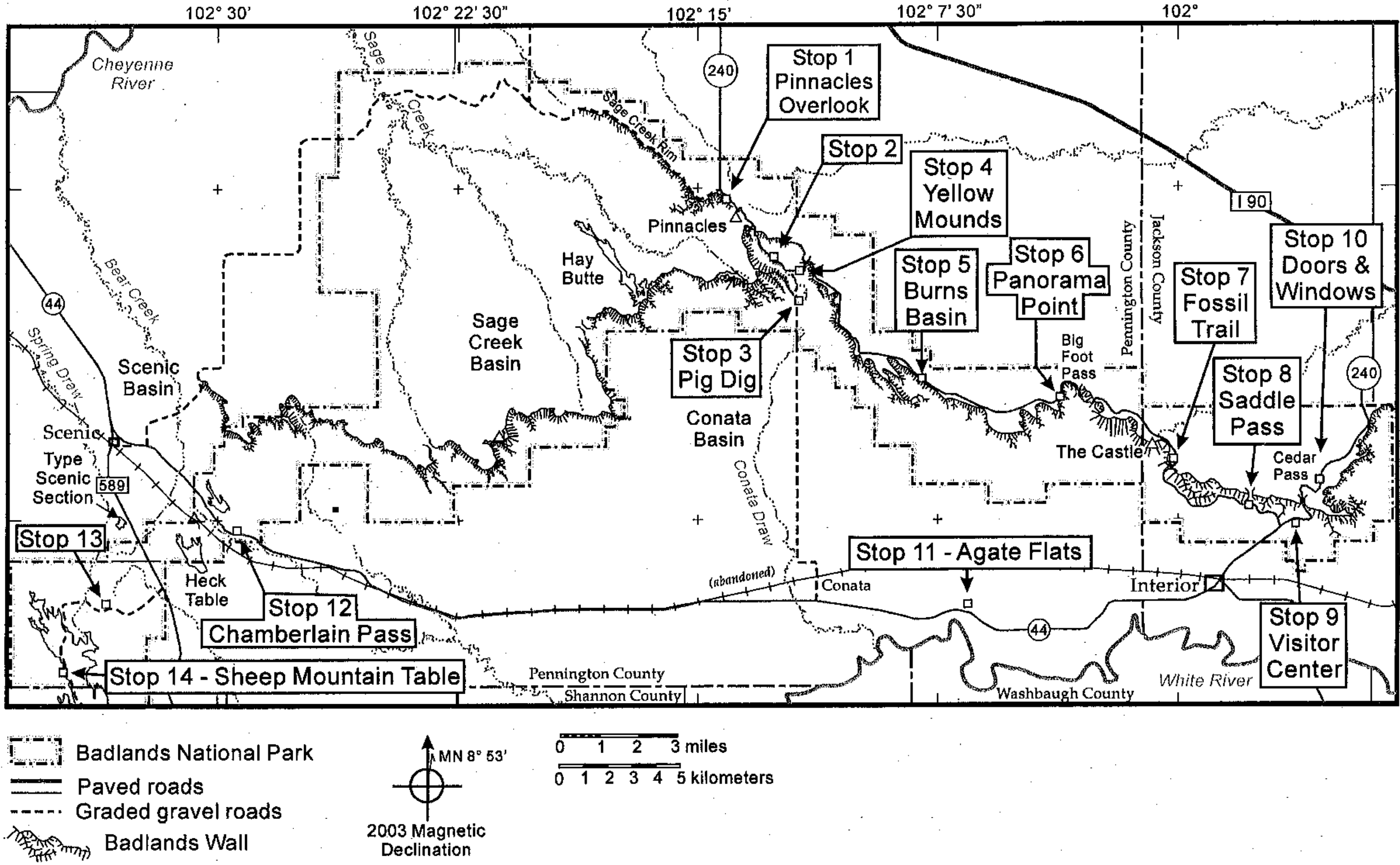


**Figure 1.** Map of the North Unit of Badlands National Park, showing geographic and geologic features and locations of the field trip stops.

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*But it is only to the geologist that this place can have any permanent attractions. He can wind his way through the wonderful cañons among some of the grandest ruins in the world. Indeed, it resembles a gigantic city fallen to decay. Domes, towers, minarets, and spires may be seen on every side, which assume a great variety of shapes when viewed in the distance.*

F. V. Hayden on the Badlands, in *The Great West,* 1880

**Stop 1 – Pinnacles Overlook.** The first overlook on Highway 240 south of Wall has one of the most spectacular views in Badlands National Park. To the west and southwest are miles and miles of badlands. The drainage basin directly below you is the headwaters of the east fork of Sage Creek. The west edge of this drainage basin is the long table capped by two grassy flats that is called Hay Butte. To give you an idea of the size of this area, the butte is 3.4 miles (5.5 km) to the southwest of the overlook and the southeast end of the butte to the northwest end of the northern grassy top of the butte is 2.7 miles (4.3 km) long. To the left of the butte is the back side of the Badlands Wall, a series of badlands ridges that separate the low prairies of the White River drainage in the south from the higher flats of the northern streams, such as Sage Creek. The Sage Creek valley is about 50 m higher than are the prairies on the south side of the Wall. The overlook is on one of the highest places in the North Unit of the Park, and the Pinnacles are the high spires at the head of Sage Creek, due south of the overlook. To the right (northwest) of the overlook is the high grassy prairie that ends in badlands along the Sage Creek Rim. A well graded dirt road runs along the Sage Creek Rim. Below you is a wilderness area that contains the Park's *Bison* herd. The grassy flats in the bottomland are the favorite resting and grazing spots for isolated buffalo bulls. The best viewing places for *Bison* is to the northwest along the Sage Creek Rim road.

All of the badlands below you are cut in the middle portion of the White River Group. The White River Group is composed of abundant volcaniclastic mudstones, siltstones, and fine-grained sandstones, and less abundant claystones, conglomerates, limestones and tuffs (lithified volcanic ash). The White River Group was deposited in the late Eocene and early Oligocene, and represents a depositional pulse in the Great Plains resulting from a great influx of volcanic ash and dust from the west. The White River Group and its equivalents extend from western North Dakota to east-central Colorado, and from western Wyoming to east central Nebraska and South Dakota (Fig. 2). This huge region was blanketed by volcaniclastic sediment, with the volcaniclastic component having an estimated volume of about 25,000 km$^3$ (Larson and Evanoff, 1998). Some of this ash is preserved as distinct tuff beds, and the western-most overlook at this stop is located on top of a widespread, very thick tuff, called the Rockyford Ash. From regional studies of the distribution, mineralogy, geochemistry, paleomagnetics and numeric ages of the tuffs in the White River sequence, Larson and Evanoff (1998) have determined that most of the tuffs was derived from eruptive centers in the Great Basin of Nevada and Utah. For example, the source eruption for the Rockyford Ash was probably in the Indian Peaks Caldera Complex of southeast Nevada and southwest Utah (Fig. 2). Individual welded-ash flows from the Indian Peaks Caldera Complex were in the magnitude of 5000 km$^3$ of erupted material, and resulted in over a meter of ash falling in South Dakota 775 mi (1250 km) downwind (Fig. 2). However, the vast majority of silt-sized volcanic ash was deposited west of Badlands, and was later blown to the area as dust or was washed into the area by streams (Fig. 3). The White River rocks are now very rich in swelling clays (smectitic clay) derived from the weathering of small volcanic glass shards.

You do not see the entire sequence of the White River Group at this site because of post Oligocene deformation. The Sage Creek Rim and the Pinnacles are along the axis of an anticline, called the Sage Creek Arch (Fig. 4). The anticline is still expressed by the high elevation at this overlook. The rocks before you are inclined (dip) to the southwest as much as 4° toward the axis of the adjacent syncline is along the main channel of Sage Creek. The syncline is expressed by the low elevation of the Rockyford Ash near the center of the Sage Creek drainage. Most of the channel of the east fork of Sage Creek lies along the axis of the syncline.

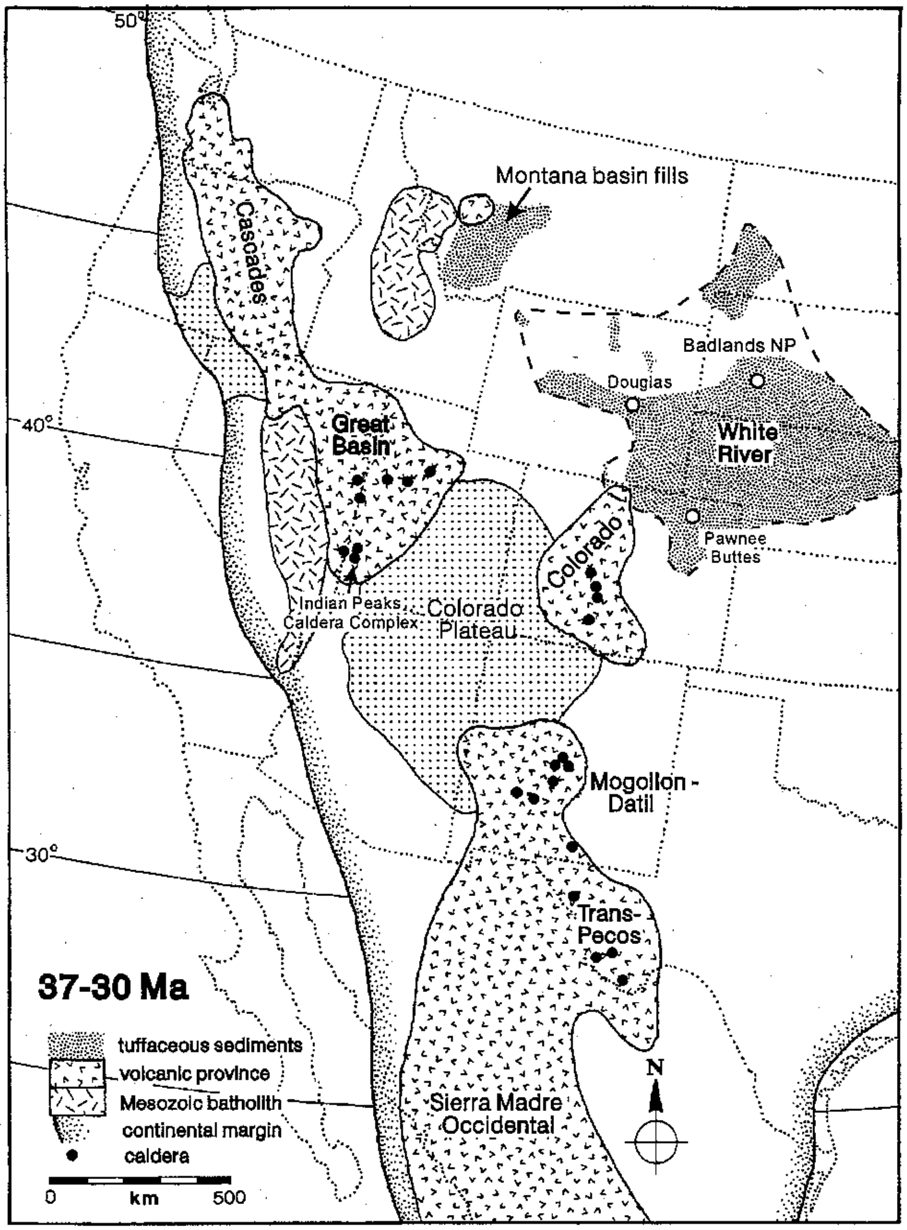


**Figure 2.** Palinspastic reconstruction of the west-central portion of North America showing the active volcanic provinces during the deposition of the White River sequence. From Larson and Evanoff, 1998.

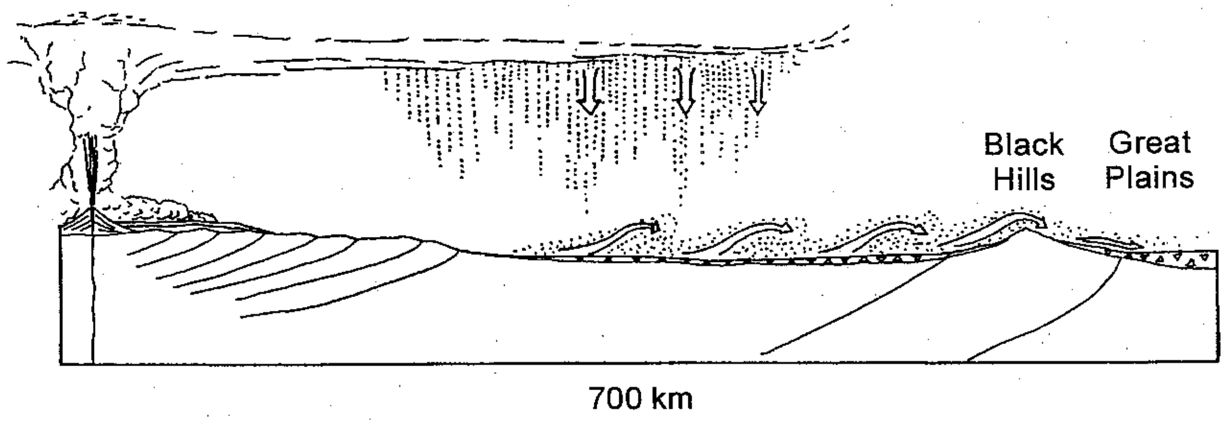


**Figure 3**. Depositional model for the accumulation of volcanic ash in the White River Group. Huge eruption columns during the development of volcanic calderas in the Great Basin (Larson and Evanoff, 1998) carried volcanic ash high into the atmosphere where high-altitude winds carried the ash primarily to the east-northeast. In some cases the ash cloud settled in the Great Plains resulting in widespread volcanic ash deposits that later became tuffs. However most of the ash fell over a wide area west of the Great Plains where surface winds later picked up the silt-sized ash as dust, that was transported eastward. This dust covered much of the topography and eventually was reworked by streams and weathered into mud.

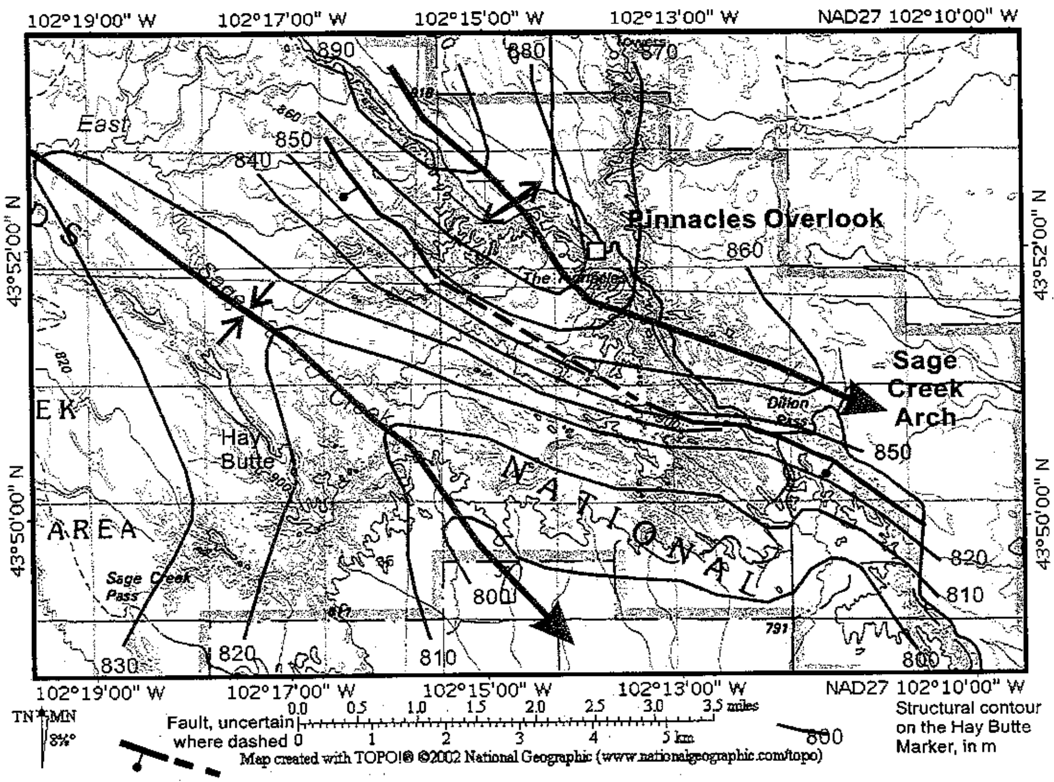


**Figure 4.** Structures in the Pinnacles, the east fork of Sage Creek and Hay Butte.

**Stop 2 – White River Group Stratigraphy.** From this undeveloped pull-off at the headwaters of Conata Draw, you can see the entire White River Group in the cliffs to the southwest (Fig. 5). The best view of this sequence is from the top of the hill just to the east of the road. Fossil bones occur on the slope towards the top of the hill, and please be careful not to disturb the bones as you walk to the top. **The collecting of fossils, rocks and any other natural items is not permitted in the Park** – please leave what you find for the enjoyment and education of others.

At this locality the White River Group rests on an unconformity on top of the Cretaceous Fox Hills Formation. The Fox Hills is composed of alternating shales and thin sandstones that have been weathered to a yellowish brown color. Marine fossils and strontium isotopes indicate that the Fox Hills in the Park is middle Maaestrictian in age. This weathered zone is called the Yellow Mounds Paleosol, and is named for the yellow hills in this area (Retallack, 1983). A second paleosol complex overlies the Yellow Mounds, is intense red in color, and is called the Interior Paleosol (Ward, 1922; Retallack, 1983). Both the Yellow Mounds and the overlying red Interior Paleosol can be seen in the drainage directly below you.

The lowest formation in the White River Group is the Chadron Formation (Fig. 6). Here the Chadron is a relatively thin sequence (about 3-5 m thick) of gray claystones that weather into rounded low hills capped by a strong popcorn surface. This "popcorn" is a result of the drying of the swelling clays in the Chadron. Vertebrates and radiometric dates of tuffs in the Chadron Formation (not in the Park) indicate a late Eocene age for its deposition.

Traditionally, the upper formation of the White River Group is the Brule Formation. The Brule is divided into the Scenic Member and the Poleslide Member from bottom to top. The Scenic Member is a series of interbedded brown mudstones and light gray sandstones, with thin, typically red, mudstone beds. The Poleslide Member is a series of interbedded siltstone and sandstone beds. The shift from the mudstones and sandstones of the Scenic to the thick siltstone beds of the Poleslide reflects a shift in environments from mostly fluvial to mostly aeolian. The shift from river channels and overbank deposits to widespread blankets of silty loess reflects a climatic shift from subhumid to semiarid conditions. In the outcrops before you, the Brule starts with brown mudstones directly above the gray Chadron claystones (near the base of the drainage) and is capped by the Rockyford Ash (the whitish band high on the ridge, see Fig. 5). Recent detailed stratigraphic studies of the Scenic Member recognizes 8 subunits within the Scenic that can be correlated throughout the North Unit of the Park. The best marker beds in the Scenic are two widespread, thick, brown mudstone units that are called the Hay Butte and Saddle Pass markers. Figure 5 shows the locations of these marker beds in the high ridge in front of you. The Hay Butte and Saddle Pass markers are distinct and extend for the entire 40 mile (64 km) length of the Badland Wall in the North Unit. Fossil vertebrates tied into radiometric dates indicate an early Oligocene age for Brule deposition.

The Rockyford Ash is the basal unit of the Sharps Formation, which traditionally includes a lower sandy siltstone sequence that is locally cut or capped by paleovalley complexes filled with fine-grained sandstones. These paleovalley fills have been traditionally called the "Sharps Channels." The Sharps has previously been excluded from the White River Group, primarily because of its fauna, but new regional studies in South Dakota and Nebraska indicate that the lower Sharps sandy siltstones are similar to the upper Brule siltstones and that no unconformity separates the two formations. However, on the basis of faunal evidence, an unconformity separates the lower Sharps from the Sharps Channels and there is a pronounced change in lithology. As a result, the Sharps Formation is herein restricted to the sandy siltstone interval and is part of the White River Group. The Sharps Channels are lithologically and temporally associated with the Arikaree Group of Nebraska, and are herein called the Arikaree Channels. The suggested changes in White River nomenclature for the Park is shown in Figure 6.

The Brule Formation was deposited on an erosional topography cut into the Chadron Formation throughout the North Unit of the Park. This is well seen in the outcrops at this stop. Locate the Hay Butte Marker in the outcrops in front of you using Figure 5. Notice the white sandstones that lie directly below the Hay Butte Marker and the brown lower Scenic mudstones that underlie the sandstones. Here the total thickness of Scenic rocks below the Hay Butte Marker is 22.5 m. As you trace the sandstone beds below the Hay Butte Marker to the right (northwest) along the base of the ridge, the sandstones thin and pinch out into the basal brown mudstones of the Scenic. At the edge of your view, the Hay Butte Marker rests upon the basal brown mudstones that have a thickness of only 10 m. Figure 7 shows a cross section through the units below the Hay Butte Marker along the ridge in front of you, showing two filled drainages between two uplands cut into the Chadron Formation. (Section MS 4 is directly in front of you, Section MS 6 is about as far as you can see to the right). An isopach map of the Scenic rocks below the top contact of the Hay Butte Marker in this area acts (Fig. 8) is a proxy for early Oligocene topography. The isopach map shows two south-flowing drainages cut into the Chadron Formation. The western ancient drainage is directly in front of you at this stop.

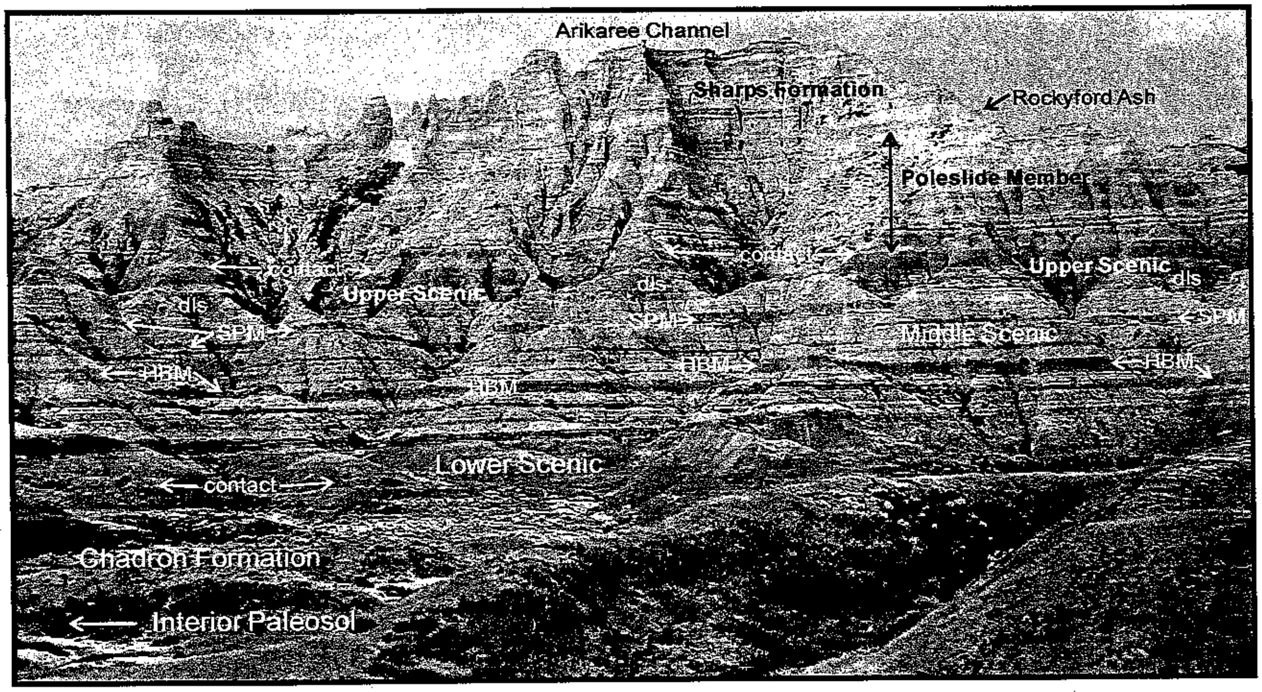


**Figure 5.** View of the entire White River Gourp exposed on the ridge south of the Pinnacles at Stop 2. HBM is the Hay Butte Marker; SPM is the Saddle Pass Marker; dls is the disappointment limestone interval. The rocks here dip 4° to the southwest, away from you in this view.

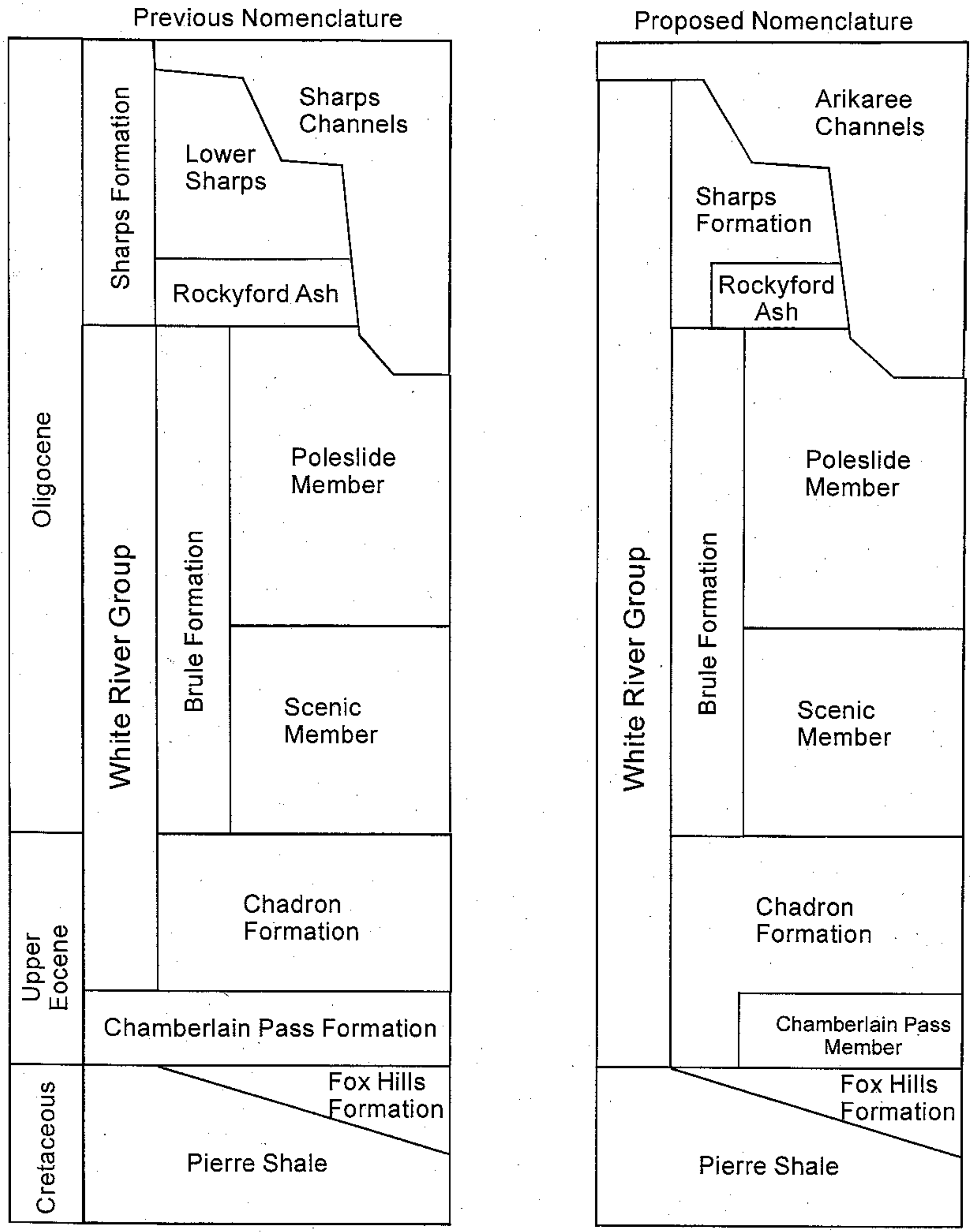


**Figure 6.** Ages, existing stratigraphic nomenclature and proposed nomenclature for the rocks in the North Unit of Badlands National Park.

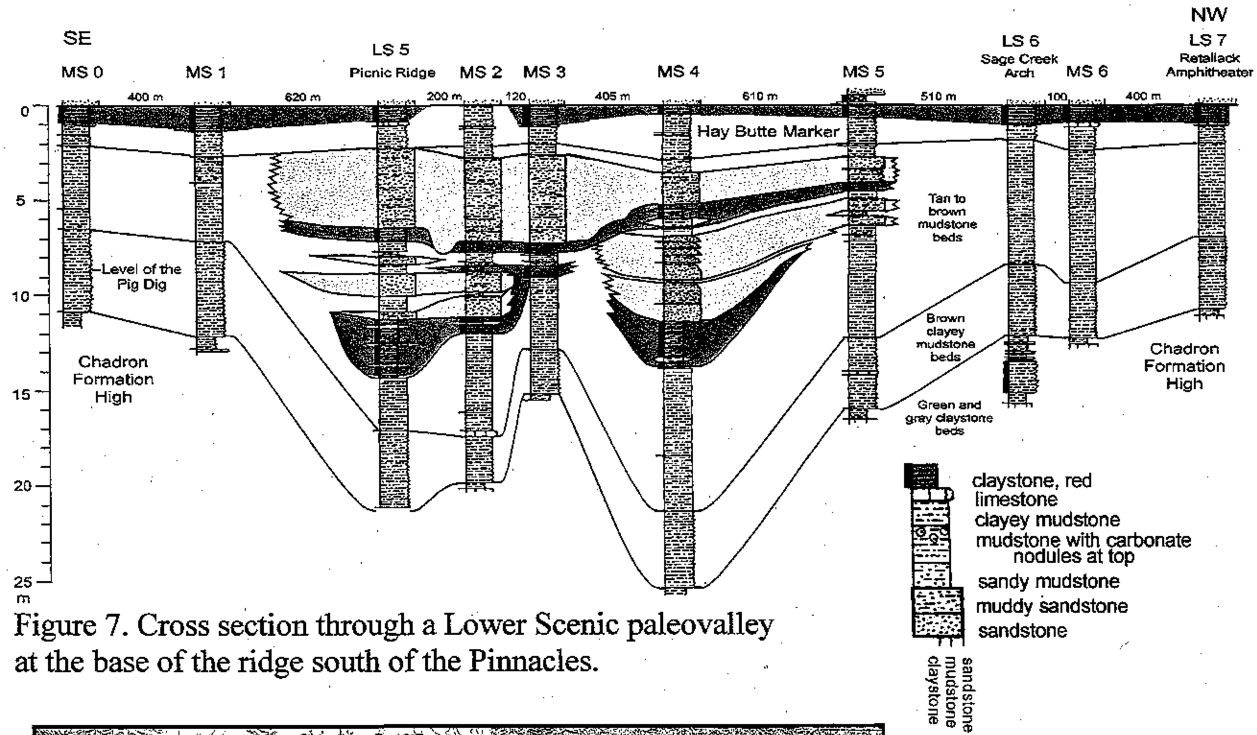


Figure 7. Cross section through a Lower Scenic paleovalley at the base of the ridge south of the Pinnacles.

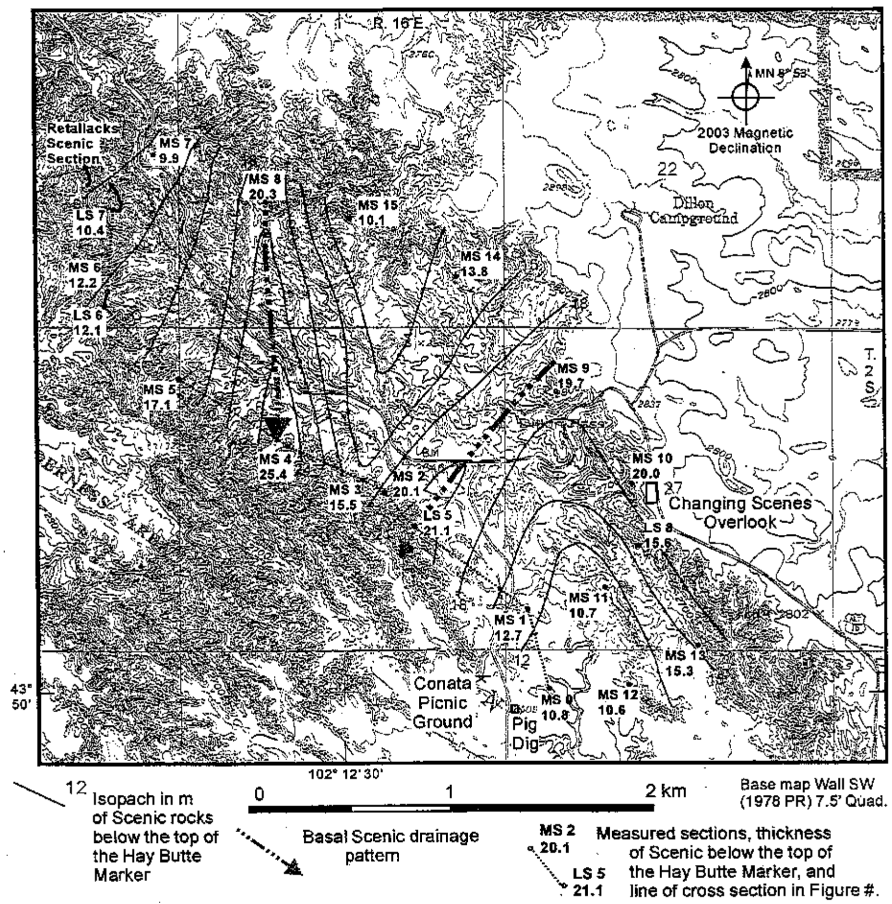


**Figure 8.** Map of isopachs of the lower part of the Scenic that reflect paleovalleys.

**Stop 3 – The Pig Dig**. The brown mudstones of the Lower Scenic are some of the most fossiliferous beds in the Park. Fossil bones of mammals and tortoises are scattered throughout the unit, but locally there are bone beds, or accumulations of skeletal materials along a single stratigraphic horizon, in the Lower Scenic. The Pig Dig is one of these bone beds. The site is named for the large pig-like entelodont called *Archaeotherium* (Fig. 9) which is so common that population studies are currently being made on this extinct pig. Other animals that are common in the site include the large rhinoceros *Subhyracodon*, the horse *Mesohippus* and the small deer *Leptomeryx*. Rare animals in the Pig Dig include the cat *Dinictis*, the large rodent *Ischyromys*, and the rabbit *Palaeolagus*. The bones occur in a greenish claystone 6.4 m below the base of the Hay Butte Marker. The geometry and internal laminations of this claystone suggest that the accumulation of bones was in and near a water hole. The site is actively excavated in the summer between Memorial Day and Labor Day, and the Park has erected a substantial but mobile shelter. The site was found and first excavated in 1996, and bones are continuing to be excavated every summer.

When walking back from the Pig Dig to the parking lot at the Conata Picnic Ground, the end of the ridge behind the picnic tables exposes the Hay Butte Marker, the Saddle Pass Marker, and a widespread series of clayey mudstones and thin discontinuous limestones, called informally the disappointment limestone interval (Fig. 10). The disappointment limestones are named because of their typical lack of fossils. All of these marker units are separated by blankets of thin bedded gray to light brown sandstone beds interbedded with distinct, laterally discontinuous, red mudstone and claystone beds. Sandstone-filled channels occur just above the Hay Butte Marker in some of the ridges just to the west of the picnic area.

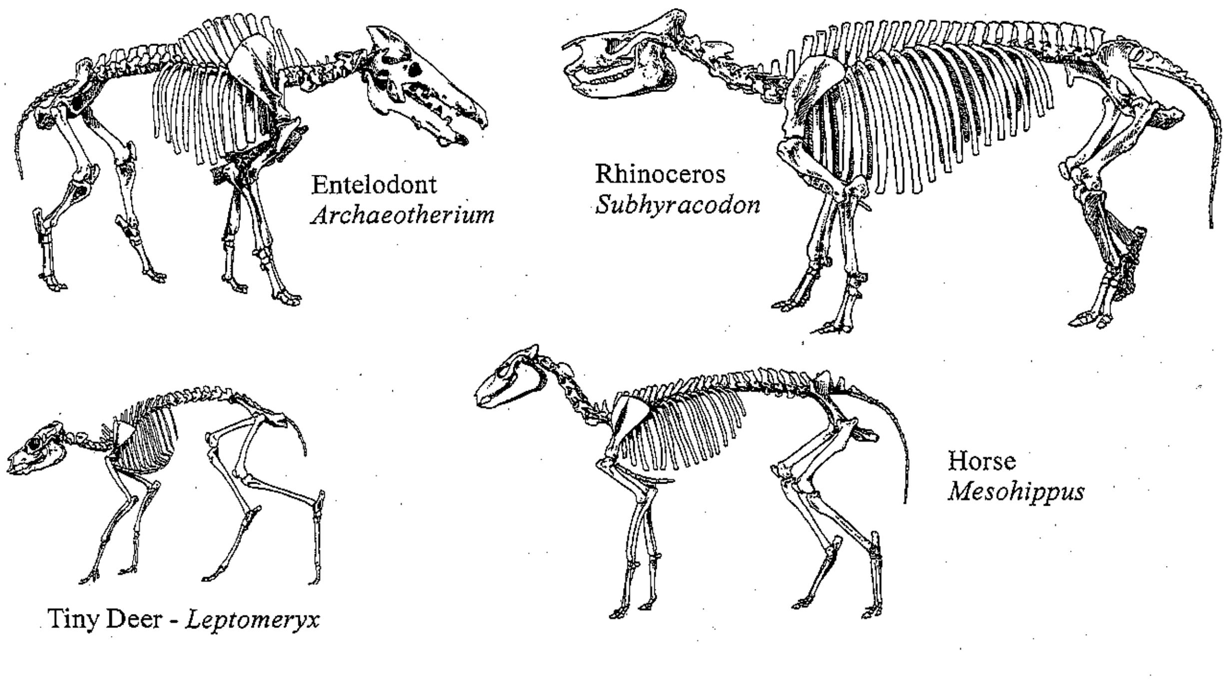


**Figure 9**. Some of the most common fossil mammals in the Pig Dig.

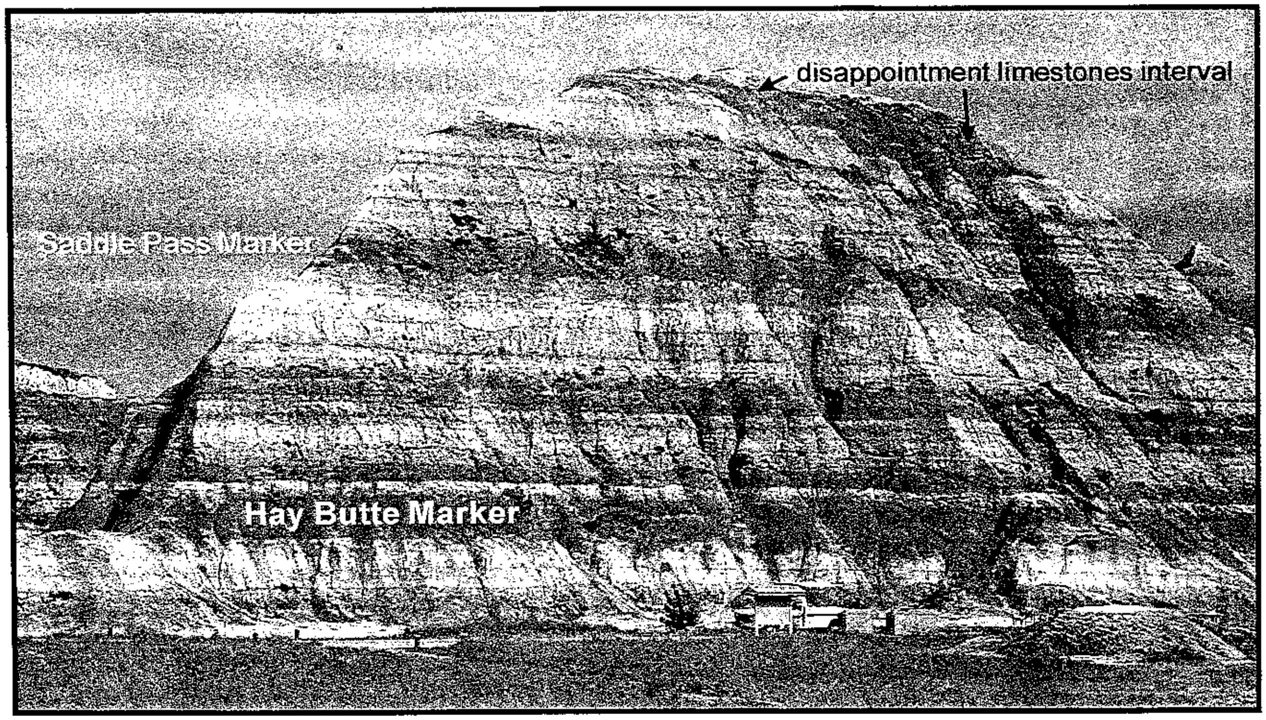


**Figure 10.** View of the Hay Butte Marker in the Middle Scenic at the Conata Picnic Ground (Stop 3). View is to the northwest from the trail to the Pig Dig.

**Stop 4 – Faults at the Yellow Mounds.** A short walk along the top of the ridge to the west of the parking area provides a spectacular view of a high angle normal fault cutting the Yellow Mounds Paleosol and the Chadron Formation. The Yellow Mounds is developed in the upper Cretaceous rocks, has been uplifted on the north side of the fault, and abuts the gray claystone of the Chadron Formation on the south side. Sixteen meters of displacement on this fault is indicated by the displacement of units in the Scenic Member in the bluffs to the southeast of this overlook. The fault is exposed along the southern flank of the Sage Creek Anticline for 1.5 km to the east-southeast, and for 2.4 kilometers to the west-northwest where it crosses the west wall of badlands. On this western side, the displacement on the fault is only 3 m. The movement on this fault is after the deposition of the Scenic Member, because the thicknesses between the individual units on either side of the fault are the same on the upthrown and down-dropped blocks.

**Stop 5 – Burns Basin Overlook.** We are now on top of the Badlands Wall, and the overlook is situated on the basal siltstones of the Poleslide Member. The canyons below you are cut into the Middle and Upper Scenic, characterized by gray sandstones and buff mudstones, respectively. The canyon is also aligned along the axis of a syncline, the Burns Basin Syncline, that plunges to the southeast. Structural contours drawn on the Hay Butte Marker indicate the axis of this syncline.

The thickness of the lower Scenic rocks below the Hay Butte Marker in the Burns Basin vary much in the same way as they do south of the Pinnacles. In places there is a thick sequence of basal Scenic mudstones and sheet sandstones below the Hay Butte Marker, and in other places the Hay Butte rests only upon the basal Scenic mudstones. This is because the Scenic Member buried a topographic ridge that extended from the Pinnacles through the west side of the Burns Basin area, and through the large, flat-topped butte you can see to the south. This ancient ridge separated two large paleovalley fills cut into the Chadron Formation, one west of the modern Hay Butte, and the other east of this overlook. Because this ancient ridge occurs on the east side of the modern Conata Basin, I refer to it as the Conata Ridge. The Burns Basin Syncline is located east of the Conata Ridge.

**Stop 6 – Panorama Point.** The road has traveled along the top of the Badlands Wall, and has come to a high point called Panorama Point that looks into a valley that flows from Bigfoot Pass. Despite the elevation, the observation deck is built upon Middle Scenic rocks, just a few meters above the Saddle Pass Marker. This position is relatively lower in the stratigraphic sequence from that at the Burns Basin Overlook because we are far up the flank from the Burns Basin Syncline and because the Scenic Member increases its thickness. The total thickness of the Scenic Member below the top of the Saddle Pass Marker in the basin below you is 49 m thick, as compared to the 25.6 m thickness of the same sequence in the Pinnacles. The reason for the doubling of thicknesses here is because we have entered an early Oligocene paleovalley. The highland that existed in the Pinnacles area extended to the southeast toward the buttes that you see to the southwest (far left) from the observation platform. Presumably the paleovalley at Bigfoot Pass also had a southeast trend parallel the ancient ridge. However, the geometry of outcrops along the Badlands Wall exposes only a cross section through this paleovalley. Thicknesses of the Scenic Member remain high east from here.

This overlook used to be called the Banded Basin Overlook, because of the prominent red stripes that occur in the light gray sandstones of the Middle Scenic. Except for the thick brown beds of the Hay Butte and Saddle Pass Markers, these red bands are typically mudstone or claystone beds that can be traced laterally for only a kilometer or two. They represent thin, muddy overbank deposits in a remarkable sequence of sheet sandstone bodies. The Hay Butte and Saddle Pass mudstone beds are unique, for they are very widespread and are not known to be cut by channel sandstones anywhere in the North Unit of the Park.

**Stop 7 – Fossil Exhibit Trail.** This short trail was originally set up to view fossils that occurred in the basal Poleslide siltstones. However, some of the countless visitors over the years has removed most of the naturally occurring fossils from this area. The current exhibits under clear plastic domes have casts of rather complete skulls of many of the fossil vertebrates that are in the Park. Unfortunately, there is still a problem of theft of these specimens, and some of the exhibits are occasionally broken into and the casts removed.

This stop provides the first good view of the Poleslide Member. The high butte to the west is called The Castle, and is capped by the Sharps Formation. The Rockyford Ash at the base of the Sharps can be seen as the ragged white band below the top. The Poleslide here includes a basal siltstone (at the level of the trail), a lower sandstone supporting the low rocky benches at the base of The Castle, a middle sequence composed primarily of buff to tan siltstones, an upper sandstone sequence, and an upper tan siltstone interval directly below the Rockyford Ash. The Poleslide rock units in this area and as far east as the east end of the Park are remarkably persistent, and 12 stratigraphic intervals can be traced across the entire area. The massive siltstones of the Poleslide represent the settling of volcaniclastic dust as loess deposits. This is in contrast to the Scenic mudstones in which the volcaniclastic dust was transported by streams or weathered into clays. Such a shift from weathered and fluvially reworked dust to relatively unaltered loess deposits represent a shift from wetter climates (at least subhumid climates) to drier, semiarid climates, using the conditions of modern dryland loess accumulation as a model (Pye and Tsoar, 1987). The tall butte to the east is called Norbeck Ridge and has a small outcrop of Rockyford Ash at its western-most point. This tuff is cut by a paleovalley filled with Arikaree sandstones that support the ridge farther to the east.

If you can shuttle a car to the next stop at Saddle Pass, there is an excellent 2 mile (3.2 km) hiking trail roughly along the Scenic/Poleslide boundary that can be made from this stop. To start your hike, go to the trailhead across the road then follow the well-marked trail. The last part of this trail drops down from the lower sandstone of the Poleslide at Saddle Pass down the Badlands Wall to the level of the lower Scenic. For the more adventurous, this trail, called the Castle Trail, extends all the way across the top of the Wall for approximately 5 miles (8.05 km), ending at the Doors and Windows Overlook (Stop 10) on the east side of the Park.

**Stop 8 – Saddle Pass Trailhead.** You are standing on the very top of the basal Scenic mudstones and are looking up through the Brule and Sharps Formations (Fig. 11). All of the widespread marker beds are in this sequence, and this is the type section of the Saddle Pass Marker (Fig. 12). Here, as in most of the North Unit, the brown mudstones of the Saddle Pass overlie a tan to near white carbonate nodular layer that has abundant trace fossils of dung beetles, solitary bees, and digger wasps, and locally abundant vertebrate fossils (though not in this area). The trail winds up the Scenic Member, crosses the basal Poleslide siltstones, and ends at the top of Saddle Pass on top of the lower Poleslide sandstone. Note that this is a very steep trail, especially where it crosses the Middle Scenic sandstones. The high ridges above Saddle Pass are in the middle and upper Poleslide siltstones and sandstones, while the highest buttes are capped by sandstones of the Arikaree Channels that have cut down into the upper Poleslide, removing the Rockyford Ash and the sandy siltstones of the Sharps Formation.

Landslides can be seen on either side of the trail, and just below the Pass, the trail crosses for a short distance landslide deposits derived from the Poleslide Member and the Arikaree Channels. The base of these landslides tend to move on the clayey mudstones of the disappointment limestone interval as groundwater filters down through the overlying siltstones and accumulates on the clay-rich rocks. The landslide debris typically includes buff mudstones of the Upper Scenic, siltstones and sandstones of the Poleslide, and coarse sandstones and pebbly conglomerates of the Arikaree Channels. This debris then flows over the Middle and Lower Scenic rocks, sometimes ending up at the base of the Badlands Wall. The upper part of the larger landslides have rotated blocks and hummocky topography that catches water and allows cedars to grow. Such cedar groves are prime habitat for deer and bighorn sheep that live along the Wall.

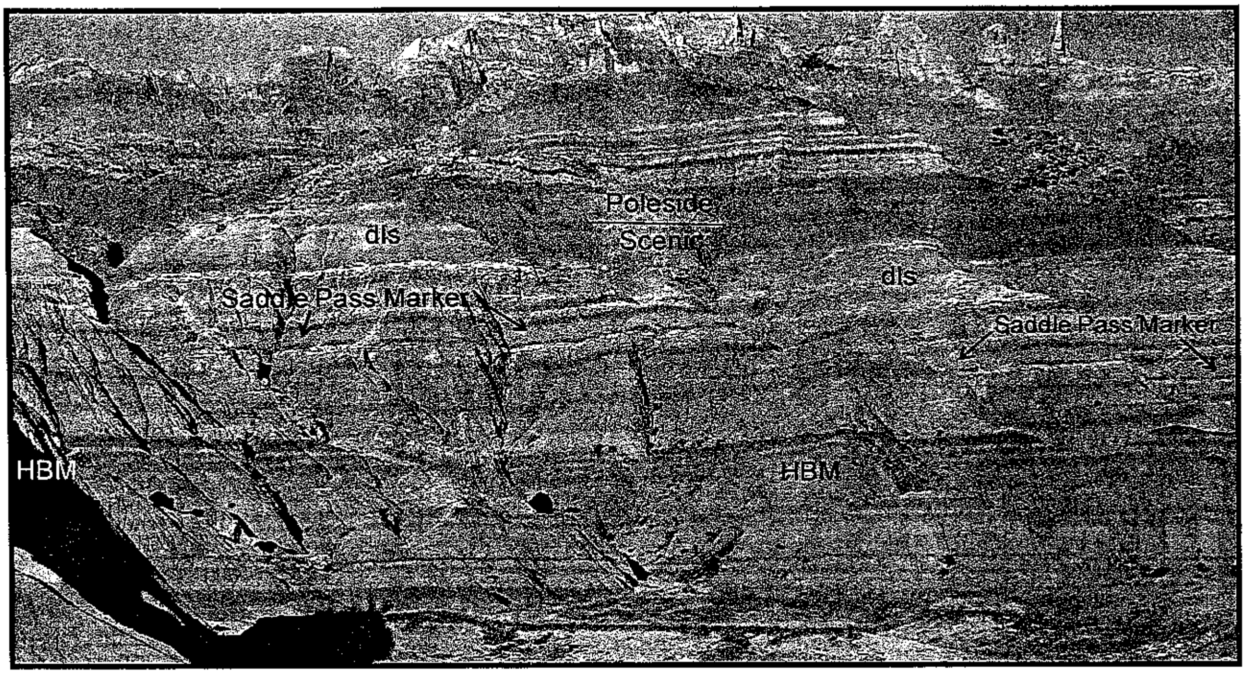


**Figure11.** Brule outcrops along the Saddle Pass Trail from the trailhead. HBM – Hay Butte Marker, SPM – Saddle Pass Marker, dls – disappointment limestone interval.

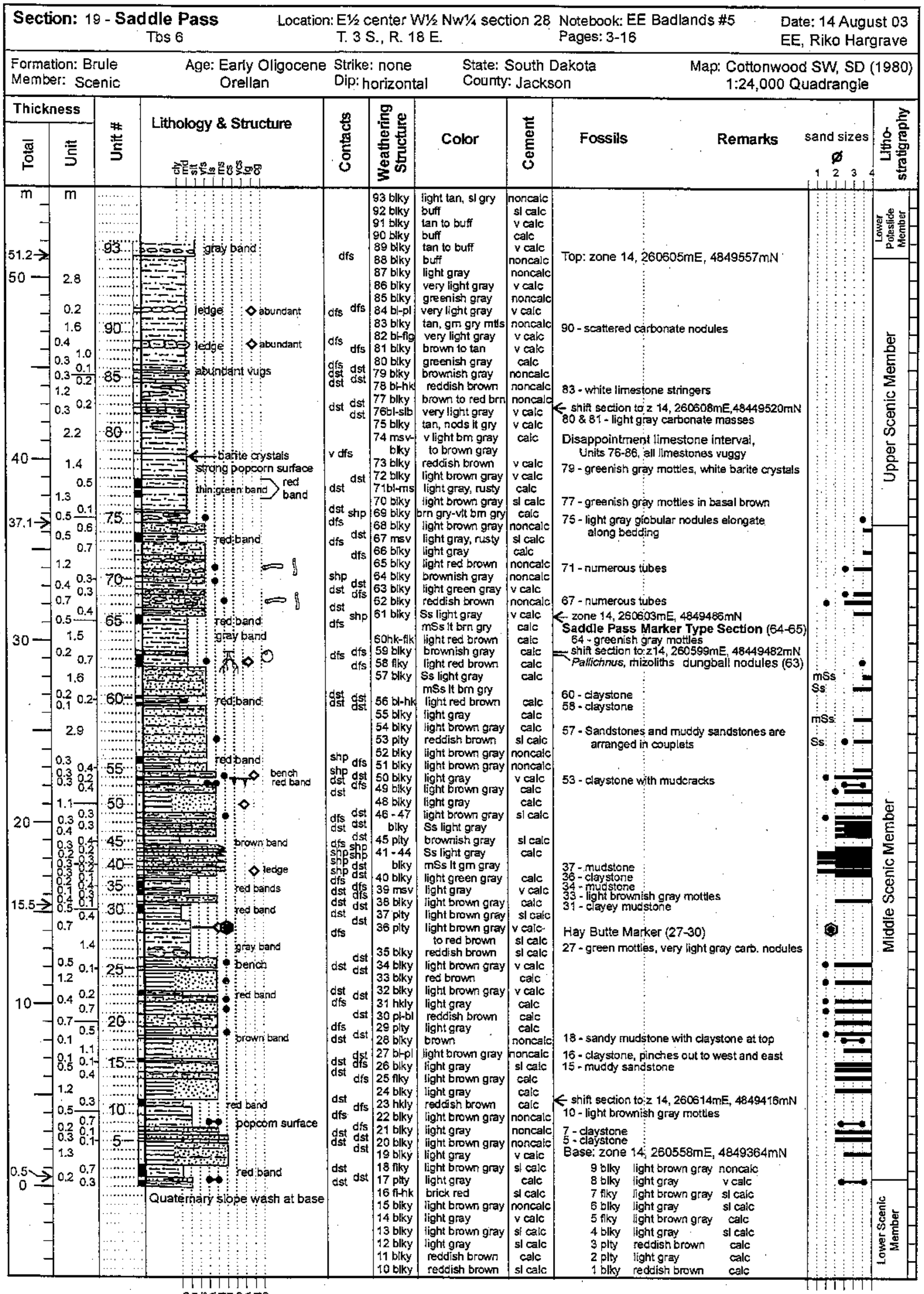


**Figure 12.** Graphic log of the Scenic Member section at Saddle Pass.

**Stop 9 – Ben Reifel Visitor Center.** The spectacular ridge to the north and northeast of the visitor center (across the highway) is called Millard Ridge. It is capped by the sandstones of the Arikaree Channels, and the Rockyford Ash is exposed as the ragged white band near the top of many of the spires. The highway climbs up the front of this ridge and reaches the top of the ridge at a gap called Cedar Pass, The Rockyford Ash occurs just above the road at Cedar Pass. This southern side of Millard Ridge also has many large landslides, several of which has caused problems in maintaining the highway.

The Park's visitor center is situated within the Upper Scenic disappointment limestone interval that can be seen in detail just to the east of the building. The disappointment limestone interval contains thin, light gray, limestone stringers within brown to greenish brown clayey mudstones. The limestones contain angular granules of mudstone that weather away on the surface of the limestones, giving the limestone a pitted surface. The carbonate stringers, mottles and abundant fossil roots (rhizoliths) and clay skins in cracks in the mudstones all indicate that the interval is a thick cumulic soil sequence. The intense weathering to form the thick soil complex probably removed all but a few trace fossils from the interval. The limestones are not lacustrine because they do not contain fossils of freshwater organisms, such as freshwater snails, ostracodes, or algal structures.

The sharp ridge immediately southeast of the visitor center exposes the upper buff mudstones of the Scenic Member, the basal tan siltstones, the lower sandstone interval, and the middle buff siltstones of the Poleslide Member (Fig. 13). The contact between the Scenic mudstones and Poleslide siltstones is very well exposed in this ridge.

The visitor center has exhibits, a short video tour, a gift shop with maps and literature about the park, picnic tables, and restrooms.

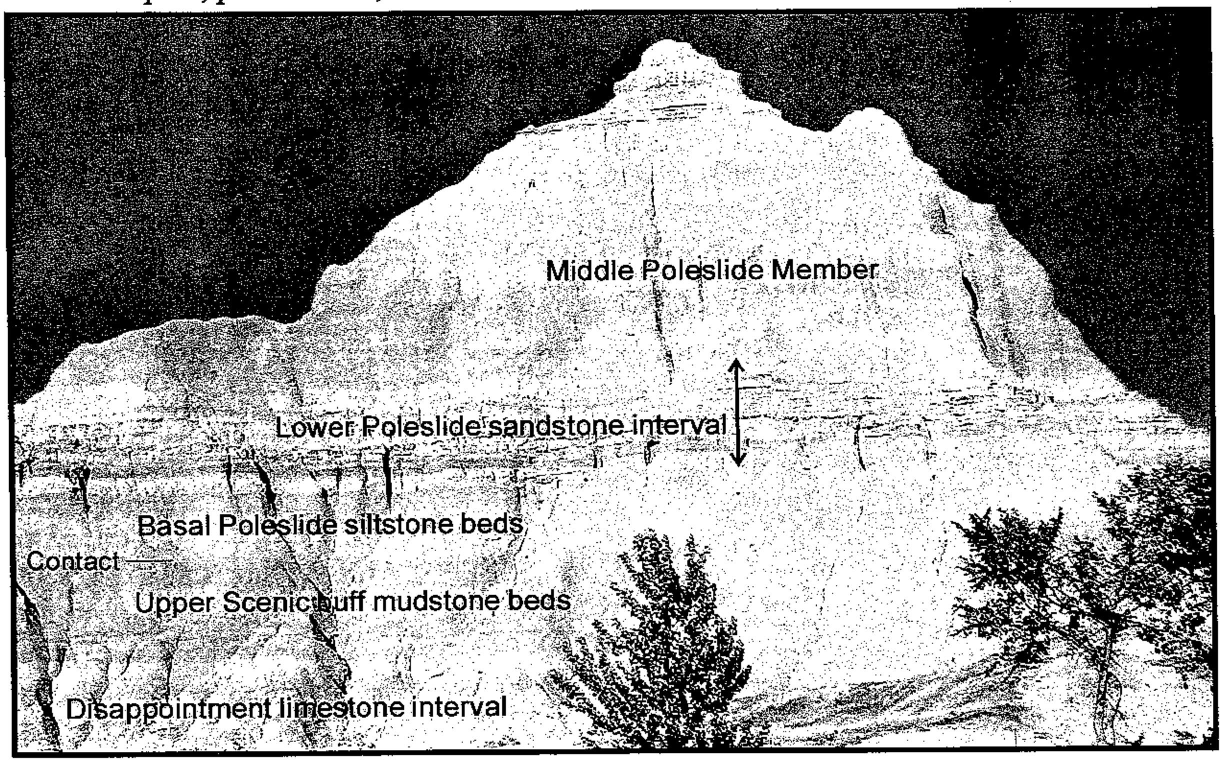


**Figure 13.** Upper Scenic and Poleslide units in the butte to the southeast of the Ben Reifel Visitor Center

**Stop 10 – Doors and Windows Overlook**. This is one of the best places in the Park to see the rocks of the Poleslide Member. The overlook is situated in the Middle Poleslide, between the lower and upper sandstone intervals. The wall to the east has numerous small gaps, or Windows that overlook extensive badlands cut into the Scenic Member. The north side of the overlook has a walking trail that extends through a large gap, or "Door," onto a bedrock bench supported by the lower Poleslide sandstone interval.

The fossil accumulations of the Scenic Member tend to be almost exclusively in mudstones where numerous bones and skeletons occur in a limited area and along a single stratigraphic horizon. Bones in the Poleslide Member tend to be scattered throughout the siltstone intervals. A recent survey of fossil sites, including vertebrate, trace and land snail fossil accumulations, in an area of about 2 $km^2$ of Poleslide outcrops near Doors and Windows resulted in over 1000 sites in all the units from the base to the top of the member. The fossil vertebrates are different in the two members. The Scenic vertebrate assemblages are dominated by the horse *Mesohippus* spp., whereas the Poleslide vertebrates are dominated by the now extinct oreodonts. Oreodonts resemble both pigs and sheep, and their remains occur in the hundreds in the Poleslide Member. Typical Poleslide vertebrates are shown in Figure 14. Overall the Poleslide vertebrate fauna probably reflected the drier conditions during Poleslide deposition.

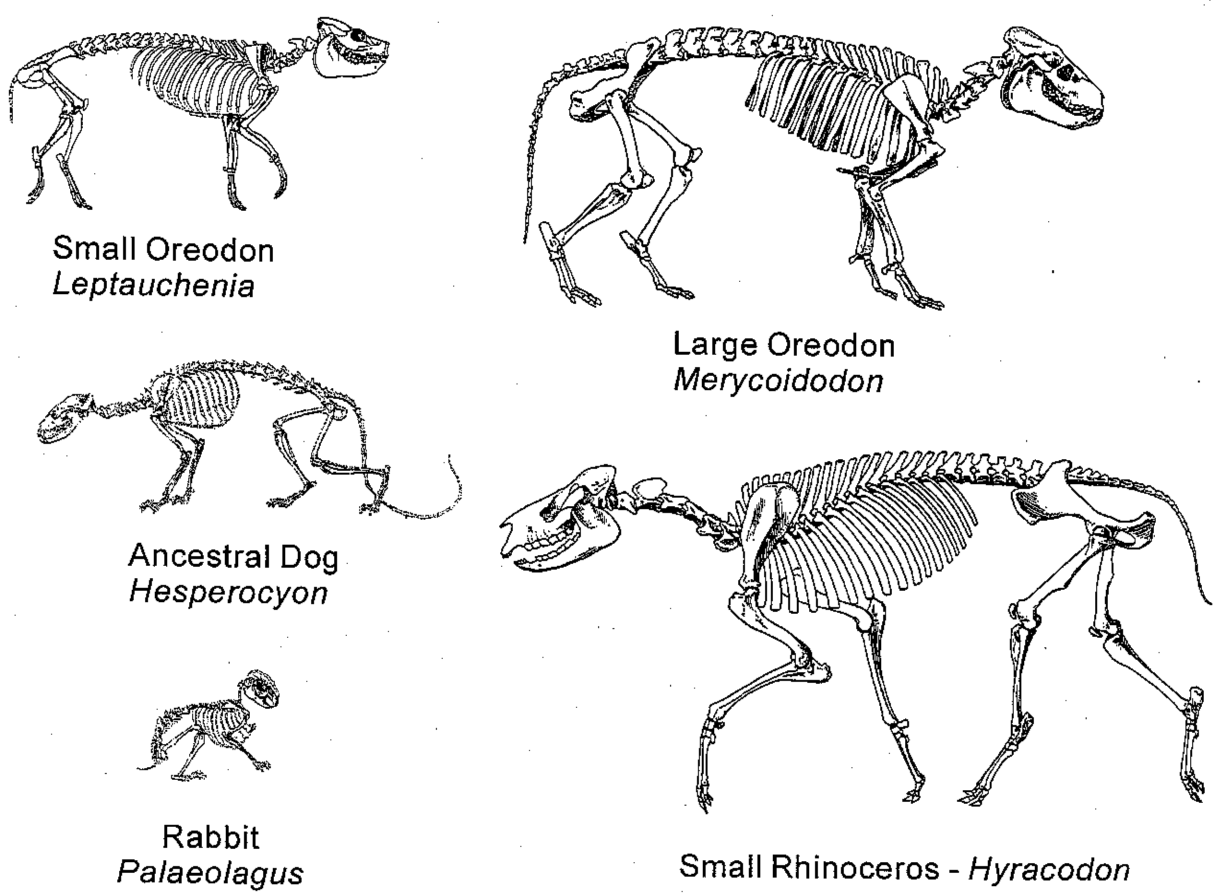


**Figure 14.** Common fossil mammals of the Poleslide Member.

**Stop 11 – Agate Flats.** This stop is west of the town of Interior along the north side of State Highway 44 on lands administered by the U.S. Forest Service as part of the Buffalo National Grasslands. We are standing near the base of the White River Group among gray claystone hills of the lower Chadron Formation. At the base of these hills is a pavement of pebble to cobble gravel composed of chert, quartz, and quartzite clasts. Some of the chert clasts contain Paleozoic fossils, primarily of Mississippian and Pennsylvanian age, indicating an original source from the Pahasapa Limestone and Minnelusa Formation in the Black Hills. Some of the chert clasts are Fairburn Agates and have very intricate multicolored bands. These were also derived from the Pennsylvanian Minnelusa Formation. The quartz and quartzite clasts were derived from the Precambrian rocks of the Black Hills. These gravels represent a sheet of gravel that was deposited in the Great Plains by streams flowing from the Black Hills sometime prior to the deposition of the White River Group. The lack of associated granite, schist, gneiss, limestone, dolomite, and sandstone clasts that must have accompanied these quartz-rich clasts is a result of intense chemical weathering of the gravels, and the removal of these less resistant clasts. Most of the chert and quartzite clasts were originally gray or brown, but now they are almost universally orange as a result of the intense weathering. The gravels accumulated at the base of the Chadron as gravel lags on the old erosion surface that is now the late Eocene unconformity. Many workers place the base of the White River Group a the base of the red Interior paleosol, but these gravels reflect the position of the old land surface on which White River sediment was deposited. These lag gravels are not restricted to western South Dakota. They also occur at the base of the White River sequence in northwest Nebraska and northeast Colorado.

**Stop 12 – Chamberlain Pass.** We have now traveled along State Highway 44 far into the western part of the North Unit of Badlands National Park. Several facies changes has occurred within the White River rocks. The basal Chadron Formation here contains a sequence of gray to brown claystone and sandstone beds. These rocks contain the huge bones of the brontotheres. Brontotheres were related to modern horses and rhinoceros' and were the size of small elephants (Fig. 15). All brontotheres became extinct near the Eocene/Oligocene boundary, and are essentially the characteristic mammal fossil of the late Eocene in the White River.

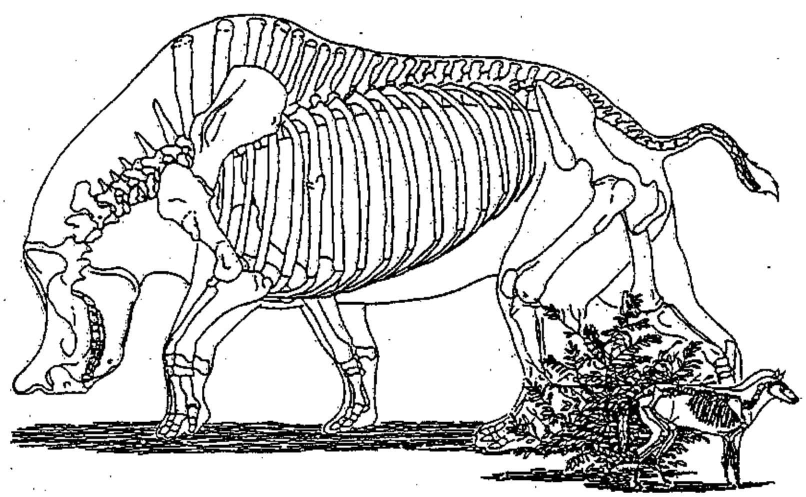

**Figure 15.** A brontothere and the horse *Mesohippus*. The bush is 1 m high.

The Scenic Member here has a similar thickness to the Scenic Member at Bigfoot Pass and Saddle Pass. However, this is because the lower part of the Scenic is much thicker while the Upper Scenic is much thinner. The reason for the thinning of the Upper Scenic is a facies change from the upper buff mudstones of the eastern Scenic to the tan siltstones of the basal Poleslide here in the west. In this area, the top of the Scenic Member is the distinct gray band found in the upper part of the large flat top buttes to the north and to the west. This band is the Heck Table Marker, a prominent gray mudstone that is named for the large flat-topped butte to the west. Below the Heck Table Marker are mudstones of the Scenic Member. Above this marker are siltstones of the Poleslide Member (here there is a sheet sandstone above the Marker). The Heck Table Marker pinches out to the east about the level of the top of the disappointment limestone interval. The Marker disappears on the east side of the large drainage basin to the northeast of where you are standing. Thus, the basal tan siltstone beds of the Poleslide Member in this area change into the buff mudstones of the Upper Scenic farther to the east. The basal Poleslide siltstones are easily seen near the top of the two flat-topped buttes north and west of here, because the drainage density is much higher on these siltstones. Basal Poleslide siltstones are intricately gullied unlike the mudstones in the Upper Scenic Member. The Hay Butte Marker is a thick brown band in the middle of the butte to the north. The Saddle Pass Marker has thinned to the west, so it is in this area a thin brown persistent band just below the highest light gray sandstone band in the butte to the north.

You have now seen the Scenic rocks in the middle, east and now west end of the North Unit. You can now appreciate the sequence of events that formed the member (Fig. 16). The Scenic Member is a composite of 4 different depositional packages. Deposition of the Scenic followed an erosional event that cut into the underlying Chadron Formation. Topographic relief at the start of Scenic deposition was in the order of 25 m. The first deposits of the Scenic is now a series of mudstones that blanket the ancient topography. Some of the mud was derived from the reworking of the Chadron clays, but some was formed from the alteration of volcanic dust as it accumulated on the hills and swales then became weathered. Eventually streams deposited muddy sand in the paleovalleys between the Chadron highs. Sand deposition stopped in the region and a sheet of mud with abundant soil features accumulated over the entire area. This mudstone with abundant pedogenic features is the Hay Butte Marker. Some of the sediment in the Hay Butte Marker accumulated as a volcanic ash, but this ash was reworked in the middle and eastern part of the North Unit. The sequence from the basal mudstones to the Hay Butte Marker is the first depositional package of the Scenic. By the end of the deposition of the Hay Butte Marker the older topography was completely buried. A sheet of sand was deposited by streams immediately after the end of Hay Butte Marker deposition. This sand deposition was followed by a second accumulation of widespread muds with strong evidence of pedogenesis, forming the Saddle Pass Marker. The Saddle Pass Marker is thicker and better developed in the middle and eastern parts of the North Unit, but it is merely a rather thin but persistant brown band in the outcrops in the west. The Saddle Pass Marker and its underlying sandstone blanket represent the second depositional package. The third depositional package includes the sandstone blanket above the Saddle Pass Marker and the overlying disappointment limestone interval. The disappointment limestone interval is the thickest series of paleosols in the Scenic, but it grades into brown mudstones with less pedogenic features to the west. Finally, the last package is represented by the buff mudstones in the middle and east areas of the North Unit. These mudstones grade into siltstones of the basal Poleslide in the western parts of the North Unit. Deposition of the Scenic Member in the middle and eastern areas of the North Unit ended with the accumulation of siltstones in the basal Poleslide Member. Both the lateral and vertical changes of mudstones to siltstones probably reflects lateral and temporal changes from moist fluvial conditions to drier aeolian conditions. As for depositional rates, the sandstones of the Middle Scenic probably represent the fastest deposition in the area, the basal and uppermost mudstones represent intermediate depositional rates, and the Hay Butte and Saddle Pass markers and the disappointment limestone interval represents times of slow deposition resulting in well developed paleosols.

**Figure 16.** Depositional history of the Scenic Member across the North Unit of Badlands National Park as shown by cross sections. The upper four cross sections show the four depositional packages. The lower cross section shows the entire cross section through the Scenic Member. The bottom line is the cross section with no vertical exaggeration. The diagram is at the end of the guidebook.

**Stop 13 – Scenic Basin.** By crossing over Chamberlain Pass, you enter the Scenic Basin named for the town of Scenic that is situated in the center of the valley. The basin is the wide valley formed by the merged headwaters of Bear Creek (to the north) and Spring Draw (to the northwest). Both Bear Creek and Spring Draw flow northward into the Cheyenne River. To the southwest is the large high mesa called Sheep Mountain Table and the Badlands Wall breaks down to a series of isolated buttes on the south side of the valley.

Fur trappers had traveled by the Badlands along the White River starting in the 1820's, and the first described fossil from the Badlands (a brontothere jaw identified by Prout, 1846, as a *Palaeotherium*) was collected by a trapper of the American Fur Company. However, the Scenic Basin was the entrance to the Badlands for the first scientific expeditions to the area. Starting at Fort Pierre, the expeditions traveled up the Teton River (now known as the Bad River), crossed over the divide to the Cheyenne River, came up Bear Creek, and went south to the White River (Fig. 17). This is the route of the first expedition led by John Evans in 1849 as a part of the geographic and geologic survey of Wisconsin, Iowa, Minnesota, and a portion of Nebraska Territory. A small but important collection of vertebrate fossils were collected during this survey, and the fossils were sent to Dr. Joseph Leidy of the Philadelphia Academy of Sciences. Leidy eventually published two monographs of the White River fossil vertebrate fauna, the first in 1854 and the second in 1869. This route was also followed by Fielding B. Meek and Ferdinand V. Hayden in 1853. This was the first trip to the west by Hayden, who returned to the area several times in the 1850's. Meek and Hayden defined the White River Series in 1857, and the geology of the White River Group was later discussed by Jacob Wortman (1893) and John Bell Hatcher (1893 and 1902) from their work around Sheep Mountain Table. In 1910, the Chicago, Milwaukee, St. Paul and Pacific railroad was built across Chamberlain Pass providing easy access to the towns of Interior and Scenic. Most of the geologic studies of the White River in the early twentieth century were made near these towns, by such workers as William Sinclair (1921), Freeman Ward (1922), and Harold R. Wanless (1922 and 1923), and John Clark (1937). It has been only recently that the detailed marker beds and contacts have been traced along the entire Badland Wall, and this only for the Scenic Member. More work is needed for understanding the detailed stratigraphy of the Poleslide Member and Sharps Formation across the North Unit.

The Scenic and Poleslide Members of the Brule Formation was named by Bump (1956). The type section for the Poleslide Member is on the south side of Sheep Mountain Table. The type section of the Scenic Member (Fig. 17) is in an isolated butte on the west side of Pennington County Road 589, 2.2 miles (3.5 km) south of the town of Scenic.

One of the interesting features of the Hay Butte Marker is that it contains a tuff that is well exposed in the Scenic Basin in the upper part of the marker bed. The tuff is a grayish band 0.3 m thick that contains euhedral biotite, and crystals of zircon, apatite, monazite and rare sphene. Monazite ($(Ce,La,Y,Th)PO_4$) is a rare mineral in the tuffs of the White River sequence. Only two other tuffs, both of early Oligocene age, have monazite crystals. One of these tuffs is near Douglas, Wyoming, and the other is at Pawnee Buttes in northeast Colorado. It is possible that all three of these are the same tuff. The tuff in the Hay Butte is near its depositional edge, for the distinct gray bed becomes indistinct east of Chamberlain Pass.

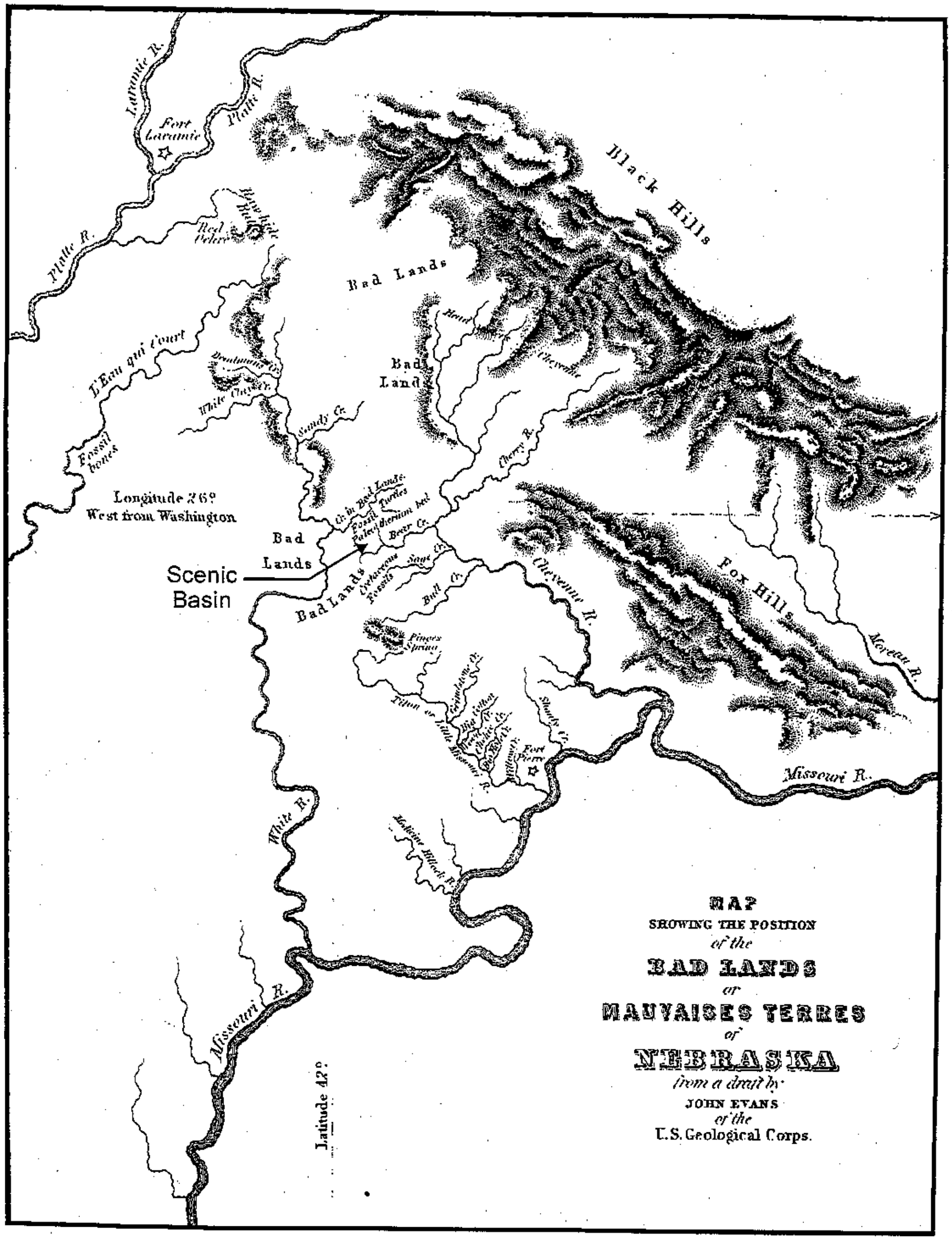


**Figure 16.** The map accompanying John Evans report on the Badlands in 1852. Note that north is to the right.

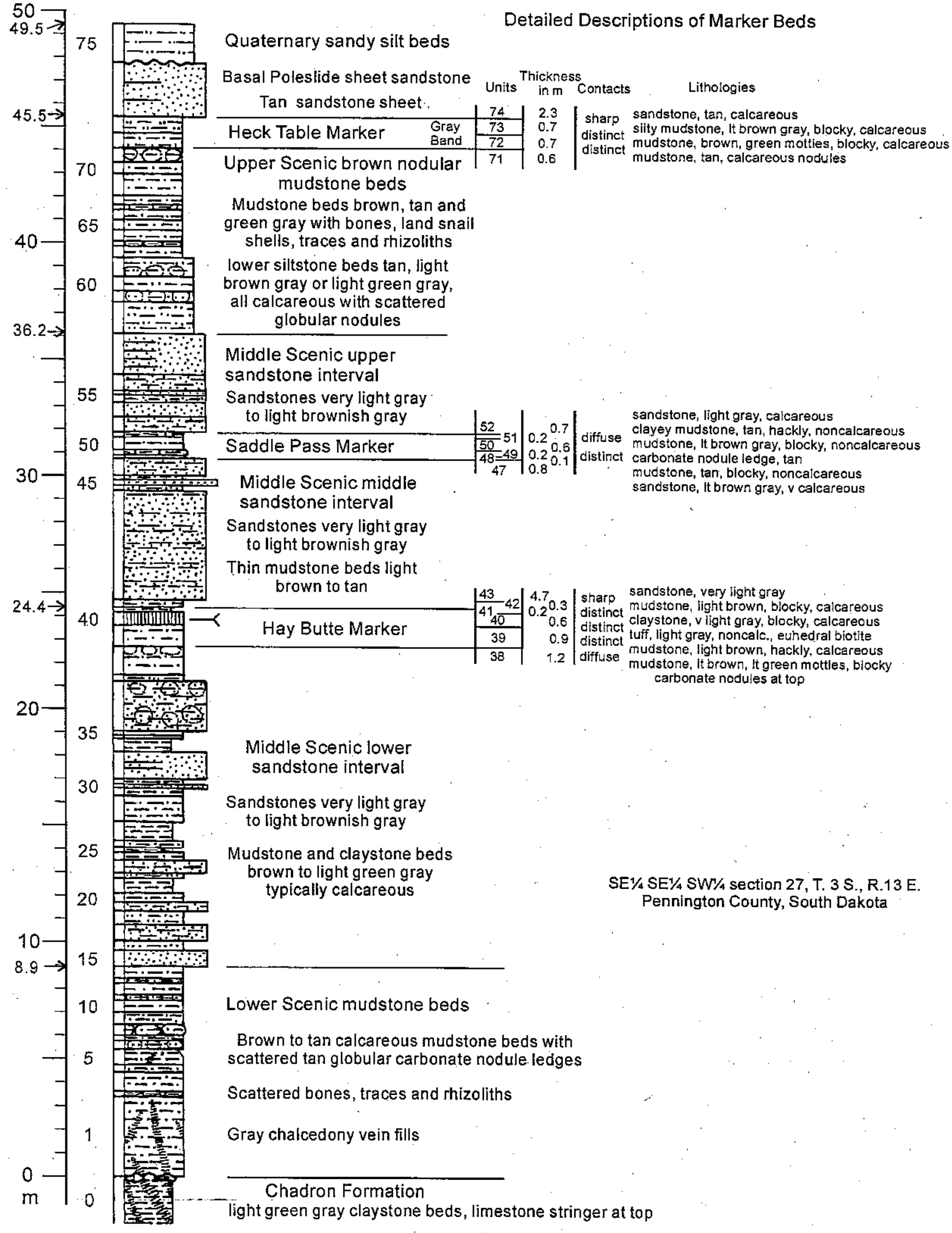


**Figure 17.** Features of the type section f the Scenic Member in the Scenic Basin.

**Stop 15 – Sheep Mountain Table Overlook.** The last stop on our tour is an unimproved overlook on the west side of Sheep Mountain Table. Note that there are no guardrails at this overlook that is situated above a very high cliff – **take care not to come too close to the edge of the cliff.**

You are gazing into the valley of Indian Creek. The hills at the base of the west wall of Sheep Mountain Table are cut into the top of the Scenic Member. The entire west wall of Sheep Mountain Table is in rocks of the Poleslide Member. High toward the south you can see a white band that is thought to be the Rockyford Ash. However, the total thickness of the Poleslide Member at Sheep Mountain Table is about 100 m, while at the Pinnacles and at Doors and Windows the Poleslide is only 50 m thick. Either Sheep Mountain Table had a rock accumulation rate double that of the Poleslide farther to the east, or the Rockyford Ash of Sheep Mountain Table is a younger tuff than the tuff of the same name at Pinnacles and Cedar Pass. Future stratigraphic work is needed to understand the exact relations between the Poleslide Member at Sheep Mountain Table and the Poleslide rocks farther to the east. If the day is clear, note the Black Hills at the skyline far to the west.

Looking east from the overlook, the broad grassy flat that caps Sheep Mountain gives an impression of what the Great Plains was like at the end of the Tertiary. This upper surface is not exactly an unaltered depositional surface, for it bevels the Sharps Formation, the Rockyford Ash, and finally the Poleslide Member from south to north. However, the Great Plains must have been remarkably flat prior to the deep erosion of Tertiary deposits forming the modern Badlands. The timing of downcutting of the Tertiary rocks in South Dakota is uncertain, but regional evidence in the Great Plains suggests that most of the erosion has been in the past 5 million years. This down-cutting continues today forming the remarkable Badlands.

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