Chapter 4
Geologic Setting

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The geologic framework of WBRB groundwater regime is the assemblage of geolgic units and structural elements that define the several groundwater basins. Geologic units are derived from mapped lithostratigraphic units: the formations, members, tongues, and so forth established in formal and informal geologic usage.

Plate I is a surface geology map of the WBRB. Detailed descriptions of the WBRB geologic units are provided in Appendix A. The cross sections on **Plate VI** show typical subsurface structure in the WBRB. Isopach maps on **Plates VII and VIII** show the variation in thickness of selected WBRB aquifers and confining units.

Plate IV maps the outcrop areas of hydrogeologic units in the WBRB on the basis of correlation of hydrogeologic and lithostratigraphic units defined on **Plates II and III** and discussed in **Section 6.1.** **Plate V** defines how WBRB geologic units were assigned to hydrogeologic units for mapping on **Plate IV**.

4.1General/historical geology

Simple to complex stratigraphic, structural, and volcanic elements are present within the WBRB. The configuration of these elements and relationships among them influence the availability of groundwater. The geologic history relevant to groundwater resources of the WBRB, as described by Libra et al. (1981), Richter (1981), and Snoke (1993), starts with the nonconformable deposition of transgressive marine sediments onto Precambrian basement rocks during Middle Cambrian time. From that time forward, the stratigraphic, structural, and volcanic elements that record the geologic history of the WBRB are as follows:

1. Paleozoic strata in the WBRB were deposited in marine and nonmarine transgressive/regressive environments. Marine limestones and dolomites are the dominant lithologies of the Paleozoic sequence, with less extensive sandstones and shales that represent beach and near-shore environments. Deposition in the Paleozoic Era was broken by long periods of erosion, as indicated in the geologic record by several regional unconformities.

2. The early Mesozoic Era was a time of shallow seas with deposition of interbedded layers (in decreasing abundance) of sandstone, siltstone, shale, carbonates, and evaporates. An emergent transition to a terrestrial environment during the Late Triassic and Early Jurassic Epochs resulted in the deposition of marginal marine, eolian, fluvial, and paludal sandstones and shales.

3. During the Early Cretaceous Epoch a thick section of interbedded shale, sandstone, siltstone, and claystone was deposited under terrestrial, shallow marine, and deltaic conditions. Late Cretaceous transgressions and regressions resulted in a thick sequence of interbedded sandstone, siltstone, claystone, and shale deposited in marine, marginal marine, coastal plane, and deltaic environments. Crustal deformation associated with the Laramide Orogeny began in the Late Cretaceous; the Lance Formation recorded the final, eastward retreat of the Cretaceous seas followed by the deposition in terrestrial environments that would prevail throughout the Tertiary Period.

4. Laramide compressional deformation continued through the early Eocene with large-scale reverse and thrust faults forming the basement-cored mountain ranges and uplifts that surrounded and separated the concurrently subsiding Wind River and Bighorn structural basins. The uplifted areas were the source of several thousand feet of Tertiary sediments composed of Mesozoic, Paleozoic and Precambrian rocks that were eroded from the uplifts and filled the basins to the extent that all but the highest areas of the surrounding uplifts were buried. These strata are composed of conglomerates, sandstones, and claystones deposited primarily in fluvial, alluvial fan, and lacustrine environments. During the middle Eocene a pile of rhyolitic and basaltic volcanic rocks several thousand feet thick (Absaroka Supergroup and intrusive rocks) were emplaced along the western side of the Bighorn Basin and in the Yellowstone area.

5. Late Tertiary normal faulting concurrent with modest extension occurred throughout Wyoming. Uplift during the past 5 million years over a broad area that encompasses the WBRB resulted in the erosion and removal of an enormous volume of Tertiary strata, exhuming the Laramide framework and sculpting the present physiography of the WBRB. The massive pile of volcanic material that forms the Yellowstone Plateau is composed of rhyolitic and basaltic rocks (Yellowstone Group) associated with the active Yellowstone mantle hotspot and caldera, erupted during the past 2.2 million years.

6. The youngest geologic units in the basin are unconsolidated Pliocene and Quaternary terrace deposits and Quaternary alluvial deposits of various thickness. These deposits, some as much as several hundred feet thick, are composed of conglomerate, gravel, sand, and finer-grained clastic material. The age and occurrence of these deposits have been correlated with recent glacial and interglacial periods by Mackin (1937).

4.2 Structural geology

The Wind River and Bighorn basins are large asymmetric intermontane structural basins formed during the Laramide Orogeny (Late Cretaceous-Eocene) that contain up to 18,000 and 33,000 feet, respectively, of Cenozoic, Mesozoic, and Paleozoic sediments deposited on Precambrian crystalline basement rocks (Libra et al., 1981; Richter, 1981). With the exception of the western Bighorn Basin that is largely covered by the Absaroka volcanics, the structural basins are bordered by compressional uplifts cored by Precambrian granite and mantled by moderately to steeply dipping sedimentary formations (Libra et al., 1981). Laramide structural trends are thought to extend westward below the massive volcanic pile of the Absaroka/Yellowstone area. Paleozoic and Mesozoic formations exposed along the flanks of the mountain ranges surrounding the WBRB were folded, faulted, and eroded from the highest areas of the uplifts during the Laramide Orogeny; they now dip basinward at angles ranging from approximately 10 degrees to vertical, and some are overturned. Strata of Paleocene through early Eocene age are also deformed around the perimeters of both structural basins but are mostly flat-lying in the interior basin areas. Numerous anticlinal structures with associated faults and fractures that formed during the Laramide Orogeny crop out along the margins of both basins. Section 5.4 discusses the substantial influence that structures, primarily those located around the basin perimeters, exert on the groundwater resources.

The topography of the WBRB generally reflects the structure and topography of the Precambrian basement surface formed by uplift, folding, faulting, and erosion of the earth's crust under compressional stress during the Sevier and Laramide orogenies. Downwarping of the structural basins and upwarping and upfaulting of the uplifts were concurrent; and the upper strata within the interior basin areas are composed of Tertiary-age sediment that was eroded from the adjacent uplifts. The insert map on **Plate I** is a structure contour map of the Precambrian basement surface in the WBRB that shows a general northwest-southeast structural trend. The geologic cross sections on **Plate VI** show Precambrian basement rocks overlain by varying thicknesses of Paleozoic through Cenozoic formations, all deformed by large-scale folding and faulting.

The major Laramide structural elements of the WBRB **(Figure 3-2)** comprise:

- The folded and faulted Precambrian basement
- The deeply buried downwarped areas of the Wind River and Bighorn basins
- The mountain ranges and uplifts that surround and separate the basins:
    - the Pryor Mountains
    - the Bighorn Mountains
    - the Washakie Range, Owl Creek Mountains, and Bridger Mountains
    - the Casper Arch and Beaver Divide
    - the Wind River Range
    - the Beartooth Mountains

There are many subsidiary structures within the WBRB, some of which are or may be important elements of existing or potential sites for local groundwater development, but discussion of these features is beyond the scope of this study.

4.3 Stratigraphy

Geologic units within the WBRB vary widely in lithology and distribution, and range in age from Precambrian crystalline rocks to recent alluvial and terrace deposits. The Wind River Basin contains a maximum of approximately 18,000 feet, the Bighorn Basin a maximum of approximately 33,000 feet, of Cenozoic through Paleozoic sedimentary strata. The explanation on **Plate I** identifies the geologic units present in the basin; the individual geologic units are described in **Appendix A**. The distribution of geologic units reflects several periods of deposition, uplift, erosion, volcanism, and reworking/re-deposition of older units as younger strata. The erosion of rocks exposed in upland areas and re-deposition in the basins is an ongoing process. Accordingly, the stratigraphic sections preserved in interior basin areas are most complete, and stratigraphic sections are less complete to non-existent at higher elevations in the surrounding mountain ranges. In some places Tertiary and Quaternary deposits directly overly Precambrian basement rocks.

4.4 Wind River Basin and surrounding mountain ranges (Richter, 1981)

The Wind River Basin contains a maximum 18,000 feet of Cenozoic through Paleozoic sedimentary strata. The Wind River structural basin is bounded on the north by the Owl Creek and Bridger Mountains, on the east by the Casper Arch, on the southeast by the Beaver Divide, on the southwest by the Wind River Range, and on the northwest by the Absaroka Range and Washakie Range **(Figure 3-2)**.

The structure contour map of the Precambrian basement surface **(Plate I, inset)** shows that the axis (deepest area) of the structural basin is located along and parallel to the abrupt northern limit of the basin, 3 to 15 miles south of the Owl Creek and Bridger Mountains. Because the basement has been eroded in the mountains, maximum structural relief between the deepest area of the basin and the highest area of the uplifts exceeds the 38,000 feet defined by the difference between elevations in the deepest part of the structural basin at approximately 24,000 feet below sea level and at Gannet Peak at nearly 14,000 feet above sea level in the Wind River Range (Blackstone, 1993).

4.5 Bighorn Basin and surrounding mountain ranges (Libra et al., 1981)

The Bighorn Basin contains a maximum of 33,000 feet of Cenozoic through Paleozoic sediments. The Wyoming Bighorn Basin is open to the north along the Wyoming/Montana border and is bounded on the northeast by the Pryor Mountains, on the east by the Bighorn Mountains, on the south by the Owl Creek and Bridger Mountains, on the west by the Absaroka volcanics, and on the northwest by the Beartooth Mountains. It is likely that Laramide structures are buried beneath the Absaroka/Yellowstone volcanic pile (Thom, 1952).

The structure contour map **(Plate I)** of the Precambrian basement surface shows that the synclinal axis of the Bighorn Basin is located along the west side of the basin and trends generally northwest-southeast, parallel to the overall structural grain of the area. Because the basement has been eroded in the mountains, maximum structural relief between the deepest area of the basin and the highest area of the uplifts exceeds the 38,000 feet defined by the difference between elevations in the deepest part of the structural basin, approximately 24,000 feet below sea level, and on Cloud Peak nearly 14,000 feet above sea level in the Bighorn Mountains (Blackstone, 1993).

4.6 Owl Creek Mountains, Bridger Mountains, and Washakie Range

The Owl Creek and Bridger mountains compose one of the three Laramide uplifts in Wyoming that trend east-west. The uplift is a continuous structural and drainage divide between the Wind River and Bighorn basins, that runs between the south end of the Absaroka Range and south end of the Bighorn Mountains. The Owl Creek and Bridger mountains were uplifted along imbricate, south-verging thrust faults. Sedimentary strata ranging in age from Cambrian to Tertiary are exposed in the range. Precambrian rocks are exposed in the Wind River Canyon and along the ridge of the Bridger Mountains east of the canyon. Minor Quaternary deposits flank the uplift north and south. The highest areas of the range are substantially lower than the highest areas of the Absaroka or Bighorn ranges.

The Washakie Range, located at the west end of the Owl Creek Mountains between the northernmost extent of the Wind River Range and southern edge of the Absaroka Range in the northwestern Wind River Basin (Love 1937), is defined by a west-northwest-trending series of en echelon, faulted folds where geologic units ranging from Precambrian to Tertiary are exposed. The north side of the Washakie Range structural trend is buried beneath the Absaroka Range volcanics.

4.7 Volcanic and geothermal areas

Plates I and IV show the Absaroka Range and the Yellowstone Plateau, major volcanic elements within the WBRB. The Yellowstone area is characterized by major high- and low-temperature geothermal features. Although lacking associated volcanic material, the Thermopolis area, on the south end of the Bighorn Basin (north flank of the Owl Creek Mountains), and thermal springs near Dubois in the Wind River Basin are also notable (low-temperature) hydrothermal areas within the WBRB.

4.7.1 Absaroka Range and Volcanic Province (Sundell, 1993)

The depositional and erosional origin of the Absaroka Range is completely different from that of the typical Laramide uplifts that bound the WBRB. The pile of middle to late Eocene volcanic material that composes the Absaroka Range and associated Absaroka Volcanic Province was deposited on top of Cenozoic, Mesozoic, and Paleozoic sedimentary strata in a shallow foreland topographic and structural basin immediately west of the Bighorn Basin **(Plate I)**. The proposed source of the volcanic material is a belt of large andesitic stratovolcanoes. The Absaroka deposits comprise primary volcanic material (minor intrusive igneous rocks, lava flows, flow breccias, pyroclastic breccias, and tuffs) and re-worked volcaniclastic material (conglomerate, sandstone, siltstone, claystone, and breccia) with a combined maximum thickness of more than 6,000 feet.

The Absaroka Volcanic Province is a remnant of a much more extensive accumulation of volcanic material that formerly covered a much larger area of northwestern Wyoming. The Absarokas represent the largest Eocene volcanic field in the Northern Rocky Mountains. Reworking of the volcanic material included gravitational slide and flow mass-movements that produced three of the largest landslides on Earth. In addition, the Absaroka volcanic rocks were deformed by Laramide folding and faulting (earliest deposits), igneous intrusion, and post-volcanic extension and compaction.

Although high precipitation and high estimated recharge rates (Section 6.2.2) indicate that the Absaroka volcanic area could contain substantial groundwater resources, the complex to chaotic stratigraphy, elevation, extremely rugged topography, volcanic terrains, harsh climate, lack of roads, and other impediments to access (e.g., National Park or Wilderness designations) severely restrict exploitation of such resources. The deeply eroded terrain and stratigraphy within the Absaroka Province greatly restricts aquifer continuity and storage within the volcanic aquifer system. Most groundwater within the volcanics probably exists in perched and isolated accumulations. Natural discharge into streams that headwater in the mountains probably contributes substantial surface flow.

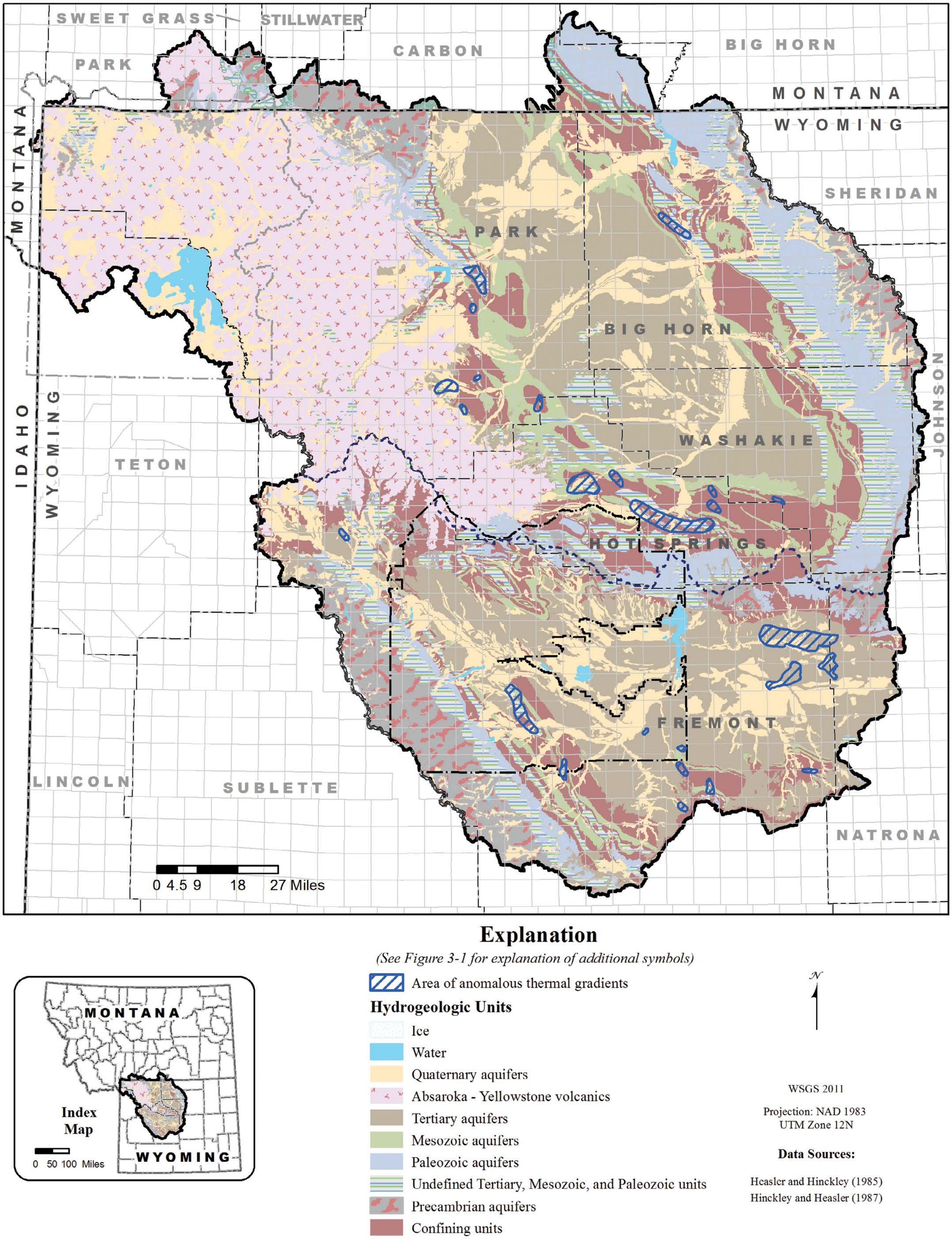

Figure 4-1. Potential hydrothermal resource areas, Wind/Bighorn River Basin, Wyoming.

4.7.2 Yellowstone Plateau (Keefer, 1971)

The Absaroka volcanic rocks are overlain by Late Pliocene and Quaternary volcanic deposits of the Yellowstone Plateau along the eastern margin of Yellowstone Park **(Plate I)**. The geology and hydrology of the Yellowstone volcanic area are dominated by the Yellowstone hotspot, associated large-scale historic volcanic events, including caldera eruptions, and ongoing widespread geothermal activity (Cox, 1976; Libra et al., 1981). The Yellowstone Plateau is separated from the rest of the WBRB by the Absaroka Range. Because most of the Yellowstone area is a National Park, the groundwater and hydrothermal resources of the area are not available for use outside the Park and are not considered relevant to this WBRB Available Groundwater Determination.

4.7.3 Geothermal resources (Heasler and Hinkley, 1985; Hinkley and Heasler, 1987)

The geothermal resources of the WBRB (exclusive of the Yellowstone Plateau) are of the low-temperature hydrothermal type, occurring where groundwater at anomalously elevated temperature (relative to the average geothermal gradient) is at a depth where it can be put to beneficial use. In this sense the hydrothermal resources are similar to direct-use groundwater resources. Hydrothermal resources of the WBRB are primarily suited to local, small-scale projects that utilize low-temperature waters for space-heating, de-icing, agriculture (e.g., greenhouses), aquaculture, recreational/ therapeutic applications (e.g., Thermopolis hot springs), or low-temperature processing.

Generally, groundwater is heated as it flows downdip into a structural basin in accord with the local geothermal gradient resulting from heat flow from deep in the earth toward the land surface. WBRB hydrothermal resources occur primarily where the heated groundwater rises to shallower depth under artesian hydraulic pressures at velocities that preclude dissipation of the heat acquired at depth. This requires vigorous upward flow through permeable up-folded strata or up faults, fracture systems, or wells. In general, the conditions that control hydrothermal resources occur only within the more productive Mesozoic and Paleozoic aquifers in the WBRB. The locations of known and potential areas of hydrothermal resource development (exclusive of Yellowstone Park) are shown on **Figure 4-1**.

4.8 Mineral resources

The development (production, processing, and transportation) of mineral resources generally requires the use and proper disposal or surface discharge of groundwater. The development of mineral resources may create avenues for groundwater contamination. In addition, the mineral content of aquifers, especially where specific minerals are concentrated (e.g., uranium, arsenic, hydrocarbons) can negatively affect groundwater quality. **Figures 5-3, 5-7, 5-8, and 5-9** show the distribution of oil-and-gas operations and other active and historic mineral development locations within the WBRB (Section 5.7.2).

Significant quantities of oil and gas have been developed in the WBRB. Substantial uranium and minor coal and feldspar have been commercially developed in the Wind River Basin. Coal, bentonite, and gypsum have been commercially developed in the Bighorn Basin. Industrial minerals including sand, gravel, clay, limestone, dolomite, shale, zeolites, talc, sulfur, and pumice have been produced within the WBRB, and some still are. The WSGS has mapped potential metal ore development areas for gold, silver, titanium, copper, and rare earths, and private companies have explored for metals; however, there are no current metal mining operations in the WBRB.

Most oil and gas has been developed in the Bighorn Basin in Mesozoic and older geologic units from stratigraphic traps and structural anticlines, and in the Wind River Basin from stratigraphic and structural traps in Tertiary and Cretaceous geologic units. Minor coalbed natural gas (CBNG) is currently being developed in the northern Bighorn Basin and the southern Wind River Basin, and there is good potential for additional CBNG development in both basins. Substantial uranium has been produced from the Wind River Formation in the southeastern Wind River Basin. Uranium is not currently being produced; however, substantial deposits remain that could be developed in the future. Bentonite is produced from Cretaceous strata in the northern Bighorn Basin. Gypsum is quarried from the Gypsum Spring Formation in the northwestern Bighorn Basin. Abundant coal is present in the WBRB in lower Tertiary and Cretaceous strata, with superior resources and minor production in the Grass Creek area of the Bighorn Basin. However, Grass Creek coal is not competitive with coal produced in other Wyoming basins and other states except for local use, so production is not expected to grow.