PRELIMINARY GEOLOGIC MAP

of the

SUNDANCE 1:100,000 SCALE QUADRANGLE

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INTRODUCTION

The Sundance (1:100,000) quadrangle is located along the western edge of the Black Hills uplift and includes the northeastern part of the Powder River Basin, Wyoming. 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.

The largest stream in the quadrangle is the Belle Fourche River, which crosses the northwest part of the quadrangle from southwest to northeast. Inyan Kara Creek, Buffalo Creek, and several others drain northwestward 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 northeastern part of the quadrangle. Iron Creek, Skull Creek, Stockade Beaver Creek, and several others flow southward from the southern parts of the quadrangle. At least three different streams named Beaver Creek drain parts of the quadrangle in three different directions: NE, NW, and SE.

Thirty-two 1:24,000 quadrangles that comprise the Sundance 1:100,000 scale quadrangle are listed northwest to southeast as follows: Edith Creek, Carlile, Wonder View, The Rocks, Sundance West, Sundance East, Red Canyon Creek, Tinton, Moorcroft, Grasshopper Butte, Iron Mountain, Linden, Pfeiffer Hill, Duling Hill, Moskee, Old Baldy, Spyglass Hill, Freda Creek, Thornton, Arrowhead Reservoir, Sheldon Creek, Inyan Kara Mountain, Dry Draw, Buckhorn, Cedar Draw, Soda Butte, Upton West, Upton East, Clay Spur, Skull Creek, Four Corners, and Parmlee Canyon.

The western Black Hills and the northeastern Powder River Basin within the Sundance 1:100,000 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 found at Mineral Hill, Black Butte, Inyan Kara Mountain, Bear Lodge Mountains, and at Devils Tower and Missouri Buttes north of the quadrangle. 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.

ECONOMIC GEOLOGY

The Sundance (1:100,000-scale) metric map, northeastern Wyoming and far northwestern South Dakota (see Attached index map), was selected for this proposal due to the significant geological values associated with the map area. This sheet 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; Hausel,1997). The geologic environment within these young intrusions is similar to Cripple Creek. Because of these similarities, the region is of interest to several exploration groups. Two companies have recently staked much of the Mineral Hill district for gold and silver, at least two companies have interests in the Bear Lodge Mountains for gold, and several prospectors have shown interest in Sand Creek for placer gold.

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

In addition, the region has potential for the development of coal, oil & gas, limestone, uranium and vanadium, bentonite, and for gemstones. Micro diamonds and some garnets were recovered from a coal seam in the Gillette area of the Powder River Basin to the west of the Sundance 1:100,000 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 potential for diamonds within the area of the Sundance Quadrangle. Beryl is reported as an accessory mineral in pegmatites in 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 from the same area.

GEOLOGIC MAP UNITS

The geology for the Sundance 1:100,000 scale quadrangle was compiled from existing mapping and supplemented by aerial photo interpretation and cursory field checks. The rock units described here apply to the thirty-two 1:24,000 scale quadrangles that comprise the

Sundance 1:100,000 scale quadrangle. These rock units were generalized and combined as expedience of the map scale. Similarly, some contacts between units, particularly Quaternary and Tertiary units, are uncertain, but are shown as solid rather than dashed lines. Geologic units within the map area range in age from Archean to Quaternary.

QUATERNARY

Holocene and Pleistocene alluvium (Qal): Alluvium comprises unconsolidated sand, silt, clay, coarse gravels and cobbles, located in and along most drainages. This unit, compiled from many sources including air photo interpretation, may include eluvial deposits, slope wash and small alluvial and colluvial deposits (Qc) along drainages. Thicknesses vary widely, from a thin veneer to several tens of feet.

Holocene and Pleistocene colluvium and slope wash (Qcs): Colluvial deposits; includes slope wash and some alluvial deposits. Although such deposits are abundant in areas of steep slopes, they are shown only in a few areas due to considerations of scale and depiction of bedrock rather than surficial geology.

Holocene and Pleistocene landslide debris (Qls): Locally derived landslide debris from unstable, generally steep slopes. This map unit was compiled from many sources (see references) and supplemented by air photo interpretation.

Holocene and Pleistocene (& ? Pliocene) terrace, pediment, and gravel deposits (Qt): 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. Terrace deposits as much as 20 feet thick in some places were mapped by Mapel and Pillmore (1963, 1964) at several locations in the south central part of the Sundance 1:100,000 scale quadrangle. They identified some of these as Quaternary and some of the highest level deposits as Tertiary. The actual ages of these deposits are unknown and they are combined in this map. A few terrace deposits were also mapped from aerial imagery.

TERTIARY

Late Miocene / Pliocene Ogallala Formation (To): Poorly exposed gravels, conglomerates, sands, and silts, ranging from 3 to 54 feet in thickness were mapped along the north, west, and east flanks of the Bear Lodge Mountains as the Miocene Ogallala Formation by Staatz (1983). The unit is expressed as broad, flat-topped ridges supporting thick pine growth or grass on thick (~20") soils. The conglomerates are poorly sorted with subangular to subrounded trachyte and phonolite clasts ranging in size from about 0.16" to 18" accompanied by minor amounts of Paleozoic debris on a white calcareous sandstone matrix. Designation of these beds as Ogallala by Staatz (1983) was based on the earlier works of Lugn and Brown (1952) and Elias (1942) and their studies of 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 on the White River. Where the White River is absent, the Ogallala is in angular unconformity with Cambrian to Jurassic sedimentary units.

Oligocene [upper Eocene] White River Formation (Twr): The White River Formation crops out as discontinuous isolated remnants on the north flank of Mineral Hill in the eastern part of the Sundance 1:100,000 scale quadrangle and in the Bear Lodge Mountains immediately north of the edge of the quadrangle. The White River Formation is composed of as much as 115 feet 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 White River Formation is Oligocene in age according to the stratigraphic nomenclature for Wyoming as set down by Love, Christiansen, and Ver Ploeg (1993). However, studies by Lilligraven (1993) interpret its age to be upper Eocene (Chadronian).

Paleocene and Eocene intrusive and volcanic rocks: Tertiary alkalic igneous rocks crop out in the eastern and north-central part of the Sundance 1:100,000 scale quadrangle where they form small stocks, laccoliths, irregular bodies, dikes, and sills where they cut rocks ranging from Precambrian to Cretaceous in age. These rocks form the central parts of several uplifts including the Bear Lodge Mountains, Mineral Hill, Black Butte, Inyan Kara Mountain, and Sundance Mountain. Most of these rocks are porphyritic and were emplaced close to the surface, had rapid cooling rates, and exhibit flow banding (Staatz, 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). 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 (Staatz, 1983). Small carbonatite outcrops are found in the Bear Lodge Mountains just north of the Sundance 1:100,000 scale quadrangle.

Phonolitic intrusive rocks (Tp): This unit represents greenish-gray to medium-gray and dark gray phonolite and related rocks that have been 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 as nepheline syenite porphyry. Phonolite is also found in the Bear Lodge Mountains north of the Sundance 1:100,000 scale 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).

Lamprophyre sill (Tl): A lamprophyre sill crops out near Miller Creek in the western part of the Bear Lodge Mountains. This sill extends for about 2.8 miles, is approximately 10- to 40-ft thick, and intrudes the middle of the Sundance Fm (Staatz, 1983). This sill consists of .04”-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" long (Staatz, 1983). Other lamprophyre outcrops are found just north of the Sundance 1:100,000 scale quadrangle.

Lamprophyre and filled amygdules.

Lamprophyre sill intruded into Sundance Fm. along South Fork Miller Creek.

Trachytic intrusive rocks (Tt): 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) identifies rocks at Inyan Kara Mountain as alkali rhyolite.

Quartz latite intrusive rocks (Tql): A small laccoliths of light-gray to tan quartz latite crop out at Sundance Mountain and a resistant flow-foliated plug of quartz latite northeast of Sundance comprises 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) classifies the rocks at Sundance Mountain as subalkalic rhyolite, and at least some of those at Sugarloaf as trachyte.

Intrusive breccia (Tb): 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" 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 about ¼ mile north of the map area.

Pyroclastic deposits (Tpy): 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" 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") vesicles filled with opal and/or chalcedony.

Paleocene Fort Union Formation: The Fort Union Formation crops out only along the western edge of the Sundance 1:100,000 scale quadrangle, and is distinguished from similar appearing strata the underlying Lance Formation by the presence of thin coal seams (Whitcomb and Morris, 1964).

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

Tullock Member (Tft): The Tullock Member is a 500- to 1100-foot 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 becomes thinner to the north, and thicker to the west from the map area. The Tullock's contact with the underlying Lance Formation is conformable. 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).

MESOZOIC

Upper Cretaceous Lance Formation (Kl): The Lance Formation consists of 500 to 1600 feet of poorly exposed, nonmarine, interbedded, yellowish-gray, friable, fine- to medium-grained sandstone, medium-gray sandy claystone, and shaley siltstone 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 thicker than a few feet, and are thin to thick bedded and cross laminated. Where thick, the sandstone 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 Lance Formation increases in thickness toward the south. Its contact with the underlying Fox Hills is located at the base of the lowest gray bentonitic clay or carbonaceous shale above the sandstone (Whitcomb and Morris, 1964).

Upper Cretaceous Fox Hills Sandstone (Kfh): The Fox Hills Sandstone is 150 to 200 feet of light-gray to light yellowish-gray, friable, very fine- to medium-grained, soft, thin bedded marine sandstone, poorly exposed in outcrops, that forms grassy ridges standing about 100 feet above the less resistant and underlying Pierre Shale. The unit is interbedded near the base, and in occasionally in the upper part, with gray sandy shale. It locally hosts 1- to 2-foot thick by several feet long brown weathering ferruginous sandstone concretions in the lower part. The contact between the Fox Hills and the Pierre is gradational through an interval of about 20 to 30 feet (Mapel, Robinson, and Theobald, 1959; Mapel and Pillmore, 1964; Whitcomb and Morris, 1964).

Upper Cretaceous Pierre Shale: About 1755 to 2575 feet of dark-gray to black shale with minor thin siltstone and silty sandstone, bentonite beds, and abundant large limestone concretions comprises the Pierre Shale (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, with its basal section is notable for uranium anomalies that lack coincident thorium (DeWitt and others, 1989). The age of the Pierre Formation 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).

Upper part of Pierre Shale (Kpu): The upper part of the Pierre Shale consists of about 300 feet of dark-gray shale interbedded in the upper 20 to 50 feet 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 long septarian limestone concretions that are also found throughout the unit (Mapel and Pillmore, 1964).

Kara bentonite member (Kpk): The Kara bentonite member is composed of about 90 feet 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 long that weather out from the bentonite are abundant (Mapel and Pillmore, 1964).

Middle part of Pierre Shale (Kpm): Roughly 900 feet of dominantly dark-gray shale makes up the middle part of the Pierre Shale. This is accompanied in the upper two thirds of its thickness by 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).

Mitten black shale member (Kps): The Mitten, 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. Mapel and Pillmore (1964) give a thickness for the Mitten of about 650 feet based on drill hole data, but also state a thickness of "several hundred feet" where poor exposures limit the accuracy of surface measurements. 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 hosts about 35 feet of interbedded yellowish-gray bentonite and shale (Mapel, Robinson, and Theobald, 1959).

Gammon ferruginous member (Kpg): The Gammon is roughly 575 to 650 feet of dominantly medium- to dark-gray, noncalcareous shale that weathers to a gray that is distinctly lighter than the 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 of this member that is gradational with the underlying Niobrara. Septarian concretions that average 1 to 2 feet in length and weather to gray are found in the upper 50 to 75 feet of this member (Mapel and Pillmore, 1964).

Upper Cretaceous Niobrara Formation (Kn): The Niobrara consists of about 150 to 225 feet 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. The Niobrara contrasts with the gray-weathering shales of the adjacent formations where calcareous beds within it weather bright orange, yellow, or light-gray. The contact between the Niobrara and the underlying Carlile 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 often hosting 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).

Upper Cretaceous Carlile Shale: The Carlile Shale is 500 to 600 feet 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).

Sage Breaks member (Kcs): The Sage Breaks member is about 290 feet of black to dark-gray shale that is mostly calcareous in the upper 50 feet, with the remainder noncalcareous. Several beds of 1- to 3-foot 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).

Turner sandstone member (Kct): The Turner sandstone member consists of about 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 couple of inches thick, is found in some localities about 120 feet above the base of the member. The base of the Turner is a persistent 2- to 6-foot 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).

Pool Creek shale member (Kcp): The Pool Creek is generally represented by about 50 to 90 feet of dark-gray noncalcareous shale with interlaminations of light-gray siltstone in the upper half, with their greatest abundance near the top. Scattered 0.5- to 1-foot long septarian limestone concretions are found in the middle part of the member (Mapel and Pillmore, 1964). In much of the area, this is referred to as the **unnamed lower member** of the Carlile Shale. The bottom part of this member is variably calcareous and contains a few interlaminations of siltstone and silty shale (Mapel and Pillmore, 1963; Whitcomb and Morris, 1964).

Upper Cretaceous Greenhorn Formation (Kg): The Greenhorn Formation (also known as the Greenhorn Limestone) averages about 70 to 100 feet in thickness, but is as much as 270 feet 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 in diameter, weather light-gray and contain veins of brown and orange calcite. The limestones at the top of the formation are often ridge-formers. The contact with the underlying Belle Fourche 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).

Upper Cretaceous Belle Fourche Shale (Kb): This unit varies from 350 to 850 feet in thickness, averaging around 700 feet (Bergendahl, Davis, and Izett, 1961), and is composed of nonresistant black to dark-gray bentonitic shale containing minor limestone lenses, and large (up to 3 feet in diameter), very hard, dark-red to purplish-black weathering siderite concretions in the basal 50 feet. The lower part of the Belle Fourche hosts several thin bentonite beds, two of which reach thicknesses of 1.5 and 3.0 feet. The base of the formation is arbitrarily placed at the top of the underlying Clay Spur Bentonite in the Mowery Formation where lithology changes from nonresistant shales above to hard siliceous shales below. The upper part of the formation is dominated by dark-gray to black shale and hosts yellow septarian limestone concretions that average 1 to 2 feet in length (Mapel and Pillmore, 1963 & 1964; Whitcomb and Morris, 1964). 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).

Upper Cretaceous Mowry Shale (Kmr): The Mowry Shale consists of 125 to 230 feet of black, generally weathering to silver-gray, hard and resistant, siliceous shale interbedded with numerous 0.1- to 1.5-foot thick bentonite beds, and a few thin siltstones. The Mowry outcrop is marked by its weathering into small, thin, brittle chips, and in many places by a moderate growth of small pine trees that are absent on adjacent units. Fossils are generally rare within the Mowry, but fish scales are abundant. In the south-central part of the map area, the lower 20 feet 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. Near the top of the formation is the Clay Spur Bentonite, a 2.5- to 4.5-foot thick bentonite bed that has been commercially mined. 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) cite an age for the Mowry Shale in Wyoming of **94-98 Ma**.

Lower Cretaceous Newcastle Sandstone (Knc): The Newcastle Sandstone is represented within the map area by 0 to about 60 feet 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. It outcrops in a light-colored band with a 2- to 5-foot 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 and the overlying Mowry. Limited local mining of the bentonite has been done. The Newcastle conformably overlies the Skull Creek Shale (Mapel and Pillmore, 1963 & 1964; Whitcomb and Morris, 1964). The Newcastle Sandstone has produced oil in the western part of the map area (De Bruin, 2002).

Lower Cretaceous Skull Creek Shale (Ksc): The Skull Creek Shale locally forms badlands and low hills that in general are sparsely vegetated with grass and sage where it crops out in the central part of the Sundance 1:100,000 scale quadrangle (Mapel and Pillmore, 1964). The 180 to 270 foot thick Skull Creek is predominantly a unit 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). 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. These dikes are in general rectilinearly oriented E-W and N-S, vary in thickness from about 0.5 to 1.5 feet, 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).

Lower Cretaceous Inyan Kara Group and Upper Jurassic Morrison Formation combined (KJim): The Inyan Kara Group includes the Fall River Formation and the Lakota Formation and is distinguished by high concentrations of uranium and only small amounts of potassium within the group (DeWitt and others, 1989). The Fall River and Lakota 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). These units are combined in the central part of the area where detailed mapping is absent.

Lower Cretaceous Fall River Formation (Kf): The Fall River Formation crops out in the central part of the Sundance 1:100,000 quadrangle, and is 100 to 200 feet 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 two-inch thick silty or finely sandy, dark-brown, iron-rich beds and nodules are common throughout the Fall River Formation. The Fall River has produced oil in the western part of the map area (De Bruin, 2002). The Fall River also contains local uranium deposits in the northern Black Hills (Bergendahl, Davis, and Izett, 1961). The Fall River is often informally separated into an upper and lower part over much of its outcrop, but is mapped as an undivided unit in the northwest-central part of the quadrangle.

Upper Fall River Formation (Kfu): The upper part of the Fall River Formation, generally 70 to 80 or more feet thick, is topped by 10 to 30 feet of thin-bedded, nonresistant siltstone, sandstone, and shale that grades upward into the overlying black marine shale of the skull creek formation. Beneath this and in sharp contact with the lower Fall River, is one or more resistant, massive to subtly crossbedded 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).

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

Lower Cretaceous Lakota Formation (Kla): The Lakota Formation varies widely in both thickness and composition across the map area, and represents a continental depositional environment. It ranges from as thin as 45 feet up to about 300 feet thick (Bergendahl, Davis, and Izett, 1961). It consists of complexly interfingering and lenticular beds of sandstone, siltstone, and claystone. 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 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. 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 of the formation here hosts abundant iron-rich, 1 mm diameter, spherical pellets (Mapel and Pillmore, 1963). Near the middle of the formation, unconsolidated claystone contains gastroliths, that is pebbles and cobbles of polished quartzite and chert (Bergendahl, Davis, and Izett, 1961).

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. The contact between the Lakota and the underlying Morrison is sharp and conformable (Mapel and Pillmore, 1963; Whitcomb and Morris, 1964). The Lakota Formation has produced oil in the western part of the Sundance 1:100,000 scale quadrangle (De Bruin, 2002). The Lakota Formation hosts uranium deposits in the northern part of the Sundance 1:100,000 scale quadrangle, and has produced uranium in the past from the vicinity of Carlile (Bergendahl, Davis, and Izett, 1961).

Upper Jurassic Morrison Formation (Jm): The Morrison Formation varies in from being totally absent in some areas to as much as 150 feet thick north of Inyan Kara Mountain, but is generally in the range of 80 to 120 feet thick across the map area. 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 of the formation 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 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 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.

Upper and Middle Jurassic Sundance and Middle Jurassic Gypsum Spring Formations combined (Jsg): These formations, described below, are mapped together in the east central part of quadrangle where more detailed mapping is lacking. Contact between this combined unit and areas with more detailed unit subdivisions described below is arbitrarily marked with a dotted line in some locations.

Upper and Middle Jurassic Sundance Formation: The Sundance Formation hosts about 375 feet 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). The formation is sequentially divided up in some areas into the Canyon Springs sandstone member at the bottom, the overlying Stockade Beaver shale, the Hulett sandstone, the LAK member, and the Redwater shale members at the top (Mapel and Pillmore, 1963 & 1964).

Redwater shale member, LAK member, and Hulett sandstone member combined (Jsh): Within the Sundance 1:100,000 scale quadrangle, these three members of the Sundance Formation are mapped as one unit.

The Redwater shale member is 35 to 165 feet 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 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 an absence of glauconite (Mapel and Pillmore, 1963 & 1964). The Redwater appears as gentle grass-covered slopes interrupted by thin resistant ledges of sandstone and limestone (Bergendahl, Davis, and Izett, 1961).

The LAK member 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 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 is the most prominent member, exposed as steeply sloping to cliff-forming outcrops that cap low ridges and buttes. It is made up 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 generally is about 55 to 90 feet thick, but is not present at some locations (Mapel and Pillmore, 1963).

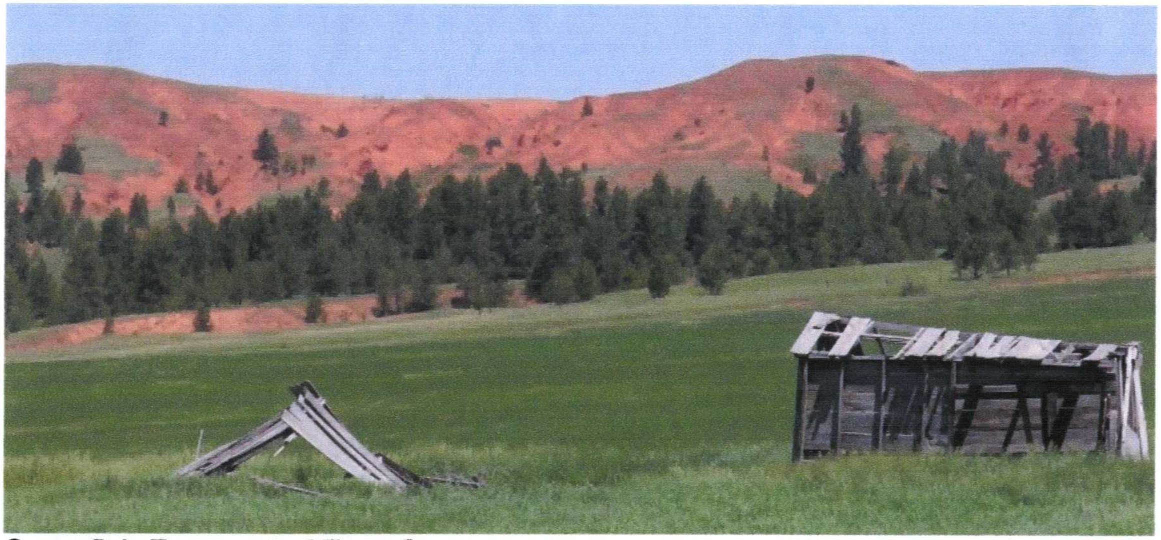
Stockade Beaver shale member, Canyon Springs sandstone member, and Middle Jurassic Gypsum Spring Formation combined (Jsb): Within the Sundance 1:100,000 scale quadrangle, these two members of the Sundance Formation and the thin to absent Gypsum Spring Formation are mapped as one unit.

The Stockade Beaver shale member 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 of the members is thick, the other is thin (Mapel and Pillmore, 1963).

The Canyon Springs sandstone member 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 shelf of fossiliferous, sandy oolitic limestone. The base of this member usually is a few inches to several feet of greenish-gray calcareous siltstone. The Canyon Springs member unconformably, but smoothly, overlies the Gypsum Springs Formation, or where it is absent, the Spearfish Formation (Mapel and Pillmore, 1963). Because of 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 Middle Jurassic Gypsum Spring Formation varies from 0 to 125 feet thick, and consists of interbedded massive white gypsum, minor red claystone, and thin gray cherty limestone (Whitcomb and Morris, 1964). The formation 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. In maps, the formation is often combined with part, or all of the overlying Sundance Formation. The Gypsum Spring unconformably overlies the Spearfish Formation (Mapel and Pillmore, 1963 & 1964).

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



Spearfish Fm. west of Four Corners.

PALEOZOIC

Lower Permian Minnekahta Limestone and Opeche Shale combined (Pmo): Where detailed mapping is lacking, these two formations are shown as a combined unit in the eastern part of the Sundance 1:100,000 scale quadrangle. The contact between the Minnekahta and the Opeche is left open-ended where the detailed mapping transitions to areas where the units are combined. The Minnekahta and Opeche are described below.

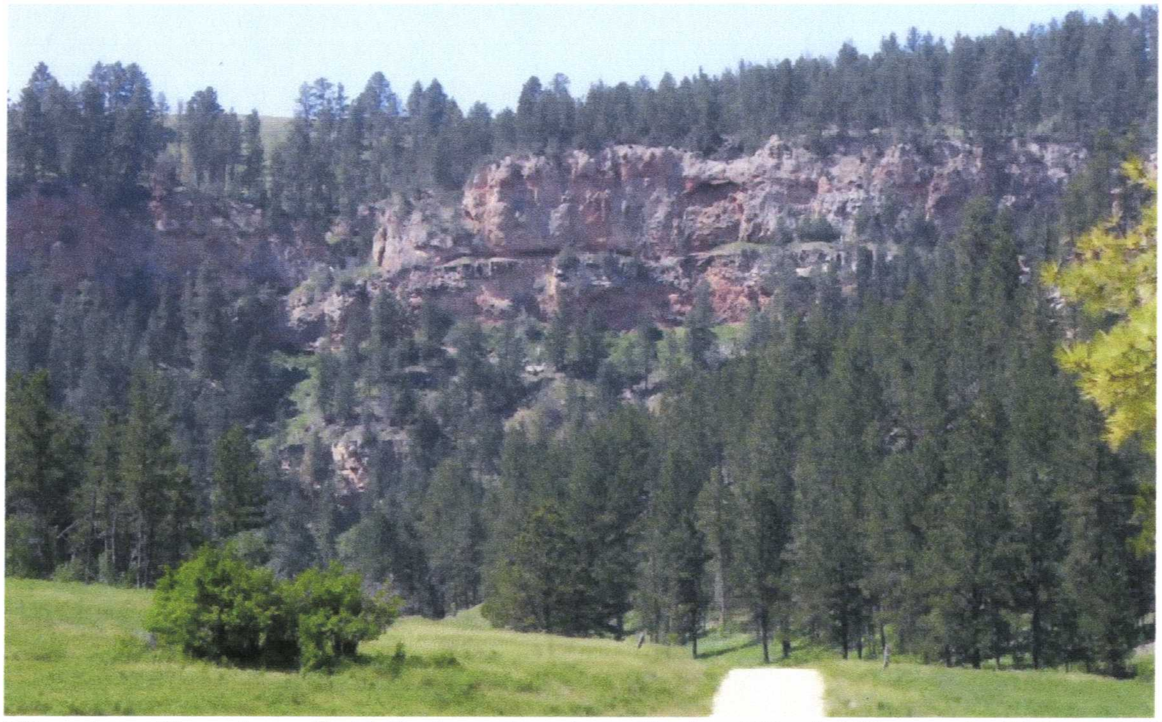
Lower Permian Minnekahta Limestone (Pmk): The Minnekahta Limestone consists of 35 to 50 feet of light-gray, finely crystalline, thin-bedded limestone and purplish- to pinkish-gray dolomitic limestone, with stylolites common throughout (Mapel and Pillmore, 1963: Whitcomb and Morris, 1964; DeWitt and others,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

Large sinkhole in Minnekahta Ls. in southeastern part of map area.

Lower Permian Opeche Shale (Po): 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). It consists of 60 to 95 feet 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 Opeche 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.

Lower Permian / Pennsylvanian Minnelusa Formation (PIPm): The Minnelusa makes up about 650 to 800 feet of thick, massive, white to yellowish- and reddish-gray, varying to gray, light-brown and red, well-sorted and cemented, crossbedded, 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 character of the formation 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 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). The Minnelusa Formation has been an oil producer near the western edge of the Sundance 1:100,000 scale quadrangle. Oil was also at one time produced from the small and abandoned Rocky Ford Field northeast of Sundance (De Bruin, 2002).



Minnelusa Fm. along Cold Springs Creek on flank of Black Hills west of Mineral Hill.

Lower Mississippian Pahasapa Limestone (Mp): The Pahasapa Limestone represents about 300 to 630 feet (550 feet in the Bear Lodge Mountains) 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 identifed near Inyan Kara Mountain, Black Buttes, along the flanks of the Bear Lodge Mountains, and along the flank of the Black Hills in the eastern part of the map area.

Lower Mississippian Pahasapa Limestone and Lower Mississippian/ Upper Devonian Englewood Formation undifferentiated (MDpe): 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. 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 (Whitcomb and Morris, 1964; DeWitt and others, 1989). This combined unit occurs in the eastern part of the quadrangle adjacent to Mineral Hill and along the Black Hills flank.

Lower Mississippian / Upper Devonian Englewood Formation (MDe): 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 (Whitcomb and Morris, 1964; DeWitt and others, 1989). The Englewood crops out in the southeastern part of the quadrangle along the Black Hills flank.

Lower Mississippian/Upper Devonian Englewood Formation, Upper Ordovician Whitewood Dolomite, Middle Ordovician Winnipeg Formation and Upper Cambrian to Lower Ordovician Deadwood Formation undifferentiated (MDO): 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 found below.

Upper Ordovician Whitewood Dolomite, Middle Ordovician Winnipeg Formation, and Upper Cambrian to Lower Ordovician Deadwood Formation undifferentiated (O€wd): These units are combined in the Tinton - Mineral Hill part of the Black Hills due to map scale, the thinness of the Whitewood and Winnipeg formations, and heavy vegetative cover and soils that obscure most of the contacts. Descriptions of these units are found below.

Upper Ordovician Whitewood Dolomite & Middle Ordovician Winnipeg Formation (Ow): These thin, poorly exposed units are mapped together due to considerations of scale and lack of detail in original mapping.

> The **Whitewood Dolomite** varies from 0 to about 150 feet thick where exposed in the Sundance 1:100,000 quadrangle, and is made up places of tan to gray dolomite (DeWitt and others, 1989). However, Staatz (1983) described the unit as a poorly exposed, light-gray, massive to thin-bedded, fine-grained limestone with pink mottles up to ~1.6" across. The Whitewood may contain chert nodules in the Tinton 1:24,000 scale quadrangle where its thickness ranges from about 50 to 60 feet (Borella, 2000). The Whitewood is mapped as a discontinuous individual unit up to 150 feet thick in the Bear Lodge Mountains (Staatz, 1983).
>
> The **Middle Ordovician Winnipeg Formation** underlies the Whitewood, is identified in some studies, but is not mapped separately in the Sundance 1:100,000 scale quadrangle where it consists of 0 to 110 feet of light-green to gray shale and siltstone (DeWitt and others, 1989). Within the Tinton 1:24,000 scale quadrangle, Borella (2000) reports a Winnipeg thickness of 66 to 82 feet. The Winnipeg was not identified in the Bear Lodge Mountains by Staatz (1983), although he described about 50 feet of shale between an upper quartzite unit of the Deadwood Formation and the Whitewood.

Upper Cambrian to Lower Ordovician Deadwood Formation (O€d): The Deadwood Formation varies in thickness from as little as 4 feet to as much as 700 feet. In the Bear Lodge Mountains, it is principally composed of quartzite and interbedded shaly limestone that has in many areas been replaced by Tertiary intrusive bodies (Staatz, 1983). A hard white medium-grained quartzite 20 to 30 feet thick marks the upper part of the Deadwood in some parts of the Bear Lodge Mountains. Beneath this is about 30 feet 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 more hard white quartzites, some thin shale or slate layers, accompanied locally by a 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 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 scale.

PRECAMBRIAN

PROTEROZOIC

Early Proterozoic (or Late Archean?) pegmatite (XWp): 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. The age of these pegmatites may be Late Archean, or they may be the same age as the Early Proterozoic (1,697 ± 33Ma) Harney Peak Granite that crops out about 20 miles southeast of the map area in South Dakota (DeWitt and others, 1989).

Early Proterozoic (or Late Archean?) metabasalt (XWb): Dark-green to black amphibolite and amphibole schist derived from 50- to 200-foot thick tholeiitic basalt and basaltic tuff crop out in the Mineral Hill area. The age of this unit may be Early Proterozoic or Late Archean (DeWitt and others, 1989).

Early Proterozoic (or Late Archean?) metagrawacke (XWgw): An unknown thickness of gray siliceous mica schist and impure quartzite, derived mostly from greywacke, crop out in the Mineral Hill area. The age of this unit may be Early Proterozoic or Late Archean (DeWitt and others, 1989).

ARCHEAN

Late Archean granite (Wgr): 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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PRELIMINARY GEOLOGIC MAP

of the

SUNDANCE 1:100,000 SCALE QUADRANGLE

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Revised August 23, 2006

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MAP UNITS

Details of geologic units are printed in a separate text.

<u>PHANEROZOIC</u>

QUATERNARY

Qal **Holocene-Pleistocene alluvium**

Qcs **Holocene-Pleistocene colluvium and slope wash**

Qls **Holocene-Pleistocene landslide debris**

Qt **Holocene-Pleistocene (& ?Pliocene) terrace, pediment, and gravel deposits**

TERTIARY

To **Late Miocene / Pliocene Ogallala Formation**

Twr **Oligocene (? upper Eocene) White River Formation**

Paleocene & Eocene intrusive and volcanic rocks (~55-54 Ma & ~50-46 Ma)

- **Tp** **Phonolitic intrusive rocks**
- **Tl** **Lamprophyre sill**
- **Tt** **Trachytic intrusive rocks**
- **Tql** **Quartz latite intrusive rocks**
- **Tb** **Intrusive breccia**
- **Tpy** **Pyroclastic deposits**

Paleocene Fort Union Formation

Tftl Tongue River and Lebo Members

Tft Tullock Member

MESOZOIC

Kl Upper Cretaceous Lance Formation

Kfh Upper Cretaceous Fox Hills Sandstone

Upper Cretaceous Pierre Shale

Kpu Upper part of Pierre Shale

Kpk Kara bentonite member

Kpm Middle part of Pierre Shale

Kps Mitten black shale member

Kpg Gammon ferruginous member

Kn Upper Cretaceous Niobrara Formation

Upper Cretaceous Carlile Shale

Kcs Sage Breaks member

Kct Turner sandstone member

Kcp Pool Creek shale member

Kg Upper Cretaceous Greenhorn Formation

Kb Upper Cretaceous Belle Fourche Shale

Kmr Upper Cretaceous Mowry Shale

Knc Lower Cretaceous Newcastle Sandstone

Ksc Lower Cretaceous Skull Creek Shale

KJim Lower Cretaceous Inyan Kara Group and Upper Jurassic Morrison Formation combined

Kf Lower Cretaceous Fall River Formation

Kfu Upper Fall River Formation

Kfl Lower Fall River Formation

Kla Lower Cretaceous Lakota Formation

Jm Upper Jurassic Morrison Formation

Jsg Upper and Middle Jurassic Sundance and Middle Jurassic Gypsum Spring Formations combined

Upper and Middle Jurassic Sundance Formation

Jsh Redwater shale member, LAK member, & Hulett sandstone member combined

Jsb Stockade Beaver shale member, Canyon Springs sandstone member, & Middle Jurassic Gypsum Spring Formation combined

ŦPs Triassic / Permian Spearfish Formation

PALEOZOIC

Pmo Lower Permian Minnekahta Limestone and Opeche Shale combined

Pmk Lower Permian Minnekahta Limestone

Po Lower Permian Opeche Shale

PIPm Lower Permian / Pennsylvanian Minnelusa Formation

Mp Lower Mississippian Pahasapa Limestone

MDpe Lower Mississippian Pahasapa Limestone and Lower Mississippian/ Upper Devonian Englewood Formation undifferentiated

MDe Lower Mississippian / Upper Devonian Englewood Formation

MDO Lower Mississippian/Upper Devonian Englewood Formation, Upper Ordovician Whitewood Dolomite, Middle Ordovician Winnipeg Formation and Upper Cambrian to Lower Ordovician Deadwood Formation undifferentiated

O€wd Upper Ordovician Whitewood Dolomite, Middle Ordovician Winnipeg Formation, and Upper Cambrian to Lower Ordovician Deadwood Formation undifferentiated

Ow Upper Ordovician Whitewood Dolomite & Middle Ordovician Winnipeg Formation

O€d Upper Cambrian to Lower Ordovician Deadwood Formation

PRECAMBRIAN

PROTEROZOIC

XWp Early Proterozoic (Late Archean?) pegmatite

XWb Early Proterozoic (Late Archean?) metabasalt

XWgw Early Proterozoic (Late Archean?) metagrawacke

ARCHEAN

Wgr Late Archean granite (2.63 Ga)

Map Symbols

Rock unit contact

Fault, dotted where projected beneath younger units

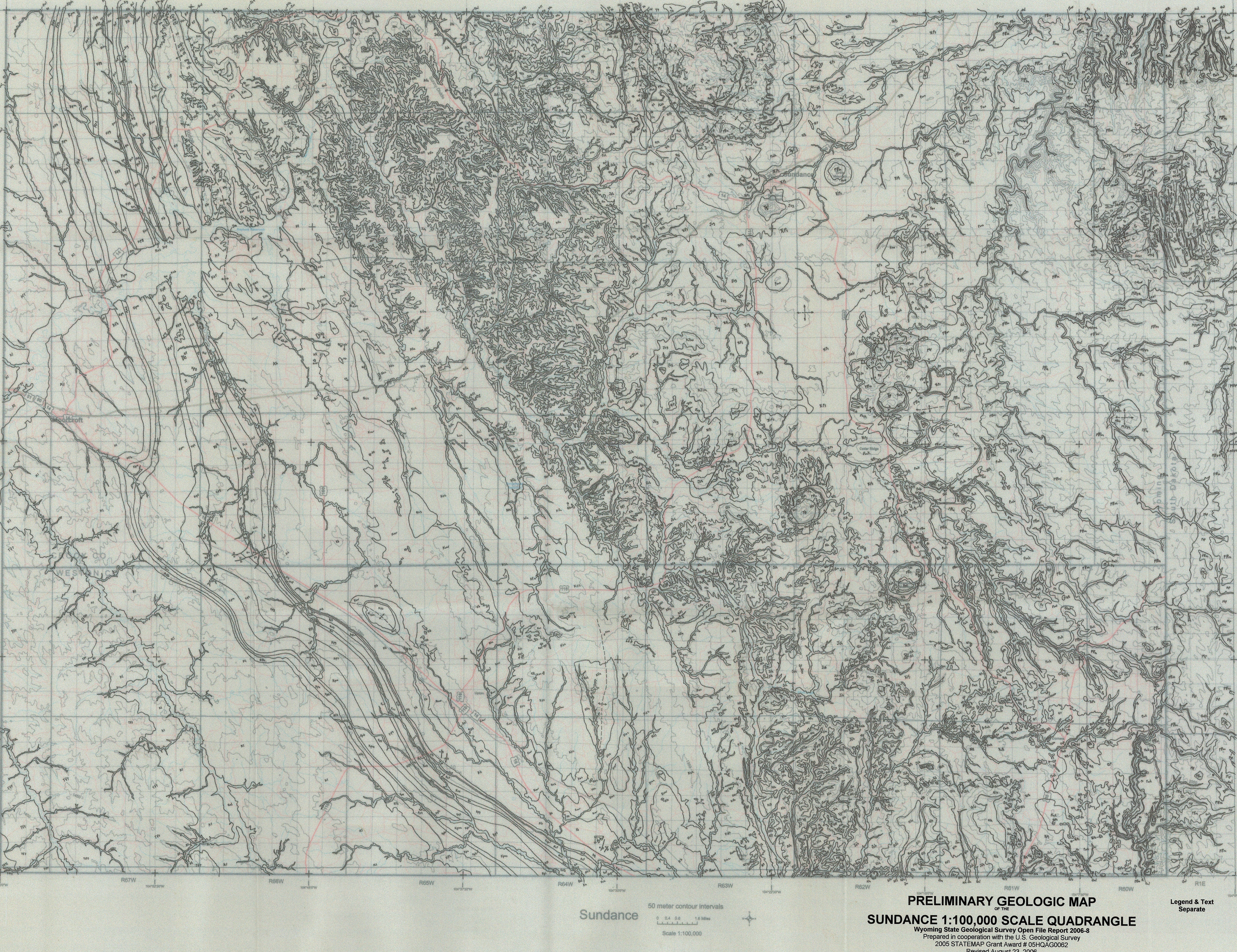
Anticline

Syncline

Dome

Strike and dip of beds

Details of geologic units are printed in a separate text.



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Legend & Text Separate