Official Bureau of Land Management Potential Fossil Yield Classification for the Geologic Formations of Montana, North Dakota, and South Dakota

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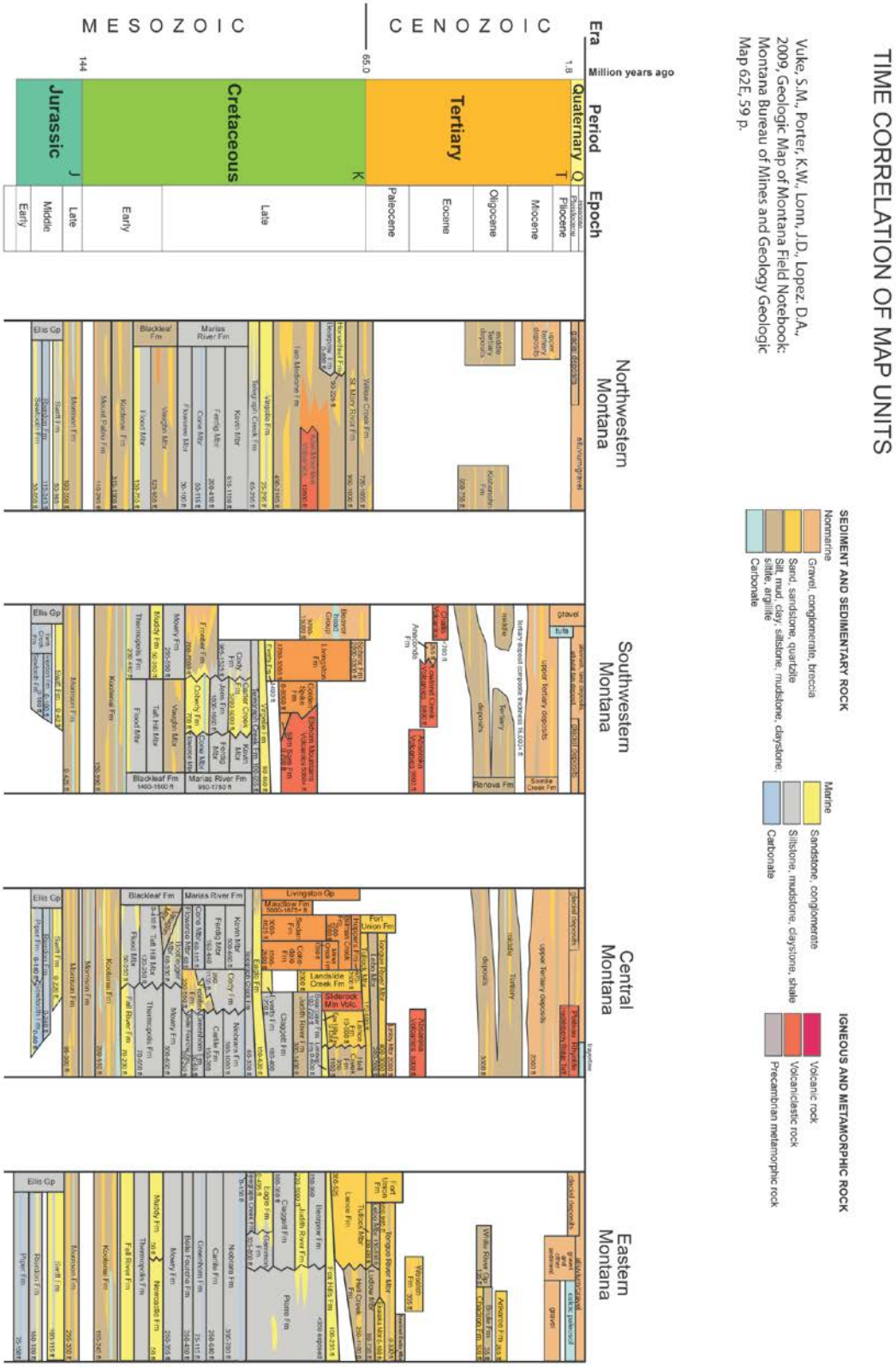
Figure1. Composite stratigraphic column for Montana.



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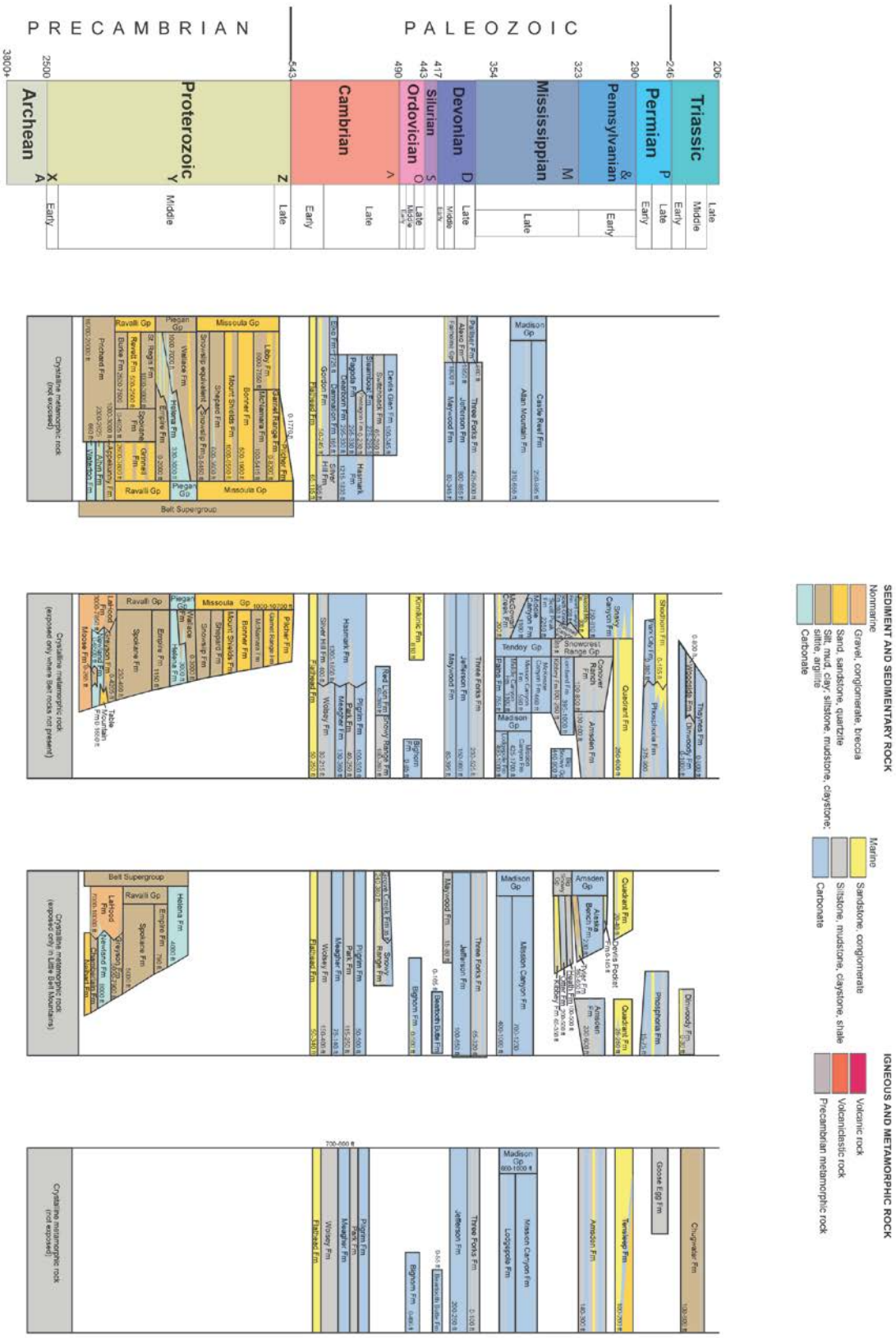

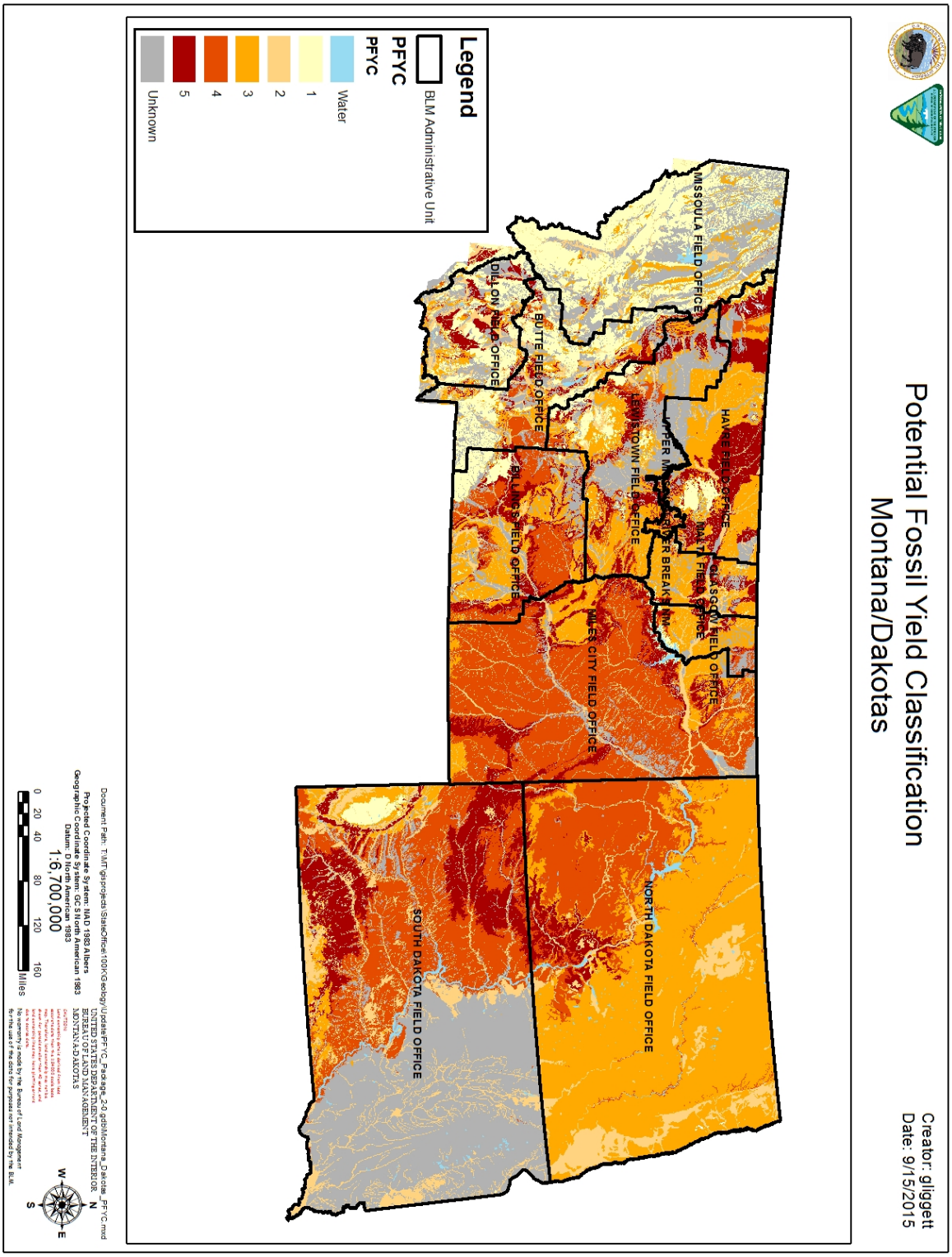

Figure 2. Potential Fossil Yield Classification map for Montana, North Dakota, and South Dakota.

Introduction

Paleontological resources (fossils) have long been recognized for their scientific, educational, and recreational value. A fossil is any evidence of past life, and includes body fossils such as shells and bones, as well as trace fossils such as footprints, burrows, trails, or other evidence of an organism's presence. Fossils are preserved in rocks and are usually discovered when they are eroding out of the rock at the surface, or during ground-disturbing activity such as road grading or trenching. Most individual organisms that lived in the past did not die in such a way as to have their remains fossilized, and fewer still will be collected and studied before they erode away. Therefore fossils are considered rare and nonrenewable.

All fossils contain information about past life, but not all fossils have significant paleontological interest. Fossils with significant paleontological interest are those that are unique, unusual, or rare, are diagnostic, stratigraphically important, and add to the existing body of knowledge. Conversely, fossils that lack sufficient paleontological interest are those that are redundant, lack provenience, are fragmentary, or otherwise are not useful for scientific investigation and therefore do not need to be preserved in perpetuity. In order to determine a fossil's paleontological interest an assessment must be made by someone who is experienced in the field of paleontology and who possesses a sufficient mastery of the existing body of knowledge to understand how a given fossil contributes to our overall understanding.

The Bureau of Land Management (BLM) has managed fossils as a valued public land resource for many years. Legal authority to manage fossils comes from a variety of laws, executive orders, and policies. The laws include the National Environmental Policy Act of 1969 (NEPA) and the Federal Land Policy and Management Act of 1976 (FLPMA). More recently, the Paleontological Resources Preservation subtitle of the Omnibus Public Land Management Act of 2009, also known by its popular name, the Paleontological Resources Preservation Act (PRPA), directs land managers within the Department of the Interior Agencies and the U.S. Department of Agriculture, but not including either Indian or Military (Department of Defense) lands, to manage and protect fossils using scientific principles and expertise. PRPA does not make a distinction between the types of organism preserved; therefore, all fossil resources of scientific interest, plants, invertebrates, and vertebrates are to be actively managed.

Fossils are found in rocks. The rocks that we see today were formed over millions, and sometimes billions, of years. When the animal or plant that we find today as a fossil was alive, the environmental conditions of that location were significantly different. For example, the rock that fossils are found in today may have been formed by sediments at the bottom of an ocean, or along the edge of a tropical river or lake. By using the evidence

preserved in the rocks, and by examining fossils, scientists can piece together the history of the Earth, its changing environmental conditions, and its changing life forms.

Given that most fossils are preserved in sediments from past environments that have been changed into rocky outcrops, understandably, most fossils are found in sedimentary rocks. The other major categories of rocks, igneous and metamorphic, are much less likely to preserve fossils—however it is not impossible.

Igneous rocks are those that are related to volcanic activity, wherein the rock is formed by the cooling of magma or lava, or during a volcanic eruption. While those environments are not generally suitable for living things, there are on rare occasions fossils associated with igneous rocks. For example, an animal may be killed by lava, but the cooling rocks might preserve an impression of the animal as a mold. Such a mold is a fossil—evidence of past life. Entire herds of rhinos have been preserved under ash deposits resulting from distant volcanic eruptions. And the development of caves or fissures in these otherwise unfossiliferous rocks could produce extensive collections of fossils.

Metamorphic rocks are those that have been changed by extremes of heat and pressure. Fossils that occur in the rocks prior to undergoing metamorphic change can be preserved as long as the metamorphism is low grade and not extreme enough to alter them beyond recognition. Such might be the case in a limestone with fossils that gets altered to a low grade metamorphic marble with fossils still visible.

Geologists have mapped the rocks exposed at the Earth's surface. Rocks that are similar in character, usually due to how they formed, are organized into mappable units called formations. Formations are formal units and are given names consisting generally of a place name and the word "formation," or the characteristic rock type. Examples include the Morrison Formation and the Aspen Shale. The place name is generally derived from the region in which the formation is first recognized.

Given that the environment in which a formation forms will strongly influence its likelihood of preserving fossils, and not all formations are equally likely to have fossils, the BLM uses a coding system to rank a formation's probability of containing significant fossils. This system is the Potential Fossil Yield Classification (PFYC) (Appendix 1), a numerical ranking from 1 (low potential) to 5 (very high potential). A sixth rank of U for unknown has been added here. This system allows land managers to predict where significant fossils will occur in order to make informed planning decisions with regard to fossil resources.

In its practical application the PFYC is intended to help land managers plan where to focus resources during the planning or execution of ground-disturbing activities, or to assess the potential for fossil resources on parcels being considered for land tenure adjustments. The system can also be used by researchers in helping them to focus attention on fossil-bearing

rock units. Or perhaps more importantly, to highlight formations whose fossil potential is little known, pointing toward gaps in our paleontological knowledge.

Management plans used by the BLM to inform the actions of resource managers use the PFYC. So do consultants working for project proponents whose projects involve public land. The system can be used to inform the project proponents of areas of high likelihood for fossil resources so adequate planning can be done to mitigate the irreversible destruction of a valued heritage resource.

However, several important points should be kept in mind. Fossils are not evenly distributed throughout a formation, and so even highly ranked formations may produce only occasional fossils in a given locality. Similarly, fossils can be found in unlikely places. For example, granite bedrock might be given the lowest potential rating, but have a crevice or cave structure that is rich in fossils. Fossils have been found in basalt (Beck, 1935), a rock type that would be easy to discount as fossil bearing. Indeed, the discovery of a fossil in a class 1 rock unit might be all the more significant given its unexpected occurrence. The system is just designed to help in planning, and cannot replace detailed analysis on a case-by-case basis by trained personnel.

Users of the system most often rely on a geologic map of the area of interest. Areas of Montana/Dakotas have been mapped at various scales, and to varying levels of precision. The PFYC is formation-based, but frequently, geologic maps show units that are lumped together for practical reasons. Those needing to implement the PFYC system should score the geologic units on maps with the highest PFYC rating given to the units separately. For example, when formations ranked 3 and 4 are mapped together, the entire combined unit should be considered as ranking a 4 for planning and mitigation purposes.

Sometimes rock units are not mapped by a formal formational unit, but are mapped based upon their geologic or lithologic character. Common examples are alluvium and glacial deposits. Commonly mapped descriptive units and their corresponding PFYC rating are included among the formal formations, especially in the section on Quaternary units.

Conventions used in this document

The document is arranged by geologic period, oldest to youngest. Within geologic periods the formations are listed in alphabetical order. In addition, an extensive index is provided.

This work is not intended as a comprehensive review of every formation. Rather, the PFYC rank for each unit is given, generally followed by a few notes about the formation's character, known fossil occurrences, and significant literature citations for that unit. The intention is to help the user see the justification for the PFYC rank, as well as have a resource for significant publications related to each formation.

Brief summaries are given at the beginning of each new geologic section to provide a general background on the geologic character, depositional, and tectonic setting for the rocks of that age. This is considered to be a "living document" in that updates and additions are made with some regularity. As such, the reader is encouraged to check the Montana State BLM website for the most current version.

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Proterozoic

The Proterozoic encompasses an immense amount of geologic time, about 2 billion years. There is very little fossil evidence from this time overall, but life was present. In several of the formations from Montana evidence of that life can be found in the form of stromatolites, or algae mounds built by biofilms of algae colonies trapping sediment in layered structures. Because of their tremendous geologic age and unlikelihood to produce fossils most of the formations from this period are not discussed in any detail. The formations listed below are in approximate stratigraphic order.

Belt Supergroup

PFYC: 1

Unless otherwise noted, the rocks in the Belt Supergroup can be assigned to PFYC 1.

Missoula Group

Pilcher Quartzite

Garnet Range Formation

McNamara Formation

Libby Formation

Bonner Quartzite

Mount Shields Formation

Shepard Formation

PFYC: 3

The Shepard contains many thinly laminated beds of siltstone with some very thin beds of sandstone, orthoquartzite, and dolomite. At and near the base of the formation are beds composed mainly of angular fragments of broken stromatolites (Mudge, 1972).

Snowslip Formation

Piegan Group

Wallace Formation

Helena Dolomite

PFYC: 3

The Helena has cyclic sequences of thinly bedded dolomite, massive stromatolite colonies, conglomerate with oolites, and oolite beds. The stromatolite colonies join to form thick widespread biostromes (Mudge, 1972).

Ravalli Group
- **Empire Formation**
- **Saint Regis Formation**
- **Revett Formation**
- **Spokane Formation**
- **Burke Formation**

Prichard Formation
Appekunny Formation
PFYC: 3

Strange fossil found in the Appekunny Formation in Glacier National Park might be among the earliest multi-cellular eukaryotes (Fedonkin, 2003; Fedonkin and Yochelson, 2002; Horodyski, 1982).

Altyn Formation
Waterton Formation
Moose Formation
LaHood Formation
Greyson Formation
Newland Formation
Chamberlain Formation
PFYC: 3

Reported to contain abundant and well-preserved filamentous and spheroidal microfossils (Horodyski and Bloesser, 1978). Determined to come from the Chamberlain Formation by Horodyski (1993).

Neihart Formation

Cambrian

Overall, the Cambrian marks a tremendous change in the Earth's fauna with the advent of hard body parts to cover and support otherwise soft-bodied animals. Almost all the major groups of organisms were evident in the proliferation of animals during what has been called the "Cambrian Explosion." Prior to the Cambrian, multicellular organisms did not have shelled skeletons, and so had limited opportunity for preservation.

Black Lion Conglomerate

PFYC: U

This unit is named for exposures on cliffs between Black Lion Mountain above Black Lion Lake. It is assigned questionably to the Cambrian, but has a resemblance to Middle Proterozoic rocks. It is ranked here as unknown for fossil potential.

Damnation Formation

PFYC: 3

The Damnation grades upward from dolomitic limestone into limestone (Mudge, 1972). Trilobites were reported in the lower 10 feet (Deiss, 1939).

Deadwood Formation

PFYC: 3

The Deadwood Formation encircles the Black Hills uplift. The rocks are mostly sandstones and sandy shales. Fossils include mollusks and trilobites (Darton, 1904; Lochman, 1965).

Dearborn Limestone

PFYC: 3

The Dearborn Limestone comprises mudstone in the lower part, and limestone in the upper. The trilobite *Glossopleura* is reported from the lower parts of the formation (Mudge, 1972).

Devils Glen Dolomite

PFYC: 3

The Devils Glen is a distinctive thick-bedded dolomite that forms light-gray massive ledges. Trilobites have been reported from thin beds of limestone (Mudge, 1972).

Flathead Formation

PFYC: 2

Includes very rare trilobite fragments, inarticulate brachiopods, and *Hyolithes* (Balster, 1971).

Gordon Shale
PFYC: 3

The Gordon is mainly dark-gray to gray-brown noncalcareous very thinly laminated clay shale, but it has many thin beds of sandstone and a few of limestone. The sandstone layers contain abundant organic trails and burrows (Mudge, 1972), and algal deposits and many trilobites have been reported (Deiss, 1939).

Grove Creek Formation
PFYC: 3

The Grove Creek Formation has variously been considered at the formation rank (Dorf and Lochman, 1940) or as a member of the Snowy Range Formation (Pierce et al., 1973). Characteristic fossils include trilobites, graptolite, and a gastropod (Balster, 1971).

Hasmark Formation
PFYC: 2

No distinctive fossils have been reported (Balster, 1971).

Meagher Formation
PFYC: 3

The Meagher Formation is persistently ledge forming. Both the lower and upper parts of the formation is fossiliferous with a variety of trilobite taxa which are common (McMannis, 1955).

Pagoda Limestone
PFYC: 3

The Pagoda contains two distinct thick members: a lower shale and an upper limestone. The lower member consists of beds of grayish-green thinly laminated to nodular clay shale, yellowish- to gray-brown limestone, and in the lower part, sandstone. The upper member consists of finely crystalline pale-yellowish-brown very thin bedded limestone, and yellowish-gray to light-yellowish-brown dolomite (Mudge, 1972). Trilobites are reported mainly from the lower part (Balster, 1971).

Park Shale
PFYC: 3

Inarticulate brachiopods and trilobites have been found at several levels within the formation (McMannis, 1955). The Park Shale conformably overlies the Meagher Formation (Klepper et al., 1957).

Pentagon Shale
PFYC: 3

The Pentagon Shale contains a trilobite fauna in the lower third of the unit (Deiss, 1939).

Pilgrim Formation
PFYC: 3

Rare to numerous Dresbachian forms (Balster, 1971). Gastropods, trilobites, brachiopods, crinoids, calcareous algae, and burrows have been reported (Lochman and Duncan, 1944).

Red Lion Formation
PFYC: 3

Various trilobites are known from the upper part (Balster, 1971; Chesson et al., 1984).

Silver Hill Formation
PFYC: 2

Silver Hill Formation in descending order consists of a calcareous shale, strongly banded in brown, white, and green with interbedded laminated limestone, limestone with thin siliceous laminae, and a dark green shale. The trilobite *Glossopleura* has been reported (Balster, 1971).

Snowy Range Formation
PFYC: 3

The snowy Range Formation is entirely of Late Cambrian age in the type area. Strata from this formation were mapped in the Big Snowy Mountains, and Ordovician trilobites were recognized there (Lindsey, 1980). A new species of Hyolitha was named as well (Malinky, 1989).

Steamboat Limestone
PFYC: 3

The Steamboat Limestone consists of mostly very thin to thin beds of limestone and dolomitic limestone. Abundant trilobites and some brachiopods occur in limestone lenses within the shale and in some of the upper limestone beds (Mudge, 1972).

Switchback Formation
PFYC: 3

The Switchback Formation is mostly noncalcareous greenish-gray thinly laminated clay shale, with local thin interbeds of dolomite, limestone, sandstone, and conglomerate. A

couple of the conglomeritic beds are reported to be fossiliferous with brachiopods, fragments of trilobites and linguloids (Mudge, 1972).

Wolsey Formation

PFYC: 3

The Wolsey Formation is gray-green to maroon, fissile, micaceous shale interbedded with thin, rusty-brown, laminated, fine-grained glauconitic and micaceous sandstones. Fossils include a number of genera of trilobites (McMannis, 1955).

Ordovician

During the Ordovician the North American landmass was significantly smaller, and much of what is now part of the continent was deposited in open ocean waters surrounding the continent. The Ordovician saw the highest sea levels of the entire Paleozoic. The global climate was hot due to volcanic release of carbon dioxide gases. The fauna was dominated by invertebrates, some of which grew to tremendous size. The first jawed fishes arose during this time.

Bighorn Dolomite

PFYC: 3

Distributed throughout the Absarokee, Beartooth, Bighorn, and Pryor mountains. Formation is missing in the Big Snowy and Little Belt mountains and Bridger Range in central Montana (Balster, 1971). Numerous species of brachiopods, pelecypods, gastropods, cephalopods, corals, and one species of trilobites have been recorded (Knechtel, 1959; Miller, 1930).

Kinnikinic Quartzite

PFYC: U

The Kinnikinic Quartzite is primarily in Idaho, but is locally recognized in the Beaverhead Range, Beaverhead County as a thin feather-edge (Sloss and Moritz, 1951). Fossils are not mentioned, but likely not abundant.

Saturday Mountain Formation

PFYC: 3

The Saturday Mountain Formation primarily outcrops in Idaho, but a few outcrops in Montana have been recognized. Trilobites, brachiopods, stromatoporoids, and cephalopods have been found in the formation (Ruppel and Lopez, 1988).

Summerhouse Formation

PFYC: 3

The Summerhouse Formation has distinctive fossils from the lower dolomite of the type section, and from the lower and middle parts of the formation. The assemblages include conodonts, trilobites, and brachiopods (Ruppel et al., 1975).

Whitewood Limestone

PFYC: 3

The Whitewood Limestone is conspicuous in the northern Black Hills. It contains straight-shelled nautiloids and corals (Darton, 1904).

Winnipeg Formation

PFYC: 2

Overlies the Deadwood Formation unconformably, and underlies the Red River Formation. The unit is considered a Group in North Dakota. The most significant fossils reported from well cuttings are conodonts (Carlson, 1960).

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Devonian

During the Devonian was the first period of adaptive radiation of terrestrial organisms, including plants with true roots and various terrestrial arthropods. The Devonian is often called "the Age of Fish" because of the diversification of ray- and lobe-finned fishes in the oceans. Extensive invertebrate organisms inhabited the oceans.

Beartooth Butte Formation

PFYC: 4

The Beartooth Butte Formation is apparently derived from a variety of underlying units, including the Bighorn Dolomite and disconformably underlies the Jefferson Limestone (Sandberg, 1961). The fauna includes eurypterids, as well as arthrodires, cyanthaspidids, rare osteostracans, and dipnoan fish (Bryant, 1933; Bryant and Ruedemann, 1934; Tetlie, 2007). There are even terrestrial plant fossils (Dorf, 1933, 1934), and the unit was reported outcropping in Half Moon Canyon in Fergus County (Fiorillo, 1998). Additional information can be found in Fiorillo (2000).

Jefferson Limestone

PFYC: 3

The Jefferson Limestone consists of a thicker lower member, and the upper Birdbear Member (Laird, 1947; Sandberg, 1965). Within some areas of Montana the Jefferson Limestone contains a large variety of megafossils, whereas in other places it is relatively unfossiliferous (Mudge, 1972). The lower member contains algal remains and colonies of Stromatopora, whereas a bed near the top of the upper member contains numerous corals (Knechtel, 1959).

Maywood Formation

PFYC: 3

The Maywood Formation is a nonresistant sequence of siltstone, limestone, and sandstone. The fauna includes brachiopods, echinoids, conodonts, ostracodes, and trochiliscids, and most significantly, placoderms (Sandberg and McMannis, 1964).

Three Forks Formation

PFYC: 3

Some authors regard the Sappington Formation as a local member of the Three Forks Formation (Balster, 1971). The Sappington is rich in brachiopods (Rodriguez and Gutschick, 1967). The unit has been reported to be fossiliferous in the Townsend Valley (Freeman et al., 1958). Also, six genera of ammoniods have been described (Korn and Titus, 2006).

Mississippian

The Mississippian is the Early Carboniferous in North America, and was a period of high ocean levels and ocean transgression over the continent. During this period as North America collided with the continents of Europe and Africa, the Appalachian Mountains experienced orogenic activity. Rock units of this period are predominately marine. Of significant note is the Heath Formation, which preserves a laggerstatte of soft-bodied organisms and tissues, as well as shelled and vertebrate animals.

Allan Mountain Formation

PFYC: 3

This formation is about 575 feet thick and composed of three members. Holothurian sclerites are found in several beds, but are especially common 12 to 13 feet above the base. Its fauna is similar to the that in the lower beds of the Lodgepole Formation (Gutschick et al., 1967). There are recognized faunal zones within the formation, principally coral assemblages, and fossils abound in the lower 50 feet of the lower member, few in the middle member, and many again in the upper member (Mudge et al., 1962).

Big Snowy Group

The fauna are widespread across the formations within the Big Snowy Group, so formations must be recognized from a combination of faunal and lithic evidence. The most abundant groups in descending order are brachiopods, ostracods, forams, pelecypods, and corals (Easton, 1962). The group includes Kibbey, Otter Creek, and Heath formations (also see Snowcrest Range Group).

Bluebird Mountain Formation

PFYC: 2

The Bluebird Mountain Formation is a cliff-forming sandstone with minor interbedded dolomite and limestone. It underlies the Snaky Canyon Formation, and its lower contact is with the Big Snowy Formation. Forams and conodonts are reported, but it is largely unfossiliferous (Skipp et al., 1979).

Cameron Creek Formation

PFYC: 3

There are often abundant brachiopods in the Cameron Creek, as well as mollusks, and trilobites (Easton, 1962).

Castle Reef Dolomite

PFYC: 3

The lower member of the Castle Reef Dolomite contains a large and diversified fauna of brachiopods and corals, with most fossils from the lower half of the member. The upper Sun River Member is not abundantly fossiliferous, but does contain corals (Mudge et al., 1962).

Charles Formation
PFYC: 3

The Charles Formation overlies the Mission Canyon. It contains corals (Sando, 1960).

Conover Ranch Formation
PFYC: 3

Occasional brachiopods and foraminifers (Wardlaw and Pecora, 1985).

Englewood Limestone
PFYC: 3

The Englewood Limestone is the basal member of the Mississippian in the Black Hills area. Fossils occur throughout, including crinoids and brachiopods (Darton, 1904).

Heath Formation
PFYC: 4 or 5

The Heath Formation is consistently more fossiliferous than the other formations of the Big Snowy Group. The following have been recorded: wood, forams, crinoids, brachiopods, pelecypods, trilobites, and conodonts (Easton, 1962). In addition, the Bear Gulch Member of this formation has produced significant fossils. Earlier workers placed the Bear Gulch in the Tyler Formation(for example Maughan, 1984), but Horner (1985) placed the Bear Gulch beds as the top of the Heath Formation and retired the Tyler as a formation.

Fossils in the Bear Gulch include invertebrate and at least 113 species of fish, including the earliest known lamprey. soft tissue, pigments, gut contents, and sexual organs are preserved (Cox, 1986; Feldman et al., 1994; Grogan and Lund, 1997, 2008; Hagadorn, 2002; Horner, 1985; Janvier and Lund, 1983; Janvier et al., 2004; Lund, 1980, 1982, 1983a, b, 1984, 1985, 1986, 1989, 1990; Lund et al., 1993; Lund and Janvier, 1986; Lund and Lund, 1985; Lund and Poplin, 1999; Lund and Poplin, 1997; McRoberts and Stanley, 1989; Melton, 1969; Morris, 1990; Poplin and Lund, 2000; Poplin and Lund, 2002; Schram et al., 2006; Schram and Horner, 1978; Scott, 1938; Welch, 1984). The Bear Gulch Member is a PFYC 5.

Kibbey Sandstone
PFYC: 3

Represents a lagoonal embayment and contains rare conodonts and plant fossils (Sando et al., 1985). A predominantly brick-red sandstone sequence, it is the most wide-spread formation of the group (Maughan and Roberts, 1967). The Kibbey Formation was reassigned to the Snowcrest Range Group from the Big Snowy Group (Sando et al., 1985; Wardlaw and Pecora, 1985).

Lodgepole Formation
PFYC: 3

The lower unit is characterized by an assemblage of simple, diminutive solitary corals (Gutschick et al., 1967; Sando and Dutro, 1960). Conodonts are abundant (Klapper, 1966). Foraminifers, holothurian plates, other echinoderm remains, bryozoans, brachiopods, snails, ostracods, worm tubes, sponge spicules, fish teeth, and other organic debris is also preserved (Gutschick et al., 1967; Knechtel, 1959; Laudon and Sevenson, 1953; Rodriguez and Gutschick, 1968, 1969). Additionally, massive mud mounds (Waulsortian bioherms) composed of mud and skeletal debris of crinoids and bryozoan also occur. They are exposed on the southern flank of the Big Snowy Mountains, and can be very large (70m thick, 700m long). They are thought to have formed in calm, deep water (Shepard and Precht, 1989; Smith and Custer, 1987). Other Waulsortian mounds occur in the Bridger Mountains, Little Belt Mountains, and the Cedar Creek Anticline (Shepard and Precht, 1989).

Lombard Limestone
PFYC: 3

The upper part of formation contains brachiopods and corals and conodonts (Sando et al., 1985).

Madison Group
The Madison Group includes the Lodgepole, Mission Canyon (see also Tendoy Group), Castle Reef, Allan Mountain, and Charles formations.

McGowen Creek Formation
PFYC: 2

The McGowen Creek Formation is an argillite sequence of Early Mississippian age, mainly in east-central Idaho. The only faunal elements are conodonts (Sandberg, 1975).

McKenzie Canyon Limestone
PFYC: 3

The McKenzie Canyon was named for carbonate rocks at the top of the Tendoy Group, between the underlying Mission Canyon and the overlying Kibbey Sandstone. Horn corals

were reported 34 m above the base, and a diverse and abundant coral coral fauna from the upper 12 m (Sando et al., 1985).

Middle Canyon Formation
PFYC: 3

The lower Middle Canyon Formation contains conodonts rare deep-water horn corals and tabulate corals. Upper member contains conodonts, horn corals, and brachiopods (Mamet et al., 1971; Sando et al., 1985).

Mission Canyon Formation
PFYC: 3

Contains locally abundant corals, rare foraminifers, and conodonts and brachiopods rare to common (Sando et al., 1985).

Otter Formation
PFYC: 3

The Otter Formation consists predominantly of greenish-gray shale (Maughan and Roberts, 1967), and can be recognized by the color it imparts to the soil (Balster, 1971). Fossils include calcareous algae, bryozoans, corals, blastoid crinoids, brachiopods, annelids, bivalves, echinoderms, ostracodes, and conodonts (Easton, 1962; Gilmour and McColloch, 1995; Scott, 1935; Webster and Waters, 2005).

Pahasapa Limestone
PFYC: 3

The Pahasapa Limestone is gray, pink, and light-yellow limestone that weathers deep gray. It is equivalent to the Madison Limestone, the name Pahasapa being used in the Black Hills area (Stratigraphic Nomenclature Committee, 2014). It is sparsely fossiliferous, but crinoids, brachiopods, and ostracodes have been reported (Brobst and Epstein, 1963; Darton, 1904, 1909).

Paine Formation
PFYC: 2

Contains rare crinoids, horn corals, foraminifers, and conodonts (Sando et al., 1985).

Railroad Canyon Formation
PFYC: 2

Found in southwestern-most Montana and adjacent Idaho, this unit is largely equivalent to the Snowcrest Range Group. It contains brachiopod and conodonts faunas, though sparse and generally abraded (Wardlaw and Pecora, 1985).

Scott Peak Formation
PFYC: 3

The Scott Peak Formation overlies the Middle Canyon with a gradational contact, usually placed at the base of the lowest conspicuous limestone ledge (Mamet et al., 1971). There are a number of microfossil zones recognized, as well as four megafaunal zones which include corals (Mamet et al., 1971).

Snowcrest Range Group
The group consists of the Conover Ranch, Lombard, and Kibbey formations.

South Creek Formation
PFYC: 2

The South Creek Formation overlies the Scott Peak Formation and consists of 300 ft of thin-bedded cherty limestone. It includes scarce to common microfossils and algae and larger invertebrates are very scarce (Mamet et al., 1971).

Surrett Canyon Formation
PFYC: 2

The Surrett Canyon forms prominent cliffs and ledges above the South Creek Formation. The lower part contains a rich coral-brachiopod fauna, and the upper contains brachiopods (Mamet et al., 1971).

Tendoy Group
The Tendoy Group includes the McKenzie Canyon, Mission Canyon, Middle Canyon, and Paine formations.

Pennsylvanian

The Pennsylvanian is also the Late Carboniferous. During the Carboniferous extensive deposits of coal formed around the world due to the existence of lush forests and swamps. The continents of the world were gradually colliding to form the supercontinent Pangaea. Parts of the globe saw glaciation. Most of the rock units discussed here are of marine origin, being off the west coast of the continent of the time, and recording both transgression and regression.

Alaska Bench Formation

PFYC: 3

Named by Freeman (1922), it is a hard, gray fossiliferous limestone that weathers red. Fossils include crinoids, brachiopods, pelecypods, and shark (Easton, 1962).

Amsden Formation

PFYC: 3

The Amsden Formation has been identified over a wide area within Wyoming, Montana, and Idaho. Fossil trilobites, echinoderms, mollusks, brachiopods, bryozoans, and coelenterates have all been reported and used in biostratigraphic correlation (Sando et al., 1975).

Amsden Group

In Montana the Amsden has both group and formation status (Vuke et al., 2007), whereas it is a formation in Wyoming (Sando et al., 1975). The group includes the Devils Pocket and Alaska Bench formations.

Devils Pocket Formation

PFYC: 2

The formation consists of a sequence of cherty dolomite, limestone, red sandstone and shale, and chert breccia. Characteristic fossils are fusilinids (Balster, 1971; Easton, 1962).

Quadrant Formation

PFYC: 2

White, yellowish, and occasional pink beds of quartzite, intercalated with beds of drab saccharoidal limestone (Balster, 1971). Fusilinids and coral have been reported (Gardner et al., 1946; Verville et al., 1990).

Snowcrest Range Group

The Snowcrest Range Group includes the Kibbey Sandstone, Lombard Limestone, and the Conover Ranch Formation.

Snaky Canyon Formation
PFYC: 2

The Snaky Canyon Formation is largely carbonate rocks interbedded with thin calcareous sandstones. The unit is variably fossiliferous, containing numerous stromatolite mounds in the lower part, and algal buildups in the upper part (Skipp et al., 1979), and a fusulinid fauna (Verville et al., 1990).

Tensleep Formation
PFYC: 2

The Tensleep Formation is a white sandstone that grades laterally into the upper Minnelusa and is interbedded with shale, carbonate, and anhydrite in southeastern Montana (Balster, 1971). Foramenifera have been reported.

Permian

The world was dominated by the supercontinent Pangaea and the superocean Panthalassa. The areas that will become parts of Montana and the Dakotas were generally off shore, where open ocean deposits and fossils predominate. The end of the Permian witnessed perhaps the largest mass extinction recorded in Earth history.

Goose Egg Formation

PFYC: 3

Red shale and sandstone with some interbeds of anhydrite, gypsum, and carbonate (Balster, 1971). Several bivalve genera have been reported from one of the units (Burk and Thomas, 1956).

Minnekahta Limestone

PFYC: 3

Grayish-red laminated very fine grained to lithographic limestone (Wolcott, 1967). It lies between the Opeche and Spearfish formation, and contains few fossils. Crinoid stems and part of a ray-finned fish were reported (Brobst and Epstein, 1963).

Minnelusa Formation

PFYC: 2

In the Hot Spring Quadrangle the exposed part of the formation is a brecciated red or yellow sandstone, and brecciated gray or yellow limestone beds. Brecciation was the result of solution removal of 200 feet of gypsum or anhydrite from the upper part of the formation and the subsequent subsidence (Bowles and Braddock, 1963; Wolcott, 1967). The Formation is only sparsely fossiliferous with clams, snails, and rare brachiopods (Balster, 1971).

Opeche Formation

PFYC: 2

Opeche Formation overlies the Minnelusa Formation (Wolcott, 1967). It is not reported to be fossiliferous.

Park City Formation

PFYC: 3

Similar to the Phosphoria in content but vertebrate remains seem less common (Yochelson and Van Sickle, 1968).

Phosphoria Formation

PFYC: 4

A number of invertebrate groups (Protozoa, Porifera, Coelenterata, Echinodermata, Bryozoa, Brachiopoda, Mollusca, and Arthropoda) are known from this unit (Ciriacks, 1963; Dutro and Yochelson, 1961; Frenzel and Mundorf, 1942; Gordon, 1966; Miller and Cline, 1934; Yochelson and Van Sickle, 1968), as well as conodonts, sharks, including the enigmatic *Helicoprion*, and fishes (Branson, 1930, 1933; Youngquist et al., 1951).

Rocky Mountain Formation

PFYC: 2

Consists of gray, well-sorted, laminated, and cross-laminated quartzite that commonly has carbonate cement (Harrison et al., 1992). Reported as being unfossiliferous.

Shedhorn Sandstone

PFYC: 3

The Shedhorn Sandstone is composed mostly of very well sorted fine- and very fine grained quartz sandstone cemented with chert, quartz overgrowths, or carbonate (Cressman and Swanson, 1964) and is interpreted as a beach or near-beach deposit. Invertebrate remains have been reported as well as fragmentary fish remains (Ciriacks, 1963; Yochelson and Van Sickle, 1968).

Triassic

The beginning of the Triassic was right after a major extinction marking the end of the Permian. The supercontinent Pangaea, formed of all the world's landmasses of the time, began to rift apart during the mid-Triassic. The northern two thirds of Montana seems to have been an erosional area, and the only deposits being in the south central part of the state (Horner, 1989). The period saw the first mammals as well as the first dinosaurs. The rocks deposited from this time show that the western edge of North America was along the mid-continent, and to the west of that was open ocean. Extensive deposits of coastal sediments, and evaporate minerals deposited in drying ocean embayments characterize the period.

Chugwater Formation

PFYC: U

Red shale, siltstone, and sandstone with intercalated anhydrite and gypsum (Darton, 1904). Historically, the formation has thought to be unfossiliferous (Balster, 1971). However, recent investigations in Wyoming showed the unit to contain body fossils and traces (Lovelace, 2015). At this point its potential in Montana is unknown.

Dinwoody Formation

PFYC: 3

Similar to the Thaynes Formation in fauna, with pelecypods and *Penticrinus* (Fraiser and Bottjer, 2005; Klecker, 1981; Newell and Boyd, 1995).

Spearfish Formation

PFYC: 2

Red shale, siltstone, and sandstone with interbedded salt and gypsum (Balster, 1971). Not known to be fossiliferous.

Thaynes Formation

PFYC: 3

The unit is extensively fossiliferous, mainly pelecypods (Boutwell, 1907; Ciriacks, 1963; Fraiser and Bottjer, 2005; Kummel, 1953; Newell and Boyd, 1995, 1999; Schubert and Bottjer, 1995), but also ammonites and *Pentacrinus*. At least one ichthyosaur specimen is known (Massare and Callaway, 1994).

Woodside Formation

PFYC: 2

Maroon and red siltstone and shale, no fossils reported (Balster, 1971).

Jurassic

The world's landmasses generally were in low latitudes as the ancient supercontinent of Pangaea was breaking up. North America generally moved westward as the Atlantic Ocean began to widen. Marine rocks were deposited in an epicontinental Sundance Sea that transgressed and regressed over the central parts of Wyoming and Montana. Along the shorelines of this sea deposits of fluvial, lacustrine, and swamp conditions were deposited, including the famous Morrison Formation with its extensive dinosaur fauna.

Ellis Group

A number of early publications identify this unit in Montana as the Sundance, and they do not further subdivide the unit. Therefore it is not certain which of the formations some fossils occur in, such as the forams (Sandidge, 1933). Also, one of the units has produced beetles (BLM records). The group includes the Swift, Rierdon, Twin Creek, Sawtooth, and Piper formations.

Fernie Formation

PFYC: 3

Occurs immediately south of the Canadian border. Lower part has black shale and gray limestone with belemnite fossils. Upper part is gray dolomitic sandstone interbedded with dark-gray siltstone and shale (Harrison et al., 1992).

Gypsum Spring Formation

PFYC: 3

Several extensive dinosaur trackway sites have been described from the Gypsum Spring Formation of Wyoming. The formation is below the Sundance, and is laterally equivalent with the Piper Formation. Trackways in both the Gypsum Spring and Sundance formations show that at least some part of those units were deposited in subaerial conditions (Kvale et al., 2001).

Morrison Formation

PFYC: 5

A great deal has been written about the fossiliferous Morrison Formation (Cooley and Schmitt, 1998; Dodson et al., 1980; Evanoff et al., 1998; Harris, 2006; Harris and Dodson, 2004; Lockley et al., 1986; Mook, 1917; Myers and Fiorillo, 2009; Myers and Storrs, 2007; Smith et al., 2006; Suttner, 1969; Turner and Peterson, 1999, 2004; Yen, 1952). Numerous noteworthy dinosaur finds, including mass death assemblages, makes the formation very paleontologically significant. Additionally, plants have been reported (Brown, 1975; Brown, 1946b; Harris, 1966; Knowlton, 1907; Newberry, 1891).

Piper Formation
PFYC: 3

Coral and numerous pelecypods known (Imlay et al., 1948).

Rierdon Formation
PFYC: 4

Mollusk species (Cobban, 1945) and ostracods (Lord and Sherrington, 1976; Peterson, 1954), and nautiloids (Kummel, 1954) are known. Also, there are insects and fishes preserved in lithographic/laminated sandstone within this unit.

Sawtooth Formation
PFYC: 3

Numerous mollusks, including ammonites and bivalves known, as well as *Pentacrinus* (Cobban, 1945).

Swift Formation
PFYC: 3

Unconformably overlies Rierdon and locally older formations, and conformably underlies Morrison Formation (Balster, 1971). Several mollusk species are known (Cobban, 1945) as well as *Pentacrinus*.

Sundance Formation
PFYC: 4

The Sundance Formation of Wyoming is equivalent to the Swift and Rierdon formations, and underlies the Morrison (Balster, 1971). The Sundance Formation has produced a wide variety of fossils, including forams (Loeblich and Tappan, 1950), ostracods (Swain and Peterson, 1951, 1952), bivalves (Wright, 1974), plesiosaurs and ichthyosaurs (O'Keefe and Street, 2009; O'Keefe et al., 2009; O'Keefe et al., 2011), and trackways (Bennett, 1997; Harris and Lacovara, 2004; Kvale et al., 2001).

Unkpapa Sandstone
PFYC: 2

In South Dakota, the Unkpapa Sandstone is considered an unfossiliferous, dune-deposited member of the Morrison (Imlay, 1947; Szigeti and Fox, 1981).

Cretaceous

Lower Cretaceous

Rocks from the Lower Cretaceous are not as extensively preserved across North America as those from the Upper Cretaceous. The midcontinent of North America saw extensive marine incursions during the first part of the Cretaceous, but also formations of more terrestrial and fluvial origin were deposited.

Blackleaf Formation

PFYC: 4

The Blackleaf Formation conformably overlies the Kootenai Formation and may unconformably overly units in the Snowcrest and Gravelly Ranges (Dyman and Nichols, 1988). The formation is overlain by the Frontier Formation in the Lima Peaks area (Dyman et al., 2008) and the Marias River formation in the Sweetgrass Arch area (Cobban et al., 1976). The first reports of more complete vertebrate fossils have recently been published (Ullmann et al., 2012), as well as the first dinosaur burrow ever described (Varricchio et al., 2007), providing paleontological significance to the unit.

Cody Shale

PFYC: 3

The lower Cody is correlative with the Greenhorn Formation, Carlile Shale, and the lower part of the Niobrara Formation of northeastern Wyoming. A marine fauna was collected at several outcrops and includes a variety of mollusk taxa and fish scales (Roberts, 1972).

Fall River Formation

PFYC: 3

The contact between the Fall River and the underlying Lakota in South Dakota is a transgressive disconformity (Waage, 1959). In Montana, the Fall River overlies the Kootenai (Balster, 1971), and is often mapped as a combined unit with the Thermopolis Shale (Lopez, 2000). The formation was named to replace use of the “Dakota” rocks in the northern Plains (Waage, 1959). A *Chimaerotheca*, or fossil egg case from a shark-like fish, was reported in South Dakota (Connor, 1963).

Inyan Kara Group

The Inyan Kara Group includes the Fall River and Lakota formations.

Kootenai Formation

PFYC: 5

The Montana Bureau of Mines and Geology use the Kootenai Formation in Montana in place of the Cloverly, however, many paleontologists continue to use the divisions of "Cloverly" in Montana as first proposed by Ostrom (1970). This unit has produced many significant mollusk (Yen, 1951), reptile (Olson, 1960; Throckmorton et al., 1981), turtle (Hay, 1908), dinosaur (Forster, 1990; Maxwell and Horner, 1994; Ostrom, 1969, 1970; Sues, 1980; Woodruff, 2012) and Cretaceous mammal fossils (Cifelli et al., 1998). It is often divided into two members, a lower crossbedded conglomerate and coarse-grained sandstone called the Pryor Conglomerate, and an unnamed sequence of siltstone, claystone, mudstone, limestone, and tuff interbedded with calcareous sandstone (Roberts, 1972).

Lakota Formation
PFYC: 5

The Lakota is the basal member of the group, overlying the Morrison Formation or the Unkpapa Sandstone across Wyoming and South Dakota (Post and Bell, 1961; Waage, 1959). The formation is composed of, in ascending order, the Chilson, Minnewaste Limestone, and Fuson members (Post and Bell, 1961; Wolcott, 1967). The Lakota Formation is a fluvial sandstone marked by increasing marine influence toward the top (Weishampel and Bjork, 1989). Dinosaur tracks have been recovered (Anderson, 1939; Lockley et al., 2001). Additionally dinosaur body fossils have been recovered (Galton and Jensen, 1975; Lucas, 1901; Weishampel and Bjork, 1989). The formation is also significant for preserving invertebrates (Sohn, 1979; Wieder and Feldmann, 1992), and fossil plants (Cahoon, 1960; Hickey and Doyle, 1977; McBride, 1893; Penhallow, 1907; Read, 1932; Ward, 1899, 1900; Wieland, 1906, 1916, 1937, 1945).

Mount Pablo Formation
PFYC: 3

The Mount Pablo Formation crops out in the Sawtooth Range, and is equivalent to the lower part of the Kootenai Formation. A palynological assemblage was reported from the unit (Mudge and Rice, 1982), but at present we should consider the fossil potential unknown.

Mowry Formation
PFYC: 3

The most widespread type of preservation of marine fossils is as flattened molds in porcelanite. Less often undistorted fossils can be found in calcareous concretions (Reeside and Cobban, 1960). Particularly abundant ammonites in concretions were reported by Reeside and Cobban (1954), including one concretion near Winnecook, Montana, with 1300 individual ammonites. The Mowry produces scattered bones and scales of fish

(Cockerell, 1919), and pterosaur, plesiosaur, and ichthyosaur bones (Reeside and Cobban, 1960). Read and Brown (1937) reported a fern from southeast of Harlowton, Montana.

Muddy Sandstone
PFYC: 3

The Muddy was deposited in a deltaic environment. Occasional plant and pelecypods reported (Balster, 1971). Plants range in size from small pieces to whole tree trunks (Vuke, 1984).

Newcastle Sandstone
PYFC: 3

Newcastle Sandstone is distributed in southeastern Montana, southwestern North Dakota, South Dakota, and eastern Wyoming (Balster, 1971). Fossils are relatively scarce, but even so plants, pelecypods and gastropods have been reported (Robinson et al., 1964), as well as a dinosaur femur (Collier, 1922).

Skull Creek Shale
PFYC: 3

Forms slopes which are grass-covered. The formation consists predominantly of dark-gray clayey shale with some locally glauconitic siltstone (Wolcott, 1967). *Inoceramus* has been reported (Balster, 1971).

Thermopolis Formation
PFYC: 4

Invertebrate body fossils are locally abundant as are trace fossils (coprolites and tracks). Extensive vertebrate zones have been reported in south-central Montana including plesiosaur, sharks, fish, and turtles (Druckenmiller, 2002; Eicher, 1960; Lash, 2011).

Upper Cretaceous

The Upper Cretaceous of Montana and the Dakotas records extensive deposits of the Late Cretaceous Interior Seaway which transgressed and regressed multiple times across central North America, cutting the continent into eastern Appalachia and western Laramidia landmasses. Additionally, this period is marked by the beginning of Laramide Orogenic activity throughout Laramidia with uplift of mountains and volcanic activity throughout the Rocky Mountain Front. The rocks of this period are typically deposits from the seaway, with varying amounts of terrestrial influence.

Adel Mountain Volcanics

PFYC: 1

Adel Mountain Volcanics were probably emplaced over a short time interval between 81-71 ma (Sheriff and Gunderson, 1990).

Bearpaw Formation

PFYC: 3

The Bearpaw produces ammonites and other mollusks, rare crabs and occasional vertebrates like marine reptiles and dinosaurs (Bishop, 1983; Feldmann et al., 1977; Holmes, 1996; Horner, 1979; Nydam et al., 2010).

Beaverhead Group.

The Beaverhead Group includes the Red Butte Conglomerate and the Lima Conglomerate, and was elevated to group status by Nichols et al. (1985). They named the Lima Conglomerate at the bottom-most unit and left the overlying material as an informal unit. Redefined the unit to include synorogenic conglomerates, sandstones, and limestones of Late Cretaceous age in southwestern Montana and adjacent Idaho (Haley and Perry, 1991; Perry et al., 1988).

Belle Fourche Formation

PFYC: 3

A gray to black shale with ironstone concretions and numerous bentonite beds. Some invertebrates have been recovered such as *Inoceramus* and *Exogyra* (Balster, 1971), fish scales as well as a modest shark fauna (Cicimurri, 2001), and an ichthyosaur from Wyoming (Breithaupt, 1985).

Big Skunk Formation

PFYC: 2

The Big Skunk Formation was named by Viele and Harris (1965). The unit was mapped as being included in the Two Medicine Formation (Schmidt, 1972). The only fossils found

occur near the middle of the D Member, but are too poorly preserved for positive identification (Viele and Harris, 1965).

Billman Creek Formation
PFYC: 3

The Billman Creek is mostly mudstone with lesser amounts of sandstone, siltsone, claystone, and conglomerate. Near the top of the Billman Creek Formation are macerated plant fragments. Also, dinosaur bones were described from several localities, as well as freshwater mollusks (McMannis, 1955; Roberts, 1972).

Carlile Formation
PFYC: 3

The Carlile is partly silty to sandy bentonitic shale containing some cephalopods (Balster, 1971). Plesiosaur and croc material has been reported in Wyoming (Breithaupt, 1985).

Carten Creek Formation
PFYC: 3

This formation was originally spelled Carter Creek by Gwinn (1961) and renamed Carten Creek. It underlies the Golden Spike Formation, and was deposited in shallow-marine, brackish-water, and fresh-water conditions (Wallace et al., 1990). A variety of pelecypods and cephalopods have been identified from the formation.

Cokedale Formation
PFYC: 3

The Cokedale is the westward nonmarine equivalent of the Claggett Shale and part of the Judith River Formation. The formation contains a pollen flora, freshwater snails, and rare dinosaur fragments (Horner, 1989; Roberts, 1972).

Colorado Group
The group includes the Niobrara, Carlile, Greenhorn formations.

Claggett Formation
PFYC: 3

Claggett Formation can be fossiliferous in certain places, producing invertebrates typical of the Pierre Shale (Cobban, 1962). Additionally, leaves, fish, sharks teeth, dinosaurs, birds, and marine reptiles have been reported (Fiorillo, 1990; Moses, 2012).

Coberly Formation
PFYC: 3

Gwinn (1961) named and briefly described the Coberly Formation. Cobban (1991) discussed the fossils from this unit, which include oyster reefs, gastropods, and pelecypods, as well as the cephalopod *Actinocamax*.

Cody Shale
PFYC: 3

The Cody Shale was identified as directly underlying the Eagle Sandstone in the Elkhorn Mountains of Jefferson and Broadwater counties, north-central Montana (Tysdal, 2011). Marine fossils were collected near Livingston, which allow correlation of the Cody with the Fort Benton and Niobrara of the Colorado Group. Pelecypods, gastropods, cephalopods, and fish scales have been identified (Roberts, 1972). Sharks and a plesiosaur were reported from Wyoming (Breithaupt, 1985).

Eagle Formation
PFYC: 3

Type of *Ornithomimus grandis* Marsh, 1890 (*Deinodon grandis* Leidy) comes from the Eagle (Russell, 1930). Type specimen came from "east side of Cow Creek, Fergus County, Montana." However, the type has been lost (Gilmore, 1920). Additionally, the Eagle has produced significant cephalopod faunas across Montana (Reeside, 1927; Thom et al., 1935), and a giant ammonite (Miller and Youngquist, 1946).

Elkhorn Mountains Volcanics
PFYC: 3

The Elkhorn Mountains Volcanics overly the Slim Sam Formation. A number of marine fossils are mixed in among the volcanic units, as well as fish teeth, algal coating, and plants (Klepper et al., 1957). Elkhorn Mountains Volcanics are above the Slim Sam and lie unconformably on the Telegraph Creek and the Eagle (Tysdal, 2000).

Everts Formation
PFYC: 3

The Everts Formation was named for exposure on Mount Everts southeast of Gardiner. The Everts contains shallow-water marine pelecypods, and locally near the top it contains fresh or brackish-water pelecypods and gastropods. Poorly preserved land plant material is sparsely present, along with thin lignite seams (Fraser et al., 1969).

Fox Hills Formation
PFYC: 4

The Fox Hills occurs from central Montana through the eastern part of the state, and into South and North Dakota (Waage, 1968). It sits gradationally on the Pierre Formation and Bearpaw, and grades into the overlying Lance or Hell Creek (Waage, 1968).

The formation is rich in pelecypods (Feldmann and Kammer, 1976; Speden, 1970), and other fossils reported include bryozoans (Cuffey et al., 1981), a crab (Feldmann et al., 1976), sharks (Becker et al., 2004), amphibian and birds (Hoganson et al., 2007), and mosasaurs and other marine reptiles (Cicimurri et al., 1999; Getman, 1994). The upper part also has plants (Brown, 1939; Delevoryas, 1964; Peppe et al., 2007).

Frontier Formation
PFYC: 3

Most of the age correlation for the Frontier Formation seems to have been done with palynologic data and marine megafuana is mostly absent (Dyman et al., 2008). Clarification of the contact with the overlying Beaverhead Group was done by Dyman et al. (1991), and the lower part of the formation was discussed by Dyman and Nichols (1988). Forams have been described (Young, 1951). Vertebrate remains from Wyoming include sharks, fish, dinosaur, and croc (Breithaupt, 1985), so the unit may preserve significant finds in lenses.

Gammon Shale
PFYC: 3

The Gammon Formation is exposed in northeastern Wyoming and western South Dakota and is equivalent to the Claggett and Eagle formations of central Montana, and the Eagle and Telegraph Creek Formation of central-southern Montana (Balster, 1971).

Golden Spike Formation
PFYC: 2

The Golden Spike Formation contains volcaniclastic and nonvolcanic sandstone, volcanic and nonvolcanic conglomerate, shale, and lava flows deposited under terrestrial conditions (Gwinn and Mutch, 1965; Wallace et al., 1990). No fossils have been found in it.

Greenhorn Formation
PFYC: 3

Extensive fossil material has not been reported from the Greenhorn, but there are fossiliferous beds containing bivalves and fish remains (Balster, 1971), and one site in South Dakota is reported to have produced a *Xiphactinus* vertebra (Connor, 1963).

Hell Creek Formation
PFYC: 5

There is a sizable literature on the Hell Creek and its extensive flora and fauna. Many significant fossils have been recovered from this unit, including plants ,(Johnson, 1993, 1996), paddlefishes (Grande and Bemis, 1991), crocodiles (Bennett, 2012), the type *Tyrannosaurus rex* (Osborn, 1905) and other theropods (Brett-Surman and Paul, 1985), ankylosaurs (Brown, 1908), ceratopsians (Brown, 1906; Horner and Goodwin, 2008; White et al., 1998), hadrosaurs, some with detailed skin impressions (Manning et al., 2009; Rohrer and Konizeski, 1960), and mammals (Archibald, 1982; Clemens, 2002; Clemens and Wilson, 2009; Lofgren, 1995; Simpson, 1927; Wilson, 2005) to name just a few examples. In recent years, dinosaur paleobiology has been greatly illuminated by discoveries in this formation (Goodwin et al., 2006; Hartman et al., 2002; Horner et al., 2011; Scannella and Horner, 2010; Schweitzer et al., 2005)

The terminal K-T event has been the subject of intense study as well (for example: Alvarez et al., 1980; Archibald and Clemens, 1982; Carpenter and Breithaupt, 1986; Labandeira et al., 2002; Longrich et al., 2012; Pearson et al., 2002; Smit and Van Der Kaars, 1984; Wilf and Johnson, 2004). Its fossil rich beds and its preservation with the overlying Fort Union of the K-T extinctions warrant the highest PFYC.

Hoppers Formation
PFYC: 2

Fossils are rare in the Hoppers, but a few freshwater snails have been found. This unit seems to correlate to the upper part of the Hell Creek Formation (Roberts, 1972).

Horsethief Sandstone
PFYC: 3

The Horsethief Sandstone is a lateral equivalent on the west end of the Bearpaw Shale. It is overlain by the St. Mary River Formation (Gill and Cobban, 1973). Fossils include *Ophiomorpha* burrows, the holotype of *Chimaerotheca montanana* (fish egg case), brackish and freshwater mollusks, and occasional fragments of dinosaur bone and eggshell (Bibler and Schmitt, 1986; Brown, 1946a; Horner, 1989).

Jens Formation
PFYC: 3

The Jens Formation overlies the Coberly, and is a thick sequence of marine shale, sandstone, tuff, and porcellanite. Based on the fossils it spans the period from middle Turonian to middle Coniacian (Wallace et al., 1990).

Judith River Formation
PFYC: 5

The Judith River is extensively fossiliferous, producing many significant finds and faunas (see for example: Blob et al., 2001; Brown, 1917; Case, 1978; Cope, 1876; Coy, 1995; Currie and Padian, 1983; Dodson, 1986; Fiorillo, 2005; Galton and Sues, 1983; Grande and Hilton, 2006; Holland, 1909; Leidy, 1856; Marsh, 1888, 1889, 1890; Rogers and Brady, 2010; Russell, 1930; Sahni, 1972).

Lance Formation
PFYC: 5

The Lance is the lateral equivalent of the Hell Creek, and contains plants (Dorf, 1940, 1942), frogs (Estes and Sanchiz, 1982), bird tracks (Lockley et al., 2004), and dinosaurs (Breithaupt, 1982; Carpenter, 1982; Gilmore, 1913; Gilmore, 1915; Gilmore, 1946). Many of these fossils were found in Wyoming, but care should be given to explore the Lance in Montana as well.

Landslide Creek Formation
PFYC: 3

The Landslide Creek Formation was named for outcrops along Landslide Creek in the northwestern part of Yellowstone National Park (Fraser et al., 1969). Fraser et al. (1969) reported scattered dinosaur bones and pollen fossils from the formation. They did not provide details on the dinosaur material. Tysdal and Nichols (1991) reexamined the pollen flora.

Lennep Sandstone
PFYC: 3

On the west end the Bearpaw grades into shallow-water volcanic-rich marine sandstones of the Lennep and Horsethief sandstones (Gill and Cobban, 1973). Known fossils include plant debris and burrows (Horner, 1989).

Lima Conglomerate
PFYC: 2

The Lima Conglomerate consists of highly polished and rounded quartzite and siltite clasts chiefly derived from the Proterozoic Lemhi Group. Clasts of other ages also appear (Perry et al., 1988). No fossils have been reported.

Livingston Formation
PFYC: 3

McMannis (1955) recognized 5 units of the thick Livingston Formation. The valley-forming unit is more fossiliferous than the other units, containing Lancian vertebrates at Bozeman Pass, and a dinosaur limb east of there.

Livingston Group
The group includes the Hoppers, Billman Creek, Miner Creek, Cokedale, Sedan, and Maudlow formations.

Marias River Shale
PFYC: 3

Upper Cretaceous shale that lies between the Blackleaf and Telegraph Creek formations on the Sweetgrass arch. A variety of ammonites, scaphites, bivalves, forams, and burrows and trails were recorded (Cobban et al., 1976).

Maudlow Formation
PFYC: 3

Like the Sedan, the Maudlow Formation was described with several informal members. A number of the members are richly fossiliferous with plant fossils, including leaves, needles, grass, and twig impressions, silicified wood, and ferns (Skipp and McGrew, 1977).

Miner Creek Formation
PFYC: 3

Miner Creek contains a number of marine pelecypods, cephalopods, and worm tubes, as well as a pollen flora. The formation correlates eastward with the lower part of the Hell Creek Formation (Roberts, 1972).

Montana Group
The Montana Group includes the Fox Hills, Bearpaw, Judith River, Claggett, Eagle, and Telegraph Creek formations.

Mosby Sandstone
PFYC: 3

This unit is exposed extensively on the Cat Creek and Devils Basin anticlines and in the intervening area. Fossils are locally very abundant and include gastropods, pelecypods, and ammonites (Cobban, 1953).

Niobrara Formation
PFYC: 3

The Niobrara Formation is a gray to dark gray marly shale that contains inoceramids and cephalopods (Balster, 1971). *Enchodus* and *Pachyrhizodus* have been reported from Wyoming (Breithaupt, 1985).

Pierre Formation
PFYC: 4

The Pierre is a dark gray, partly silty to sandy shale with abundant bentonite beds and scattered concretions. Numerous species of *Baculites* and other cephalopods occur (Balster, 1971; Cobban, 1962). Additionally a couple of rare decapods have been described (Bishop, 1973, 1976, 1978). A juvenile plesiosaur was reported from South Dakota (Martin, 1994), a mosasaur, sharks and a bird in North Dakota (Hoganson et al., 1999), and given the marine reptiles (Breithaupt, 1985; Cicimurri and Everhart, 2001; O'Keefe, 2008) and sharks (Cook et al., 2011; Lucas et al., 1985) from this formation in other states this unit should be carefully explored.

Red Butte Conglomerate
PFYC: 2

The Red Butte Conglomerate is dominated by boulder and cobble clasts with minor sandstone and silt interbeds. It is overlain by the Sage Creek Formation (Haley and Perry, 1991). No significant fossils have been reported.

Sedan Formation
PFYC: 3

The Sedan Formation contains several different informal members. Silicified wood and plant impressions, mollusks, and dinosaur bone, including one identified as *Gorgosaurus*, are reported for some of the units (Skipp and McGrew, 1977).

Slim Sam Formation
PFYC: 2

Slim Sam was named by Klepper et al. (1957) and revised by Tysdal (2000). Age of the unit is provided by stratigraphy and biostratigraphy of units surrounding the Slim Sam. Pelecypods, scaphites, and plant frags have been reported (Klepper et al., 1957) but fossils are sparse.

Sphinx Conglomerate
PFYC: 2

The Sphinx Conglomerate is the basal unit of the Bozeman Group who age was assigned to the Late Cretaceous (Tysdal et al., 1986), but unlike many of the other units in the group, the Sphinx is unfossiliferous.

St. Mary River Formation
PFYC: 4

St. Mary River Formation outcrops in restricted parts of southwestern Alberta and northwestern Montana. Dinosaurs have been reported (Brown and Schlaikjer, 1942;

Weishampel and Horner, 1987), as well as significant mulituberculate faunas (Hunter et al., 2010).

Telegraph Creek Formation
PFYC: U

The Telegraph Creek conformably underlies the Eagle Formation, and the lateral Eagle equivalent Virgelle Formation. The units contains bivalves and cephalopods (Balster, 1971; Reeside, 1927) and is ranked as U for being largely unexplored.

Two Medicine Formation
PFYC: 5

The Two Medicine Formation has produced some of the most significant dinosaur discoveries, including eggs, juveniles, and nests of the hadrosaur *Maiasaura*, as well as insect traces, other dinosaur, bird, and mammal fossils, sometimes in extensive bonebeds (Chin, 2007; Gates et al., 2011; Goodwin, 1992; Hirsch and Quinn, 1990; Horner, 1982; Horner, 1984a; Horner, 1984b; Horner, 1989, 1999; Montellano et al., 2000; Rogers, 1992; Russell, 1930; Sampson, 1995; Varricchio and Chiappe, 1995; Varricchio et al., 1999).

Virgelle Formation
PFYC: 3

The Virgelle Formation underlies the Two Medicine Formation, and is a distinctive cliff-forming unit. It contains well sorted, fine grained, calcareous, micaceous, and arkose sands. Fossils are scarce (Mudge, 1972), but ammonites and pelecypods have been reported.

Willow Creek Formation
PFYC: 3

This formation overlies the St. Mary River Formation and thought to be Late Cretaceous to early Paleocene age (Cobban, 1955; Stebinger, 1916). Only a single dinosaur bone has been reported (Russell, 1968), but is essentially unknown in potential.

Paleogene

During the Paleogene in western Montana numerous intermontane basins were created by uplift and filled with sediments. Attempts have been made to trace lithologic units between basins with varying degrees of success (Hanneman and Wideman, 1991; Kuenzi and Fields, 1971; Kuenzi and Richard, 1969). This has led to the naming of many intrabasinal formations as well as the changing formational rank of existing formations from one basin to another. The Sage Creek Basin contains the most extensive temporal suite of Paleogene/Neogene vertebrates know from any of the basins in Montana (Tabrum, 2013).

Across eastern Montana and into the Dakotas there are also extensive deposits of Paleogene rocks including the Fort Union and Wasatch.

Bear Formation

PFYC: 4

The Bear Formation is a Paleocene aged unit about 500-600 feet thick, above the Hell Creek and below the Fort Union. The Simpson Quarry has produced a significant Puercan mammal assemblage, as well as leaves, mollusks, and lower vertebrates (Buckley, 1995; Hartman et al., 1989). It occurs in the Crazy Mountain Basin.

Blacktail Creek Formation

PFYC: 4

The type section for the formation was determined by Hibbard and Keenmon (1950) to be near the center of sec. 8, T. 11 S., R. 6 W., which is on BLM land. Numerous mammal fossils have been recovered from this region (Douglass, 1902; Hibbard and Keenmon, 1950; MacDonald, 1956). The unit is Whitneyan to Arikareean in age (Tabrum, 2013).

Brule Formation

PFYC: 5

A wide variety of fossils have been reported from the Brule, including burrows (Retallack, 1984), footprints (Bjork, 1976), birds (Hoganson, 2013; Hoganson et al., 1998; Murphy et al., 1993), and mammals (Bjork, 1975; Harksen and Macdonald, 1969; Hoganson et al., 1998).

Bullion Creek Formation

PFYC: 4

Bullion Creek produced an alligator, *Wannaganosuchus brachymanus* (Erickson, 1982b), the crocodile *Leidyosuchus*, plant leaves and fruits (Manchester, 2001; Melchior, 1976) , birds (Benson, 1999; Erickson, 1975, 1991), as well as trace fossils (Kihm and Hartman,

1995; Melchior and Erickson, 1979). Kihm and Hartman (2004b) recommended to abandon the name Bullion Creek in favor of the Tongue River.

Cannonball Formation
PFYC: 4

The Cannonball is variously considered a member of the Fort Union Formation or a formation. It has produced at least 22 taxa of vertebrates, including sharks, rays, boney fish, turtle, croc, and champsosaur (Cvancara and Hoganson, 1993). Additionally, invertebrates include forams (Fox and Olsson, 1969; Fox and Ross, 1942), crabs (Holland and Cvancara, 1958), and lobster (Feldmann and Holland, 1971).

Chadron Formation
PFYC: 4

The Chadron Formation is the basal formation within the White River Group, and has produced significant fauna, including the strange brontotheres and other significant fossils (Clark, 1937; Graham, 2008; Hough and Alf, 1956; Smith, 2006; Terry, 1998b).

Challis Volcanics
PFYC: U

The Challis Volcanics is referred to either as group or supergoup, and contains very mixed lithology of basaltic andesite, latite, rhyodacite, rhyolite flows, ash-flow tuffs, and tuff and flow breccias, and even sandstones (for example Leonard and Marvin, 1982). Some units are known to be fossiliferous (Axelrod, 1968; Edelman, 1975; Erwin and Schorn, 2006). Therefore, the PFYC rank is considered unknown.

Chamberlain Pass
PFYC: 2

The Chamberlain Pass is the lowest formation of the White River Group, and contains the Interior and Weta Paleosol Series (Terry, 1998a; Terry and Evans, 1994). It is not reported to be fossiliferous.

Cook Ranch Formation
PFYC: 5

Disconformably overlies the Sage Creek Formation (Wood, 1934), and includes Oligocene vertebrates (Hough, 1955; Korth and Tabrum, 2011; Tabrum et al., 1996) of Chadronian to Orellan age (Tabrum, 2013).

Deep River Formation
PFYC: 4

These Arikareean beds have produced numerous fossil vertebrates and invertebrates (Barnosky, 1981; Barnosky, 1982; Black, 1961b; Koerner, 1940; Matthew and Mook, 1933; Rensberger, 1981; Roth and Emberton, 1994; Scott, 1894; Wang et al., 1999).

Dell Beds

PFYC: 5

Introduced by Fields et al. (1985) as an informal unit of formational rank that unconformably overlies the Sage Creek Formation. The Dell beds are in turn disconformably overlain by the Cook Ranch Formation (Tabrum et al., 1996). Vertebrate fossils recovered from this unit are referred to the lower Douglass Draw local fauna or the distinct Hough Draw local fauna. Total thickness is estimated to be 300-400 feet, and could be in excess of 500 feet (Tabrum et al., 1996). The unit is Uintan in age (Tabrum, 2013).

Fort Union Formation

PFYC: 4

The use of the name Fort Union, and the various member units across multiple states, has a complex history (Brown, 1962; Clemens and Hartman, 2014). An overview of the entire unit is given here, and each of the various subunits also have their own entries. The Fort Union was first named by Meek and Hayden (1861) for exposures in what was then the Nebraska Territory, around Fort Union, very close to the modern border between Montana and North Dakota on the Missouri River. Meek and Hayden referred to the unit as the Fort Union or Great Lignite Group and they correlated this unit around “the whole country around Fort Union, extending north into the British possessions, to unknown distances; also southward to Fort Clark. Seen under the White River Group on North Platte River above Fort Laramie. Also on west side Wind River Mountains.”

Early concepts of the rock unit were closely tied to concepts of the Lance and Laramie formations, and the situation became very complicated. In fact, through the first half of the twentieth century, sorting out the relationships of the rocks in question across Wyoming, Montana, and the Dakotas, and trying to define the boundary between the Cretaceous and “Eocene” beds, came to be called the “Laramie problem.” (At the time, it was not recognized that another geologic epoch preceded the Eocene, which we now recognize as the Paleocene). A great deal of the early literature was devoted to the “Laramie problem” (see Brown, 1907, 1914; Cross, 1909; Knowlton, 1909, 1914; Stanton, 1909, 1914; Stanton and Knowlton, 1897).

The debates and confusion continued at least until the mid-twentieth century (Brown, 1952). Jepsen (1940) wrote “after about three quarters of a century of use of ‘Fort Union’ and ‘Wasatch,’ it is unusual to find, among stratigraphers and paleontologists, two similar conceptions of the correct applications of the terms.” Finally, Jensen and Varnes (1964b) noted “the position of the Tertiary-Cretaceous boundary is no longer actively disputed…and is placed

at the contact of the Hell Creek formation…with the overlying Fort Union formation" (p. F17). A good summary of the issues can be found in Clemens and Hartman (2014).

While working out the stratigraphic relations, geologists described and named various subunits within the larger Fort Union package. In chronological order of naming (see Table 1 and Figure 1 for stratigraphic context), the Tongue River was the first unit to be recognized (Taff, 1909), and was described as an upper member of coal-bearing rocks in the Sheridan area. The type area of the Lebo Member was described a year later (Stone and Calvert, 1910), and is along Lebo Creek in the Crazy Mountain region.

TABLE 1. CURRENTLY RECOGNIZED MEMBERS OF THE FORT UNION IN MONTANA AND THE DAKOTAS.

Montana	**South Dakota**	**North Dakota**
Linley/Sentinel Butte	Tongue River	Sentinel Butte
Tongue River (Melville)	Cannonball	Tongue River
Ekalaka	Ludlow	~~Bullion Creek~~ Abandoned
Lebo/Ludlow		~~Slope~~ Abandoned
Tullock (Bear)		Ludlow/Cannonball

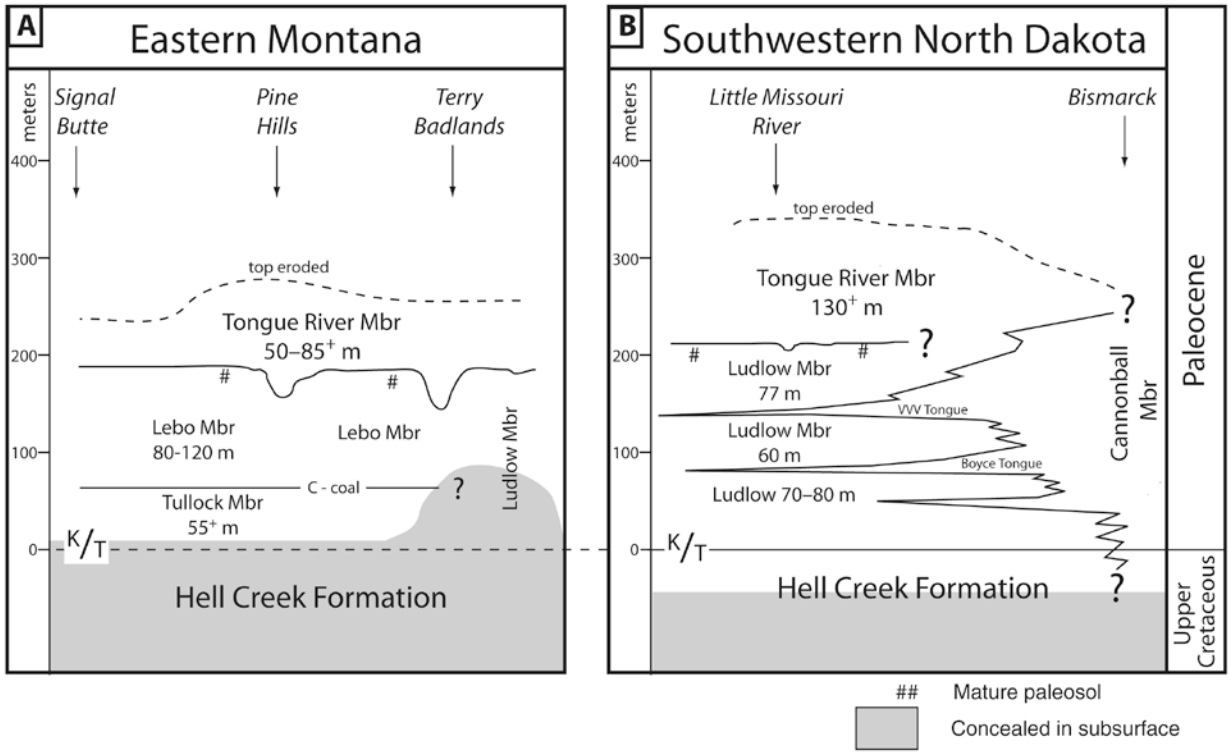

FIGURE 1. STRATIGRAPHIC SUCCESSION IN EASTERN MONTANA (A) AND SOUTHWESTERN NORTH DAKOTA (B) OF THE UNITS OF THE FORT UNION. FROM (BELT ET AL., 2005).

In the Dakotas the Cannonball Marine Member (initially assigned to the Cretaceous Lance Formation) was identified as a Paleogene shallow marine deposit (Lloyd, 1914). In the Dakotas and parts of Montana (Belt et al., 2004; Luft, 1986), the unit overlying the Hell Creek is the Ludlow, named by Lloyd and Hares (1915). The Ludlow is equivalent to the combined Tullock and Lebo in eastern Montana and the Dakotas where distinguishing the two units becomes difficult (Brown, 1962). The Tullock was named by Rogers and Lee (1923), also initially as a member of the Lance. In the Crazy Mountain area of Montana yet another unit immediately overlying the Hell Creek, the Bear Formation, was named by Simpson (1937). Simpson also named a member above the Lebo in that area he called the Melville. However, the terms Bear and Melville have not been adopted by other geologists (Hartman et al., 1989).

Additional units were defined in the Dakotas, including the Sentinel Butte established by Leonard (1908), which was included as a member of the Fort Union Formation by Leonard and Smith (1909). The Sentinel Butte has been variously referred to as a formation, member, and even a facies (Carlson, 1979, 1983; Fastovsky and McSweeney, 1991; Royse, 1967; Royse and Holland, 1969; Thom and Dobbin, 1924). The Slope and Bullion Creek were also established as formal units (Clayton et al., 1977). However, later workers urged the abandonment of the terms Slope and Bullion Creek on the grounds that they were not lithologically distinct from the Tongue River (Belt et al., 2005; Kihm and Hartman, 2004b). The most recently proposed unit is

the sandy Ekalaka Member in southeastern Montana (Belt et al., 2002). The Fort Union is variously considered a formation or group across its extent, and is given formation status on the Montana state map (Vuke et al., 2007). The formation records an active period of deposition, coal production, and tectonic events from the early Paleogene (Belt et al., 1992).

Each of the lowest members of the Fort Union (the Bear, Tullock, Ludlow, and Cannonball) has produced significant fossils of both vertebrates and plants. Indeed, intense study of these units and their relationship with the underlying Cretaceous units, and the tempo of dinosaur extinction, has been active ever since the discussions of the "Laramie problem." Scientifically important plants and animals have been described (for example Archibald, 1977, 1982, 1987, 2000, 2002; Archibald et al., 1982; Archibald and Clemens, 1982; Archibald et al., 2010; Brown, 1962; Clemens, 2011; Cope, 1876; Dorf, 1940; Douglass, 1908c; Gidley, 1909, 1915, 1919, 1922, 1923; Jepsen, 1930; Knowlton, 1893; Moore et al., 2014; Simpson, 1928, 1929, 1935, 1936, 1937; Wilson, 2014a, b; Zhang and Archibald, 2007). The earliest primates come from the lowest member (Sloan and Van Valen, 1965), as well as archaic pantodonts (Simons, 1960). The Simpson Quarry is a classic locality of importance (Buckley, 1995, 1997; Hartman et al., 1989).

The Cannonball outcrops in North and South Dakota, and documents the last marine incursion into central North America at the beginning of the Paleogene. In places it overlies the Hell Creek, and intertongues laterally with the Ludlow (Figure 1). Bivalves, and crab burrows and body fossils are known (Cvancara, 1966, 1976; Holland and Cvancara, 1958). At least 22 vertebrate taxa have been identified from the Cannonball, including sharks, boney fishes, turtles, champsosaurs, and crocodylians (Cvancara and Hoganson, 1993).

The higher members of the Fort Union have also proven to be significantly fossiliferous. Plants occur in all the members: "nearly every shale, clay, and sandstone, contains well-preserved fossil plants, among which are mosses, ferns, cycads, conifers, palms, water-lilies, birches, hazels, hickories, oaks, viburnums, and many other dicotyledons" (Brown, 1952, 1962). The Lebo has produced several classic Paleocene localities as well (Krause and Gingerich, 1983; Roberts, 1972; Simons, 1960; Simpson, 1937). As many as 57 mammal species were reported in the Crazy Mountain Basin alone (Simpson, 1935), which include primarily Lebo and Tongue River beds.

The Tongue River is a major surface coal producer. Reports of fossils include pollen (Nichols, 1999; Wilson and Webster, 1946), plants (Kihm and Hartman, 2004a); (Simpson, 1937), trace fossils including footprints (Belt et al., 2005; Peabody, 1954), mollusks (Bickel, 1977; Hanley and Flores, 1987), sharks, fishes, amphibians, (Estes, 1976), and significant mammal faunas. Several classic mammal faunas come from this upper member, including the Scarritt Quarry, the Douglass Quarry, and several others. Many of these sites are type localities for early mammal taxa (Gidley, 1909, 1915; Gingerich et al., 1983; Krause and Gingerich, 1983; Robinson and Honey, 1987; Simpson, 1928, 1929, 1935, 1936, 1937).

Whereas the previous quarries from the Tongue River are from central Montana, and the lithology toward the east does change (note the use of the Ludlow for a combined Tullock and Lebo), the more eastern rocks also contain fossils (Table 2).

TABLE 2. SELECTED FOSSIL QUARRIES FROM THE FORT UNION BEDS MATCHED WITH THEIR LITHOSTRATIGRAPHIC MEMBERSHIP.

Lithostratigraphy	Quarry
Sentinel Butte Tongue River	Medicine Rocks
	Wannagan Creek
	Brisbane and Judson (ND)
	Bangtail
	Scarritt
	Douglass
Lebo	Siberling
	Gidley
	Numerous Simpson localities
Tullock Ludlow Cannonball	Brown Ranch
	Simpson
Hell Creek	Hell Creek Faunas

In eastern Montana there is a fauna from several Medicine Rocks localities in Carter County (Gingerich, 1976; Krause, 1987; Rose, 1975; West, 1976). And significant mammals have been reported from the Tongue River in North Dakota (Hartman and Kihm, 1991; Holtzman, 1978; Kihm and Hartman, 2004b). In addition, there have been many publications related to the Wannagan Creek Quarry in North Dakota (Erickson, 1982a, b, 1991, 1999; Melchior and Erickson, 1979; Melchior and Hall, 1983).

In summary, the various members of the Fort Union beds in Montana and the Dakotas have all produced significant floras and faunas, and the available evidence does not point to one unit being significantly different from the others in fossil potential. For all these reasons, the entire

Fort Union across the management area was ranked as at least a PFYC 4. The only reason not to make the Fort Union a PFYC 5 is in recognition that fossils seem to occur in localized deposits, but additional evidence could alter this opinion.

Golden Valley Formation
PFYC: 4

The Golden Valley Formation has been divided into two members, the lower Bear Den Member, and the overlying Camels Butte Member (Hickey, 1977; Murphy, 2001). Fish, amphibians, reptiles, birds, and mammals have all been reported (Jepsen, 1963; West, 1973).

Linley Conglomerate
PFYC: U

Name used for rocks between Linley and the Beartooth Mountains, an area of about 5 square miles. In this area is a conglomeratic sandstone, tilted and with a marked unconformity on the Fort Union rocks (Calvert, 1916). No fossils were reported.

Lowland Creek Volcanics
PFYC: 1

Crops out over 800 square miles north and west of Butte. K-Ar age determinations indicate that the Lowland Creek is older than the Climbing Arrow at 48 ma (Smedes and Thomas, 1965).

Ludlow Formation
PFYC: 4

At times the Ludlow is considered a member of the Fort Union. The Ludlow consists of unconsolidated mud and sand, as well as lignitic and coal beds (Belt et al., 2004), and includes rocks between the Hell Creek and the Tongue River in some areas. This section is one of the most important for recording the Cretaceous-Paleogene transition (Fastovsky, 1987).

Milligan Creek Formation
PFYC: 3

The Milligan Creek is part of the Eocene in age and part of the Bozeman Group, has a gradational contact with the underlying Sphinx, and is overlain by the Climbing Arrow. The formation is thought to be of eolian-lacustrine origin, and includes snails, clams, and ostracodes (Robinson and Barnett, 1963).

Mount Wallace Formation
PFYC: 1

Mount Wallace Formation is an Eocene sequence of andesite, trachybasalt, and latite lava flows and flow breccias, rhyodacite welded ash-flow tuff and interlayered volcanic sediments. It includes the Slough Creek Tuff Member. The formation is not fossiliferous (Smedes and Prostka, 1972).

Passamari Formation
PFYC: 4

Exposed on Sweetwater Creek in the Upper Ruby River Basin, the lower part consists of light tan fissile shale containing volcanic ash and a light tan blocky silty shale without ash. The upper part consists mainly of very light buff and very light gray thin-bedded calcareous shale (Balster, 1971). Fossils include insects and plants (Becker, 1959, 1960a, b, c, 1961), fish scales, and a nearly complete bird with feather impressions (Becker, 1960a; Dorr and Wheeler, 1964). It is Oligocene or Miocene in age.

Red Bluff Formation
PFYC: U

The Oligocene Red Bluff Formation was formally named by Kellogg (1994) and includes an upper member of siltstone, sandstone, conglomerate, typically tuffaceous, and a lower diamictite member. Both have clasts of silica-rich rocks, and no fossils are mentioned. However, it will be ranked as an unknown.

Renova Formation
PFYC: 5

The rocks equivalent to the Renova Formation have been correlated across several basins, including the Ruby, Jefferson, Three Forks, Townsend and Clarkston basins, and within the various basins different formation and member names have been applied (Kuenzi and Fields, 1971). The Renova Formation includes the Bone Basin, Climbing Arrow, and Dunbar Creek members. It is equivalent to Milligan Creek and the Passamari formations (Fields et al., 1985; Kuenzi and Fields, 1971; Vuke et al., 2004). Fossilized wood, some very large stumps, have been reported in the Climbing Arrow (Robinson and Barnett, 1963).

Several classic fossil localities come from this unit, and many significant fossils (Douglass, 1899, 1905, 1908b; Hoffman, 1971; Riel, 1963; Robinson and Barnett, 1963; Tabrum and Fields, 1980; Tabrum et al., 2001; Tabrum et al., 1996). The Red Hill member (informal) of the Renova includes the Sphinx (Robinson and Barnett, 1963) and Conrow Creek conglomerates, and should be coded as PFYC U.

Sage Creek Formation
PFYC: 5

Named by Douglass (1903). Wood and later Kay collected in this unit, as well as the overlying Cook Ranch Formation (Tabrum et al., 2001; Tabrum et al., 1996). Unit was also collected by Wood (1934) and Hough (1955; 1958). Vertebrate faunas are scattered (Tabrum et al., 2001), but given their significance the unit is classed as PFYC 5. The formation is Bridgerian aged (Tabrum, 2013).

Sentinel Butte Formation
PFYC: 4

Sentinel Butte of North Dakota is part of the Fort Union Group, and contains significant floras and wood (Clausen, 1953; Crane et al., 1990; Fastovsky and McSweeney, 1991; Hoganson and Campbell, 1997; Manchester et al., 1999; Pigg and DeVore, 2005, 2010; Stull et al., 2012; Zetter et al., 2011), freshwater clams and insects (Erickson, 1983), fish (Newbrey and Bozek, 2000; Newbrey and Bozek, 2003), birds (Hoganson, 2013; Stidham et al., 2012), and mammals (Hartman and Kihm, 1991; Kihm et al., 1993) have all been reported.

Sepulcher Formation
PFYC: 3

Named for Sepulcher Mountain, Yellowstone National Park, the Sepulcher Formation is divided into a conglomerate facies at the base, Elk Creek Basalt, Lost Creek Tuff, Daly Creek, Fortress Mountain members. A thin black shale bed in the conglomerate facies contains Eocene plant remains, and the Fortress Mountain Member contains abundant petrified trees concentrated in more than 30 distinct fossil forest horizons. Some of the trees are over 4 feet in diameter and are preserved upright (Smedes and Prostka, 1972).

Sharps Formation
PFYC: 4

Sharps Formation of South Dakota and Nebraska was named in Harksen et al. (1961) as the basal formation of the Arikaree Group in Shannon County, SD. The fauna includes insectivores, rodents, carnivores, artiodactyls, and perissodactyls (Harksen et al., 1961; Rensberger, 1980). More recently it has been suggested that the Sharps should belong with the White River Group (McConnell and DiBenedetto, 2012).

Slim Buttes
PFYC: 3

Slim Buttes was named by (Malhotra and Tegland, 1960) as a unit underlying the Chadron in South Dakota. It contains a Duchesnean fauna of vertebrates.

Slope Formation
PFYC: 3

Slope and the Bullion Creek were named by Clayton et al. (1977). Several authors have urged that the term Slope Formation be abandoned (Belt et al., 2004; Kihm and Hartman, 2004b) urged that the term Slope Formation be abandoned.

Toston Formation
PFYC: 5

The Toston Beds are apparently in part of wholly equivalent to the Dunbar Creek Formation (Balster, 1971). However, mammal fossils have been reported from this unit (Wang et al., 1999).

Wasatch Formation
PFYC: 3

Formation contains somber gray-brown and gray shale, some carbonaceous shale, and thin beds of brown calcareous sandstone. Clam and snail shells are so abundant in several beds of sandstone that the units have a coquinoid appearance. In their study Bryson and Bass (1973) reported that numerous fossils were collected that were a distinct Wasatch fauna, however, they do not itemize the taxa collected.

White River Group
The White River Badlands of South Dakota contain the largest assemblage of known late Eocene and Oligocene fossil mammals, as typified in Badlands National Park. The group includes the Brule and Chadron formations. In South Dakota it also includes the Chamberlain Pass.

Neogene

In western Montana during the Neogene sediments continued to fill intermontane basins with some formations spanning the Paleogene/Neogene boundary. Many of these deposits are not differentiated at the formation level.

Arikaree Formation

PFYC: 5

Few specimens have been reported from the Arikaree Formation in Montana, but many have been reported from South Dakota and Nebraska. Balster (1971) reported fossil seeds and vertebrate bones, and there is at least one bird reported (Shufeldt, 1915).

In South Dakota the Arikaree Group includes the Rosebud, Harrison, Turtle Butte, Monroe Creek, and Sharps formations.

Batesland Formation

PFYC: 4

The Batesland Formation is a paleo-valley fill of Hemingfordian age in the Rosebud Formation. At least one significant vertebrate fauna has been identified, the Flint Hill quarry of the University of California. A number of species of mammals and birds have been described (Harksen and Macdonald, 1967; Harksen et al., 1961; Martin, 1976, 1978; Miller, 1944; Miller and Compton, 1939)

Bozeman Group

The original formation of the Bozeman Group as proposed (Robinson, 1967; Robinson and Barnett, 1963) was modified subsequently. The Group contains classic fossil localities originally collected by Douglass (Douglass, 1902, 1903, 1908a, 1909) and later explored by many others. The Bozeman Group includes the Sphinx Conglomerate, Milligan Creek, Climbing Arrow, Dunbar Creek, Sixmile Creek, Renova, and Toston formations. The formations span across the Paleogene/Neogene boundary.

Cabbage Patch Beds

PFYC: 4

These are massive gray siltstone, gray ash, and buff siltstone. The beds contain fossil mammals (Konizeski and Donohoe, 1958; Rasmussen, 1977; Riel, 1964).

Flaxville Formation

PFYC: 3

The Flaxville Formation is in extreme northeastern Montana and is reported to be fossiliferous (Denson and Gill, 1965; Jensen and Varnes, 1964a; Storer, 1969), however the

fossils in at least parts of the formation are thought to be re-worked from older units (Balster, 1971).

Flint Creek Beds
PFYC: 5

The Flint Creek beds are composed of fine-grained, tuffaceous mudstones and siltstones of Barstovian age. Originally named by Douglass (1903) from which he reported a snake and several species of mammals. Various institutions sent crews to the region including Carnegie, Frick Collection of the American Museum, University of Montana, and the University of Kansas (Black, 1961a; Douglass, 1907; Pierce and Rasmussen, 1989; Wang et al., 1999).

Fort Logan Formation
PFYC: 5

Douglass (1903) erected the name Fort Logan for the older units that had ambiguously been lumped as "Deep River" beds. Several vertebrate faunas have been reported from the Fort Logan (Black, 1961b; Koerner, 1940).

Harrison Sandstone
PFYC: U

Originally named by Hatcher for rocks exposed in the vicinity of Harrison Nebraska, the unit was extended into South Dakota by Skinner et al. (1977). Also considered a member of the Arikaree Formation.

Hepburn's Mesa Formation
PFYC: 4

Barnosky and Labar (1989) established the middle Miocene Hepburn's Mesa Formation in Park County, Montana. There is a mammal fauna associated with this formation, mostly rodents (Carrasco, 1998; Hopkins, 2004; Kraatz and Barnosky, 2004).

Kishenehn Formation
PFYC: 4

The Kishenehn Formation is contained in a half-graben with synorogenic basin fill, accumulating a thickness exceeding 11,000 ft in northern Montana. It ranges in age from the late Eocene through the early Miocene, and so spans the Paleogene/Neogene boundary. The first fossils reported were mollusks, but extensive collections of fossil mammals, fishes, insects, gastropods, ostracodes, bivalves, and macroflora have been recovered (Constenius et al., 1989; Greenwalt et al., 2013).

Little Sage Creek Bed
PFYC: 3

Little Sage Creek bed is an informal name for rocks exposed in the Sage Creek Basin and they are Barstovian in age (Tabrum, 2013), overlying the Blacktail Deer Creek Formation (Fields et al., 1985). The Little Sage Creek bed is not very fossiliferous, but has produced *Merychippus* specimens (Hough, 1958).

Madison Valley Formation
PFYC: 4

This unit consists of fluvial rocks with rare lacustrine lenses. The unit was variously called the Bozeman lake beds, Loup Fork, Madison Valley beds, and Bozeman formation (Dorr, 1956). Turtle (Oelrich, 1950) beaver, horse, camel, bear-dog, rhino, and chalicothere (Dorr and Wheeler, 1964; Douglass, 1903) have been found.

Monroe Creek Formation
PFYC: 3

The Monroe Creek, early Miocene from South Dakota, has produced faunas of microverts, especially those collected from anthills that produced fish, amphibian, reptiles, birds, and mammal remains (MacDonald, 1963; Macdonald, 1972).

Ogallala Formation
PFYC: 3

The Ogallala is a wide-spread unit across the central plains states from Texas through South Dakota. It is a source of interest as a major aquifer, and it has also produced significant floras and faunas in Kansas and Nebraska (for example Green, 1956; Hesse, 1935; Matthew, 1899; Thomasson, 1977; Thomasson et al., 1990). In South Dakota the Ogallala is a group, including the Ash Hollow, Valentine, and Fort Randall formations. The interpretations of these units have been complex, so for the purposes of this work they will all be considered together, and given the same PFYC rank.

Rimroad Gravel
PFYC: U

Described as a coarse, sandy, fluvial gravel distributed along the high divide between the Yellowstone River and the Redwater Creek to the west. Speculated to be Oligocene or Miocene in age based upon its relationship to the Flaxville. No fossils are reported in the literature (Howard, 1960).

Rosebud Formation
PFYC: 3

The Rosebud Formation of Nebraska and South Dakota has produced significant snakes (Holman, 1976), rabbits (Green, 1972), and dogs (Loomis, 1936).

Sixmile Creek Formation
PFYC: 5

Established by Robinson (1967), Sixmile Creek Formation is about 2,000 feet thick and divided into three informal members: the metamorphic fanglomerate unit overlain by the feldspathic sandstone unit followed by the pebble conglomerate member (Monroe, 1976). Robinson thought that the Sixmile Creek contained a significant hiatus covering the late Arikareean and Hemingfordian, but later authors do not recognize that it spans that hiatus, and is Barstovian to Hemphillian in age. Fields et al. (1985) used the term Little Sage Creek Beds for equivalent rocks.

Tertiary Sand and Gravel
PFYC: U

The Tertiary is no longer recognized as a formal unit, however the term is still in wide use, and appears in the literature and on many geologic maps. The term refers to the geologic period that lasted from 66 million to 2.5 million years ago, following the Cretaceous and preceding the Quaternary. That time interval is now divided into the Paleogene and the Neogene. Sand and gravel deposits often contain significant vertebrate fossils, however they are often in isolated pockets or lenses. They should be carefully reviewed on a case-by-case basis.

Turtle Butte Formation
PFYC: U

Part of the Arikaree in South Dakota. Not much information seems to be available, so it is being ranked as unknown.

Wiota Gravels
PFYC: 3

Named for the Wiota railroad station on the Great Northern Railroad, these preglacial gravel deposits are widespread in Valley, Roosevelt, and Sheridan counties, Montana (Jensen and Varnes, 1964a). Mammoth has been reported, but it is thought that the gravel spans at least the Pliocene through Pleistocene age.

Quaternary

Quaternary deposits were strongly influenced by glacial activity of the Pleistocene. Extensive deposits of glacial till and subsequent fluvial deposits across the region are extensive. Most of these deposits have not been given formation names and are frequently mapped based on lithologic character and estimated age. Care should be taken with these deposits with regard to fossil resources as it is very hard to predict which deposits might be fossiliferous. Many of these types of deposits contain significant floras and faunas, although the distribution of fossils is often spotty. General guidelines for PFYC ranks are given below. These deposits should not be underestimated for their fossil potential. Recent, Holocene and disturbed deposits are ranked very low potential for obvious reasons.

Perhaps the best documented Pleistocene site in Montana is the Merrell Locality (Dundas, 1992; Hill and Davis, 2005). Another site is the Doeden fauna (Hill and Schweitzer, 1999; Wilson and Hill, 2000, 2002; Wilson et al., 2005). Additional faunas and localities have been reported as well (Hill, 2001, 2006, 2007).

Alluvium, Alluvial Fans

PFYC: U, 2

Alluvial deposits can cover a wide range of geologic times and depositional settings. If it can be discerned from the map that the unit is very young, Holocene, it can be coded as 2. However, generalized map units of alluvium, fans, and older alluvial deposits should be coded as unknown.

All igneous and metamorphic units

PFYC: 1

Although given the lowest PFYC rank, these rocks cannot be completely discounted for their fossil potential, and should be reviewed on a case-by-case basis. For example important collections of entire herds of animals have been caught in ash falls (Otto, 1997).

Cave accumulations

PFYC: 4

Cave deposits are often complex, but caves can contain very significant fossil accumulations (for example, Anderson, 1968; Andrews, 1990; Davis et al., 1996; Heaton, 1988; Martin and Gilbert, 1978; Melton, 1985), so they deserve careful consideration for fossils.

Clinker

PFYC: 1

Clinker deposits are thought to be the result of coal seam fires from the geologic past. They are often a brick-red claystone with the consistency of fired clay. Clinker is mined commercially as a construction aggregate.

Coleharbor Group
PFYC: 3

The name Coleharbor Formation was proposed by Bluemle (1971) for all glacial sediments in North Dakota. The unit is now considered a group. A wide variety of depositional environments are represented including rivers and streams, and lakes (Bluemle, 1971). Fossils include plants, mollusks, insects, amphibians, and mammals like beavers, and large mammals like horses, bison, and giant ground sloth (Hoganson and Murphy, 2003). Occurrence of fossils are scattered and are typically in low density.

Colluvium, Avalanche, Debris Flow, and Landslide Deposits
PFYC: 2

These rock types would not generally be expected to preserve fossils.

Eolian Deposits
PFYC: 2

Eolian deposits would not generally be expected to preserve fossils.

Glacial Drift, Till, Moraines
PFYC: U

Like other types of alluvium, these deposits can produce fossils, and being glacial in origin it is known that these deposits are at least Pleistocene in age. Therefore, they should be considered generally as unknown unless there are reasons to downgrade their rank. Moraines and tills, for example, in their undisturbed state are probably not very likely to contain fossils; however, when those deposits got reworked in fluvial systems fossils often got incorporated in them, which is why gravel pits often produce important fossils.

Huckleberry Ridge Tuff
PFYC: 3

Huckleberry Ridge is one of the Yellowstone Group tuffs.

Java Formation
PFYC: 3

The Java Formation was named by Hedges (1987) and includes a significant fauna in at least one paleostream channel deposit from the Irvingtonian, including fish, amphibians,

reptiles, birds and mammals (Holman, 1977, 2003; Martin, 1973; Martin, 1989a, b; Martin and Tedesco, 1976).

Kintyre Formation
PFYC: 3

Named by Jensen and Varnes (1964a), the Kintyre was deposited as outwash from a glacial ice sheet in the Fort Peck area. It was not reported to be fossiliferous, but likely should be considered to have an unknown fossil potential.

Lake Deposits
PFYC: 3

Units mapped at lake deposits should at least be considered as rank 3 until they have been reviewed.

Lava Creek Tuff
PFYC: U

The Lava Creek Tuff was named as a formation within the larger Yellowstone Group (Christiansen and Blank, 1972). The Lava Creek has also been recognized as a member of the Pearlette family of ash beds within the western United States.

Mesa Falls Tuff
PFYC: U

The Mesa Falls is one of the Yellowstone Group tuffs.

Oahe Formation
PFYC: 2

The Oahe Formation consists largely of unlithified silt in North Dakota. It is thought to be largely wind-blown sediment, and contains a few recognized paleosols (Clayton et al., 1976). There are some archaeological finds in the unit, including butchered bison bones, but seems to have little fossil potential.

Paludal deposits
PFYC: U

Paludal deposits are associated with marshes. They are given a rank of unknown for their fossil potential.

Pollock Formation
PFYC: U

Although there are thin surface exposures of this formation north of Pollock, South Dakota, most of the unit is buried. It is thought to be late Wisconsin in age, but there is no mention of fossils (Hedges, 1972).

Tailings, mine dumps, and slag piles

PFYC: 1

Very recently disturbed sediments are not old enough to contain fossils, and as often man-made accumulations, will not be fossiliferous.

Yellowstone Group

The Yellowstone Group contains three ash-flow tuff units, the Huckleberry Ridge, the Mesa Falls, and the Lava Creek tuffs (Christiansen and Blank, 1972).

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