

WYOMING STATE GEOLOGICAL SURVEY

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EXPLANATION AND DISCUSSION

to accompany Map Series 78,

**Geologic map of the Sundance 30' x 60' Quadrangle,
Crook and Weston counties, Wyoming, and
Lawrence and Pennington counties, South Dakota**

Compiled and mapped
by
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INTRODUCTION

The Sundance 30' x 60' (1:100,000-scale) Quadrangle is located along the west edge of the Black Hills uplift and includes the northeastern part of the Powder River Basin, Wyoming encompassing the area from 44° to 44°30' north latitude and 104° to 105° west longitude. The Sundance 1:100,000-scale map comprises 32 1:24,000-scale quadrangles (Figure 1).

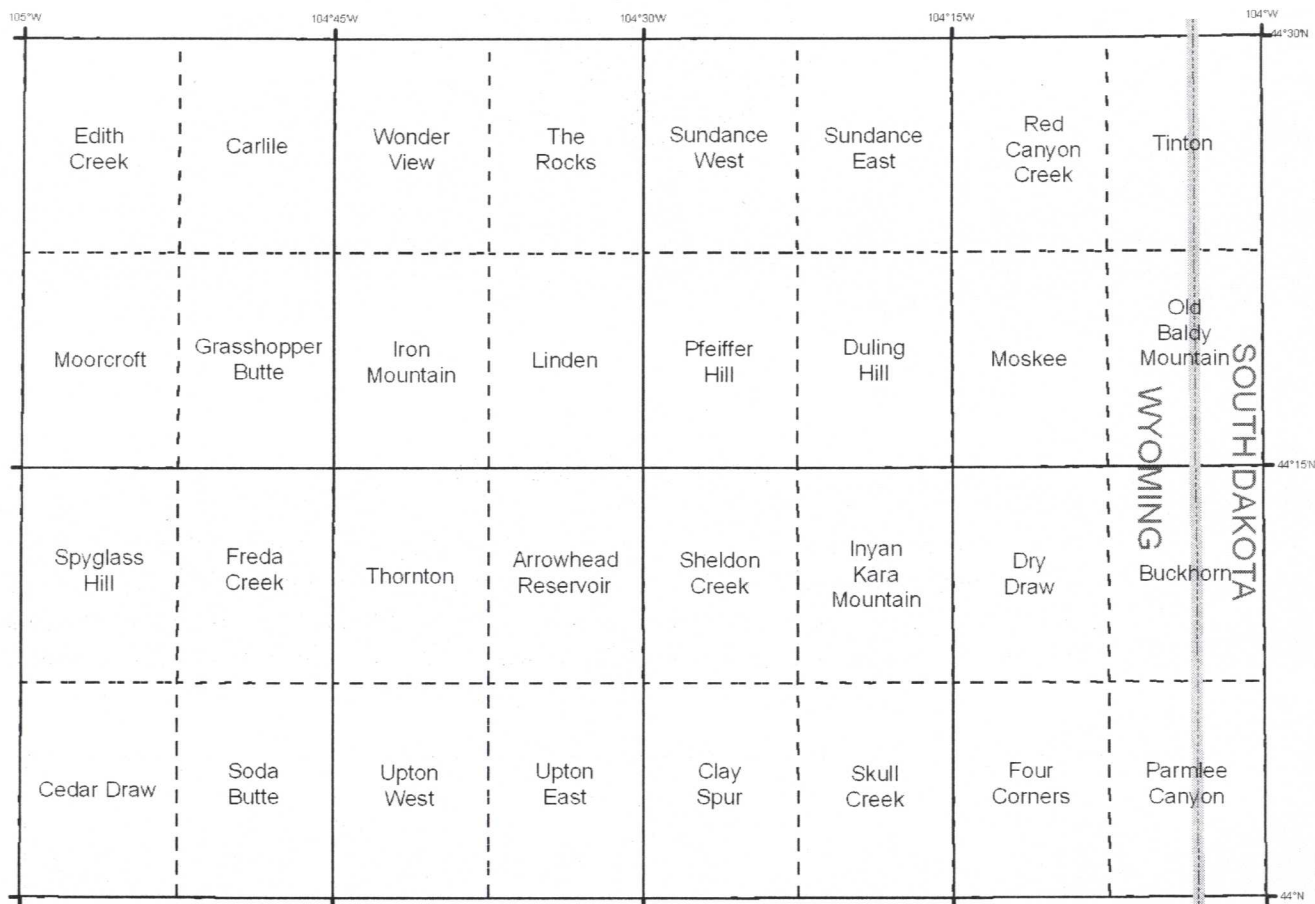


Figure 1. Index to 7.5-minute U.S. Geological Survey topographic maps of the Sundance 30' x 60' Quadrangle.

The map overlaps about 2 ¾ miles into South Dakota, and includes the Wyoming communities of Sundance, Moorcroft, and Upton, as well as several small settlements. Land use within the area is dominated by ranching, recreation, and timbering. Interstate Highway 90 crosses the northern part of the quadrangle, connecting Moorcroft and Sundance, and continuing northeastward off the mapped area to Spearfish, South Dakota. U.S. Highway 14 crosses the northwest corner of the quadrangle; U.S. Highway 16 cuts across the southwest part of the quadrangle; and U.S. Highway 85 passes through the southeast part of the quadrangle. State Highway 116 connects Sundance and Upton, and State Highway 585 connects Sundance and Four Corners. The highest elevation in the quadrangle is approximately 6,960 feet (2,121 m) in the Bear Lodge Mountains, and the lowest elevation is approximately 3,940 feet (1,200 m) along the Belle Fourche River in the northwest part of the quadrangle.

The largest stream in the quadrangle, the Belle Fourche River, flows across the northwest part of the quadrangle from southwest to northeast. Inyan Kara Creek, Buffalo Creek, and several others

drain northwest to the Belle Fourche from much of the western part of the quadrangle. Sundance Creek, Cold Springs Creek, and Beaver Creek flow northeast from the northeast part of the quadrangle. Iron Creek, Skull Creek, Stockade Beaver Creek, and several others flow south from the southern parts of the quadrangle. At least three different streams named Beaver Creek drain parts of the quadrangle in three different directions: northeast; northwest; and southeast.

Geologic setting

The western Black Hills and the northeastern Powder River Basin within the Sundance 30' x 60' Quadrangle expose geologic units ranging in age from Late Archean/Early Proterozoic to Quaternary. Precambrian rocks are exposed at Mineral Hill and in the Bear Lodge Mountains. Tertiary intrusions are exposed at Mineral Hill, Black Butte, Inyan Kara Mountain, Bear Lodge Mountains, and at Devils Tower and Missouri Buttes north of the quadrangle. Similar intrusive rocks may also exist at depth within some domal uplifts in the same area. Paleozoic and Mesozoic sediments dominate the outcrops surrounding uplifts and intrusive centers. The only Tertiary sedimentary units within the Sundance Quadrangle are the Oligocene White River Formation, which is found near the flanks of the Bear Lodge Mountains and on the north flank of Mineral Hill, and the Late Miocene / Pliocene Ogallala Formation mapped by Staatz (1983) in the Bear Lodge Mountains. Quaternary deposits include alluvium, colluvium and slope wash, landslide debris, and terrace, pediment, and gravel deposits.

The Black Hills uplift is a broad, 200-mile (320 km)-long north-northwest-trending, Precambrian-cored Laramide uplift that separates the Powder River Basin to the west from the Williston Basin to the northeast. The Sundance 30' x 60' Quadrangle is located on the west flank of the Black Hills between the central core of the uplift, located to the east in South Dakota, and the Powder River Basin. In general, Paleozoic and Mesozoic sedimentary rocks in the quadrangle dip westward off the Black Hills uplift into the Powder River Basin along two or more north- to north-west- oriented basement-controlled monoclinal flexures. The Fanny Peak monocline in the extreme eastern part of the quadrangle affects Cambrian through Pennsylvanian rocks, and is defined by a zone of steep dips. The Black Hills monocline in the western part of the quadrangle is defined by several zones of steep dips affecting mostly Upper Cretaceous rocks at the surface. The gently dipping rocks in the central part of the quadrangle nearest the Black Hills monocline are locally folded into tight anticlines and synclines whose axes are parallel or subparallel to the monocline. Farther east, Mesozoic and older rocks are locally folded into small domes that may be related to intrusion of igneous rocks. Some of the domes, such as Sundance Mountain, Inyan Kara Mountain, and Black Buttes contain exposed igneous rocks in their cores while others, such as Green Mountain, Strawberry Mountain, and Lime Buttes may have unexposed igneous cores. Several of the largest igneous intrusives, such as the Bear Lodge Mountains and the Tinton-Mineral Hill area, have uplifted and exposed Precambrian crystalline rocks.

Most faulting is associated with igneous intrusions, dome structures, or flexures along the Black Hills monocline. Normal faults usually have less than 100 feet (30 m) of displacement and cannot be traced for more than a few miles. The fault around the intrusion at Inyan Kara Mountain, however, has a maximum vertical displacement of about 600 feet (183 m) (Robinson and others, 1964).

Economic Geology

The Sundance 30' x 60' Quadrangle map was selected as a STATEMAP project because of the significant geological values associated with the map area. This map includes the southern portion of the Bear Lodge Mountains, Black Buttes, and Mineral Hill alkalic complexes, which host associated metals deposits. These areas are currently of potential economic interest for gold

and rare earth elements. Resources also include copper, silver, lead, zinc, tin, manganese, niobium, tantalum, and fluorite (Hausel and Sutherland, 1988; Hausel, 1989, 1997). The geologic environment within these young intrusions is similar to that of Cripple Creek. Because of these similarities, several exploration groups are interested in the region. Two companies have recently staked much of the Mineral Hill district (**Figure 2**) for gold and silver, at least two companies have interests in the Bear Lodge Mountains for gold and rare earth elements, and several prospectors have shown interest in Sand Creek for placer gold.



Figure 2. Tinton Mine near the WY-SD border in the Mineral Hill district.

In addition, the region has potential for development of coal, oil and gas, limestone, uranium and vanadium, bentonite, and gemstones. Micro diamonds and some garnets were recovered from a coal seam in the Gillette area of the Powder River Basin, west of the Sundance 30' x 60' Quadrangle (Finkelman and Brown, 1989). The Sundance Quadrangle is underlain by Archean rocks of the Wyoming Province, which is considered to have potential to host diamonds. No investigation has been made into the diamond potential of the Sundance Quadrangle. Beryl is reported as an accessory mineral in pegmatites of the Mineral Hill area which straddles the WY-SD state line. Fluorite occurs in the Bear Lodge Mountains immediately north of Sundance, and thin veins of green and white opal are also reported in the same area.

GEOLOGIC MAP UNITS

The geology of the Sundance 30' x 60' Quadrangle was compiled from existing mapping (**Figure 3**) at varying scales using non-digital methods, and supplemented by aerial photo interpretation and cursory field checks. The rock units described here apply to the 32 1:24,000-scale quadrangles that make up the quadrangle. Some rock units were generalized and combined, or very small outcrops were exaggerated to allow depiction at the 1:100,000 map scale. Some contacts between units, particularly Quaternary and Tertiary units, are uncertain, but are shown as solid rather than dashed lines. The preliminary version of this map was published as a blackline map plotted from a scan of the original by the WSGS as Open File Report 06-8 (Sutherland and Hausel, 2006).

Qcs Colluvium and slope wash – Colluvial deposits, including slope wash and some alluvial deposits, are abundant in areas of steep slopes, but are shown only in a few areas due to considerations of scale and depiction of bedrock rather than surficial geology.

Qls Landslide debris – This unit consists of locally derived landslide debris from unstable, generally steep slopes. It was compiled from many sources (see references) and supplemented by aerial photo interpretation.

Quaternary and Tertiary surficial deposits

QTt Terrace, pediment, and gravel deposits (Holocene, Pleistocene, and (?)Pliocene) – Gravel covered terrace and/or cobble, sand, gravel and silt covered terraces merge in places with eluvial, alluvial and colluvial deposits. Different terrace levels were not designated, although some areas have multiple levels of terraces. Mapel and Pillmore (1963, 1964) mapped terrace deposits as much as 20 feet (6.1 m) thick at several locations in the south central part of the Sundance 30' x 60' Quadrangle, and identified some as Quaternary and some of the highest-level deposits as Tertiary. The actual ages of these deposits are unknown and are combined on this map. For this compilation, a few terrace deposits were also mapped from aerial imagery.

Tertiary sedimentary rocks

To Ogallala Formation (late Miocene/Pliocene) – Staatz (1983) mapped the Miocene Ogallala Formation where he found poorly exposed gravels, conglomerates, sands, and silts ranging from 3 to 54 feet (0.9 to 16.5 m) thick along the north, west, and east flanks of the Bear Lodge Mountains. The formation is expressed as broad, flat-topped ridges supporting dense pine growth or grass on thick (~20 inches or 51 cm) soils. Conglomerates are poorly sorted, with subangular to subrounded trachyte and phonolite clasts ranging in size from about 0.16 to 18 inches (0.4 to 46 cm) accompanied by minor amounts of Paleozoic debris in a white calcareous sandstone matrix. Staatz (1983) based his designation of these beds as Ogallala by was based on the earlier works of Lugin and Brown (1952) and Elias (1942) and their studies of the fossil seeds *Stipidium commune* and *Biorbia fossila*. Contact with the underlying White River Formation on the northwest side of the Bear Lodge is an unconformity on an irregular erosion surface cut into the White River Formation. Where the White River is absent, the Ogallala has an angular unconformity with Cambrian to Jurassic sedimentary units.

Twr White River Formation [Oligocene or upper Eocene(?)] – The White River Formation is composed of as much as 115 feet (35 m) of poorly bedded, friable, tan to buff and white to gray, siltstone, tuffaceous claystone, and clay, with minor limestone lenses (Robinson, Mapel, and Bergendahl, 1964; Staatz, 1983). The formation crops out as discontinuous isolated remnants on the north flank of Mineral Hill in the eastern part of this quadrangle, and in the Bear Lodge Mountains immediately north of the quadrangle. Love, Christiansen, and Ver Ploeg (1993) assigned an Oligocene age to the White River Formation, but Lilligraven (1993) interpreted its age as upper Eocene (Chadronian).

Fort Union Formation (Paleocene) – The Fort Union Formation crops out only along the west edge of the Sundance 30' x 60' Quadrangle, and is distinguished from similar-appearing strata the underlying Lance Formation by the presence of thin coal seams (Whitcomb and Morris, 1964). It is mapped as two separate units described below.

Tftl Tongue River and Lebo members undivided – The Tongue River and Lebo Members are found only in the extreme southwest corner of the map area. The Tongue River is 400 to 900 feet (122 to 274 m) of massive yellowish gray sandstone interbedded with light-gray shale and numerous coal beds. The Lebo is 200 to 250 feet (61 to 76 m) of medium- to dark-gray shale interbedded with light-gray sandstone and a few thin coal beds (Mapel, Robinson, and Theobald, 1959).

Tft Tullock Member – The Tullock Member is a 500- to 1100-foot (152 to 335 m) thick sequence of light to yellowish gray and brown, fine- to medium-grained, massive, friable and generally lenticular sandstones interbedded with siltstone, claystone, and numerous thin beds of subbituminous coal. The Tullock thins to the north, and thickens west of the map area. Its outcrop is expressed by abrupt-crested and gullied ridges and narrow winding valleys that sharply differ from the gently rounded topography of the underlying Lance Formation (Mapel, Robinson, and Theobald, 1959; Bergendahl, Davis, and Izett, 1961; Whitcomb and Morris, 1964). The contact between the Tullock and the underlying Lance Formation is conformable.

Tertiary intrusive and volcanic rocks

Alkalic igneous rocks (Paleocene and Eocene) – Tertiary alkalic igneous rocks crop out in the eastern and north-central part of the Sundance 30' x 60' Quadrangle where they form small stocks, laccoliths, irregular bodies, dikes, and sills where they cut rocks ranging in age from Precambrian to Cretaceous. These rocks form the central parts of several uplifts including the Bear Lodge Mountains, Mineral Hill, Black Butte, Inyan Kara Mountain, and Sundance Mountain (**Figure 4**). Most of these rocks are porphyritic, were emplaced close to the surface, had rapid cooling rates, and exhibit flow banding (Staat, 1983). Extrusive flows and pyroclastic deposits are found in limited areas where magma reached the surface in the Bear Lodge Mountains. Duke (2005) described magmatism as progressing from east to west in three pulses beginning in the South Dakota Black Hills at ~58 Ma, with later pulses at ~55-54 Ma (includes the Mineral Hill area near the WY-SD stateline) and ~50-46 Ma (includes the Bear Lodge Mountains, and Devils Tower and Missouri Buttes to the northwest on the adjacent Devils Tower 30' x 60' Quadrangle). The largest volume of the intrusive rocks is either trachyte or Phonolite, with smaller amounts of latite, syenite, nepheline syenite, lamprophyre, pseudoleucite porphyry, and intrusive breccias (Staat, 1983). Small carbonatite outcrops occur in the Bear Lodge Mountains just north of the Sundance Quadrangle.

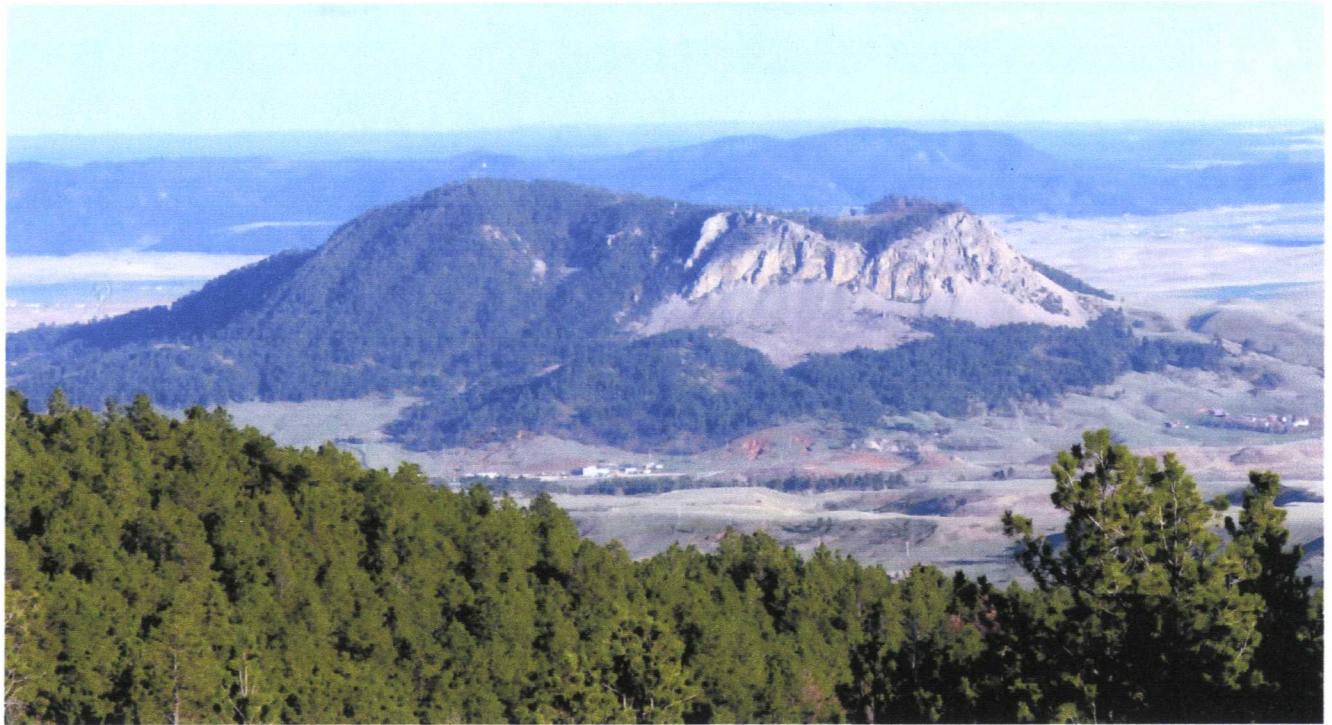


Figure 4. Sundance Mountain is a quartz latite laccolith that has intruded Triassic and younger rocks, which dip steeply around the core of the intrusion. View to the southeast from the Bear Lodge Mountains. The Black Buttes intrusive complex is the dark ridge beyond Sundance Mountain, and the Black Hills are on the horizon.

Tp Phonolitic intrusive rocks – Greenish gray to medium gray and dark gray phonolite and related rocks are combined due to considerations of map scale. These include rocks in the Mineral Hill area that were mapped by Welch (1974) as syenite, syenodiorite, lamprophyre, pseudoleucite, pyroxenite, and others. They also include rock units mapped at Black Buttes by Elwood (1978) as both phonolite and nepheline syenite porphyry. Phonolite is also found in the Bear Lodge Mountains north of the Sundance Quadrangle.

The phonolite bodies contain anomalously high concentrations of strontium and barium. The pyroxenite, diorite, lamprophyre, feldspathoidal breccias, and related rocks found near Mineral Hill host anomalously high concentrations of iron, titanium and gold (Welch, 1973). These are highly magnetic with positive gravity anomalies that distinguish them geophysically from surrounding rocks. They contain phenocrysts of andesine, analcime, leucite, nepheline, aegerine-augite, biotite, and sphene within a fine-grained groundmass of plagioclase, biotite, feldspathoids and other accessory minerals (DeWitt and others, 1989).

Tl Lamprophyre sill – A lamprophyre sill crops out near Miller Creek in the western part of the Bear Lodge Mountains. This sill extends for 2.8 miles (4.5 km), is approximately 10 to 40 feet (3 to 12 m) thick, and intrudes the middle of the Sundance Fm (Staat, 1983) (**Figure 5**). This sill consists of .04-inch (0.1 cm) -long phenocrysts (18-25% augite, 2-5% magnetite, <1% apatite and biotite) within a matrix rich in small plagioclase and mafic microlites, accompanied by calcite- and feldspar-filled amygdules up to 1.5 inches (3.8 cm) long (Staat, 1983) (**Figure 6**). Other lamprophyre outcrops are found just north of the Sundance Quadrangle.



Figure 5. Lamprophyre sill intruded into Sundance Formation along South Fork Miller Creek.



Figure 6. Lamprophyre with filled amygdulcs.

- Tt Trachytic intrusive rocks** – Small stocks, laccoliths, sills, and dikes of iron-stained, reddish brown to tan trachyte crop out in the Bear Lodge Mountains (Staatz, 1983), at Inya Kara Mountain, Black Buttes, and in the Mineral Hill area. This unit includes rocks that were mapped at Black Buttes by Elwood (1978) as nordmarkite, trachyte porphyries, and feldspathic breccias. Duke (2005) identified rocks at Inyan Kara Mountain as alkali rhyolite.
- Tql Quartz latite intrusive rocks** – A small laccolith of light gray to tan quartz latite crops out at Sundance Mountain (**Figure 3**), and as a resistant flow-foliated plug of quartz latite northeast of Sundance that makes up the bulk of a feature referred to as the Sugarloaf complex. Both of these are accompanied by peripheral dikes of foyaite (Lisenbee and Martin, 1988). The fault-controlled Sugarloaf complex also includes some breccias and bedded tuffs. Duke (2005) classified the rocks at Sundance Mountain as subalkalic rhyolite, and at least some of those at Sugarloaf as trachyte.
- Tb Intrusive breccia** – Intrusive breccia in the north-central part of the Bear Lodge Mountains is made up of angular to rounded rock fragments up to 3.9 inches (9.9 cm) in size. Hosted within an aphanitic to fine-grained igneous matrix, rock fragments are dominated by light gray volcanic rock with small sanidine phenocrysts, and occasionally include fragments of granite and Deadwood Formation quartzite. The breccia commonly weathers red or yellow from iron oxides (Staatz, 1983). This breccia surrounds the only carbonatite dike in the area, which crops out approximately ¼ mile (0.4 km) north of the map area.
- Tpy Pyroclastic deposits** – Small pyroclastic deposits varying from volcanic breccia to tuff were mapped near Lytle Creek on the west side of the Bear Lodge Mountains by Staatz (1983). The gray to light brown breccia is composed of subangular to subrounded fragments up to 1.6 inches (4.1 cm) across, mostly of porphyritic volcanic rock, within a glassy matrix. The light brown to white tuff contains as much as 10% crystal fragments within a devitrified glass (ash). Both the breccia and tuff host tiny (<0.04 inches or 0.10 cm) vesicles filled with opal and/or chalcedony.

MESOZOIC SEDIMENTARY ROCKS

Upper Cretaceous sedimentary rocks

- Kl Lance Formation** – The Lance Formation consists of 500 to 1600 feet (152 to 488 m) of poorly exposed, nonmarine, interbedded, yellowish-gray, friable, fine- to medium-grained sandstone, medium-gray sandy claystone, and shaley siltstone that is accompanied by minor beds of carbonaceous shale and bentonitic clay in the lowest part (Bergendahl, Davis, and Izett, 1961). The sandstone beds are generally lenticular, no more than a few feet thick, and are thin to thick bedded and cross laminated. Where sandstone beds are thick, they may locally host calcareous concretions up to several feet in diameter (Whitcomb and Morris, 1964). The Lance crops out in the western part of the map area as grassy knolls and ridges of moderate relief (Mapel and Pillmore, 1964). The formation increases in thickness toward the south. Its contact with the underlying Fox Hills Sandstone is placed at the base of the lowest gray bentonitic clay or carbonaceous shale above the sandstone (Whitcomb and Morris, 1964).
- Kfh Fox Hills Sandstone** – The Fox Hills Sandstone is 150 to 200 feet (46 to 61 m) of light gray to light yellowish gray, friable, very fine- to medium-grained, soft, thin-bedded marine sandstone. The fox Hills is poorly exposed and forms grassy ridges standing about 100 feet (30 m) above

the less resistant and underlying Pierre Shale. The unit is interbedded with gray sandy shale near the base, and occasionally in the upper part. It locally hosts 1- to 2-foot (0.3 to 0.6 m)-thick by several feet long brown weathering ferruginous sandstone concretions in the lower part. The contact between the Fox Hills and the underlying Pierre Shale is gradational through an interval of about 20 to 30 feet (6 to 9 m) (Mapel, Robinson, and Theobald, 1959; Mapel and Pillmore, 1964; Whitcomb and Morris, 1964).

Pierre Shale – The Pierre Shale is approximately 1755 to 2575 feet (535 to 785 m) of dark-gray to black shale with minor thin siltstone and silty sandstone, bentonite beds, and abundant large limestone concretions (Mapel, Robinson, and Theobald, 1959; Bergendahl, Davis, and Izett, 1961; Mapel and Pillmore, 1964). Geochemically, bentonite beds within the unit host anomalous concentrations of lanthanum, niobium, and rubidium; black shales contain anomalous antimony, bismuth, cadmium, vanadium, and zinc; and concretionary horizons are anomalous in chromium, manganese, nickel, and zinc. In general, the Pierre in the Black Hills area is radiometrically distinguished from surrounding units by anomalously high potassium concentrations. Its basal section is notable for uranium anomalies that lack coincident thorium (DeWitt and others, 1989). The age of the Pierre Shale is **72-78 Ma** (Love and Christiansen, 1985).

Along the west flank of the Black Hills, various workers have subdivided the Pierre into as many as five parts that include an unnamed upper part, the Kara bentonite member, an unnamed middle part, the Mitten black shale member, and the Gammon ferruginous member at the base (Mapel and Pillmore, 1964).

Kpu Unnamed upper part – The upper part of the Pierre Shale consists of about 300 feet (91 m) of dark gray shale that is interbedded in the upper 20 to 50 feet (6 to 15 m) with a few laminae of light-gray, very fine-grained sandstone and siltstone. It also hosts several beds of gray septarian limestone concretions containing orange and brown calcite. The base of the upper part of the Pierre is a prominent ridge-forming, gray-weathering bed of 3- to 4-foot (0.9 to 1.2 m)-long septarian limestone concretions that are also found scattered throughout the unit (Mapel and Pillmore, 1964).

Kpk Kara Bentonitic Member – The Kara bentonite member is composed of approximately 90 feet (27 m) of gray bentonitic shale and interbedded gray shale that weathers to a light gray soil almost devoid of vegetation. Barite nodules up to 2 inches (5 cm) long that weather out from the bentonite are abundant (Mapel and Pillmore, 1964).

Kpm Unnamed middle part – Approximately 900 feet (274 m) of mostly dark-gray shale makes up the middle part of the Pierre Shale. The upper two thirds of its thickness contains gray-weathering limestone concretions and some red-weathering concretions. The member becomes slightly silty toward the south in its lower few hundred feet (Mapel and Pillmore, 1964).

Kps Mitten Member – The Mitten member, composed of dark-weathering shale, crops out as a line of low hills and ridges between the slightly less resistant Gammon member and the middle part of the Pierre Shale. The upper part of the Mitten hosts abundant large, fossiliferous, dark-gray septarian limestone concretions that weather brown to dark reddish orange. Small red-weathering ferruginous concretions are found within the middle part of the member. The base of the unit contains about 35 feet (11 m) of interbedded yellowish-gray bentonite and shale (Mapel, Robinson, and Theobald, 1959). Mapel and Pillmore (1964) gave a thickness for the Mitten of about 650 feet

(198 m) based on drill hole data, but also state a thickness of “several hundred feet” where poor exposures limited the accuracy of surface measurements.

Kpg Gammon Ferruginous Member – The Gammon member is approximately 575 to 650 feet (175 to 198 m) of mostly medium to dark gray, noncalcareous shale that weathers to a distinctly lighter gray than soils on adjacent units. The Gammon appears as a light-colored band on aerial imagery. The shale is occasionally silty, with some thin, very fine-grained glauconitic sandstone lenses near the middle of the member. Numerous beds of orange to dark red weathering, closely-spaced tabular ferruginous concretions varying from a few inches to a few yards long distinguish all but the lower 100 feet (30 m) of this member. Septarian concretions that average 1 to 2 feet (0.3 to 0.6 m) in length and weather to gray are found in the upper 50 to 75 feet (15 to 23 m) of this member (Mapel and Pillmore, 1964). The Gammon is gradational with the underlying Niobrara Formation.

Kn Niobrara Formation – The Niobrara consists of about 150 to 225 feet (46 to 69 m) of yellowish to light gray shale and marl, along with numerous thin beds of bentonite, particularly near the top (Bergendahl, Davis, and Izett, 1961; Whitcomb and Morris, 1964). The outcrop of the nonresistant Niobrara is generally covered by slope wash and alluvium in shallow valleys and on gentle slopes, although it may form some bare slopes and be exposed in the sides of gullies. Unlike the gray-weathering shales of the adjacent formations, the calcareous beds of the Niobrara weather bright orange, yellow, or light-gray. The contact between the Niobrara and the underlying Carlile Shale is sharp but conformable. The top of the Niobrara is mapped at the top of a thin zone of bentonite beds that is also the upper limit of yellow-weathering chalky shale (Mapel and Pillmore, 1964). The Niobrara is distinguished geochemically by its soils, which often host high concentrations of selenium (DeWitt and others, 1989). The age of the Niobrara Formation is about **83 Ma** (Love and Christiansen, 1985). This formation becomes thicker to the south and east (Mapel, Robinson, and Theobald, 1959).

Carlile Shale – The Carlile Shale is 500 to 600 feet (152 to 183 m) thick, and is made up of black to dark-gray sandy shale that hosts large concretions and interbedded bentonite. The lower part of the formation contains minor interbedded siltstone and sandstone (Bergendahl, Davis, and Izett, 1961; Mapel and Pillmore, 1963; Whitcomb and Morris, 1964). The black shales contain anomalous amounts of antimony, lead, and vanadium. The bentonite beds host anomalous concentrations of lithium and rubidium (DeWitt and others, 1989).

Kcs Sage Breaks Member – The Sage Breaks member is about 290 feet (88 m) of black to dark gray shale that is mostly calcareous in the upper 50 feet (15 m), with the remainder noncalcareous. Several beds of 1- to 3-foot (0.3 to 0.6 m)-long, septarian concretions that host coarsely crystalline brown and white calcite veins are found within the shale. These light gray-weathering concretions are markedly different than the yellow weathering ones seen in the underlying Turner member (Mapel and Pillmore, 1964).

Kct Turner Sandstone Member – The Turner sandstone member consists of approximately 185 feet of dominantly dark gray shale interlaminated with light gray siltstone and a few thin, brown-weathering, fine-grained sandstones. Beds of yellow- to yellowish gray-weathering silty limestone concretions that contain yellow calcite veins characterize much of the Turner member. A discontinuous chert granule conglomerate, no more than a few inches thick, is found in some

localities about 120 feet (37 m) above the base of the member. The base of the Turner is a persistent 2- to 6-foot (0.6 to 1.8 m)-thick, ridge-forming, light gray sandstone that hosts scattered granules and pebbles of phosphatic material and chert, as well as locally abundant fish teeth (Mapel and Pillmore, 1964). The Turner sandstone has produced oil in the western part of the map area (De Bruin, 2002).

Kcp Pool Creek Shale Member – The Pool Creek consists of 50 to 90 feet (15 to 27 m) of dark gray noncalcareous shale with interlaminae of light gray siltstone in the upper half that are most abundant near the top. Scattered 0.5- to 1-foot (0.2 to 0.3 m)-long septarian limestone concretions are found in the middle part of the member (Mapel and Pillmore, 1964). In much of the area, this member is referred to as the **unnamed lower member** of the Carlile Shale. The bottom part of the Pool Creek is variably calcareous and contains a few interlaminae of siltstone and silty shale (Mapel and Pillmore, 1963; Whitcomb and Morris, 1964).

Kg Greenhorn Formation – The Greenhorn Formation (also known as the Greenhorn Limestone) averages 70 to 100 feet (21 to 30 m) in thickness, but is as much as 270 feet (82 m) thick just south of the map boundary near Newcastle (Bergendahl, Davis, and Izett, 1961). This unit consists of gray to brown calcareous to noncalcareous shale and marl, with scattered thin interbeds of tan to light gray sandy limestone, and bentonite. Brown, fossiliferous, sandy limestone beds and zones of septarian limestone concretions are found at the top of the formation. These concretions, as much as 5 feet (1.5 m) in diameter, weather light-gray and contain veins of brown and orange calcite. The limestones at the top of the formation often form ridges. The contact with the underlying Belle Fourche Shale is at the base of the main body of olive-gray or brown, locally calcareous shale in the lower Greenhorn (Mapel and Pillmore, 1963, 1964; Whitcomb and Morris, 1964).

Kb Belle Fourche Shale – This unit varies from 350 to 850 feet (107 to 259 m) in thickness, averaging around 700 feet (Bergendahl, Davis, and Izett, 1961). It is composed of nonresistant, black to dark gray bentonitic shale containing minor limestone lenses, and large (up to 3 feet or 0.9 m in diameter), very hard, dark red to purplish black-weathering siderite concretions in the basal 50 feet (15 m). The upper part is dominated by dark gray to black shale, and hosts yellow septarian limestone concretions that average 1 to 2 feet (0.3 to 0.6 m) in length (Mapel and Pillmore, 1963, 1964; Whitcomb and Morris, 1964). The lower part of the formation hosts several thin bentonite beds, two of which reach thicknesses of 1.5 and 3.0 feet (0.5 and 0.9 m). The base of the formation is arbitrarily placed at the top of the underlying Clay Spur Bentonite in the Mowry Formation, where lithology changes from nonresistant shales above to hard siliceous shales below. Chromium, manganese, and niobium are anomalously abundant in the black shales, while the bentonite beds are geochemically characterized by anomalous concentrations of hafnium, lanthanum, lithium, rubidium, and thorium. Small uranium and thorium radiometric anomalies distinguish the Belle Fourche from surrounding units (DeWitt and others, 1989).

Kmr Mowry Shale – The Mowry Shale consists of 125 to 230 feet (38 to 70 m) of black, generally silver-gray weathering, hard and resistant, siliceous shale interbedded with numerous 0.1- to 1.5-foot (3 to 46 cm)-thick bentonite beds, and a few thin siltstones. The Mowry weathers into small, thin, brittle chips, and in many places hosts a moderate growth of small pine trees that is absent on adjacent units. Fossils are generally rare within the Mowry, but fish scales are abundant. Near the top of the formation is the Clay Spur Bentonite, a 2.5- to 4.5-foot (0.8 to 1.4 m)-thick bentonite bed that has been

commercially mined. In the south-central part of the map area, the lower 20 feet (6 m) is soft, weathers a grayish-black, and is overlain by a thin, brown-weathering siltstone or fine-grained sandstone. To the north and west, this sandstone is replaced by a zone of brown-weathering, silty, cone-in-cone concretions. The Mowry is distinguished radiometrically from surrounding formations by uranium and thorium anomalies, and is geochemically characterized by anomalous concentrations of lead and manganese within the black shales (Mapel and Pillmore, 1963, 1964; DeWitt and others, 1989). Love and Christiansen (1985) cited an age for the Mowry Shale in Wyoming of **94-98 Ma**.

Lower Cretaceous sedimentary rocks

Knc Newcastle Sandstone – The Newcastle Sandstone consists of 0 to 60 feet (0 to 18 m) of lenticular, light brown to gray sandstone and siltstone interbedded with subordinate thin beds of black to brown carbonaceous shale and bentonite. The silt and shale content of the formation increases to the north across the map area. The Newcastle outcrops in a light-colored band with a 2- to 5-foot (0.6 to 1.5 m)-thick bed of resistant, grayish to white to yellowish gray, very fine-grained sandstone near the top of the formation. In some areas where the sandstone is absent, the remaining beds are indistinguishable from the underlying Skull Creek Shale and the overlying Mowry. Limited local mining of the bentonite has occurred. The Newcastle conformably overlies the Skull Creek Shale (Mapel and Pillmore, 1963, 1964; Whitcomb and Morris, 1964), and has produced oil in the western part of the map area (De Bruin, 2002).

Ksc Skull Creek Shale – The 180- to 270-foot (55 to 82 m)-thick Skull Creek Shale consists predominantly of black shale hosting radiometric uranium and thorium anomalies and anomalous concentrations of lead and manganese (Bergendahl, Davis, and Izett, 1961; DeWitt and others, 1989). Where it crops out in the central part of the Sundance 30' x 60' Quadrangle, the Skull Creek locally forms badlands and low hills sparsely vegetated with grass and sage (Mapel and Pillmore, 1964). The unit hosts scattered siderite concretions throughout that weather to a red color. Tabular to oval cone-in-cone limestone concretions that weather to a yellow color are occasionally found in the upper part of the formation. The upper part of the unit also hosts numerous near-vertical, well-cemented, very fine-grained light gray sand dikes in the vicinity of sec.36, T49N, R65W, near the center of the quadrangle. Generally, these dikes are rectilinearly oriented E-W and N-S, vary in thickness from about 0.5 to 1.5 feet (15 to 46 cm), and penetrate neither the lower part of the formation nor the overlying Newcastle Sandstone. Scattered and generally discontinuous grayish white laminated siltstone beds with apparent worm-trails on bedding surfaces occur near the center of the formation. The contact with the underlying Fall River Formation is gradational (Mapel and Pillmore, 1963, 1964).

Kf Fall River Formation – The Fall River Formation crops out in the central part of the Sundance 30' x 60' Quadrangle, and is 100- to 200-feet (30 to 61 m)-thick (DeWitt and others, 1989). The formation represents a transition from the continental deposits of the underlying Lakota Formation to the black marine shale in the overlying Skull Creek Shale (Bergendahl, Davis, and Izett, 1961). One- to 2-inch (2.5 to 5.1 cm) thick silty or finely sandy, dark brown, iron-rich beds and nodules are common throughout the formation. The Fall River Formation has produced oil in the western part of the map area (De Bruin, 2002) and contains local uranium deposits in the northern Black Hills (Bergendahl, Davis, and Izett, 1961). The Fall River is often informally mapped as two informal upper and lower units over much of its outcrop, but is mapped as an undivided unit in the northwest and central parts of the quadrangle.

Kfu Upper Fall River Formation – The upper part of the Fall River Formation, generally 70 to 80 feet (21 to 24 m) or more thick, is topped by 10 to 30 feet (3 to 9 m) of thin-bedded, nonresistant siltstone, sandstone, and shale that grades upward into the overlying black marine shale of the skull creek formation. Beneath this uppermost part, and in sharp contact with the lower Fall River, is one or more resistant, massive to subtly cross-bedded layers of well-sorted, fine- to very fine-grained, friable, tan-weathering sandstones. These form ledges and cliffs at the tops of ridges and are generally persistent, but in places they thin and interfinger with siltstone (Mapel and Pillmore, 1963).

Kfl Lower Fall River Formation – The lower part of the Fall River Formation is generally about 60 to 65 feet (18 to 20 m) thick and forms steep grassy slopes. It consists mostly of nonresistant, dark gray silty shale and siltstone, thinly interbedded with yellowish to light gray, fine-grained sandstone and siltstone. A pair of thin (up to 20 feet (6 m) thick), persistent ledges of tan-weathering siltstone is conspicuous in the lower 40 feet (12 m) of the formation in some areas. The lower 20 to 40 feet (6 to 12 m) of the formation is dominated by dark-gray carbonaceous shale and siltstone (Bergendahl, Davis, and Izett, 1961; Mapel and Pillmore, 1963).

Kla Lakota Formation – The Lakota Formation varies widely in both thickness and composition across the map area, and represents a continental depositional environment. It ranges from 45 feet (14 m) up to about 300 feet (91 m) thick (Bergendahl, Davis, and Izett, 1961). It consists of complexly interfingering and lenticular beds of sandstone, siltstone, and claystone. The sandstone is well-sorted, fine- to coarse-grained, locally crossbedded and occasionally conglomeratic. The claystone is locally interbedded with lignite and limestone lenses. The Lakota is variegated in tones of brown to gray, reddish to yellowish brown, yellow, and occasionally green, with reds and purples near the top in some areas. Near the middle of the formation, unconsolidated claystone contains gastroliths (i.e. pebbles and cobbles of polished quartzite and chert) (Bergendahl, Davis, and Izett, 1961). The contact between the Lakota and the underlying Morrison is sharp and conformable (Mapel and Pillmore, 1963; Whitcomb and Morris, 1964). The outcrop of the Lakota is characterized by forested ledges and cliffs that contrast with the overlying steep grassy slopes of the lower part of the Fall River Formation.

In the Carlile area, the upper part is dominated by claystone, and the lower part is dominated by generally massive sandstone that weathers to rounded cliffs (Bergendahl, Davis, and Izett, 1961). In other areas, no such distinction is obvious. The upper part of the formation in the Inyan Kara Mountain area is siltstone and claystone that weathers to an easily observed light gray, yellow, or pink soil. The top 5 to 10 feet (1.5 to 3 m) of the formation here hosts abundant iron-rich, .04-inch (1 mm)-diameter, spherical pellets (Mapel and Pillmore, 1963).

The Lakota Formation has produced oil in the western part of the Sundance 30' x 60' Quadrangle (De Bruin, 2002). The Lakota Formation hosts uranium deposits in the northern part of the quadrangle, and has produced uranium in the past near Carlile (Bergendahl, Davis, and Izett, 1961).

Lower Cretaceous and Upper Jurassic sedimentary rocks

KJ Inyan Kara Group (Lower Cretaceous) and Morrison Formation (Upper Jurassic) combined – The Inyan Kara Group (which includes the Fall River Formation and the

Lakota Formation) and the Morrison Formation are combined in the central part of the area where detailed mapping is absent. The Inyan Kara Group is distinguished by high concentrations of uranium and only small amounts of potassium (DeWitt and others, 1989). The Fall River and Lakota formations are separated by a regional unconformity marked in places by a change from variegated claystones below in the Lakota Formation to dark carbonaceous shale in the overlying Fall River Formation. Subtly, the sandstones in the Fall River tend to be more tabular and of greater lateral extent than the more lenticular sands of the Lakota (Mapel and Pillmore, 1963; Whitcomb and Morris, 1964).

Jurassic sedimentary rocks

Jm Morrison Formation (Upper Jurassic) – The Morrison Formation is generally 80 to 120 feet (24 to 37 m) thick across the map area, but is totally absent in some areas, and is up to 150 feet (46 m) thick north of Inyan Kara Mountain. It comprises a sequence of light greenish gray to green, pink and grayish red siltstone and claystone accompanied by thin, lenticular light gray sandstones and shaly limestones. The upper part is darker colored and noncalcareous, whereas the lower part is lighter and calcareous. Locally, the upper part may contain barite nodules up to 2 inches (5 cm) in diameter (Bergendahl, Davis, and Izett, 1961). The lenticular sandstones, which are well-sorted, very fine-grained, and weakly cemented, are typically less than 6 feet (1.8 m) thick, occasionally cross-bedded and ripple-marked, and are concentrated in the lower part of the formation. The limestone lenses similarly concentrate in the lower part of the formation. Contact with the underlying Sundance Formation is gradational, and is picked at the top of a persistent bed of yellow-weathering sandstone (Mapel and Pillmore, 1963; Whitcomb and Morris, 1964). However, Bergendahl, Davis, and Izett (1961) state that that this contact in the Carlile area is fairly sharp and gradational over the space of only a few inches.

Jsg Sundance and Gypsum Spring formations combined – These formations, described below, are mapped together in the east-central part of quadrangle where more detailed mapping is lacking. On the geologic map, the distinction between this combined unit and areas with more detailed unit subdivisions (described below) is shown as a dotted line with the same weight as a formation contact.

Sundance Formation (Upper and Middle Jurassic) – The Sundance Formation comprises about 375 feet (114 m) of light- to reddish- to yellowish-gray, and glauconitic green siltstone and shale, with thin interbeds of shaley sandstone, glauconitic sandstone, and white limestone (Bergendahl, Davis, and Izett, 1961; Whitcomb and Morris, 1964). In some areas, the formation is sequentially divided into the Redwater Shale Member at the top, the underlying LAK member, the Hulett Sandstone, the Stockade Beaver Shale, and the Canyon Springs Sandstone Member at the bottom (Mapel and Pillmore, 1963, 1964).

Jsh Redwater Shale Member, LAK Member, and Hulett Sandstone Member combined – Within the Sundance 30' x 60' Quadrangle, the upper three members of the Sundance Formation are mapped as one unit.

The **Redwater Shale Member (Upper Jurassic)** is 35 to 165 feet (11 to 50 m) of generally nonresistant, glauconitic, greenish gray shale and sandy shale interbedded with light-gray siltstone, sandstone, and limestone. The top of the member is capped with a persistent 2- to 5-foot (0.6 to 1.5 m)-thick layer of yellow-weathering, calcareous, thin-bedded, very fine-grained to silty sandstone or sandy limestone. Its contact with the underlying LAK member is marked by a

sharp color change from gray to pink and from glauconitic to non-glauconitic (Mapel and Pillmore, 1963, 1964). The Redwater Shale Member appears as gentle grass-covered slopes interrupted by thin resistant ledges of sandstone and limestone (Bergendahl, Davis, and Izett, 1961).

The **LAK Member (Middle Jurassic)** consists primarily of poorly exposed, nonresistant, very fine-grained, massive to weakly thin-bedded pink sandstone and siltstone. It is generally 60 to 80 feet (18 to 24 m) thick and contrasts in its color and lack of calcareous cement with the underlying Hulett sandstone member, although the contact between them is gradational over several feet (Mapel and Pillmore, 1963).

The **Hulett Sandstone Member (Middle Jurassic)**, the most prominent member of the Sundance Formation, is exposed as steeply sloping to cliff-forming outcrops that cap low ridges and buttes. It consists of light gray to light yellowish gray, varying to pink, slabby to massive, often crossbedded, and ripple-marked, fine-grained, calcareous sandstone, with a few interbeds of greenish gray silty shale and siltstone at the top and base of the unit. Its contact with the underlying Stockade Beaver shale member is gradational. The Hulett member ranges from 55 to 90 feet (17 to 27 m) thick, but is absent at some locations (Mapel and Pillmore, 1963).

Jsb Stockade Beaver Shale Member, Canyon Springs Sandstone Member, and Gypsum Spring Formation combined – Within the Sundance 30' x 60' Quadrangle, these two members of the Sundance Formation and the thin to absent Gypsum Spring Formation are mapped as one unit.

The **Stockade Beaver Shale Member (Middle Jurassic)** is predominately noncalcareous to slightly calcareous, greenish gray fissile shale with some interbedded and interlaminated light gray calcareous siltstone and very fine-grained sandstone near the top. The Stockade Beaver Shale has a sharp contact with the underlying Canyon Springs Member, and varies inversely in thickness with it; where one is thick, the other is thin (Mapel and Pillmore, 1963). The Stockade Beaver Shale is 50 to 90 feet (15 to 27 m) thick (Robinson, Mapel, and Bergendahl, 1964).

The **Canyon Springs Sandstone Member (Middle Jurassic)** is dominated by light yellowish gray to locally mottled or banded pink and yellow, friable, nonresistant, very fine-grained calcareous sandstone. The top of the Canyon Springs is marked in at least one location by a 5-foot (1.5-m)-thick shelf of fossiliferous, sandy oolitic limestone. The base of this member usually is a few inches to several feet of greenish gray calcareous siltstone. This member is 0 to 90 feet (0 to 12 m) thick (Robinson, Mapel, and Bergendahl, 1964). The Canyon Springs Member unconformably, but smoothly, overlies the Gypsum Springs Formation, or where the Gypsum Springs is absent, the Spearfish Formation (Mapel and Pillmore, 1963). Because of its poor exposures and thinness, the Canyon Springs is often combined on maps with the underlying Gypsum Spring Formation and the overlying Stockade Beaver Shale Member.

The **Gypsum Spring Formation (Middle Jurassic)** comprises 0 to 125 feet (0 to 38 m) of interbedded massive white gypsum, minor red claystone, and thin gray cherty limestone (Whitcomb and Morris, 1964). It typically crops out as a single massive white gypsum ledge, but is locally absent in some areas such as near

Strawberry Mountain, in the southeastern part of the map area, where it was removed by erosion prior to the deposition of the overlying Sundance Formation. It is often combined with part or all of the overlying Sundance Formation on geologic maps. The Gypsum Spring unconformably overlies the Spearfish Formation (Mapel and Pillmore, 1963, 1964).

MESOZOIC AND PALEOZOIC SEDIMENTARY ROCKS

TRPs Spearfish Formation (Triassic / Permian) – The upper part of the 450- to 825-foot (137 to 252 m)-thick Spearfish Formation is thinly and poorly bedded, ripple-marked and cross-laminated red siltstone, and silty claystone and sandstone. The lower part of the formation is made up of thin-bedded red siltstone and silty claystone interbedded with white gypsum/anhydrite beds more than 10 feet (3 m) thick that are accompanied by minor thin discontinuous limestones (Mapel and Pillmore, 1963). The formation weathers to smooth gentle slopes and valleys (**Figure 7**). The unit is distinguished radiometrically from adjacent strata by its anomalous concentrations of potassium and uranium (DeWitt and others, 1989).



Figure 7. Spearfish Formation west of Four Corners.

PALEOZOIC SEDIMENTARY ROCKS

Pmo Minnekahta Limestone and Opeche Shale combined – These two formations are shown as a combined unit in the eastern part of the quadrangle where detailed mapping is lacking. The Minnekahta and Opeche are described below.

Pmk Minnekahta Limestone (Lower Permian) – The Minnekahta Limestone consists of 35 to 50 feet (11 to 15 m) of light gray, finely crystalline, thin-bedded limestone and purplish to pinkish gray dolomitic limestone, with stylolites common throughout (Mapel and Pillmore, 1963; Whitcomb and Morris, 1964; DeWitt and others, 1989). Large sinkholes (**Figure 8**) cut the entire thickness of the formation in some areas of the Black Hills.



Figure 8. Large sinkhole in Minnekahta Limestone in the southeastern part of the quadrangle.

Po Opeche Shale (Lower Permian) – The Opeche Shale consists of 60 to 95 feet (18 to 29 m) of alternating nonresistant beds of maroon and reddish brown shale, fine-grained to silty sandstone, siltstone, and claystone, and thin-bedded anhydrite and gypsum (Mapel and Pillmore, 1963; Whitcomb and Morris, 1964). The formation is generally covered with red residuum, and forms a slope between the cliffs or thick ledges of the overlying Minnekahta Limestone and the underlying cliff-forming breccia and sandstone of the upper part of the Minnelusa Formation. The Opeche Shale disconformably overlies the Minnelusa Formation with a sharp contact, and is equivalent to the lower part of the Goose Egg Formation in central Wyoming (Love, Christiansen, and Ver Ploeg, 1993).

PIPm Minnelusa Formation (Lower Permian / Pennsylvanian) – The Minnelusa comprises 650 to 800 feet (198 to 244 m) of thick, massive, white to yellowish and reddish gray, varying to gray, light-brown and red, well-sorted and cemented, cross-bedded, fine- to coarse-grained sandstone accompanied by varying amounts of red and white solution breccia, purplish gray to pink limestone and dolomite, and red, purple, and black shale (Bergendahl, Davis, and Izett, 1961; Mapel and Pillmore, 1963; Whitcomb and Morris, 1964). The Minnelusa Formation (**Figure 9**) is variable in lithologic details across the region. Solution (or collapse) breccia is dominantly represented by anhydrite in the subsurface, and is well exposed in the upper 164 feet (50 m) of the formation in the Tinton 1:24,000-scale Quadrangle (Borella, 2000). The basal part of the formation is distinguished radiometrically by slight uranium anomalies (DeWitt and others, 1989). Oil is produced from the Minnelusa Formation near the western edge of the Sundance 30' x 60' Quadrangle, and was also produced in the past from the small abandoned Rocky Ford Field northeast of Sundance (De Bruin, 2002).

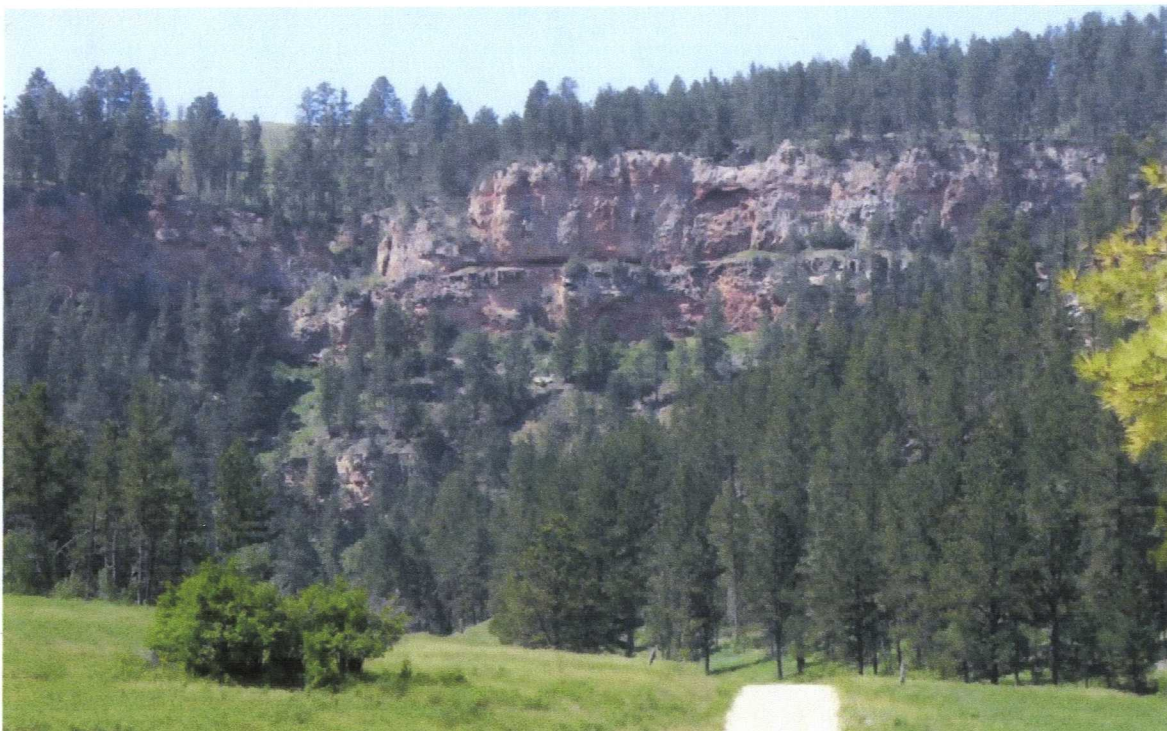


Figure 9. Minnelusa Formation along Cold Springs Creek on the west flank of the Black Hills, west of Mineral Hill.

- MD Pahasapa Limestone and Englewood Formation undifferentiated** – Where the Englewood Formation is present, it is generally mapped with the Pahasapa because of its thinness; in the Black Buttes area it was combined with underlying units (Elwood, 1978). The Englewood Formation underlies the Pahasapa with a gradational contact in places. This combined unit occurs in the eastern part of the quadrangle adjacent to Mineral Hill and along the flank of the Black Hills.
- Mp Pahasapa Limestone (Lower Mississippian)** – The Pahasapa Limestone consists of approximately 300 to 630 feet (91 to 192 m) of cliff-forming, white to light gray and tan, very fine-grained, thick-bedded, cavernous limestone and dolomitic limestone that contains nodules and layers of chert in some outcrops (Whitcomb and Morris, 1964; DeWitt and others, 1989). The Pahasapa Limestone is equivalent, at least in part, to the Madison Limestone farther west in Wyoming. This unit is identified near Inyan Kara Mountain, at Black Buttes, along the flanks of the Bear Lodge Mountains (where it is 550 feet or 168 m thick), and along the flank of the Black Hills in the eastern part of the map area.
- MDe Englewood Formation (Lower Mississippian / Upper Devonian)** – The Englewood Formation underlies the Pahasapa with a gradational contact in places. It is composed of pink to purplish and light gray, thin-bedded and shaley dolomitic limestone, which varies in thickness from about 30 to 60 feet (9 to 18 m) (Whitcomb and Morris, 1964; DeWitt and others, 1989). The Englewood crops out in the southeastern part of the quadrangle along the flank of the Black Hills.
- Pzl Englewood Formation, Whitewood Dolomite, Winnipeg Formation, and Deadwood Formation undifferentiated** – These units are undifferentiated in two small areas within

the Black Buttes area (Elwood, 1978). Descriptions of the Whitewood Dolomite, Winnipeg Formation, and Deadwood Formation are given below.

O€ Whitewood Dolomite, Winnipeg Formation, and Deadwood Formation undifferentiated – These units are combined in the Tinton - Mineral Hill part of the Black Hills because of map scale limitations, the thinness of the Whitewood and Winnipeg formations, and the heavy vegetative cover and soils that obscure most of the contacts.

Ow Whitewood Dolomite and Winnipeg Formation – These thin, poorly exposed units are mapped together in some areas due to considerations of map scale and lack of detailed original mapping.

The **Whitewood Dolomite (Upper Ordovician)** varies from 0 to approximately 150 feet (46 m) thick where exposed in the Sundance 30' x 60' Quadrangle, and consists of tan to gray dolomite (DeWitt and others, 1989). Staatz (1983) described the unit as a poorly exposed, light gray, massive to thin-bedded, fine-grained limestone with pink mottles up to approximately 1.6 inches (4 cm) across. The Whitewood may contain chert nodules in the Tinton 1:24,000 scale quadrangle where its thickness ranges from 50 to 60 feet (15 to 18 m) (Borella, 2000). The Whitewood is mapped as a discontinuous individual unit up to 150 feet (46 m) thick in the Bear Lodge Mountains (Staatz, 1983).

The **Winnipeg Formation (Middle Ordovician)** underlies the Whitewood, and is identified in some studies, but is not mapped separately in the Sundance 30' x 60' Quadrangle. It consists of 0 to 110 feet (34 m) of light green to gray shale and siltstone (DeWitt and others, 1989). Within the Tinton 1:24,000 scale quadrangle, Borella (2000) reported a Winnipeg thickness of 66 to 82 feet (20 to 25 m). The Winnipeg was not identified in the Bear Lodge Mountains by Staatz (1983), although he described about 50 feet (15 m) of shale between an upper quartzite unit of the Deadwood Formation and the Whitewood.

O€d Deadwood Formation (Upper Cambrian to Lower Ordovician) – The Deadwood Formation varies from as little as 4 feet (1.2 m) to as much as 700 feet (213 m) thick. In the Bear Lodge Mountains, it is dominantly quartzite and interbedded shaly limestone that has been replaced by Tertiary intrusive bodies in many areas (Staatz, 1983). A hard white medium-grained quartzite 20 to 30 feet (6 to 9 m) thick marks the upper part of the Deadwood in some parts of the Bear Lodge Mountains. Beneath this is about 30 feet (9 m) of brown to red, medium-grained, thin-bedded quartzite with locally present worm burrows. The remaining lower part of the formation comprises fine-grained pink to red limestone with glauconitic silty partings interbedded with at least three additional hard white quartzites, some thin shale or slate layers, and a local basal conglomerate (Staatz, 1983; DeWitt and others, 1989).

Elwood (1978) describes the upper part of the Deadwood Formation in the Black Buttes Area as 150 feet (46 m) of red to green, flaggy limestone and dolomite, dolomitic siltstone, and dark-gray shale; the remainder of the (assumed) much thicker unit is not exposed.

The Deadwood is mapped as an individual unit in the Black Buttes area, and in the Bear Lodge Mountains, but is combined with overlying formations in the Mineral Hill area due to considerations of map scale.

PRECAMBRIAN CRYSTALLINE ROCKS

PROTEROZOIC

- XWp Pegmatite (Early Proterozoic or Late Archean?)** – Pink to light tan pegmatite bodies in the Mineral Hill area are characterized by anomalously high concentrations of tin and lithium, as well as minor beryllium and boron. Smith and Wayland (1939) and Welch (1974) both separated the pegmatites into two types: either tin-bearing or simple. However, map scale considerations required combining the two. These pegmatites may be Late Archean, or they may be the same age as the Early Proterozoic ($1,697 \pm 33\text{Ma}$) Harney Peak Granite that crops out about 20 miles (32 km) southeast of the map area in South Dakota (DeWitt and others, 1989).
- XWb Metabasalt (Early Proterozoic or Late Archean?)** – Dark green to black amphibolite and amphibole schist derived from 50- to 200-foot (15- to 61-m)-thick tholeiitic basalt and basaltic tuff crop out in the Mineral Hill area. This unit may be Early Proterozoic or Late Archean (DeWitt and others, 1989).
- XWg Metagreywacke (Early Proterozoic or Late Archean?)** – An unknown thickness of gray siliceous mica schist and impure quartzite, derived mostly from greywacke, crop out in the Mineral Hill area. This unit may be Early Proterozoic or Late Archean (DeWitt and others, 1989).

ARCHEAN

- Wg Granite (Late Archean)** – Light gray to tan, medium-grained granite in the Bear Lodge Mountains occurs as isolated bodies within a larger mass of Tertiary igneous rocks. As such, the granite is fractured and somewhat altered. Common minerals in the Bear Lodge granite are quartz (20 to 35%), albite, and microcline, with accessory minerals represented by biotite, apatite, magnetite, monazite, hornblende, anatase, galena, rutile, pyrite, fluorite, and zircon. U-Th-Pb zircon analysis from the Bear Lodge Mountains gives a minimum age of **2.63 Ga** (Staatz, 1983).

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