WYOMING STATE GEOLOGICAL SURVEY
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Laramie, Wyoming

Geology – Interpreting the past to provide for the future

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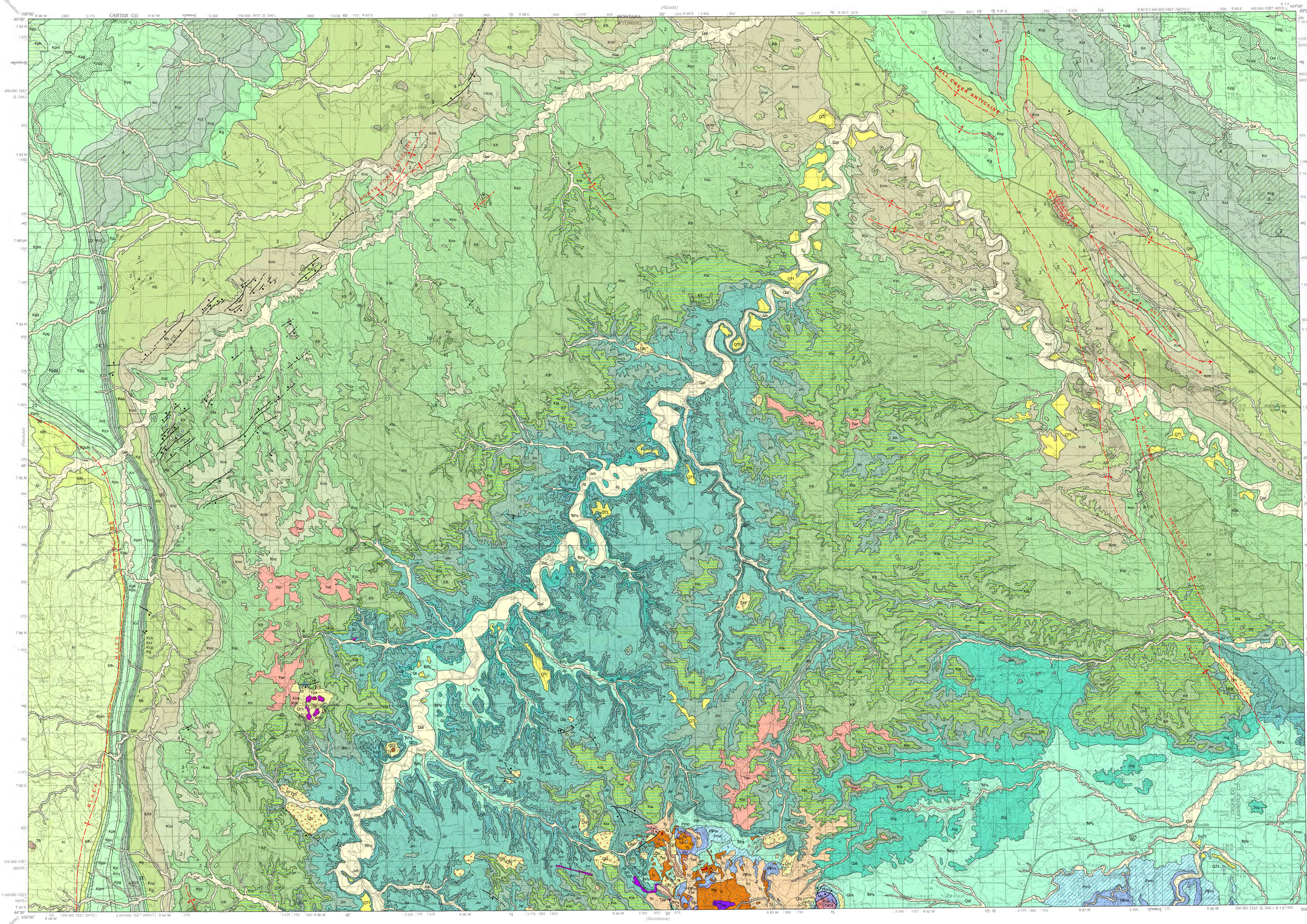
Prepared in cooperation with the U.S. GEOLOGICAL SURVEY

MAP SERIES 81
Devils Tower 1:100,000 - scale Geologic Map

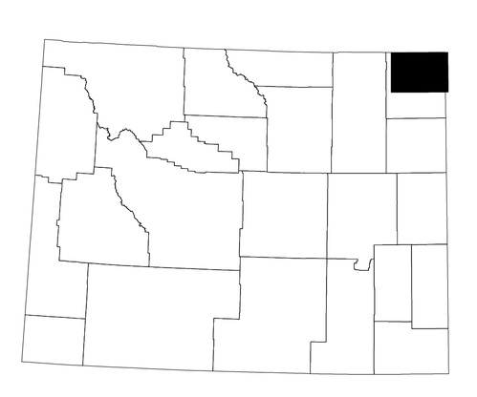


Base map from U.S. Geological Survey Devils Tower, Wyoming - South Dakota-Montana 1:100,000 - scale metric topographic map, 1979.

Projection: Universal Transverse Mercator (UTM), zone 13
North American Datum of 1927 (NAD 27)
10,000-meter grid ticks: UTM, zone 13
25,000-foot grid ticks: Wyoming State Plane Coordinate System, east zone, South Dakota coordinate system, north zone, and Montana coordinate system, south zone

SCALE 1:100,000
Contour interval 20 meters

UTM GRID CONVERGENCE (GN)
1979 MAGNETIC DECLINATION (MN) AT CENTER OF SHEET
DIAGRAM IS APPROXIMATE
0°19' 6 MILS; 14° 249 MILS



WYOMING QUADRANGLE LOCATION

GEOLOGIC MAP OF THE DEVILS TOWER 30' x 60' QUADRANGLE, CROOK COUNTY, WYOMING, BUTTE AND LAWRENCE COUNTIES, SOUTH DAKOTA, AND CARTER COUNTY, MONTANA,

compiled and mapped
by
Wayne M. Sutherland
2008

Digital cartography by Justin E. Scott, Vandy L. Jones, David W. Lucke, and Robin W. Lyons

Editing and map design by Richard W. Jones

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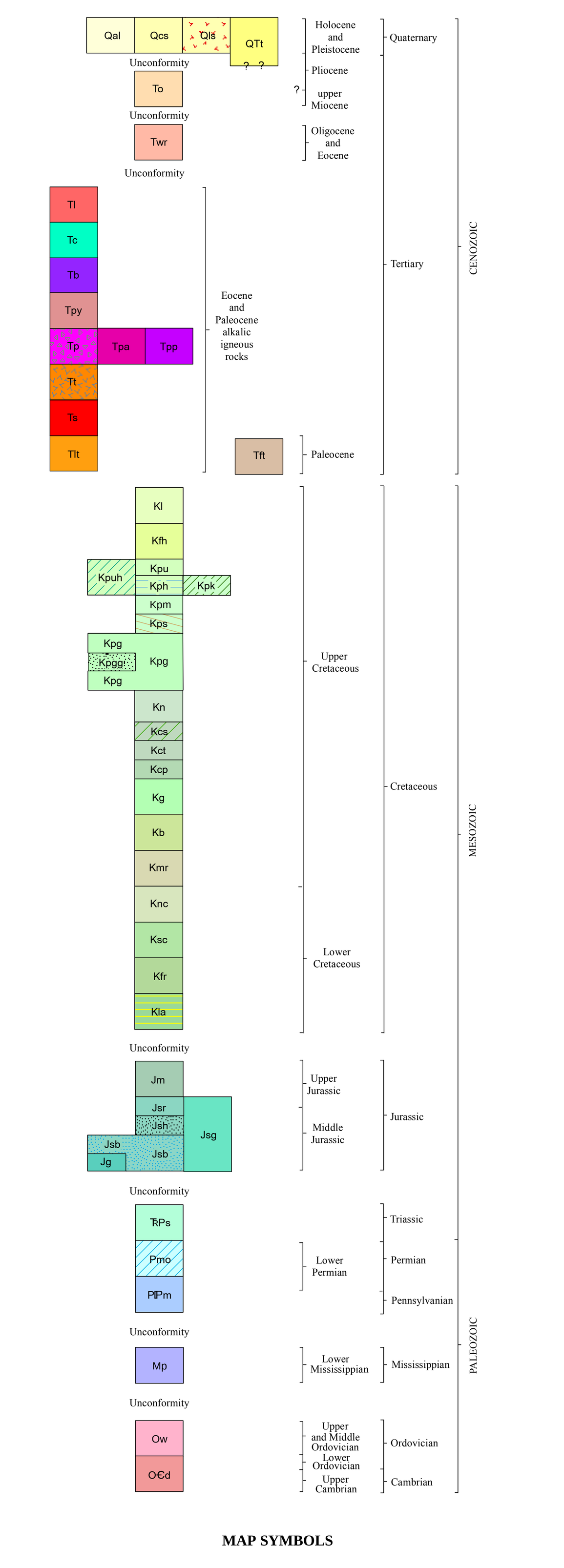
A digital version of this map is also available on CD - ROM.

CORRELATION OF MAP UNITS



MAP SYMBOLS

Formation contact

Fault—Dashed where approximately located, dotted where projected or inferred beneath younger units; ball and bar on downthrown side

Anticlinal axis—Approximately located; arrow on end indicates direction of plunge

Synclinal axis—Approximately located; arrow on end indicates direction of rise

Monoclinal axis—Approximately located; shorter arrow on steeper dipping limb

Strike and dip of beds—Symbol without number indicates dip direction only

Uranium occurrence

DESCRIPTION OF MAP UNITS

Quaternary surficial deposits

Qal **Alluvium**—Unconsolidated sand, silt, clay, coarse gravels, and cobbles located in and along most drainages; may include eluvial deposits, slope wash, small alluvial and colluvial deposits along drainages, and some older terrace deposits along drainages. Thickness varies widely, from a thin veneer to several tens of feet (6+ m)

Qcs **Colluvium and slope wash**—Colluvial deposits, talus, slope wash, and some alluvial deposits; abundant in areas of steep slopes, but shown only where thickest

Qls **Landslide debris**—Locally derived debris from unstable, generally steep slopes

Quaternary and Tertiary surficial deposits

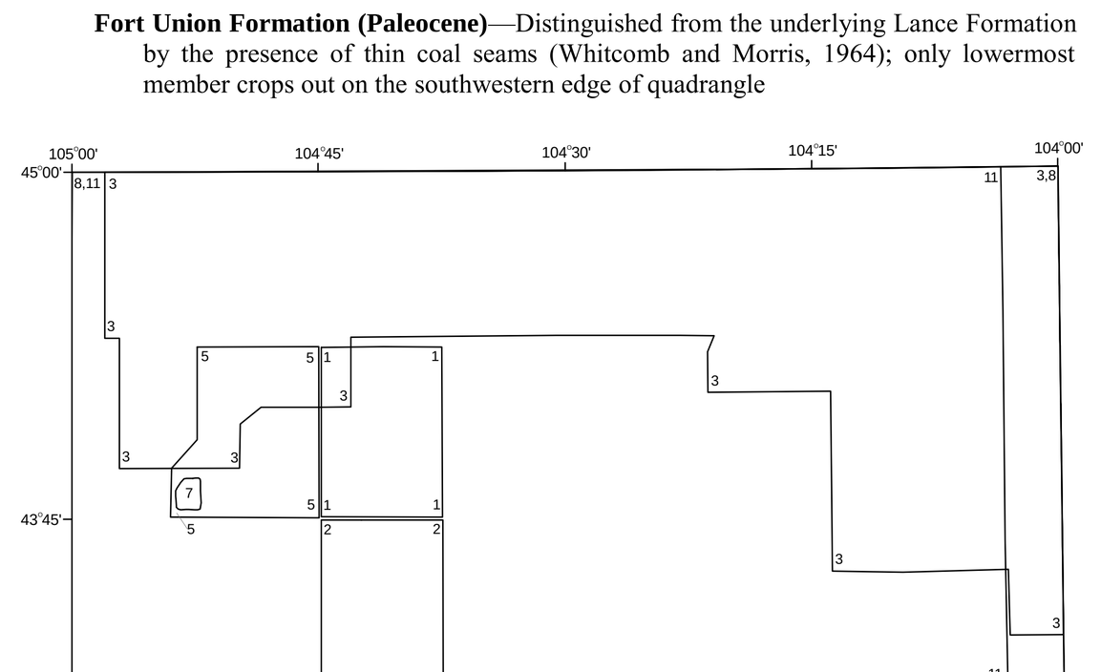
QTt **Terrace, pediment, and gravel deposits (Holocene, Pleistocene, and (?) Pliocene)**—Gravel-covered terrace and/or cobble-, sand-, gravel-, and silt-covered terraces; merge in places with eluvial, alluvial, and colluvial deposits; vary from thin veneers to as much as 40 feet (12 m) thick

Tertiary sedimentary rocks

To **Ogallala Formation (Pliocene/upper Miocene)**—Poorly exposed gravels, conglomerates, sandstones, and siltstones, ranging from 3 to 54 feet (0.9 to 16 m) in thickness. Conglomerates are poorly sorted with subangular to subrounded trachyte and phonolite clasts ranging in size from about 0.16 to 1 inch (0.4 to 2.5 cm) accompanied by minor amounts of Paleozoic debris in a white calcareous sandstone matrix. Contact with the underlying units is an unconformity, angular where the White River Formation is absent

Twr **White River Group (Oligocene and upper Eocene)**—Tan to buff and white to gray, poorly bedded, friable siltstone, tuffaceous claystone, and clay, with minor limestone lenses; as much as 115 feet (35 m) thick (Robinson and others, 1964; Staatz, 1983). Individual formations (Chadron and Brule) that compose the group elsewhere in eastern Wyoming were not identified or distinguished on this quadrangle. Age of lower part re-assigned to Eocene based on redefinition of Oligocene-Eocene boundary (Lillegraven, 1993)

Fort Union Formation (Paleocene)—Distinguished from the underlying Lance Formation by the presence of thin coal seams (Whitcomb and Morris, 1964); only lowermost member crops out on the southwestern edge of quadrangle



INDEX TO GEOLOGIC MAPPING
(numbers are those listed in the REFERENCES CITED AND SOURCES OF GEOLOGIC DATA)

EXPLANATION

(See accompanying pamphlet for references, detailed descriptions, and discussion)

Tft **Tullock Member**—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; 500 to 1,100 feet (150 to 330 m) thick; thins to north and thickens west of the map area

Tertiary intrusive and related volcanic rocks

Alkalic igneous rocks (Eocene and Paleocene)—Crop out in the south-central part of the Devils Tower 30? x 60? Quadrangle; form sills, plugs, dikes, and irregular bodies that intrude rocks ranging in age from Cambrian to Cretaceous; mostly porphyritic, were emplaced close to the surface, had rapid cooling rates, and exhibit flow banding (Staatz, 1983); extrusive flows and pyroclastic deposits in limited areas; radiometric ages ~50 to 46 Ma (Mega-annum or millions of years before present) (Duke, 2005). Largest volume of these intrusive rocks is either trachyte or phonolite with smaller amounts of latite, syenite, nepheline syenite, lamprophyre, pseudoleucite porphyry, and intrusive breccias (Staatz, 1983)

Tl **Lamprophyre intrusions**—Two small lamprophyre bodies in northwestern Bear Lodge Mountains intrude lower part of the Sundance Formation and the Spearfish Formation

Tc **Carbonatite dike**—Weathered, exposed carbonatite is brown to yellowish-brown mottled; unweathered carbonatite encountered in drill holes is light gray to white and banded with pink, green, white, or purple accessory minerals. Carbonatite is mostly calcite, but contains accessory rare-earth minerals, strontianite fluorite, pyrite pyrrhotite, sphalerite, galena, and locally abundant acmite and actinolite

Tb **Intrusive breccia**—Angular to rounded rock fragments up to 3.9 inches (9.9 cm) hosted within an aphanitic to fine-grained igneous matrix; rock fragments mostly light-gray volcanic rock with small sanidine phenocrysts, with fragments of granite and Deadwood Formation quartzite. Commonly weathers red or yellow from iron oxides (Staatz, 1983); surrounds the only carbonatite dike in the area

Tpy **Pyroclastic deposits**—Small deposits varying from volcanic breccia to tuff; breccia is gray to light brown composed of subangular to subrounded fragments up to 1.6 inches (4 cm) across, mostly of porphyritic volcanic rock, within a glassy matrix; tuff is light brown to white, contains crystal fragments within a devitrified glass (ash)

Tp **Phonolitic intrusive rocks**—Greenish-gray to light- and medium-gray or dark-gray phonolite and related rocks; 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); found at Missouri Buttes

Tpa **Phonolitic agglomerate**—Vesicular aphanitic groundmass with rounded to angular mineral grains; hosts igneous and sedimentary rock fragments (Robinson and others, 1964); occurs in the north-central part of the Missouri Buttes

Tpp **Pseudoleucite porphyry**—Phonolite containing 5 to 20% large white pseudoleucite crystals up to 3.8 cm (1.5 inches) in diameter by 0.5 to 1.0 cm (0.2 to 0.4 inch) long within a medium-gray aphanitic matrix; mapped as pseudoleucite porphyry on the northwestern edge of the Bear Lodge Mountains (Staatz, 1983)

Tt **Trachytic intrusive rocks**—Reddish-brown to tan, iron-stained trachyte in small stocks, laccoliths, sills, and dikes in the Bear Lodge Mountains; Duke (2005) described Devils Tower as a trachyte diatreme

Ts **Syenite and nepheline syenite intrusive rocks**—Dominantly syenite, generally composed of 60 to 80% potassium feldspar accompanied by some plagioclase and 20 to 35% aegirine-augite or augite

Tlt **Latite intrusive rocks**—Unaltered light-gray porphyritic latite that generally contains 30 to 35% phenocrysts ranging from 0.5 to 1.2 mm (0.02 to 0.047 inch) in diameter and dominated by white plagioclase; black prismatic hornblende varies from 1 to 15% of the latite (Staatz, 1983)

Upper Cretaceous sedimentary rocks

Kl **Lance Formation**—Yellowish-gray, friable, fine- to medium-grained sandstone interbedded with medium-gray sandy claystone, and shaley siltstone accompanied by minor beds of carbonaceous shale and bentonitic clay in the lowest part; poorly exposed, nonmarine; thickness ranges from approximately 500 feet (150 m) in the north to 1,600 feet (490 m) in the south

Kfh **Fox Hills Sandstone**—Predominantly brown sandy shale and argillaceous siltstone accompanied by a few sandstone beds; 125 to 200 feet (38 to 61 m) thick in the southwestern part of quadrangle (Robinson and others, 1964)

Pierre Shale—Dark-gray to black shale with minor thin siltstone and silty sandstone, some sandy shale, and numerous bentonite beds (Knechtel and Patterson, 1962; Robinson and others, 1964); thickness ranges from 1,600 to 2,500 feet (490 to 760 m)

Formally mapped and subdivided from top to bottom into an unnamed upper part, the Kara and the slightly older Monument Hill bentonite members, an unnamed middle part, the Mitten Black Shale Member, and the Gammon Ferruginous Member at the base which contains the Groat sandstone bed

Kpu **Unnamed upper part**—Light-gray to black shale interbedded in the upper 10 to 50 feet (3 to 15 m) with a few laminae of light-gray, very fine-grained sandstone and siltstone; approximately 150 to 300 feet (46 to 91 m) thick

Kpk **Kara Bentonite Member**—Gray bentonitic shale and interbedded gray shale; weathers to a light-gray soil almost devoid of vegetation (Robinson and others, 1964; Mapel and Pillmore, 1964); thickness approximately 90 to 100 feet (27 to 30 m)

Kpuh **Unnamed upper part and Monument Hill Bentonite Member undivided**—Mapped as one unit in much of the northwestern part of the quadrangle

Kph **Monument Hill Bentonite Member**—Dark-gray shale and bentonitic shale, with several light-gray bentonite beds generally less than 1.5 feet (0.5 m) thick in upper part; 150 feet (46 m) thick

Kpm **Unnamed middle part**—Dominantly dark-gray shale; upper two-thirds contains gray-weathering limestone concretions and some red-weathering concretions; lower half is generally sandy; approximately 450 feet (140 m) thick (Knechtel and Patterson, 1962; Robinson and others, 1964)

Kps **Mitten Black Shale Member**—Dark-weathering shale; maximum thickness within the quadrangle is approximately 450 feet (140 m), decreasing to 150 feet (46 m) to the north in Carter County, Montana (Robinson and others, 1964)

Kpg **Gammon Ferruginous Member**—Dominantly dark-gray, noncalcareous shale that weathers to a light gray; approximately 700 to 800 feet (210 to 240 m) thick (Robinson and others, 1964)

Kpgg **Groat Sandstone Bed (of the Gammon Ferruginous Member)**—Light-gray to yellowish-gray, medium- to fine-grained glauconitic to ferruginous sandstone; characteristically cross-bedded, ripple marked, calcareous, and friable; 35 to 125 feet (11 to 38 m) thick. Crops out about 150 feet (46 m) below the top of the Gammon Ferruginous Member and grades laterally southward into sandy or silty shale in the west-central part of the quadrangle (Robinson and others, 1964)

Kn **Niobrara Formation**—Yellowish-gray to light-gray shale and marl along with numerous thin beds of bentonite, particularly near the top; approximately 150 to 225 feet (46 to 69 m) thick (Whitcomb and Morris, 1964)

Carlile Shale—Black to dark-gray sandy marine shale that hosts abundant calcareous, ferruginous, and phosphatic concretions, and some interbedded bentonite layers; lower part contains minor interbedded siltstone and sandstone; 500 to 600 feet (150 to 180 m) thick (Knechtel and Patterson, 1962; Robinson and others, 1964; Whitcomb and Morris, 1964) . Subdivided into three members:

Kcs **Sage Breaks Member**—Black to dark-gray predominantly noncalcareous shale, moderately calcareous in the upper 50 feet (15 m); approximately 200 to 300 feet (61 to 91 m) thick; thins to southeast (Knechtel and Patterson, 1962; Robinson and others, 1964)

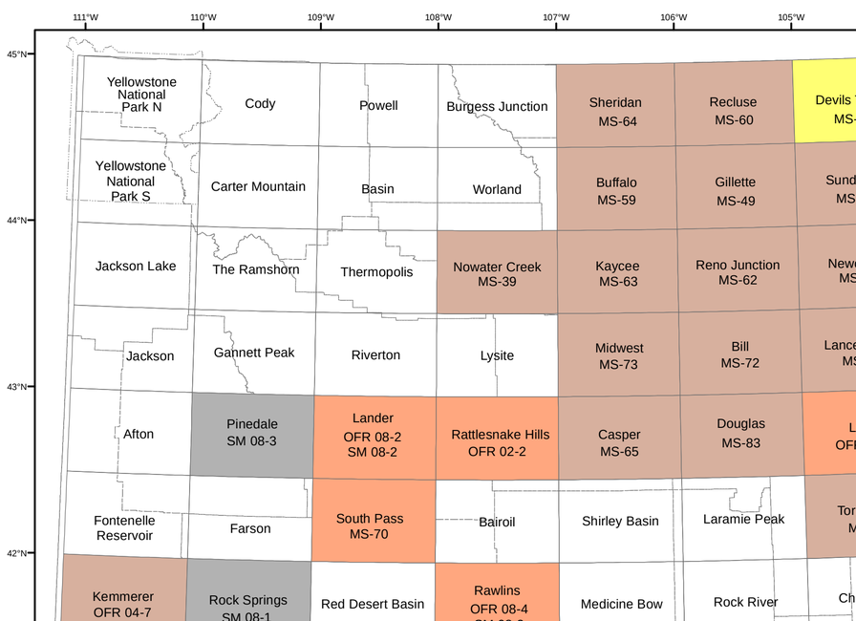
Kct **Turner Sandstone Member**—Dominantly dark-gray shale and sandy shale interlaminated with a few thin beds of light-gray siltstone and brown-weathering, fine-grained sandstone; approximately 150 to 210 feet (46 to 64 m) thick (Knechtel and Patterson, 1962; Robinson and others, 1964)

Kcp **Pool Creek Shale Member**—Dark-gray noncalcareous shale with interlaminations of light-gray siltstone in the upper half; approximately 70 to 150 feet (21 to 46 m) thick (Knechtel and Patterson, 1962; Whitcomb and Morris, 1964)

Kg **Greenhorn Formation**—Gray to brown calcareous shale and marl with scattered thin interbeds, lenses, and concretions of tan to light-gray sandy limestone; thickness varies from about 70 feet (21 m) thick in the central and western parts of the map area to as much as 370 feet (310 m) thick in the northeast corner near the South Dakota border (Knechtel and Patterson, 1962

Kb **Belle Fourche Shale** —Black-weathering, nonresistant, black to dark -gray bentonitic shale containing minor limestone lenses; lower part contains several thin bentonite beds, two of which reach thicknesses of 1.5 and 3.0 feet (0.5 and 0.9 m), respectively; t hickness varies from approximately 850 feet (260 m) in the western part of the q uadrangle to about 450 feet (140 m) near the South Dakota border in the eastern part (Knechtel and Patterson, 1962; Robinson and others, 1964)

Kmr **Mowry Shale** —Black, generally si lver-gray weathering, hard and resistant, siliceous shale interbedded with numerous 0.1 - to 1.5-foot (0.03 to 0.46 m) -thick bentonite beds, and a few thin siltstones; 195 to 250 feet (59 to 76 m) thick. Near top of the formation is the 2.5- to 7-foot (0.8 to 2.1 m)-thick Clay Spur Bentonite that has been commercially mined (Knechtel and Patterson, 1962; Robinson and others, 1964). Love and Christiansen (1985) cited a radiometric age for the Mowry Shale of 94 to 98 Ma.



KEY TO ABBREVIATIONS
Wyoming State Geological Survey maps: Open File Report (OFR), Hazards Section Digital Map (HSDM), and unpublished STATEMAP project (SM).

INDEX TO 1:100,000-SCALE BEDROCK GEOLOGIC MAPS OF WYOMING

Lower Cretaceous sedimentary rocks

Knc **Newcastle Sandstone**—Complexly interbedded light-brown to gray sandstone and siltstone and subordinate thin beds of black to brown carbonaceous shale, coal, and bentonite; unit is approximately 60 feet (18 m) thick near the center of the quadrangle but thins in some areas to 20 feet (6 m) or less and is completely absent on the flanks of the Colony anticline in T. 57 N., R. 61 W.

Ksc **Skull Creek Shale**—Predominantly dark-gray to black, soft, flaky, noncalcareous shale with thin beds of siltstone or sandstone near its top and its base; thin bentonite beds near its base, and common siderite and limestone concretions throughout; thickness 240 to 270 feet (73 to 82 m) (Davis and Izett, 1962; Robinson and others, 1964)

Kfr **Fall River Formation**—Interbedded light- to yellowish-gray and tan, fine- to very fine-grained quartz sandstone, siltstone, dark-gray shale, and carbonaceous shale; 120 to 150 (37 to 46 m) feet thick. Contains local uranium deposits, mostly within the upper sandstones (Maxwell and Robinson, 1978; Davis, and Izett, 1962) and is known to produce oil at localities outside of the map area (De Bruin, 2002)

Kla **Lakota Formation**—Complexly interfingering and lenticular beds of light-gray to light yellowish-gray claystone, siltstone, and conglomeratic sandstone; minor components include carbonaceous debris, siderite concretions, selenite, bentonite, authigenic chert masses, and silicified wood; thickness varies locally from approximately 75 feet (23 m) up to about 300 feet (91 m) in thickness, but may average 165 to 200 feet (50 to 61 m) across much of the quadrangle (Davis and Izett, 1962; Robinson and others, 1964)

Jurassic sedimentary rocks

Jm **Morrison Formation (Upper Jurassic)**—Light greenish-gray to green, pink and grayish-red siltstone and claystone accompanied by thin, lenticular light-gray sandstones and shaly limestones; formation may be totally absent in some areas to as much as 145 feet (44 m) thick, but generally ranges from 80 to 100 feet (24 to 30 m) thick across the map area (Robinson and others, 1964)

Jsg **Sundance and Gypsum Spring formations undivided**—Formations are mapped together in the southeastern part of quadrangle where more detailed mapping is lacking

Sundance Formation (Upper and Middle Jurassic)—Light- to reddish- to yellowish-gray and glauconitic green siltstone and shale, with thin interbeds of shaley sandstone, glauconitic sandstone, and white limestone; generally from 375 to 400 feet (110 to 120 m) thick, but is only 230 feet (70 m) thick in the southwestern part of the quadrangle (Bergendahl and others, 1961; Whitcomb and Morris, 1964; Robinson and others, 1964). Unconformably overlies the Gypsum Spring Formation, or where the Gypsum Spring is absent, the Spearfish Formation

From top to base, the Sundance is divided into five members: Redwater Shale, LAK, Hulett Sandstone, Stockade Beaver Shale, and Canyon Springs Sandstone. On the Devils Tower 30ʹ x 60ʹ Quadrangle, the upper two members are mapped together; the Hulett Sandstone is mapped separately; and the lower two members along with the Gypsum Spring, in areas where only a partial thickness of Gypsum spring is present, are mapped together.

Jsr **Redwater Shale and LAK members undivided**

Redwater Shale Member (Upper Jurasic)—Greenish-gray shale, nonresistant, glauconitic, interbedded with light-gray, calcareous, fine-grained sandstone, and gray, sandy, fossiliferous, oolitic limestone; approximately 170 to 195 feet (50 to 59 m) thick in the Devils Tower 30ʹ x 60ʹ Quadrangle(Robinson and others, 1964), although it has been thinned by erosion to only about 30 feet (9 m) near Sawmill Gulch (T. 54 N., R. 66 W.) where the Lakota unconformably overlies it

LAK Member (Middle Jurassic)—Yellowish-gray to pink, very fine-grained, massive to weakly thin-bedded, poorly sorted, nonresistant sandstone; generally 40 to 60 feet (12 to 18 m) thick near the Belle Fourche River (Robinson and others, 1964)

Jsh **Hulett Sandstone Member (Middle Jurassic)** —Light-gray to light yellowish-gray, varying to pink, slabby to massive, often cross-bedded, and ripple-marked, fine-grained, firmly cemented sandstone; 55 to 90 feet (17 to 27 m) thick (Robinson and others, 1964)

Jsb **Stockade Beaver Shale and Canyon Springs Sandstone members undivided ±Gypsum Spring Formation**—Where the Gypsum Spring Formation is thin (as remnants) to absent, it is combined and mapped with the Stockade Beaver and Canyon Springs; where the Gypsum Spring Formation is shown as a separate unit, the designator Jsb indicates only the Stockade Beaver and Canyon Springs

Stockade Beaver Shale Member (Middle Jurassic)—Dark greenish-gray fissile shale, predominately noncalcareous to slightly calcareous, with some interbedded and interlaminated light-gray calcareous siltstone and very fine-grained sandstone near the top; thickness between approximately 50 and 90 feet (15 and 27 m) and varies inversely with the thickness of the Canyon Springs (Robinson and others, 1964)

Canyon Springs Sandstone Member (Middle Jurassic)—Light yellowish-gray to locally mottled or banded pink and yellow, friable, nonresistant, very fine-grained calcareous sandstone interbedded with siltstone, shale, and limestone; approximately 37 feet (11 m) thick in the Belle Fourche valley. Unconformably overlies Gypsum Spring Formation, or where the Gypsum Spring is absent, the Spearfish Formation (Robinson and others, 1964)

Jg **Gypsum Spring Formation (Middle Jurassic)**—Interbedded massive white gypsum, minor red claystone, and thin gray cherty limestone (Whitcomb and Morris, 1964); thickness varies from 0 to approximately 125 feet (38 m) 8 miles (13 km) northeast of Hulett near Beaver Creek. Locally absent in some areas where it was removed by erosion prior to the deposition of the overlying Sundance Formation; mapped as a separate unit in limited outcrops in the west-central part of the quadrangle (Robinson and others, 1964)

Mesozoic and Paleozoic sedimentary rocks

ƦPs **Spearfish Formation (Triassic/Permian)**—Upper part dark is reddish-brown, thinly and poorly bedded, ripple-marked and cross-laminated, fine-grained sandstone, siltstone, and sandy shale; lower part is thin-bedded red siltstone and silty claystone interbedded with white gypsum/anhydrite beds more than 20 feet thick; 450 to 825 feet (140 to 250 m) thick (Robinson and others, 1964)

Paleozoic sedimentary rocks

Pmo **Minnekahta Limestone and Opeche Shale undivided (Lower Permian)**

Minnekahta Limestone—Light-gray, finely crystalline, thin-bedded limestone and purplish- to pinkish-gray dolomitic limestone, with stylolites common throughout; large sinkholes cut the entire thickness of the formation in some areas; approximately 40 feet (12 m) thick (Robinson and others, 1964; Whitcomb and Morris, 1964; DeWitt and others, 1989)

Opeche Shale—Maroon to reddish-brown siltstone and silty shale in alternating nonresistant beds, and a few locally occurring thin seams of gypsum; 60 to 90 feet (18 to 27 m) (Robinson and others, 1964; Whitcomb and Morris, 1964)

PIPm **Minnelusa Formation (Lower Permian/Pennsylvanian)**—Light-gray to pink sandstone interbedded with gray sandy dolomite and limestone and minor red siltstone, shale, and local gypsum beds; upper 20 to 50 feet (6 to 15 m) is light yellowish-gray, fine-grained and calcareous, resistant, cliff-forming sandstone that often forms cavernous ledges (Robinson and others, 1964; Whitcomb and Morris, 1964); approximately 650 to 800 feet (200 to 240 m) thick

Mp **Pahasapa Limestone (Lower Mississippian)**—Gray, very fine-grained, generally thick-bedded, cavernous, massive, hard, cliff-forming limestone and dolomitic limestone that contains nodules and layers of chert in some outcrops (Whitcomb and Morris, 1964; Staatz, 1983; DeWitt and others, 1989); approximately 500 to 575 feet (150 to 180 m) thick. [Note: the Lower Mississippian/Upper Devonian Englewood Formation mapped below the Pahasapa to the south on the Sundance 30' x 60' Quadrangle (Sutherland, 2007) is not mapped, identified, or recognized in the Bear Lodge Mountains.]

Ow **Whitewood Dolomite and Winnipeg Formation undivided (Upper and Middle Ordovician)**—Light-gray, fine-grained, massive to thin-bedded limestone, poorly exposed, with pink mottles up to about 1.6 inches (4.1 cm) across; approximately 145 feet (44 m) thick (Staatz, 1983). [Note: 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. This shale is presumed to be the Winnepeg Formation on the Devils Tower Quadrangle.]

O€d **Deadwood Formation (Upper Cambrian to Lower Ordovician)**—Principally quartzite and interbedded shaly limestone that has in many areas been replaced by Tertiary intrusive bodies; upper part is a hard, white, medium-grained quartzite 20 to 30 feet (6 to 9 m) thick underlain by approximately 30 feet (6 m) of brown to red, medium-grained, thin-bedded quartzite with locally present worm burrows. Remaining lower part is 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); crops out only in the Bear Lodge Mountains. Varies widely in thickness across the region, but near Sheep Mountain, on the east side of the Bear Lodge Mountains, Staatz (1983) measured a partial section more than 880 feet (270 m) thick

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(numbers are those on INDEX OF GEOLOGIC MAPPING)

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PRELIMINARY GEOLOGIC MAP

OF THE

DEVILS TOWER 30’ x 60’ QUADRANGLE

Wyoming State Geological Survey Open File Report 2007-06

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INTRODUCTION

The Devils Tower 30’ x 60’ Quadrangle is located along the northwestern 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 Hulett and Beulah, as well as several small settlements such as Aladdin. Land use within the area is dominated by ranching, recreation, timbering, and bentonite mining in the northeastern part of the quadrangle.

The largest stream in the quadrangle is the Little Missouri River, which flows north across the western part of the quadrangle. The slightly smaller Belle Fourche River flows northeastward across the west-central part of the map area to the north-central part (only about six miles from the Little Missouri) where it abruptly turns southeast, around the northern end of the Bear Lodge Mountains, to flow out of the central-eastern edge of the quadrangle. Lytle Creek, Blacktail Creek, and Beaver Creek drain the western and northwestern Bear Lodge Mountains into the Belle Fourche. Redwater Creek, South and Middle Fork of Hay Creek, and Oak Creek drain the eastern Bear Lodge Mountains eastward into the Belle Fourche. Sand Creek flows northward, then eastward across the southeastern corner of the quadrangle, draining the Mineral Hill area lying to the south in the Sundance 1:100,000 Quadrangle.

Thirty-two 1:24,000 quadrangles that comprise the Sundance 30’ x 60’ quadrangle are listed northwest to southeast as follows: Moulton Creek, Storm Draw, Page Draw, Gaff Creek, Antelope Gulch, Devils Run, Shepard Reservoir, Gravel Draw, Cedar Ridge, Wood Canyon, Strawberry Hill, Seely, Mona, Stony Point, Kruger Lake, Middle Creek Butte, Garland Hill, New Haven, Moore Hill, Hulett, Alva, The Notch, Aladdin, Slaughter Reservoir, Oshoto, Missouri Buttes, Devils Tower, Sherrard Hill, Black Hills, Sugarloaf Mountain, Schoolmarm Butte, and Beulah.

The northwestern Black Hills and the northeastern Powder River Basin within the Devils Tower 30’ x 60’ quadrangle expose geologic units ranging in age from Late Cambrian / Early Ordovician to Quaternary. The oldest rocks are exposed in the Bear Lodge Mountains. Tertiary intrusions crop out in the Bear Lodge Mountains, and at Devils Tower and Missouri Buttes in the south-central part of the quadrangle. Paleozoic outcrops concentrate closely around the northern Bear Lodge Mountains in the south and central part of the quadrangle, with Mesozoic outcrops dominating the majority of the quadrangle. Tertiary sedimentary units within the Devils Tower Quadrangle include isolated outcrops of the Oligocene White River Formation in and northeast of the Bear Lodge Mountains and on higher elevations between the Belle Fourche and Little Missouri rivers, 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.

ECONOMIC GEOLOGY

Uranium mineralization occurs in carbonaceous sandy layers within the upper part of the Early Cretaceous Fall River Formation, which wraps around the northern end of the Bear Lodge uplift in the central and northeastern part of the map area. Uranium was produced from the Fall River in the 1950s, was of interest in the late 1970s (Davis and Izett, 1962). With current (2006) major increases in uranium prices, the Fall River in this area is again the target of uranium exploration and possible future development.

Small amounts of bentonite were produced from Cretaceous units in the northern Black Hills began during the 1920s. However, measurable steady production began with the establishment of the first local mill for processing finished powdered bentonite in 1934. Additional mills in 1935, 1941, and 1946 helped to make the Northern Black Hills bentonite district (including parts of Montana and South Dakota) the largest bentonite producer in the nation by 1949 (Knechtel and Patterson, 1962). The northern and northeastern part of the Devils Tower 30’ x 60’ Quadrangle remains a major bentonite producer.

ACC bentonite mill at Colony, WY. Photo by W.M. Sutherland, 2007.

This map includes the northern portion of the Bear Lodge Mountains alkalic complex which host associated metals deposits. These are currently of potential economic interest for gold and rare earth elements (REE). 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 the young intrusions is similar to Cripple Creek, CO. Because of these similarities, the region is of interest to several exploration groups. Two companies conducted gold/REE exploration activities, including drilling in the Bear Lodge Mountains during 2006.

GEOLOGIC MAP UNITS

The geology for the Devils Tower 30' x 60' 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 Devils Tower 1:100,000 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 Late Cambrian / Early Ordovician 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, small alluvial and colluvial deposits (Qc) along drainages, and some older terrace deposits along drainages. Thicknesses vary widely, from a thin veneer to several tens of feet.

Holocene and Pleistocene colluvium and slope wash (Qcs): This unit includes colluvial deposits, talus, 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. Terrace deposits vary from thin veneers to as much as 40 feet thick. Knechtel and Patterson (1962) mapped as many as 6 terrace levels, ranging from 30 feet to more than 450 feet above the Belle Fourche River in the north-central and northeastern part of the quadrangle. These were combined in this map compilation. 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.

A local channel conglomerate was noted along Sand Creek, one mile south of Beulah by R.W. Jones while field-checking the quadrangle with the author during May, 2007. The well indurated channel conglomerate forms a resistant ridge above the Triassic/Pernian Spearfish Formation into which it is cut. The conglomerate is overlain by a thin local Quaternary terrace deposit. No investigation was conducted in the surrounding area for additional similar deposits.

Tertiary (?) Ogallala Fm. along Sand Creek south of Beulah. Photo by W.M. Sutherland.

Oligocene [upper Eocene] White River Formation (Twr): The White River Formation crops out as discontinuous isolated remnants northwest of the Bear Lodge Mountains and on some of the higher elevations between the Belle Fourche and Little Missouri rivers. 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 south-central part of the Devils Tower 30’ x 60’ Quadrangle where they form sills, plugs, dikes, and irregular bodies that intrude rocks ranging from Cambrian to Cretaceous in age. These rocks are found in the central part of the Bear Lodge Mountains, Missouri Buttes, and at Devils Tower. 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** near the WY-SD Stateline, and **~50-46 Ma** that includes the Bear Lodge Mountains, Devils Tower, and Missouri Buttes. Accompanying this trend is a transition from subalkalic magmatism in the east to extremely alkalic to the west. Alteration to varying degrees is common and includes fenitization, silicification, carbonate, hydrothermal, and sericitization (Duke, 2005). The largest volume of the intrusive rocks is either trachyte or phonolite with smaller amounts of latite, syenite, nepheline syenite, lamprophyre, pseudoleucite porphyry, agglomerate, intrusive breccias, and carbonatite (Robinson, Mapel, and Bergendahl, 1964; Staatz, 1983).

Aerial view of Devils Tower showing columnar structures. Photo by W.M. Sutherland, 1979.

Lamprophyre small intrusions (Tl): Two small lamprophyre bodies about one mile west of Hershey Creek dome in the northwestern Bear Lodge Mountains intrude the lower part of the Sundance Formation and the Spearfish Formation. A lamprophyre sill also intrudes the middle of the Sundance Fm near Miller Creek in the western part of the Bear Lodge Mountains immediately south of the Devils Tower 30’ x 60’ Quadrangle. 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).

Carbonatite dike (Tc): One carbonatite dike that cuts intrusive breccia and is exposed in an old exploration trench was mapped by Staatz (1983) on top of the Bear Lodge Mountains in the SE corner of Sec.7 and the SW corner of Sec.8, T52N, R63W. Similar dikes have been cut by several drill holes at other localities within the Bear Lodge Mountains. The exposed carbonatite is brown to yellowish-brown mottled as contrasting with unweathered carbonatite encountered in drill holes that appears light-gray to white and banded with pink, green, white, or purple accessory minerals. Carbonatite is mostly calcite, but contains accessory rare-earth minerals, strontianite fluorite, pyrite pyrrhotite, sphalerite, galena, and locally abundant acmite and actinolite. The most common rare-earth minerals are pink ancylite $[(Ce,La)(SrCa)(CO_3)_2(OH)\cdot H_2O]$ and brown bastnaesite $[(Ce,La)FCO_3]$ (Staatz, 1983).

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 from the southern quadrangle boundary.

Pyroclastic deposits (Tpy): Small pyroclastic deposits varying from volcanic breccia to tuff were mapped by Staatz (1983) near Lytle Creek on the west side of the Bear Lodge Mountains and at Hershey Creek dome. 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.

Phonolitic intrusive rocks (Tp): This unit represents greenish-gray to light- and medium-gray or dark gray phonolite and related rocks found at Missouri Buttes and on the northwestern edge of the Bear Lodge Mountains.

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). Duke (2005) describes Missouri Buttes as diatremes made up of both phonolite and trachyte. In the absence of detailed mapping, Missouri Buttes is depicted as phonolite as mapped by DeWitt and others (1989).

A sill, up to 60 feet thick and 1000 feet long intrudes the base of the Hulett sandstone member of the Sundance Formation in Barlow Canyon, about three miles northeast of Missouri Buttes. Darton and O’Harra (1906) note that the sandstone above the sill is unaltered. They refer to the sill as syenite porphyry, but elaborate that excessive decomposition of their specimen limited proper classification and state that it could be phonolite.

Duke's most recent classification is generally used for both Missouri Buttes and Devils Tower, whereas smaller outcrops in the Bear Lodge Mountains follow Staatz (1983) where greater map detail is available, or. As these rocks are studied further, classifications of specific outcrops may be subject to change.

Missouri Buttes from the west. Photo by W.M. Sutherland, 2007.

Phonolitic agglomerate (Tpa): Vesicular aphanitic groundmass with rounded to angular mineral grains, and hosting igneous and sedimentary rock fragments are described by Robinson, Mapel, and Bergendahl (1964) in the north-central part of the Missouri Buttes. They also describe two other small agglomerate outcrops in the immediate area that are too small to be shown on this map.

Pseudoleucite porphyry (Tpp): Pseudoleucite porphyry mapped by Staatz (1983) crops out on the northwestern edge of the Bear Lodge Mountains. This distinctive map unit is a phonolite containing 5% to 20% large white pseudoleucite crystals up to 3.8 cm in diameter by 0.5 to 1.0 cm long within a medium-gray aphanitic matrix.

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. This unit includes a major part of the Bear Lodge Mountains mapped by Staatz (1983) as trachyte and phonolite and as 'younger trachyte and phonolite' dikes. These were all lumped together by Dewitt and others (1989) and characterized by anomalously high concentrations of rubidium, zirconium, niobium, and barium. Duke (2005) describes

Devils Tower as a trachyte diatreme. Duke's most recent classification (as discussed above under phonolite) is used for Devils Tower.

Syenite and nepheline syenite intrusive rocks (Ts): Small intrusions of syenite and nepheline syenite were mapped in the vicinity of Hershey Creek dome in the northern Bear Lodge Mountains by Staatz (1983). Syenite dominates, and generally is made up of 60% to 80% potassium feldspar accompanied by some plagioclase and 20% to 35% aegirine-augite or augite.

Latite intrusive rocks (Tlt): Hershey Creek dome, mapped on the north end of the Bear Lodge Mountains by Staatz (1983) is dominated by unaltered light-gray porphyritic latite that generally contains 30% to 35% phenocrysts in the size range of 0.5 to 1.2 mm that are dominated by white plagioclase. The most abundant mafic mineral us usually black prismatic hornblende in varying amounts of 1% to 15%.

Tullock Member of the Paleocene Fort Union Formation (Tft): The Tullock Member in the lower part of the Fort Union Formation crops out only along a small part of the southwestern edge of the Devils Tower 30' x 60' Quadrangle. It is distinguished from similar appearing strata in the underlying Lance Formation by the presence of thin coal seams (Whitcomb and Morris, 1964).

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. The generally lenticular, thin to thick bedded and cross laminated sandstone beds are no more than a few feet thick. Where thick, the sandstone may locally host round to cylindrical calcareous concretions up to several feet thick and tens of feet long (Robinson, Mapel, and Bergendahl, 1964; Whitcomb and Morris, 1964). The Lance crops out along the southwestern edge of the map area as grasslands with gentle buttes and ridges supported by the more resistant sandstones.

The Lance Formation reaches its maximum thickness of about 1600 feet in Weston County to the south of the Devils Tower 30' x 60' Quadrangle, and thins northward to about 500 feet north of the Montana border. Its contact with the underlying Fox Hills is located at the base of the lowest gray bentonitic clay or carbonaceous shale believed to delineate the change from marine rocks below to nonmarine deposits above (Robinson, Mapel, and Bergendahl, 1964; Whitcomb and Morris, 1964).

Upper Cretaceous Fox Hills Sandstone (Kfh): The Fox Hills Sandstone comprises 125 to 200 feet of predominantly brown sandy shale and argillaceous siltstone accompanied by a few sandstone beds in the southwestern part of the Devils Tower 30' x 60' Quadrangle. The Fox Hills in that area generally crops out as a scarp, rising as much as 100 feet above the low rolling terrain of the underlying Pierre Shale (Robinson, Mapel, and Bergendahl, 1964).

To the southwest, the Fox Hills changes to poorly exposed light-gray to light yellowish-gray, friable, very fine- to medium-grained, soft, thin bedded marine sandstone that forms grassy ridges standing about 100 feet above the less resistant and underlying Pierre Shale. The Fox Hills 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; Robinson, Mapel, and Bergendahl, 1964; Whitcomb and Morris, 1964).

Upper Cretaceous Pierre Shale: The Pierre Shale within the Devils Tower 30' x 60' Quadrangle is made up of about 1600 to 2500 feet of dark-gray to black shale with minor thin siltstone and silty sandstone, some sandy shale, and numerous bentonite beds, (Knechtel and Patterson, 1962; Robinson, Mapel, and Bergendahl, 1964). Large limestone concretions are abundant in some areas (Mapel, Robinson, and Theobald, 1959; Bergendahl, Davis, and Izett, 1961; Whitcomb and Morris, 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. 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 Formation is **72-78 Ma** (Love and Christiansen, 1985).

Along the west flank of the Black Hills, various workers have subdivided the Pierre into numerous parts. Those depicted on the Devils Tower 30' x 60' Quadrangle include an unnamed upper part, the Kara and the slightly older Monument Hill bentonite members, an unnamed middle part, the Mitten black shale member, and the Gammon ferruginous member at the formation's base that contains the Groat sandstone bed. Stratigraphic relationships between the Pierre Shale and the overlying Fox Hills Sandstone and the underlying Niobrara Formation are conformable (Robinson, Mapel, and Bergendahl, 1964).

> **Upper part of Pierre Shale (Kpu):** The upper part of the Pierre Shale is made up of light-gray to black shale interbedded in the upper 10 to 50 feet with a few laminae of light-gray, very fine-grained sandstone and siltstone. It 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 (Robinson, Mapel, and Bergendahl, 1964). Beneath the upper part of the Pierre is either the Kara, or the Monument Hill bentonitic members, about 150 to 300 feet below the top of the formation.

Kara bentonite member (Kpk): The Kara bentonite member is composed of about 90 to 100 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 (Robinson, Mapel, and Bergendahl, 1964; Mapel and Pillmore, 1964). The Kara crops out only in the southwest corner of the quadrangle.

Upper part of Pierre Shale & Monument Hill bentonite member undifferentiated (Kpuh): These two units are not mapped separately in much of the northwestern part of the quadrangle.

Monument Hill bentonite member (Kph): The 150-foot thick Monument Hill bentonite member is composed primarily of dark-gray shale and bentonitic shale, accompanied in the upper part by several light-gray bentonite beds generally less than 1.5 feet thick. Large fibrous calcite concretions are found within several zones in this member, and some areas exhibit abundant concretions up to 1.5 inches in size that are composed of radiating fibrous to wedge-shaped barite crystals (Knechtel and Patterson, 1962).

Middle part of Pierre Shale (Kpm): Roughly 450 feet of dominantly dark-gray shale makes up the middle part of the Pierre Shale. This middle part of the Pierre was included in the upper part of the formation by Robinson, Mapel, and Bergendahl, 1964). It is accompanied in the upper two thirds of its thickness by gray-weathering limestone concretions and some red-weathering concretions. The lower half of this member is generally sandy (Knechtel and Patterson, 1962; Robinson, Mapel, and Bergendahl, 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. Robinson, Mapel, and Bergendahl, (1964) give a thickness for the Mitten of about 150 feet in Carter County, Montana, with its thickness increasing southward along the west flank of the Black Hills. Its maximum thickness within the Devils Tower 30’ x 60’ Quadrangle is about 450 feet.

The upper part of the Mitten hosts abundant large, fossiliferous, dark-gray septarian limestone concretions that weather brown to dark reddish-orange. It also contains dark-red weathering siderite concretions. Small red-weathering ferruginous concretions are found within the middle part of the member. The base of the unit is characterized by hard dark-gray shale and numerous beds of yellowish-gray bentonite (Mapel, Robinson, and Theobald, 1959; Robinson, Mapel, and Bergendahl, 1964).

Gammon ferruginous member (Kpg): The Gammon is roughly 700 to 800 feet of dominantly dark-gray, noncalcareous shale that weathers to a light-gray, 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 and middle

parts of this member. A 1- to 2-foot thick bentonite bed, about 75 feet below the top of this member, weathers to form a light-gray marker that can be traced along its outcrop for several miles (Robinson, Mapel, and Bergendahl, 1964).

Groat sandstone bed of the Gammon ferruginous member (Kpgg): The Groat sandstone bed is 35 to 125 feet of light-gray to yellowish-gray, medium-to fine-grained glauconitic to ferruginous sandstone that crops out about 150 feet below the top of the Gammon ferruginous member. This sandstone is characteristically crossbedded, ripple marked, calcareous, and friable. The top of this bed in many exposures is marked by about 10 feet of sandstone that forms a low scarp, whereas its lower edge is gradational over about 50 feet into the underlying beds of the Gammon member. The Groat sandstone bed grades laterally southward into sandy or silty shale in the west-central part of the quadrangle (Robinson, Mapel, and Bergendahl, 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 (Whitcomb and Morris, 1964). The outcrop of the nonresistant Niobrara commonly forms a shallow valley. 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, and is in places marked by a layer of phosphatic nodules. 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 (Robinson, Mapel, and Bergendahl, 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 marine shale that hosts abundant calcareous, ferruginous, and phosphatic concretions, and some interbedded bentonite layers. The lower part of the formation contains minor interbedded siltstone and sandstone shale (Knechtel and Patterson, 1962; Robinson, Mapel, and Bergendahl, 1964; 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 200 to 300 feet of southeastward-thinning black to dark-gray predominantly noncalcareous shale that is moderately calcareous in the upper 50 feet. 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 (Knechtel and Patterson, 1962; Robinson, Mapel, and Bergendahl, 1964).

Turner sandstone member (Kct): The Turner sandstone member consists of about 150 to 210 feet of dominantly dark-gray shale and sandy shale interlaminated with a few thin beds of light-gray siltstone and brown-weathering, fine-grained sandstone. Beds of yellow to yellowish-gray weathering silty limestone concretions that contain yellow calcite veins characterize much of the Turner member. The base of the Turner

is a ledge-forming 2- to 6-foot thick, light-gray, fine- to coarse-grained calcareous sandstone that hosts scattered granules and pebbles of phosphatic material and chert as well as locally abundant fish teeth (Knechtel and Patterson, 1962; Robinson, Mapel, and Bergendahl, 1964).

Pool Creek shale member (Kcp): The Pool Creek is generally represented by about 70 to 150 feet of dark-gray noncalcareous shale with interlaminations of light-gray siltstone in the upper half, with their greatest abundance near the top. Scattered 6-inch to 3-foot diameter septarian limestone concretions are found in the middle part of the member. The upper part contains clay ironstone concretions and white-weathering, phosphatic claystone nodules (Knechtel and Patterson, 1962). 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 (Knechtel and Patterson, 1962; Whitcomb and Morris, 1964).

Upper Cretaceous Greenhorn Formation (Kg): The Greenhorn Formation varies from about 70 feet thick in the central and western parts of the map area to as much as 370 feet thick in the northeast corner near the South Dakota border (Knechtel and Patterson, 1962). This unit consists of gray to brown calcareous shale and marl with scattered thin interbeds, lenses, and concretions of tan to light-gray sandy limestone. This unit also contains some thin beds of dark noncalcareous shale and bentonite. Brown, fossiliferous, sandy limestone beds and zones of septarian limestone concretions are found at the top of the formation. These 2- to 6-foot diameter concretions weather light-gray and contain veins of coarsely crystalline white, yellow, and brown calcite. The limestones at the top of the formation are often ridge-formers. The contact with the underlying Belle Fourche is the base of a thin (6- to 12-foot thick) limestone beneath olive-gray or brown, locally calcareous shale of the lower Greenhorn, and on top of soft, dark-gray shale of the underlying Belle Fourche Shale (Knechtel and Patterson, 1962; Robinson, Mapel, and Bergendahl, 1964; Whitcomb and Morris, 1964).

Upper Cretaceous Belle Fourche Shale (Kb): This unit varies in thickness from about 850 feet in the western part of the Devils Tower 30’ x 60’ Quadrangle to about 450 feet near the South Dakota border in the eastern part of the map area. It is composed of black-weathering, nonresistant, black to dark-gray bentonitic shale containing minor limestone lenses. Dark-red to purplish-black weathering, irregularly rounded, slightly magnetiferous siderite concretions ranging up to 5 feet in their longest dimension and hosted within soft grayish-black shale characterize the basal 50 feet of the formation. Several thin bentonite beds are hosted within the lower part of the Belle Fourche, 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 black-weathering shales above to gray-weathering, hard, siliceous shales below (Knechtel and Patterson, 1962; Robinson, Mapel, and Bergendahl, 1964).

The upper part of the formation is dominated by dark-gray to black shale with a few thin laminae of light-gray, very fine grained friable sandstone or siltstone. This part of the Belle Fourche hosts scattered red-weathering ironstone concretions numerous gray- to yellow- and red-weathering septarian limestone concretions (Knechtel and Patterson, 1962; Robinson, Mapel, and Bergendahl, 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 195 to 250 feet of black, generally silver-gray weathering, 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. Near the top of the formation is the Clay Spur Bentonite, a 2.5- to 7-foot thick bentonite bed that has been commercially mined (Knechtel and Patterson, 1962; Robinson, Mapel, and Bergendahl, 1964). 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 (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 near the center of the Devils Tower 30’ x 60’ Quadrangle is about 60 feet thick, but thins in some areas to 20 feet or less. It consists of complexly interbedded light-brown to gray sandstone and siltstone and subordinate thin beds of black to brown carbonaceous shale, coal, and bentonite. The silt and shale content of the formation are highly variable, and in the northeast part of the quadrangle, the formation is characterized by massive beds of medium- to coarse-grained sandstone very similar to the Fall River Formation (Knechtel and Patterson, 1962).

Along the western edge of the quadrangle, the Newcastle crops out as a prominent hogback, but is generally more subtle in the northeastern part of the map area, and is completely absent on the flanks of the Colony anticline in T57N, R61W. In some areas where the sandstone is absent, the remaining beds are indistinguishable from the underlying Skull Creek and the overlying Mowry. The contact between the Newcastle and the underlying Skull Creek is gradational and conformable. Bentonite has been mined locally from the Newcastle Formation (Knechtel and Patterson, 1962; Davis and Izett, 1962; Robinson, Mapel, and Bergendahl, 1964). The Newcastle Sandstone has produced oil in the southwestern corner of the map area, and is an important oil source farther west (Robinson, Mapel, and Bergendahl, 1964; 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 western, northern, and northeastern parts of the Devils Tower 30’ x 60’ Quadrangle. The 240 to 270 foot thick Skull Creek is predominantly a unit of soft flaky, dark-gray to black noncalcareous shale accompanied by thin beds of siltstone or sandstone near its top and its base, thin bentonite beds near its base, and common siderite and limestone concretions throughout. The siderite concretions that weather red to purplish-black are most abundant in the lower third of the formation, and the tabular to oval cone-in-cone limestone concretions that weather to yellow, yellowish-brown or light gray are locally concentrated in the upper part. The upper part of the unit also hosts numerous near-vertical, well-cemented, very fine-grained light-gray sand dikes that are occasionally accompanied by slickensides (Knechtel and Patterson, 1962). The contact with the underlying Fall River Formation is gradational (Davis and Izett, 1962; Robinson, Mapel, and Bergendahl, 1964). The Skull Creek also hosts radiometric uranium and thorium anomalies and anomalous concentrations of lead and manganese (DeWitt and others, 1989).

The upper and lower parts of the Skull Creek are separated as two map units within the Wood Canyon (SE quarter of the Cedar Ridge 15 minute Quadrangle) 1:24,000 scale Quadrangle by Maxwell and Robinson (1978), but are represented as one unit within the Devils Tower 30’ x 60’ Quadrangle.

View south across the Little Missouri River alluvium in the northwestern part of the quadrangle; north-dipping Newcastle Sandstone in foreground; Skull Creek Shale forms tan to gray gentle slopes beyond alluvium; Fall River Fm. forms flats above trees at far center. Photo by W.M. Sutherland, 2007.

Lower Cretaceous Fall River Formation (Kf): The Fall River Formation crops out in the central part of the Devils Tower 30’ x 60’ Quadrangle, and is 120 to 150 feet thick. The Fall River is composed of interbedded light- to yellowish-gray and tan, fine- to very fine-grained quartz sandstone, siltstone, dark-gray shale, and carbonaceous shale. The formation represents a transition from the variegated claystone and silty claystone continental deposits of the underlying Lakota formation to the black fluviomarine shale in the overlying Skull Creek Shale. One- to two-inch thick silty or finely sandy, dark-brown, iron-rich beds and nodules are scattered within the thicker sandstones of the Fall River Formation, whereas the thinner sandstones often host dark-brown to reddish-brown, resistant seams and thin iron oxide cemented layers (Robinson, Mapel, and Bergendahl, 1964). Heavy minerals from the Fall River, in order of decreasing abundance include zircon, tourmaline, staurolite, rutile, garnet, and chloritoid (Davis and Izett, 1962; Mapel, Chisholm, and Bergenback, 1964).

The Fall River contains local uranium deposits, mostly within the upper sandstones (Maxwell and Robinson, 1978; Davis, and Izett, 1962). This formation is known to produce oil at localities outside of the map area (De Bruin, 2002).

The Fall River is often informally separated into an upper and lower part, and is so mapped by Davis and Izett (1962) in the Strawberry Hill 1:24,000 scale Quadrangle. It is further subdivided into three map units within the Wood Canyon (SE quarter of the Cedar Ridge 15 minute) 1:24,000 scale Quadrangle Maxwell and Robinson (1978). However, the Fall River is shown as a single undivided unit within the Devils Tower 30' x 60' Quadrangle.

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 with complexly interfingering and lenticular beds of light-gray to light yellowish-gray claystone, siltstone, and conglomeratic sandstone. Minor components of the formation include carbonaceous debris, siderite concretions, selenite, bentonite, authigenic chert masses, and silicified wood. The formation varies locally from about 75 feet up to about 300 feet in thickness, but may average 165 to 200 feet across much of the Devils Tower 30' x 60' Quadrangle (Davis and Izett, 1962; Robinson, Mapel, and Bergendahl, 1964). In the Carlile area near the south western edge of the quadrangle, the upper part of the formation is dominated by claystone, and the lower part by generally massive sandstone that weathers to rounded cliffs (Bergendahl, Davis, and Izett, 1961). In other areas, no such distinction is obvious, and the whole formation is generally silty, sandy, and granular claystone. The coarser sandstones are generally crossbeded. Sandstones within the Lakota are highly silicified in the vicinity of Missouri Buttes in T53 & 54N, R66W (Robinson, Mapel, and Bergendahl, 1964).

The contact between the Lakota and the underlying Morrison varies from sharp and locally unconformable to gradational and interfingering. The Lakota is separated from the underlying Morrison by the Lakota's thick sandstones, minor carbonaceous shale, and its near absence of calcareous claystones and limestones (Robinson, Mapel, and Bergendahl, 1964). The Lakota Formation has produced uranium in the past from the vicinity of Carlile, outside the southern edge of the quadrangle (Bergendahl, Davis, and Izett, 1961).

Tan Lakota Sandstone cliff near Aladdin; yellowish sandstone ridge at top is the Fall River Fm. Photo by W.M. Sutherland, 2007.

Upper Jurassic Morrison Formation (Jm): The Morrison Formation varies in from being totally absent in some areas to as much as 145 feet thick, but is generally ranges from 80 to 100 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 (Robinson, Mapel, and Bergendahl, 1964). 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 over a very short distance, and is picked at the top of a persistent bed of yellow-weathering sandstone. This contact represents a transition from the underlying marine rocks of the Sundance Formation to the nonmarine strata of the Morrison (Robinson, Mapel, and Bergendahl, 1964).

Upper and Middle Jurassic Sundance and Middle Jurassic Gypsum Spring Formations combined (Jsg): These formations, described below, are mapped together in the southeast 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 to 400 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. However, it is only 230 feet thick in the southwestern part of the quadrangle at Sawmill Gulch (Bergendahl, Davis, and Izett, 1961; Whitcomb and Morris, 1964; Robinson, Mapel, and Bergendahl, 1964). The Sundance unconformably overlies the Gypsum Spring Formation, or where the Gypsum Spring is absent, the Sundance unconformably overlies the Spearfish Formation. The Sundance 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.

The Redwater, LAK, and Hulett members are combined as one unit to the south in the Sundance 30’ x 60’ Quadrangle. Within the Devils Tower 30’ x 60’ Quadrangle, the Hulett Sandstone member is shown as a separate unit, whereas the Redwater and LAK comprise another separate map unit.

> **Redwater shale member and LAK member combined (Jsr):** Within the Devils Tower 30’ x 60’ Quadrangle, these two members of the Sundance Formation are mapped as one unit.
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> > **The Redwater shale member** is generally about 170 to 195 feet thick in the Devils Tower 30’ x 60’ Quadrangle, although it has been thinned by erosion to only about 30 feet near Sawmill Gulch (T54N, R66W) where the Lakota overlies it unconformably. It is made up of generally nonresistant, glauconitic, greenish-gray shale interbedded with light-gray, calcareous, fine-grained sandstone, and gray, sandy, fossiliferous, oolitic limestone. The limestone occurs as beds up to 4 feet thick in the upper part of the member. The top of the member is capped

with a persistent 2- to 30-foot thick layer of yellow-weathering, calcareous, thin-bedded sandstone that contains seams of red and white, or blue chert up to ½ inch thick in some areas. Its contact with the underlying LAK member is marked by a sharp color change from gray to pink and from glauconitic to nonglauconitic in the LAK (Robinson, Mapel, and Bergendahl, 1964).

The LAK member consists primarily of poorly sorted, nonresistant, yellowish-gray to pink, very fine-grained, massive to weakly thin-bedded sandstone with a few very thin beds of green silty shale in the uppermost 5 to 10 feet. The LAK is generally 40 to 60 feet thick near the Belle Fourche River. The contact with the underlying Hulett Sandstone is gradational over several feet, and is arbitrarily picked at the change from the softer massive sandstone of the LAK to the more evenly bedded ledge-forming Hulett (Robinson, Mapel, and Bergendahl, 1964).

The Hulett sandstone member (Jsh): The Hulett sandstone is the most prominent member of the Sundance Formation varies from 55 to 90 feet thick and is exposed as a single cliff-forming outcrop that can be traced for many miles. It is made up of light-gray to light yellowish-gray, varying to pink, slabby to massive, often crossbedded, and ripple-marked, fine-grained, firmly cemented sandstone. The lower 10 to 15 feet of the member often hosts a few thin partings of greenish-gray shale. Its contact with the underlying Stockade Beaver shale member is gradational, and is picked at the horizon where shale becomes more abundant than sandstone (Robinson, Mapel, and Bergendahl, 1964).

Stockade Beaver shale member, Canyon Springs sandstone member, and Middle Jurassic Gypsum Spring Formation combined (Jsb): Within the Devils Tower 30’ x 60’ Quadrangle, these two members of the Sundance Formation and, in some areas, the thin to absent Gypsum Spring Formation are mapped as one unit. In areas where the Gypsum Spring Formation (Jg) is shown as a separate unit, the designator (Jsb) indicates only the Stokade Beaver and Canyon Springs members.

The Stockade Beaver shale member is predominately noncalcareous to slightly calcareous, dark greenish-gray fissile shale with some interbedded and interlaminated light-gray calcareous siltstone and very fine-grained sandstone near the top. The Stockade Beaver contact with the underlying Canyon Springs is generally gradational over a small interval of about one foot. The thickness generally ranges from about 50 to 90 feet, and varies inversely in thickness with the Canyon Springs; where one of the members is thick, the other is thin (Robinson, Mapel, and Bergendahl, 1964).

The Canyon Springs sandstone member, around 37 feet thick in the Belle Fourche valley, is composed of light yellowish-gray to locally mottled or banded pink and yellow, friable, nonresistant, very fine-grained calcareous sandstone interbedded with siltstone, shale, and limestone. The top of the Canyon Springs is marked in some locations by a 5-foot shelf of fossiliferous, sandy oolitic limestone. The base of this member in the Belle Fourche valley usually contains coarse grains and pebbles up to 2 inches in diameter of gray and brown chert. This basal conglomerate at one location on Beaver Creek (T55N, R64W, Sec.1: S1/2) includes rounded, polished chert and limestone boulders up to 1.5 feet in diameter. The Canyon Springs member unconformably, but smoothly, overlies

the Gypsum Springs Formation, or where it is absent, the Spearfish Formation (Robinson, Mapel, and Bergendahl, 1964). 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 (Jg): The Gypsum Spring Formation is mapped as a separate unit in limited outcrops in the west-central part of the quadrangle. It varies in thickness from 0 to about 125 feet in its northern-most exposure 8 miles northeast of Hulett near Beaver Creek. The Gypsum Spring 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 where it was removed by erosion prior to the deposition of the overlying Sundance Formation. The Gypsum Spring Formation is often combined with part, or all of the overlying Sundance Formation in its map depiction, and is thus combined where it is found only as remnants. The contact of the Gypsum Spring the underlying Spearfish Formation is unconformable where it hasn't been entirely removed by pre-Sundance erosion (Robinson, Mapel, and Bergendahl, 1964).

Belle Fourche River valley view from high on Devils Tower. The red-orange flat area across the river above the alluvium is the Spearfish Formation overlain in the slopes beyond by the Gypsum Spring Formation then the Canyon Springs sandstone and Stockade Beaver shale members of the Sundance Fm. The tan upper cliff in the background is the Hulett Sandstone member overlain by the LAK and Redwater shale members of the Sundance Fm. Photo by W.M. Sutherland, 1969.

Triassic / Permian Spearfish Formation (dPs): The 450- to 825-foot thick Spearfish Formation crops out along the Belle Fourche River and its tributaries in the central part of the quadrangle, along the flanks of the Bear Lodge Mountains in the south central part, and on the northwest flank of the Black Hills in the southeast part. The lower part of the Spearfish is made up of thin-bedded red siltstone and silty claystone interbedded with white gypsum/anhydrite beds more than 20 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, dark reddish-brown fine-grained sandstone, siltstone, and sandy shale. The contact between the Spearfish Formation and the underlying Minnekahta Limestone is sharp, but conformable (Robinson, Mapel, and Bergendahl, 1964). The unit is distinguished radiometrically from adjacent strata by its anomalous concentrations of potassium and uranium (DeWitt and others, 1989).

PALEOZOIC

Lower Permian Minnekahta Limestone and Opeche Shale combined (Pmo): These two formations are shown as a combined unit in the southeastern part of the Devils Tower 30' x 60' Quadrangle.

> **Lower Permian Minnekahta Limestone:** The Minnekahta Limestone consists of about 40 feet of light-gray, finely crystalline, thin-bedded limestone and purplish- to pinkish-gray dolomitic limestone, with stylolites common throughout. The limestone produces a petroliferous odor when unweathered pieces are freshly broken. Outcrops generally form almost bare dipslopes or cliffs. The lower part becomes silty and forms a gradational contact over a span of a few inches with the underlying Opeche Shale (Robinson, Mapel, and Bergendahl, 1964; Whitcomb and Morris, 1964; DeWitt and others, 1989). Large sinkholes cut the entire thickness of the formation in some areas of the Black Hills.
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> **Lower Permian Opeche Shale:** 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 90 feet of alternating nonresistant beds of maroon to reddish-brown siltstone and silty shale, and a few locally occurring thin seams of gypsum (Robinson, Mapel, and Bergendahl, 1964; 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 (Phm): The Minnelusa Formation crops out in the Bear Lodge Mountains and in the southeastern part of the Devils Tower 30' x 60' Quadrangle. The Minnelusa is composed of about 650 to 800 feet of light-gray to pink sandstone interbedded with gray sandy dolomite and limestone and minor red siltstone, shale, and local gypsum beds. The upper 20 to 50 feet of the formation is light yellowish-gray, fine-grained and calcareous, resistant, cliff-forming sandstone that often forms cavernous ledges (Robinson, Mapel, and Bergendahl, 1964; Whitcomb and Morris, 1964). The character of the formation is variable in lithologic details across the region. 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

Devils Tower 30’ x 60’ Quadrangle and at the Burnt Hollow field northeast of Hulett. The Minnelusa is a major producer in the Powder river Basin to the west (De Bruin, 2002).

Lower Mississippian Pahasapa Limestone (Mp): The Pahasapa Limestone within the Devils Tower 30’ x 60’ Quadrangle crops out only in the Bear Lodge Mountains. It is represented by about 500 to 575 feet of massive, hard, cliff-forming, gray, very fine-grained, generally thick-bedded, cavernous, limestone and dolomitic limestone that contains nodules and layers of chert in some outcrops (Whitcomb and Morris, 1964; Staatz, 1983; DeWitt and others, 1989). The lower part of the Pahasapa is medium- to thin-bedded, and its lower contact is marked by a change from gray limestone to the pink-mottled light-gray Whitewood Dolomite (Staatz, 1983). The Pahasapa Limestone is equivalent, at least in part, to the Madison Limestone farther west in Wyoming.

Upper Ordovician Whitewood Dolomite (Ow): The **Whitewood Dolomite** is about 145 feet thick where it forms discontinuous exposures within the Devils Tower 30’ x 60’ Quadrangle in the Bear Lodge Mountains. It consists of poorly exposed, massive to thin-bedded, light-gray, fine-grained limestone with pink mottles up to about 1.6 inches across (Staatz, 1983).

Upper Cambrian to Lower Ordovician Deadwood Formation (Oed): Within the Devils Tower 30’ x 60’ Quadrangle, this unit crops out only in the Bear Lodge Mountains. The Deadwood Formation varies widely in thickness across the region, but is represented near Sheep Mountain, on the east side of the Bear Lodge Mountains by a partial section measured by Staatz (1983) at more than 880 feet thick. In the Bear Lodge Mountains, the Deadwood is principally composed of quartzite and interbedded shaly limestone that has in many areas been replaced by Tertiary intrusive bodies. 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).

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MAP UNITS

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)

Tl **Lamprophyre small intrusions**

Tc **Carbonatite dike**

Tb **Intrusive breccia**

Tpy **Pyroclastic deposits**

Tp **Phonolitic intrusive rocks**

Tpa **Phonolitic agglomerate**

Tpp **Pseudoleucite porphyry**

Tt **Trachytic intrusive rocks**

Ts **Syenite and nepheline syenite intrusive rocks**

Tlt **Latite intrusive rocks**

Tft **Paleocene Fort Union Formation**

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

Kpuh Upprt part & Monument Hill member undifferentiated

Kph Monument Hill bentonite member

Kpm Middle part of Pierre Shale

Kps Mitten black shale member

Kpg Gammon ferruginous member

Kpgg Groat sandstone bed of 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

Kf Lower Cretaceous 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

Jsr Redwater shale member & LAK member combined

Jsh Hulett sandstone member

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

Jg **Middle Jurassic Gypsum Spring Formation**

dPs **Triassic / Permian Spearfish Formation**

PALEOZOIC

Pmo **Lower Permian Minnekahta Limestone and Opeche Shale combined**

Phm **Lower Permian / Pennsylvanian Minnelusa Formation**

Mp **Lower Mississippian Pahasapa Limestone**

Ow **Upper Ordovician Whitewood Dolomite & Middle Ordovician Winnipeg Formation**

Oed **Upper Cambrian to Lower Ordovician Deadwood Formation**

Map Symbols

Rock unit contact

Fault, dotted where projected beneath younger units

Anticline

Syncline

Strike and dip of beds, number denotes measured dip