4 PALEONTOLOGIC RESOURCES

This Paleontological Identification section describes potential paleontological resources located in the Northern Border study area. This area includes the following states: Washington, Montana, Idaho, North Dakota, Minnesota, Wisconsin, Michigan, Ohio, Pennsylvania, New York, Vermont, New Hampshire, and Maine. The Paleontological Study Area (PSA) includes a 100-mile-wide zone along the Northern Border. While most paleontological studies focus on the most detailed information available, this study attempts to give a broad but useful overview of the paleontologically sensitive geological units by state.

Background research conducted for this study consisted of a literature and map review and a generalized fossil locality search. Most paleontological investigations commonly use a scale of 1:24,000 to describe the paleontological sensitivities of geological units. For the purpose of this study, such a resolution is not feasible. This research identified the geologic units at a scale of 1:25,000,000 and the types of fossils in geologic units that may be within or adjacent to the study area (see Figures H-12 through H-20). Creating a paleontological overview at the above scale has been a major challenge for paleontology and geology alike.

A research platform for creating a nationwide database, PaleoPortal is maintained by the University of California Museum of Paleontology (UCMP) and is the result of collaboration between UCMP, the Paleontological Society (PS), the Society of Vertebrate Paleontology (SVP), and the U.S. Geological Service (USGS). It gives access to dozens of museum-collection databases and records of fossil finds throughout the United States in correlation with geological maps by the USGS. The information presented in this document relies heavily on the peer-reviewed texts within the PaleoPortal platform (PaleoPortal, 2010).

Within the PSA four major geological groups were identified: sedimentary rocks, volcanic rocks, plutonic rocks, and metamorphic rocks. Of these rock groups, only sedimentary rocks have a high or moderate potential for containing paleontological materials. Both plutonic and volcanic rocks rarely contain fossils because igneous environments are not suitable for living things. Metamorphic rocks rarely contain fossils because the conditions of metamorphism tend to alter the texture of the rocks and destroy any fossils contained within. Consequently, only sedimentary units will be considered for the purpose of this study. Metamorphic or igneous rocks are mentioned in the rare cases when they do contain fossils.

4.1 PALEONTOLOGICAL SENSITIVITY

Paleontological resources include fossil plants and animals and other evidence of past life such as preserved animal tracks and burrows. The paleontological sensitivity of a geologic unit is determined by its potential to contain paleontological resources (SVP, 1995). The paleontological sensitivity of a geologic unit may be classified according to SVP guidelines (SVP, 2010) as follows:

> *High Potential* - Rock units are considered to have a high potential for containing significant, nonrenewable, fossiliferous resources if vertebrate or significant invertebrate fossils or significant suites of plant fossils have been recovered. These units include, but are not limited to, sedimentary and volcanic formations that contain significant nonrenewable paleontological resources and sedimentary rock units temporally or lithologically suitable for

the preservation of fossils. Sensitivity comprises both of the following: 1) the potential for yielding abundant or significant vertebrate fossils or for yielding a few significant fossils that are large or small, vertebrate, invertebrate, or botanical, and 2) the importance of recovered evidence for new and significant taxonomic, phylogenetic, ecologic, or stratigraphic data. Areas that contain potentially datable organic remains older than recent and areas that may contain new vertebrate deposits, traces, or trackways are also classified as significant.

Undetermined Potential - Specific areas underlain by sedimentary rock units for which little information is available are considered to have undetermined fossiliferous potentials. Field surveys by a qualified vertebrate paleontologist to specifically determine the potentials of the rock units are required before mitigation programs to reduce impacts can be developed.

Low Potential - Reports in the paleontological literature or field surveys by a qualified vertebrate paleontologist may allow determination that some areas or units have low potentials for yielding significant fossils. Such units will be poorly represented by specimens in institutional collections. These deposits generally will not require protection or salvage operations [SVP, 2010].

The SVP identifies vertebrate fossils, their taphonomic and associated environmental data, and fossiliferous deposits as significant, nonrenewable, paleontological resources. Botanical and invertebrate fossils and assemblages may also be considered significant (SVP, 1995). Due to the rarity of fossils and the scientific information they provide, a paleontological resource can be considered significant (Scott and Springer, 2003) if the resource does any of the following:

- Provides data on the evolutionary relationships and developmental trends among organisms, both living and extinct;
- Provides data useful in determining the age(s) of the geologic unit or stratigraphy, as well as timing of associated geological events;
- Provides data on a community level;
- Demonstrates unusual or spectacular circumstances in the history of life; and/or,

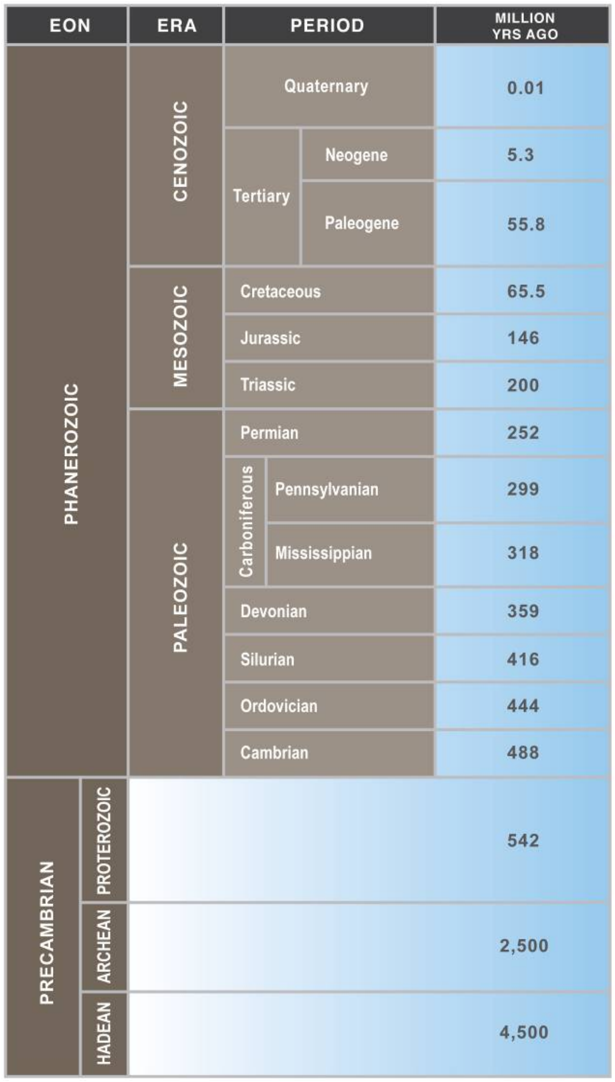
Is not abundant or found in other geographic locations and may be in danger of being depleted or destroyed by the elements or by vandalism.

Paleontological resources must be evaluated to determine if any of the criteria above are applicable. Proper identification of paleontological resources is often difficult in the field; therefore, the recovery, preparation, and analysis of paleontological resources are necessary to determine their significance. This process must be done by, or under the supervision of, a qualified paleontologist (SVP, 1995). Microvertebrate fossils are generally not visible to the naked eye; although initial sifting may be conducted in the field, analysis for microinvertebrates requires laboratory processing of bulk samples from paleontologically sensitive geologic units (SVP, 1995; Scott and Springer, 2003).

4.2 PALEONTOLOGICAL RESOURCES WITHIN THE STUDY AREA

The following paragraphs describe only the geological units with a potentially high paleontological sensitivity within the PSA. Geological-mapping units are indicated with respect to the geological study-area maps at the end of this section. Multiple paleontologically sensitive geological units within the PSA do not occur on these maps due to the previously described selection of a large-scale resolution for the PSA. Generalized geological units and a PSA summary for each state are described below. The order in which the paleontologically relevant geologic ages occurred is found in Figure H-12.

Figure H-12. Geologic Timeline for Eons, Eras, and Periods Important to the Paleontologic Resources of the Northern Border



4.2.1 NEW ENGLAND REGION

4.2.1.1 Maine

Summary

Paleontologically sensitive geological units in Maine's PSA include Paleozoic and Cenozoic deposits. Fossiliferous Paleozoic deposits have been destroyed by metamorphism associated with *orogenies*, or mountain-building events, within the southern portion of the PSA only. In all other areas, the Paleozoic deposits are intact. Paleozoic deposits represent sea-level fluctuations and include habitats ranging from nearshore to deepwater. Fossils from these geological units include numerous invertebrates. Cenozoic deposits consist of retreating glacial deposits containing many different plant and large-vertebrate fossils.

Quaternary - Quaternary glaciation peaked in Maine nearly 20,000 years ago, leaving the state covered with a thick layer of ice. The weight of the overriding glaciers had temporarily depressed the crust, allowing the sea to flood areas far inland, and glacial clay was deposited on the seafloor. Common fossils include clams, snails, and barnacles, although mammoth, walrus, and seal remains have also been found (Churchill-Dickson, 2010).

Devonian - The fossiliferous deposits in Maine from this time represent a variety of habitats. Nearshore marine settings were dominated by brachiopods, although bivalves, corals, crinoids, conodonts, gastropods, ostracods, and trilobites have also been found. Fully terrestrial habitats existed as well, and fragmented plant fossils have been preserved in a few rock units (Churchill-Dickson, 2010).

Silurian - Common nearshore fauna of this time period included brachiopods, corals, bivalves, conodonts, gastropods, ostracods, trilobites, and stromatoporoids. Graptolites, trace fossils, and some brachiopods dominate the deepwater deposits (Churchill-Dickson, 2010).

Ordovician - All fossil-bearing deposits in Maine were formed in the marine realm and represent habitats ranging from nearshore to deepwater basins. The nearshore fauna are dominated by brachiopods but also contain snails, trilobites, corals, and clams. Graptolites and rare occurrences of brachiopods, trilobites, and conodonts are found in the deeper-water deposits (Churchill-Dickson, 2010).

Cambrian - Maine has a few deepwater fossils from this time (Churchill-Dickson, 2010).

Precambrian - During the Precambrian, Maine did not yet exist. The first parts of Maine were not assembled until the Ordovician, when ancient landmasses were accreted to North America during a mountain-building event. Preserved in a few places are Late Precambrian sediments that were likely deposited in deep water and that contain a few trace fossils (Churchill-Dickson, 2010).

4.2.1.2 New Hampshire

Summary

Paleontologically sensitive geological units in New Hampshire's PSA include only a very small area in the north of the state. These paleontologically sensitive units are only of Cenozoic age because metamorphism associated with the orogenies destroyed or altered any sediments formed during Paleozoic times. Cenozoic deposits consist of retreating glacial deposits containing many different plant and large-vertebrate fossils.

Quaternary - During much of the Quaternary, thick sheets of ice covered New Hampshire, and after the glaciers melted, the present sea level was reached approximately 3,000 to 5,000 years ago. The fossil evidence of plants and pollen from Pleistocene sediments in New Hampshire indicate that species of herbs and sedges, spruce, balsam poplar, willow, and dwarf birch trees grew in the area when the ice sheets periodically retreated (Springer, 2008a).

Devonian - During an episode of mountain building, igneous rocks were formed and older rocks were metamorphosed. These igneous and metamorphic rocks contain no fossils (Springer, 2008a).

Silurian - Rocks of this time interval are metamorphic and igneous and do not contain fossils (Springer, 2008a).

Ordovician - Rocks of this time interval are entirely metamorphic and igneous and do not contain fossils (Springer, 2008a).

Cambrian - There are no fossils in the few rocks in New Hampshire that may be of Cambrian age (Springer, 2008a).

Precambrian - Precambrian rocks in New Hampshire are predominantly metamorphic; no fossils are found in them (Springer, 2008a).

4.2.1.3 Vermont

Summary

Paleontologically sensitive geological units in Vermont's PSA include Paleozoic and Cenozoic deposits. Paleozoic deposits containing fossils are sparse in Vermont, and metamorphism associated with the orogenies destroyed or altered any sediments formed at this time. Paleozoic sediments include sandstone, siltstone, and mudstone and contain bryozoans, brachiopods, cephalopods, gastropods, sponges, and trilobites. Cenozoic deposits consist of Pleistocene glacial deposits containing large-vertebrate fossils.

Quaternary - During much of the Quaternary, a thick sheet of ice covered Vermont. The weight of the ice depressed the surface of the land, allowing ocean waters to infiltrate the lakes of this region. In westernmost Vermont, fossils in lake deposits indicate that the salinity fluctuated as lake waters mingled with ocean water entering through the St. Lawrence River to the north. As the glaciers melted, the land was able to rebound in elevation, building a barrier to the ocean so that freshwater-lake conditions returned. Sediments left by the melting ice can be found in many areas. Mastodons, ground sloths, and saber-toothed cats roamed the PSA (Mehrtens, 2008).

Silurian - Most rocks of Silurian age were metamorphosed during later tectonic activity, and few marine fossils are found in them (Mehrtens, 2008).

Ordovician - Tropical seas in Vermont were rich in marine life, including the some of the first corals as well as bryozoans, brachiopods, cephalopods, gastropods, sponges, and trilobites (Mehrtens, 2008).

Cambrian - Tracks and trails of trilobites are common in the muddy and sandy shoreline sediments deposited during this time (Mehrtens, 2008).

Precambrian - Precambrian rocks in Vermont are mostly metamorphic and do not contain any fossils (Mehrtens, 2008).

4.2.2 GREAT LAKES REGION

4.2.2.1 New York

Summary

Paleontologically sensitive geological units in New York's PSA include predominantly Paleozoic and Cenozoic deposits. Paleozoic deposits represent a fast-rising and then eventually falling sea level. Fossils of trilobites, brachiopods, clams, and other marine organisms can be found in these rocks. Other geological units within the PSA represent early deltas that contained small-forest and other plants. Cenozoic deposits consist of Pleistocene glacial deposits, such as terminal and lateral moraines, containing large-vertebrate fossils.

Quaternary - Glacial deposits across New York and the northeastern United States record the movements of enormous ice sheets. The ice sheets helped to shape the landscape of New York, scraping off loose rock materials, gouging the bedrock beneath the ice as it advanced, and scouring river valleys. The Finger Lakes are a famous example of New York lakes formed by glacial scouring. Mammoths and mastodons roamed the landscape (Picconi, 2006). Fossil mastodons, bison, and other mammals may be found where unconsolidated deposits vary near the surface. Freshwater snail and clam fossils occur along old drainage systems (RASNY, 2010).

Carboniferous - Thick accumulations of peat were compressed over time and transformed into layers of coal. This geological unit is not known to contain fossils (Picconi, 2006).

Devonian - The most fossiliferous limestones include coral reefs and inter-reef deposits of shallower bottoms; deeper-water limestones contain abundant chert (flint) nodules. Relatively clear waters over the shallower shelf favored a profusion of brachiopods, bryozoans, corals, crinoids, and trilobites. Mollusks were more prominent east of the foreland basin (closer to shore) where silts and sands accumulated under more turbid waters (RASNY, 2010).

Silurian - With a changing sea level in the Silurian, the inland ocean covering western New York became extremely shallow, and circulation was poor (Picconi, 2006). Trace fossils, occasional brachiopods, nautiloids, and even rare jellyfish imprints may be found. Near the end of the Silurian, the sea became deeper but apparently remained very salty, and the shallowest areas were home to a strange fauna dominated by eurypterids (RASNY, 2010).

Ordovician - During the Early Ordovician, the rocks formed in New York were predominantly limestone and dolostone. Toward the end of the Ordovician, volcanic islands formed along a subduction zone between North America and Western Europe. Fossils from this time include trilobites, graptolites, and bryozoans (Picconi, 2006).

Cambrian - Early during the Late Cambrian, global sea level rose, flooding New York with a shallow sea. Sedimentary rocks were formed from sand, silt, and clay deposited in this sea (Picconi, 2006). The fossil record is scarce from this time period but includes numerous records of trilobites (Bassett et al., 1976).

Precambrian - The Grenville Mountains formed during the Precambrian as North America collided with an ancient supercontinent and the sandstone, shale, and limestone deposited earlier were squeezed and pushed up onto the margin of the early North-American continent. The intensity of the collision metamorphosed the rocks as follows: 1) sandstone became quartzite, gneiss, or schist; 2) limestone became marble; and 3) shale became gneiss and schist. These rocks are the oldest found in the PSA. The Precambrian fossil record in these rocks consists predominantly of bacteria or microfossils (Picconi, 2006).

4.2.2.2 Pennsylvania

Summary
Paleontologically sensitive geological units in Pennsylvania's PSA include predominantly Paleozoic and Cenozoic deposits. Paleozoic deposits range from shallow marine deposits that contain limestone and mudstones to terrestrial sandstone deposits. Inscribed in the Cenozoic deposits of the PSA is also the continental collision of Gondwana. Fossils include many different marine forms, such as trilobites, and terrestrial deposits such as scale trees and ferns. Cenozoic deposits include glacial deposits containing large-vertebrate fossils.

Quaternary - Ice sheets covered much of the PSA during the Late Quaternary. Sediments left by the melting ice can be found in many areas. Mastodons, ground sloths, and saber-toothed cats roamed most of the state. Fossils of plants, such as willow and sedge, help paleontologists decipher the complex climatic history of Pennsylvania during the Quaternary (Springer, 2008b).

Jurassic – Jurassic-era deposits are found in Pennsylvania but not within the PSA (Springer, 2008b).

Triassic – Triassic-era deposits are found in Pennsylvania but not within the PSA (Springer, 2008b).

Permian - Since the Permian was primarily a time of erosion in the state, few outcrops of this age have been identified. However, ostracods and a few tiny fish teeth have been recovered (Springer, 2008b).

Carboniferous - Vast swamps developed in the lowland areas, and enormous amounts of plant matter accumulated, making the fossil record of today (Springer, 2008b).

Devonian - The muddy sea floor of Pennsylvania was home to brachiopods and tall, flower-like crinoids (Springer, 2008b).

Silurian - Colonial corals flourished on the limy sea floor as did bryozoans, brachiopods, and tiny ostracods (Springer, 2008b).

Cambrian - A shallow sea rose to cover the state, and sediments eroding off the land formed a sandy sea floor inhabited by trilobites, brachiopods, and other marine organisms. Cambrian rocks contain stromatolites typical of a shallow-water environment (Springer, 2008b).

4.2.2.3 Ohio

Summary

Paleontologically sensitive geological units in Ohio's PSA include only Paleozoic and Cenozoic sedimentary deposits. Paleozoic deposits ranging from sandstone and siltstone to mudstone reflect changing sea levels. Other sedimentary deposits also include deltas and swamp deposits. Cenozoic deposits represent the massive glacial advances and retreats and contain many different large-vertebrate fossils.

Quaternary - There were massive glacial advances and retreats in Ohio during the Early Quaternary (Pleistocene). The fossil record from these glacial times consists of mammoths, mastodons, ground sloths, giant beavers, and musk oxen (Ausich, 2006).

Permian - Layers of rocks are preserved from this time period and indicate that the area was fully terrestrial. Lakes, rivers, and other habitats dominated the landscape; fossils of ferns and horsetails are common (Ausich, 2006).

Carboniferous - During the Early Carboniferous, sediments from the eroding Appalachian Mountains to the east formed extensive marine deposits of muds and silts. Brachiopods are common fossils of this time. Other fossils include early trees and vines (Ausich, 2006).

Devonian - Shallow tropical seas continued to cover Ohio during the Early Devonian, producing thick deposits of limestones on the sea floor. Fossils of brachiopods, crinoids, trilobites, and placoderms (armored fish) are found in shales formed during this time (Ausich, 2006).

Silurian - Large coral and sponge reefs separated the shallower waters across much of Ohio from the deeper waters of the Michigan Basin to the north and the Appalachian Basin to the east. Corals, brachiopods, and stalked echinoderms are common fossils from these ancient reefs (Ausich, 2006).

Ordovician - Muds from the emerging Taconic Mountains in the northeast were deposited in shallow tropical seas teeming with abundant sea-floor life. Fossils of brachiopods, bryozoans, corals, and crinoids are common in the Ordovician rocks in southwestern Ohio (Ausich, 2006).

4.2.2.4 Michigan

Summary

Paleontologically sensitive geological units in Michigan's PSA include some of the oldest known fossils from the Precambrian, including filamentous algae. Most parts of the PSA are covered with Paleozoic-age rocks representing shallow, tropical seas as well as nearshore coal-forming swamps. Other deposits consist of Cenozoic glacial deposits containing large-vertebrate fossils.

Quaternary - There are abundant Quaternary glacial deposits in Michigan. Glaciers up to a mile thick advanced over Michigan at least four times during the Early Quaternary (Pleistocene), carving out the Great Lakes and sculpting the present-day landscape of lakes, hills, and swamps. Fossils from this time include freshwater clams, snails, fish, amphibians, and birds as well as mammals such as mammoths, mastodons, musk oxen, and giant beavers (Brandt, 2006).

Carboniferous - The shallow seas that had covered Michigan left behind invertebrate marine fossils such as crinoids, blastoids, clams, and corals. Plants dominate the fossil record of this time period (Brandt, 2006).

Devonian - Fossils are particularly abundant in the rocks of this time and include trilobites, many species of brachiopods, cephalopods, snails, crinoids, and *Hexagonaria*, the coral more commonly known as the Petoskey Stone, Michigan's state rock. The vertebrates are represented by fossilized plates of armored fish (Brandt, 2006).

Silurian - Coral reefs grew around shallow seas in Michigan. Fossils of this period include corals, bryozoans, crinoids, trilobites, brachiopods, clams, snails, and cephalopods (Brandt, 2006).

Ordovician - North America was positioned over the equator, and a shallow sea in Michigan was host to a diverse, tropical marine fauna dominated by brachiopods, trilobites, crinoids, and corals (Brandt, 2006).

Cambrian - Because North America was situated over the equator at this time, the climate was tropical, and invertebrate marine organisms such as trilobites and brachiopods proliferated (Brandt, 2006).

Precambrian - Some of the oldest rocks in North America are within the PSA. These metamorphic and igneous rocks are the remnants of mountain ranges raised during the Precambrian collision of landmasses that formed the beginnings of the North American continent. Partially metamorphosed sedimentary rocks contain fossil evidence of the earliest eukaryotes (organisms whose cells have a nucleus), a filamentous alga (Brandt, 2006).

4.2.2.5 Wisconsin

Summary

Paleontologically sensitive geological units in Wisconsin's PSA include Paleozoic sandstone, siltstone, and mudstone representing shallow-sea environments. A large range of marine life from brachiopods to sharks as well as soft-bodied fossils has been found. Other deposits are of Cenozoic age and represent glacial deposits containing wooly mammoth and other large-vertebrate fossils.

Quaternary - During the Quaternary, massive glacial ice sheets influenced North America, and nowhere are their effects more striking than in Wisconsin. Glaciers deposited large boulders called erratics, created drumlins, gouged bedrock, and formed the scenic landscapes comprising moraines, eskers, and kettle lakes of today's Wisconsin. Animals adapted to a cold climate mark the fossil record of this time, such as the wooly mammoth, large beaver, and horses. Fossils of seal, walrus, and whale are found along the Great Lakes (Barreto, 2005).

Ordovician - A shallow sea covered Wisconsin, and sediments representing the nearshore environment contain fossils of colonial corals, bryozoans, and cephalopods (Barreto, 2005).

Cambrian - Wisconsin had a tropical climate and was covered by a shallow sea teeming with diverse life forms. Fine-grained sediments eroding from adjacent landmasses settled on the sea floor. The deposits of sandstone and shale preserve the remains and traces of intriguing ancient sea life and thin-shelled brachiopods. Studying Wisconsin's Cambrian fossil record reveals many mysteries of early evolution, ancient ancestors, and bizarre experimental life forms that left no living descendants (Barreto, 2005).

Precambrian - The earliest history of Wisconsin is recorded by ancient rocks of Precambrian age, but they do not contain fossils (Barreto, 2005).

4.2.3 EAST OF THE ROCKIES REGION

4.2.3.1 Minnesota

Summary

Paleontologically sensitive geological units in Minnesota's PSA include predominantly Precambrian and Cenozoic deposits. Banded iron formations and stromatolites mark Precambrian deposits. Paleozoic deposits consist of tropical sandy coastline and shallow marine deposits. Limestone and dolostone are common from this age. Cenozoic deposits include mostly glacial deposits containing mastodons, mammoths, musk ox, and other large mammals.

Quaternary - The alternating advance and retreat of glaciers dominated the Quaternary of Minnesota. The glaciers left behind thick blankets of muddy sediment, as well as sand and gravel carried by streams formed from melting glacial ice. Enormous lakes formed south of the retreating ice sheets and streams flowing out of these lakes carved the major river valleys that we see in Minnesota today. Mastodons, mammoths, musk ox, and other large mammals roamed the Quaternary landscape (Runkel, 2006).

Cretaceous - A northeastern extension of the Western Interior Seaway frequently covered much of Minnesota during this time. A muddy coastline gave way to a shallow sea floor that was home to oysters, clams, ammonites, and crocodiles (Runkel, 2006).

Devonian - During the Devonian, a shallow sea covered parts of Minnesota. Within these waters, the skeletons of marine organisms slowly accumulated and contributed to the limy sediments on the sea floor. These sediments eventually formed limestone with a rich fossil record (Runkel, 2006).

Ordovician - A shallow, tropical sea covered most of Minnesota during the Ordovician and, at times, may have flooded the entire state. For much of this period, the skeletons of marine organisms accumulated and contributed to the limy sediments on the sea floor. Early in the Ordovician, microbial organisms that formed stromatolites and microbial mats dominated the sea. Later in Ordovician time, "shelly" fossils were most common, chiefly bryozoans, brachiopods, crinoids, and mollusks (Runkel, 2006).

Cambrian - The sediments that were deposited in the warm, shallow sea were mostly sandy and contain a record of life dominated by trilobites, brachiopods, and strange, shelled organisms called hyoliths (Runkel, 2006).

Precambrian - Sedimentary structures formed by the activity of bacteria, such as stromatolites, are common in Precambrian rocks. These fossils are typically primitive, single-celled organisms (Runkel, 2006).

4.2.3.2 North Dakota

Summary

Paleontologically sensitive geological units in North Dakota's PSA consist predominantly of Mesozoic and Cenozoic deposits. Paleozoic deposits only exist in the PSA in the most eastern part of the state. Paleozoic deposits represent fluctuating sea levels with large assemblages of different marine invertebrates. Mesozoic deposits are predominantly of shallow marine origin and include many fishes, reptiles, and birds. Cenozoic deposits range from subtropical, swampy lowlands to glacial deposits.

Quaternary - Glaciers flowed across the northeastern two-thirds of North Dakota during the Quaternary, and debris deposited by the melting ice still covers much of the surface. Fossils of mastodons, mammoths, horses, bison, giant ground sloths, and camels have been recovered from Quaternary deposits in the state (Springer, 2006a).

Tertiary - Most of North Dakota was above sea level during the Tertiary, and volcanic ash deposits became layers of bentonite clay interbedded with the river and lake deposits derived from erosion of the rising Rocky Mountains. Fossils of freshwater mollusks, titanotheres, crocodile-like champsosaurs, and primitive trees such as sequoia, bald cypress, magnolia, and ginkgo can be found in these rocks (Springer, 2006a).

Cretaceous - During the Cretaceous, North Dakota was either completely or partially covered by a warm, shallow sea called the Western Interior Seaway. Fine-grained sediments, mostly silt and clay, were deposited on the seafloor. Entombed in these rocks are fossils of marine reptiles as well as sharks, rays, ratfish, birds, and numerous marine invertebrates (Springer, 2006a).

Jurassic - Fossils of gastropods, bivalves, echinoderms, and foraminifera are found in Jurassic rocks of North Dakota (Springer, 2006a).

Triassic - North Dakota's Triassic rocks are not commonly exposed at the surface, but information about them comes from drill cores (Springer, 2006a).

Silurian - Corals, trilobites, and other invertebrates inhabited the shallow, subtropical seas. Near the end of the Silurian, the seas receded, and karst topography developed on the eroding land surface. Silurian rocks are exposed at the surface only in a small area in the northeastern part of the state (Springer, 2006a).

Ordovician - Diverse assemblages of invertebrate animals including corals, cephalopods, trilobites, brachiopods, bryozoans, and graptolites inhabited the shallow marine environments. Ordovician rocks are exposed at the surface only in a small area at the eastern edge of the state (Springer, 2006a).

Cambrian - The most abundant fossils in Cambrian rocks are those of conodonts, but there are also remains of brachiopods and trilobites. Cambrian rocks are not exposed at the surface, but information about them comes from drill cores (Springer, 2006a).

4.2.3.3 Montana

Summary

Paleontologically sensitive geological units in Montana's PSA consist predominantly of Precambrian, Cretaceous, and Tertiary sedimentary units. Precambrian sedimentary units include shallow-sea stromatolites and trace fossils. Paleozoic deposits are from warm and shallow marine waters that created a thin blanket over almost all of Montana. Mesozoic deposits are of terrestrial and tropical marine origin. The Cenozoic marks the retreat of the ocean and the onset of a colder period. Deposits from the Cenozoic thus range from those of tropical, shallow seas to glacial deposits.

Quaternary - Quaternary deposits are found primarily in the western regions of the state (Varricchio, 2006). During the Quaternary, the climate became increasingly wetter, and this wetness invigorated streams that began to carve deep valleys into the plains of Montana. Glaciers carved out serrated rows of jagged mountain peaks and flattened the northern third of the state. Several large, ice-dammed lakes occupied much of the state as well. Mammoths, dire wolves, and musk ox roamed the regions to the front of the ice sheets.

Tertiary - Tertiary vegetation varied significantly as climates alternated between wet and dry intervals. Large titanotheres, dogs, and other mammals mark the fossil record for the Tertiary in northern Montana (Varricchio, 2006).

Cretaceous - The Cretaceous was a geologically active time in Montana, and the western part of the state experienced mountain building and episodes of violent volcanism. Climates were warm, with wetter conditions near the coast and seas that existed in Montana at that time and seasonally arid ones in the shadow of the mountains. Terrestrial ecosystems supported a wide diversity of plants and animals, such as many dinosaurs including one of the most famous, *Tyrannosaurus rex* (Varricchio, 2006).

Jurassic - Warm, shallow seas covered much of Montana throughout most of the Jurassic. Small, sluggish rivers carried terrestrial sediments to the east and northeast, forming a low coastal plain. Montana's oldest dinosaur fossils are found among ferns (Varricchio, 2006).

Triassic - A hot, arid landscape stretched across Montana throughout most of the Triassic. Fossils from marine rocks include brachiopods and ammonites (Varricchio, 2006).

Carboniferous - For most of the Early Carboniferous, warm marine waters ranging from deep to shallow covered the state. The diverse marine fauna included algae, sponges, worms, arthropods, bivalves, cephalopods, brachiopods, and nearly 100 species of fish. Rainwater dissolved limestones, forming the karst topography seen today in parts of Montana (Varricchio, 2006).

Devonian - The Devonian Period in the PSA recorded a diversity of marine life, including crinoids, sponges, brachiopods, mollusks, and conodonts. Devonian deposits even include plant spores washed or blown in from nearby lands (Varricchio, 2006).

Silurian - Very little remains of any Silurian rocks in Montana due to high rates of erosion in the Devonian, although there are subsurface Silurian rock layers in the eastern third of the state (Varricchio, 2006).

Ordovician **–** Warm marine waters supported a diversity of algae, crinoids, bryozoans, brachiopods, and corals, and remnants of some of the earliest vertebrates also occur (Varricchio, 2006).

Cambrian - Shallow seas flooded over Montana, and limestones and shales were deposited. When the seas retreated, sandy beach deposits accumulated. Trilobites represent the most abundantly fossilized animals of the time, and their remains are common in many Cambrian rocks from the state.

Precambrian - From about 1.5 billion years ago to 800 million years ago, a thick sequence of sandy and muddy deposits accumulated in the western part of Montana. These sediments represent the west coast of the early North American continent and contain the oldest evidence of life in Montana. Fossils include stromatolites as well as traces left by marine animals crawling along the sea floor (Varricchio, 2006).

4.2.4 WEST OF THE ROCKIES REGION

4.2.4.1 Idaho

Summary

Paleontologically sensitive geological units in Idaho's PSA include Precambrian, Paleozoic, Mesozoic, and Cenozoic deposits. Precambrian deposits contain stromatolites and trace fossils. Paleozoic deposits are terrestrial and marine and represent fluctuating sea levels. Mesozoic deposits are shallow marine sedimentary rocks. Cenozoic deposits consist of lake and river deposits as well as retreating glacial deposits containing large-vertebrate fossils.

Quaternary - Quaternary deposits include glacial valley sediments, layers of wind-blown glacial dust. Two hundred species of vertebrates are known from the Quaternary fossils of Idaho. The most common fossils are of mammoths, horses, camels, bison, mountain sheep, ground sloths, rodents, rabbits, birds, snakes, lizards, and fish (Springer, 2006b).

Tertiary - Tertiary river and lake sediments contain fossils of fish, rodents, rabbits, horses, rhinos, camels, pronghorns, oreodonts (sheep-like mammals), and plants (Springer, 2006b).

Jurassic - Outcrops of Jurassic rocks occur only in southern Idaho, not along the Northern Border (Springer, 2006b).

Triassic - Outcrops of Triassic rocks occur only in southern Idaho, not along the Northern Border (Springer, 2006b).

Permian - The Permian Phosphoria Formation of eastern Idaho is mined for its rich phosphate deposits and contains fossils of spiral-toothed sharks, fishes, corals, brachiopods, snails, bryozoa, octopus and squid, pelecypods, and ostracods (Springer, 2006b).

Devonian - Late Devonian rocks in Idaho are mostly shallow- to moderate-depth marine sediments. A variety of well-preserved marine fossils in these layers including corals, sponges, gastropods, pelecypods, ostracods, cephalopods, conodonts, and fishes have been found. Scattered river deposits have produced fossils of a variety of primitive fishes (Springer, 2006b).

Ordovician - A shallow sea covered parts of Idaho during the Ordovician, and large, thick deposits of Ordovician marine sediments are known. These deposits contain a variety of fossils including algae, brachiopods, trilobites, ostracods, graptolites, corals, gastropods, sponges, and very large trace fossils (Springer, 2006b).

Cambrian - A shallow sea covered parts of Idaho during the Cambrian. The northernmost outcrops are metamorphosed and yield only a sparse fauna, mostly trilobites and brachiopods (Springer, 2006b).

Precambrian - Slightly to moderately metamorphosed Precambrian sediments can be seen in northernmost Idaho. The only known Precambrian fossils in the state are stromatolites (Springer, 2006b).

4.2.4.2 Washington

Summary

Paleontologically sensitive geological units in Washington's PSA include Precambrian rocks; Paleozoic sandstone, shale, and limestone from ancient shorelines; and deep and shallow Mesozoic marine sediments. Cenozoic deposits include shallow marine sandstone and siltstone as well as glacial deposits containing large-vertebrate fossils.

Quaternary - During the Quaternary, glaciers carved the landscape of northernmost Washington and the Puget Sound area in the western part of the state. Larger mammals are represented in Pleistocene deposits by mammoth and mastodon teeth and tusks as well as the bones of giant sloths (Nesbitt, 2010).

Tertiary - Mountain building marks this period in Washington's PSA and many of the rocks formed during this time are igneous. Marine waters covered the state east of the Cascades during part of this time interval. The sedimentary rocks formed in these waters contain fossils of clams, snails, and crabs as well as a high diversity of whales and rare marine birds. Coastal swamps were home to a variety of plant and insect life. Fossil leaves, fruit seeds, flowers, and insects occur in great abundance in some of the rocks formed in these swamps. Footprints and rare teeth indicate that small mammals roamed the landscape (Nesbitt, 2010).

Cretaceous - Mid-Cretaceous marine ammonite and clam fossils are found east of Mt. Baker in the Cascades Range. Fossils of Late Cretaceous ammonites, clams, snails, and marine reptiles occur in the westernmost San Juan Islands, the adjacent Gulf Islands, and Vancouver Island of British Columbia (Haugerud et al., 2009; Nesbitt, 2010).

Jurassic and Triassic - The rocks of the Nooksack terrain include exposures of fossil-rich Jurassic sedimentary rocks on the west side of Mt. Baker. This thick sequence of marine sandstones and dark shales lies over volcanic rocks that were formed in an island arc. Fossils of clams, snails, and ammonites can be found in the black shales. No Triassic fossils have been found in Washington, as most Triassic rocks are volcanic in nature (Nesbitt, 2010).

Ordovician - Exposures of Ordovician slates occur in the northeastern-most corner of Washington. These rocks are metamorphosed shales formed from muds that were deposited in a deep ocean off the west coast of North America. In general fossils are abundant in these rocks; although trilobite fossils are rare (Nesbitt, 2010).

Precambrian - Most of the land that is now Washington State did not exist along the West Coast of North America until the Jurassic. Late Precambrian rocks from the ancient North-American continent extend a few kilometers into easternmost Washington. These rocks show mud cracks, ripple marks, and very rare trace fossils. These units are not paleontologically sensitive (Nesbitt, 2010).

Figure H-13. Geologically Relevant Strata along the Northern Border in Washington and Idaho

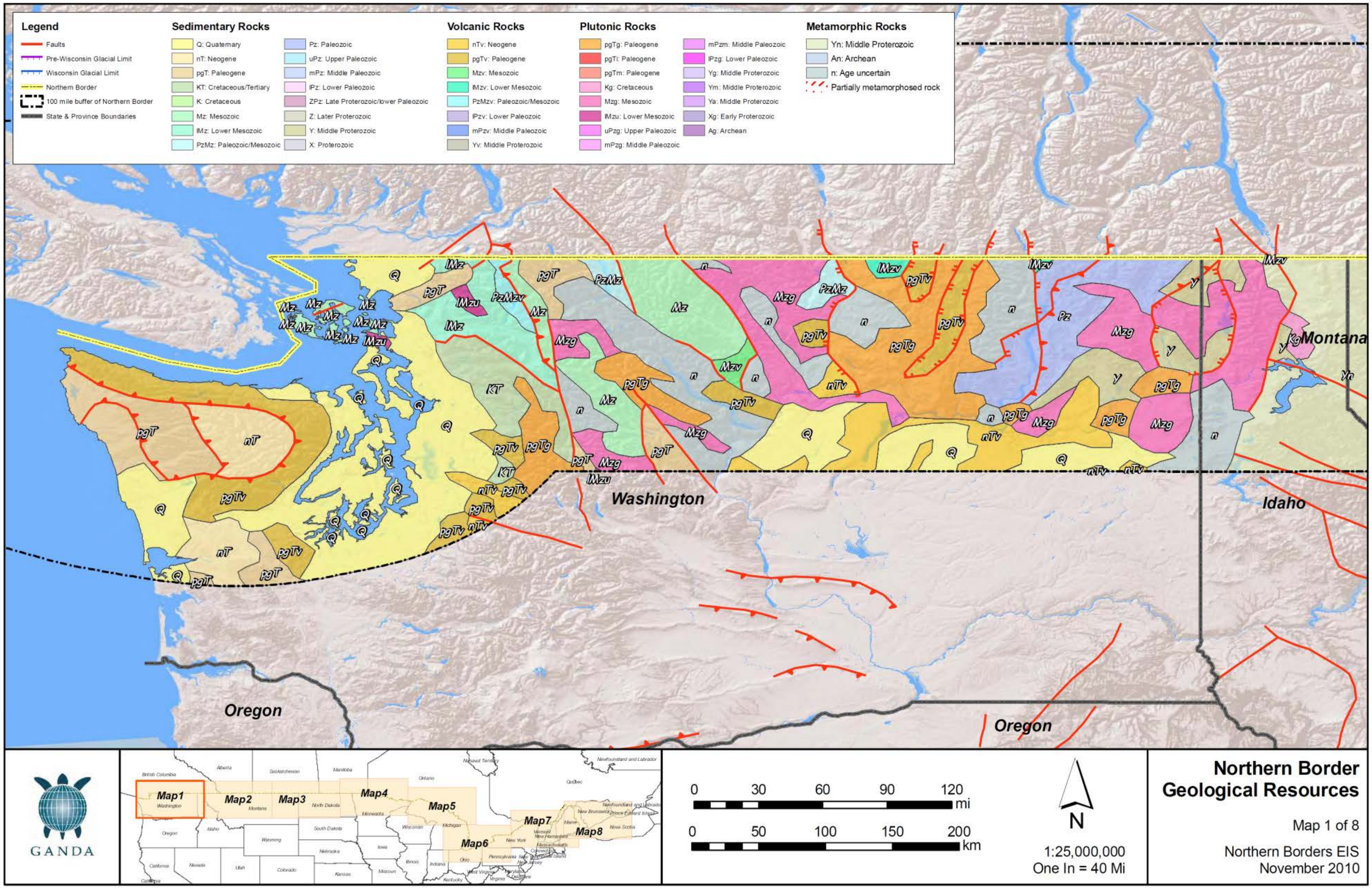


Figure H-14. Geologically Relevant Strata along the Northern Border in Western and Central Montana