Pryor Mountains
Vermillion Valley Geology

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The Vermillion Valley Viewpoint

In addition to providing a spectacular and photogenic view, the Vermillion Valley Viewpoint is an excellent place to learn about the geology of the Pryor Mountains. With the guidance provided in these notes you can see much of the geologic history culminating in the Pryor Mountains and their structure. The Valley is named for the intense red color of the Chugwater Formation.

How to get to Vermillion Valley Viewpoint

Use the Pryor Mountain Map Set (*www.PryorMountains.org*) to get to the junction of Crooked Creek Road and Helt Road. There are several ways to get to this point. The "Notes" with the Pryor Mountain Map Set give directions from Cowley WY (Follow Crooked Creek Rd) and from Warren MT (Follow either Helt Rd or Gyp Springs Rd to Crooked Creek Rd). Alternatively follow the Pryor Mountain Road guide (*www.PryorMountains.org*) from Bridger MT and turn south on Crooked Creek Rd. (The viewpoint is 14.8 miles south on Crooked Creek Road. That is 5.6 miles south of the USFS/BLM boundary fence.)

From the Crooked Creek Rd – Helt Rd junction, drive 0.6 mile north on Crooked Creek Rd and you are there. You can't miss it! The road crests a hill and suddenly the red Vermillion Valley fills the foreground. This is it. The foreground is dominated by the north-south valley underlain by the bright red Chugwater Formation.

There is no place to park beside the road right at the viewpoint. But about 100 yards south there are a couple wide spots suitable for parking. Park and walk back (north) to the crest. Climb up road bank to the flat area east (right) of the road. The GPS coordinates of the Viewpoint are: 45.0159 N, 108.4257 W.

Why is the Chugwater Red?

The red color of the Chugwater rocks is produced by fine particles of the mineral hematite (iron oxide, Fe_2O_3) in the rock. Only a few percent of hematite can make a rock bright red. (Hematite is actually used as a pigment in red paint.) Hematite can form in strongly oxidizing environments at and near the earth's surface in tropical soils, or, in acid, saline lakes, such as those presently found in southwest Australia. In these situations, many other chemical elements are leached away, leaving iron and aluminum in insoluble oxides and hydroxides. The red sediments of the Chugwater could: (1) be tropical soils, (2) have come from tropical hematite-rich soils eroded and then deposited in rivers, lakes and the sea, and/or (3) precipitated from the acid, saline lake waters and settled on the lake bottoms.

Over geologic time, this part of North America has slowly moved north, from straddling the equator 500 million years ago (mya) into warm temperate latitudes by 100 mya. So, much of the time tropical environments have been the norm. See the paleogeographic reconstructions on the Vermillion Valley Geology page at *www.PryorMountains.org*.

Horizontal Layers

Rocks visible from this viewpoint were originally deposited in a sequence of horizontal layers (Figure 1) over a period of some 200 million years during the Mississippian, Pennsylvanian, Permian, Triassic, Jurassic and Cretaceous Geologic Periods from more than 300 mya to 100 mya. During much of this time this part of the future Montana was covered by a shallow sea. Several thousand feet of sediments settled to the seafloor; or in lakes, rivers and marshes at times when the sea had receded. The rocks we now see are records from those hundreds of millions of years.

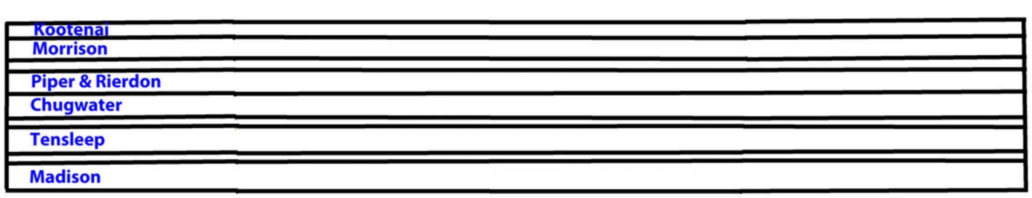
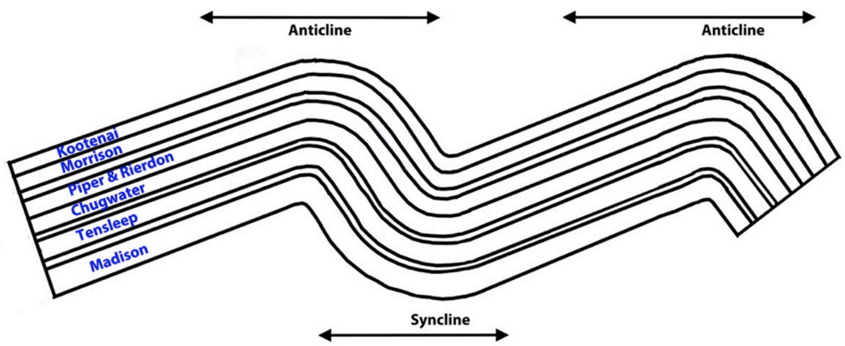


Figure 1: Vertical cross-section of the originally horizontal layers visible from the Viewpoint (now folded and eroded). Other layers above and below, not shown here, are shown in the Stratigraphic Column.

Layers Tilt and Fold

Figure 2: *Vertical cross-section of the layers in Figure 1 after folding* and *showing anticlines and syncline.*



70 to 55 million years ago (mya) the movement of tectonic plates caused an east-west compression of the earth's crust. Resulting thrust faults in the metamorphic and igneous basement rocks forced the overlying sedimentary layers to tilt and fold. After this compression a vertical, east-west cross-section of these sediments would have shown the layers to be folded (Figure 2). As a result each layer was now shaped like a large letter "M" leaning hard toward the east. Bends which are convex upward are called anticlines. Concave upward bends are called synclines. In this case they are called asymmetric folds since, from west to east, they rise gently and fall steeply.

Uplift and Erosion

The crests of these two anticlines would much later become Big Pryor and East Pryor Mountains. Approximately 20 mya the whole area began to be lifted to higher elevation and the top layers began to erode away. Most of the younger layers on top of the thick Madison have eroded away on the upper west-facing slopes leaving the Madison limestone as the surface layer for much of the Pryors. This surface is cut by many rugged and deep canyons. Because of the asymmetry of the original folding the west facing slopes of both East Pryor and Big Pryor Mountains are gentle, but the east facing slopes are steep and cliffy.

From the Vermillion Valley Viewpoint, we see (Figure 3) to the northeast the gentle west facing slopes of East Pryor Mountain with rugged canyons eroded into the limestone. To the northwest we see the steeper east face of Big Pryor Mountain. The unseen (from the viewpoint) west face of Big Pryor Mountain is similar to the west face of East Pryor, and the unseen east face of East Pryor Mountain is similar to the east face of Big Pryor. Crooked Creek Canyon runs from north to south between these two mountain blocks and passes to the east of the viewpoint.

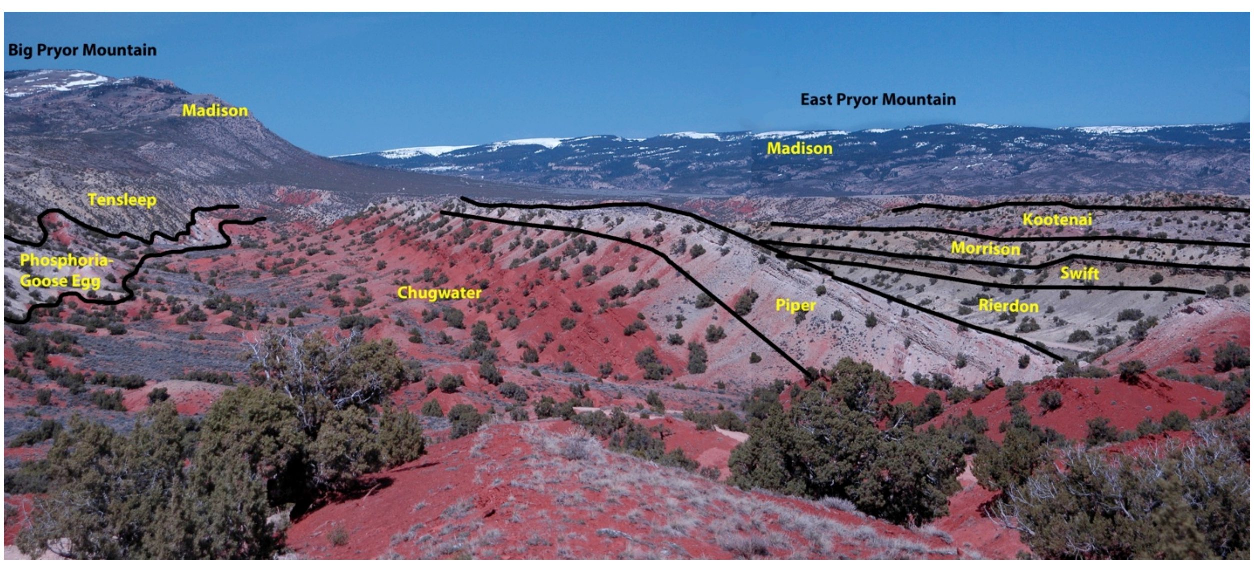


Figure 3: View North from Vermillion Valley Viewpoint.
Black lines indicate approximate contacts between formations in all photos.

Vermillion Valley is Different

The older Madison Limestone forms the surface of the higher parts of the Pryors seen in the distance, north from the viewpoint. But in the lower elevation foreground seen from the viewpoint, the Madison is far under ground – covered by younger rock layers which have been eroded from the high peaks, but not here at Vermillion Valley. To understand why this is true see the discussion of "*Plunging Folds*" on page 4.

As a result of the geologic history outlined above we can now see, in one view from the Vermillion Valley Viewpoint, surface exposures of many different geologic formations instead of just the top layer of a horizontal layer cake. Here many younger layers deposited on top of the Madison Limestone are steeply tilted on the east side of the Big Pryor anticline. (Figure 4)

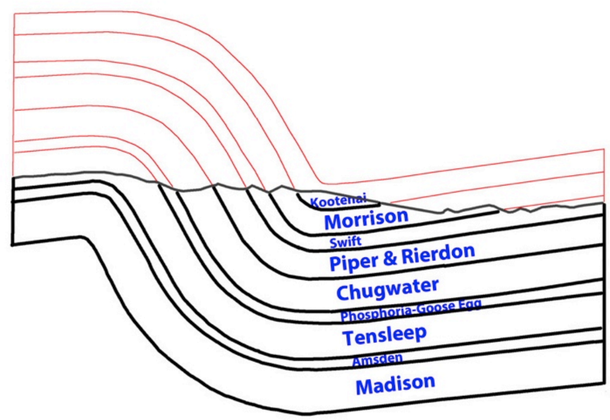


Figure 4: Vertical cross-section of the Vermillion Valley structure today. The part of the fold in red has been eroded away. The right part of the diagram is too far east to be visible from the viewpoint. The diagram was constructed based on field measurements.

Erosion has cut a relatively horizontal surface across the area leaving eroded remnants of the folds. The ridges are composed of rock layers that resist erosion while the valleys are underlain by less resistant rocks. In this view the ridge formers are limestones and sandstones of the Madison, Amsden, Tensleep, Swift and Piper. The steeply dipping (up to 60^{o}) resistant layers result in steep sided ridges called *hogbacks*.

As uplift of the area has occurred, the rivers and their tributaries, with steeper gradients, have cut into the rocks. More powerful streams have been able to cut gaps through some of the ridges (See where the road passes through such a gap in Figure 5.), but mostly the streams cut their beds in less resistant rocks. The streams seen here are essentially all ephemeral, being dry most of the time.

Reading Geologic History

Looking north from the viewpoint, we see in the foreground, scanning west to east (left to right), a record of more than 150 million years of geologic history. In sequence we see the progressively younger formations: Tensleep, Phosphoria-Goose Egg, Chugwater, Piper, Rierdon, Swift, Morrison and Kootenai Formations. During this time the sea covering this part of the future Montana repeatedly receded and advanced. Geologists see this in the types of sediment deposited and in the fossils they contain.

The Tensleep Sandstone was deposited partly on a shallow seafloor nearshore and partly as wind laid sand dunes inland, but near the coast. The Phosphoria Formation here was deposited on a shallow sea floor, while the Goose Egg Formation was deposited nearshore in more saline water perhaps in shallow lagoons or lakes, or on adjoining mud flats. The Chugwater is very similar to the Goose Egg and was likely deposited not far from the sea in ephemeral lakes and small streams.

The Piper limestones in the hogback represent an incursion of the sea across dry land. Above the Piper, the Rierdon and Swift represent a continuation and shallowing of that sea. Then, the Morrison represents coastal plain deposits after the sea receded.

Actually, if we were to look very closely at this Tensleep-Morrison interval, we could see evidence for several smaller fluctuations in sea level as well.

Gypsum is Special

Chemically, the mineral gypsum is hydrated calcium sulfate ($CaSO_4 \cdot 2H_2O$). Gypsum beds are found in the Goose Egg, Chugwater, and Piper formations, interlayered with sedimentary rocks such as sandstone, shale, and limestone. The soft, fine-grained beds of gypsum cropping out in this area are snow white, but are usually covered by mud washed down from soils above.

Although less soluble than rock salt (halite, NaCl), gypsum is more soluble in water than most other rock forming minerals. It commonly forms by precipitation from saline water as the water evaporates. Evaporating 1,000 meters of normal seawater yields less than a meter of gypsum. Within a mile of this viewpoint there is a 10 meter thick layer of gypsum at the base of the Piper Formation.

The presence of these gypsum beds indicates special climatic and geographic conditions in the ancient world. They require an arid climate providing a high rate of evaporation, and a partial barrier to retain concentrated brine in an isolated arm of the sea or a saline lake near the sea.

Because gypsum is relatively soluble in water, it usually does not last long exposed at the surface of the earth, except in arid regions like the south Pryor desert.

A Gap in the History

There is an approximately 70 million year gap between the Chugwater and the Piper Formations. This is called an unconformity. What happened here during those 70 million years? The geologic record is missing. Perhaps more sediments were deposited on top of the Chugwater. If they were, they were eroded away before changing conditions allowed the deposition of the Piper.

At the viewpoint you are standing on the red Chugwater Formation. If you walk a few hundreds yards to the east, to the top of the ridge, you will be standing on the Piper Formation. In between you will have crossed the unconformity – the 70 my gap in the geologic record.

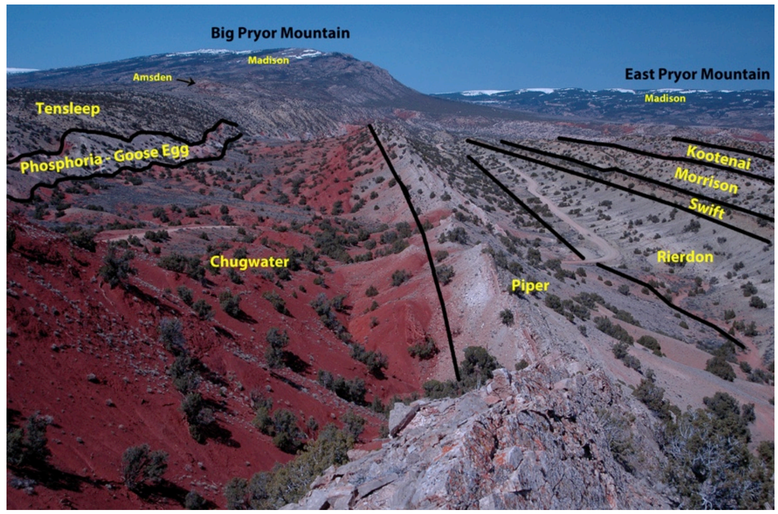


Figure 5: View north from ridge of Piper Formation east of Viewpoint.

Plunging Folds

The two anticlines and the syncline in the Pryors are also slightly tilted down toward the south. Geologically, these structures are referred to as south-plunging asymmetric folds.

From the Vermillion Valley Viewpoint we can see the crest line of the plunging anticline. (Figure 6.) The resistant Tensleep Sandstone drapes over the crest, dipping steeply eastward on the east side and dipping more gently westward on the west. The crest line plunges gently southward. The red patch farther to the north up Big Pryor Mountain in the center right is the underlying Amsden Formation. The Tensleep, originally above the Amsden, has eroded away exposing the Amsden. Higher (and farther north) still is the Madison Limestone originally deposited beneath the Amsden. There even the Amsden is eroded off the anticline. Because the anticline plunges to the south, or rises to the north, we see older layers exposed farther north.

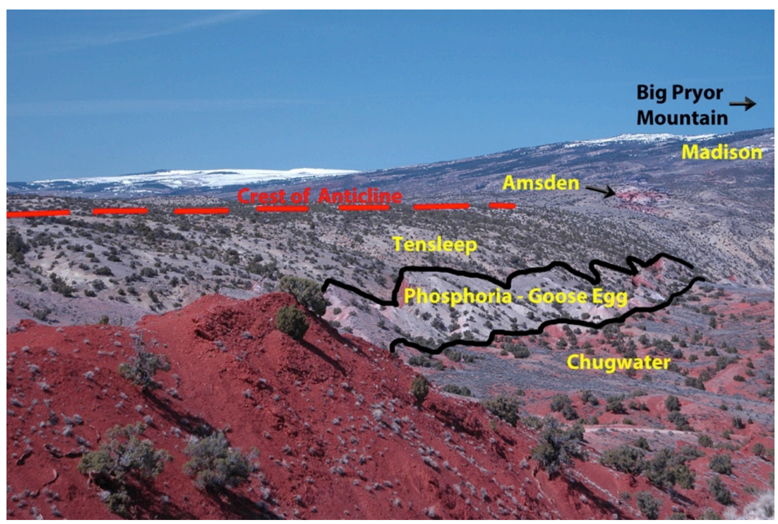


Figure 6: View northwest from viewpoint showing Tensleep Formation draping over the crest of the anticline.

To the south, southwest of the viewpoint, the Tensleep also disappears under younger layers just as the Madison does.

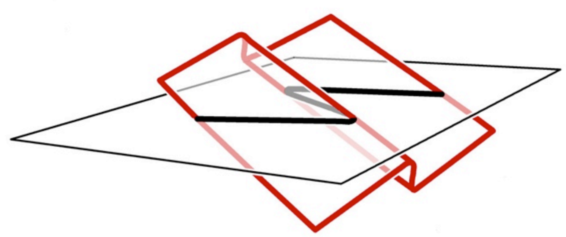
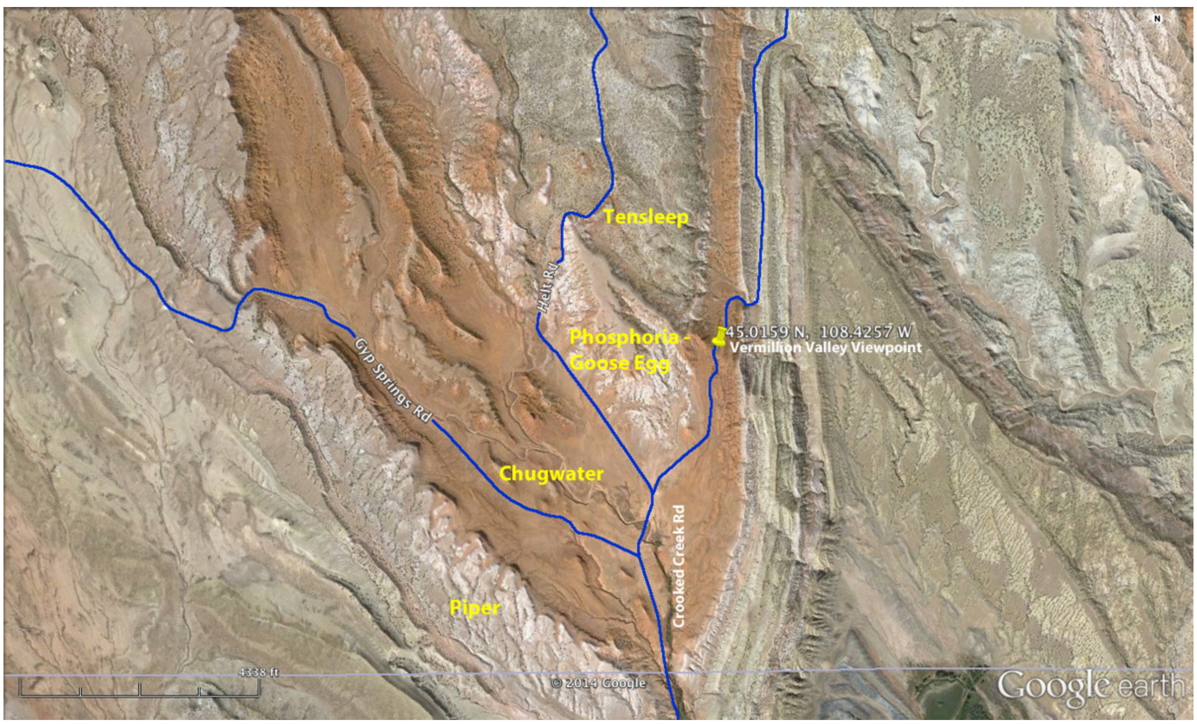


Figure 7: Red lines represent one layer in a plunging anticline-syncline fold. Black indicates a horizontal erosional surface. Note thick black zigzag where the folded layer intersects horizontal plane.

Notice on the sketch (Figure 7) of a plunging fold that a horizontal erosional surface exposes each formation as a "V" shape pointing in the direction of the plunge for anticlines, and opposite the plunge direction for synclines. For an anticline-syncline pair this makes a zigzag. The view from Google Earth (Figure 8) vividly shows this pattern in the Vermillion Valley area. Although someone walking around the area of Vermillion Valley would do a lot of climbing up and down on the human scale, on the scale of the folds and the Google Earth view the surface is quite flat. See the erosional surface in Figure 4.

Figure 8: The ZigZag pattern of geologic formations in the Google Earth view indicates a plunging anticline and syncline. The yellow pin marks Vermillion Valley Viewpoint. Note Crooked Creek, Helt, and Gyp Springs Roads shown in blue.



Because the anticline is asymmetric with a gentle west and steep east slope, the west branch of the "V" is wide and the east branch is narrow on the Google Earth view.

Sources

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Geologic Formations visible from the Vermillion Valley Viewpoint

Formation: The word "formation" usually is very narrowly defined in geology. In geology a formation is a mappable lithostratigraphic unit (a distinct rock layer or series of rock layers). Mappable means that its top and its bottom can be represented by two separate lines on a geologic map. The name of a formation consists of the word "Formation", or the name of the dominant rock type in the formation, with a capital letter, preceded by a geographical name. For example, the Madison Limestone, where Madison refers to Madison Range in southwestern Montana where the formation was first described in 1893. The outcrop of this formation in the Madison Range is referred to as the type locality of the formation. Another example of a formation name would be the Chugwater Formation.

It is assumed that a formation, when it formed, extended continuously from the type locality to any place it is now found. For example, the Madison extends across Wyoming and Montana, into North and South Dakota, Idaho, and Utah. The same rocks even extend beyond but are known by different names, such as the Redwall Limestone in the Grand Canyon of Arizona. Locally, the Madison extends from the top of the Pryors down under the Bighorn Basin to the west and reappears standing vertically ("the Palisades") along the Beartooth Front near Red Lodge.

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In this area the **Kootenai Formation** comprises the lower Pryor Conglomerate Member and the upper member of the Kootenai. The **Pryor Conglomerate** Member comprises brown conglomerate and pebbly sandstone 20 to 60 feet thick. The upper member of the Kootenai comprises reddish, purplish, and greenish shale interbedded with tan sandstone and thin gray limestone. The total thickness of the Kootenai is 200 to 250 feet. The sediments of the Kootenai were deposited in rivers and lakes during the early Cretaceous Period. Kootenai fossils include plants, freshwater mollusks, and dinosaurs. The dinosaur Deinonychus, a 10 foot long predator, was discovered in the Kootenai just a few miles from Pryor Mountain Road in 1964, and has been important in establishing the close relationship between dinosaurs and birds. The Kootenai Formation was named in 1885 after the Kootanie Tribe for rocks exposed in southern Alberta. In Wyoming the Kootenai is called the Cloverly Formation.

The **Morrison Formation** comprises tan sandstone, gray to reddish shale, coal, and thin gray limestone. These sediments of the Morrison were deposited in rivers, lakes and swamps during the late Jurassic Period. Fossil dinosaurs are common in the Morrison. Near Pryor Mountain Road, a large number of disarticulated bones of juvenile Diplodocus-like sauropods were found in the Morrison in 1994. These were interpreted as the remains of a herd of young animals of a single species. Here the formation is about 300 feet thick. The Morrison was named for outcrops near the town of Morrison, Colorado, near Denver, in 1896.

The **Swift Formation** is about 100 feet thick, comprising tan sandstone and some gray shale. These sediments were deposited nearshore in the late Jurassic sea. Common fossils include oysters and belemnites. The Swift Formation was named in 1945 for exposures along Swift Reservoir in Pondera County, Montana. In Wyoming, the rocks of the Swift are considered part of the Sundance Formation.

The **Rierdon Formation** is about 150 feet thick and is made up of mostly gray shale and thin gray limestones originally deposited offshore in the Late Jurassic sea. Fossils include abundant oyster-like mollusks and belemnites, as well as fish and ammonites. The Rierdon was named in 1945 for outcrops in Rierdon Gulch along the Rocky Mountain Front in Teton County, Montana. In Wyoming, rocks of the Rierdon are considered part of the Sundance Formation.

The **Piper Formation** comprises about 100 feet of reddish shale, gray shale, gray limestone and white gypsum. The reddish shale and some gray shale were deposited in fresh or brackish lakes. The limestones and other gray shales were deposited on the Middle Jurassic seafloor. The gypsum was deposited from highly saline water. Fossils include oysters and other bivalves, corals, and crinoids. The Piper Formation was named in 1945 for rocks exposed near Piper, Montana, on the north side of the Big Snowy Mountains.

The **Chugwater Formation** comprises about 500 feet of red shale, siltstone, and sandstone likely deposited in ephemeral, saline lakes, mud flats and small streams during the Early Triassic. It is essentially without fossils. The Chugwater was named for rocks exposed along Chugwater Creek near Iron Mountain, Wyoming, in 1904.

The **Goose Egg Formation** comprises up to 30 feet of red shale and sandstone interbedded with gypsum and dolostone; likely deposited in a restricted arm of the sea or a saline lake. It is essentially without fossils.he Goose Egg was named in 1956 for the Goose Egg Post Office in east-central Wyoming.
This formation is found discontinuously in the Pryors, and is best seen to the east and southeast part of the Pryors.

The **Phosphoria Formation** here comprises less than 10 feet of pinkish gray limestone and hard tan sandstone embedded with gray chert masses. Fossils include brachiopods, clams, snails, and bryozoans. These sediments were deposited on a shallow sea floor during the Permian Period. The Phosphoria was named in 1912 for rocks exposed along Phosphoria Gulch in southeastern Idaho.

The **Tensleep Sandstone** is composed of about 200 feet of white to light tan, fine-grained, quartz-rich sandstone. The sand was deposited on a shallow seafloor nearshore and as wind laid dunes near the coast during the Pennsylvanian (Late Carboniferous) Period. It contains fossil foraminifera. The Tensleep was named in 1904 for rocks exposed in Tensleep Canyon, Wyoming. Crude oil is produced from the Tensleep in the subsurface of the Bighorn Basin.

The **Amsden Formation,** which is about 200 feet thick, comprises reddish shale, gray shale, and gray limestone. These sediments were deposited on a shallow seafloor from late Mississippian to early Pennsylvanian time. Fossils include brachiopods. The Amsden Formation was named in 1904 for outcrops along the Amsden Branch of the Tongue River west of Dayton, Wyoming.

The **Madison Group** comprises two formations exposed in Montana, an upper Mission Canyon Limestone, and a lower Lodgepole Limestone. Both of these formations consist of gray limestone, the Mission Canyon being massive and thick-bedded, the Lodgepole thin-bedded. The total thickness of the Madison in this area is about 1000 feet. Common fossils include brachiopods, crinoids, corals, and bryozoans. All of the Madison in this area was deposited on a shallow seafloor during the Mississippian Period. The Madison was named in 1893 for outcrops in the Madison Range in southwestern Montana. The Mission Canyon Limestone and Lodgepole Limestone were each named in 1922 for a canyon in the Little Rocky Mountains in northcentral Montana. Caves are common in the Mission Canyon Limestone. The Madison has been the most productive reservoir of oil and natural gas in the Bighorn Basin and the Williston Basin. On the southwest side of Big Pryor Mountain, Madison limestone is quarried as a source of chemically pure calcium carbonate.

This Stratigraphic Column shows the sequence and approximate thicknesses of geologic formations. Formations seen from the Vermillion Valley Viewpoint range from the Madison through the Kootenai. From Kellerlynn, (2011).

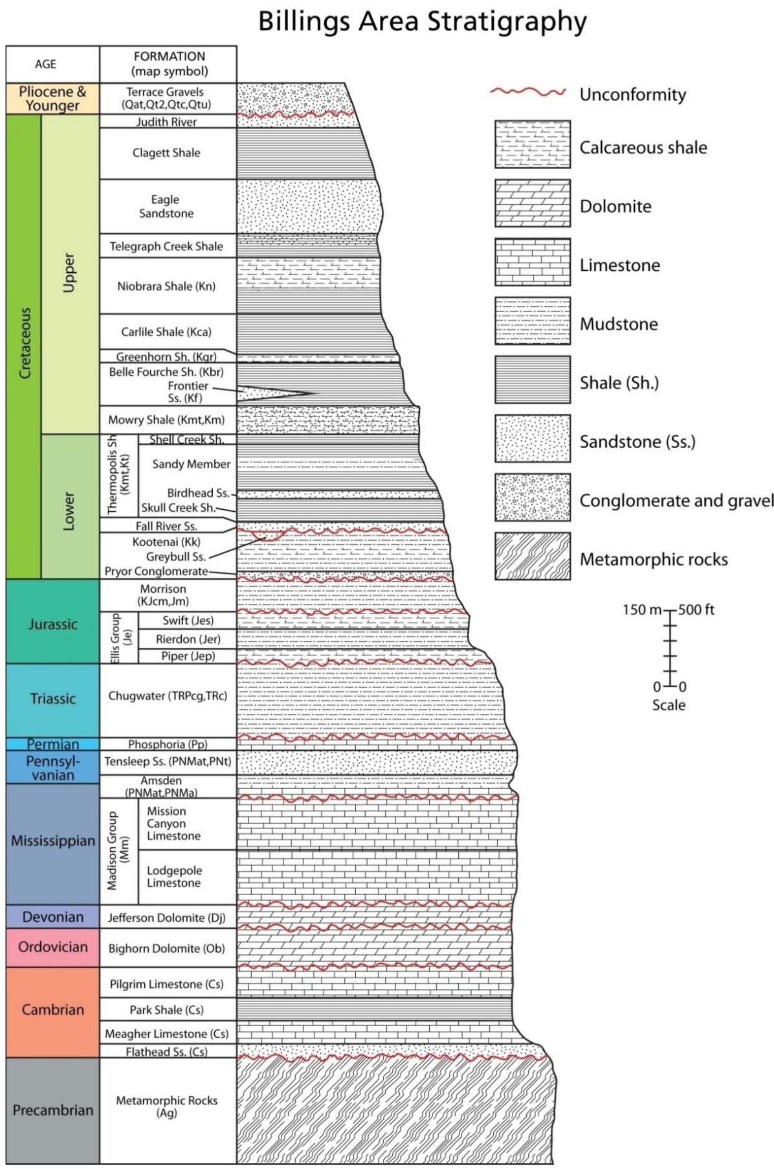

Figure 3. Stratigraphic column for the rocks in the Billings area. Billings is approximately 90 km (56 mi) from the Montana-Wyoming border in Bighorn Canyon National Recreation Area. This stratigraphic column encompasses many of the rock units included within the digital geologic map (GIS) data included for Bighorn Canyon National Recreation Area. The map unit symbols are indicated in parentheses. Not all of these units are exposed within Bighorn Canyon. Rock units with a more vertical profile are more erosion resistant, and tend to form cliffs (such as Madison Group [Mm]) rather than slopes (such as the Thermopolis Shale [Kmt, Kt]). The "Cambrian sedimentary rocks, undivided" unit (Cs) encompasses a variety of units that are separately listed on this column. For more detail, refer to the "Geologic Map Data" section. Standard U.S. Geological Survey timescale colors are used. Graphic drafted by Trista Thornberry-Ehrlich (Colorado State University) after a stratigraphic column provided by David Lopez (geologist/consultant).

4 NPS Geologic Resources Division

Rocks seen from the Vermillion Valley Viewpoint range from the Mississippian into the Cretaceous Periods. This Geologic Timescale chart shows the ages in millions of years (Ma) and other information. From Kellerlynn, (2011).

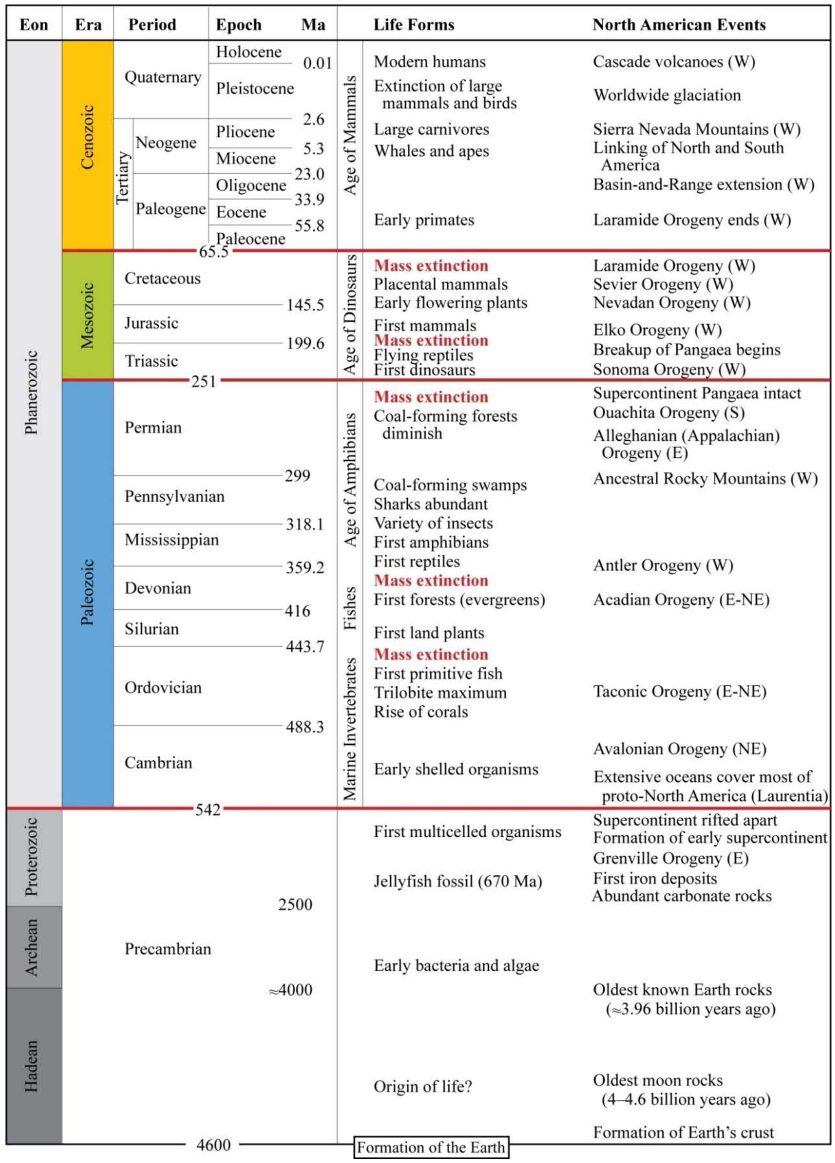

Figure 15. Geologic timescale. Included are major life history and tectonic events occurring on the North American continent. Red lines indicate major unconformities between eras. Radiometric ages shown are in millions of years (Ma). Compass directions in parentheses indicate the regional location of individual geologic events. Drafted by Trista Thornberry-Ehrlich (Colorado State University) with information from the U.S. Geological Survey (http://pubs.usgs.gov/fs/2007/3015) and the International Commission on Stratigraphy (http://www.stratigraphy.org/view/php?id=25).

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