2.1 Topography, Geology, Minerals, and Paleontological Resources

The description of existing conditions in the PRB study area for topography, geology, and minerals was based on the Final EIS and Proposed Plan Amendment for the PRB Oil and Gas Project (BLM 2003a). The information presented in that document was updated based on other information sources including the Wyoming Oil and Gas Conservation Commission (WOGCC) on-line production data, public BLM documents, IHS Energy Services™ (IHS) well data, Wyoming State Geological Survey and U.S. Geological Survey (USGS) publications, other published documents, and the past and present action descriptions presented in the PRB Coal Review Task 2 Report (ENSR 2005a).

The description of existing conditions in the PRB study area for paleontological resources was based on the Final EIS and Proposed Plan Amendment for the PRB Oil and Gas Project (BLM 2003a). Other regional EAs and EISs were reviewed; however, the need to update the information in the oil and gas EIS was not identified.

2.1.1 Key Issues

The key issues for topography, geology, and minerals are potential conflicts primarily involving mineral extraction issues. One concern is the potential conflict between CBNG operators and mine operators. Another concern is the potential loss of resources when one form of mineral extraction potentially results in the loss of another recoverable mineral resource. In addition to gross acreage disturbance, alteration of the land surface is a concern.

The key issue for paleontological resources is the potential loss of scientific and educational values due to the damage, destruction, or improper collection of fossil resources in association with development activities.

2.1.2 Study Area

The study area for topography, geology, minerals, and paleontological resources generally includes all or portions of Campbell, Johnson, Sheridan and Converse counties (**Figure 1-1**). It includes all of the area administered by the BLM Buffalo Field Office, a portion of the area administered by the BLM Casper Field Office, and a portion of the TBNG, which is administered by the USFS (**Figure 1-2**). State and private lands also are included in the study area (**Figure 1-3**). However, some historical predictions of mineral production trends came from documents (BLM 1996, 1981) that analyzed mineral production in project areas defined differently from this study area. Some information concerning the mineral production history occurred outside of the defined study area; however, this information is presented because of the relevance to the study area. In addition, certain aspects of general geology (stratigraphy, structural geology) are discussed for the entire PRB, including Montana.

2.1.3 Current Conditions

2.1.3.1 Topography and Physiography

The PRB is located within the Upper Missouri Basin Broken Lands physiographic subprovince that includes northeastern Wyoming and eastern Montana to the Canadian border (USGS 1970). The topography generally is of low to moderate relief with occasional buttes and mesas (Radbruch-Hall et al. 1980). The underlying bedrock in some areas is very erodible, which in places results in heavily dissected to badland-type topography. The general topographic gradient slopes down gently (generally southwest to northeast) with elevations ranging from 5,000 to 6,000 feet above mean sea level (amsl) on the southern and western portions of the basin to less than 4,000 feet amsl on the north and northeast along the Montana state line. The Wyoming portion of the basin is bounded on the west by the Big Horn Mountains and the Casper Arch, on the south by the Laramie Mountains, on the southeast by the Hartville Uplift, and on the east by the Black Hills **(Figure 2.1-1)**.

The major drainages in the basin flow from south to north or east to west and include the Tongue, Powder, Belle Fourche, and Cheyenne rivers (**Figure 1-1**). Most of the drainages in the area are intermittent and have flows during high precipitation events or during periods of snowmelt. The drainages are part of the upper Missouri River Valley drainage basin. The Tongue River flows from the Big Horn Mountains and drains a small portion of the northwestern part of the study area. The north-flowing Powder River and major tributaries also have head waters in the Big Horn Mountains and drain much of the western portion of the PRB. The Belle Fourche River flows northeast and its drainage basin occupies much of the northeastern part of the study area. The Cheyenne River drains the southeastern part of the PRB and generally flows to the east.

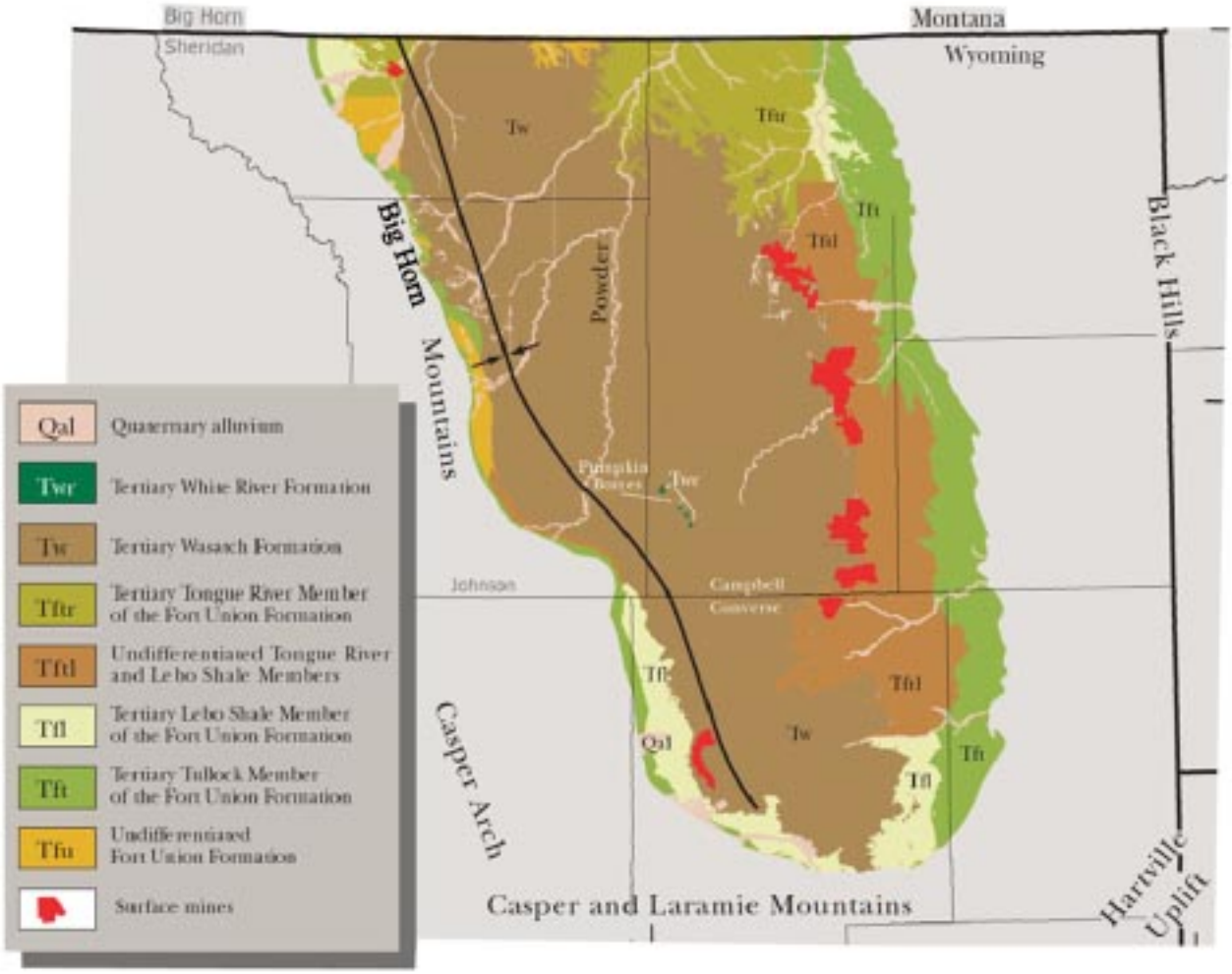
Surface coal mining alters the topography in mining areas by causing changes in slope, lowering the general land surface, and changing the physical nature of the surficial materials and overburden. The topography is affected only where mining occurs. Oil and gas exploration and development alter the landscape through leveling the land surface for drilling pads and cutting and filling during road construction. Oil and gas development affects topography to a much lesser degree than coal mining; however, it is more widespread than coal mining.

2.1.3.2 Geology

Statigraphy and Geologic History

The PRB contains Phanerozoic rocks (younger than Precambrian) over 17,000 feet in thickness. These rocks range in age from Cambrian to Tertiary (Love et al. 1993) **(Figure 2.1-2)**. In addition, there are unconsolidated alluvial and surficial deposits. Most of the rocks older than Tertiary outcrop along edges of the study area and also are found in the subsurface of the basin or are exposed along the margins of the basin. The following contains brief summaries of the rocks that are found in the study area.

Precambrian Era. The Precambrian rocks that are exposed in the adjacent mountain ranges and underneath the Phanerozoic rocks in the basin are complex assemblages of igneous and metamorphic rocks (Houston 1993). The Precambrian rocks are the oldest at billions of years old.



Powder River Basin Coal Review

Figure 2.1-1

General Geology of the Powder River Basin

Source: Flores et al. 2001.

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Era	System	Series	Stratigraphic Units		
			West		East
Cenozoic	Quaternary	Holocene	Undifferentiated unconsolidated deposits		
	Tertiary	Oligocene	White River Formation		White River Formation
		Eocene	Wasatch Formation	Moncrief Member	Wasatch Formation
				Kingsbury Member	
		Paleocene	Fort Union Formation	Tongue River Member	
				Lebo Shale Member	
				Tullock Member	
Mesozoic	Upper Cretaceous		Lance Formation		Lance/Hell Creek Formation
			Fox Hills Sandstone		Fox Hills Sandstone
			Lewis Shale		Pierre Shale
			Mesaverde Formation	Teapot Sandstone Member	
				Parkman Sandstone Member	
			Cody Shale	Sussex Sandstone Member	Niobrara Formation
				Shannon Sandstone Member	Carlisle Shale
			Frontier Formation		
					Greenhorn Formation
					Belle Fourche Shale
	Lower Cretaceous		Mowry Shale		
			Muddy Sandstone		Newcastle Sandstone
			Thermopolis Shale		Skull Creek Shale
			Cloverly Formation		Fall River Formation
					Lakota Formation
	Jurassic		Morrison Formation		
			Sundance Formation		
			Gypsum Spring Formation		
	Triassic		Chugwater Group or Formation		Spearfish Formation
Paleozoic	Permian		Goose Egg Formation		Goose Egg Formation
					Minnekahta Limestone
					Opeche Shale
	Pennsylvanian		Tensleep Sandstone		Minnelusa
			Amsden Formation		
	Mississippian		Madison Limestone		Pahasapa Limestone
					Englewood Limestone
	Devonian		No Units		
	Silurian		No Units		
	Ordovician		Bighorn Dolomite		Whitewood Dolomite
			Harding Sandstone		Winnepeg Formation
	Cambrian		Gallatin Limestone		Deadwood Formation
			Gros Ventre Formation		
			Flathead Sandstone		
Precambrian			Precambrian rocks		

Source: Love et al. 1993.

Figure 2.1-2 Stratigraphic Chart for the Powder River Basin

Paleozoic Era. During early Paleozoic time, present-day Wyoming and much of the Rocky Mountain west were located along a fairly stable continental shelf (Lageson and Spearing 1991).

The area generally was inundated by shallow seas, and fluctuations in sea level resulted in the deposition or erosion of sediments. The rocks that were deposited on this shallow continental shelf were the result of numerous changes in sea level referred to as transgressions (relative rise in sea level); or regressions (relative falling of sea level or movement of coastlines seaward). Changes in sea level also caused many deposits to be eroded resulting in unconformities (or gaps) in the rock record. The rocks that were deposited from the Cambrian to Mississippian time period are typical of rocks that originally were deposited in a shallow marine environment. For instance, the Mississippian-age Madison Limestone is a massive carbonate that is widespread across Wyoming and is typical of conditions extant during the Paleozoic (Craig et al. 1972).

In the later Paleozoic, the sandstones of the Pennsylvanian represent an influx of sediment due to the uplift of the ancestral Rocky Mountains and a change to continental deposits in some areas. Erosion from the uplifts resulted in the deposition of the Tensleep Sandstone and equivalents across the Rocky Mountain region. In the study area, Pennsylvanian rocks on the west side of the basin are represented by the Amsden and Tensleep Formations (Love et al. 1993). On the east side of the basin, the Tensleep Formation equivalent is the Minnelusa Formation. During the Permian, conditions changed to alternating shallow marine to continental environments as indicated by the shale, limestone, and anhydrites of the Goose Egg Formation.

Mesozoic Era. During the beginning of the Mesozoic Era, northeastern Wyoming continued to be dominated by fluctuations of the western margin of North America. Early Mesozoic rocks of the Triassic System are represented by the Chugwater Group in the western part of the basin and the Spearfish Formation in the east. The formations are similar and consist of red shale, limestone, sandstone, and gypsum (Watson 1980). During the Triassic, the Wyoming shelf was emergent, and much of the deposits laid down were terrestrial in origin typified by the red beds and evaporites of the Chugwater Group (Picard 1993).

During middle Mesozoic Era, the Wyoming shelf alternated between emergent and submerged, resulting in Sundance Formation deposits of the Jurassic System. The Sundance Formation rocks are representative of a transgressive-regressive sequence during the middle and late Jurassic. The Sundance Formation consists of sandstone and shale. The Canyon Springs Sandstone Member of the Sundance Formation was deposited during the advance of the sea onto the Wyoming shelf (Picard 1993). The Canyon Springs often consists of a calcareous, oolitic sandstone with well-rounded and frosted quartz grains (Watson 1980). Generally, the upper portion of the Sundance Formation has more shale. At the end of the Jurassic, terrestrial conditions predominated resulting in the Morrison Formation, which is characterized by stream deposits that were laid down on an alluvial plain. The Morrison Formation, is characterized by shale of various pastel colors (often red, green, and purple) with interbedded sandstone, siltstone, and conglomerate (Watson 1980).

Rocks from the later part of the Mesozoic Era belong to the Cretaceous System. When describing Cretaceous rocks, they are usually divided into upper and lower Cretaceous. In the lower part of the lower Cretaceous are sandstones that are loosely correlated and referred to as the Lakota Conglomerate and Fall River Sandstone. The Lakota and Fall River are sometimes indistinguishable and make up the Inyan Kara Group. The sandstones occasionally are separated

by the Fuson Shale; however, it is often not present (McGookey et al. 1972; Watson 1980). Above the Inyan Kara Group is a black marine shale that in the western part of the basin is called the Thermopolis Shale and in the east is called the Skull Creek.

During the Cretaceous, a feature known as the Western Interior Seaway developed from the Gulf of Mexico to the Arctic Ocean (McGookey et at. 1972). During the Cretaceous, there were numerous episodes of transgressions and regressions that resulted in the deposition of thousands of feet of sedimentary rock. Following the deposition of the Lakota Conglomerate, the first major Cretaceous transgression began resulting in the deposition of the marginal marine Fall River Sandstone then the Thermopolis-Skull Creek Shale. A regression followed that resulted in the deposition of the widespread Muddy Sandstone. In northeastern Wyoming, the Muddy-equivalent is referred to locally as the Newcastle Formation.

The upper Cretaceous rocks consist of numerous formations that vary from west to east, indicative of the changing environments spatially and temporally across the basin during upper Cretaceous time. On the west side of the basin above the Muddy Sandstone, there are the Mowry Shale, Frontier Formation, Cody Shale, Mesaverde Formation, Fox Hills Sandstone, and Lance Formation. Above the Muddy-Newcastle Sandstone on the east are the Belle Fourche Shale, Greenhorn Formation, Carlile Shale, Niobrara Formation, Pierre Shale, Fox Hills Sandstone, and the Lance Formation (Love et at. 1993). The Mowry Shale is composed of black siliceous shale characterized by numerous bentonite beds (Watson 1980). The Carlile Shale is composed of non-calcareous shale and yellowish sands. The Niobrara Formation is composed of gray to black marine shale. The top of the Niobrara is often composed of limestone or calcareous shale (McGookey et al. 1972).

At the close of the lower Cretaceous, sea level rose and the Mowry Shale was deposited. The Frontier Formation resulted from several transgression-regression cycles and from west to east grades from fluvial to marine (Steidtmann 1993). The near shore and transitional marine deposits of the Frontier Formation in the western part of the basin grade to the east into the Belle Fourche Shale and Greenhorn Limestone, which represent shallow marine conditions. After the Frontier, the Niobrara transgression resulted in the deposition of the marine Carlile, Niobrara, and Pierre Shale sequence (McGookey et al. 1972). Following the Niobrara Transgression, a regressive sequence, the Mesaverde Formation, was deposited and is composed of sandstone and shale that were deposited in near-shore and marginal marine environments in western and central Wyoming, including portions of the PRB (Steidtmann 1993). On the east side of the PRB, the Mesaverde equivalent, the Pierre shale and associated sandstones, are marine in origin. The last major Cretaceous transgression resulted in the deposition of the Lewis Shale. Within the Lewis Shale are sandstones and siltstones that were deposited in marine and transitional marine environments (Van Horn and Shannon 1989). The last Cretaceous unit, the Lance Formation, was deposited under regressive conditions and is composed of sandstones, carbonaceous shale, and coal (Watson 1980).

Cenozoic Era. The earliest Tertiary System rocks (Paleocene Series) are the Fort Union Formation that is composed of sandstone, conglomerate, shale, and coal (Watson 1980). The depositional environments of the Fort Union consisted of fluvial systems with flood plains and peat swamps (Flores et al. 1999). The Fort Union is the major coal-producing unit in the region; the detailed stratigraphy of this unit is discussed in the Coal Resources subsection of Section 2.1.3.3, Mineral Resources. Eocene Series rocks in the PRB are represented by the Wasatch Formation, which generally is described as being composed of distinctively colored (pastel green, pink, and yellow)

mudstone, sandstone, and siltstone (Watson 1980). The Wasatch Formation also contains numerous coal beds (Flores et al. 1999). There are two distinct members of the Wasatch Formation in the northern part of the PRB, the Kingsbury Conglomerate and the Moncrief Gravel. The Oligocene Series White River Formation is the youngest of the Tertiary formations in the PRB. The White River is composed of mudstone, sandstone, and conglomerate with volcanic ash beds (Watson 1980).

Near the end of the Cretaceous, mountain building began in western Wyoming. As the mountains were uplifted, erosion occurred and sediment was transported into the shallow Cretaceous seaway. In the PRB, the uppermost Cretaceous unit, the Lance Formation, was derived from alluvial plain deposits marking the end of the Cretaceous (Lilligraven 1993). Also at the end of the Cretaceous and the beginning of Tertiary time, another episode of mountain building was occurring in the area. This episode of mountain building is referred to as the Laramide Orogeny (Lageson and Spearing 1991). Uplift of the Precambrian basement occurred through the movement of Precambrian basement blocks along low- to high-angle reverse faults. This period of mountain building resulted in the mountain ranges that are adjacent to the basin: the Big Horn Mountains, the Laramie Mountains, and the Black Hills. The Hartville Uplift is also of Laramide origin. The uplifted blocks of basement rock were eroded, and the sediment was deposited resulting in the Fort Union and Wasatch formations.

In the later Tertiary (Oligocene-Miocene), large volcanic eruptions occurred to the west and north of the area. Prevailing winds carried the ash aloft over an extensive area, and thick layers of ash were deposited as a result of these eruptions. These ash deposits are found in the White River Formation. Erosion along the mountain fronts has removed the mantle Tertiary deposits in most places resulting in abrupt changes in elevation along the mountain fronts.

Unconsolidated Quaternary deposits consist of alluvium, terraces, colluvium, gravels, and pediments (Love and Christiansen 1985). Alluvial deposits generally are associated with alluvial valleys of the major rivers and tributaries.

Structural Geology

The PRB is one of a number of structural basins in Wyoming and the Rocky Mountain area that were formed during the Laramide Orogeny. The basin is asymmetric with a structural axis that trends generally northwest to southeast along the western side of the basin (Flores et al. 1999). From the eastern margin of the basin, the rocks dip from 2 to 5 degrees to the structural axis (**Figure 2.1-1**). From the western edge of the basin, the rocks generally dip approximately 20 to 25 degrees to the axis of the basin. Along the margins of the basin adjacent to the Big Horn Mountains, Laramie Mountains, and the Hartville Uplift are large-scale reverse faults where blocks of the basement-cored uplifts were displaced during the Laramide Orogeny. Other structural elements by which the basin is structurally defined are the Black Hills to east, the Casper Arch on the southwest **(Figure 2.1-1)**, and the Miles City Arch on the north in Montana. These elements are structurally high, but there are no major bounding faults or dislocations. Along the west side of the Black Hills, gently dipping sedimentary rocks ramp onto the Precambrian core of the Black Hills with only minor faults (Grose 1972). The Casper Arch is a broad anticlinal area that trends northwest from the north end of the Laramie Mountains to the Big Horn Mountains. The Miles City Arch is a gentle anticlinal feature that trends northwest from the Black Hills and forms the north structural boundary of the PRB in Montana that separates it from the Williston Basin to the north. In addition

to the major structural elements that define the basin, there are a number of folds on the western and southern margins of the basin. Much of the basin has very little internal structure, and the large area of west-dipping rocks east of the basin axis contains few, if any, major folds or dislocations.

Geologic Hazards

Earthquakes occur when energy is released as blocks of the earth's crust move along areas of weakness or faults. There are no identified active faults in the study area (USGS 2004). An active fault is a fault that has demonstrated movement within the last 11,000 years. The study is located in an area of low risk from ground shaking if a maximum credible earthquake were to occur in the region (Frankel et al. 1997).

Most of the project area is underlain by Cretaceous and Paleocene shale, siltstone, and sandstone. These rocks have high clay content and can be very unstable. Geologic formations in the project area that are known to be very susceptible to landslides are the Pierre Shale, Cody Shales, and the Paleocene-age Fort Union Formation (Radbruch-Hall et al. 1980). Landslide occurrence is greatest along the Powder River in Johnson and Sheridan counties and along the Little Powder River north of Gillette (BLM 2003a). Slope instability also can occur in surface mine highwalls.

The PRB Oil and Gas EIS (BLM 2003a) discussed a number of potential hazards that could be associated with CBNG production. The potential hazards discussed were landslides, subsidence, gas seepage, and spontaneous combustion. There was no evidence of the occurrence of any of the aforementioned hazards in relation to CBNG production within the PRB.

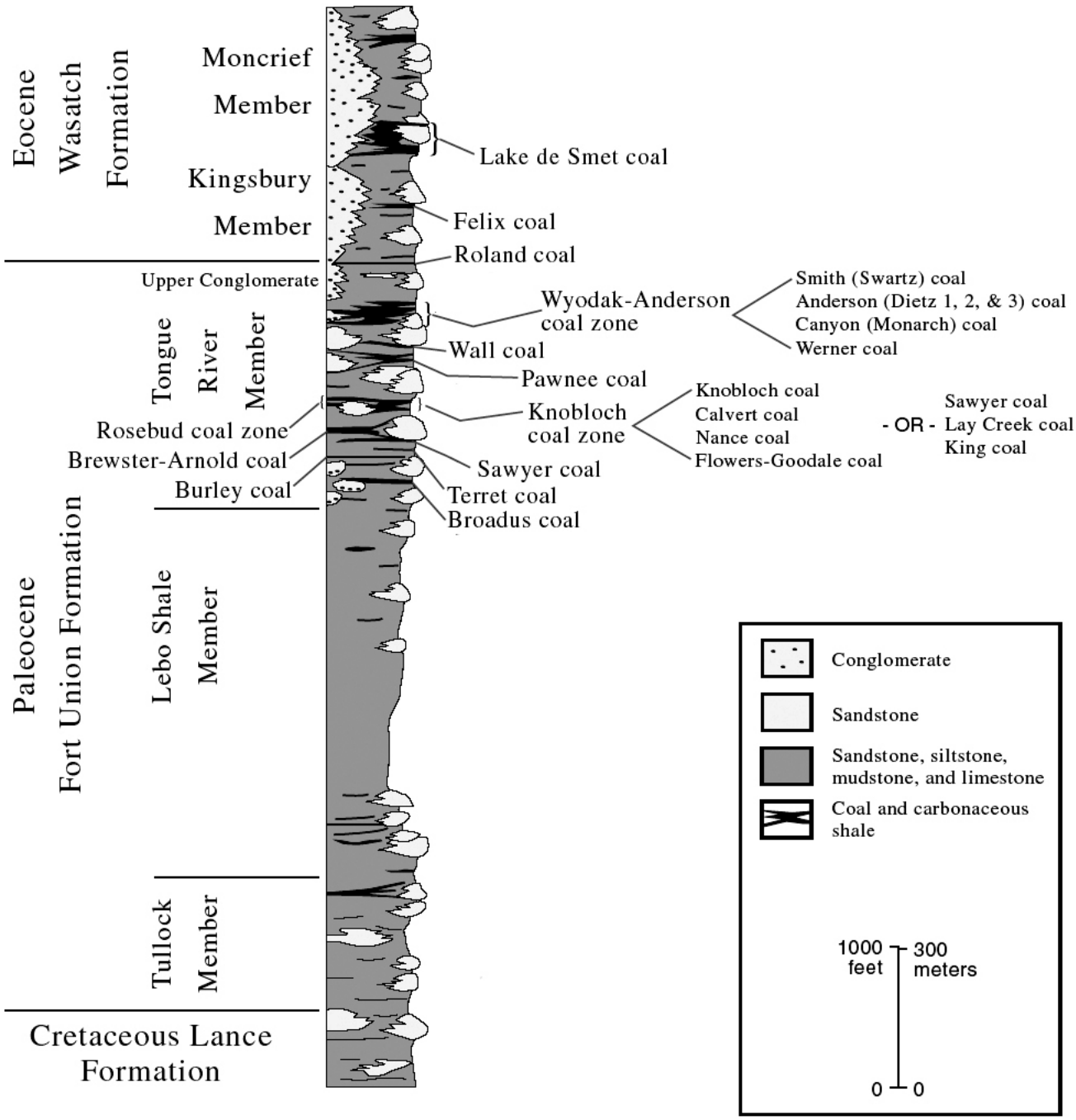
2.1.3.3 Mineral Resources

Coal Resources

Geology and Stratigraphy of the Fort Union Formation. Most of the coal resources of the basin are found in the Fort Union and Wasatch formations. Most of the coals are in the Paleocene Fort Union Formation. Although coals are present in the Wasatch, they are not as economically important as the coals in the Fort Union. The following is a general description of the stratigraphy of the Fort Union Formation.

The Fort Union and equivalent strata were deposited across a broad area of the Rocky Mountain Region from Northwestern Colorado to Montana and western North Dakota. In the PRB, the formation ranges in thickness from over 5,200 feet in the west to 2,300 feet in the east (Curry 1971). The thickest part of the formation is found along the structural axis of the basin (see **Figure 2.1-1**). The Fort Union is divided into three members and from oldest to youngest are the Tullock, Lebo, and Tongue River (**Figure 2.1-3**). The Tullock Member is up to 740 feet thick and consists of yellow calcareous sandstone and shale and carbonaceous shale beds (Watson 1980). The Lebo Shale Member consists of shale and interbedded sandstone. The Tongue River Member is composed of massive sandstone, shale, and thick coal beds. The coal beds in the Tongue River Member range from a few inches to more than 200 feet thick (Flores et al. 1999).

The Tongue River Member of the Fort Union Formation contains most of the economically important coal zones. The initial understanding of the coal stratigraphy in the PRB was based on the assumption that coal seams in the Tongue River Member were laterally continuous over many



Powder River Basin Coal Review

Figure 2.1-3

Stratigraphic Column
Ft. Union and Wasatch Formations

Source: Flores et al. 2001.

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miles (Flores and Bader 1999). However, with the advent of more data associated with the large number of drill holes for coal exploration, CBNG, non-CBNG, and oil, the coal stratigraphy is now thought to be more complex. A number of coal seams have been identified and mapped in the Wyoming portion of the PRB (**Figure 2.1-3**). Coal stratigraphy is complex due to the nature of the environments in which the coal was originally deposited. The swamps (where the organic material that is deposited and eventually becomes coal) associated with the fluvial systems are not often laterally continuous over many miles or aerial extent. Often coals split (one bed becomes several beds), overlap, or end abruptly. It is not possible to detect these discontinuities without the aid of numerous outcrop and borehole sampling points.

Coal Quality. Coal quality for the Wyodak-Anderson coal is shown in **Table 2.1-1**. The information in **Table 2.1-1** was derived from numerous coal samples from the Wyodak-Anderson coal which produces from over 20 mines in the PRB (Stricker and Ellis 1999). As a result, the values in the table provide a general representation of the Wyodak coal. The data indicate that the coal is subbituminous, generally low sulfur, and has low concentrations of metallic constituents. The low sulfur nature of the coal has made it sought after because of its cleaner burning characteristics for power generation. Often utilities will blend PRB coal with higher sulfur coals in order to achieve air quality emissions compliance.

Table 2.1-1
Analytical Results for Coal in the Wyodak-Anderson Coal Zone[1]

Variable	Number of Samples	Range		Mean
		Minimum	Maximum	
Moisture[2]	300	14.50	42.30	27.66
Ash[2]	279	2.86	25.06	6.44
Total sulfur[2]	279	0.06	2.40	0.48
Calorific value[3]	277	3,740.00	9,950.00	8,220.00
Sulfur dioxide (pounds)[4]	277	0.14	7.88	1.24
MMMFBtu[5]	277	4,580.00	10,560.00	8,820.00
Antimony[6]	144	<0.01	17.00	0.49
Arsenic[6]	158	<0.20	19.00	2.60
Beryllium[6]	151	<0.078	3.30	0.54
Cadmium[6]	151	<0.007	3.00	0.21
Chromium[6]	161	<0.59	50.00	6.10
Cobalt[6]	160	<0.38	27.00	1.90
Lead[6]	162	<0.50	17.00	3.00
Manganese[6]	161	0.18	210.00	26.00
Mercury[6]	162	<0.006	27.00	0.13
Nickel[6]	161	<0.71	35.00	4.60
Selenium[6]	151	<0.08	16.00	1.10
Uranium[6]	157	<0.11	12.00	1.30

[1]Samples collected from the Wyodak-Anderson coal zone in the Wyoming and Montana PRB.
[2]Values are in percent and on an as-received basis.
[3]Value is in British thermal units (Btu).
[4]Value is in pounds per million Btu and on an as-received basis.
[5]Value is in Btu on a moist, mineral-matter-free (MMMF) basis.
[6]Values are in parts per million (ppm) on a whole-coal and remnant moisture basis.

Source: Stricker and Ellis 1999.

Conventional Oil and Gas

Drilling for non-CBNG resources has declined considerably in the last 15 years (from a high of 199 in 1990 to 32 in 2003) averaging 100 wells per year for all categories of wells (production, injection, wildcats) (IHS 2004). However, there remains potential for finding and developing non-coal bed production in the deeper areas of the basin. The USGS (2002) estimates that the PRB (Wyoming and Montana) may have undiscovered hydrocarbon resources (mean) of 1.5 billion barrels of oil and 1.2 trillion cubic feet of gas (non-CBNG). Much of this resource may be in the deeper sparsely drilled parts of the basin.

Waning interest in oil can be seen in the decline of oil production. In 2003, conventional oil and gas production from the PRB was approximately 19.5 million barrels of oil and 47 billion cubic feet (BCF) of gas (WOGCC 2004). That compares with a production of 50.5 million barrels of oil and 64.4 BCF of gas in the PRB in 1989; CBNG production in 1989 was insignificant. Non-coal bed hydrocarbon production from the PRB study area in 2003 was 12.9 million barrels of oil and 41 BCF gas. There were approximately 3,500 active conventional oil and gas wells at that time in the PRB (not counting seasonally produced wells) (ENSR 2005a).

CBNG

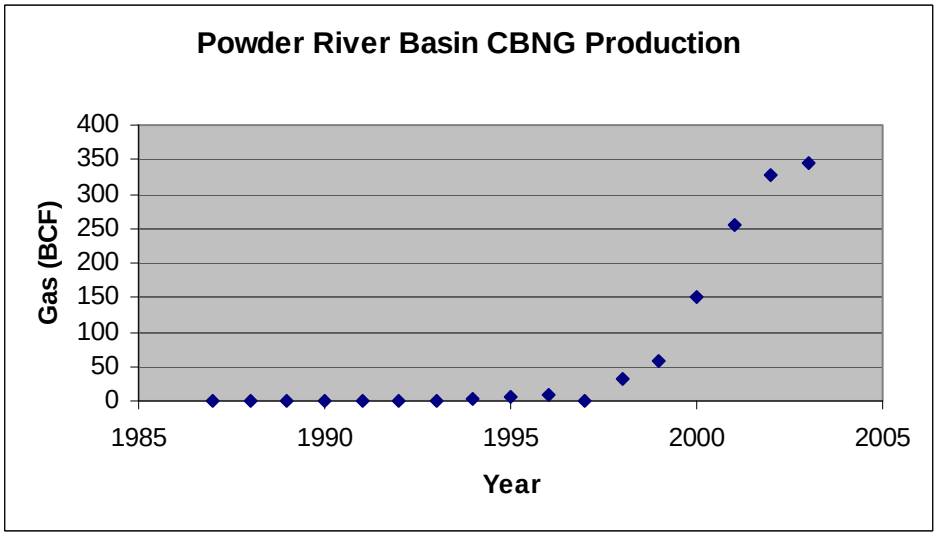
Total production for 2003 was 346 BCF, or 88 percent of the total gas production from the basin (WOGCC 2004). From 1987 to 2003, the total cumulative gas production from PRB coals was over 1.2 trillion cubic feet, and the total cumulative water production was approximately 2.3 billion barrels (ENSR 2005a). As can be seen on the chart of yearly CBNG production **(Figure 2.1-4)**, annual CBNG production increased rapidly from 1999 through 2002 and appears to have started to level off in 2003. Annual water production (**Figure 2.1-4**) increased between 1999 and 2002, but started to decrease slightly in 2003.

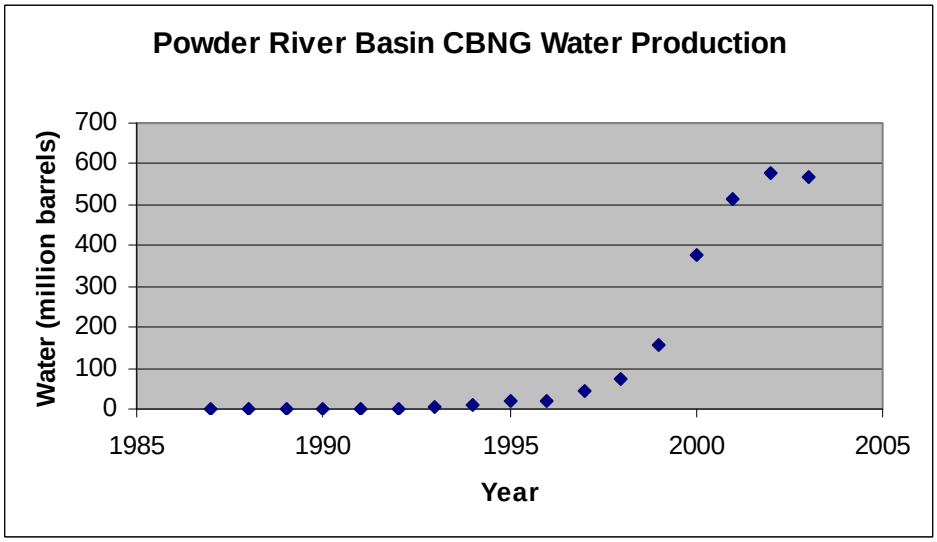
Other Mineral Resources

Other mineral resources in the PRB study area include uranium, bentonite, clinker, and aggregate. Uranium is found in the Wasatch, Fort Union, and Lance formations. There are three defined uranium districts in the PRB; Pumpkin Buttes, Southern Powder River, and Kaycee (BLM 2003b). Numerous uranium mining sites were present in these districts, but were mined out or uneconomic. Uranium currently is mined in the Southern Powder River District at Smith Ranch and Highland/Morton Ranch (Harris 2003). Uranium is produced by the in situ leach method at both locations (Harris 2003). Wyoming produced 1.6 million pounds of yellowcake (the raw uranium production material) in 2002. There are several bentonite localities in the PRB and bentonite in the study area is mined at Kaycee, Wyoming (Wyoming Mining Association 2004). Clinker is formed when coal beds burn and the adjacent rocks become baked. Clinker is used as road surfacing material and is found in extensive areas in the study area (BLM 2003b). Terrace and alluvial deposits associated with the larger streams in the study area are mined for sand and gravel. The more important aggregate mining localities are in Johnson and Sheridan counties (USGS 2003b).

2.1.3.4 Paleontological Resources

The paleontological resources found on public lands are recognized by the BLM as constituting a fragile and nonrenewable scientific record of the history of life on earth, and so represent an





Source: WOGCC 2004.

Figure 2.1-4 Annual CBNG and Water Production

important and critical component of America's natural heritage. Once damaged, destroyed, or improperly collected, their scientific and educational value may be greatly reduced or lost forever. In addition to their scientific, educational, and recreational values, paleontological resources can be used to inform land managers about interrelationships between the biological and geological components of ecosystems over long periods of time.

While there are no laws specifically aimed at the management of paleontological resources, a number of laws address paleontology. For example, the Archaeological Resource Protection Act of 1979 (16 USC 470ee) prohibits the unauthorized removal of fossils that are in an archaeological context. The Federal Cave Resources Act of 1988 (16 USC 4306) prohibits the removal of paleontological resources when they are taken without authorization from a designated significant cave. The BLM utilizes other more general laws and authorities to protect paleontological resources. These laws include Theft of Government Property (18 USC 641), Damage to Government Property (18 USC 1361), and the Federal Land Policy Management Act (43 USC 1733).

In addition, BLM Manual 8720, *General Procedural Guidance for Paleontological Resource Management*, is intended to provide a consistent and comprehensive approach to the management of paleontological resources including identification, evaluation, protection, and use (BLM 1998).

Scientifically significant paleontological resources, including vertebrate, invertebrate, plant, and trace fossils, are known to occur in many of the geologic formations within the study area. These fossils are documented in the scientific literature, in museum records, and are known by paleontologists and land managers familiar with the area.

The paleontologic potential of the study area was evaluated using the Probable Fossil Yield Classification developed by the USFS and used by the BLM. The classifications include:

- Class 1: Igneous and metamorphic geologic units (excluding tuffs) that are not likely to contain recognizable fossil remains.

- Class 2: Sedimentary geologic units that are not likely to contain vertebrate fossils or scientifically significant nonvertebrate fossils.

- Class 3: Fossiliferous sedimentary geologic units where fossil content varies in significance, abundance, and predictable occurrence.

- Class 4: Class 4 geologic units are Class 5 units that have lowered risks of human-caused adverse impacts or lowered risk of natural degradation. Proposed ground-disturbing activities would require assessment to determine whether significant paleontological resources occur in the area of a proposed action and whether the action would impact the resources.

- Class 5: Highly fossiliferous geologic units that regularly and predictably produce vertebrate fossils or scientifically significant nonvertebrate fossils and that are at high risk of natural degradation or human-caused adverse impacts.

There are 34 mapped geologic units (Flores et al. 2001; Love et al. 1987) within the study area. Of these, 1 is classified as Class 1, 2 are classified as Class 2, 27 are classified as Class 3, none are classified as Class 4, and 4 are classified as Class 5. The 4 units classified as Class 5 are the Morrison, Lance, Wasatch, and White River formations.

Most of the geologic formations exposed at the surface within the study area are exposed only along the margins of the PRB. The most widely distributed units are the Wasatch and Fort Union formations, both of which are discussed below. The Morrison and Lance formations outcrop in the western portion of the basin; however, in the vicinity of the coal mines and CBNG activity in the eastern portion of the basin, these formations occur at depth. Within the study area, the highly fossiliferous White River Formation (Class 5) occurs only on Pumpkin Buttes in southwestern Campbell County.

The Wasatch Formation (Class 5) is by far the most geographically widespread formation in the study area and is the bedrock geologic formation exposed at the surface in most of the basin (Murphey et al. 2001). Because surface exposures are mostly vegetated, the formations within the PRB historically have not been perceived to be as rich in fossils as nearby basins, such as the Bighorn and Wind River, which have extensive badland exposures. Nevertheless, the ubiquitous anthills in the basin contain locally abundant remains of small animal fossils (mouse to rabbit sized), which can be successfully sampled even in vegetated areas.

Murphey et al. (2001) discovered that no institution has collected articulated bones from the lower Eocene part of the Wasatch Formation in the PRB. The Eocene-age fossils consist primarily of isolated teeth, with more complete dental or upper jaw fragments comprising approximately 10 percent of the total number of specimens in the University of Colorado Museum's collections. Articulated material, particularly a partial skeleton of the reptile *Champsosaurus gigas*, is known from older deposits of the Wasatch Formation. Such finds are very rare and appear to be restricted to the Paleocene-age part of the formation. The Wasatch Formation fossil localities include 106 localities recorded at the University of Colorado Museum, 4 localities recorded at the University of Wyoming Museum of Geology, and 46 localities listed in Delson (1971), who was collecting for the American Museum of Natural History. These localities originally were documented by Wood (Delson 1971).

The Fort Union Formation (Class 3) is not as widely distributed as the Wasatch Formation, but occurs around the margins of the basin. This formation contains locally abundant fossil vertebrates, invertebrates, and plants, and displays an important time interval during the early Tertiary evolution of mammals. No fossil localities in the Fort Union Formation within the study area were identified during the museum record search for this analysis; however, they do occur nearby in Montana.

Other fossil localities occur in the Mesaverde, Mowry, White River, and Gros Ventre formations. Fossil localities outside the study area and within formations that extend beyond the study area boundary also were identified during this analysis. Data from fossil localities outside the study area were used in the class designations recommended for formations that occur within the study area.

The lack of localities from any of the geologic units in the study area does not mean that scientifically significant fossils are not present. Much of the area within and surrounding the PRB in Wyoming has not been adequately explored for paleontological resources, and new scientifically significant fossil occurrences are being discovered regularly.

2.1.4 Comparison to Previous Predictions

2.1.4.1 Topography and Physiography

PRB coal leasing NEPA documents (BLM 1973, 1979, 1981, 1984, 1994, 1995a, 2000a,b, 2003c) describe potential effects to topography from coal mining. Some of these effects can include changes to slopes from the original land surface, lower average surface elevation of the mined tract, and increased the homogeneity of backfilled materials compared to the original overburden. The Powder River Regional Coal Final EIS (BLM 1981) and the Coal Development Status Check (BLM 1996) did not address topography as a separate impact topic; however, the EISs listed above indicated that direct impacts to topography would be “insignificant.” It did not identify the potential impacts. The effects identified above are based on decades of surface mining in the area. The magnitude of such effects appear to be predictable depending on particular site characteristics including thickness and volume of coal seams, overburderden, and interburden; bulking characteristics of overburden and interburden material; and slope of the original land surface. The Coal Development Status Check compared predictions to actual numbers of acres that were disturbed and reclaimed. The recent documents do not identify a level of significance of the topographic impacts.

2.1.4.2 Geology

The Powder River Coal Region Final EIS (BLM 1981) described the direct impacts to geology as permanent removal of the coal and destruction of the overlying strata. In addition, it was stated that the impacts of coal removal would be long-term and irreversible. Other documents (BLM 1994, 1995a, 2000, 2003c) describe impacts in terms of physical aspects of the overburden and the changes that occur during coal mining and the potential loss of coal that is not readily mineable. The Coal Development Status Check (BLM 1996) does not address impacts to geology. Loss of unrecoverable coal would be an irretrievable impact. Those conclusions would be an accurate assessment of the current impacts of coal mining to geology in the PRB study area.

The Powder River Coal Region Final EIS (BLM 1981) and the Coal Development Status Check (BLM 1996) did not identify geological hazards with regard to coal mining, nor do the more recent NEPA documents (BLM 1994, 1995, 2000, 2003b). The PRB Oil and Gas Final EIS (BLM 2003a) describes potential geologic hazards with respect to oil and gas extraction (e.g., subsidence, gas seepage, and spontaneous combustion). To date, no evidence has been presented to change the conclusions in the PRB Oil and Gas Final EIS (BLM 2003a) concerning CBNG production and potential hazards.

To summarize, impacts to geology occur within the mining areas, are part of the mining process, and are permanent. The area of impacts to overburden geology is the same as the direct mining disturbance associated with the removal of soil, overburden, and coal. The cumulative effects increase incrementally for each year of mining and would continue as long as mining occurs.

2.1.4.3 Mineral Resources

Coal Resources

In the Powder River Coal Region Final EIS (BLM 1981), it was estimated that selection of the preferred alternative in that EIS would result in an annual production of approximately 318.4 million tons of coal by 1990 (Campbell and Converse counties, Wyoming) (BLM 1981, 1996). Actual production for those counties in 1990 was 162.6 million tons. Actual production did not reach the predicted 1990 level until 1999, when 320 million tons were mined (Lyman 2003). The differences between the predicted and actual tonnages may be due to a variety of factors. Low energy prices in general in the 1980s and the early 1990s did not encourage transporting Powder River coal into more markets. However, by the late 1990s, Powder River coal was making great gains because of increasing demand by out-of-state utilities to meet increasingly stringent air quality standards, the stable price for Wyoming coal compared to other important low-sulfur fuel (natural gas), and the competitive price compared to other fuels. The annual coal production in 2003 was 379.3 million tons (ENSR 2005a).

In the 1970s and 1980s, several projects were proposed to convert coal into gas (by plant or in situ methods) and convert coal into synthethic liquid fuel (BLM 1981). Most of these proposed projects were never implemented, because low energy prices in the 1980s and 1990s made such projects commercially infeasible. Although three test facilities were constructed, no commercial production has occurred; these facilities either have been dismantled or are no longer in use (ENSR 2005a).

Conventional Oil and Gas Resources

In 1979, the BLM predicted that oil and gas production in Campbell and Converse counties would be approximately 33.6 million barrels of oil in 1990 (BLM 1996). The actual production was approximately 31.4 million barrels. Also in 1979, it was predicted that natural gas production in the counties would be 48.2 BCF in 1990. The actual gas production was 50.8 BCF. The annual production in 2003 was 13.0 million barrels of oil and 378.3 BCF of natural gas (ENSR 2005a).

CBNG

Recent recoverable resource estimates for CBNG range from 16 to 28 trillion cubic feet (TCF) of gas (BLM 2001a). The Powder River Coal Region Final EIS (BLM 1981) did not address CBNG. In 1990, the BLM prepared an EA in which it was estimated that within the EA study area of southwestern Campbell and eastern Johnson counties, there was a CBNG resource of 27 TCF. This earlier estimate was based on available data at the time and was without regard to production economics, only estimated gas in place. However the estimate is remarkable in its accurate order of magnitude in comparison with later estimates based on several years of production and better knowledge of gas in place. The EA estimated that 1,000 CBNG wells would be drilled and over a 20-year period potentially could recover approximately 301 BCF of the estimated resource (1.1 percent). The EA was conducted in an effort to determine the potential effects of CBNG production. As discussed earlier, only a few CBNG wells had been drilled up to that time; soon after the EA was issued, industry interest in the CBNG play waned because of disappointing results of the early developments. However, by the mid-1990s, there was renewed interest in the play and as discussed above, activity began to increase at geometric rates.

The number of producing wells as of the end of 2003 appears to be consistent with relatively recent BLM projections of drilling activity (BLM 2001a). Over 12,900 CBNG wells were in production at the end of 2003, and an additional 1,800 wells were completed and shut-in and presumably soon to be in production (ENSR 2005a). This number is in the BLM's estimated range for productive wells by the end of 2003 for the low to medium (16 to 23 TCF) resource recovery scenarios (BLM 2001a).

Other Mineral Resources

In 1979, the predicted uranium production for 1990 was approximately 4.7 million tons, and the actual production was approximately 524 tons (BLM 1996). In the period from 1979 to 1990, the demand for uranium fuel in the U.S. plummeted as a result of the Three-Mile Island nuclear power plant disaster.

In 1979 it was estimated that sand, gravel, and scoria mining would disturb 1,280 acres in 1990 (BLM 1996). The actual disturbance was 162 acres in 1990.

Due to the lack of information relative to their specific locations and the low overall associated acreage, which per subwatershed would be minimal, disturbance acreages associated with uranium, sand, gravel, and scoria mines were not quantified for the PRB Coal Review.

2.1.4.4 Paleontological Resources

Predictions relative to potential future impacts to paleontological resources were not presented in the Coal Development Status Check (BLM 1996) or earlier coal leasing NEPA documents for the Wyoming PRB (BLM 1973, 1979, 1981, 1984).