

The Geology of the Vore Site and The Black Hills

Alvis L. Lisenbee, Prof. Emeritus, South Dakota School of Mines and Technology

Sinkholes

From Rapid City to Sundance, Wyoming, Interstate Highway 90 exhibits a curving path, following a red-floored valley, locally known as the “Red Valley” or the “Racetrack” as it forms a great oval enclosing the tree-covered ridges of the Black Hills. The red sandstone and siltstone of the valley floor comprise the Spearfish Formation, originally described by a pioneering geologist named Nelson Horatio Darton at the town of that name.

A few miles west of the Wyoming border, a white teepee stands beside the highway overlooking a depression in the broad valley floor. This depression is not unique in this area, others are found nearby, but it is unusual in that the white gypsum beds exposed amongst the red rock walls of this depression form a cliff over which Indian peoples of the past drove herds of buffalo to their destruction. In more recent years, a ranching family named Vore herded cattle on this land, careful to prevent their livestock from falling to a similar fate.

How do sinkholes form?

“Sinkholes” result from the collapse of the roof of a cave formed in the underlying rocks. Such depressions may be dry, as is the case at the Vore Site, or filled with water, as observed a few miles to the east in South Dakota at the McNeeney Fish Hatchery at Mirror Lake. At Hot Springs, in the southern Black Hills, a similar sinkhole in the Spearfish Formation was the spectacular death scene for over sixty mammoths. The mammoths descended into such a depression in order to water at a small lake but were unable to climb back up the steep surrounding slopes.

Caves are abundant in the Black Hills and result as rocks such as limestone or gypsum are dissolved by ground water. As shown diagrammatically in Figure 1, caves occur in four different rock units: the Pahasapa Limestone, the Minnelusa Formation, the upper Minnekahta Limestone, and the Spearfish Formation. The sizes of such caves are highly variable. Within the Pahasapa Limestone in the southern Black Hills, the third-longest (Jewell) and fifth-longest (Wind) caves known in the world are present. Small caves are common in this formation as well and are also present in the Minnelusa Formation, the upper Minnekahta Limestone (a gypsum layer), and to a lesser degree within the gypsum beds of the Spearfish Formation.

Collapse of the ceiling of a cave causes the overlying material to sink into the cavity (Figure 2) and to become a broken mass of rock. Such a zone may grow upward and eventually cause the Earth’s surface to subside forming a sinkhole, although not all collapse zones reach the surface. The collapsed material beneath the sinkhole forms a “pipe” of broken and collapsed rock extending downward to the original level of the cave.

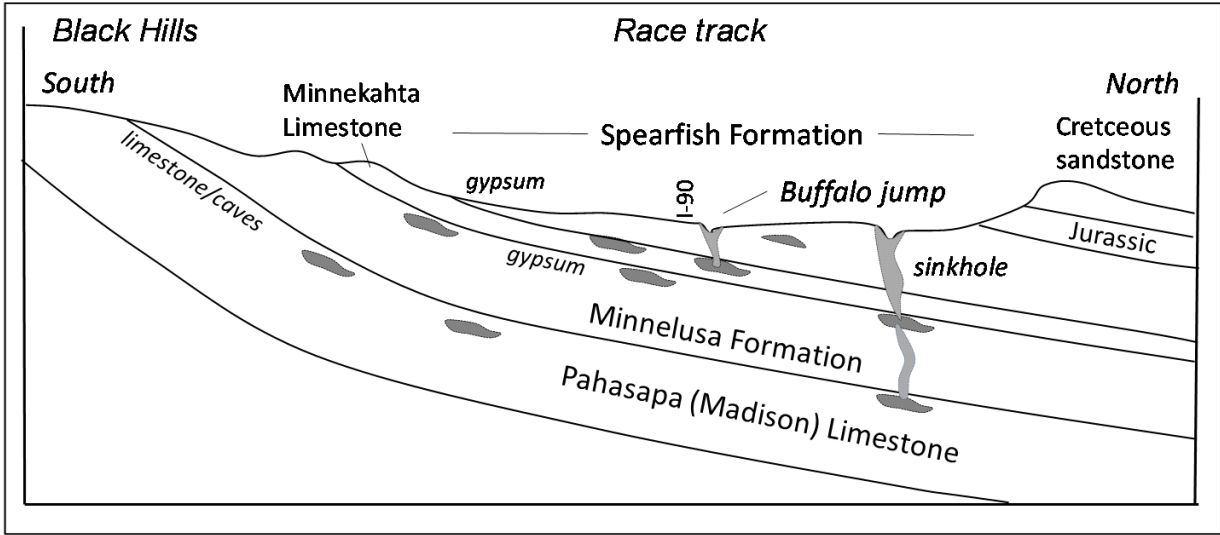


Figure 1. Diagrammatic north-south cross section illustrating the geologic character of the “Red Valley” in the area of the Vore Buffalo Jump. The sequence of stacked sedimentary rocks contains increasingly younger formations from south to north, deposited over a period of approximately 235 million years (~345 to 110 million years). The Vore Site is a sinkhole in the Triassic age (~245 million years) Spearfish Formation. The base of the “pipe” beneath the surface feature at the Vore Site extends downward to at least to the Minnekahta Limestone and, perhaps, to the Minnelusa Formation.

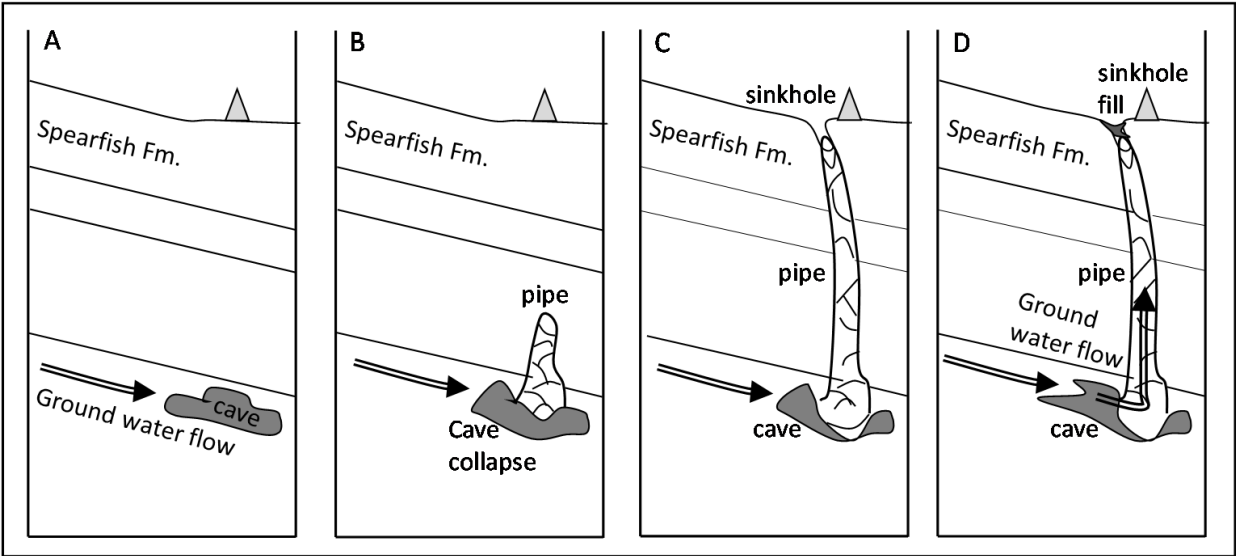


Figure 2. Diagrammatic representation of sinkhole formation. The first stage of sinkhole formation involves formation of a cave (A) due to solution of limestone or gypsum into groundwater. Subsequently (B, C), a breccia pipe forms due to collapse of the roof of the cave. The pipe may work its way to the surface. Ultimately, the sinkhole will be filled (D) with mud from streams as well as debris from the walls of the sinkhole. The absence of water in the Vore sinkhole suggests that it does not extend into the water-charged Pahasapa Formation.

Those pipes that reach to the surface may either cause the ground level to sink slowly or may result in a catastrophic collapse. Such catastrophic failures still occur in the Red Valley around the Black Hills today and cause damage to structures and roads. Other areas of slow subsidence likely occur but are less obvious. Full development of some sinkholes may result from many small collapses over a long period of time.

How did the Vore Site sinkhole form?

At the Vore Site, the gypsum forming the cliff at the rim of the pit (Figure 3) is not the cause of the sinkhole: The culprit lies at some depth beneath the current bone-filled floor, possibly as gypsum layers lower in the Spearfish Formation or as gypsum layers at the top of the Minnekahta Limestone 200-300 feet below the surface. If the cave were in the upper Minnelusa Formation it would be 400-500 feet below the present ground level; the Pahasapa Limestone (Figure 1) lies 800-900 feet deep at the Vore Site.

The white gypsum layer (Figure 3) exposed in the walls of the Vore Site sinkhole is significant, however. It forms the steep cliff on the south side of the pit over which the buffalo were likely driven in order to be killed or disabled on the pit floor.

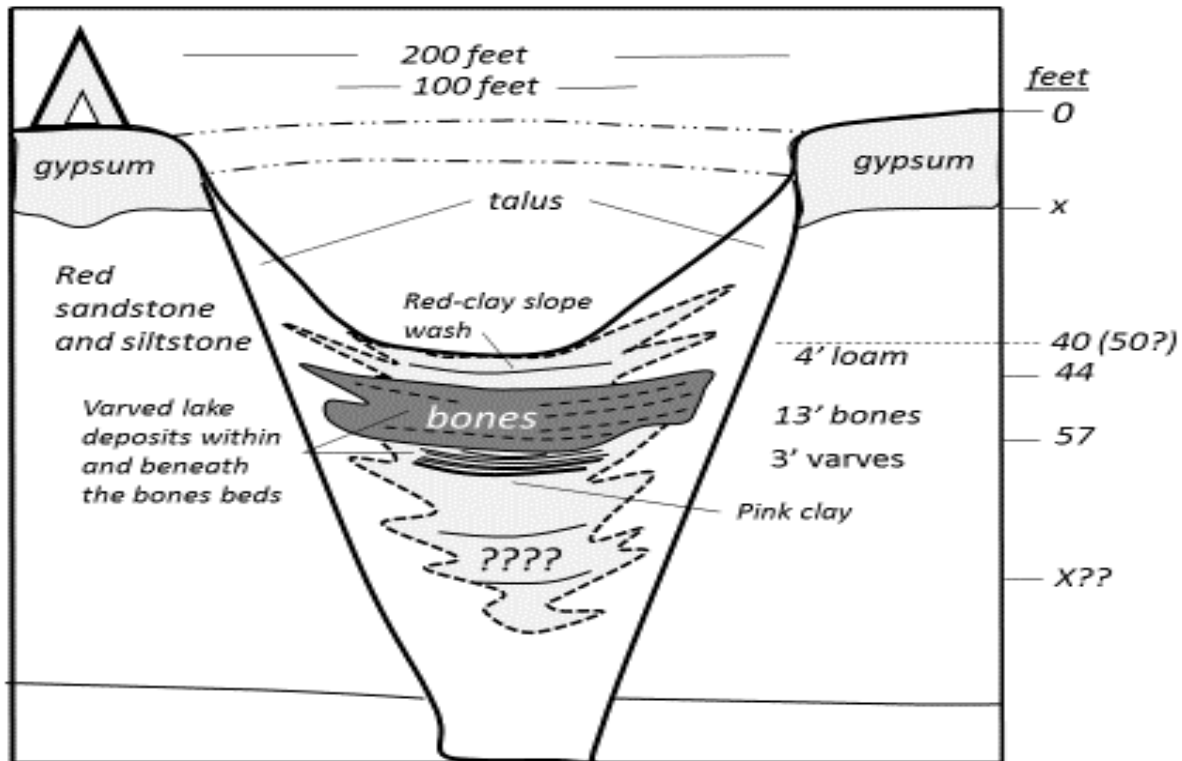


Figure 3. Diagrammatic cross section of the Vore Site sinkhole.

Both the Pahasapa Limestone and the Minnelusa Formation are major aquifers surrounding the Black Hills and are known to be the source (as shown by the chemistry of the water) of the springs which fill Mirror Lake and other small lakes in the area near the Vore Site. The water in these formations is under such pressure that it rises as though the broken rock mass were truly a pipe in a well, connecting the formation below with the Earth's surface. The ultimate source of the water is rain and snow falling on the outcrop (the area where the formation is exposed at the surface of the Earth) or the streams that sink into the formations as they flow outward from the Hills. As such, the Black Hills are the source for water pumped from wells many miles outward from this "Island in the Prairies".

That a pond existed at the Vore Site during the time of the buffalo jump activity is suggested by the presence of varved deposits (alternating light- and dark-colored layers of sand/silt/clay and organic material interpreted to represent one year of deposition). Such deposits most commonly form in cold regions where the surfaces of ponds or lakes freeze in the winter, preventing lighter-colored sediment from sinking to the lake bottom. Such lighter layers are summer deposits.

As there is no longer a pond in the Vore sinkhole, where did the water to make the pond come from? It is possible that more moisture was falling in the region during the time the sinkhole was used as a buffalo jump (from about 1550 to 1800). A second possibility is that a clay plug had formed in the pipe beneath the pit and acted as a dam. It is also possible that the pressure within the groundwater in underlying layers was greater during the period of Vore Site use, pushing the water up to the base of the pit. A unique answer to these possibilities is not possible with the geologic information currently available. In any case, varved sediments are observed interlayered with the bones of the buffalo killed in the Vore sinkhole (Reher and Frison, 1980, p. 8), and three feet of varves also underlie the bone bed (Fig. 1) indicating the presence of a pond here before the first use of the site as a buffalo jump.

When did sinkholes form in the Spearfish Formation?

As will be outlined in the section below on the geological history of the Black Hills, the Red Valley has maintained its current shape for approximately the past five million years. Throughout this time, the flow of water through the underlying formations (Figure 3) has produced caves and the collapse of such caves likely caused sinkholes.

When did the Vore Site sinkhole form?

Crago (2003) reports that the varved layers contained within, and below, the bone beds are believed to have formed in the period 1512 to 1663 A. D. The first bison kill was dated to 1559. Therefore, the Vore site sinkhole appears to have been in existence by approximately 1,500 A.D. and may have existed for many years or even centuries previously.

How long do sinkholes last?

Sinkholes are not long-lasting features in a geological context but may well be so in human terms. For example, the Mammoth Site at Hot Springs, which was present sometime between 25 and 150 thousand years ago, was totally filled in and erosion of the surrounding red rocks had left it as a small hill by the time of the first discovery of mammoth bones there.

The rate at which infilling occurs is likely highly variable. In some cases, the holes fill with debris washed in by streams. In others, the slopes of the pit are made less steep by collapse of the walls and the deeper portion fills with mud carried in runoff from rain or snow. Such processes may act in only a few decades or extend over hundreds of years.

In the years since the last deposition of bones at the Vore Site, sometime between 1770 and 1800 A.D. (Crago, 2003; Reher and Frisson, 1980), when horses and guns made this type of on-foot hunt obsolete, a mud fill has covered them to a depth of three and one-half to four feet (Figure 1) (Crago, 2003; Reher and Frisson, 1980, pp. 1 and 8). This suggests an average rate of infill of 0.19-0.24 inches per year during the past 220 years. If such rates were maintained, the current sinkhole might fill in approximately 2,000 years. The actual rate of infill, in the long term, is unknown, but a period of thousands of years is likely to fill this particular pit. Similarly, the sinkhole may have existed for centuries before the Native American people began using it as a buffalo jump or could have been newly formed at that time.

The Geologic Story of the Black Hills (a brief version)

The geologic history of the Black Hills may be told in six chapters based upon the ages of the rock units, as revealed to dozens of geologists who have studied various aspects recorded in the rocks over the past 140 years. Geologic maps of the Black Hills (Figure 4) show a succession of rock units forming an elongated bullseye pattern with the longer dimension oriented in the north-south direction. Within this pattern, the oldest rocks (Precambrian igneous and metamorphic rocks of the “basement”) are exposed in the central portion of the Hills and progressively younger sedimentary layers form rings surrounding the central mass. Note that the area of rocks that are uplifted extends into Wyoming and is much greater than the area of the topographic Black Hills themselves.

In order to outline the geologic evolution of this region, it is necessary to understand a few of the principles that geologists use in such an endeavor and how they relate to the pattern shown on the geologic map. For the sedimentary rocks that surround the Black Hills there are four “principles” that allow an understanding of original extent and configuration. These principles are interpreted based on their relationships to the red rocks of the Spearfish Formation on which the Vore Site is located:

1. *Original Horizontality:*

The layers of sandstone and mudstone that comprise the Spearfish Formation and that now tilt gently downward toward the north at the Vore Site were horizontal when they were deposited by ancient streams.

2. *Lateral Continuity:*

These red rocks now underlie the Red Valley surrounding the Black Hills, but this is not their full extent within the region. They extend outward beneath the Earth's surface and are encountered in wells (water and petroleum) in all direction from the Hills and continue throughout the Rocky Mountain region. This means:

- a. They were deposited across the entire region before the Black Hills and the Rocky Mountains formed.
- b. Originally, they covered the entire Black Hills (before the Black Hills were uplifted). These deposits have been eroded from the pine-tree covered areas seen to the south of the Vore Site.

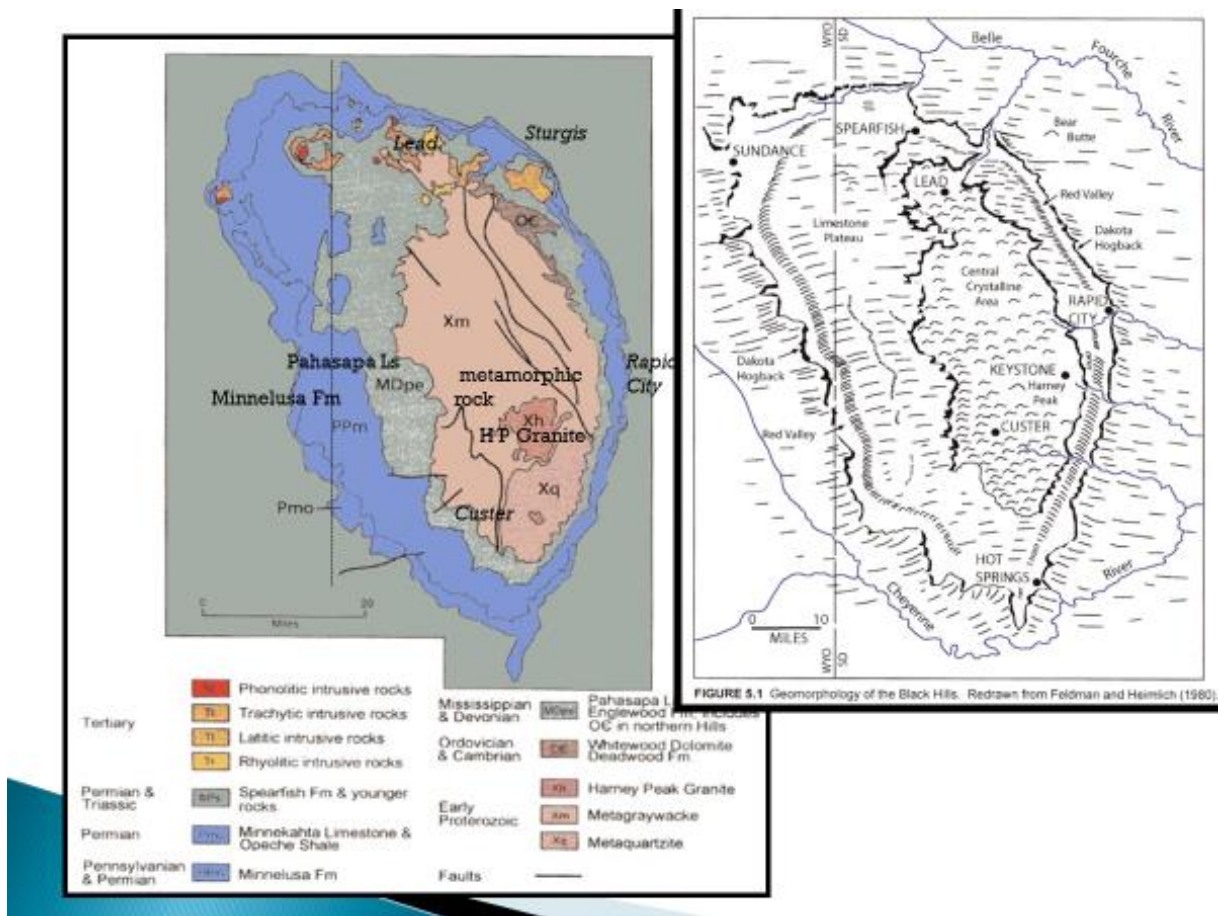


Figure 4. Geologic map (left) and physiographic map (right) of the Black Hills uplift.

3. *Superposition:*

In the original layer-cake configuration of sedimentary layers, each layer is younger than the one below it. As shown in Figure 1, for example, the Spearfish Formation is younger than the Minnekahta Limestone, which underlies it, but older than the Jurassic Sundance Formation which overlies it. The Sundance Formation is exposed at the base of the hills on the horizon to the north of the Vore Site. The Jurassic rocks are older than the Cretaceous rock layers that overlie them and that form the crest of this distant ridge.

4. *Faunal Succession:*

Faunal succession is inferred by the fossils found in many of the rock layers of the Hills (although none have been found in the Spearfish Formation). Fossils are not the same in all rock layers, but the same fossils may be found at different places in sedimentary rocks of similar ages. This occurs if both rocks were formed in the same setting (e.g., in an ocean or a stream) at the same time. For example, the dinosaurs that were quite common in South Dakota and Wyoming in the Jurassic were different from those that lived there in the Cretaceous – and no dinosaurs lived into the Tertiary time period.

Chapter 1. The Precambrian (2,500-1,715 million years ago)

As shown in Figures 3 and 7, the central area of the Black Hills is underlain by rocks of Precambrian age. The oldest of these formed two and one-half or more billion years ago. Although such rocks are only a very small portion of the total in the Black Hills, they are the basement throughout Wyoming. Most of the basement rocks within the South Dakota side of the Black Hills were deposited in oceans 2.0-1.75 billion years ago.

About 1.74 billion years ago, the original layers of sandstone, shale, and basalt in the area shown on Figure 4 were included into the roots of a great mountain chain (developed in the Trans-Hudson orogeny, which means mountain building event). During this process the layers were intensely folded and heated to form new rocks (called metamorphic rocks due to their change in form) such as quartzite, schist, and meta-basalt. This great mountain range extended northward from the South Dakota-Nebraska border to Hudson Bay in Canada and would have been similar in height to the Himalaya Mountains today. The massive gold deposits (at least 40 million ounces of gold) known as the Homestake mine was formed within the roots of this chain.

Best-known of these ancient rocks is the Harney Peak granite, which was intruded into the roots of the mountain chain at 1.715 billion years. These rocks provide the bases for the carvings of the massive monuments at Mt. Rushmore and Crazy Horse memorials.

During the 1.2 billion year-long interval between emplacement of the Harney Peak granite and the first advances of Cambrian seas into this area, one-quarter of the life of the Earth

passed – and no rocks remain here to record what happened. One thing is clear, however. During this time period the entire Trans-Hudson mountain chain was eroded to a flat landscape with no hill higher than about 200 feet.

Chapter 2. The Paleozoic Era (540-251 million years ago)

The geologic story of the Black Hills region is reflected in the sedimentary rock layers which formed, one upon another here. As illustrated in Figure 4, the layers (called formations when those of similar types and ages are lumped together) are exposed around the Black Hills as a series of oval-shaped rings. If one drives outward in any direction from the center of the Black Hills, each ring that is crossed is younger than the one before it. In most directions when one reaches the prairies the rocks are composed of Mesozoic-aged shales that overlie the Paleozoic rocks.

The Paleozoic rocks are composed of sandstone, limestone, and shale and were deposited in warm ocean waters. Based upon the types of fossils present and the nature of the magnetic character of these rocks, they formed near the equator. This means that the North American continent has moved northward about 2,800 miles in the last 320 million years.

Figure 5 illustrates the vertical sequence of the sedimentary rock packages found in the Black Hills region. The oldest, those at the base, are called the Deadwood Formation, named for the town of Deadwood, South Dakota, where they are best exposed. Geologic time is divided into “Periods” and these are listed on the left side of the chart. The Deadwood Formation, the base of which formed as beaches along the shores of the advancing Cambrian Sea, was deposited partly in the Cambrian and partly in the Ordovician Period. Other formations, for example, the previously mentioned Minnelusa Formation (Pennsylvanian and Permian in age) and the Pahasapa Limestone (Mississippian Period) also formed in oceans. The seas did not remain throughout the entire Paleozoic time, however. Shorelines advanced and retreated many times across the region during this era. Animal life was prolific in the seas throughout this time, including trilobites, snails, mollusks, and fishes. Creatures came afoot onto the land only later in the Paleozoic.

To the south of the Vore Site, the nearest pine-tree covered hills are underlain by the Minnekahta Limestone, the youngest formation of the Paleozoic Era in the Black Hills. The higher hills seen in that direction are underlain by older Paleozoic units.

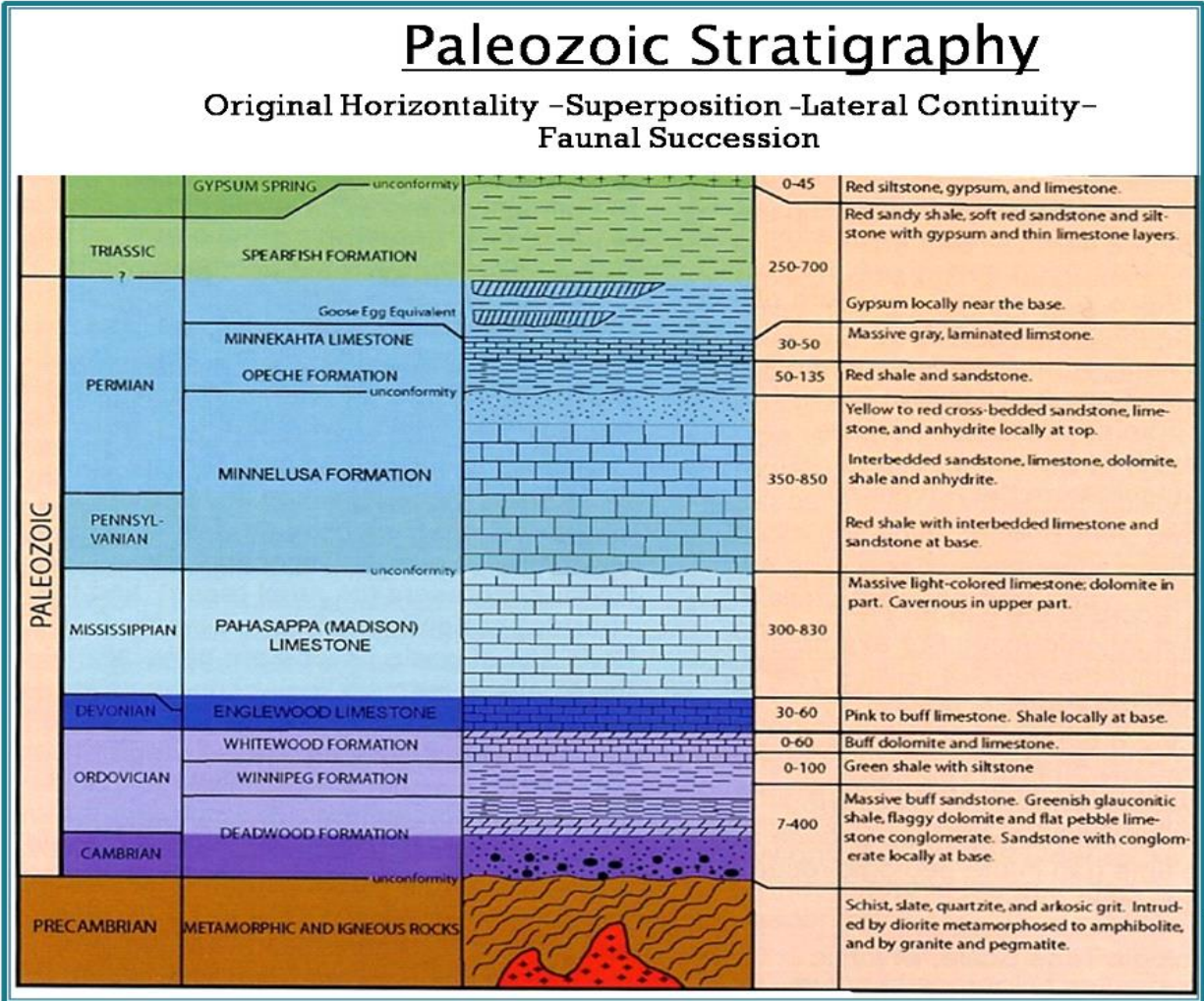


Figure 5. Paleozoic stratigraphic chart.

Chapter 3. The Mesozoic Era (251-65.5 million years ago)

The Mesozoic Era is composed of three Periods, the Triassic, the Jurassic, and the Cretaceous. The oldest formation of this group of rocks, as shown in Figure 6, is the Spearfish Formation. The red sandstone, siltstone, and white gypsum layers found at the Vore Site are part of the Spearfish Formation. These rocks were deposited in streams and the flood plains that surrounded them during a time of desert conditions across western North America. The white gypsum formed as precipitates, either in lakes or during short-term advances of the oceans into this area.

The Jurassic period is represented in the Sundance Formation (deposited in a warm ocean) and the dinosaur-bearing Morrison Formation. The lowest of the Cretaceous units are in the Lakota Formation (Figure 6). As illustrated in Figure 1, these rock layers are present on the skyline to the north of the Vore Site where the Jurassic rocks lie in the slopes of a ridge capped

by the Cretaceous sandstone layers. The prairies beyond this ridge, as well as across much of South Dakota, are fossil-rich (ammonites, etc.). The black shales formed in the Western Interior Cretaceous seaway. This major ocean extended across the continent from the Arctic Sea to the Gulf of Mexico and separated North America into two continents, Laramidia to the west and Appalachia to the east.

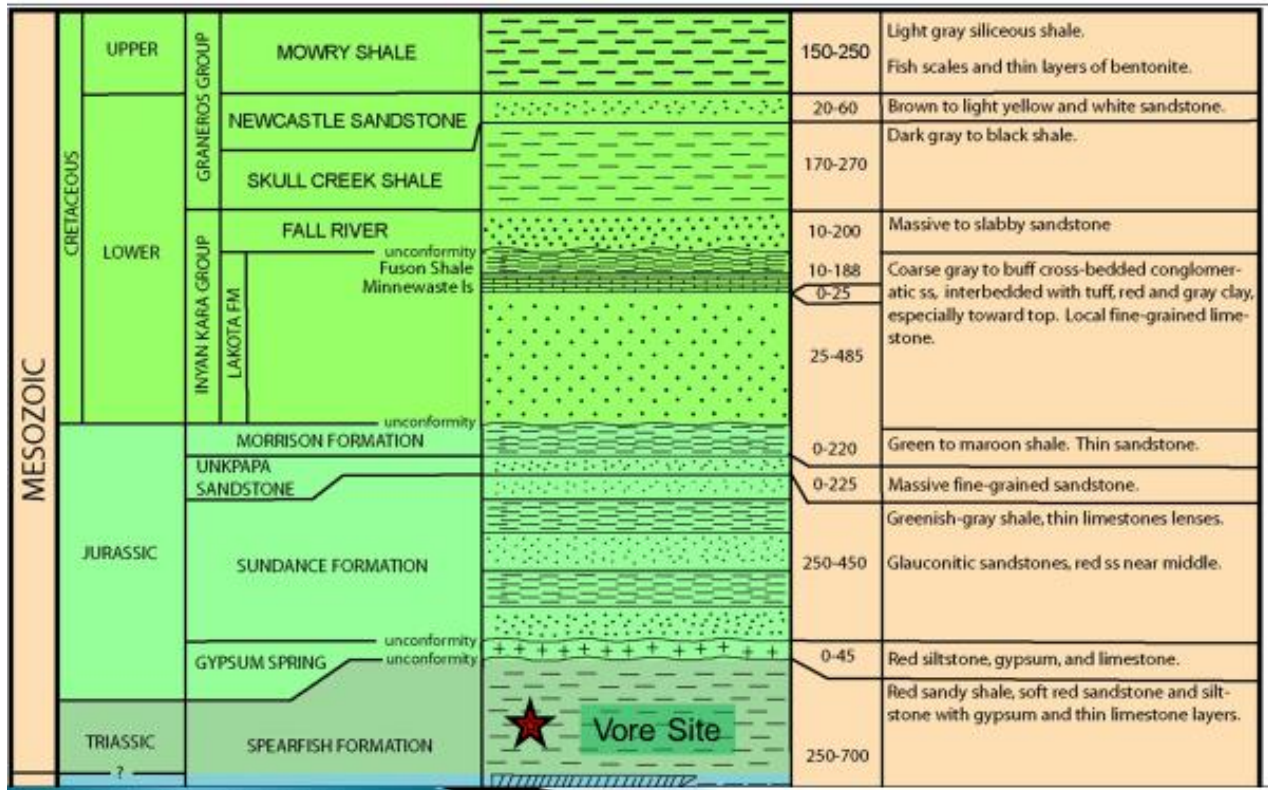


Figure 6. Mesozoic stratigraphic chart. Note that the Vore Site (star), which is now exposed at the Earth's surface, lies in the Spearfish Formation, which, at one time, was buried by as much as 3,500 feet of other layers (not all of which are shown in the section).

Chapter 4. The Black Hills uplift (64-37 million years ago)

The Black Hills, the most centrally located mountain range in North America, is the easternmost of the Northern Rocky Mountain ranges. Geologists refer to an area such as the Black Hills, in which the crust of the Earth has bulged upward, forming a mountain range, as an uplift. The area that was uplifted is actually larger than the topographic Black Hills (which are underlain by rocks more resistant to erosion than are the Cretaceous shales that surround it). The region of uplift extends from the Nebraska border to the south into southeastern Montana to the northwest.

The first detailed geological study of the mountains of the Northern Rockies was along the route of the Transcontinental Railroad in the Laramie Range of southeastern Wyoming. The

style of the mountain formation there, in which a Precambrian core is pushed up over an adjoining basin, gave rise to the name “Laramide-type” for all such mountains. The Black Hills is such a Laramide uplift, although not as fully developed as most of the others to the west.

The Precambrian basement in the central Black Hills area rose as much as 7,000 feet relative to the surrounding areas, but it is unlikely that a mountain range of such height formed initially – erosion was carving away at the rising mass right from the start. In addition, the region was at, or near, to sea level when the uplift began – the great Cretaceous ocean that covered all of central North America had only retreated into North Dakota at this time, and there were tropical swamps in the Powder River basin of what is now southeast Montana and northeast Wyoming along streams that flowed into that ocean. As the seas departed and uplift first began, the Precambrian basement was buried beneath approximately 7,000 feet of sedimentary rock layers.

How did the Black Hills form?

This question is still being explored by geologists. There is an overall understanding that the crust of Earth has been squeezed here (Figure 7), somewhat like what might happen in a great bench vice with the jaws closing from the east-northeast and west-southwest. The result is similar to placing one’s hands onto the edges of a sheet of typing paper lying on a table and pushing them together: The paper folds upward in the middle. What is unresolved by geologists who consider the problem is what happens at depth beneath the Hills to allow the sliding. Is there a great, but gently dipping, fault on which the overlying material moves upward or does rock flow into the bulge from below?

When did the Black Hills uplift form?

Layers of sedimentary rocks that were deposited before an uplift occurs are tilted (folded) during the uplift process. Those deposited after uplift is complete will not. The youngest rocks to be folded in the Black Hills area were deposited at the very end of the Cretaceous period. The oldest that are unfolded are the Late Eocene-Oligocene White River Group. Therefore, the Black Hills began to form about 64 million years ago, and the uplifting process was over and much erosion had occurred by 37 million years ago.

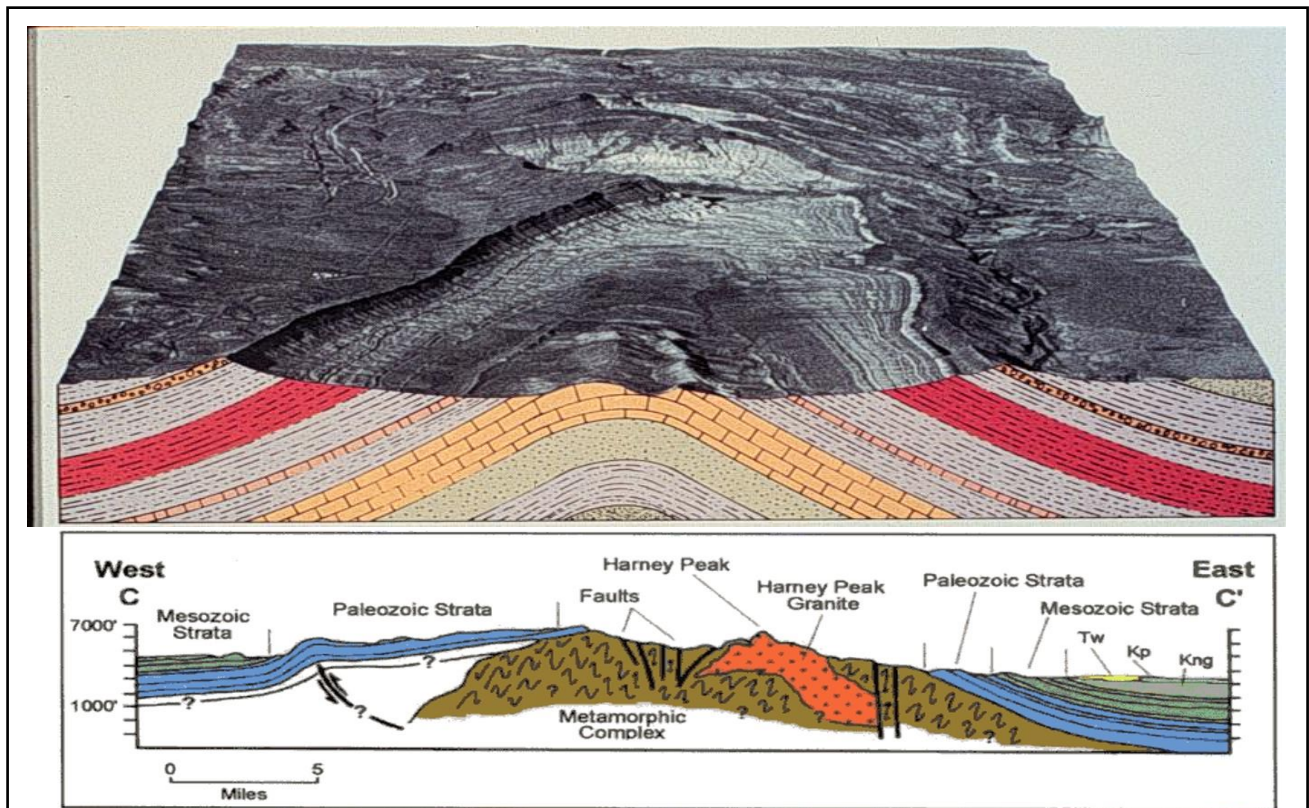


Figure 7. Cross section illustrating an anticline/dome. The upper figure shows a block diagram of an anticline, a fold in which the opposing sides (called the limbs) are inclined downward (dip) away from the center. The U-shaped valley would be similar to the Red Valley of the Black Hills. The lower cross section illustrates the nature of the broad anticlinal fold (dome) that comprises the Black Hills uplift. Precambrian rocks (shown in brown and red) form the “basement” beneath the Paleozoic rocks (blue) that underlie the Mesozoic rocks (green). The Powder River basin lies at the left margin of the cross section: parts of the White River Badlands are shown in yellow (labeled Tw) on the right.

Tertiary intrusions (40-60 million years ago)

In addition to the broad arching of the Black Hills region that formed the uplift, the Laramide development also included the intrusion of liquid rock (called magma). As the Black Hills were uplifted in the early Tertiary, magma intruded into the Precambrian basement and upward into the Paleozoic and Mesozoic sedimentary rocks along a band extending from Bear Butte, near Sturgis, South Dakota to Devils Tower (and a bit beyond) in Wyoming. This occurred in the time period of about 40 to 60 million years ago, with the older intrusions toward the eastern end and the younger toward the western end of this zone. Because these igneous intrusions tend to be very hard, they form many of the higher peaks seen to the south as one travels along Interstate Highway 90 from Whitewood, South Dakota to Sundance, Wyoming or within the Bear Lodge Mountains north of Sundance.

Where do Bear Butte and Devils Tower fit into the Black Hills story?

The igneous rocks of both Devils Tower (Figure 8) and Bear Butte (Figure 9), as well as many other of the igneous bodies in this area, extend far beneath the surface, cutting across

layers of sedimentary rocks and having a carrot-like shape called a *stock* by geologists. In other places, the magma flowed in between the sedimentary layers and formed a mushroom-shaped body called a *laccolith* (Figure 9). The laccolith causes the rock layers above to arch into a dome shape. Some of the intrusions formed near-vertical slabs called *dikes*. Excellent examples of dikes are seen in the walls of the Homestake Open Cut in Lead as cream-colored stripes ascending the east pit wall.

Are there igneous rocks near the Vore Site?

Not in the immediate area. They are numerous in the region, however. The Bear Lodge Mountains, which form the skyline west of the Site, are made entirely of igneous rock. Just south of I-90 near Sundance is the circular Green Mountain (Figure 9), which is a dome above a laccolith. On the south side of Sundance, Sundance Mountain is a laccolith from which all of the sedimentary cover has been eroded. On the skyline to the southeast of the Site is Crow Peak, a partially exposed laccolith.

Phonolite stock at Devils Tower

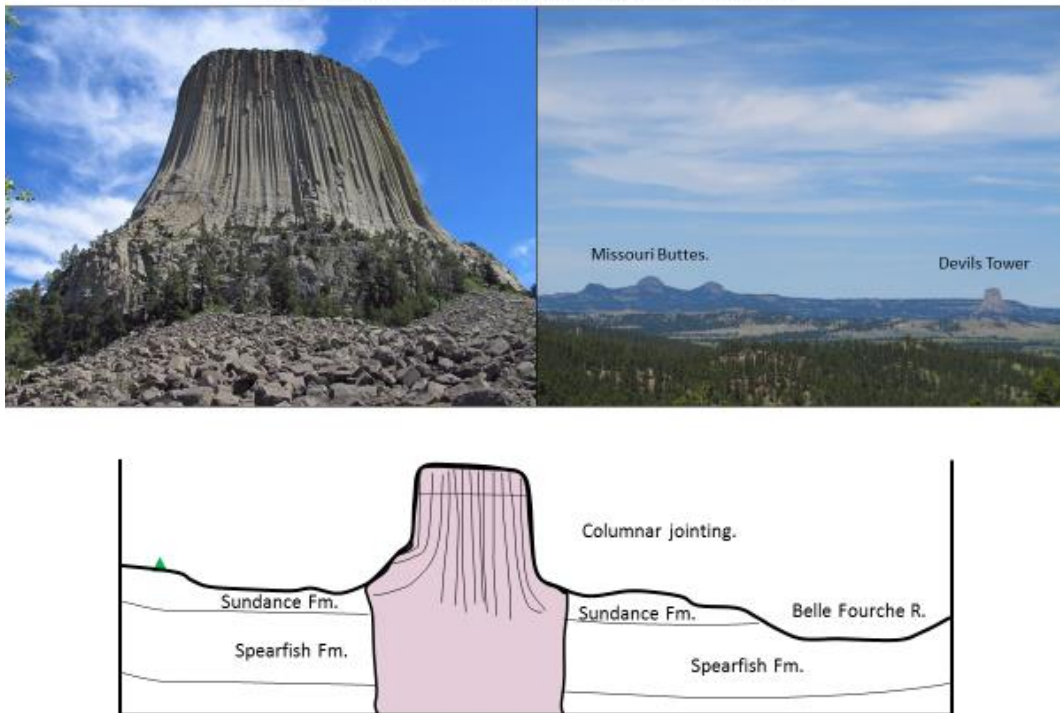


Figure 8. Photograph and cross section view of the stock at Devils Tower. The vertical cracks form in the igneous rock after it has frozen from the liquid state of the magma. As the solid rock cools, it continues to shrink and cracks form around vertical columns as the heat is released upward.

Were there volcanos in the Black Hills in the Tertiary?

None of the size of Mt. Fujiyama or the giant caldera in Yellowstone Park. A few small volcanos did exist of a type that sent up small eruptions of broken rock fragments called lapilli. Such eruptions do little damage and cover only a small area.

Erosion

During the topographic rise of the Black Hills uplift, erosion removed as much as 7,000 feet of Paleozoic and Mesozoic sandstone, shale, limestone, and some unknown amount of Precambrian schist and granite from the uplifted core of the range.

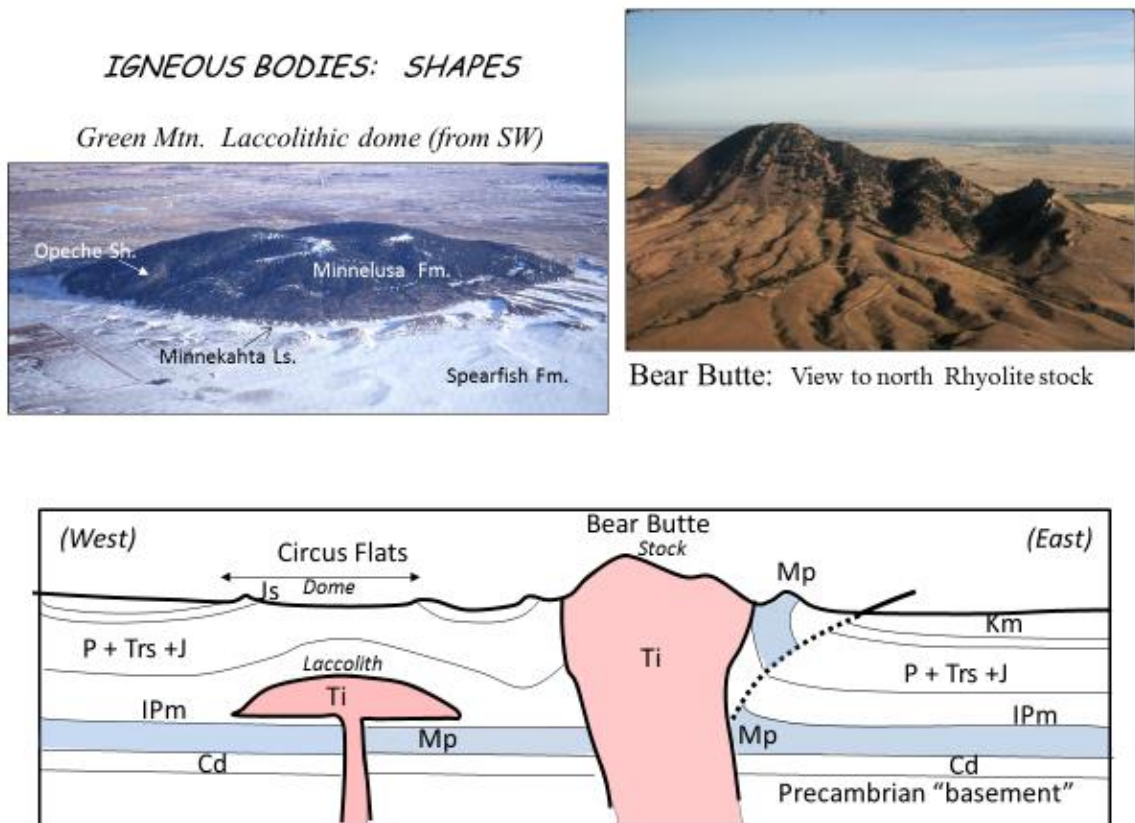


Figure 9. Photographs and cross sections of the stock at Bear Butte, South Dakota and the laccolithic domes at Circus Flats and Green Mountain, Wyoming.

Where did the eroded material go?

Various places. Streams carrying mud, sand, and gravel flowed westward from the rising Black Hills, depositing new sedimentary layers that are known as the Ft. Union Formation and the Wasatch Group in the sinking Powder River Basin that also has thick deposits of coal. Other streams carried debris northward into northwestern South Dakota and North Dakota depositing it

in the retreating ocean known as the Cannonball Sea. No deposits of this age are present along the east side of the Black Hills. If rivers flowed outward in this direction, they carried their sediments onward, ultimately into the Gulf of Mexico.

Chapter 5. The Badlands (37-27 million years ago)

What happened when uplift of the Black Hills ceased?

By 37 million years ago construction of the Black Hills, through the processes of uplift, emplacement of igneous rocks, and erosion, was completed and a new period of sedimentary deposition had begun in this region. These younger sedimentary layers were formed of river deposits, carried from the Black Hills, and volcanic ash blown by the wind from mega-volcanoes in central Nevada.

Cenozoic Stratigraphy

Continental Deposits

--Sandstone --Mudstone --(Limestone)

FORMATION		SECTION	THICKNESS	DESCRIPTION	
CENOZOIC TERTIARY	QUATERNARY	SANDS & GRAVELS	0-50	Sand, gravel, and boulders.	
	PLIOCENE	OGALLALA GROUP	0-100	Light colored sands and silts.	
	MIOCENE	ARIKAREE GROUP	0-500	Light colored clays and silts. White ash beds at base.	
	OLIGOCENE	WHITE RIVER GROUP	0-600	Light colored clay with sands, sandstone channel fillings, and local limestone lenses.	
	Eocene	WASATCH	unconformity		
	PALEOCENE	FORT UNION FORMATION	TONGUE RIVER GROUP	0-425	Light colored clays and sands with coal beds farther north.
			CANNONBALL MEMBER	0-225	Green marine shales and yellow sandstones, the latter common as concretions.
			LUDLOW MEMBER	0-350	Somber gray clays and sandstones with thin beds of lignite.
			HELL CREEK MEMBER	425	Somber-colored soft, brown shale and gray sandstone with thin lignite lenses in the upper part. Lower half more sandy. Many log-like concretions and thin lenses of iron carbonate.
	?				

Figure 8. Tertiary age formations of the Black Hills, Badlands, and Powder River Basin. The Paleocene and Eocene Ft. Union and Wasatch Formations are found in the Powder River Basin on the west side of the Black Hills uplift. The Eocene-Oligocene White River Group rock remains east of the Black Hills, but at one time covered the entire region.

Slowly, over a period of several million years, the sediments formed, layer by layer, until they were ultimately several hundred feet thick in the Badlands east of the Black Hills along the White River. Due to this geographic association, the layers are referred to by geologists as the White River Group. They covered the Black Hills as well, however, and perhaps only Black Elk Peak (previously known as Harney Peak) was exposed, standing above a great, sloping plain.

Fossils are very numerous and very well preserved (silicified) in the White River Group. These include turtles, hyenas, saber-toothed cats, the first dogs, bear-dogs, deer, camels, horses, large rhinoceros-like brontosaurus, sheep-like oreodonts, and many others. These creatures lived on vast flood plains surrounded by temperate forests.

What is an unconformity?

An unconformity is a gap in the geological record, that is, a missing period of geologic time. Two reasons are possible for such a missing group of rocks. Either rocks that formed during this time were removed by erosion or none were formed at all in this area.

Erosion from the Black Hills uplift created a major unconformity at the base of the White River Group. In the Badlands east of the Black Hills, the White River Group overlies Cretaceous rocks and the missing time interval is about 35 million years. Westward toward the Black Hills, older and older layers underlie the White River deposits so that in the core of the Hills they rest on the Precambrian rocks and the interval of missing time is about 1,700 million years: this represents about one-third of the age of the Earth. Although once present, all of the White River deposits have been removed from the Red Valley in the Spearfish to Sundance area.

Chapter 6. The Exhumation of the Black Hills (the last 6 million years)

If the Black Hills were covered by White River sedimentary rocks, what happened to this cover?

Beginning five to six million years ago, the entire northern Great Plains and northern Rocky Mountain region were elevated into a broad arch. When the Earth's surface is elevated the gradient on streams increases, and water flows faster. This faster rate of flow gives the water power to erode its banks. As a result, the Tertiary sedimentary rocks that had covered the Black Hills were mostly eroded away. Only in a few places do remnants of the White River Group, which form the Badlands, remain in ancient valleys within the Black Hills.

Where did the sand and mud that formed all of these layers go when removed from this region?

The creeks and rivers exiting the Black Hills acted as giant conveyor belts carrying the debris to first to the Missouri River, then on to the Mississippi River and, ultimately, into the Gulf of Mexico where new rock layers, thousands of feet thick were deposited during this time.

The result of this massive erosion is that the mountains and valleys seen in these Hills today are quite similar to the topography that existed here 37 million years ago at the time the White River deposits began to form.