# Map Unit Properties Table: Bighorn Canyon National Recreation Area

**Rows shaded in gray indicate geologic map units that do not occur within Bighorn Canyon National Recreation Area but are included in the digital geologic data (see Attachment 1).**

| Age | Unit Name (Symbol) | Description | Geologic Issues | Geologic Features and Processes | Geologic History and Park Connections |
|---|---|---|---|---|---|
| QUATERNARY (Holocene and Pleistocene) | Alluvium (Qal) | Well to poorly stratified, dominantly clast-supported, and moderately well sorted gravel, sand, silt, and clay along active channels of rivers, streams, and tributaries. Includes alluvial terrace deposits less than 1.8 m (6 ft) above river or stream. Pierce (1997) included alluvial fans and glacial outwash. Thickness as much as 10 m (35 ft).<br><br>Vuke et al. (2000) described the alluvium of the Big Horn River as mainly pebbles, cobbles, and boulders of limestone and dolomite, andesite and other mafic volcanic rocks, quartzite, granitic rocks, sandstone, and chert, in descending order of abundance. Most sediment in tributaries draining areas underlain by Cretaceous sandstone and shale bedrock is sand, silt, and clay (Lopez 2000). | Flooding—Areas covered by Qal have the potential to flood.<br><br>Frost Heaving—Terrace soils have frost-heaving potential.<br><br>Mineral Resources—Placer gold deposits along the Bighorn River prior to inundation behind Yellowtail Dam. Sand and gravel. | Seeps and Springs—**Alluvium (Qal)** over **Mowry Shale (Km)** (and other Cretaceous shales) hosts springs. | May make up terraces, alluvial fans, or glacial outwash, in addition to active stream channels. |
| | Alluvial fan deposits (Qaf) | Gravel, sand, silt, and clay deposited in fans by modern streams along major valley margins. Display characteristic fan-shaped map pattern and convex upward profile. Typically grade upstream into Qal. Vuke et al. (2000) mapped crudely stratified, gravel-matrix supported fan at mouth of ephemeral stream at base of Big Horn Mountains near Fort Smith. Thicknesses range from very thin at toes to as much as 15 m (50 ft) at heads of fans. | Flooding—Sites of flood-water runoff.<br><br>Mineral Resources—Sand and gravel. | Seeps and Springs—Source of groundwater. | Characteristic fan-shaped deposits. Contains Lava Creek B ash, 400,000 years old (Reheis et al. 1984). |
| | Landslide deposits (Qls) | Rock and soil that moved downslope in discrete units, through mass-wasting processes that resulted in irregular or hummocky surfaces, with characteristically concentric swales and ridges near downslope limits. Locally, consist of internally cohesive, rotated slump blocks. Thickness 30 m (100 ft) to 46 m (150 ft). | Mass Wasting—Active landslide potential.<br><br>Mineral Resources—Sand and gravel | None documented in GRI report. | Landsliding is actively modifying the landscape. |
| | Gravelly sheetwash alluvium (Qgac) | Poorly to moderately well stratified and well sorted gravel, sand, silt, and clay. Derived from higher level alluvial terrace deposits, and to a lesser extent from bedrock sandstone and shale. Thickness up to 25 m (82 ft). | Mass Wasting—Sheetwash promotes erosion and potentially mass wasting.<br><br>Mineral Resources—Sand and gravel. | None documented in GRI report. | Sheetwash erosion is actively modifying the landscape. |
| QUATERNARY (Holocene and Pleistocene?) | Alluvial gravels, terrace levels 1–3, undivided (Qat) | Gravel, sand, silt, and clay underlying terraces 6 m (20 ft) to 61 m (200 ft) above present elevation of modern streams and rivers. Equivalent to Qat1–Qat3, mapped on the Billings quadrangle to the north (Lopez 1996). | Frost Heaving—Terrace soils have frost-heaving potential.<br><br>Mineral Resources—Sand and gravel. | Paleontological Resources—Musk ox vertebrae (Reheis 1987).<br><br>Terraces—Provides evidence of dynamic nature of fluvial processes and tectonic activity. | Records fluvial and tectonic activities over the past 2.02 million years. |
| | Middle level stream terraces (Qt2) | Composed of the Chapman, Powell, Sunshine, and Emblem bench terraces, the no. 2 terrace of Alden (mapped in 1932), and nos. 2, 3, 4, and 5 terraces of Andrews et al. (1947). | Frost Heaving—Terrace soils have frost-heaving potential.<br><br>Mineral Resources—Sand and gravel. | Terraces—Provides evidence of dynamic nature of fluvial processes and tectonic activity. | Records fluvial and tectonic activities over the past 2.02 million years. |
| QUATERNARY (Pleistocene) | Pediment deposits (Qp) | Thin veneer of poorly rounded to subangular rock debris, including limestone fragments derived from Heart Mountain detachment fault masses, and surficial material deposited on smooth, gently sloping erosion surfaces cut on bedrock. | Mass Wasting—Rockfall debris. | Structural and Tectonic Features and Processes—Heart Mountain fault is not in the immediate vicinity of Bighorn Canyon National Recreation Area. | Records landscape-scale erosion. |
| QUATERNARY | Cody terrace (Qtc) | Unconsolidated silt and sand. 30 m (100 ft) to 49 m (160 ft) above the Shoshone River. Commonly capped by pebbles and cobbles. | Frost Heaving—Terrace soils have frost-heaving potential.<br><br>Mineral Resources—Sand and gravel. | Terraces—Provides evidence of dynamic nature of fluvial processes and tectonic activity. | The most extensive and highest of a series of benches on the Shoshone River. |
| | Undifferentiated terrace deposits (Qtu) | Fragmentary terrace deposits (silt and sand deposits with gravel caps) along the Bighorn and Shoshone rivers and Little Dry Creek. | Frost Heaving—Terrace soils have frost-heaving potential.<br><br>Mineral Resources—Sand and gravel. | Terraces—Provides evidence of dynamic nature of fluvial processes and tectonic activity. | Records fluvial and tectonic activities over the past 2.02 million years. |

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| Age | Unit Name (Symbol) | Description | Geologic Issues | Geologic Features and Processes | Geologic History and Park Connections |
|---|---|---|---|---|---|
| QUATERNARY | Undifferentiated pediment and in stream beach deposits (Qu) | Sloping surfaces cut on bedrock and usually mantled with rock fragments. | Mass Wasting—Rockfall debris. | None documented in GRI report. | Records landscape-scale erosion. |
| QUATERNARY–TERTIARY (Pleistocene and Pliocene?) | Landslide deposits (QTls) | Unconsolidated mixture of soil and blocks of local bedrock along the flanks of the Pryor Mountains uplift. Surface form obliterated by later erosion. | Mass Wasting—Older (likely inactive) landslide deposits occurring at the base of the Pryor Mountains. | None documented in GRI report. | Records occurrences of past landsliding. |
| | Pediment gravel deposits (QTpg) | Angular and subangular, coarse gravel derived from local bedrock, mostly limestone. Pediment surface is slightly dissected. Thickness 3 m (10 ft) to 9 m (30 ft). | Mineral Resources—Gravel. | None documented in GRI report. | Forms smooth surfaces sloping away from the Pryor and Bighorn mountains. |
| UPPER CRETACEOUS | Mesaverde Formation (Kmv) | <u>Upper part</u>: Interbedded light-gray sandstone and gray shale. <u>Lower part</u>: Massive, light-buff, ledge-forming sandstone containing thin, lenticular coal beds. Thickness 200 m (656 ft) to 400 m (1,312 ft). | Mass Wasting—Shale may cause erosion and mass movement. Lower part forms ledges.<br><br>Mineral Resources—Coal. | None documented in GRI report. | Regressive marine sequence deposited in Cretaceous Interior Seaway. |
| | Cody Shale (Kc) | Shale, light to dark gray, calcareous in lower half. Uppermost beds consist of sandstone, shale, and thin bentonite beds. Thickness about 680 m (2,230 ft). | Shrink-Swell Potential—Bentonite may cause shrink and swell.<br><br>Mass Wasting—Shale may cause erosion and mass movement.<br><br>Mineral Resources—Bentonite. Moderate oil and gas potential in shale units. | Paleontological Resources—Abundant mollusks, fish scales, and some reptile bones (Santucci et al. 1999). | Transgressive marine sequence deposited in Cretaceous Interior Seaway. |
| | Lowermost 580 m (1,900 ft) of the Cody Shale (Kcl) | Mainly gray shale, calcareous in lower part. Changed from Kca on source map due to symbol conflict with Carlile Shale (Rioux 1994). | Mass Wasting—Shale may cause erosion and mass movement. | Paleontological Resources—Abundant mollusks, fish scales, and some reptile bones in **Cody Shale (Kc)** (Santucci et al. 1999). | Deposited in Cretaceous Interior Seaway. |
| | Niobrara Shale (Kn) | Olive-gray and dark brownish-gray fissile shale with abundant, thin bentonite beds. Contains thin beds of very calcareous, laminated sandstone, siltstone, and sandy limestone near the top. Medium light-gray to pale yellowish-brown concretions up to 0.6 m (2 ft) in diameter commonly present. Contains a 3-m- (9-ft-) thick bed of calcareous shale 23 m (75 ft) above the base of the formation. Thickness 125 m (410 ft) to 213 m (700 ft).<br><br>Lopez (2000) placed upper contact at change from calcareous shales to non-calcareous shales of Telegraph Creek, and basal contact below ledge-forming zone of closely spaced, fossiliferous, gray septarian concretions with veins of brown calcite. | Shrink-Swell Potential—Bentonite may cause shrink and swell.<br><br>Mass Wasting—Shale may cause erosion and mass movement.<br><br>Mineral Resources—Bentonite. | Paleontological Resources—Bivalves (*Anomia* sp., *Inoceramus deformis*, *Pteria nebrascana*, and *Veniella* sp.), cephalopods (*Baculites codyensis*, *Baculites mariasensis*, *Baculites sweetgrassensis*, and *Scaphites impendicostatus*), oysters (*Ostrea congesta*), ammonites (*Clioscaphites vermiformis*), and indeterminate nautiloids, gastropods, pelecypods, echinoid spines, and fish scales. | Deposited in Cretaceous Interior Seaway. |
| | Carlile Shale (Kca) | Very dark-gray to dark bluish-gray fissile shale, with dark-gray sandy shale at the base and in the middle. Interval about mid-section contains laminae and thin beds of argillaceous, platy, light brownish-gray to light olive-gray sandstone. The lower sandy shale contains two bentonite beds 0.6 m (2 ft) to 0.9 m (3 ft) thick. The uppermost part contains closely spaced, medium-gray calcareous septarian concretions, with thick veins of dark-brown calcite. Lopez (2000) identified septarian concretions and nodules, ranging from light-gray to dark-yellowish-orange. Thickness 76 m (250 ft) to 91 m (300 ft). Basal contact placed above last calcareous shale in the underlying Greenhorn Formation (Lopez 2000). | Shrink-Swell Potential—Bentonite may cause shrink and swell.<br><br>Mass Wasting—Shale may cause erosion and mass movement.<br><br>Mineral Resources—Bentonite. Septarian concretions and nodules. | Paleontological Resources—Cephalopods (*Baculites besairiei*, *Scaphites corvensis*, and *Scaphites nigricollensis*), bivalves (*Crassatellites reesidei*, *Inoceramus altus*, *Inoceramus flaccidus*, and *Veniella goniophora*), bryozoans (*Membraniporina* sp.), clams (*Nucula* sp.), oysters (*Ostrea congesta*), ammonites (*Placenticeras stantoni* and *Prionocyclus wyomingensis*), and gastropods (*Tritonium kanabense*). | Sandstone beds locally support growth of pine trees, but otherwise surface exposures are nearly bare of soil and vegetation.<br><br>Deposited in Cretaceous Interior Seaway. |

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|---|---|---|---|---|---|
| UPPER CRETACEOUS | Greenhorn Formation (Kgr) | Dark bluish-gray calcareous, poorly resistant shale that weathers very light brownish-gray. Typically poorly exposed. Locally, contains numerous light-gray calcareous septarian concretions, and a thick zone of bentonitic shale or bentonite at the base. Upper contact marked by change to non-calcareous shale. Thickness 23 m (75 ft) to 35 m (115 ft). | Shrink-Swell Potential—Bentonite may cause shrink and swell.<br><br>Mass Wasting—Shale may cause erosion and mass movement.<br><br>Mineral Resources—Bentonite. | Paleontological Resources—Ammonites (*Allocrioceras annulatum* and *Vascoceras catinus*), bivalves (*Mytiloides labiatus* and *Plicatula* sp.), oysters (*Ostrea* sp.), cephalopods (*Scaphites delicatulus*, *Watinoceras reesidei*, *Pseudaspidoceras* sp., and *Quitmaniceras* sp.), and fish bones. | Deposited in Cretaceous Interior Seaway. |
| UPPER CRETACEOUS | Frontier Formation (Kf) | Thick, lenticular, gray sandstone, gray shale, brown carbonaceous shale, and bentonite. Contains large sandstone concretions. Hosts Torchlight Sandstone Member at top and Peay Sandstone Member in lower part. Interfingers with the upper part of the **Belle Fourche Formation (Kbf)**. Thickness 106 m (348 ft) to 182 m (600 ft). | Shrink-Swell Potential—Bentonite may cause shrink and swell.<br><br>Mass Wasting—Shale may cause erosion and mass movement.<br><br>Mineral Resources—Stucco bentonite bed mined in the area, about 60 m (200 ft) above the base, thickness 2 m (7 ft). Moderate oil and gas potential. | None documented in GRI report. | Deposited in Cretaceous Interior Seaway. |
| UPPER CRETACEOUS | Belle Fourche Formation (Kbf) | Dark-gray, fissile shale, containing ferruginous concretions and bentonite beds. In upper part, light-gray and brownish-gray calcareous concretions about 15 cm (6 in) to 30 cm (1 ft) in diameter, and light-brown to dark yellowish-orange concretions up to 1.2 m (4 ft) in diameter. Thickness up to 145 m (475 ft). | Shrink-Swell Potential—Bentonite may cause shrink and swell.<br><br>Mass Wasting—Shale may cause erosion and mass movement.<br><br>Mineral Resources—Bentonite: 1.8-m- to 2.1-m- (6- to 7-ft-) thick bentonite bed in lower part; the Soap Creek bentonite bed in the middle part, which is 60 m (197 ft) thick; and a 1.8-m- to 2.1-m- (6- to 7-ft-) thick bentonite bed in the upper part. | None documented in GRI report. | Deposited in Cretaceous Interior Seaway. |
| UPPER CRETACEOUS | Mowry Shale (Km) | Light-gray to medium-gray siliceous, very fine- to fine-grained sandstone and siltstone, with silvery sheen interbedded with medium dark-gray fissile shale. Shale weathers to bluish white. Locally, some sandstone beds are highly silicified, resulting in very hard quartzite. Thickness 76 m (250 ft) to 120 m (395 ft). | Shrink-Swell Potential—Bentonite may cause shrink and swell.<br><br>Mass Wasting—Shale may cause erosion and mass movement.<br><br>Mineral Resources—Contains several bentonite beds, typically 0.3 m (1 ft) to 1.2 m (4 ft) thick, including Clay Spur bentonite, which is 3 m (10 ft) thick and lies about 15 m (50 ft) below top. Chert pebbles. | Paleontological Resources—Fish scale impressions are common in many beds (Richards 1955). | Deposited in Cretaceous Interior Seaway. |
| UPPER AND LOWER CRETACEOUS | Mowry Shale and Thermopolis Shale, undivided (Kmt) | Upper sequence: Gray and brown shale, in part siliceous, containing numerous bentonite beds. Thickness 100 m (328 ft) to 135 m (443 ft).<br><br>Lower sequence: Soft, black shale containing numerous bentonite beds. Thickness 120 m (394 ft) to180 m (591 ft). Muddy Sandstone Member of Thermopolis Shale about 60 m (197 ft) above base. | Shrink-Swell Potential—Bentonite may cause shrink and swell.<br><br>Mass Wasting—Shale may cause erosion and mass movement.<br><br>Mineral Resources—Bentonite. Oil and gas. | Paleontological Resources—See individual unit descriptions. | Deposited in Cretaceous Interior Seaway. |
| LOWER CRETACEOUS | Thermopolis Shale (Kt) | Upper part: Dark-gray fissile shale. Lower part: Dark-gray to olive-gray fissile shale with interbeds and laminae of olive-gray and light olive-gray, argillaceous sandstone. Contains thin bentonite beds and zones of iridescent, very dusky-purple to grayish-black ferruginous concretions (“ironstones”). Rioux (1994) noted round dahllite concretions at base.<br><br>Lopez (2000) and Vuke et al. (2000) included the Fall River Sandstone with the Thermopolis Shale. The Fall River Sandstone underlies the Thermopolis Shale and is an upward-coarsening sequence of interbedded, medium dark-gray, fissile shale and fine-grained, quartzose, light brownish-gray to moderate yellowish-brown sandstone. Sandstone coarsens and beds thicken slightly up section, commonly rippled, burrowed to bioturbated, and moderately to heavily limonite and hematite stained. Combined thickness 183 m (600 ft) to 213 m (700 ft). | Shrink-Swell Potential—Bentonite may cause shrink and swell.<br><br>Mass Wasting—Shale may cause erosion and mass movement.<br><br>Mineral Resources—Bentonite. | Paleontological Resources—Mollusks, fish bones, sharks teeth, and marine reptile bones (David Lopez, geologist/independent consultant, written communication, January 31, 2011). Trace fossils (burrows and bioturbation). | Deposited in Cretaceous Interior Seaway. |

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|---|---|---|---|---|---|
| LOWER CRETACEOUS | Kootenai Formation (Kk) | Reddish-brown, olive-gray, and dusky-purple bentonitic mudstone interbedded with lenticular, fine- to coarse-grained sandstone. Thin zones of light-gray nodular limestone common in upper part. Greybull Sandstone Member (thick, lenticular, fine-grained sandstone) locally present at top. Pryor Conglomerate Member at base is brown conglomerate and pebbly coarse-grained sandstone, 6 m (20 ft) to 18 m (60 ft) thick. Total thickness 59 m (195 ft) to 75 m (245 ft). | Mass Wasting—Landslides and slumps common.<br><br>Mineral Resources—Bentonite. | Structural and Tectonic Features and Processes—Exposed in massive anticline. Pryor Conglomerate Member forms hogbacks. | Deposited in Cretaceous Interior Seaway.<br><br>Equivalent to Clovery Formation (Wyoming terminology). |
| LOWER CRETACEOUS AND UPPER JURASSIC | Cloverly Formation and Morrison Formation, undivided (KJcm) | Cloverly Formation: "Rusty beds" with thin ironstone beds, sandstone, and dark-gray shale overlying lenticular channel sandstones of the Greybull Sandstone Member in the upper 49 m (160 ft). Remainder is varicolored shale and gray sandstone not easily separated from underlying Morrison Formation.<br><br>Morrison Formation: Pale green and varicolored shale, mudstone, and white, lenticular, ledge-forming sandstone beds, locally cross-bedded. Combined thickness 189 m (620 ft). | Mass Wasting—Shale may cause erosion and mass movement. Sandstone beds in Morrison Formation form resistant ledges.<br><br>Mineral Resources—Clay and shale. Coal. Moderate oil and gas potential. | None documented in GRI report. | Cloverly Formation named from Cloverly Post Office on eastern side of the Bighorn Basin.<br><br>Nonmarine setting. |
| UPPER JURASSIC | Morrison Formation (Jm) | Variegated, mainly greenish-gray and pale reddish-brown mudstone. Very fine to fine-grained, quartzose, calcareous, cross-bedded sandstones are commonly present at about midsection, 1.5 m (5 ft) to 3 m (10 ft) thick but locally can be as much as 9 m (30 ft) thick. Total thickness 91 m (300 ft) to 107 m (350 ft). | Mineral Resources—Low oil and gas potential. | Paleontological Resources—Contains fragmentary dinosaur bones in the nonmarine sediments (Santucci et al. 1999). *Allosaurus* remains were discovered in the Morrison Formation on Bureau of Land Management property about 32 km (20 mi) south of the national recreation area (Santucci et al. 1999). A sauropod track locality was identified on the west side of Sykes Mountain in the upper portion of the Salt Wash Member (Engelmann and Hasiotis 1999). Contains tetrapod swim tracks (Harris and Lacovara 2004; Mickelson 2005). Turner et al. (2004) reconstructed the ancient ecosystem of the Morrison Formation.<br><br>Structural and Tectonic Features and Processes—Exposed in massive anticline. | Perhaps the most well-known dinosaur-bearing formation in the western United States.<br><br>Upper contact at the base of the Pryor Conglomerate Member of the **Kootenai Formation (Kk)**. Basal contact at the top of fossiliferous limy sandstone and coquina of the underlying **Swift Formation (Jes)**.<br><br>Marine, freshwater, and terrestrial settings. |
| UPPER JURASSIC | Swift Formation (Jes) | Greenish-gray to yellowish-gray fine- to coarse-grained, plane-bedded or cross-bedded, glauconitic, fossiliferous sandstone or very sandy limestone coquina at the top. Medium-gray poorly resistant claystone interbedded with silty to sandy moderately resistant, greenish-gray claystone in the lower part. Greenish-gray to yellowish-gray, poorly resistant, glauconitic, fossiliferous sandstone at the base and one or more similar thin glauconitic sandstones higher in the unit. Thickness about 35 m (115 ft). | Mass Wasting—Poorly to moderately resistant to erosion. Forms resistant ledges and hogbacks.<br><br>Mineral Resources—Low oil and gas potential. | Paleontological Resources—Coquina.<br><br>Structural and Tectonic Features and Processes—Exposed in massive anticline. | Upper formation of **Ellis Group**.<br><br>Marine depositional setting. |
| UPPER JURASSIC | Rierdon Formation (Jer) | Light-gray limestone, brownish-gray, sandy oolitic limestone, and light yellowish-gray, fine-grained calcareous sandstone. Greenish-gray to light-brown calcareous shale in lower part. Thickness about 55 m (180 ft). | Mass Wasting—Shale may cause erosion and mass movement. Sandstone forms resistant ridge; limestone forms smooth slopes.<br><br>Mineral Resources—Building stone (oolitic limestone). | Structural and Tectonic Features and Processes—Exposed in massive anticline. | Middle formation of **Ellis Group**.<br><br>Marine depositional setting. |
| UPPER JURASSIC | Sundance Formation (Js) | Gray-green sandstone, siltstone, and shale with thin fossiliferous limestone. Resistant glauconitic, cross-bedded sandstone at top. Thickness about 113 m (370 ft). | Mass Wasting—Top (sandstone) resistant to erosion. Shale may cause erosion and mass movement. | Paleontological Resources—Cephalopods (*Belemnites* sp.), bivalves (*Gryphaea* sp.), and star-shaped crinoid columnals (*Pentacrinus* sp.) (Richards, 1955). In the Crooked Creek area, the Rierdon Formation (part of Sundance Formation of Wyoming terminology) contains fossil fish (David Lopez, geologist/independent consultant, written communication, January 31, 2011). | Extensive, covering parts of Montana, Wyoming, Colorado, and South Dakota.<br><br>Largely marine with abundant fauna. |

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|---|---|---|---|---|---|
| UPPER AND MIDDLE JURASSIC | Sundance Formation and Gypsum Spring Formation, undivided (Jsg) | Sundance Formation (Upper and Middle Jurassic): Green and gray shale, greenish-gray, glauconitic, limy sandstone, and thin beds of gray, fossiliferous limestone. Thickness 110 m (360 ft) to 140 m (374 ft).<br><br>Gypsum Spring Formation (Middle Jurassic): Red and gray shale, fossiliferous limestone, and gypsum. Gypsum bed at base up to 30 m (98 ft) thick. Total thickness 20 m (65 ft) to 70 m (230 ft). | Mass Wasting—Poorly to moderately resistant to erosion.<br><br>Mineral Resources—Gypsum. | Caves and Karst—Dissolution possible in gypsum beds.<br><br>Paleontological Resources—See individual unit descriptions. | See individual unit descriptions. |
| MIDDLE JURASSIC | Gypsum Spring Formation (Jgs) | Red-brown silty shale with interbedded gypsum, limestone, and dolomite. Thickness about 61 m (200 ft). | Mass Wasting—Poorly consolidated and readily eroded.<br><br>Mineral Resources—Massive, white gypsum bed at base. | Caves and Karst—Dissolution possible in gypsum beds. | Occurs in Yellowstone province, Snake River basin, Greater Green River basin, Wasatch uplift, Uinta basin, and Uinta uplift.<br><br>Represents basal deposits of transgressive sea. |
| MIDDLE JURASSIC | Piper Formation (Jep) | Upper part: Brownish-red claystone, with scattered streaks of green claystone interbedded with brownish-red siltstone. Middle part: White dolomitic limestone bed and gray-to-lavender chalcedony nodules. Medium-gray limestone and white dolomitic limestone interbedded with red claystone and white gypsum. Lower part: Dark brownish-red claystone, with lenses of white gypsum underlain by massive white gypsum, interbedded with some brownish-red claystone, siltstone, and medium-gray limestone. Thickness 23 m (75 ft) to 46 m (150 ft). | Mass Wasting—Forms resistant ledge below smooth slopes of the **Rierdon shales (Jer)**.<br><br>Mineral Resources—Gypsum. Chalcedony nodules. | Caves and Karst—Dissolution possible in gypsum beds.<br><br>Structural and Tectonic Features and Processes—Exposed in massive anticline. | Includes distinctive "red beds."<br><br>Named for town of Piper, Montana.<br><br>Lower formation of **Ellis Group**.<br><br>Marine depositional setting. |
| JURASSIC | Ellis Group, undivided (Je) | Consists of the **Swift Formation (Jes)**, **Rierdon Formation (Jer)**, and **Piper Formation (Jep)**. See descriptions of individual units. | Mass Wasting—Poorly to moderately resistant to erosion. **Swift Formation (Jes)** forms ledges.<br><br>Mineral Resources—Oil and gas. Gypsum. | Structural and Tectonic Features and Processes—Forms hogbacks. Part of Montana folded belt province. | Marine depositional setting.<br><br>Equivalent to Sundance Formation of Wyoming terminology. |
| TRIASSIC | Chugwater Formation (TRc) | Interbedded moderate reddish-brown, fine-grained sandstone, siltstone, and mudstone. Thin light-gray limestone bed is present near the top. Rioux (1994) noted thin sandstone beds near the top and dolomite lenses. Gypsum beds are common in lower part. Typically, strike valleys develop at the base of the Chugwater Formation above resistant rocks of the **Phosphoria (Pp)** and **Tensleep (PNt)** formations. Thickness 137 m (450 ft) to 250 m (820 ft). | Mass Wasting—Poorly to moderately resistant to erosion. Parent material for highly erodible soils.<br><br>Mineral Resources—Gypsum thickens to about 3 m (10 ft) locally. | Seeps and Springs—Produces groundwater high in sulfates (attributed to gypsum). Hosts springs.<br><br>Paleontological Resources—The only fossils from this unit occur in the gray chert pebbles within the basal conglomerate, which Richards (1955) reported as Pennsylvanian fauna eroded from the **Tensleep Formation (PNt)** or **Amsden Formation (PNMa)**.<br><br>Structural and Tectonic Features and Processes—Exposed in massive anticline. | Very scenic, brick-red color.<br><br>Deposited across the shoreline zone of a shallow coastal shelf. |
| LOWER TRIASSIC AND PERMIAN | Chugwater Formation and Goose Egg Formation, undivided (TRPcg) | Chugwater Formation: Red to dark reddish-brown, generally thin-bedded, locally cross-bedded, calcareous or gypsiferous, fine-grained and very fine-grained sandstone and siltstone.<br><br>Goose Egg Formation: Light-gray, very light-gray or pink, finely crystalline gypsum, interbedded with red, fine-grained sandstone and siltstone. Occurs only locally. Combined thickness about 150 m (492 ft). | Mass Wasting—Potential for erosion.<br><br>Mineral Resources—Gypsum. | Caves and Karst—Dissolution possible in gypsum beds.<br><br>Structural and Tectonic Features and Processes—Exposed in massive anticline. | Prominent, resistant 1.5-m- (5-ft-) thick, light-gray limestone ledge about 35 m (115 ft) below the top of the **Chugwater Formation (TRc)**. |
| LOWER TRIASSIC AND PERMIAN | Goose Egg Formation (TRPg) | Upper unit: Greenish-gray shale, some dolomite and gypsum. Thickness 15 m (50 ft). Middle unit: Gray, resistant cherty dolomitic limestone and dolomite. Thickness 27 m (90 ft). Lower unit: Mostly red shale with some gypsum, dolomite; thin phosphorite and blue gray chert at top, probably equivalent to the **Phosphoria Formation (Pp)** to the west. Thickness 40 m (130 ft). Total thickness about 82 m (270 ft).<br><br>Pierce (1997) described the formation as follows: Red sandstone and siltstone, white gypsum, and a few thin beds of dolomite. Thickness about 50 m (164 ft). | Mass Wasting—Shale may cause erosion and mass movement.<br><br>Mineral Resources—Gypsum. Phosphorite. | Caves and Karst—Dissolution possible in gypsum beds. | Deposited in a shallow lagoon or tidal flat adjacent to the Phosphoria sea. The hematitic rocks suggest marginal marine, high humidity, and warm arid climate. Chemically deposited rocks suggest submergence of detrital source area or increased evaporation rate. |

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| Age | Unit Name (Symbol) | Description | Geologic Issues | Geologic Features and Processes | Geologic History and Park Connections |
|---|---|---|---|---|---|
| PERMIAN | Phosphoria Formation (Pp) | Light-gray limestone, sandstone and quartzite, commonly grayish-pink, cherty. Lopez (2000) noted that because the formation is a very thin remnant, it was mapped separately only where scale allowed, but otherwise included with the **Tensleep Formation (PNt)**. Thickness 3 m (10 ft) to 15 m (50 ft). | Mineral Resources—Radioactive layers (uranium). Locally, a reddish-brown variety of chert, known as Dryhead Agate, mined and collected for lapidary purposes. Phosphorite. Hydrocarbon source rock. | None documented in GRI report. | Cyclic marine deposit (upwelling and geothermal conditions). |
| PENNSYLVANIAN | Tensleep Sandstone (PNt) | Very light-brown to light yellowish-brown, very fine-grained to medium-grained, well-sorted, well-rounded, cross-bedded, porous-to-tightly cemented sandstone. Locally, contains some thin limestone beds, nodular chert, dolomite, or silty green shale. Also, locally silicified to form quartzite (Lopez 2000). Thickness up to 61 m (200 ft). | Mass Wasting—Shale may cause erosion and mass movement.<br><br>Mineral Resources—High oil and gas potential. Nodular chert. | Seeps and Springs—Source of groundwater. Hosts springs.<br><br>Paleontological Resources—Foraminifera (*Bradyina* sp.) and fusulinids (*Climacammina* sp., *Fusulina rockymontana*, *Pseudostaffella* sp., *Wedekindellina euthysepta*, and *W. excentrica*) (Richards 1955).<br><br>Structural and Tectonic Features and Processes—Exposed in massive anticline. | Named for extensive exposures in walls of lower canyon of Tensleep Creek in Bighorn and Powder River basins, Big Horn County, Wyoming.<br><br>Extends along flanks of Bighorn Range.<br><br>Marine and shoreline setting. |
| UPPER AND MIDDLE PENNSYLVANIAN, MIDDLE PENNSYLVANIAN TO UPPER MISSISSIPPIAN | Amsden Formation and Tensleep Sandstone, undivided (PNMat) | <u>Tensleep Sandstone (Upper and Middle Pennsylvanian)</u>: Light-gray, well-sorted, cross-bedded and massive sandstone. Thin beds of gray limestone and dolomite in lower part. Thickness 40 m (131 ft) to 75 m (246 ft).<br><br><u>Amsden Formation (Middle Pennsylvanian to Upper Mississippian)</u>: Red shale contains some gray, dolomitic limestone and chert and hematite nodules. Basal part commonly red siltstone or sandstone. Thickness 45 m (147 ft) to 90 m (295 ft). | Mass Wasting—Shale may cause erosion and mass movement.<br><br>Mineral Resources—Uranium. Oil and gas. Chert and hematite nodules. | See individual unit descriptions. | See individual unit descriptions. |
| LOWER PENNSYLVANIAN AND UPPER MISSISSIPPIAN | Amsden Formation (PNMa) | Light-red to red, purple, green, or light-brown shale, siltstone, and sandstone, interbedded with very light-gray to gray limestone and dolomite that locally contains chert. Lopez (2000) also included mudstone in description. Thickness ranges from 43 m (140 ft) to 91 m (300 ft). Locally, tectonically thinned to only a few feet along the margins of Pryor Mountains uplift (Lopez 2000). | Mass Wasting—Shale may cause erosion and mass movement.<br><br>Mineral Resources—Uranium. Low oil and gas potential. | Paleokarst—Unconformably overlies karst surface developed on limestone of the **Madison Group (Mm)**.<br><br>Paleontological Resources—Marine invertebrates, including sponge spicules, fusulinids (*Climacammina* sp., *Pseudostaffella* sp., and *Profusulinella* sp.), and foraminifera (*Calcitornellids*, *Bradyina* sp., and *Tetrataxis* sp.) (Richards 1955). | Represents widespread Kaskaskia paleokarst surface.<br><br>Characteristically produces pink staining on underlying cliffs of **Madison Group (Mm)**.<br><br>Deposited in a transgressive sea. |
| MIDDLE MISSISSIPPIAN | Madison Group, undivided (Mm) | Light-gray to light brownish-gray limestone and dolomitic limestone. Thick-bedded to massive in the upper part (<u>Mission Canyon Limestone</u>) and thin-bedded to thick-bedded in the lower part (<u>Lodgepole Limestone</u>). Also contains thin, interbedded gray shales. Locally, at base, is <u>Cottonwood Canyon Member</u> (Lower Mississippian and Upper Devonian), which consists of gray dolomite, dolomitic siltstone, and sandstone about 5 m (16 ft) thick. Total thickness 149 m (490 ft) to 305 m (1,000 ft). | Mass Wasting—Shale may cause erosion and mass movement.<br><br>Mineral Resources—Upper massive beds of very pure limestone are quarried in the southwest part of the Pryor Mountains for industrial uses and lime production. Oil and gas potential; geologic and production zones A–D developed by oil exploration (McCaleb and Wayhan 1969). Collapse features may host low-grade uranium deposits. | Seeps and Springs—Major water-bearing unit in the region. Hosts springs.<br><br>Caves and Karst—Fractures. Collapse features and caves are common at the upper karst surface, which is infilled with shale from the overlying **Amsden Formation (PNMa)**. Provides evidence of past cave formation and hosts present-day caves. Caves within Madison Group may preserve Quaternary fossils.<br><br>Paleontological Resources—Highly fossiliferous formation within the national recreation area. Produces abundant marine invertebrates, including bryozoans, corals, brachiopods, and crinoids (Santucci et al. 1999). Crushing teeth of the cochliodont (fish) *Hybodus* also occur. | Historical lime production at Lime Kiln Creek along the Ok-A-Beh road.<br><br>Forms the walls of Bighorn Canyon.<br><br>Widespread across Idaho, Montana, North Dakota, South Dakota, and Wyoming.<br><br>Marine depositional setting. |

**Rows shaded in gray indicate geologic map units that do not occur within Bighorn Canyon National Recreation Area but are included in the digital geologic data (see Attachment 1).**

| Age | Unit Name (Symbol) | Description | Geologic Issues | Geologic Features and Processes | Geologic History and Park Connections |
|---|---|---|---|---|---|
| UPPER DEVONIAN | Three Forks Formation and Jefferson Formation, undivided (Dtj) | Three Forks Formation: Light gray to brownish-gray thin- to medium-bedded, silty to shaly limestone and dolomite interbedded with greenish-gray shale, siltstone, and sandstone.<br><br>Jefferson Formation: Dark brownish-gray, dolomitic, partly granular limestone. Combined thickness about 60 m (198 ft). | Mass Wasting—Shale may cause erosion and mass movement.<br><br>Mineral Resources—Low oil and gas potential. Has fetid smell of petroleum. | Paleontological Resources—See individual unit descriptions. | Occurs in central Montana uplift; Montana folded belt and Yellowstone provinces; and Bighorn, Wind River, and Greater Green River basins.<br><br>Maine depositional setting. |
| UPPER DEVONIAN | Jefferson Formation (Dj) | Dolomitic limestone, light brownish-gray, fetid, poorly exposed, typically occurs as float above **Bighorn Dolomite (Ob)**. Total thickness about 76 m (250 ft). | Mineral Resources—Dark-colored dolomites have fetid smell of petroleum. | Paleontological Resources—Marine invertebrates. Brachiopods (*Atrypa* sp.) and coral (*Amplexiphyllum* sp.) (Richards 1955). | Marine deposit, probably deposited in shallow water. |
| MIDDLE ORDOVICIAN | Bighorn Dolomite (Ob) | Very light-gray to very pale-orange micritic dolomite and dolomitic limestone. Has characteristic pock-marked surface due to differential weathering. Thickness 120 m (394 ft) to 152 m (500 ft). | Mass Wasting—Upper part thin- to thick-bedded; lower part massive and resistant. Forms resistant cliffs in lower reaches of deep canyons.<br><br>Mineral Resources—Moderate oil and gas potential. Chert. | Caves and Karst—Potential for caves. Cavities have connection to local legends of "Little People" who reside in the Pryor Mountains (Lopez 1995).<br><br>Seeps and Springs—Hosts springs.<br><br>Paleontological Resources—An archaeogastropoda was discovered at Bighorn Canyon (Santucci et al. 1999). | Named for Bighorn Mountains.<br><br>Marine depositional setting. |
| MIDDLE AND UPPER CAMBRIAN | Cambrian sedimentary rocks, undivided (Cs) | Light-red sandstone and quartzite, greenish-gray shale and sandy shale, gray thin-bedded limestone and greenish-gray flat-pebble limestone conglomerate. Thickness 213 m (700 ft) to 244 (800 ft). | Mass Wasting—Slumping possible, notably in Bull Elk Basin. Erosion potential. | None documented in GRI report. | Equivalent to the Flathead, Gros Ventre, and Gallatin formations of Wyoming, or the Flathead, Wolsey, Meagher, Park, and Pilgrim formations of Montana. |
| ARCHEAN | Granitic gneiss and schist (Ag) | Pale- to moderate-red granitic gneiss, medium dark-gray, quartzofeldspathic gneiss, biotite-hornblende schist, quartzite, and aplite. Contains mafic dikes and quartz veins. | None documented in GRI report. | None documented in GRI report. | Oldest rocks in the national recreation area and some of the oldest on Earth. Part of the Wyoming Province of Archean rocks. |