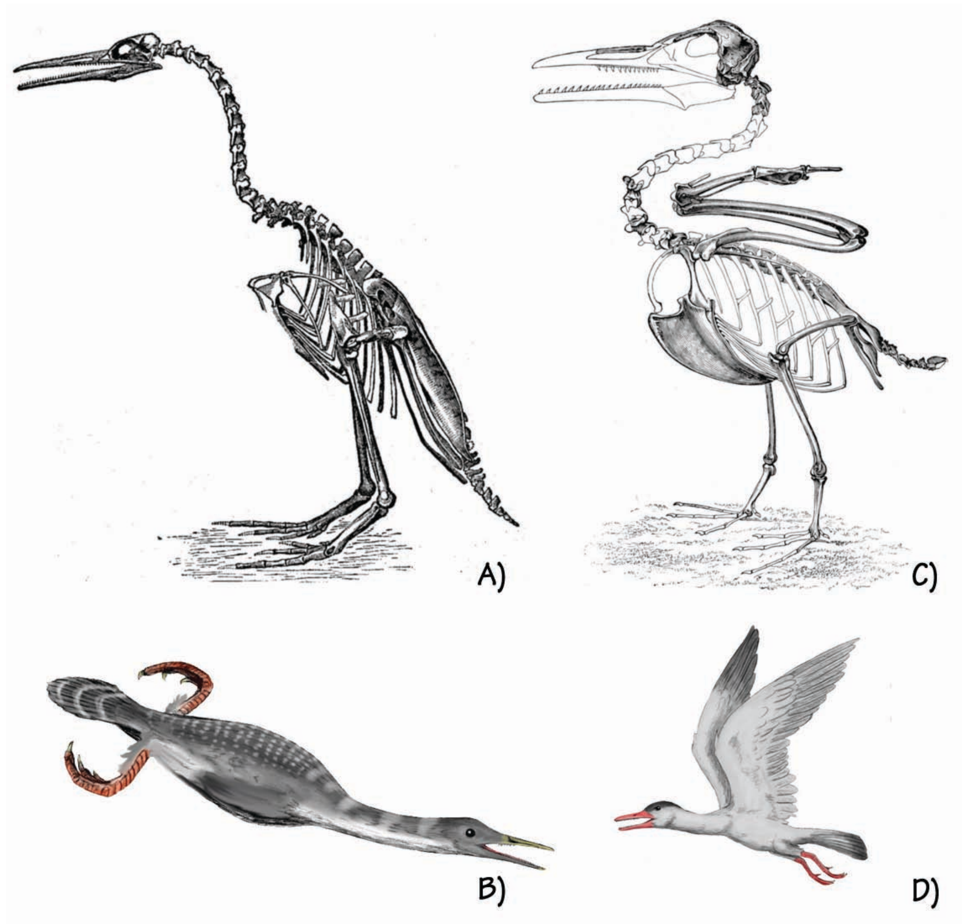
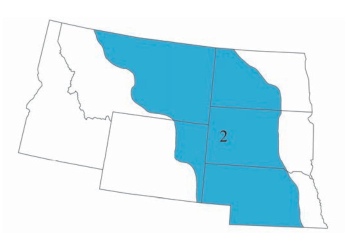


Figure 3.25: Toothed birds found in Cretaceous deposits of the Western Interior Seaway. A) and B) The large, flightless Hesperornis. *About 6 feet (1.8 meters) long. Reconstructed skeleton and life restoration. C) and D) The smaller flying* Icthyornis, *with a wingspan around 50 centimeters (20 inches). Reconstructed skeleton and life restoration.*

diverse and abundant, and are especially common fossils in Cretaceous rocks of the Dakotas, Wyoming, and Montana (*Figure 3.29*). The late Cretaceous Pierre Shale, which is exposed widely across this area, is especially famous for its beautifully preserved ammonoids. Most ammonoids are coiled flat, in a single plane. One fascinating aspect of ammonoid evolution, however, was the appearance of shells with bizarre shapes, called heteromorphs ("different shape"). These unique ammonoids were especially prevalent in the Cretaceous period. The shells of heteromorphs were uncoiled or three-dimensionally (helically) coiled (*see Figure 3.29B–D*). Since there are no similar life forms today to which to compare them, it has been difficult to figure out how they lived—most current paleontological thinking suggests heteromorphs floated or swam.



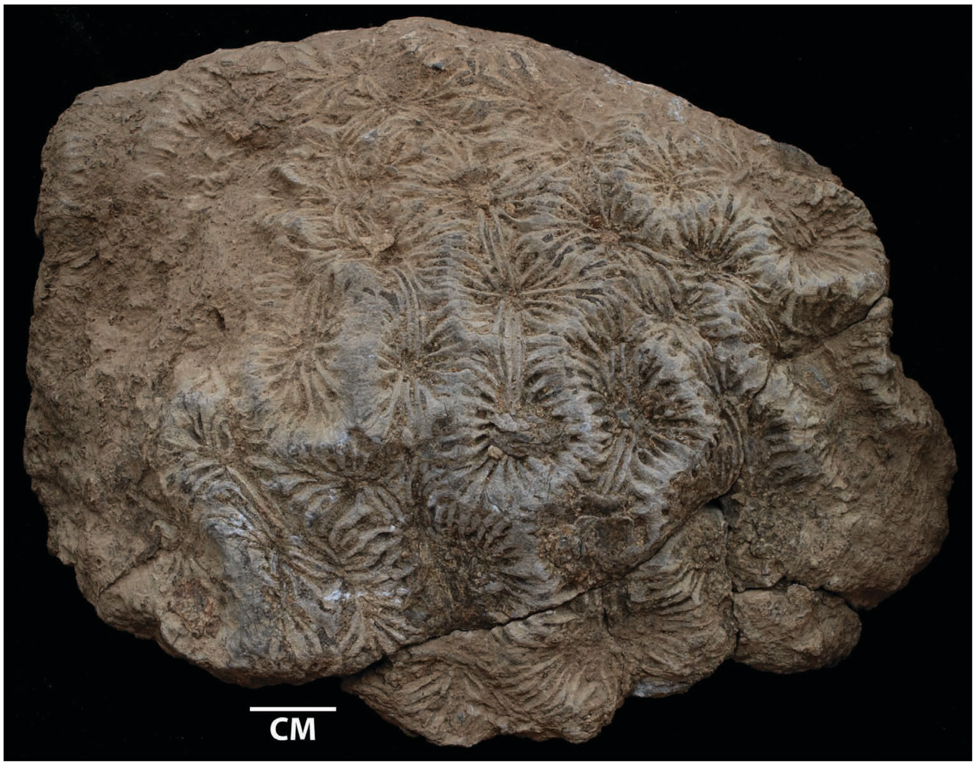


Figure 3.26: Jurassic coral, Thecomeandra vallieri, *from western Idaho. Specimen about 10 centimeters (4.25 inches) across.*

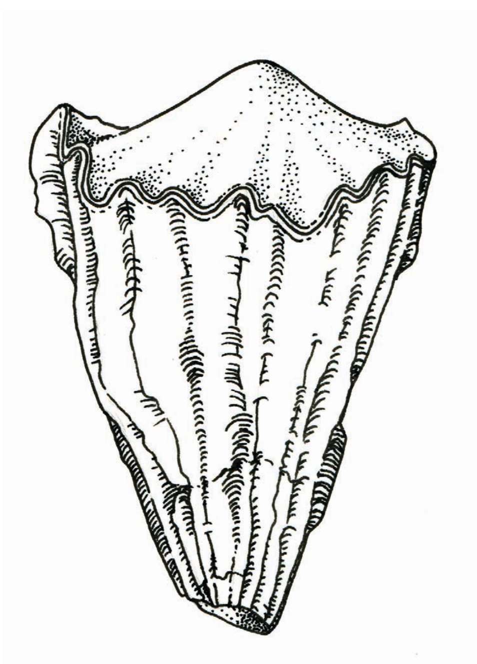
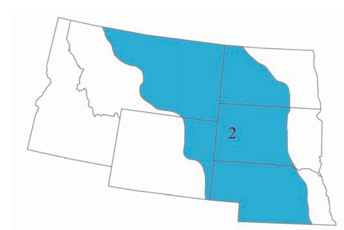


Figure 3.27: Rudists were unusual cone- or cylinder-shaped bivalves that clustered together in reef-like structures and went extinct at the end of the Mesozoic era. They ranged in size from a few centimeters to more than 50 centimeters (1.5 feet) tall.



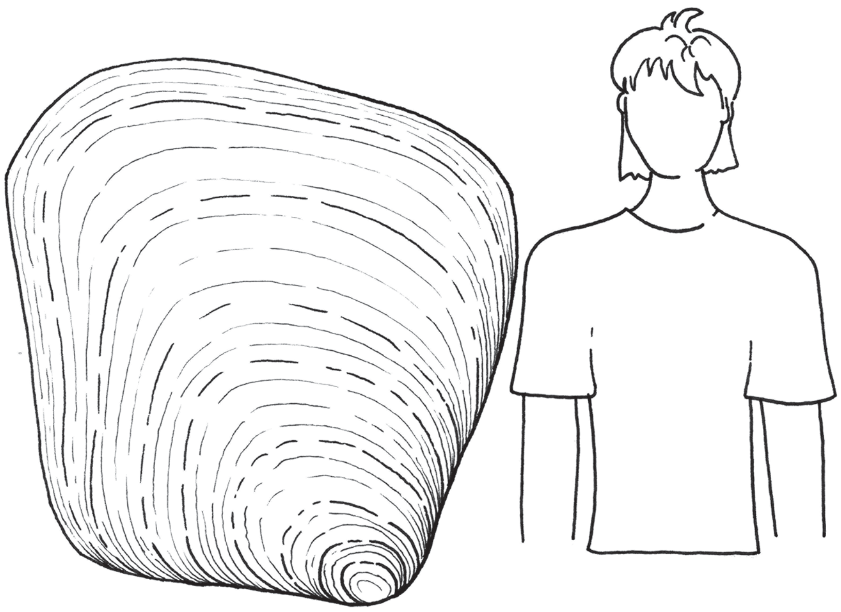


Figure 3.28: Giant inoceramid bivalve, Platyceramus platinus, *from the Cretaceous Niobrara Chalk of Kansas. About 1.2 meters (4 feet) in diameter.*

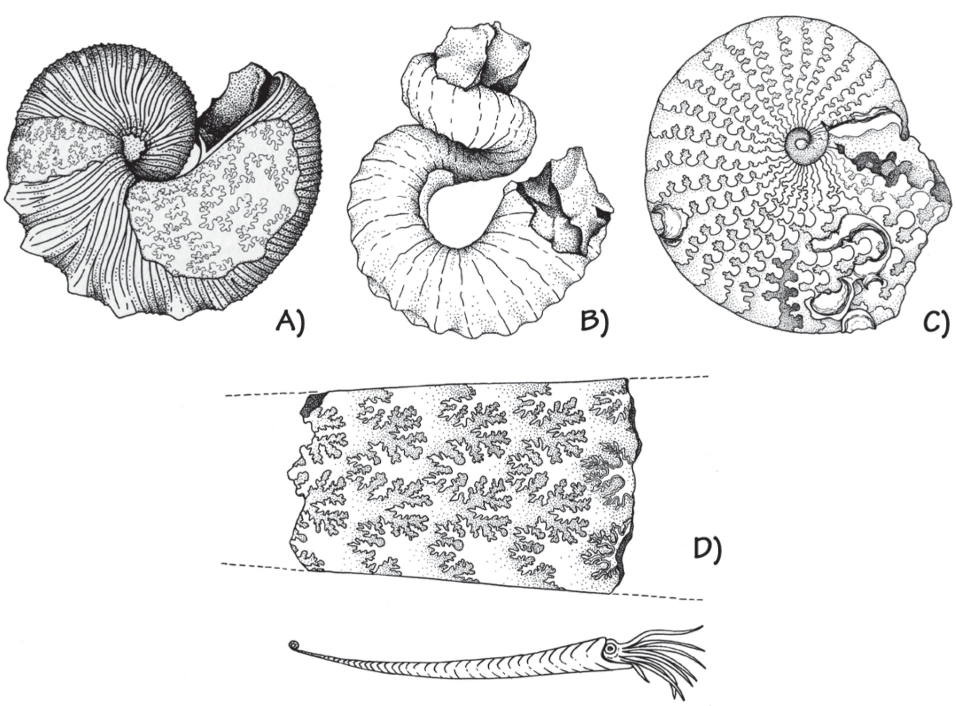
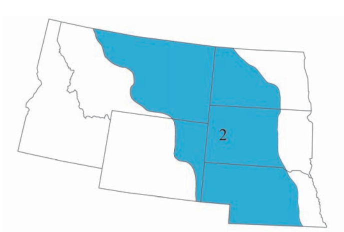
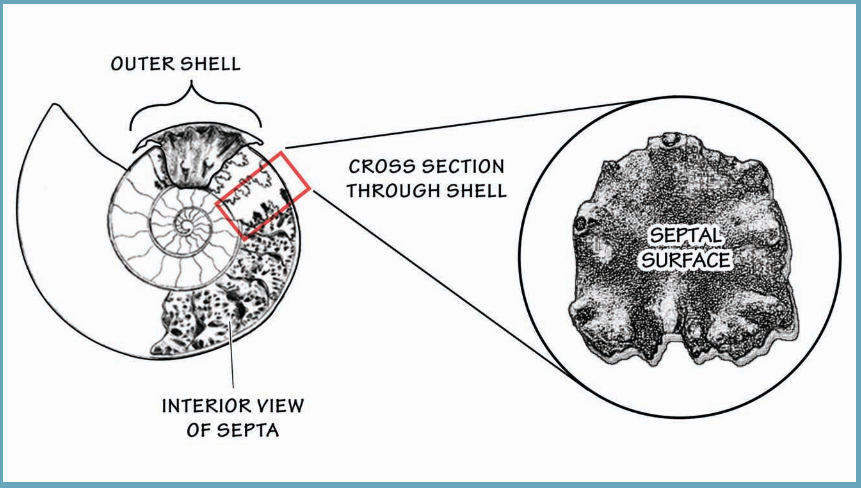


Figure 3.29: Ammonoids from the late Cretaceous of the Western Interior Seaway. A) Ammonite, Jeletzkytes, *about 10 centimeters (4 inches) in diameter. B) Heteromorph ammonite,* Didymoceras, *about 15 centimeters (6 inches) in diameter. C) Ammonite,* Engonoceras, *about 15 centimeters (6 inches) in diameter. D) Straight heteromorph ammonite,* Baculites, *fossil, usually 3-4 centimeters (2 inches) in diameter and 60 centimeters (2 feet) long. E)* Baculites *life restoration.*

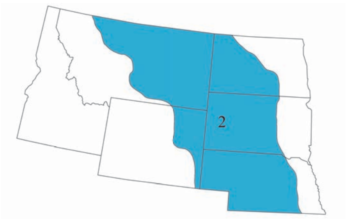


Ammonoids

Ammonoids are a major group of cephalopods that lived from the Devonian to the end of the Cretaceous. Both nautiloids (the group that today contains the chambered nautilus) and ammonoids have chambered shells subdivided by walls, or septa (plural of septum). These shells are frequently, but not always, coiled. The term "ammonoid" refers to the larger group of these extinct cephalopods, distinguished by complex folded septa. Within ammonoids, "ammonites" is a smaller sub-group, distinguished by the extremely complex form of their septa. Ammonites were restricted to the Jurassic and Cretaceous periods. The form of the septa in nautiloids and ammonoids is not visible in a complete shell; it is most often seen in the trace of the intersection between the septum and the external shell. This trace is called a suture. Sutures are usually visible in fossils when sediment has filled the chambers of a shell, and the external shell has been broken or eroded away.



Ammonite shell break-away cross-section; surface plane of a septum and sediment-filled chamber.



Abundant tiny fossils called foraminifera (*Figure 3.30*) are found throughout Cretaceous sediments of the Western Interior Seaway. Foraminifera, or "forams," as they are frequently called, are single-celled organisms (**protists**) with shells made of **calcium carbonate**. They live in the ocean in huge numbers, both at the bottom and floating in the water column, and are extremely important as index fossils and paleoenvironmental indicators.

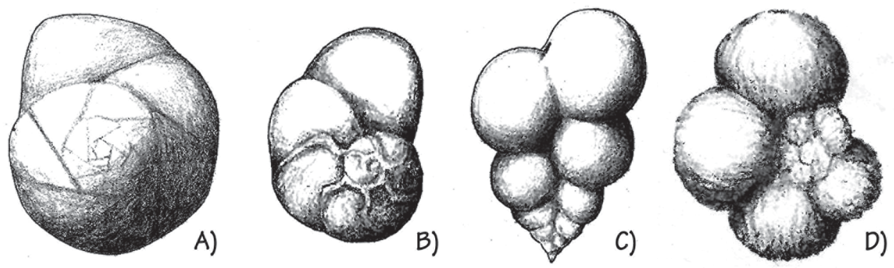


Figure 3.30: Cretaceous foraminifera. A) Pulvinulina*, 0.3 millimeters (0.01 inches). B)* Rotalia*, 0.4 millimeters (0.02 inches). C)* Pseudotextularina*, 0.3 millimeters (0.01 inches). D)* Globigerina*, 0.4 millimeters (0.02 inches).*

protists *• a diverse group of single-celled eukaryotes.*

calcium carbonate *• a chemical compound with the formula $CaCO_3$, commonly found in rocks in the mineral forms calcite and aragonite, as well as the shells and skeletons of marine organisms.*

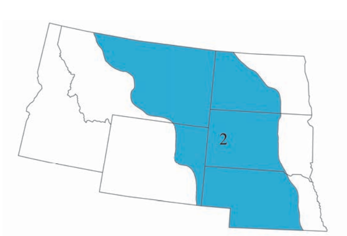
pterosaurs *• extinct flying reptiles with wingspans of up to 15 meters.*

meteorite *• a stony or metallic mass of matter that has fallen to the Earth's surface from outer space.*

During the late Cretaceous period (67–65 million years ago), the area that is now southeastern Montana, northeastern Wyoming, and northwestern South Dakota was a broad floodplain to the east of the developing Rocky Mountains, leading into the shallow marine Western Interior Seaway. The sediments deposited in these transitional environments (*Figure 3.31*) contain the remains of organisms that lived both on land and in the sea. The terrestrial layers, deposited by meandering rivers, contain abundant plant fossils—including numerous flowering plants (*Figure 3.32*), which had just begun to colonize the landscape. Terrestrial deposits also contain abundant fossils of land-dwelling animals that lived near the seaway, including insects, freshwater snails and clams, turtles, **pterosaurs**, small mammals (*Figure 3.33*), birds, amphibians, and, most famously, dinosaurs (*Figure 3.34*).

In the early twentieth century, the first skeletons of *Tyrannosaurus rex* were discovered in one of these floodplain deposits, the Hell Creek Formation. The boundary between the Cretaceous and Paleogene periods was also identified at the top of this sandstone layer. Detailed work in the late twentieth century refined the placement of the boundary; it is now marked by a concentration of the element iridium, usually at the top of the Hell Creek but sometimes in the lower part of the overlying Fort Union Formation (*Figure 3.35*). The iridium is thought by most geologists to have come from the impact of a large comet or **meteorite**, which was likely a primary cause of the mass extinction that marks the end of the Cretaceous period.

Until recently, *Tyrannosaurus* was known from only a few specimens. In recent decades, however, remains of more than 40 individuals have been discovered in the Hell Creek Formation in Montana and South Dakota, and *T. rex* is today one of the best-known dinosaurs.



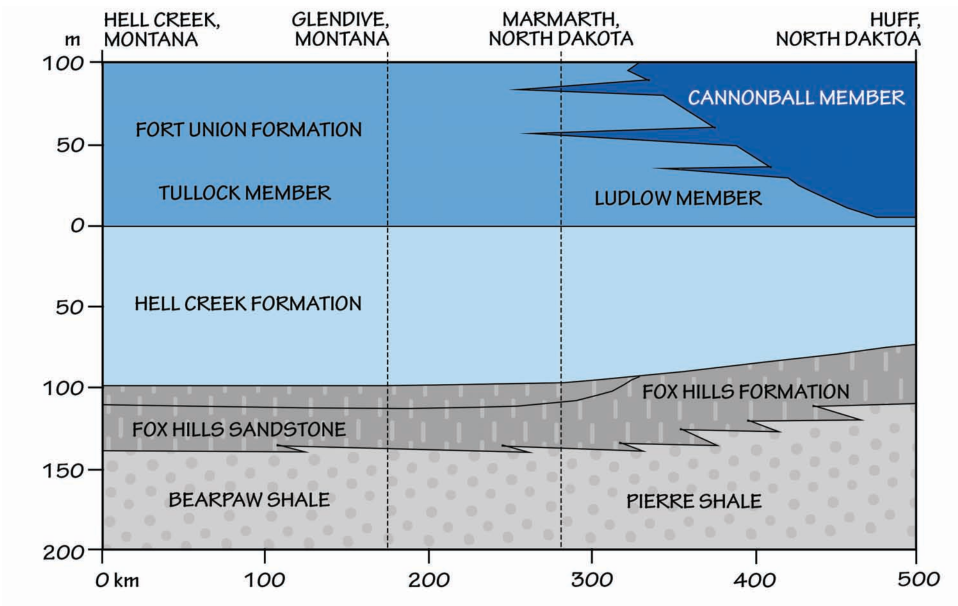


Figure 3.31: Simplified stratigraphy of the western margin of the Western Interior Seaway across Montana and North Dakota during the late Cretaceous period.

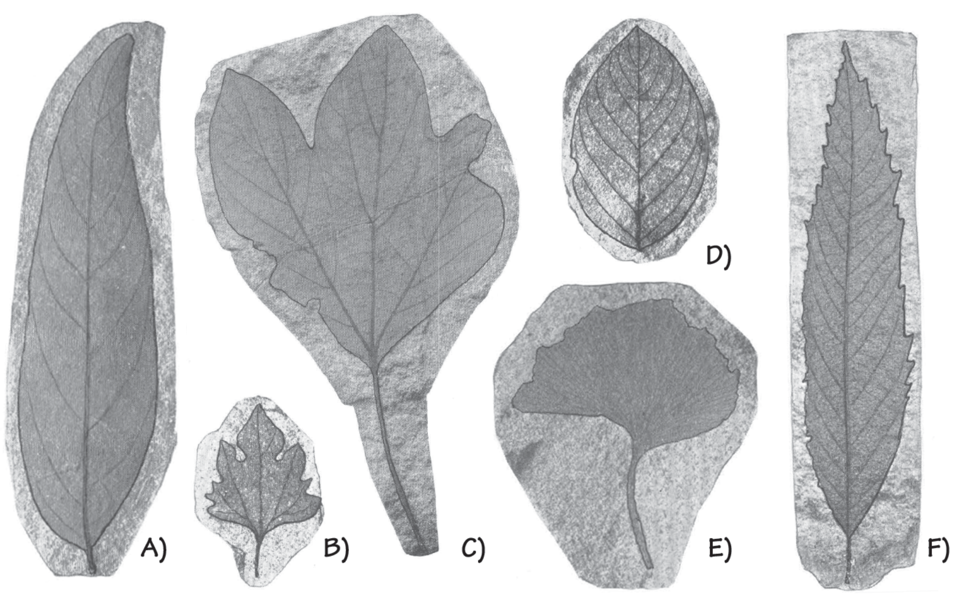
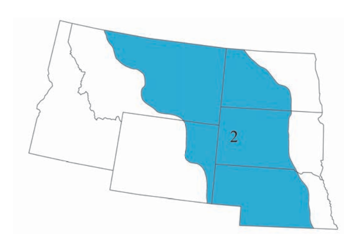


Figure 3.32: Late Cretaceous terrestrial plant fossils from the Fox Hills and Hell Creek formations. A) Sapindus cretaceus. *B)* Cissites colgatensis. *C)* Sassafras montana. *D)* Cornus praeimpressa. *E)* Gingko laramiensis. *F)* Dryophyllum subfalcatum. *Leaves range from 5 to 15 centimeters (2 to 6 inches) in length. All to scale.*



3 Fossils

Region 2

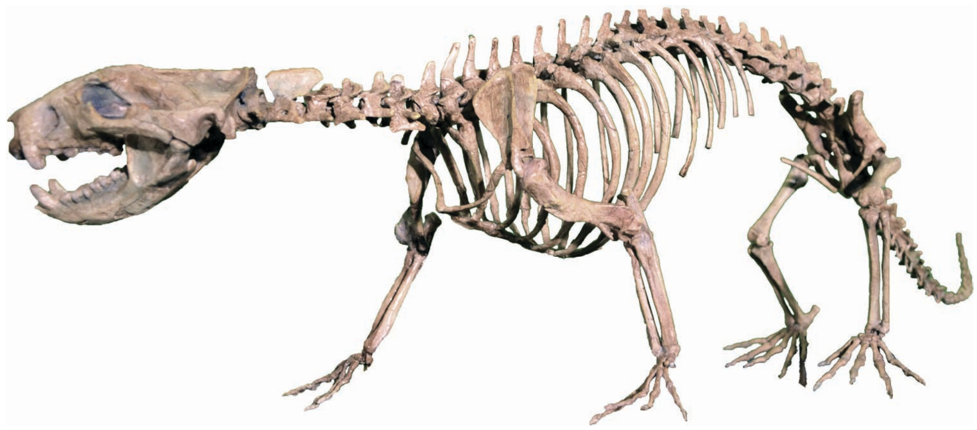
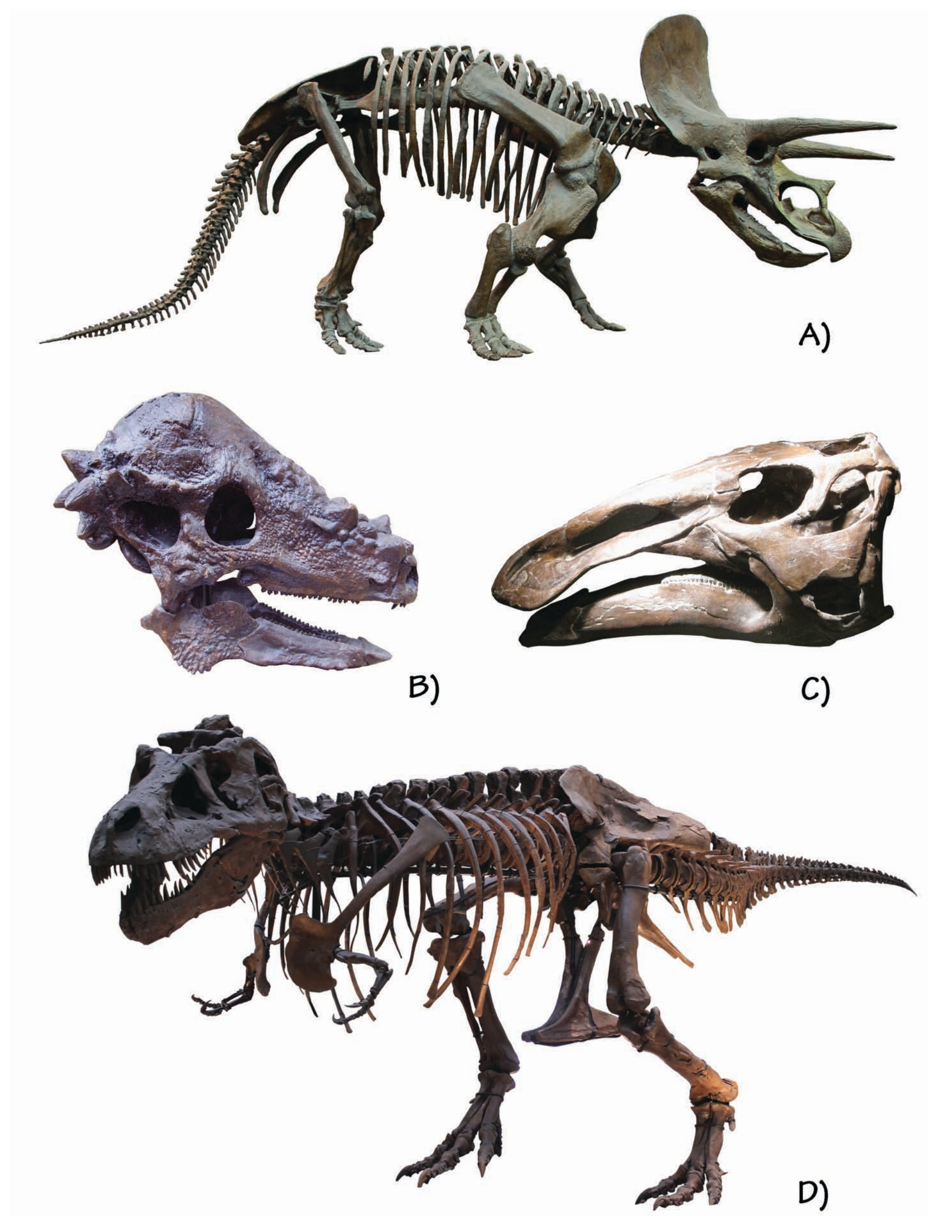
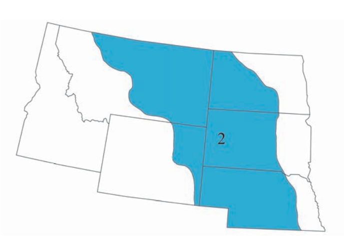


Figure 3.33: Didelphodon vorax*, a marsupial from the late Cretaceous period. About 1 meter (3 feet) long.*

Figure 3.34 (at right): Late Cretaceous dinosaurs found in South Dakota and Wyoming. A) Triceratops horridus*, about 8 meters (28 feet) long. B) Skull of* Pachycephalosaurus*, body length about 4.5 meters (15 feet). The bony dome on the skull can be up to up to 25 centimeters (10 inches) thick. C) Skull of* Edmontosaurus*, body length up to 13 meters (43 feet). D)* Tyrannosaurus rex*, about 12.5 meters (40 feet) long.*

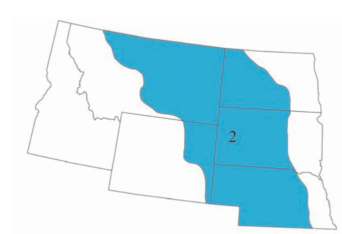




The Hell Creek Formation is most famous for its multiple bone beds containing abundant dinosaurs, including (in addition to *T. rex*) the giant horned *Triceratops*, the "ostrich dinosaurs" *Struthiomimus* and *Ornithomimus*, the armored *Ankylosaurus* and dome-headed *Pachycephalosaurus*, and the large hadrosaurs *Edmontosaurus* and *Anatotitan* (*see Figure 3.34*). Several dinosaur "mummies" have also been found in the Hell Creek beds (*Figure 3.36*). These exceptionally preserved fossils were formed when a dinosaur was buried suddenly, preserving impressions of skin and other traces of soft anatomy.

Figure 3.35: The Cretaceous–Paleogene (K–Pg) boundary (red arrow) along Interstate 25, Raton Pass, Colorado. (See TFG website for full-color version.)

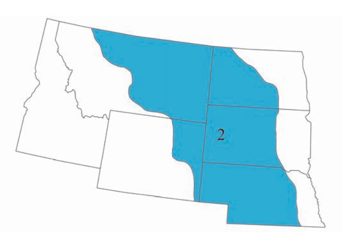
Figure 3.36 (at left): A fully articulated and partially mummified skeleton of a subadult hadrosaur, Brachylophosaurus canadensis, *nicknamed "Leonardo." The specimen was found in northern Montana and is exhibited at the Phillips County Museum in Malta, Montana.* Brachylophosaurus *reached 9 meters (30 feet) in length. Inset: Skin impression from a hadrosaur,* Edmontosaurus, *nicknamed "Dakota." This specimen was found in North Dakota and is now on display at the North Dakota Heritage Center in Bismarck. Photograph about 15 centimeters (6 inches) in width.*



Maiasaura

In the late 1970s and 1980s, nests of dinosaur eggs—some containing embryos—were discovered in rocks of Montana's Two Medicine Formation, as well as adult skeletons of the same dinosaur. It was named *Maiasaura*, meaning "good mother lizard." *Maiasaura* was a medium-sized hadrosaur, about 8 meters (26 feet) long. It was bipedal and plant-eating. *Maiasaura* was the first dinosaur ever found associated with nests of babies, and its embryos were the first ever found of a dinosaur. One of the sites where these fossils were found was named Egg Mountain, west of Choteau in Teton County, Montana. The fossils showed that *Maiasaura* made a shallow nest in the ground about 2 meters (6.5 feet) in diameter, in which it laid clutches of 30 to 40 eggs. Because different nests had different-sized babies, paleontologists suggested that the babies were living in the nests when they died, and were being cared for by their parents. *Maiasaura* has only been found in Montana, and is the Montana state fossil.

Model of a Maiasaura *nest with hatchlings.* Maiasaura *eggs were about 15 centimeters (6 inches) long.*



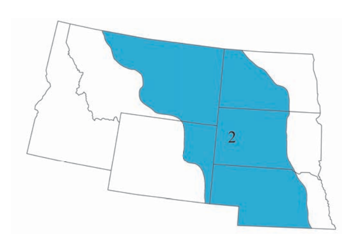
The early and mid-Cenozoic was a time of significant tectonic activity in the Northwest Central States. The Western Interior Seaway disappeared by the end of the **Paleocene**, and most of the region became dry land, yet extensive sedimentary deposits represent lakes, rivers, and floodplains. The uplift of mountain ranges to the west was a source of sediment that was transported and deposited by rivers in **basins** throughout the Great Plains and Rocky Mountain regions. Thick ash beds were also deposited in this area by periodic **volcanic** eruptions throughout the Cenozoic. The shrinking Western Interior Seaway is represented in the Dakotas by the Paleocene Cannonball Formation, which contains abundant and diverse mollusks, shark teeth, and occasional land plants (*Figure 3.37*).

See Chapter 2: Rocks to learn about igneous deposits left by Cenozoic volcanism.

Paleocene *• a geologic time interval spanning from about 66 to 56 million years ago.*

Figure 3.37: Teredo Petrified Wood, the state fossil of North Dakota, from the Paleocene Cannonball Formation. Specimen approximately 15 centimeters (about 6 inches) in diameter. Before burial and fossilization, this permineralized "petrified" wood was bored by a group of clams known as teredinids (one genus of which is Teredo*). These clams are also known as "shipworms" for their tendency to "foul" wooden ships, docks, and other human structures.*

Cenozoic rocks preserve a fossilized view of ecosystems dramatically different from those of the Cretaceous. The dinosaurs disappeared, and mammals replaced them as the dominant large vertebrates on land. During this time, the environment was initially warm and humid, with widespread tropical



Eocene *• a geologic time period extending from 56 to 33 million years ago.*

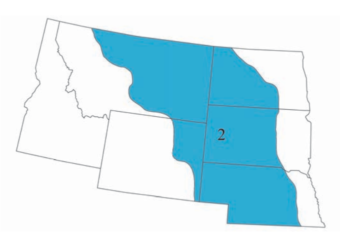
Oligocene *• a geologic time interval spanning from about 34 to 23 million years ago.*

climate *• a description of the average temperature, range of temperature, humidity, precipitation, and other atmospheric/hydrospheric conditions a region experiences over a period of many years (usually more than 30).*

Miocene *• a geological time unit extending from 23 to 5 million years ago.*

Neogene *• the geologic time period extending from 23 to 2.6 million years ago.*

badlands *• a type of eroded topography that forms in semi-arid areas experiencing occasional periods of heavy rainfall.*



and subtropical forests, but as global temperatures fell in the late **Eocene** and **Oligocene**, the **climate** of the Northwest Central became more arid, and grasslands replaced forests in many areas. Fossil land mammals are particularly common in Cenozoic sediments of the Great Plains, beginning with the Paleocene and Eocene, and continuing through the **Miocene**. These fossils can be found in thick sequences of layered sedimentary rock, which accumulated in lakes and rivers that fed into the numerous basins across the region (*Figure 3.38*). The abundant fossil mammals preserved in these rocks form one of the most complete records of mammal evolution known anywhere in the world. Mammals are so numerous and diverse here that they are commonly used as index fossils. (It is unusual to use vertebrates for biostratigraphy, because they are frequently much rarer than invertebrate fossils.) There is even a special series of terms—known as the North American Land Mammal Ages—used to describe the relative ages determined by fossil mammals.

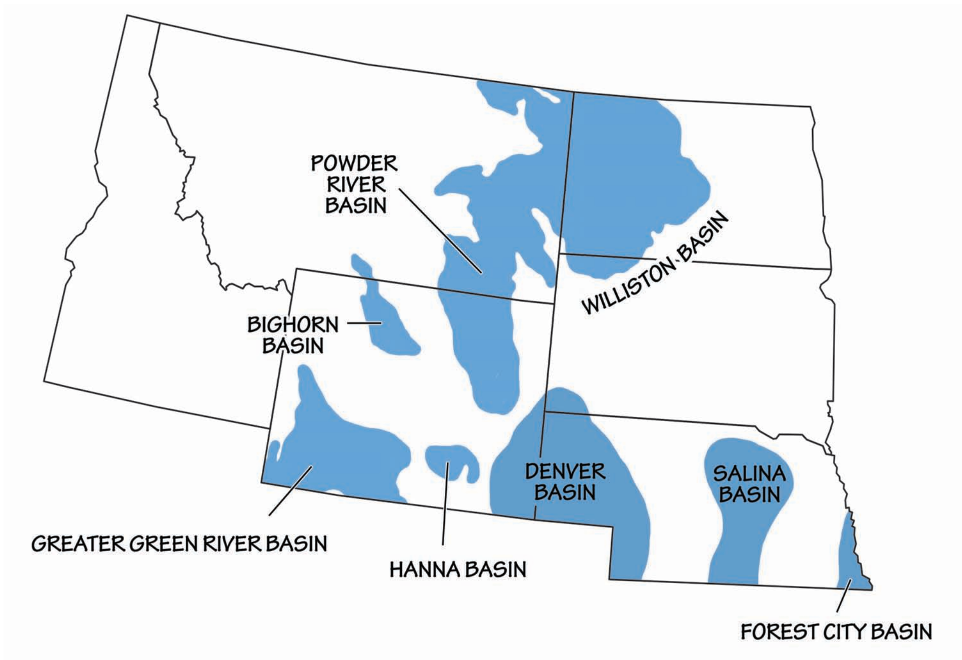


Figure 3.38: Sedimentary basins of the Northwest Central.

Paleogene and early **Neogene** mammals from this region include a great diversity of hoofed mammals, as well as carnivores, and—surprisingly—primates (*Figures 3.39–3.40*). Paleocene and Eocene mammals, as well as fossil plants, are particularly common and diverse in the Williston Basin of the Dakotas and the Bridger and Uinta Basins of Wyoming and Utah (*Figure 3.41*). Oligocene mammals are best known from the White River **Badlands**—an area of western South Dakota with a deeply eroded landscape, through which the White River flows. The rocks here are late Eocene to Oligocene in age (about 40–30 million years old), and were deposited by rivers moving through an environment much warmer and wetter than it is today. These rocks contain some of the most abundant, diverse, and well-preserved Paleogene fossil mammals found anywhere in the world (*Figure 3.42*), including extinct relatives of modern groups, such as camels and horses; groups that left no living descendants, such as the pig-like **entelodonts**; and the sheep-like **oreodonts**, which were the most abundant mammals in this savannah-like environment.

See Chapter 4: Topography to learn more about badland topography in the Northwest Central.

entelodont • *an extinct family of omnivorous artiodactyl mammals that look somewhat like pigs but are actually thought to be more closely related to hippos.*

oreodont • *an extinct ungulate (hoofed animal) related to modern camels.*

volcanic ash • *fine, unconsolidated pyroclastic grains under 2 millimeters (0.08 inches) in diameter.*

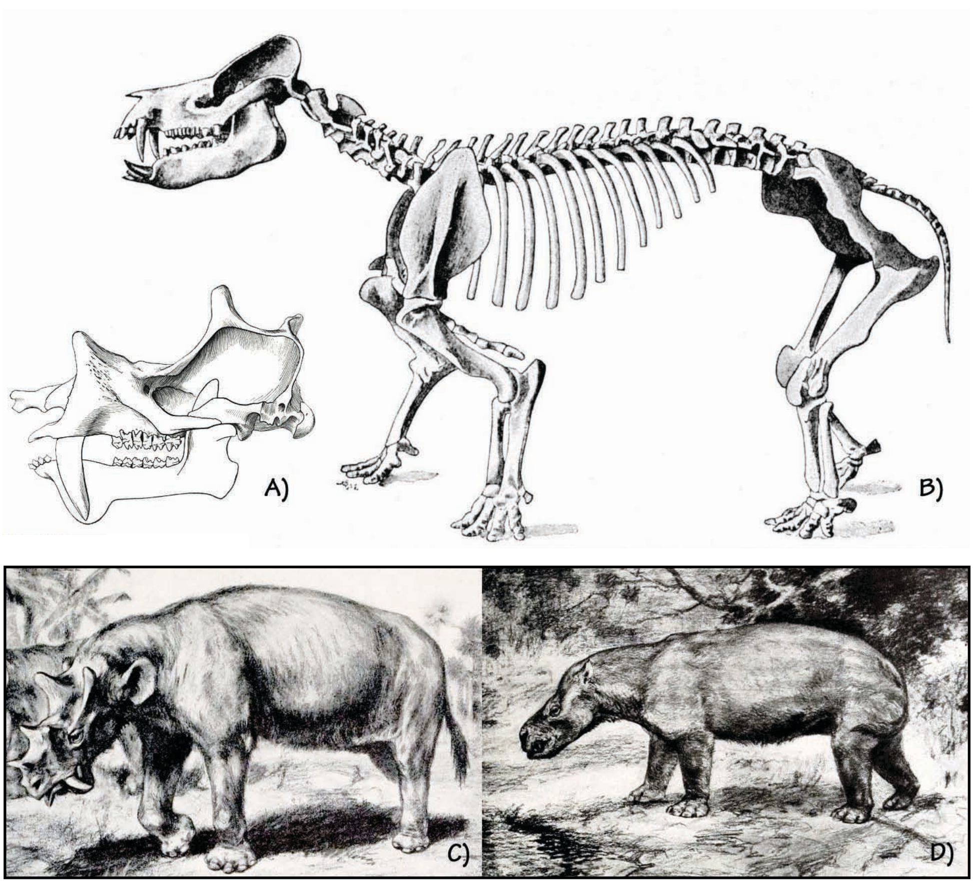
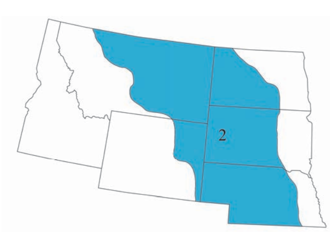


Figure 3.39: Paleocene-Eocene browsing mammals of the Great Plains. A) and C) Uintatherium *skull and life restoration. Body about 4 meters (13 feet) long. B) and D)* Coryphodon *skeleton and life restoration. Body about 2.25 meters (2.4 feet) long.*

Miocene mammals are abundantly preserved in a number of deposits, including the spectacular Agate Fossil Beds of western Nebraska, and the Ashfall Fossil Beds of northeastern Nebraska. Many of these fossil beds formed as a result of rapid burial in **volcanic ash**. The spectacular fossils exposed at Agate Fossil Beds National Monument and Ashfall Fossil Beds State Historical Park reveal that during the early Miocene (about 21–19 million years ago), this area was a grassy savanna, similar to those in today's East Africa. Miocene Nebraska was filled with diverse and abundant large mammals (*Figure 3.43*), including the



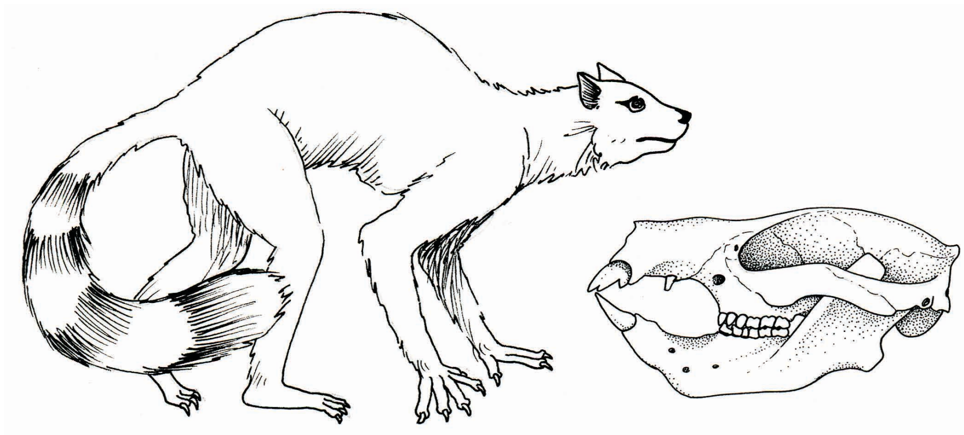


Figure 3.40: Skull and restoration of Plesiadapis*, a Paleocene arboreal primate-like mammal. Body about 60 centimeters (2 feet) long.*

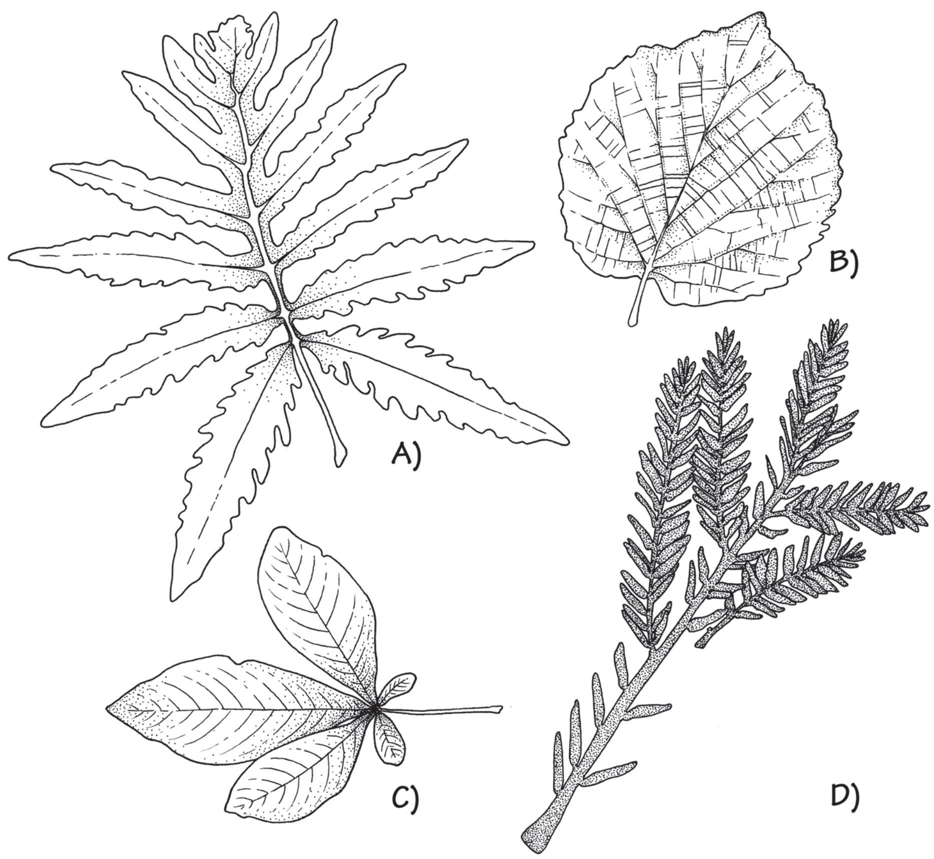
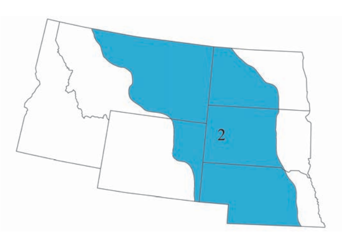


Figure 3.41: Leaves of the Fort Union Formation, a geological unit extending into the Williston Basin. A) Onoclea sensibilis. *B)* Davidia antiqua. *C)* Aesculus hickeyi. *D)* Metasequoia occidentalis. *Leaves range from 10 to 20 centimeters (4 to 8 inches) long. All to scale.*



Region 2

agate • *a crystalline silicate rock with a colorful banded pattern. It is a variety of chalcedony.*

quartz • *the second most abundant mineral in the Earth's continental crust (after feldspar), made up of silicon and oxygen (SiO_2).*

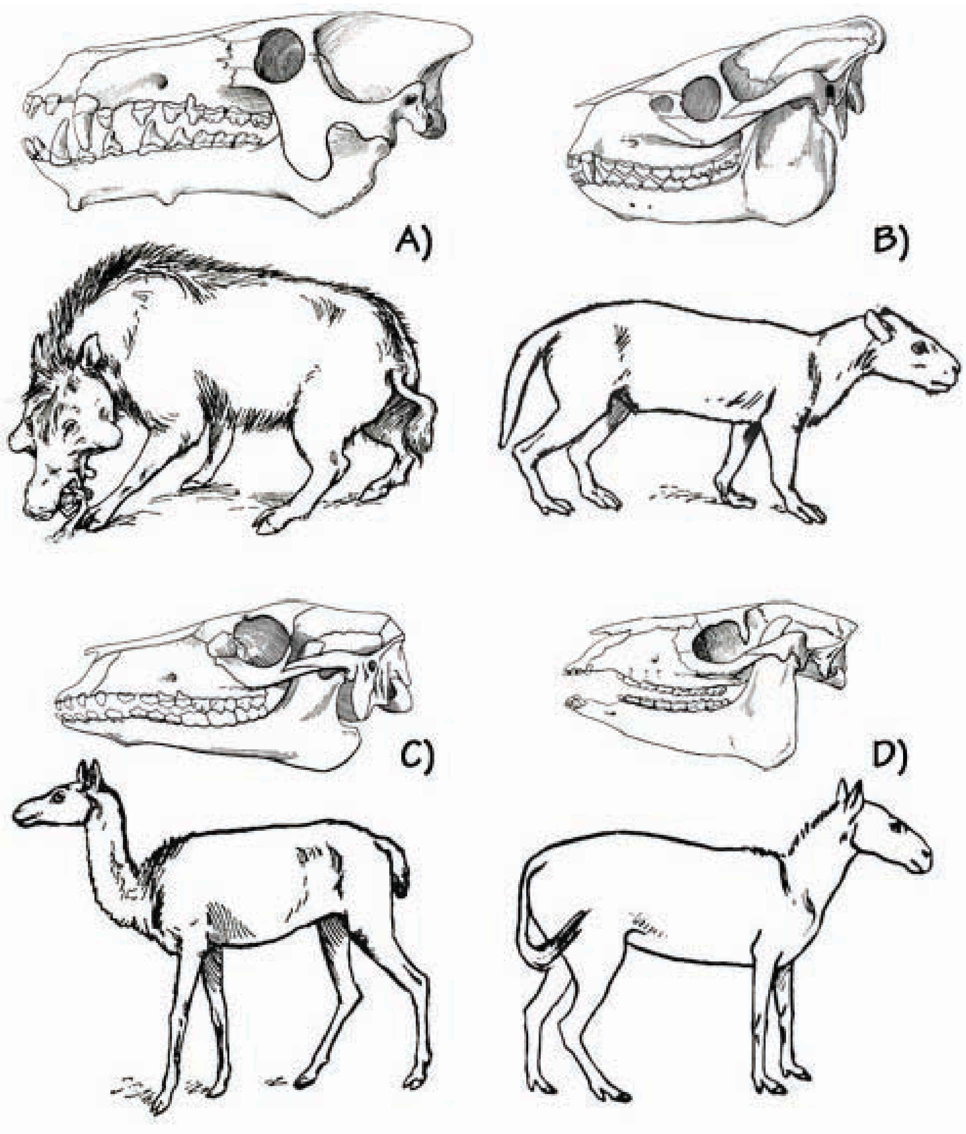
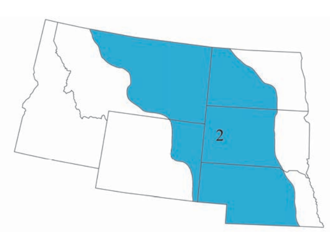


Figure 3.42: White River mammals. A) Archaeotherium, *an entelodont; skull and restoration. Skull about 6.5 centimeters (2 feet) long; body 1.4 meters (4.5 feet) tall at the shoulder. B)* Merycoidodon, *an oreodont; skull and restoration. Body about 1.4 meters (4.5 feet) long. C)* Poebrotherium, *a proto-camel; skull and restoration. Skull about 13 centimeters (5 inches) long; body about 90 centimeters (3 feet) tall. D)* Mesohippus, *an early horse; skull and restoration. Body about 60 centimeters (2 feet) tall.*

small "gazelle-camel" *Stenomylus*, the short-legged rhino *Menoceras* (the first rhino with horns), the carnivorous "beardog" *Daphoenodon*, the fierce-looking giant entelodont *Daeodon* (formerly *Dinohyus*), the bizarre clawed herbivore *Moropus*, and the "land beaver" *Paleocastor*, which dug spectacular long spiral burrows known today as the trace fossil *Daemonelix* (*Figure 3.44*).

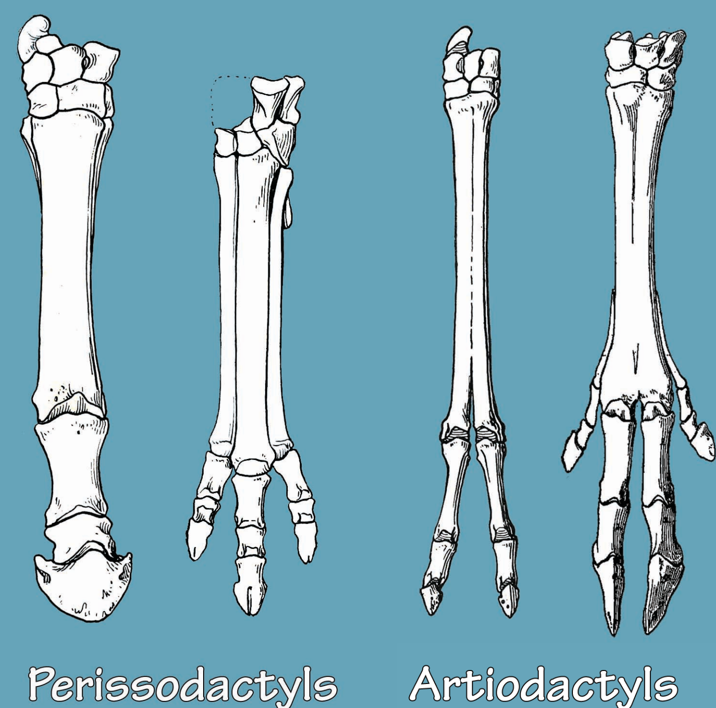
The *agate* that gives this deposit its name is a variety of *quartz* called *chalcedony*. It is found in a thin band along ash deposits just above the Miocene bone beds, and ranges in color from amber to light gray.

chalcedony • *a crystalline silicate mineral that occurs in a wide range of varieties.*



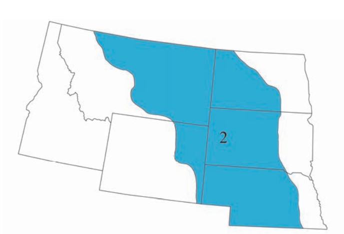
Hoofed Mammals

Herbivorous (plant-eating) ungulates (hoofed mammals) are classified into two major groups depending on the number of hooves (toes) per foot. Artiodactyls have an even number of hooves on each foot. This group of animals includes pigs (two hooves), deer, and cows (both with four hooves per foot). Perissodactyls have an odd number of hooves on each foot, and include horses (one hoof) as well as tapirs and rhinoceroses (three hooves).



Equus*, a horse (left) and* Hyracodon*, a rhinoceros (right).*

Procamelus*, a camel (left) and* Hippocamelus*, a deer (right).*



Most of the fossils in the Agate Springs quarries were excavated from a bone bed that is as much as 60 centimeters (2 feet) thick in some areas. Particularly famous are clusters of skeletons from the rhino *Menoceras* (*Figure 3.45*). These animals may have preferred to spend most of their time lying in shallow ponds or stream courses. When a multi-year drought occurred and the food supply disappeared, the *Menoceras* remained at the waterhole where they died. When water flowed again, the seasonal stream buried their bodies beneath layers of mixed **sandy** sediments and volcanic ash.

sand • *rock material in the form of loose, rounded, or angular grains, and formed as a result of the weathering and decomposition of rocks.*

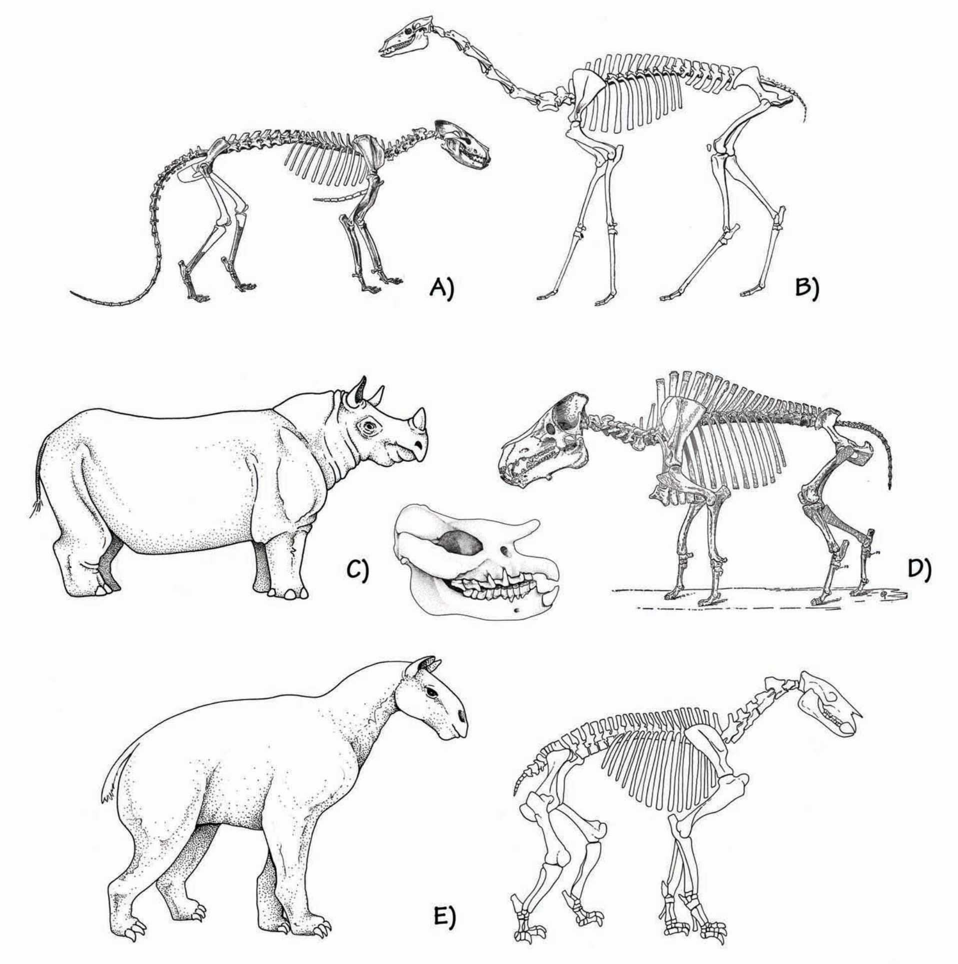
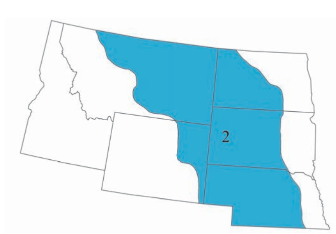


Figure 3.43: Fossil mammals from the Miocene of Nebraska. A) Beardog, Daphoenodon*; skeleton about 1.6 meters (5.5 feet) long. B) Camel,* Oxydactylus*; skeleton about 2.5 meters long (8.2 feet) long, 1.2 meters (3.9 feet) tall at the shoulder. C) Rhinoceros,* Teleoceras*; restoration and skull. Body about 4 meters (13 feet) long. D) Entelodont,* Daeodon*; skeleton. Skull about 90 centimeters (3 feet) long; body about 1.8 meters (6 feet) tall at the shoulder E. Chalicothere,* Moropus*; restoration and skeleton. Body about 2.4 meters (8 feet) tall at the shoulder.*

Some of the most common vertebrate fossils in Eocene and Oligocene sediments in Nebraska and the Dakotas are not mammals, however, but tortoises. Tortoises are a group of turtles that live on land, and have short, strong legs used for support and digging burrows. In contrast, most turtles live in the water and have webbed feet to help them swim efficiently, but will venture onto land occasionally to lay eggs. Two of the most common types of fossil tortoise are *Stylemys* from the Oligocene of Nebraska and *Hesperotestudo* from the Miocene of Nebraska and Kansas (*Figure 3.46*).



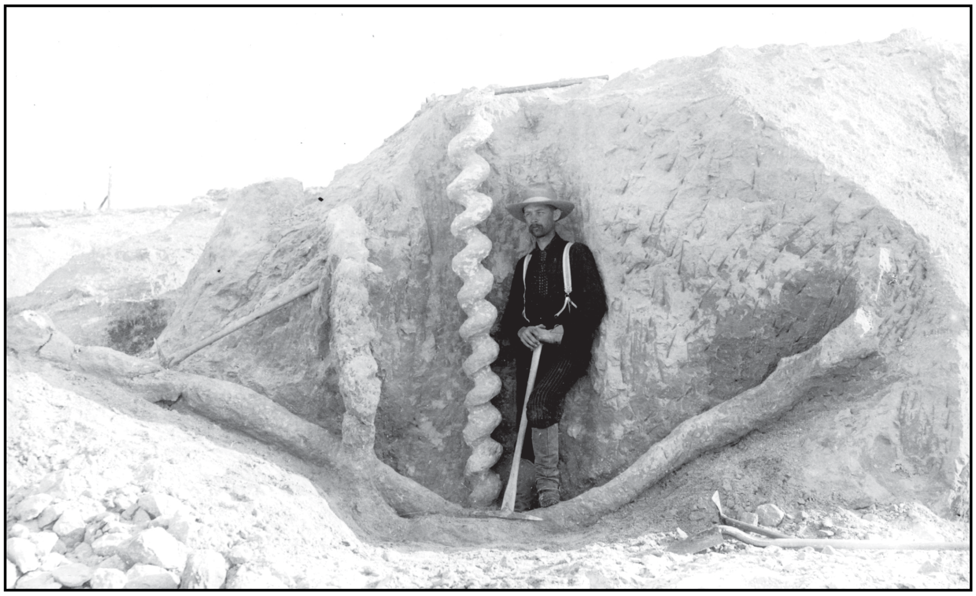
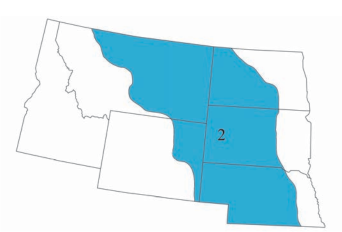


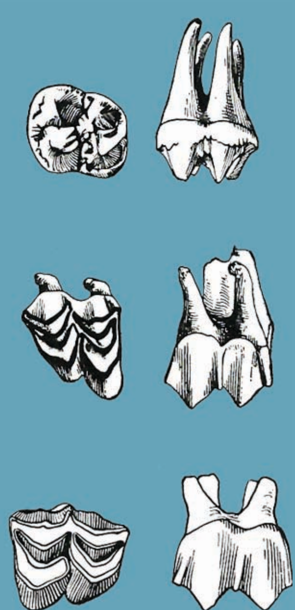
Figure 3.44: Fossil burrows, known as Daemonelix *("devil's corkscrew"), of the extinct beaver* Palaeocastor. *This large burrow was discovered in the late 19th century at Agate Fossil Beds National Monument.*

Figure 3.45: Bone bed of the Miocene rhinoceros Menoceras *at Agate Springs, Sioux County, western Nebraska. Slab is about 2 meters (6 feet) across.*



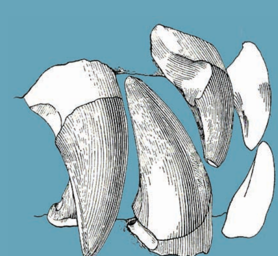
Fossil Mammals: It's (almost) all about the teeth

Mammals have evolved into an amazing variety of shapes and sizes, and much of this diversity and success is due to their teeth! Mammals are "warm-blooded," meaning they can regulate their own body temperature. This requires a high metabolism, energy that is derived from food. Mammals meet their heavy food requirements with the help of a distinctive chewing system, starting with their teeth. Unlike reptiles, most mammals – including humans – have several different kinds of teeth in their mouths. Also unlike reptiles, some of these teeth are highly complex, with many bumps and grooves on the chewing surfaces. This range of tooth forms allows mammals to efficiently eat many different kinds of food. It also allows different kinds of mammals to eat different foods. This means that different mammals usually have very different teeth, and that you can often identify a mammal species using only its teeth. This is extremely important for studying fossils, because mammal teeth are frequently found as fossils. Mammal paleontology is therefore largely the study of fossil teeth.

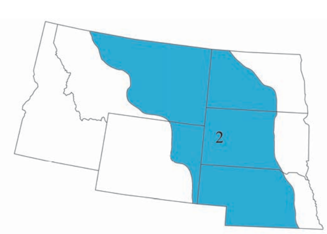


Upper right side dentition of Hyaenodon*, a dog-like carnivore.*

Upper molar of peccary (Tagassu), *deer* (Odocoileus), *and camel* (Poebrotherium).



Incisors and canines of the entelodont Archaeotherium.



Pleistocene • *a subset of the Quaternary, lasting from 2.5 million to about 11,700 years ago.*

mammoth • *an extinct terrestrial mammal belonging to the Order Proboscidea, from the same line that gave rise to African and Asian elephants.*

last glacial maximum • *the most recent time the ice sheets reached their largest size and extended farthest towards the equator, about 26,000 to 19,000 years ago.*

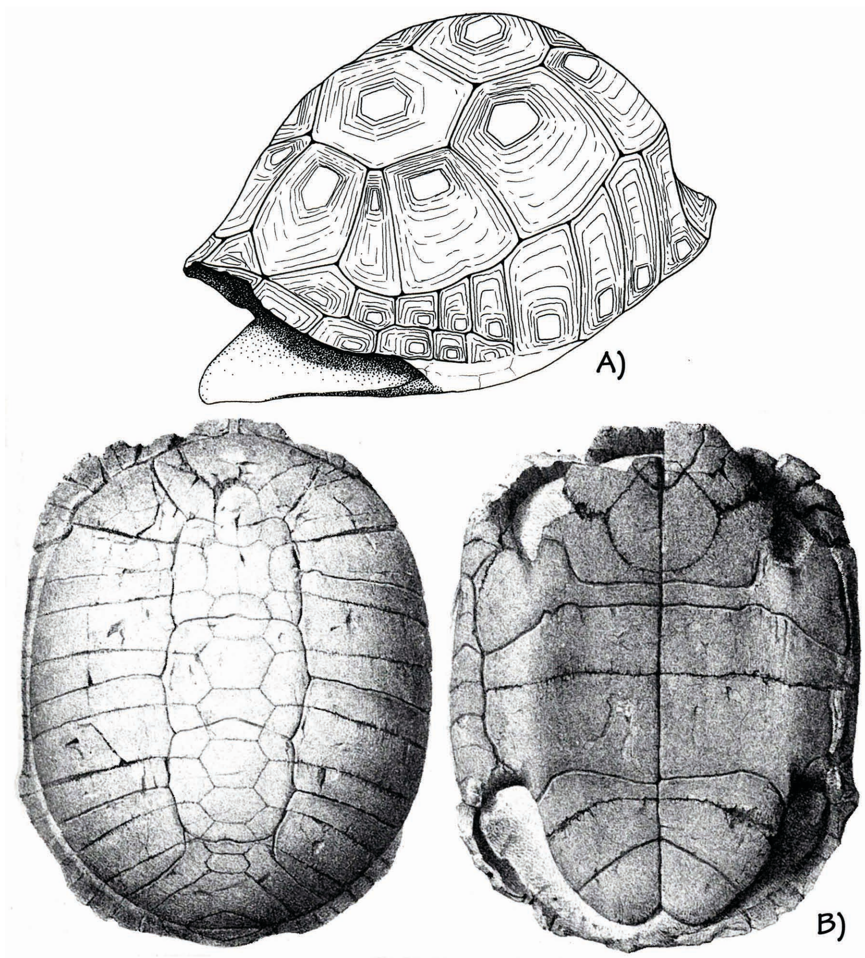
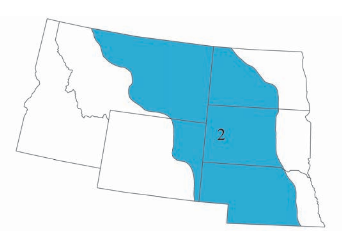


Figure 3.46: Tortoise fossils of the Great Plains. A) Geochelone orthopygia*, about 1 meter (3 feet) long. B)* Stylemys nebrascensis*, top (left) and bottom (right). Shell about 10 centimeters (4 inches) long.*

The cooling temperatures that affected all of North America at the beginning of the **Pleistocene** epoch, around 2.5 million years ago, brought an influx of new mammals to the Great Plains. These included **mammoths**, rodents, bison, and musk oxen.

Bison first appear in North America in the late Pleistocene, around 200,000 years ago, having migrated from Asia across the Bering Land Bridge. The oldest and largest of the several species that evolved here was the "giant bison," *Bison latifrons*, which had horns measuring up to seven feet tip-to-tip, a shoulder height of 2.5 meters (8.2 feet), and may have weighed over 2000 kilograms (4400 pounds)—up to twice the size of the modern American bison (*Figure 3.47*). The giant bison became extinct around 20,000–30,000 years ago, at the beginning of the **last glacial maximum**. Bones of this species, as well as those of other extinct species such as *Bison antiquus*, are common throughout the Great Plains, especially in Nebraska.



Region 2

glacier • *a body of dense ice on land that does not melt away annually and has sufficient mass to move under its own weight.*

ice age • *a period of global cooling of the Earth's surface and atmosphere, resulting in the presence or expansion of ice sheets and glaciers.*

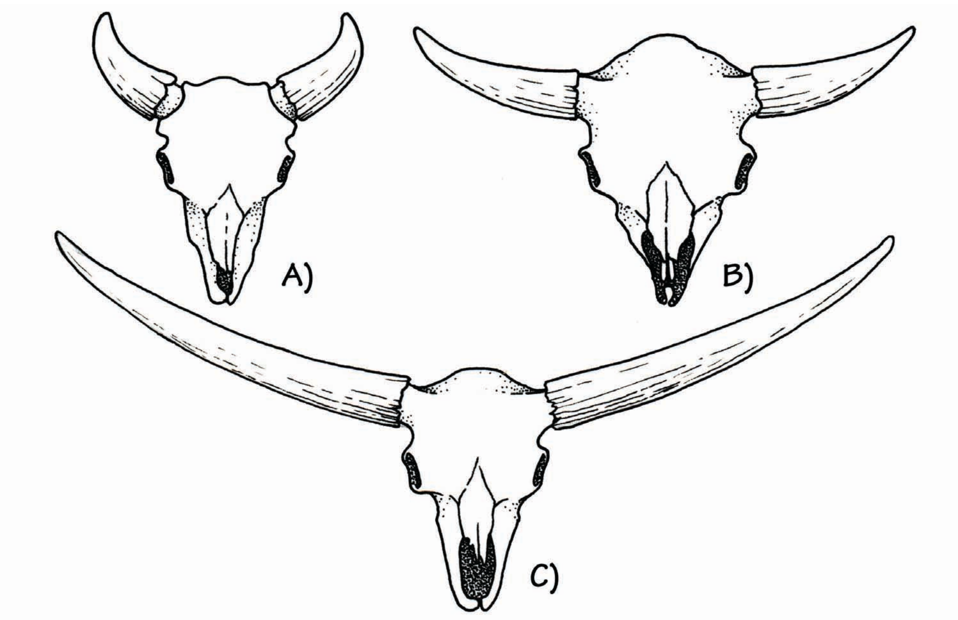
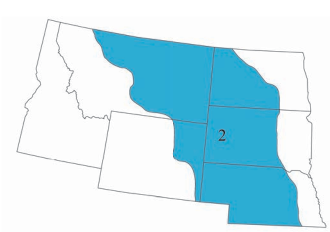


Figure 3.47: Skulls of two of the most common Pleistocene bison species, compared to the modern American bison (to scale). A) Bison bison *(Recent), horn span 66 centimeters (2 feet). B)* Bison antiquus *(extinct), horn span 1 meter (3 feet). C)* Bison latifrons *(extinct), horn span 2 meters (7 feet).*

Mammoths were close cousins of modern elephants that lived across North America and Eurasia for several million years. A number of different kinds of mammoths lived throughout North America (including the Rocky Mountains and Great Plains regions), until they became extinct around 10,000 years ago. The most familiar kind of mammoth is the woolly mammoth, *Mammuthus primigenius*, which lived in colder climates close to the **glacial** front (*Figure 3.48*). Farther south, other large mammoths were abundant. The Columbian mammoth, *Mammuthus columbi (Figure 3.49),* and the imperial mammoth, *Mammuthus imperator,* were previously thought to have been separate species, but paleontologists have recently concluded that they actually belonged to the same species. At Mammoth Site in Hot Springs, South Dakota, the skeletons of at least 60 mammoths (mostly Columbian) are preserved together with the bones of many other **ice age** mammals, including camel, llama, giant short-faced bear, wolf, coyote, and prairie dog. This extraordinary fossil assemblage formed around 26,000 years ago, when a cavern in the Minnelusa Limestone collapsed, creating a sinkhole into which the animals fell.



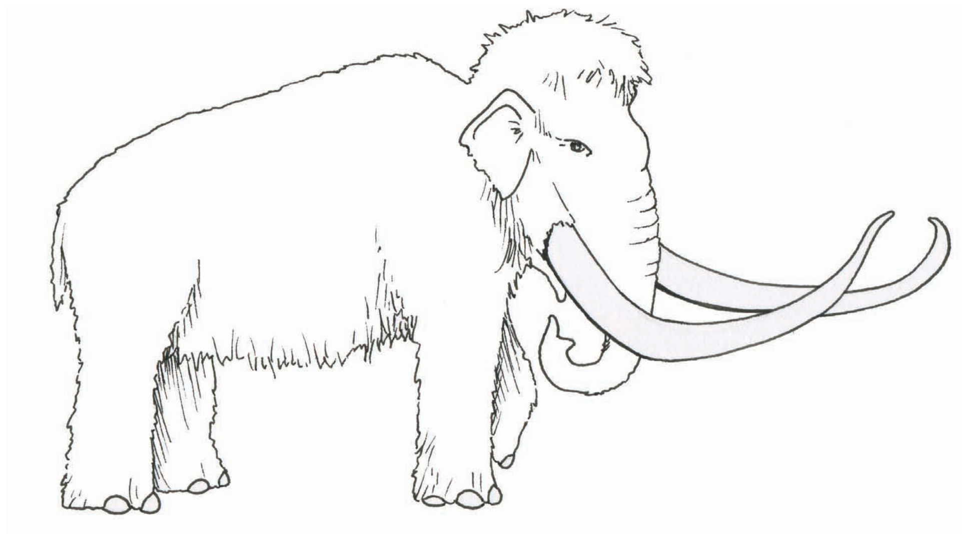


Figure 3.48: Woolly mammoth, Mammuthus primigenius*; about 3.5 meters (10 feet) high at the shoulder.*

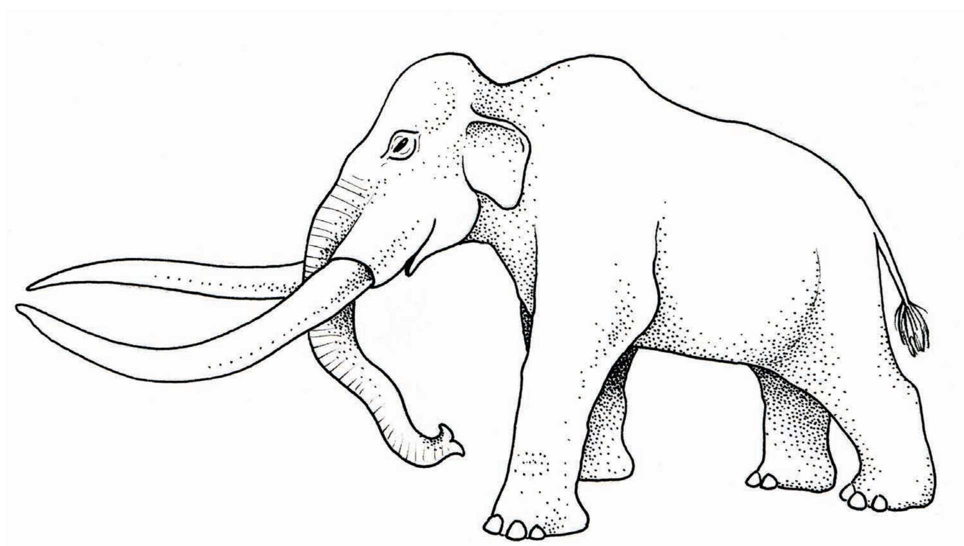
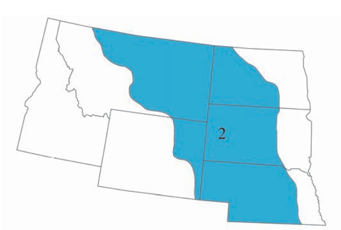
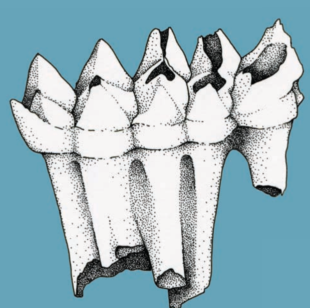


Figure 3.49: Columbian mammoth, Mammuthus columbi; *about 4 meters (13 feet) high at the shoulder.*



Mastodons and Mammoths

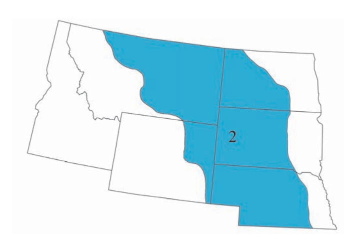
These two kinds of ancient elephants (or, more technically, proboscideans) are frequently confused. Both were common during the Pleistocene, but they had different ecological preferences and are usually found separately. Mammoths are close cousins of modern African and Asian elephants; *mastodons* are more distant relatives, from a separate line of proboscideans that branched off from the modern elephant line in the Miocene. Mastodons have a shorter, stockier build and longer body; mammoths are taller and thinner, with a rather high "domed" skull. In skeletal details, the quickest way to tell the difference is with the teeth: mastodons have teeth with conical ridges, a bit like the bottom of an egg carton; mammoths, in contrast, have teeth with numerous parallel rows of ridges. The teeth are indicative of the two species' ecological differences. Mastodons preferred to bite off twigs of brush and trees, while mammoths preferred tough siliceous grasses. Thus, mastodon teeth are more suitable for cutting, while mammoth teeth are more suitable for grinding.



A mastodon tooth, suitable for chewing twigs and tree leaves. About 20 centimeters (8–9 inches) long.

A mammoth tooth, suitable for grinding grass and soft vegetation. About 25 centimeters (almost a foot) long.

mastodon *• an extinct terrestrial mammal belonging to the Order Proboscidea, characterized by an elephant-like shape and size, and massive molar teeth with conical projections.*



Large mammals are not the only life forms preserved from the ice age. Freshwater and land mollusks are common to abundant in many soft sediment deposits across the Great Plains (*Figure 3.50*).

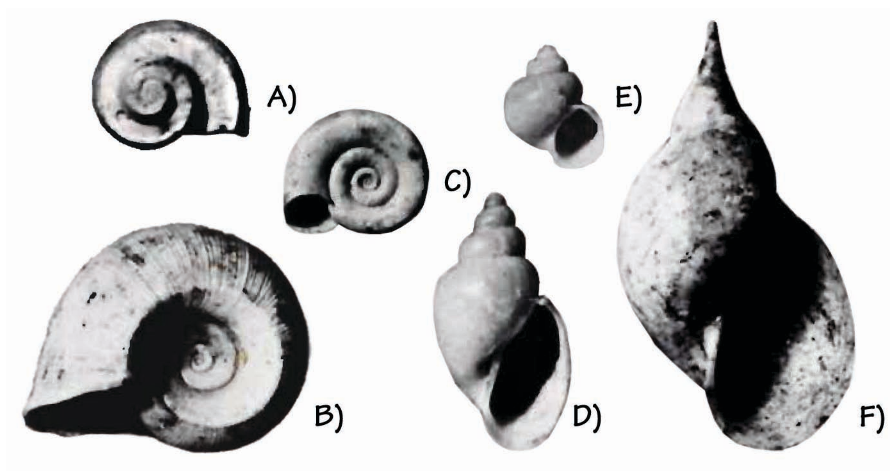
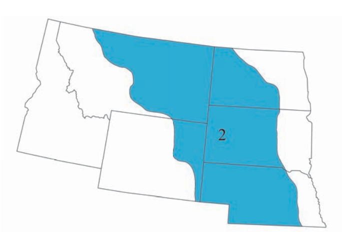


Figure 3.50: Pleistocene land snails of North Dakota. A) Valvata tricarinata*, about 4 millimeters (0.25 inches) in diameter. B)* Helisoma anceps*, about 6 millimeters (0.3 inches) in diameter. C)* Gyraulus parvus*, about 2 millimeters (0.1 inches) in diameter. D)* Lynnaea humilis*, about 6 millimeters (0.3 inches) tall. E)* Amnicola limosa*, about 4 millimeters (0.25 inches) tall. F)* Lynnaea stagnalis*, about 4 centimeters (1.6 inches) tall.*

Gastropods

Commonly known as snails, gastropod mollusks encompass terrestrial, freshwater, and marine species, and include varieties with and without shells (e.g., slugs). Gastropods are among the most diverse groups of organisms—only insects have more named species. The soft parts of gastropods are similar to those of bivalves, but the former typically have coiled shells and are usually much more active. Gastropods are present in Paleozoic and Mesozoic rocks, but are more commonly found in Cenozoic rocks.



Fossils of the Rocky Mountains
Region 3

Late Precambrian rocks are exposed in northwestern Montana (especially in Glacier National Park) and northern Idaho. They include limestones formed from carbonate sediments deposited on a warm, shallow sea floor. These rocks contain fossils called **stromatolites**, layered domes formed by mats of bacteria known as blue-green algae or cyanobacteria (*Figure 3.51*).

See Chapter 2: Rocks to learn more about stromatolites.

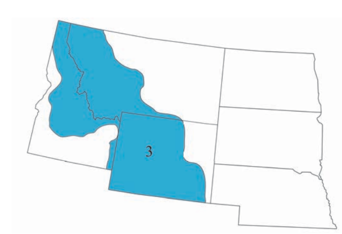
Figure 3.51: Stromatolites lie exposed on the surface of the Grinnell Glacier cirque in Glacier National Park, Montana. These fossils were previously covered by ice and have only recently been exposed. Large specimens are greater than 0.6 meters (2 feet) in diameter.

Shallow marine waters continued to cover most of this area through the early part of the Paleozoic (Cambrian-Silurian), supporting a great diversity of life including trilobites, **graptolites**, brachiopods, and cephalopods. The sea retreated briefly during the middle Devonian, exposing the earlier rocks to erosion and resulting in **unconformities** in the geological record. Sea level rose again in the late Devonian, covering nearly all of Montana, Wyoming, and part of Idaho. These late Paleozoic seas were filled with diverse and abundant fusulinid foraminifera (*see Figure 3.3*) as well as crinoids, conodonts, mollusks, sponges, brachiopods, graptolites, and fish, including sharks.

stromatolite • *regularly banded accumulations of sediment created by the trapping and cementation of sediment grains in bacterial mats.*

graptolite • *an extinct colonial invertebrate animal characterized by individuals housed within a tubular or cup-like structure.*

unconformity • *the relation between adjacent rock strata for which the time of deposition was separated by a period of nondeposition or erosion.*



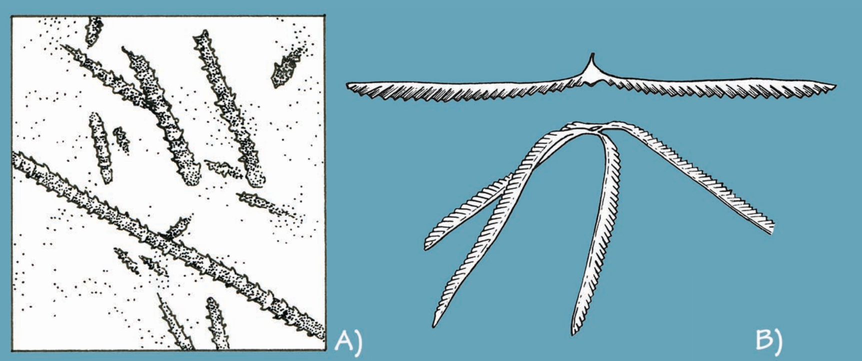
Region 3

Triassic • *a geologic time period that spans from 252 to 201 million years ago.*

coal • *a combustible, compact black or dark-brown carbonaceous rock formed by the compaction of layers of partially decomposed vegetation.*

Graptolites

Graptolites (meaning "rock writing") are an extinct group of colonial, free-floating organisms. They lived from the Cambrian to the Carboniferous, and were relatives of modern hemichordates such as acorn worms. Graptolites are frequently preserved as thin, black, sawblade-like streaks across black shale; tiny cups along these structures held individual animals. Graptolites are often useful as index fossils.

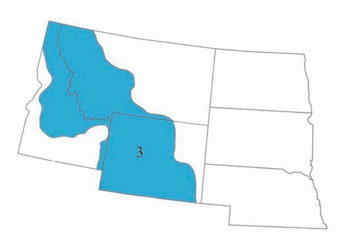


A) Specimen with many fragments of colonies of* Climacograptus*. Slab is 7.5 centimeters (3 inches) on each side.
B) Restoration of what graptolite colonies may have looked like when they were alive and floating in the water.

Mesozoic rocks in eastern Idaho contain abundant marine invertebrates, especially clams, snails, and ammonoids, of **Triassic** and Jurassic age (*Figure 3.52*). Fossils from the early Cretaceous include those of fish, turtles, crocodilians, gastropods, bivalves, and plants (*Figure 3.53*). In addition, a variety of dinosaur fossils (bone, teeth, and eggshell fragments) have been found from ceratopsians, *Ankylosaurus*, and theropods. Similarly, late Cretaceous deposits of Idaho contain **coal**, leaves, and freshwater clams.

Cretaceous rocks are well exposed in many parts of Wyoming, particularly around the edges of the Bighorn Basin. Notable fossils here include flat clams, such as *Inoceramus*, some of which reached enormous sizes (*see Figure 3.28*), and heteromorph ammonoids including *Didymoceras* (*see Figure 3.29B*).

During the Paleogene, the Western Interior Seaway advanced across the continent for the final time before tectonic uplift caused it to drain away. The warm, humid climate allowed the growth of lush forests. Plants that grew in these



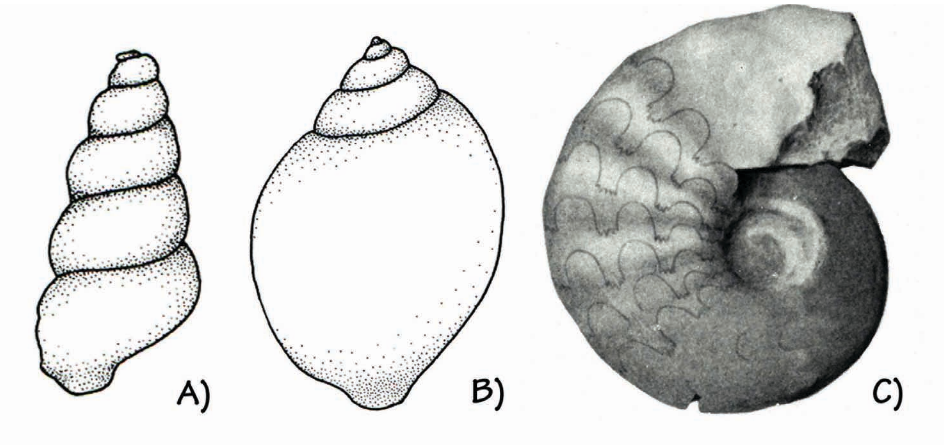


Figure 3.52: Triassic fossils of Idaho. A) and B) Gastropods, Polygyrina *(A) and* Naticopsis *(B), each about 5 centimeters (1.5 inches) tall. C) Ammonoid cephalopod,* Meekoceras, about 6 centimeters (2.5 inches) in diameter.

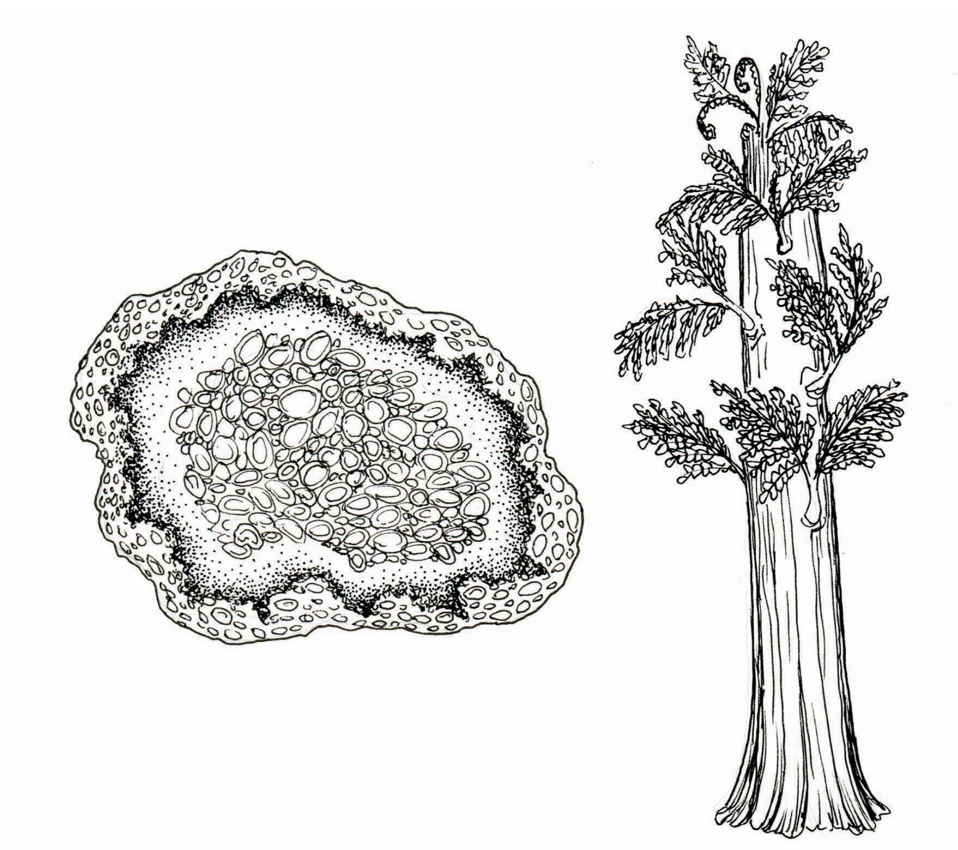
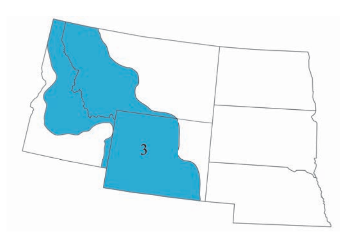


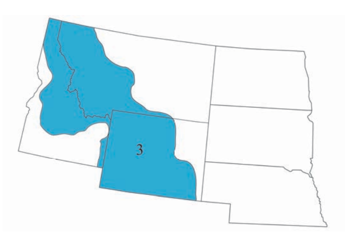
Figure 3.53: Tree fern, Tempskya, *Cretaceous; cross-section and reconstruction. Cross-section about 30 centimeters (1 foot) in width.*



color (mineral) *• a physical property determined by the presence and intensity of certain elements within the mineral.*

chert *• a sedimentary rock composed of microcrystaline quartz.*

lacustrine *• of or associated with lakes.*



forests, including magnolia, ginkgo, sequoia and cypress, were preserved as the coal that is mined today in places such as Wyoming. Lakes were widespread, and were sites of deposition for thick, organic-rich sediments. The most extensive and well-known of these is the Green River Formation, a layer of cream-**colored** shale 600–2000 meters (1970–6560 feet) thick, with occasional layers of **chert** and limestone.

See Chapter 7: Energy to learn about fossil fuel deposits in the Northwest Central.

The Green River Formation outcrops across a large area of southwest Wyoming, northwest Colorado, and northwest Utah, and composes the largest known accumulation of **lacustrine** sedimentary rock in the world. Its sediments accumulated in a system of lakes that covered this area during the Eocene, between 58 and 40 million years ago (*Figure 3.54*). The Green River is famous for the great number of well-preserved fossils found in its lake and river sediments, especially aquatic organisms such as fish, gastropods, and algae, but also many terrestrial plants and animals, including the oldest known bat (*Figures 3.55–3.57*). Well-preserved specimens of the fish *Knightia* are commonly found in the Green River Formation, and it is one of the most abundant vertebrate fossils in the world. A member of the herring family, the average *Knightia* is 7–12 centimeters (3–5 inches) long. *Knightia* are thought to have fed on algae, tiny crustaceans, and insects, and they were a major source of food for many of the larger fish in these Eocene lakes. They are commonly found in mass mortality or "death bed" layers because they swam in schools. The abundant plant and animal life preserved in the Green River Formation is also the reason for its status as a major oil shale deposit.

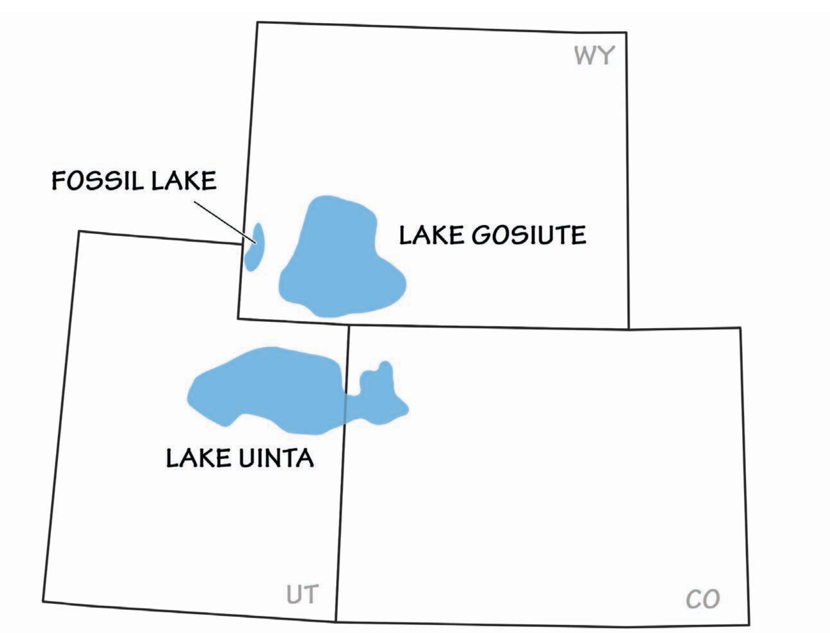


Figure 3.54: The Eocene Green River Formation. This map shows the size and location of the various lakes in which Green River sediments were deposited at different times during the Eocene epoch.

*Figure 3.55: The fossil-rich silicate rock known as "*Turritella *agate" is a popular gemstone from the Green River, but it is actually a misnomer.* Turritella *is a marine gastropod, whereas these snails—properly assigned to the genus* Elimia*—lived in freshwater. Slab is 6 centimeters (2.3 inches) wide.*

Figure 3.56: The perch-like fish Knightia*, the most common fossil vertebrate in the Green River rocks. Specimen is about 10 centimeters (4 inches) long.*

The Eocene was a time of extensive volcanism in the Rocky Mountain region. This is reflected in the occurrence of **silica**-rich layers in the Green River Formation, which formed from **weathered** volcanic ash, as well as the famous Yellowstone Petrified Forest (*Figure 3.58*). This extraordinary assemblage of multiple layers of volcanic ash contains numerous upright-standing, petrified **tree** trunks and abundant transported logs and stumps. It formed when ash was repeatedly eroded off of volcanoes and re-deposited in **braided streams** and rivers.

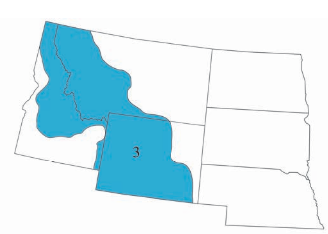
Region 3

silica • *a chemical compound also known as silicon dioxide (SiO_2).*

weathering • *the breakdown of rocks by physical or chemical means.*

tree • *any woody perennial plant with a central trunk.*

braided stream • *a stream consisting of multiple, small, shallow channels that divide and recombine numerous times, forming a pattern resembling strands of braided hair.*



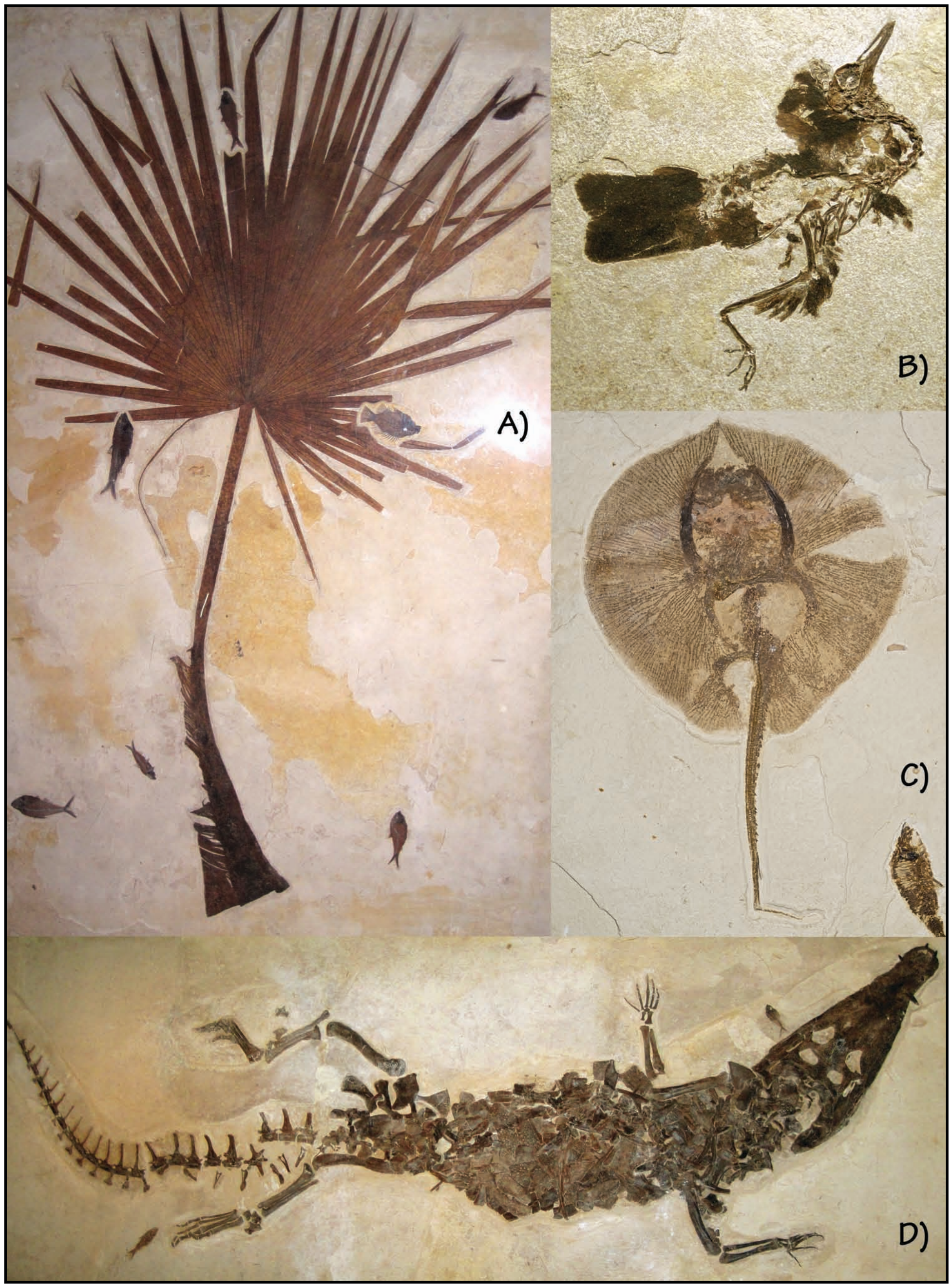
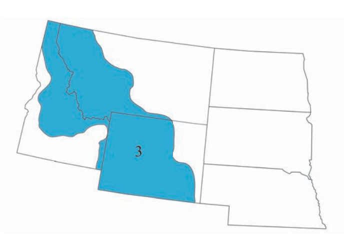


Figure 3.57: Well-preserved fossils from the Green River Formation, southwestern Wyoming. A) Palm frond, Sabalites powelli, *about 1.2 meters (4 feet) long, with fossil fish* Knightia. *B) An undetermined bird species with preserved feathers, about 25 centimeters (10 inches) long. C)* Heliobatis radians, *a stingray, about 40 centimeters (16 inches) long, with fossil fish. D)* Borealosuchus wilsoni, *a crocodilian, reached lengths of 4.5 meters (15 feet).*



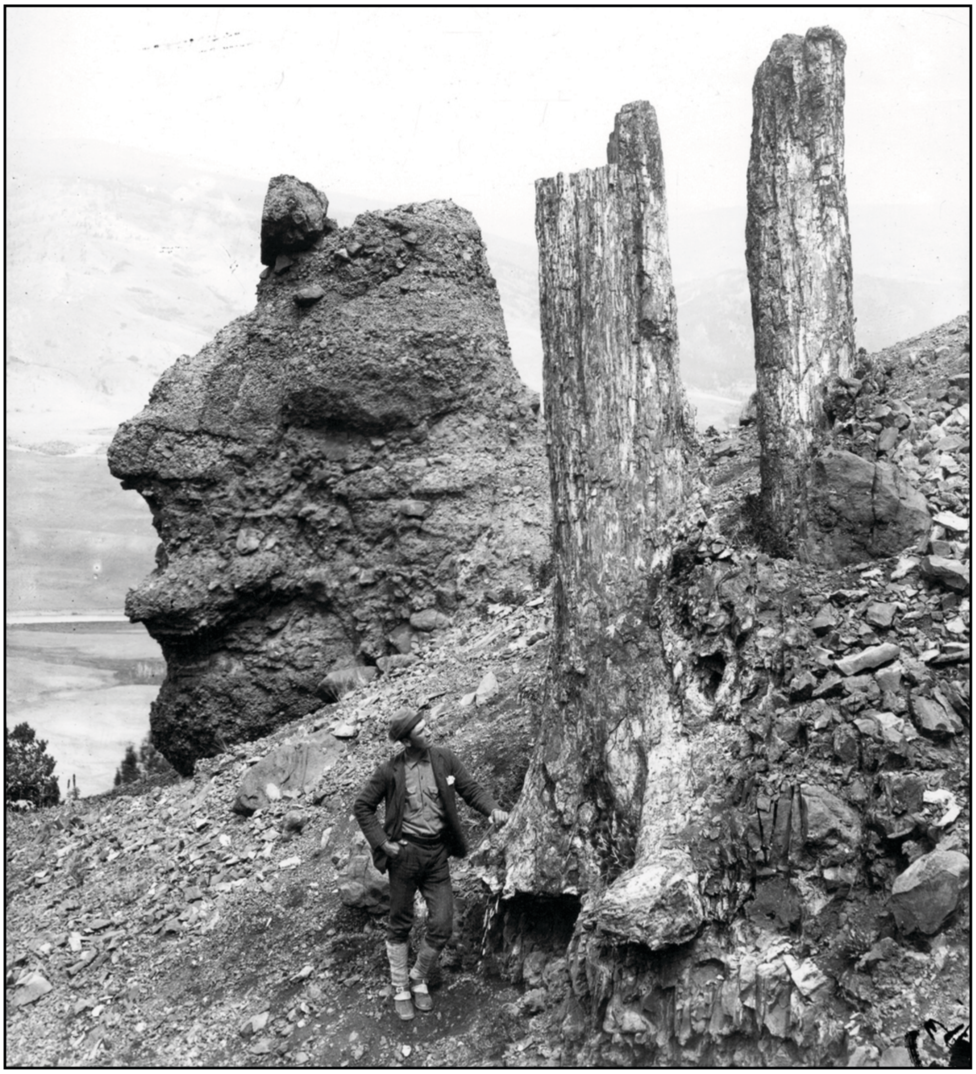


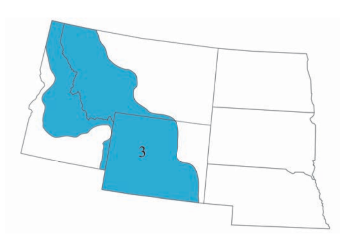
Figure 3.58: Specimen Ridge, overlooking the Lamar River, Yellowstone National Park, Wyoming. These fossil tree trunks are preserved in the position they occupied when they were alive, around 48 million years ago during the Eocene epoch, before they were buried suddenly in a volcanic eruption. This photo was taken around the year 1887. Note man standing at bottom for scale.

Region 3

oxidation *• a chemical reaction involving the loss of at least one electron when two substances interact.*

basalt *• an extrusive igneous rock, and the most common rock type on the surface of the Earth.*

During the Paleocene and Eocene epochs (65 to 34 million years ago) a number of archaic groups of mammals arose and went extinct (*see Figure 3.39*), and many of today's modern mammal groups evolved. Fossil bones of these mammals occur in several areas of northern Idaho, including the Tolo Lake Fossil Site in Idaho County. Abundant leaf and plant remains from this time period can also be found in northern Idaho (Shoshone and surrounding counties), where an ancient lake (approximately 15 million years old) provided ideal conditions for the fossilization of soft plant parts. Fossils in the Miocene Clarkia Fossil Beds (*Figure 3.59*) are so well preserved that some leaves even retain their original color; most are yellow, orange, and brown since they were shed during fall months (although they rapidly **oxidize** and turn black when exposed to air). The lake formed when a basin was dammed by **basalt** flows on the Columbia River



Plateau. Although best known for its plants, the Clarkia Beds also contain well-preserved fossil fish, snails, and insects. Like most **lagerstätten** deposits, the Clarkia Beds probably formed in a low-oxygen sedimentary environment, which slowed decay of the organic remains.

See Chapter 4: Topography for more information about the Columbia River Flood Basalts.

__lagerstätte__ • fossil deposit containing animals or plants that are preserved unusually well, sometimes even including the soft organic tissues.

__Proterozoic__ • a geologic time interval that extends from 2.5 billion to 541 million years ago.

__hot spot__ • a volcanic region thought to be fed by underlying mantle that is anomalously hot compared with the mantle elsewhere.

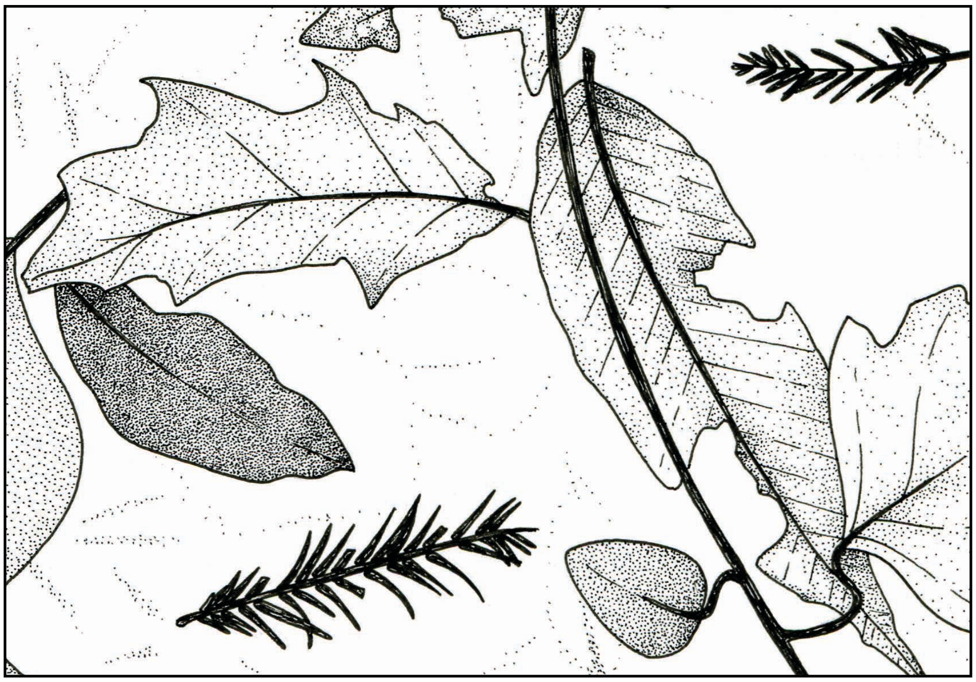


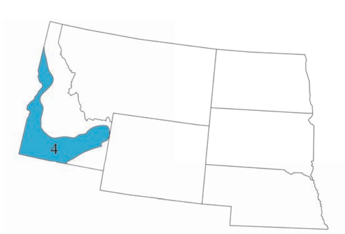
Figure 3.59: A slab of leaves from the Clarkia flora, about 13 centimeters (5 inches) across.

Fossils of the Columbia Plateau
Region 4

Rock formations from the late **Proterozoic** are the oldest fossil-bearing formations in the Columbia Plateau region. The earliest fossils found here are stromatolites, similar to those seen in Montana's Glacier National Park (*see Figure 3.51*), which have been reported in the Gospel Peak area of northwestern Idaho.

See Chapter 2: Rocks to learn more about rhyolite and basalt in the Columbia Plateau.

Paleozoic rocks are not present in the Columbia Plateau, as the land has been covered with igneous rock related to eruptions of the Yellowstone **hot spot** as it moved along the track of the Snake River Plain.



Triassic rocks occur in two areas of Idaho. Along the state's border with Oregon and southern Washington lie deposits of metamorphosed volcanic and sedimentary rocks that contain a variety of marine fossils, primarily from adjacent areas of Oregon. These include corals, sponges, ammonoids, clams, gastropods, echinoids, and bryozoans. In southeastern Idaho, Triassic deposits are largely composed of marine sedimentary rocks with sparse fossils, except for the Thaynes Formation, which contains fossils of fish, crinoids, bivalves, gastropods, ammonoids (*see Figure 3.52*), crustaceans, and shark teeth. The Columbia Plateau has Triassic red beds and thin deposits of coal, both of which indicate some terrestrial deposition.

Outcrops of Jurassic-aged rocks occur in western Idaho, along the border with Oregon and southern Washington. These rocks, formed mostly in deep water marine environments, have been slightly metamorphosed. Fossils from these rocks include ammonoids and oysters. Jurassic rocks in the southeastern part of the state are mostly shallow marine yielding mostly poorly preserved fossils, including crinoids, oysters, sea urchin spines, ammonoids, and corals (*see Figure 3.26*).

The Neogene river and lake sediments of westernmost central and southern Idaho contain abundant and beautifully preserved fossils of fish, rhinos, rodents, rabbits, horses, camels, and many other species. The Hagerman Fossil Beds National Monument on the Snake River just northwest of Twin Falls, in south-central Idaho is the most famous of these deposits, and includes Horse Quarry. This particular outcrop has yielded hundreds of fossils of zebra-like horses, *Equus simplicidens*, that are about 3.5 million years old (*Figure 3.60*). Tolo Lake in western Idaho near the Washington-Oregon border is known for its Quaternary-aged mammoth fossils.

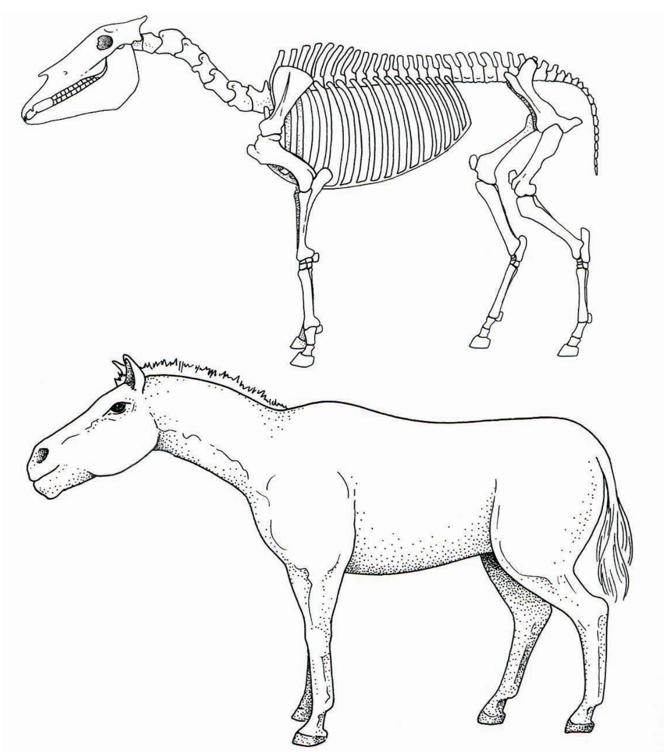
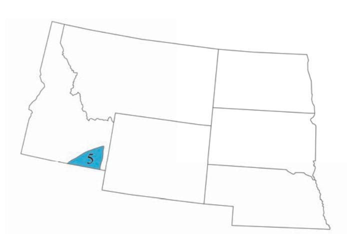


Figure 3.60: Neogene horse, Equus simplicidens*; skeleton and reconstruction 110–145 centimeters (43–57 inches) tall at the shoulder.*

archaeocyathid • a vase-shaped organism with a carbonate skeleton, generally believed to be a sponge.

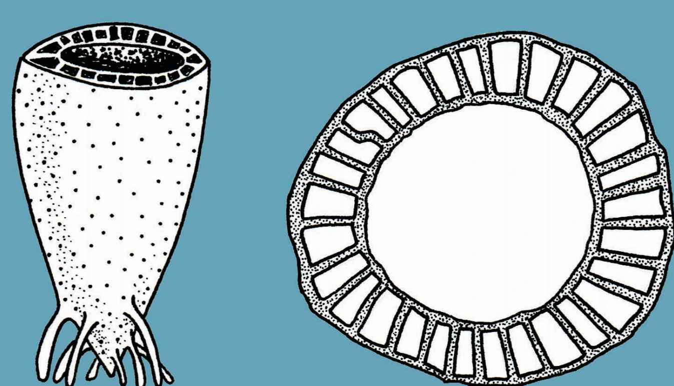


Fossils of the Basin and Range
Region 5

The mountain ranges of southeastern Idaho contain thick sections of early Paleozoic marine sedimentary rocks, mostly sandstones and limestones, deposited during the Cambrian and Ordovician periods. Early Cambrian rocks (variously assigned to the Brigham, Camelback Mountain, and Gibson Jack formations) contain *Skolithos* and other Cambrian trace fossils (*see Figure 3.14*), as well as occasional trilobites. Sponge-like **archaeocyathids** are present in shale and limestone formations. The Ordovician Swan Peak Quartzite contains abundant large trace fossils, as well as trilobites and brachiopods.

Archaeocyathids

Archaeocyathids were the first important animal reef builders, originating in the early Cambrian. These vase-shaped organisms had carbonate skeletons and are generally believed to be sponges. They went extinct in the late Cambrian, but were very diverse. Archeocyathids are often easiest to recognize in limestones by their distinctive cross-sections.



Archaeocyathids are found in lower Cambrian rocks in northern California and southern Oregon. Their vase-shaped calcite skeletons commonly reached lengths of 5 to 20 centimeters (2 to 8 inches).

Region 5

The most abundant Paleozoic rocks in this region are early **Carboniferous** (Mississippian) marine sediments consisting mostly of carbonates, but also some sandstones and shales. Mississippian limestones (known variously as the Madison, Mission Canyon, or Lodgepole formations) contain abundant horn corals, tabulate corals, and spiriferid brachiopods (*Figure 3.61*), and represent a warm, clear-water carbonate environment. The late Carboniferous (Pennsylvanian) is represented by the same marine sediments, but both the variety and quantity of fossils are inferior to those found in Mississippian strata. Nonetheless, fossil algae, foraminifera, bryozoa, brachiopods, crinoids, and corals have been reported from sediments of this age.

Carboniferous • *a geologic time period that extends from 359 to 299 million years ago.*

gravel • *unconsolidated, semi-rounded rock fragments larger than 2 millimeters (0.08 inches) and smaller than 75 millimeters (3 inches).*

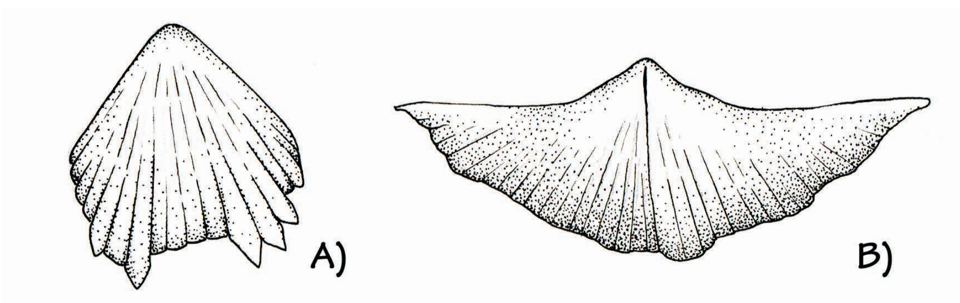


Figure 3.61: Paleozoic brachiopods of southeastern Idaho. A) Macropotamorhyncus insolitus. *B)* Prospira albapinensis. *Both about 2–4 centimeters (1–1.5 inches) wide.*

Southeastern Idaho also contains a thick sequence of early Triassic marine strata, and several horizons (especially the Thaynes and Dinwoody formations) contain biostratigraphically significant ammonoids. Overlying Jurassic rocks, especially the Twin Creek Limestone, contain well-preserved ammonoids and bivalves.

See Chapter 6: Glaciers to learn more about glacial lakes that formed during the last ice age.

Sand and **gravel** deposits in southeastern Idaho that were laid down in association with glacial Lake Bonneville have yielded fossils of Pleistocene bison (*see Figure 3.47*), camels, muskoxen, and horses.

State Fossils

Idaho
Equus simplicidens (horse, Neogene) (*Figure 3.60*).

Montana
Maiasaura peeblesorum (hadrosaur dinosaur; Cretaceous) (*Maiasaura Box, p. 112*).

Nebraska
Mammuthus columbi (Columbian mammoth; Neogene) (*Figure 3.49*).

North Dakota
Teredo Petrified Wood (petrified wood; Paleocene) (*Figure 3.37*).

South Dakota
Triceratops horridus (ceratopsian dinosaur; Cretaceous) (*Figure 3.34A*).

Wyoming
Knightia eocaena (fish; Eocene) (*Figure 3.57*).

Resources

General Books on the Fossil Record and Evolution

Allmon, W. D., 2009, *Evolution & Creationism: A Very Short Guide, 2nd edition*, Paleontological Research Institution, Ithaca, NY, 128 pp.

Benton, M. J., 2008, *The History of Life: A Very Short Introduction*, Oxford University Press, Oxford, UK, 170 pp.

Fenton, C. L., and M. A. Fenton, 1958, *The Fossil Book: A Record of Prehistoric Life*, Doubleday, Garden City, NY, 482 pp. (A well-illustrated classic.)

Fortey, R. A., 1998, *Life: A Natural History of the First Four Billion Years of Life on Earth*, Alfred A. Knopf, New York, 346 pp.

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Garcia, F. A., & D. S. Miller, 1998, *Discovering Fossils: How To Find and Identify Remains of the Prehistoric Past*, Stackpole Books, Mechanicsburg, PA, 212 pp.

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The *Teacher-Friendly* Guide™

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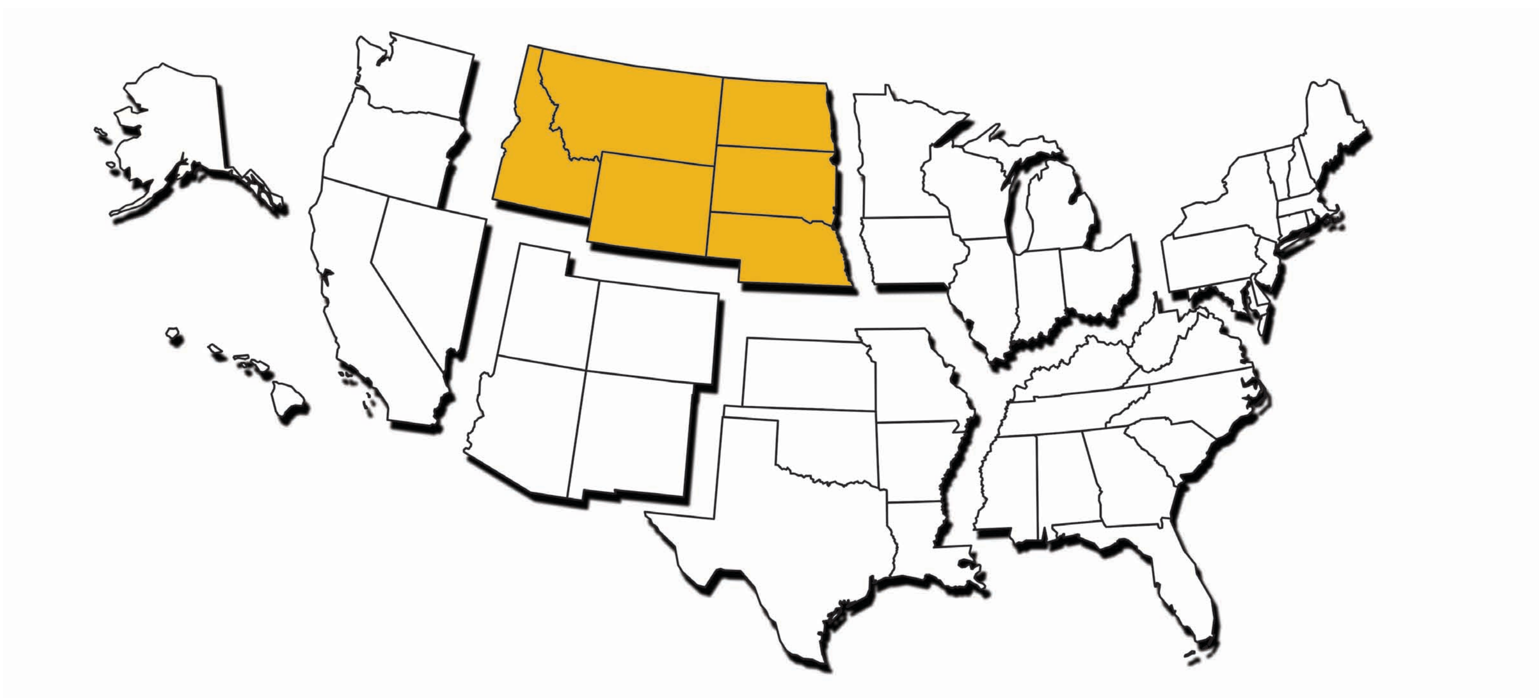

Edited by Mark D. Lucas, Robert M. Ross, & Andrielle N. Swaby

Paleontological Research Institution
2015

ISBN 978-0-87710-511-4
Library of Congress no. 2015951888
PRI Special Publication no. 49

1259 Trumansburg Road
Ithaca, New York 14850 USA
http://priweb.org

First printing September 2015

This material is based upon work supported by the National Science Foundation under grant DRL-0733303. Any opinions, findings, and conclusions or recommendations are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. The publication also draws from work funded by the Arthur Vining Davis Foundations and The Atlantic Philanthropies.

The interactive online version of this *Teacher-Friendly Guide*™ (including downloadable pdfs) can be found at http://teacherfriendlyguide.org. Web version by Brian Gollands.

The Teacher-Friendly Guide™ series was originally conceived by Robert M. Ross and Warren D. Allmon. Original illustrations in this volume are mostly by Jim Houghton (The Graphic Touch, Ithaca), Wade Greenberg-Brand, and Christi A. Sobel.

Layout and design by Paula M. Mikkelsen, Elizabeth Stricker, Wade Greenberg-Brand, and Katherine Peck.

Cite this book as:
Lucas, M. D., R. M. Ross, & A. N. Swaby (eds.), 2015, *The Teacher-Friendly Guide to the Earth Science of the Northwest Central US.* Paleontological Research Institution, Ithaca, New York, x + 450 pp.

Cite one chapter as (example):
Allmon, W. D., and D. S. Friend, 2015, Fossils of the Northwest Central US. Pages 81–141, in: M. D. Lucas, R. M. Ross, & A. N. Swaby (eds.). *The Teacher-Friendly Guide to the Earth Science of the Northwest Central US.* Paleontological Research Institution, Ithaca, New York.

On the back cover: Blended geologic and digital elevation map of the Northwest Central US. Each color represents the age of the bedrock at the surface. Adapted from Barton, K.E., Howell, D.G., Vigil, J.F., *The North America Tapestry of Time and Terrain*, US Geological Survey Geologic Investigations Series I-2781, http://pubs.usgs.gov/imap/i2781.