Evaluation of Economically Extractable Coal Resources in the Gillette Coal Field, Powder River Basin, Wyoming

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Contents

Figures

Tables

ABSTRACT

The Powder River Basin, and particularly the Gillette coal field that contains the exceptionally thick Upper Wyodak coal bed, contains some of the largest deposits of low-sulfur subbituminous coal in the world (Molnia and Pierce, 1992). The Upper Wyodak coal, as well as other potentially minable coal in the Gillette coal field, was studied to determine how much coal is in the ground and how much of it could be economically extracted, given current and foreseeable economic factors and mining restrictions. We designed a hypothetical extraction plan to facilitate the computation of this estimate of recoverable and economic resources. This plan eliminates coal resources in areas of the coal field where mining could not take place due to various technological, societal, and environmental restrictions, and considers only the amount of coal that could be produced with current mining practices and equipment commonly used in the Powder River Basin.

Coal-development considerations in the study area include railroads, Federal highways, pipelines, power lines, wildlife habitat, and alluvial valley floors. Some, but not all, of these factors can be mitigated so that surface mining of the coal could proceed. Geologic factors such as thick overburden, thin coal beds, sand channel wash-outs, faults, and areas of burned coal and surrounding rock (clinker) can require special equipment and mine plans that add to the cost of coal production.

We estimated the original coal resource in the Gillette coal field, for all coal beds assessed and with no restrictions applied, to be 136.1 billion short tons. The estimates show that available coal, which is the part of the original coal resource that is accessible for mine development under current regulatory and land-use constraints, represents about 89 percent of the original resource. Recoverable coal, which is the available coal remaining after the coal is mined and processed, represents about 80 percent of the original coal resource. Economically recoverable coal, which is the recoverable coal that can be mined, processed, and marketed at a profit, represents only 1.3 percent of the original resource at a coal sales price of $3.00 per ton, 5.1 percent at a sales price of $4.00 per ton; 10.4 percent at a l sales price of $5.00 per ton; 17 percent at a sales price of $6.00 per ton; and 32.8 percent at a sales price of $7.00 per ton.

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Allan M. Ochs, a geologist and contractor for the project, was the data base manager and worked with USGS personnel to correlate individual coal beds in the Gillette coal field. Tracey J. Mercier, a Geographic Information System (GIS) consultant from True North Mapping, produced many of the graphics used in this report. Gary McIntosh, of Slick Rock Software Design, provided customization and development of mine costing and economics software programs.

Workers from other government agencies also assisted with various aspects of this report. Charlie Gaskill, of the U.S. Bureau of Land Management in Casper, Wyoming, supplied land-use information, and Edward Heffern, of the U.S. Bureau of Land Management in Cheyenne, Wyoming, supplied digital files delineating the eastern outcrops of the beds and areas containing clinker from

the burning of Wyodak coal beds. Dave Hutton, of the Wyoming Oil and Gas Conservation Commission in Casper, Wyoming, provided information on the locations and status of oil and gas wells within the study area. Norm Braz, of the U.S. Bureau of Land Management in Casper, Wyoming, supplied digital data that shows the extent of mined-out areas within the study area as of January 2000.

Several software packages were used to accomplish this study. Any mention of these software packages are for descriptive purposes only and does not imply endorsement by the USGS.

INTRODUCTION AND OBJECTIVES

Traditional USGS procedures to estimate national coal reserves use standardized mining recovery factors that are applied throughout coal regions to obtain the estimated tonnage of recoverable coal. Those estimates are general in nature and do not take into consideration the amount of coal that cannot be mined because of environmental concerns, societal conflicts, site-specific geologic factors, coal loss due to mining and preparation technology, and economic constraints. Published studies by the USGS that include economic evaluations of extractable coal resources indicate that application of site-specific restrictions to estimates of available coal resources significantly reduces the amount of coal that is considered economically recoverable.

This study of extractable coal in the Gillette coal field not only includes a resource analysis, but also applies an economic evaluation that is customized to the environmental, technological, cultural, and energy-related infrastructure of the Gillette coal field in the Powder River Basin, Wyoming (fig. 1). The economic recoverability aspect of the study considers the many restrictions that can affect the profitable extraction of coal. Mining production costs, current mining machinery and methods, coal transport to the market place, present and near-future market conditions, and the gross calorific value, ash yield, and sulfur content of the available coal are all factors that influence the amount of coal that can be mined at a profit.

This detailed information regarding the amount of coal that can be economically produced contributes to the body of knowledge that can be used to make local, State, and Federal energy and land-use policy decisions. In addition, this information can aid government and other planners in determining the possible socio-economic effects on their regions as coal resources are developed and eventually become depleted.

PREVIOUS COAL RESOURCE CALCULATIONS IN THE GILLETTE AREA

There have been a number of previous studies that have estimated coal resources in the Powder River Basin. Such studies have used various defined study areas and have included different coal beds or coal zones. There have been a multitude of purposes for which resources are calculated, and there have been differences in criteria, such as variations in coal thickness and overburden categories, used for calculation. There have also been changes in calculation methods themselves.

The earliest estimate of coal resources in the Gillette coal field was by Dobbin and others (1927, p. 20). They estimated the tonnage of the Gillette coal field to be 14.4 billion short tons (bst). The area included in their coal field designation was about 3,000 sq mi, twice the 1,500 sq mi area of this study (see table 1 for conversion to metric units and other values). However, they used only outcrop measurements for their calculation and were not able to model subsurface coals; almost no subsurface data was available at that time.

Berryhill and others (1950) provided a calculation of total original reserves of subbituminous coal in Wyoming by township, overburden thickness, and coal bed thickness. Coal tonnage estimates given for 86 townships entirely or partly within the Gillette coal field total about 45 bst. Coal beds included in that estimate were not limited to the Wyodak-Anderson stratigraphic interval, but included all beds greater than 2.5 ft thick, with overburden less than 2,000 ft. Berryhill's estimates are the sum of measured, indicated, and inferred reserve tonnages (as defined by Berryhill and others, 1950) for these townships.

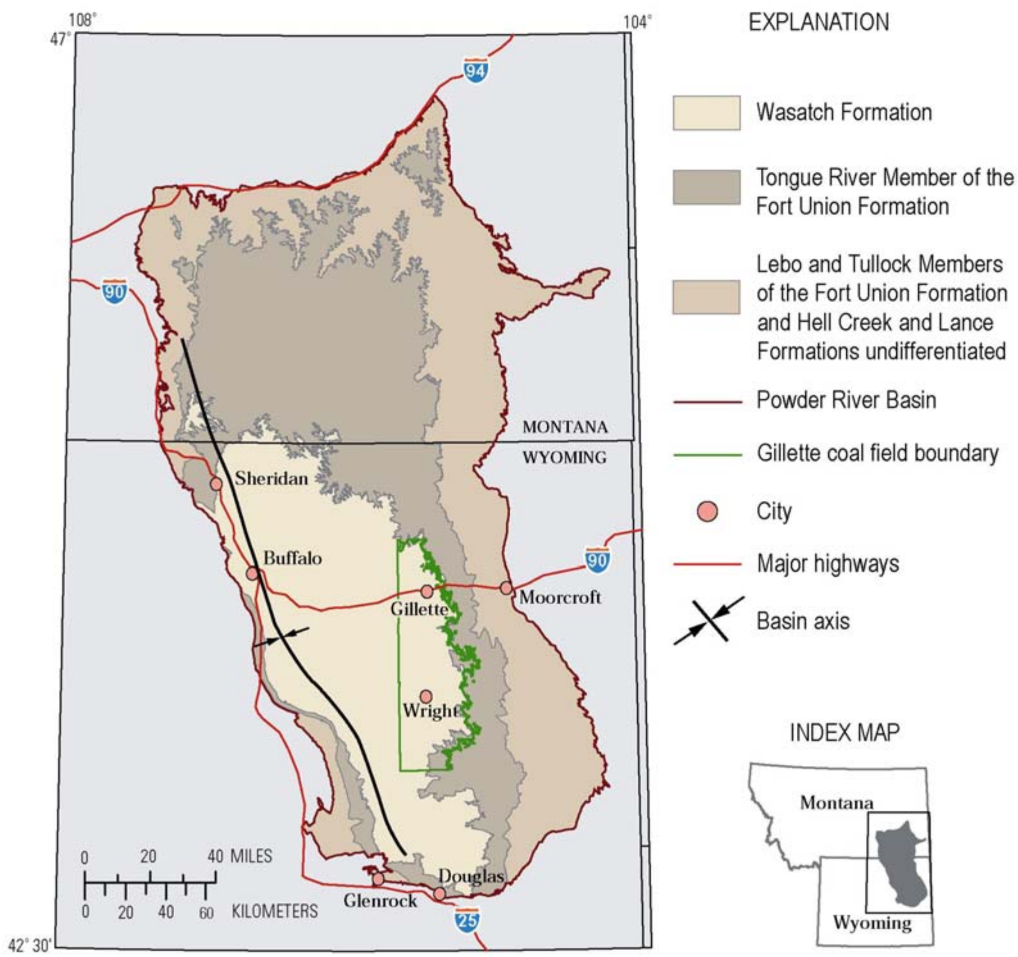

Figure 1. Generalized geologic map of the Powder River Basin showing the axis of the basin and the location and extent of the Gillette coal field.

Trent (1986) published an estimate of 225 billion tons of non-leased, Federal coal in the quadrangles that fall within the Gillette coal field, included were coal beds greater than 5 ft thick at depths of less than 3,000 ft. No resources were included for leased Federal coal, State coal, fee (private) coal, or lands encompassed by coal prospecting permits and preference right lease applications. Coal beds included in Trent's estimate were not limited to those beds within the Wyodak-Anderson stratigraphic interval.

Table 1. Abbreviations and conversions. All tonnage measurements are given in short tons

To convert from	To	Multiply by
Feet (ft)	Meters (m)	0.3048
Miles (mi)	Kilometers (km)	1.609344
Square miles (sq mi)	Square kilometers (sq km)	1.609344
Pounds (lbs)	Kilograms (kg)	0.4536
Short tons (2,000 lbs)	Metric tons (2,204.6 lbs)	0.90718474
Millions of short tons (mst)	Short tons	1,000,000
Billions of short tons (bst)	Short tons	1,000,000,000
Acre-feet	Short tons of subbituminous coal	1,750

Ayers (1986) published an estimate of 1.06 trillion tons of coal in the Tongue River Member of the Fort Union Formation within the Wyoming part of the Powder River Basin. He included coal beds greater than 2 ft thick to depths of less than 3,000 ft.

Glass (2001) published an estimate of 1.03 trillion tons of coal for the Wyoming part of the Powder River Basin, which included coal beds of any thickness and to all depths, even greater than 6,000 ft. Glass (2001) also estimated remaining strippable reserve base for the Wyodak coal bed to be 17.9 bst, using a 200-ft cut-off depth for overburden. This is the largest reserve base for any single coal bed in Wyoming.

Ellis and others (1999) published an estimate of 110 bst of coal in the Wyodak- Anderson coal zone, as defined by the Fort Union Coal Assessment Team (1999), within the Gillette coal field. That estimate was derived from stratigraphic data interpreted from electric logs that were run in about 2,000 drill-hole locations. Resources were calculated using total coal thickness, the sum of all coal beds over 2.5 ft thick, for all coal beds included in the zone (table 2). All of the coal was assumed to be subbituminous in rank, with a conversion factor of 1,770 short tons of coal per acre-foot. Parting material, coal less than 2.5 ft in thickness, coal above or below Wyodak-Anderson clinker, and coal within active lease areas were not included in the resource calculations.

Comparison of the previous resource estimates shows the usefulness of periodically recalculating coal resources for an area when more and better data become available over time. The economic coal recoverability calculations in the present report are a refinement of previous coal resource studies in the Gillette coal field. Our estimates include data on how much of the total coal resource (1) has already been mined, (2) could be produced using specific mine models, and (3) could be produced at a profit at given market values. These more specific resource calculations add to the body of knowledge available for State and Federal agencies to determine the amount of coal that could actually be produced within the Gillette coal field, thereby contributing to decisions regarding energy policy and future land use.

Table 2. Names used in different publications for coal beds in the area of the Gillette coal field. The beds in the Wyodak-Anderson coal zone are listed from upper to lower; however, many of the beds are only in certain parts of the coal field, stratigraphically equivalent, or splits of other beds

Montana name	**Kent and others, 1980a**	**Pierce and others, 1990**	**Fort Union Coal Assessment Team, 1999, and Glass, 1999**	**Molnia and others, 1997, 1999, and Osmonson, 2000**	**This report**
Not applicable	Smith	Roland/Badger	Smith		**Wyodak rider**
	Upper Wyodak	Wyodak or upper Wyodak (Anderson-Canyon)	Wyodak-Anderson coal zone= Swartz, Badger, School, Sussex, Big George, Wyodak, Anderson, Dietz	Main Wyodak	**Upper Wyodak**
	Canyon		Canyon		**Canyon**
Cook	Werner	Lower Wyodak	Werner		**Lower Wyodak/Werner**
Wall	Gates	Upper Kennedy			**Gates/Kennedy**
Pawnee	Kennedy				
Cache	Carson				

DEFINITIONS

The present study includes determinations of original, available, recoverable, and economically recoverable (extractable) resources, a terminology that has been used in many USGS coal studies (see Carter and Gardner, 1989; Eggleston and others, 1990; Molnia and others, 1999; Osmonson and others, 2000). The following definitions were applied in our resource evaluation:

- ***Original resource***—The total amount of coal tonnage in the ground prior to mining.
- ***Available resource***—That part of the original coal resource that is accessible for mine development under current regulatory and land-use constraints. Alluvial valley floors and producing oil and gas wells are examples of constraints that may restrict coal mining in their immediate vicinities. The available resource does not include coal that has been previously mined.
- ***Recoverable resource***—That part of the available coal that is left after mining losses and cleaning losses are subtracted. Costs involved with the extraction and cleaning of the coal are not considered, nor is the potential selling price of the coal.
- ***Economically recoverable resource***—That part of the recoverable coal that can be mined, cleaned, and marketed at a profit (depends on the mine location, the characteristics of the coal bed, the quality of the coal, and the mining methods used). Also known as a reserve.

The present report contains many different measurements and abbreviations. Table 1 shows conversions for measurements used. All coal resource numbers are reported in short tons.

For the purpose of this study the term *coal bed* is used for coal bodies with no parting. The term *coal unit* is used for the assessed coal and includes coal beds plus parting material. This represents the stratigraphic interval used for the coal resource calculations. Additionally, when the term *Gillette coal field* is used we are only referring to the area in which economically recoverable coal resources were calculated. This differs from the *Gillette study area*, which includes area outside of the coal field. Considering data from drill holes outside of the coal field was essential to the

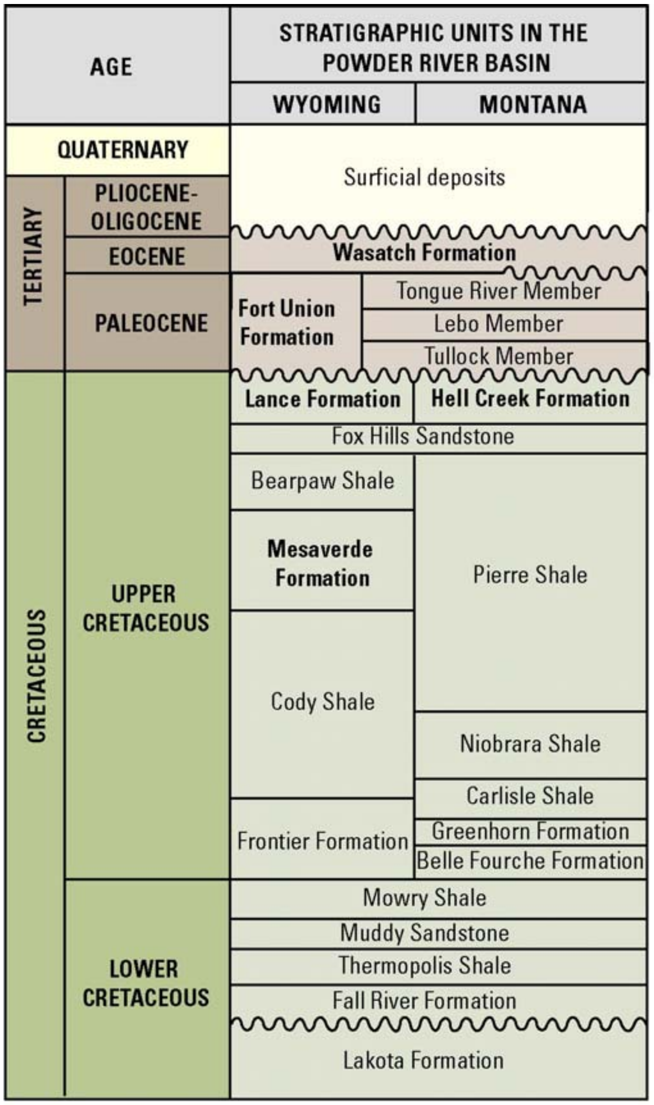

Figure 2. Generalized stratigraphic column for the Powder River Basin, Wyoming and Montana. Formation names inbold type are those formations that contain coal. Wavy lines indicate an unconformity.

correlation of coal beds and to the production of accurate coal thickness and overburden isopach maps used in this study.

GEOLOGIC SETTING AND STUDY AREA

The Powder River Basin covers about 22,000 sq mi in northeastern Wyoming and southeastern Montana (fig. 1). The axis trends northwest- southeast, near the west edge, and the basin floor is markedly asymmetrical with steep dips on the west side and gentle dips on the east.

The Wasatch Formation (Eocene) covers about one-third of the Powder River Basin, with the underlying Fort Union Formation (Paleocene) exposed at the surface along the basin boundaries. Within the Wyoming part of the Powder River Basin, the Wasatch contains coal beds that have heat values, agglomeration characteristics, and fixed carbon and volatile matter content that place them as subbituminous C in apparent rank (Glass, 2001). These coal beds, some of which are stratigraphically equivalent to each other, are named (from younger to older): (1) the Lake de Smet, which occurs in the northwest and splits into the Walters, Healy, Schuman, Timar, Cameron, Dry Creek, Murray, and Ucross beds to the east; (2) the Ulm1, Ulm 2, and Scott beds that occur in the north; (3) the Felix, which is found in many places within the Wyoming part of the basin; and (4) the Badger, and School beds, which are in the south. The Wasatch conformably overlies the Fort Union in the center of the basin and unconformably overlies the Fort Union along the basin margins (fig. 2). The boundary between the two formations is generally placed above the Roland coal bed (table 2).

Rocks in the Fort Union Formation lie unconformably lie on the Lance Formation (Upper Cretaceous) (fig. 2). The Fort Union Formation in Wyoming is made up of three members, from upper to lower: the Tongue River Member, the Lebo Member, and the Tullock Member. The Formation (fig. 1) contains some of the thickest and most extensive deposits of low-sulfur subbituminous coal in the world (Molnia and Pierce, 1992), most of which is from the Wyodak-Anderson coal zone in the Tongue River Member (Fort Union Coal Assessment Team, 1999). These coal beds, some of which are stratigraphically equivalent to each other, are named (from younger to older): the Swartz, Badger, School, Sussex, Big George, Wyodak, Anderson, Dietz, Canyon, and Werner.

The Gillette coal field (figs. 1 and 3) encompasses about 1,500 sq mi in the east-central part of the Powder River Basin in Campbell County, Wyoming. The east boundary is based on the Wyodak-Anderson coal outcrop and Wyodak-Anderson clinker (Kent and Berlage, 1980; Heffern and others, 1993; Heffern and Coates, 1999; and Coates and Heffern, 1999). In areas to the east and northeast, where outcrop and clinker information was not available and where coal beds assessed for this study were not present in drill holes, the coal field boundary was refined using the contact between the Wasatch Formation and the Fort Union Formation shown in maps by Kent and Berlage (1980) and Boyd and Ver Ploeg (1997). The north and south boundaries of the study area were delineated by the closest township and range lines that encompassed the area of active mining around Gillette (T. 40-52 N. and R. 69-73 W.). The west boundary, at R. 73 W., corresponds to the west boundary used for the coal resource assessment of the Gillette coal field by Ellis and others (1999). Figure 4 shows the mines in the Gillette coal field, and the 7.5-minute quadrangle maps that are within the study area.

In the Gillette study area, rocks dip 2 to 3 degrees to the west (Ellis and others, 1999). The Fort Union Formation is at the surface in most locations. Coal within the Tongue River Member of the Fort Union is as much as 200 ft thick in the area and the coal beds merge, split, and are cut out by channels within short distances (Ellis and others, 1999). Stratigraphic relations are complex and correlations of individual beds are difficult. The named coal beds assessed in this report are the Wyodak rider, Upper Wyodak, Canyon, Lower Wyodak/Werner, and Gates/Kennedy. The relationship of these beds to the beds in the Wyodak-Anderson coal zone is shown on table 2.

COAL MINING

Coal mining in the Powder River Basin began in 1883 near the cities of Glenrock and Douglas, in the southern part (fig. 1). The development of railroad lines in 1886 and 1887 influenced growth in mining activity. The first mines were underground, with the Inez Mine near Douglas and the Deer Creek Mine near Glenrock each producing about 13,000 short tons of coal in 1888 (Gardner and Flores, 1989). The Cole Creek, Buffalo Fuel Company, and Dietz Mines opened soon after. By 1925 there were 17 additional underground mines opened in Sheridan County. In 1905, mines in Sheridan County were producing about 550,000 tons of coal annually (Trumbull, 1905). The first strip mine, the Peerless Mine near Gillette, Wyoming, was opened in 1924 (Gardner and Flores, 1989) and a 90-ft- thick bed was mined. Soon after, a large strip mine, the Wyodak Coal and Manufacturing Company, opened and in 1925 produced about 33,600 short tons of coal. By the mid-1900s advancements in strip mining equipment and mining techniques made strip mining much more profitable. Most underground mines closed or the companies switched over into surface mining ventures.

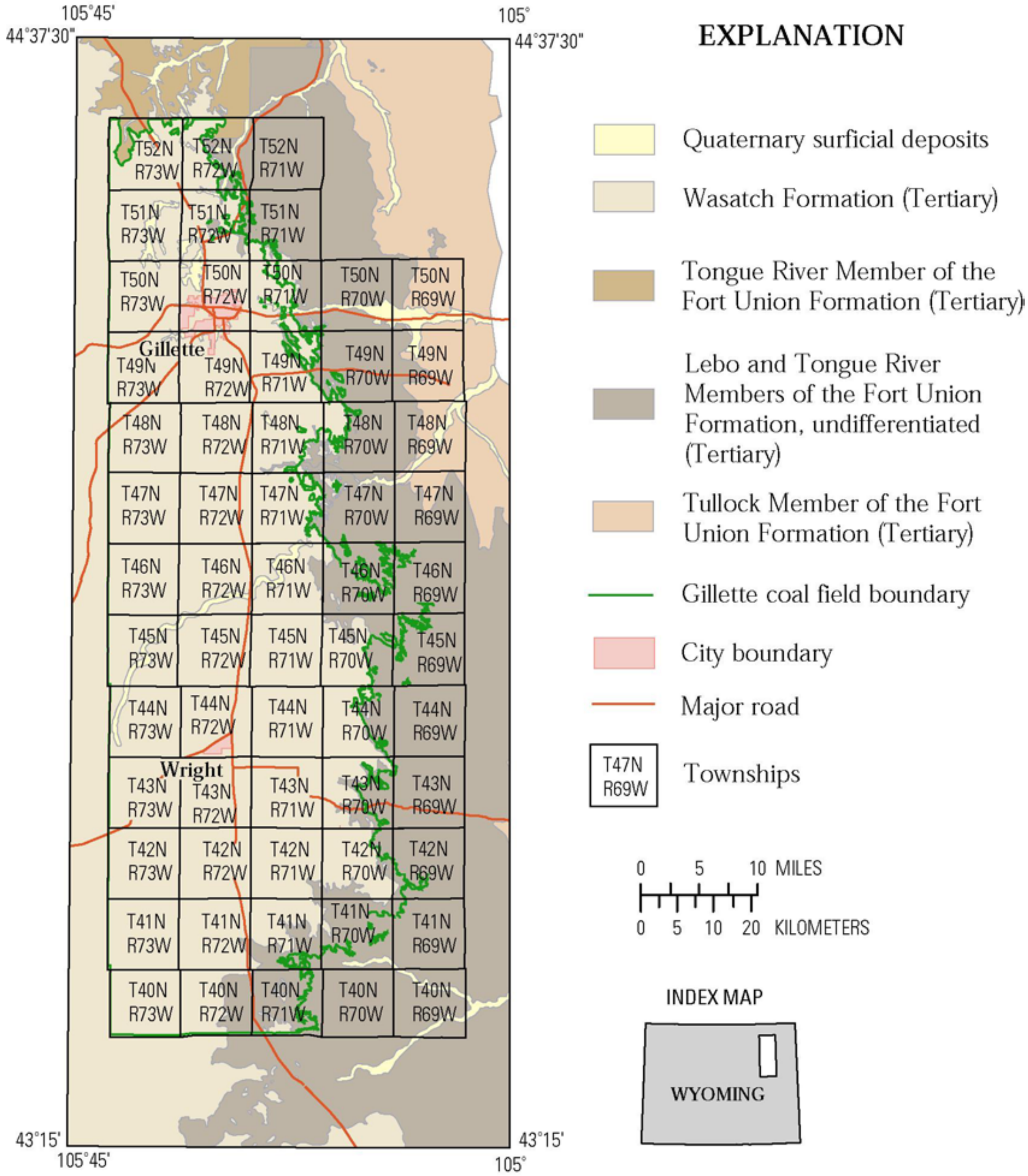

Figure 3. Geologic map showing Tertiary and younger rocks, major roads, and the location of townships in the Gillette study area.

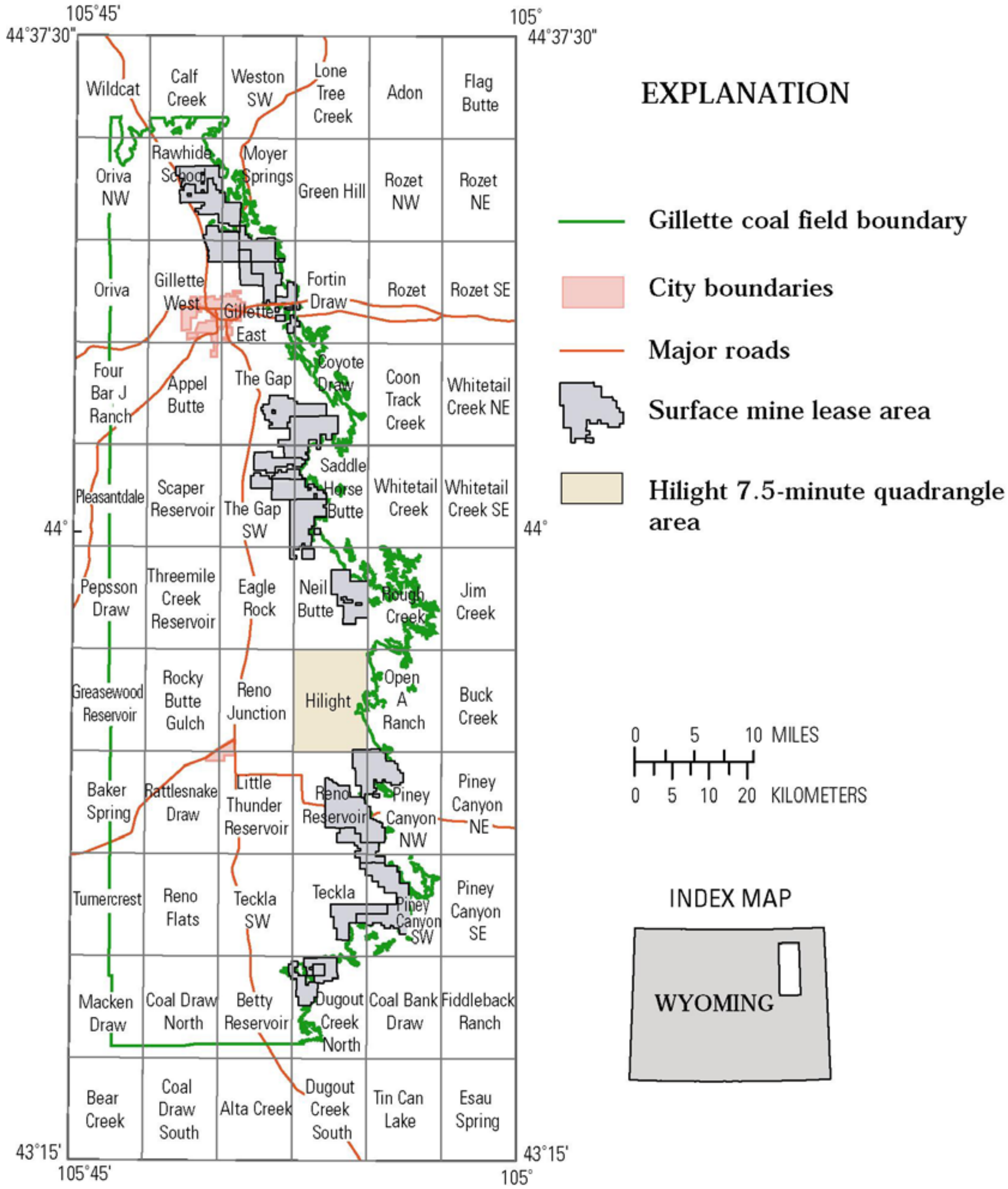

Figure 4. Map showing locations of surface coal mines and 7.5-minute quadrangle maps in the Gillette study area.

Prior to 1950 most coal was used for locomotive fuel, with minor amounts used to fuel power plants, sugar factories, and cement plants, or used for local heating (Mapel, 1958). In the 1960s, because of the national need for additional electrical energy, power plants were built adjacent to the producing mines. At that time coal utilization shifted from railroad fuel to fuel for power generation.

In 1999, nine of the ten coal mines with the largest production in the United States were located in the Gillette coal field (Glass, 2001). All production from these mines is through surface mining methods. Year 2000 production from all of the mines in the Gillette coal field contributed about 30 percent (about 323 million of short tons (mst)) of the total 2000 coal production of 1,075 mst (Resource Data International, 2002). The Gillette coal field contains 12 active coal mines (fig. 4), all producing from the Tongue River Member of the Fort Union Formation (Resource Data International, Inc., 2002).

OTHER ENERGY COMMODITIES IN THE AREA

Energy commodities currently being developed in the Powder River Basin, in addition to coal, are conventional oil and gas and coalbed methane. Although coalbed methane is a gas, we discuss it separately, because there are potential conflicts and concerns specific to the development of that resource that do not apply to conventional oil and gas development.

Powder River Basin oil and gas development began in 1887, with the discovery of an oil and gas field near Moorcroft, Wyoming. There are currently more than 35,000 oil and gas wells within the area of the Gillette coal field (IHS Energy Group, 2001). Current infrastructure for production and transport of oil and gas in the area includes roads, pipelines, pump houses, separators, and several gas-processing plants. Generally, there is little conflict between coal development and conventional oil and gas development in the Powder River Basin. Conventional oil and gas development is primarily from stratigraphic units below the extractable coal seams. Additionally, conventional oil and gas development is primarily in the central part of the basin, whereas the coal mining is along the basin margins. Where oil and gas development and coal mining occur in the same areas, mining is confined to areas outside a specific buffer distance from wells, pipelines, and other oil and gas related structures.

Coalbed methane development in the Powder River Basin began with two wells in 1981 and, as of July 20, 2001, a total of 18,578 wells had been drilled or been permitted to be drilled (Wyoming Oil and Gas Conservation Commission, 2001). Resource specialists estimate that over 50,000 coalbed methane wells will be drilled in the next 20 years. The production life of a coalbed methane well, which depends on the distance of the well from adjacent wells and how much methane is in the coal, is estimated to be from 10 to 12 years, although production from multiple seams can extend the life of the well by another 10 to 30 years (De Bruin and others, 2002).

To produce coalbed methane, a large volume of groundwater is released from the coal. The groundwater can be discharged to holding ponds for consumption by livestock, discharged to existing drainage systems, released into the atmosphere through the use of misting towers, or re-injected into another stratigraphic unit. Concerns regarding possible contamination of existing surface water, the quality of water in holding ponds, the production of saline crust on the ground surface, the lowering of the water table, and possible contamination or depletion of groundwater in existing aquifers are currently being studied and addressed in the Powder River Basin.

Conflicts have arisen between coal mining and coalbed methane development. One conflict involved the ownership of coalbed methane- whether it belonged to the owner of the oil and gas estate or the owner of the coal estate. The U.S. Supreme Court resolved this in 1999, when they ruled that coalbed methane is part of the oil and gas estate. In addition, the court specified that the owner of the methane leases has the right to gain access and to develop their estate, and that owners of the land surface should be adequately compensated for damage to their property resulting from methane extraction.

There has undoubtedly been a large volume of coalbed methane that has been lost due to previous mining of coal in the Gillette coal field. It is anticipated that (1) coalbed methane extraction in a given area will have priority over coal mining; and (2) if coal mining precedes methane extraction, the owners of coalbed methane leases may have to be compensated for lost gas. A current joint USGS and Bureau of Land Management (BLM) cooperative project is attempting to estimate the amount of gas that has been lost due to previous and current mining within the area of coalbed methane leases (Flores and others, 2001). Results of this study have been posted on a BLM website (at www.wy.blm.gov/minerals/og/res.mgt.html). The Wyoming congressional delegation is also trying to determine ways to arbitrate conflicts between the coalbed methane and coal industries (DeBruin and others, 2002).

COAL BED GEOLOGY

Coal Bed Nomenclature

Correlation of individually named coal beds across the entire Powder River Basin is difficult. The fluvial systems responsible for deposition of the coal beds created pinch-outs, splits, wants, channels, and bed mergers (Flores and others, 1999). Ayers (1986) states: *"Attempts to correlate seams across an entire basin are not only futile, but are also counter to our understanding of the existing coal depositional systems…. Previous studies…. show that the boundaries of Tongue River coal seams are established by the framework elements of the host sediments. Most coal seams are continuous over distances of tens of miles (commonly 30 to 50 miles)."*

This difficulty in correlating individual beds throughout the Powder River Basin also applies to correlating the beds throughout the Gillette coal field, despite the numerous attempts to identify, trace, and name beds locally. Table 2 shows some of the names used for coal beds and zones within the area. A report by Kent and others (1980), covering the northernmost part of our study area that falls within the Spotted Horse coal field of Olive (1957), established a coal-bed nomenclature system that has become the standard for much of the Powder River Basin in Wyoming. As described below, they retained certain existing coal-bed nomenclature and revised other nomenclature by introducing new coal-bed names. Pierce and others (1990), in another report, covered the southwestern part of our study area and extended the use of coal bed names from Kent and others (1980).

Kent and others (1980) retained and used coal bed names as defined by Olive (1957) for the Spotted Horse coal field. In descending order, these names are Felix, Arvada, Roland (Baker, 1929), Smith, Anderson, and Canyon. Kent and others (1980) also (1) recognized the Swartz coal bed of McKay and Mapel (1973) as occurring between the Smith and Anderson coal beds in certain areas; and (2) used the name Wyodak in the sense of Mapel (1973), which refers to the 90-ft-thick coal bed exposed by surface mining about 5 miles east of Gillette, Wyoming.

Names of coal beds below the Canyon coal-- the Cook, Wall, Pawnee, and Cache-- were not retained by Kent and others (1980) in the Spotted Horse coal field because those names originated in Montana coal fields at locations many miles from the Spotted Horse coal field of Wyoming and direct correlations were not warranted in their view. Also, previous workers had used the Wall name to represent different beds in different coal fields. For these reasons, Kent and others (1980) decided to introduce a new set of names (table 2). They explained that *"Many regional coal-correlation problems remain unresolved and usage of Montana names such as Cook, Wall, Pawnee or Cache to identify coal beds in the Recluse (Wyoming) area implies coal-correlations that have not yet been established. In order to avoid those implications, these Montana names are subordinated.... and new names are introduced here for certain coal beds below the Canyon.... The names selected are those* *of owners of ranches near the reference sections."*

For the northernmost part of our study area, we used Kent and others (1980) to make the following correlations:

- **Wyodak rider** is equivalent to the Smith coal bed
- **Upper Wyodak** contains Smith, Swartz, and Anderson, where there is no separate Wyodak rider.
- **Canyon** occurs in very limited areas and is an upper split of the Lower Wyodak coal bed. The lower split, or the main part of the **Lower Wyodak/Werner** coal bed, contains the Werner coal bed.
- **Gates/Kennedy** occurs below the Lower Wyodak/Werner coal bed.

Pierce and others (1990) used the coal bed nomenclature of Kent and others (1980) as discussed above, and continued that nomenclature southward into the southern Powder River Basin. Their publication covers the southwestern part of the Gillette coal field; for that area, we used Pierce and others (1990) to make the following correlations:

- **Wyodak rider** is their Roland coal bed
- **Upper Wyodak** is the Anderson-Canyon coal bed
- **Gates/Kennedy** occurs below the Lower Wyodak coal bed.

The differences between the correlations we made from Kent and others (1980) and those made from Pierce and others (1990) reflect the distance between their study areas and the changes in coal depositional systems from the northern part to the southern part of the Powder River Basin, Wyoming.

Flores and others (1999 [Chapter PF]) defined a coal zone called the Wyodak-Anderson coal zone in the Powder River Basin, which includes many named coal beds in the upper part of the Tongue River Member of the Fort Union Formation. Coal beds in this coal zone are, from top to bottom, the Smith, Swartz, Badger, School, Sussex, Big George, Wyodak (which includes the Lower Wyodak/Werner and Upper Wyodak of this report), Anderson, Dietz, Canyon, and Werner (table 2). Some of these beds are splits of other beds or are stratigraphically equivalent to other beds. Additionally, many of the beds are found only in certain parts of the basin. The Smith, Anderson, Wyodak, and Canyon beds are mined at the surface in the Gillette coal field.

Coal Bed Correlations

The data set containing stratigraphic information used by us for resource calculations and for geologic characterizations includes 1,798 data points within the Gillette coal field and 448 data points within a three-mile-wide band surrounding the field (fig. 5). Data we used was obtained from Flores and others (1999) and was generated by the Fort Union Coal Assessment Team as part of the USGS National Coal Resource Assessment. They correlated the top and base of the Wyodak-Anderson coal zone in many of the drill holes that we used in our Gillette coal field study (fig. 5). For our study of economically extractable coal we correlated and modeled individual beds to both within and outside of the Wyodak-Anderson coal zone, as defined by Flores and others (1999), to determine feasibility of extraction. The five coal beds in the Gillette coal field that were modeled for extraction, and for which resources were calculated are: the Wyodak rider, Upper Wyodak, Canyon, Lower Wyodak/Werner, and Gates/Kennedy. Not all drill holes in our data set encountered all five of the coal beds.

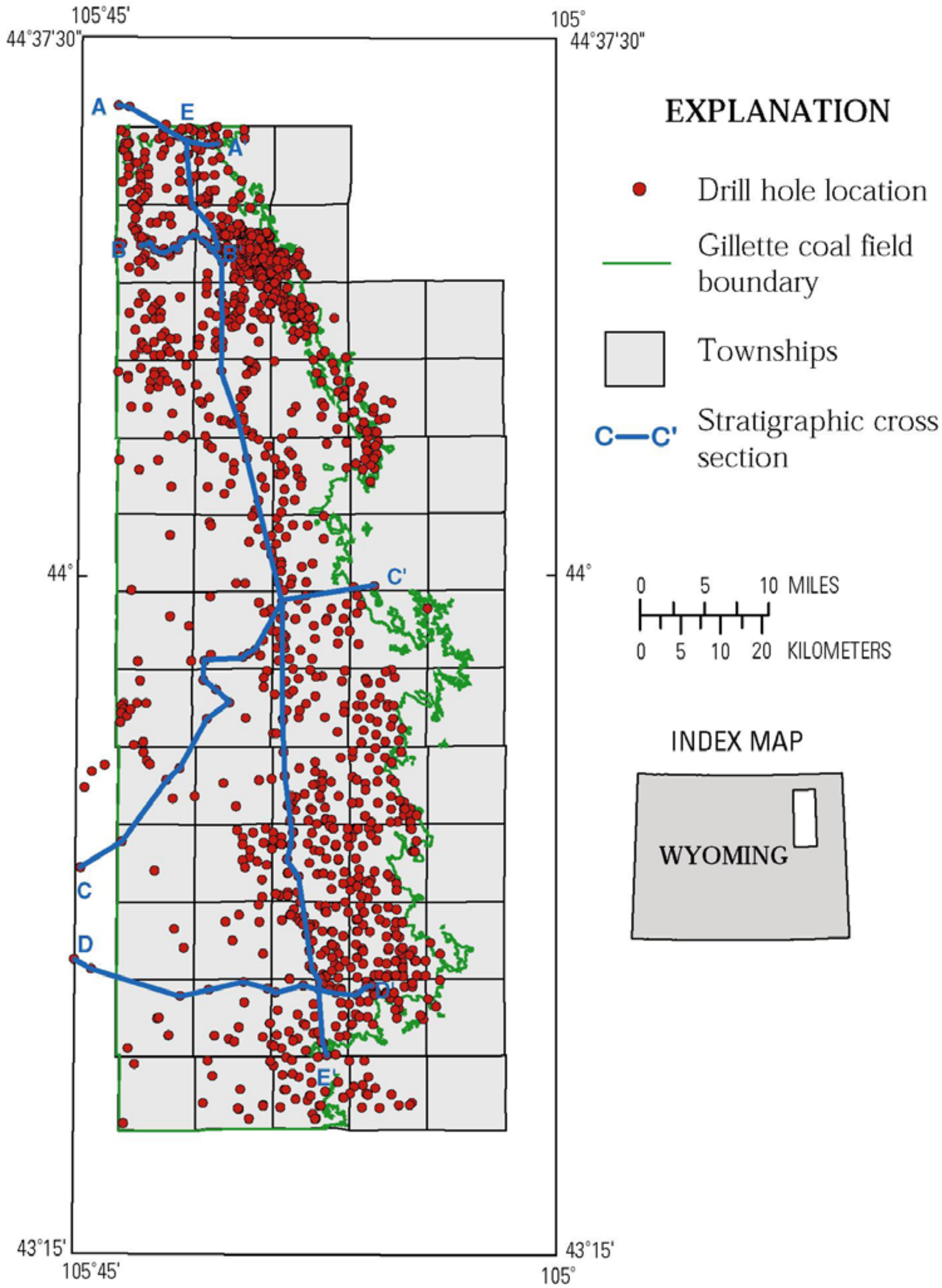

Figure 5. Map showing drill hole locations for stratigraphic data used in this study and locations of cross sections A-A' through E-E' (figs. 7 through 11).

In the southern part of the study area, we correlated the Wyodak rider with the Roland coal bed, as recognized by Pierce and others (1990) (table 2). The Roland coal bed is not included in the Wyodak-Anderson zone; however, in the southern part of the study area the Roland coal bed is found in the same general stratigraphic position as the Smith coal bed, which is included in the zone, and the Smith bed is absent. Thus we correlated the Wyodak rider coal bed to the Roland coal bed in the southern part of the Gillette coal field, and it served as the top of our studied stratigraphic interval in that part of the field. Our study also included the Gates or Kennedy coal beds, referred to here as the Gates/Kennedy coal bed, which occurs below the Werner coal bed, and is the lowermost coal bed in the Wyodak-Anderson coal zone as recognized by Flores and others (1999). In our study, we included the Gates/ Kennedy coal bed in those places where the coal is a thick and relatively continuous coal bed that could be mined with the coal beds above it. Figure 6 includes two columnar sections that represent the general stratigraphic relations of coal beds assessed in the Gillette coal field. Figures 7, 8, 9, 10, and 11 show cross sections in various parts of the study area that give a more detailed picture of the complex stratigraphic relations of the coal beds that were assessed.

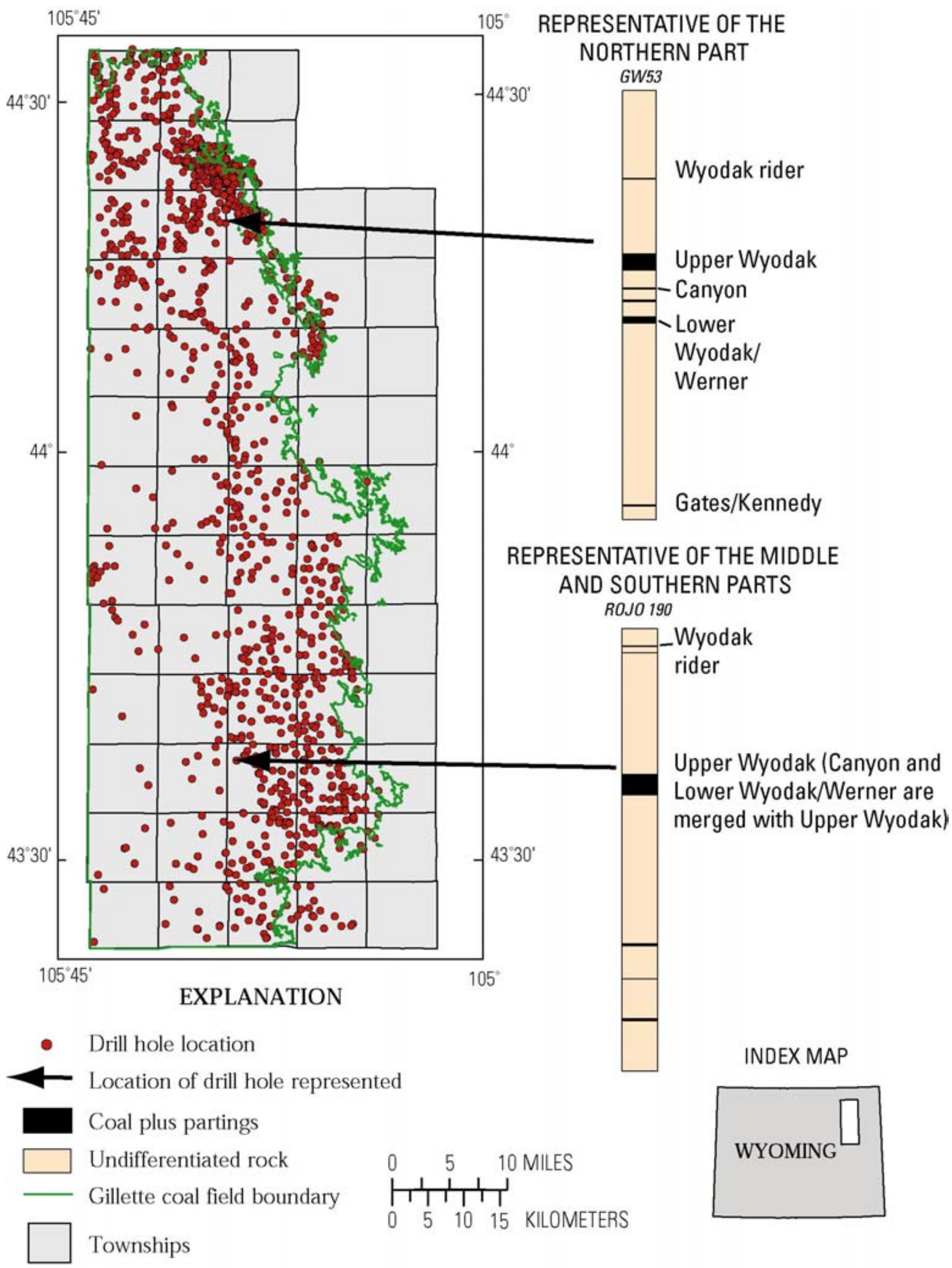

Figure 6. Representative stratigraphic sections showing coal assessed in the Gillette coal field, Wyoming. See figure 11 for more detailed coal bed correlations for the sections shown on this figure.

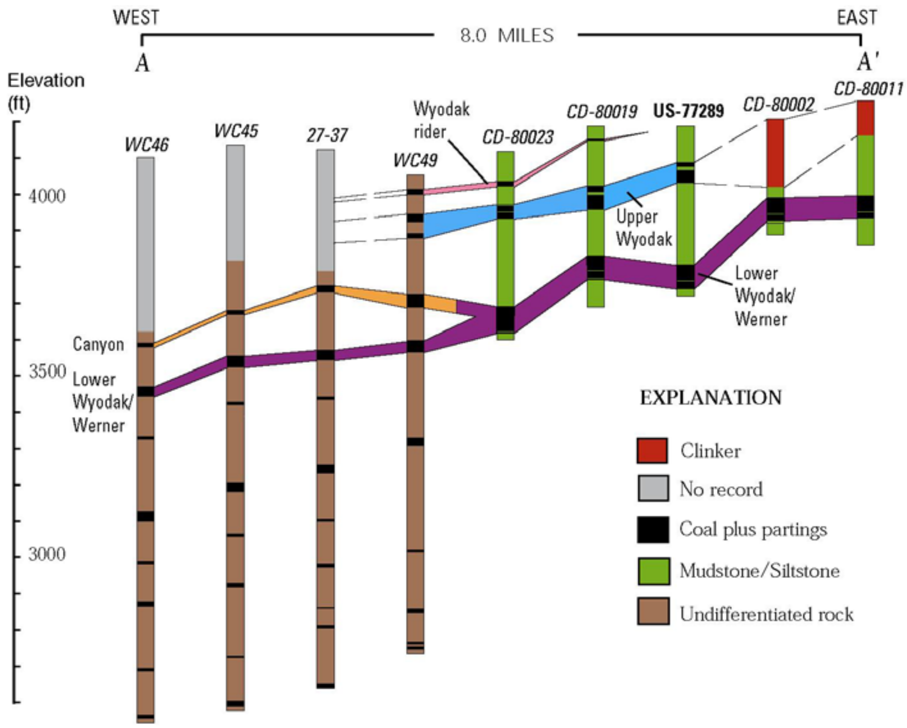

Figure 7. West-east stratigraphic cross section A-A' showing correlation of coal beds assessed in the northern part of the coal field See figure 6 for location of cross section. Drill hole also shown in cross section E-E' (fig. 11) is labelled in bold type.

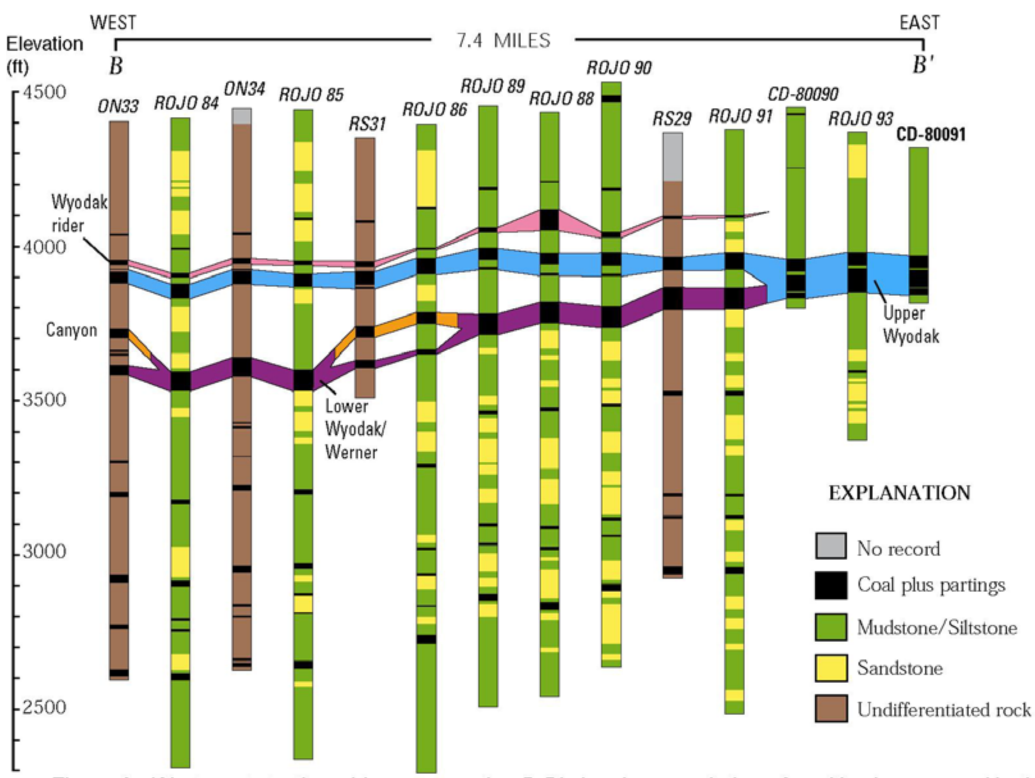

Figure 8. West-east stratigraphic cross section B-B' showing correlation of coal beds assessed in the northern part of the coal field. See figure 6 for location of cross section. Drill hole also shown on cross section E-E' (fig.11) is labelled in bold type.

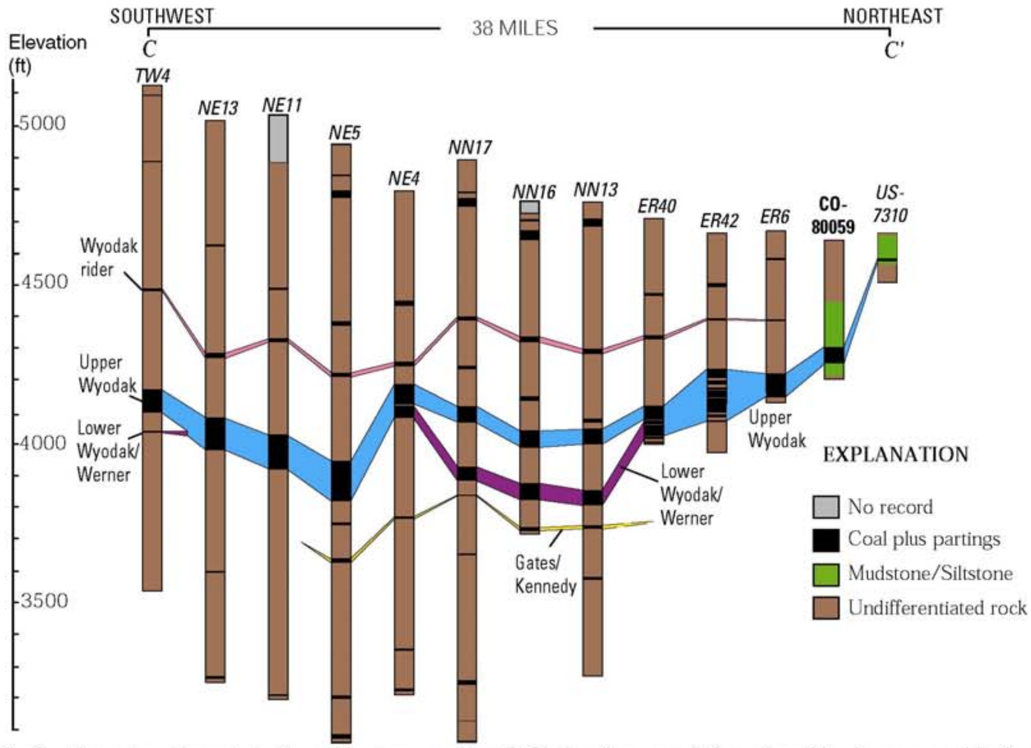

Figure 9. Southwest-northeast stratigraphic cross section C-C' showing correlation of coal beds assessed in the middle part of the Gillette coal field. See figure 6 for location of cross section. Drill hole also shown on cross secion E-E' labeled in bold type.

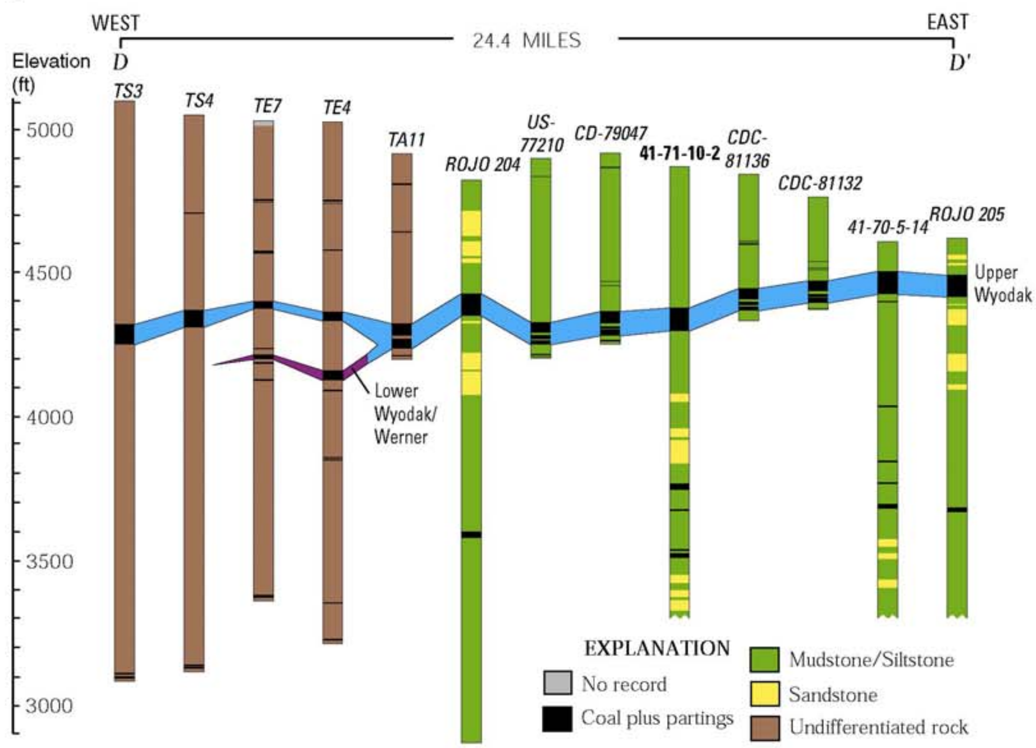

Figure 10. West-east stratigraphic cross section D-D' showing correlation of coal beds assessed in the south part of the coal field. See figure 6 for location of cross section. Drill hole also shown on cross section E-E' (fig. 11) is labeled in bold type.

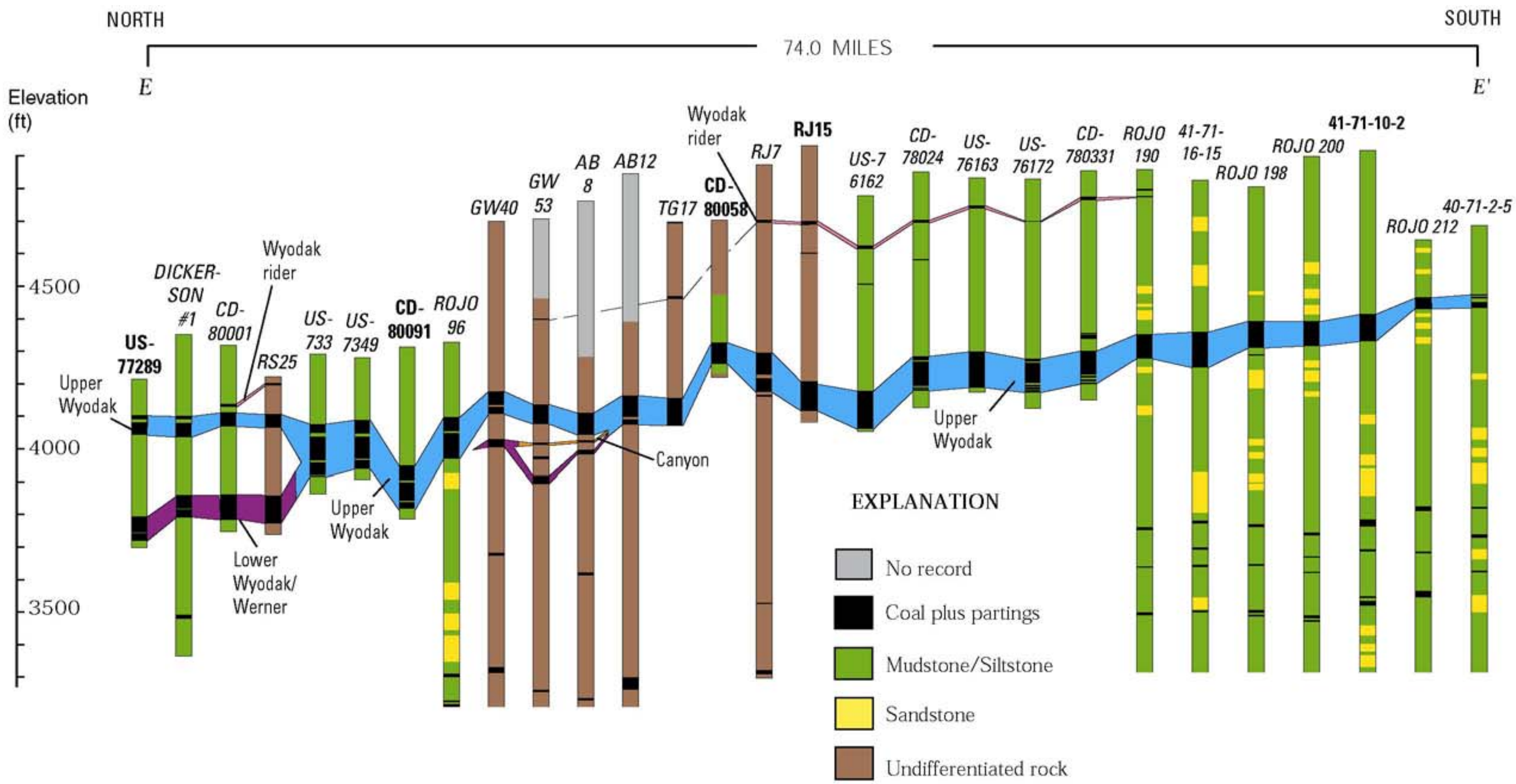

Figure 11. North-south stratigraphic cross section E-E' showing correlation of coal beds assessed in the coal field. See figure 6 for location of cross section. Drill holes also shown on cross sections A-A' through D-D' (figs. 7 through10) are labeled in bold type.

The following are brief descriptions of the coal beds that were assessed in the Gillette coal field. The given thickness of each is that of the coal-mining unit, which is that of the coal plus the parting material.

Wyodak rider:
This bed occurs as a rider splitting from the Upper Wyodak bed. It is continuous throughout the northern three-quarters of the study area, with a lateral extent of approximately 747 sq mi (fig. 12). The bed ranges from 3 ft to just over 30 ft in thickness and commonly includes 1 to 3 partings varying from 0.5 ft to 4 ft thick (fig. 13). Overburden ranges from zero at the outcrop to 1,091 ft along the west side of the Gillette coal field.

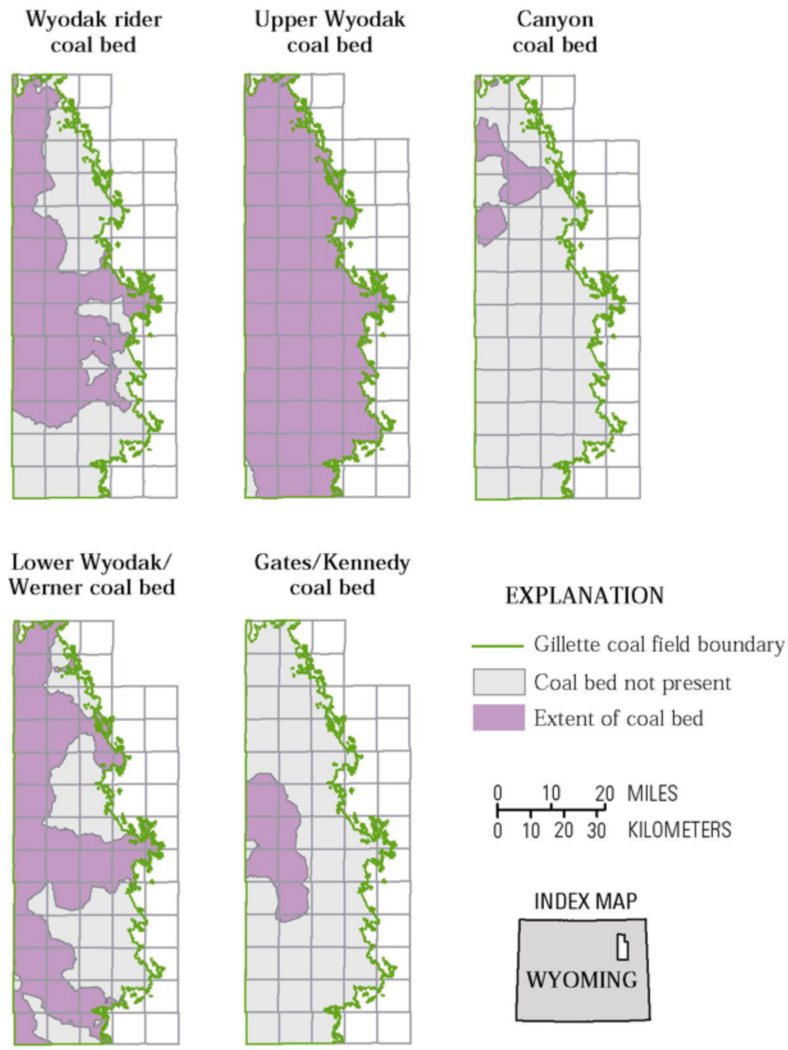

Figure 12. Map showing areal distribution of the Wyodak rider, Upper Wyodak, Canyon, Lower Wyodak/Werner, and Gates/Kennedy coal beds.

Upper Wyodak:
The thickest and most contiguous of the coal beds studied, the Upper Wyodak occurs everywhere in the coal field except for a small area in the southwestern corner, covering a total of about 1,440 sq mi (fig. 12). This bed is equivalent to the Main Wyodak coal bed that was included in coal availability and recoverability studies in the Hilight quadrangle (fig. 4) by Molnia and others (1997, 1999) and Osmonson and others (2000). The Upper Wyodak coal bed ranges from 0 ft to 172 ft in thickness (fig. 14) and includes as many as five partings. The partings consist mostly of claystone, ranging from 1 ft to 20 ft in thickness. The thicker partings occur mostly in the northern one-third of the study area. The continuity of the bed is shown in figures 8, 9, 10, and 11. Thinning of the bed toward the west is an artifact of the bed splitting into the Lower Wyodak/Werner coal bed, as shown in figures 8 and 10, and of a general stratigraphic thinning trend. Overburden ranges from zero at the outcrop to 1,447 ft (fig. 15) along the west side of the coal field.

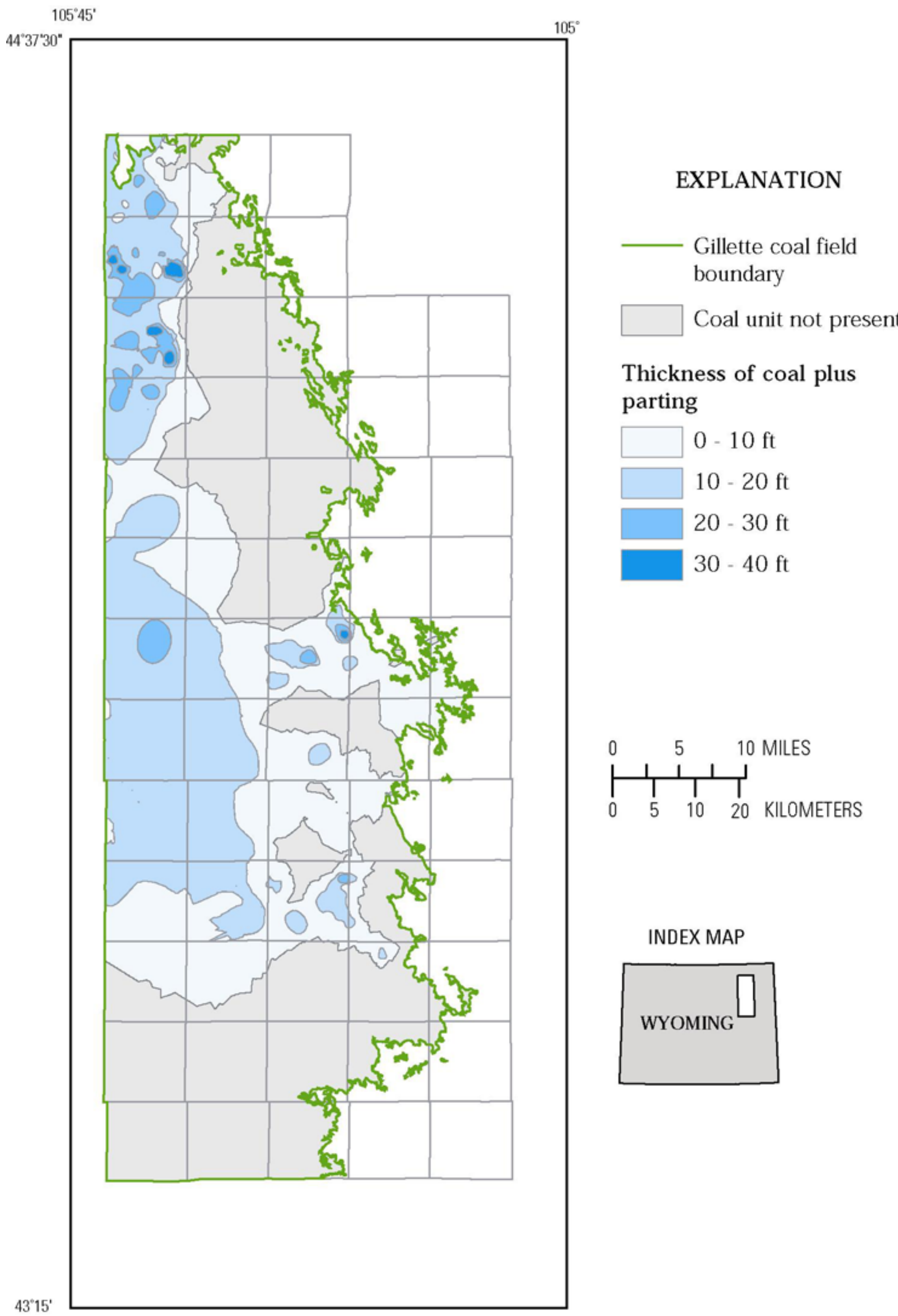

Figure 13. Isopach map showing thickness of coal plus partings in the Wyodak rider coal-mining unit.

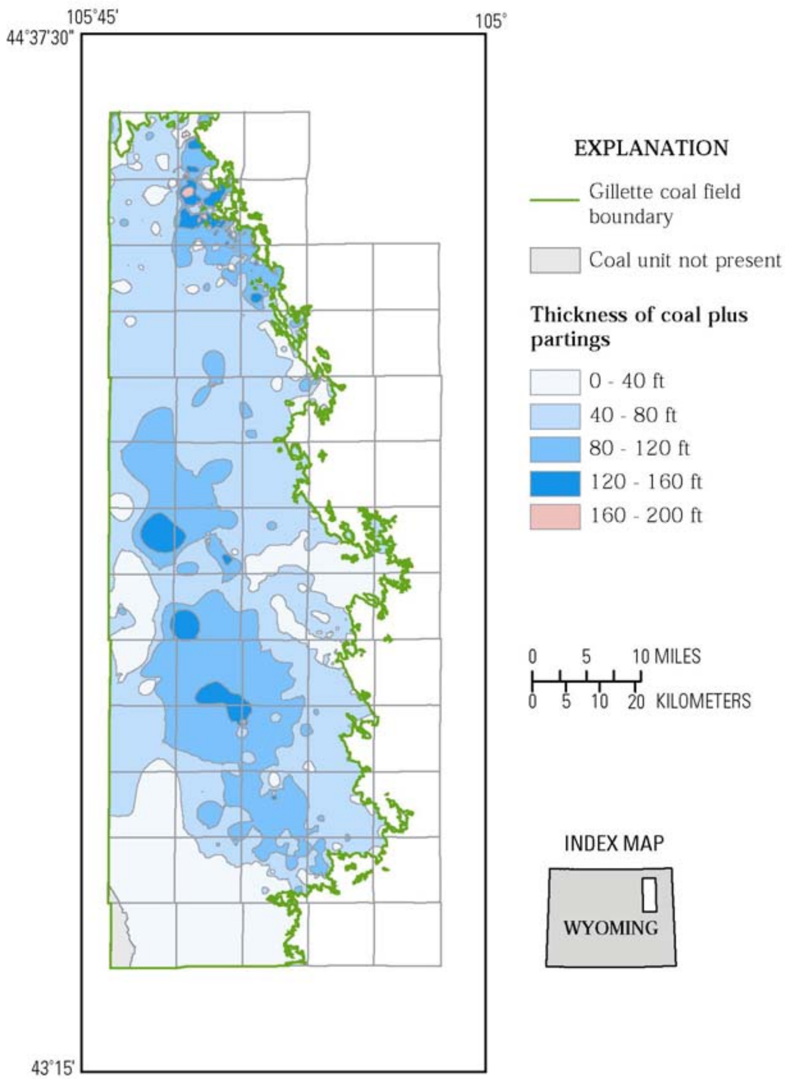

Figure 14. Isopach map showing thickness of coal plus partings for the Upper Wyodak coal-mining unit.

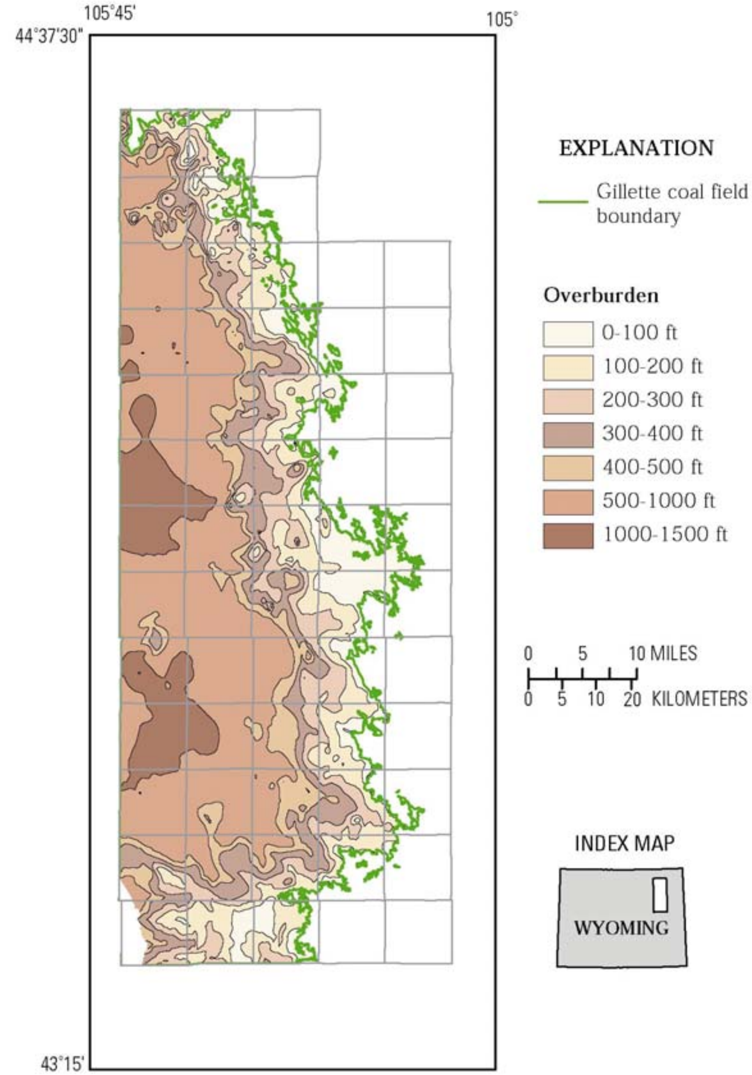

Figure 15. Isopach map showing the thickness of rock above the Upper Wyodak coal bed.

Canyon:
The Canyon bed is the most areally limited bed that is mined in the Gillette coal field. It splits from the Lower Wyodak/Werner to become a bed above it, and covers only about 120 sq mi. The pod nature of this bed is evident in figure 12, although the bed becomes more continuous to the northwest. The bed reaches thicknesses of about 40 ft, and commonly includes 2 or 3 mudstone partings that are 3 ft to 8 ft thick (fig. 16). Cross sections in figures 7, 8, and 11 show the Canyon bed splitting from the Lower Wyodak/Werner coal. Overburden ranges from 112 ft in the eastern part of the coal field to 1,225 ft in the western part.

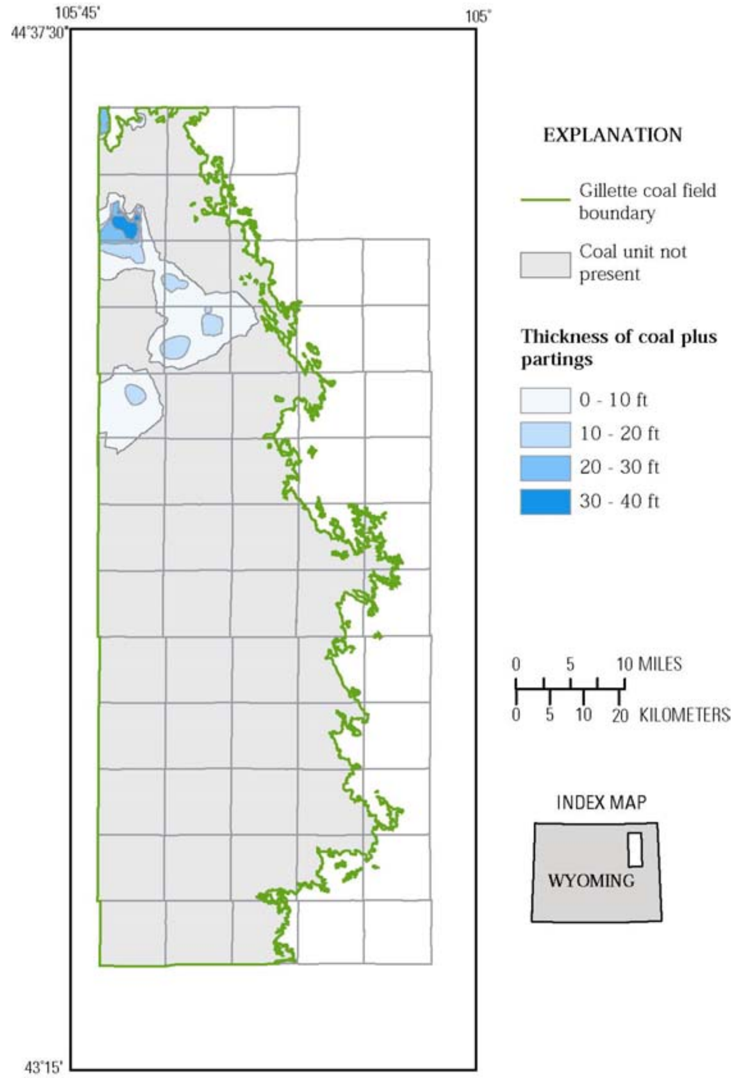

Figure 16. Isopach map showing thickness of coal plus partings for the Canyon coal-mining unit

Lower Wyodak/Werner:
The Lower Wyodak/Werner bed is a lower split from the Upper Wyodak coal bed. It covers an area of about 875 sq mi (fig. 12). Thickness ranges from 10 ft to 120 ft, with the thickest part occurring in the northern part of the field. One to five partings are common, ranging from 0.5 ft to 25 ft in thickness. Figure 17 shows the thickness of the coal bed plus partings. The large blank areas on the eastern limit of the coal field are split lines where this bed merges with the Upper Wyodak coal. Cross sections in figures 8, 9, 10, and 11 show the Lower Wyodak/Werner coal splitting from the Upper Wyodak in the northern part of the coal field and thinning to a featheredge in the southern part. Overburden ranges from zero at the outcrop along its eastern extent to a maximum of 1,577 ft to the west.

Gates/Kennedy:
The Gates/Kennedy bed, as correlated in this study, covers approximately 209 sq mi in the northern part of the coal field (fig. 12). The bed attains thicknesses of as much as 42 ft, including 1 or 2 partings that are 2 to 11 ft thick (fig. 18). The thickness of the coal plus partings is shown on figure 18. Overburden ranges from 771 ft along its eastern extent to a maximum of 1,713 ft to the west.

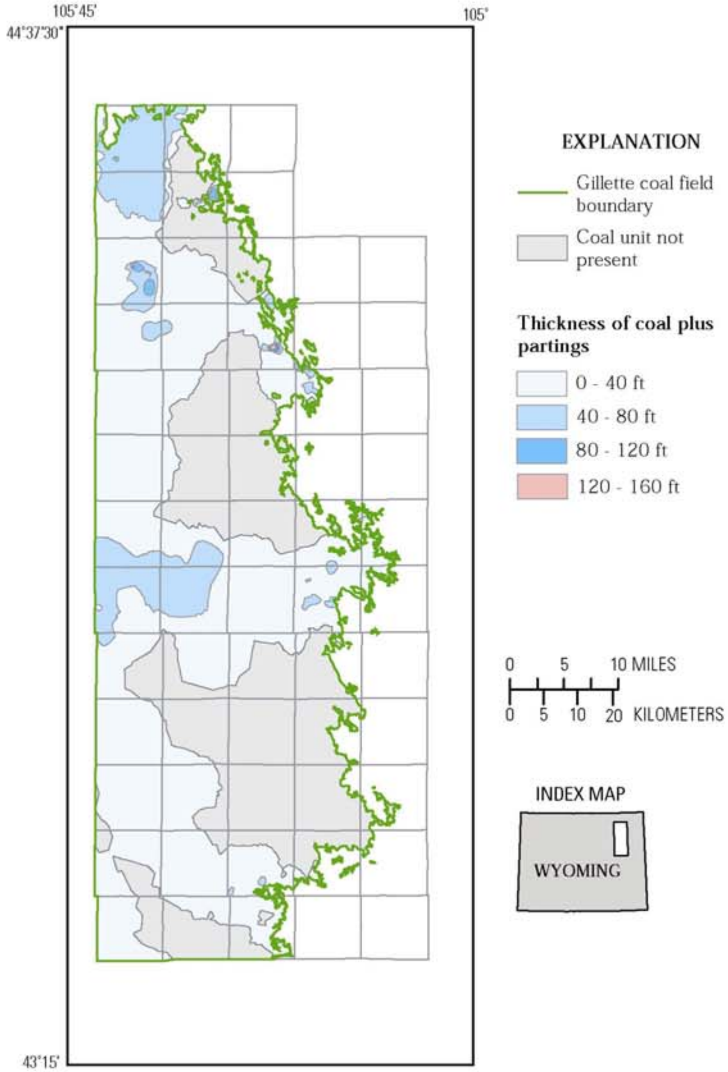

Figure 17. Isopach map showing thickness of coal plus partings for the Lower Wyodak/Werner coal-mining unit.

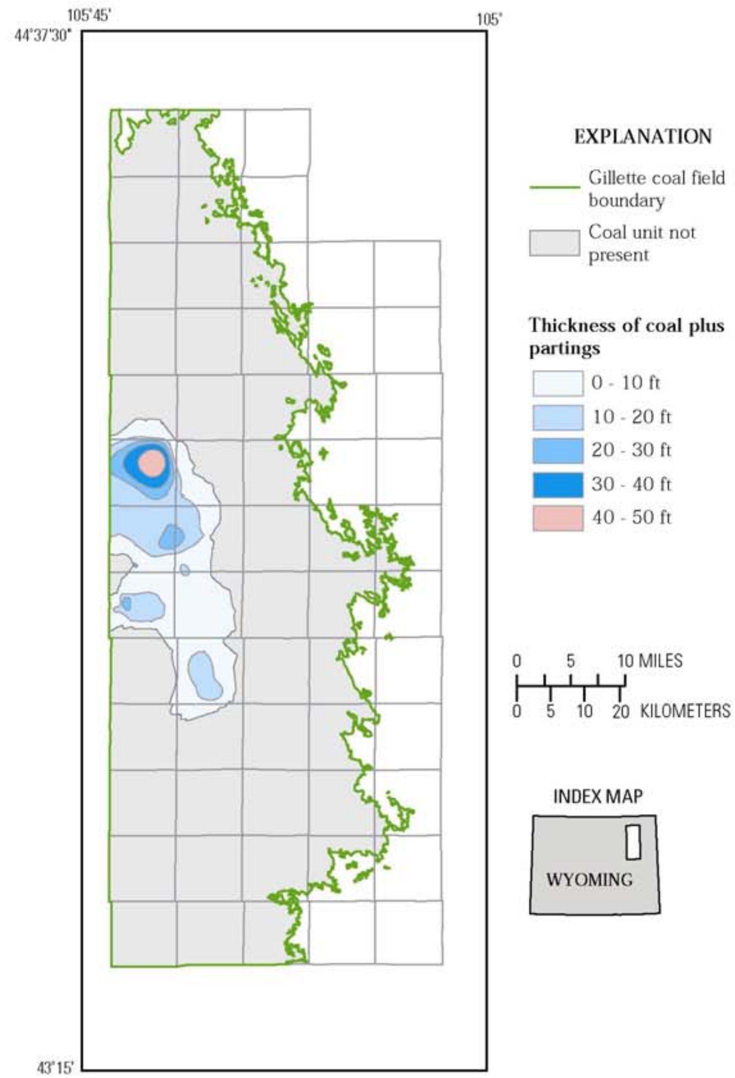

Figure 18. Isopach map showing thickness of coal plus partings for the Gates/Kennedy coal-mining unit.

COAL GEOCHEMISTRY

Coal from the Fort Union Formation in the Gillette coal field is generally considered to be clean, and compliant with SO_2 emissions standards (U.S. Environmental Protection Agency, 1996). The Clean Air Act mandates that coal-fired power plants not release emissions containing more than 1.2 pounds of SO_2 per million Btu. The low content of sulfur in coal from the Powder River Basin (Stricker and Ellis, 1999), and specifically within the Gillette coal field (Ellis and others, 1999), makes this coal an excellent product for mixing with noncompliant coal from other areas.

Coal quality in the Wyodak-Anderson coal zone in the Gillette coal field study area reported by Ellis and others (1999) included analyses from a total of 108 locations. The weighted average of values from each data point location indicates total sulfur content of from 0.20 to 1.16 percent, with a mean of 0.48 percent and ash content of from 3.5 to 25.06 percent, with a mean of 7.45 percent. For comparison, low total sulfur content is considered to be less than or equal to 1 percent by weight and low ash yield is considered to be less than or equal to 8 percent by weight (Wood and others, 1983). Pounds of SO_2 per million Btu for Wyodak-Anderson coal ranges from 0.44 to 3.27 with a mean of 1.25. The gross calorific value of the coal samples ranges from 3,740 to 9,950 Btu/lb, with a mean of 8,220 Btu/lb. More detailed information on coal quality of the coal within the Wyodak-Anderson coal zone is given in Stricker and Ellis (1999) and Ellis and others (1999).

Other coal analyses for coal beds that are at least partially correlative to the beds assessed in this study include those reported by Glass (2001), such as the Wyodak, Anderson, Canyon, and Smith. Coal thickness ranges and analytical values for these beds are shown in table 3; all are subbituminous C in apparent rank. The Canyon and Anderson beds, which have been identified in the western part of the coal field, coalesce to the east to form the thick Upper Wyodak coal bed (table 2).

Table 3. Summary data of selected coal quality parameters for some coal beds in the Gillette coal field, Powder River Basin, Wyoming. Data are from Glass (2000) and are listed according to the coal bed names used in that report. Table 2 indicates the relations of these beds to the coal beds assessed in our report. All values are on an as-received basis.

Data	Coal beds			
	Anderson	Canyon	Wyodak	Smith
Coal thickness range (ft)	10-50	11-65	25-190	5-20
Number of samples	9	9	59	1
Moisture range (percent)	24.9-34.	26.5-31.5	21.1-36.9	31.8
Mean moisture (percent)	29.5	29.6	29.8	31.8
Ash range (percent)	3.5-12.2	3.1-7.4	3.9-12.2	4.7
Mean Ash (percent)	6.5	5.1	6.0	4.7
Total sulfur range (percent)	0.17-1.13	0.14-0.92	0.2-1.2	0.63
Mean total sulfur (percent)	0.52	0.34	0.5	0.63
Heat value range (Btu)	7,130-8,740	7,540-8,610	7,420-9,600	7,990
Mean heat value (Btu)	7,900	8,290	8,220	7,990
Fixed carbon range (percent)	29.0-38.0	31.8-38.4	29.6-41.4	34.8
Mean fixed carbon (percent)	33.9	34.6	33.5	34.8
Volatile matter range (percent)	26.5-34.	28.7-33.3	26.5-35.5	28.7
Mean volatile matter (percent)	30.1	30.7	30.7	28.7

About 300 million short tons of coal were supplied in 2000 to coal-fired power plants from the in the Gillette coal field (fig. 4) (Resource Data International, 2002). According to the 2002 COALdat database (Resource Data International, Inc., 2002), the average coal quality of Fort Union Formation coal supplied to electrical power plants in 2000 from mines in the Gillette coal field was 0.34 percent total sulfur, 5.17 percent ash, 0.79 pounds of SO_2 per million Btu, and 8,530 Btu/lb. The quality of coal produced from these mines, reported by sub-areas in the Gillette coal field, is shown in table 4.

Table 4. Summary of quality of coal supplied to coal-fired power plants in 2000 from mines in the Gillette coal field (Resource Data International, Inc., 2002). Data are listed by the location of mines within the coal field (fig. 2). The "combined" category is coal that was supplied to power plants from mines located in different parts of the coal field. Proximate, ultimate, and heat of combustion values are reported on an as-received basis. Btu is British thermal units.

Coal quality parameter	Northern part	Middle part	Southern part	Combined areas	From all of the mines
Minimum ash (percent)	5.01	4.44	4.41	4.67	4.41
Maximum ash (percent)	6.68	5.51	5.31	5.0	6.68
Mean ash (percent)	5.64	5.14	5.00	4.83	5.17
Minimum total sulfur (percent)	0.36	0.31	0.20	0.33	0.20
Maximum total sulfur (percent)	0.56	0.35	0.38	0.33	0.56
Mean total sulfur (percent)	0.43	0.33	0.29	0.33	0.34
Minimum gross calorific value (Btu)	8,056	8,342	8,568	8,433	8,056
Maximum gross calorific value (Btu)	8,342	8,596	8,875	8,820	8,875
Mean gross calorific value (Btu)	8,198	8,487	8,755	8,627	8,529
Minimum lbSO_2/million Btu	0.89	0.71	0.45	0.75	0.45
Maximum lbSO_2/million Btu	1.40	0.83	0.87	0.79	1.40
Mean lbSO_2/million Btu	1.04	0.77	0.65	0.77	0.79

For the individual coal beds we studied, there were a limited number of analyses available. Figure 19 shows the sample locations. The coal quality data set for this study is made up of 140 coal samples that were analyzed for proximate, ultimate and heat-of combustion values, and 157 coal samples that were analyzed for selected potentially environmentally hazardous trace elements. Represented in the suite of samples were the Wyodak rider, Upper Wyodak, and Lower Wyodak/Werner beds. These were no analyses from the Canyon or Gates/Kennedy beds. Tables 5 and 6 show minimum, maximum and mean coal quality values for these analyses. A more detailed discussion of coal quality in the Powder River Basin and in the Gillette coal field can be found in Ellis (2002).

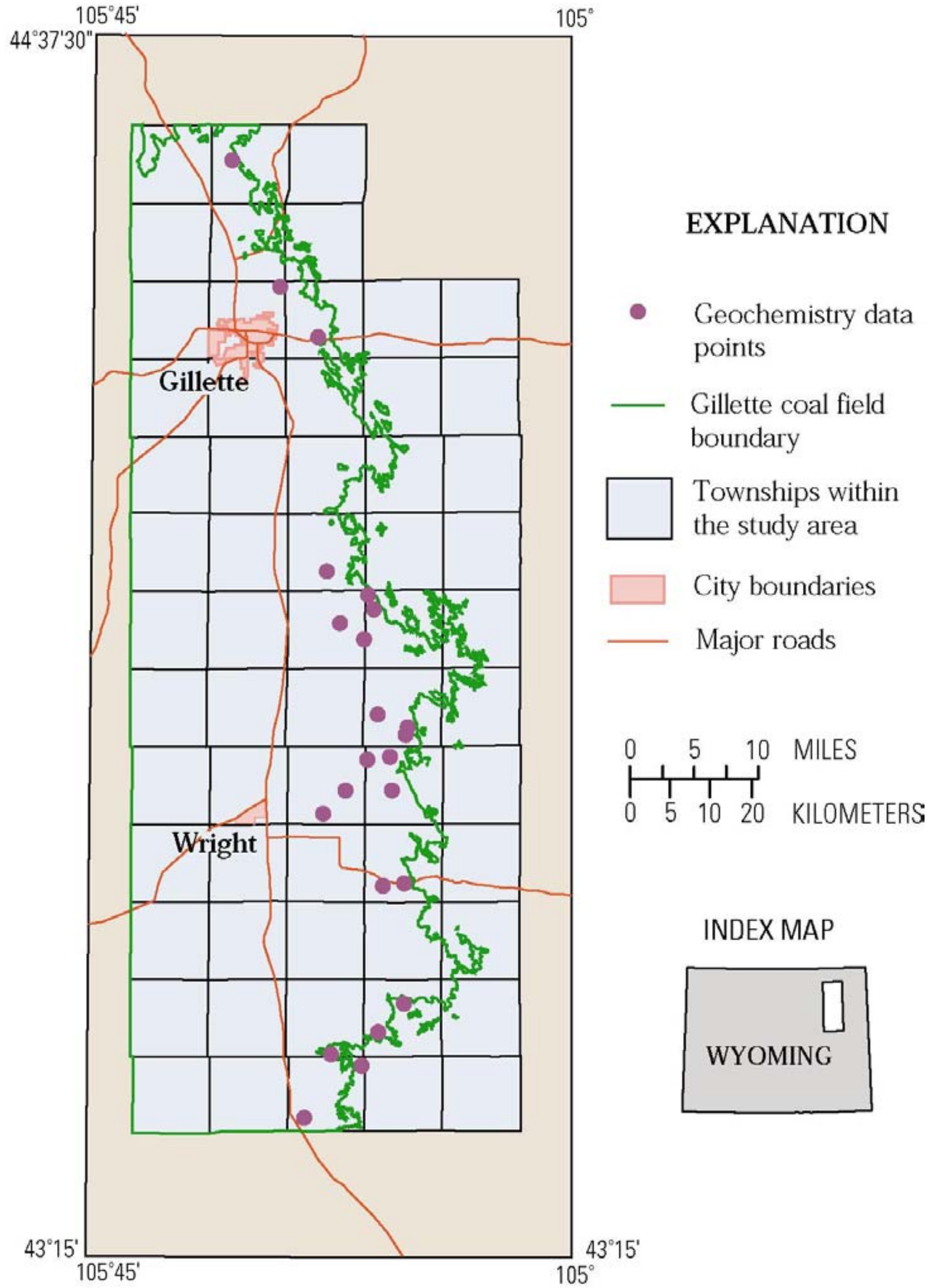

Figure 19. Map showing the drill hole locations for geochemical data usedin this study.

Table 5. Proximate and ultimate analyses and heat values, on an as-received basis, for coal assessed for this study in the Gillette coal field, Powder River Basin, Wyoming. Data were not available for the Canyon or the Gates/Kennedy coal beds.

Parameter	Data	Wyodak rider	Upper Wyodak	Lower Wyodak/Werner	All assessed coal units
Moisture (percent)	Minimum	20	15	25	15
	Maximum	27	35	32	35
	Mean	23	27	27	27
Ash (percent)	Minimum	9.7	2.5	4.2	2.5
	Maximum	19.1	19.68	8.2	19.68
	Mean	12.90	5.80	5.83	6.01
Total sulfur (percent)	Minimum	0.80	0.13	0.20	0.13
	Maximum	1.50	2.30	0.40	2.30
	Mean	1.13	0.46	0.27	0.46
Lb SO_2/million Btu	Minimum	0.35	0.25	1.45	0.25
	Maximum	0.71	3.68	3.02	3.68
	Mean	0.55	1.70	2.40	1.73
Calorific value (Btu)	Minimum	7,890	7,170	7,576	7,170
	Maximum	9,409	9,950	8,980	9,950
	Mean	8,500	8,569	8,472	8,554
Moist, mineral-matter free Btu	Minimum	9,156	8,246	8,311	8,246
	Maximum	10,562	10,572	9,407	10,572
	Mean	9,879	9,193	9,039	9,211
Fixed carbon (percent)	Minimum	29.7	25.5	4.1	4.1
	Maximum	33.1	44.5	39.3	44.5
	Mean	30.8	35.0	33.6	34.8
Volatile matter (percent)	Minimum	30.30	24.75	28.80	24.75
	Maximum	37.80	37.80	55.70	55.70
	Mean	33.23	31.71	33.50	31.87

Table 6. Values for trace elements considered potentially hazardous air pollutants in analyses of assessed coal from the Gillette coal field, Powder River Basin, Wyoming. Data are from the Economic and Environmental Evaluation of Extractable Coal Resources (E4CR) database. The E4CR dataset does not contain data for the Canyon or Gates/Kennedy coal units. All trace element contents are reported in parts per million and are on a whole-coal and remnant-moisture basis.

Potentially Hazardous Air Pollutant Trace Elements					
Parameter	Data	Wyodak rider	Upper Wyodak	Lower Wyodak/ Werner	All coal units
Arsenic	Minimum	3.6	0.35	0.33	0.33
	Maximum	65	30	3	65
	Mean	20	2.1	0.88	2.5
Lead	Minimum	2.4	0.14	0.76	0.14
	Maximum	7.7	14	7.6	14
	Mean	5.04	2.5	2.9	2.5
Mercury	Minimum	0.14	0.02	0.02	0.02
	Maximum	0.35	3.8	0.16	3.8
	Mean	0.26	0.21	0.07	0.20
Selenium	Minimum	1.5	0.05	0.18	0.05
	Maximum	2.2	6.7	1.7	6.7
	Mean	1.8	1.01	0.59	1.01
Uranium	Minimum	1.4	0.08	0.01	0.01
	Maximum	2.9	3.2	1.2	3.2
	Mean	2.1	0.61	0.46	0.64

Potentially Hazardous Air Pollutant Trace Elements					
Parameter	**Data**	**Upper Wyodak**	**Lower Wyodak/ Werner**	**Wyodak rider**	**All coal units**
Arsenic	Minimum	0.35	0.33	3.6	0.33
	Maximum	30	3	65	65
	Mean	2.1	0.88	20	2.5
Lead	Minimum	0.14	0.76	2.4	0.14
	Maximum	14	7.6	7.7	14
	Mean	2.5	2.9	5.04	2.5
Mercury	Minimum	0.02	0.02	0.14	0.02
	Maximum	3.8	0.16	0.35	3.8
	Mean	0.21	0.07	0.26	0.20
Selenium	Minimum	0.05	0.18	1.5	0.05
	Maximum	6.7	1.7	2.2	6.7
	Mean	1.01	0.59	1.8	1.01
Uranium	Minimum	0.08	0.01	1.4	0.01
	Maximum	3.2	1.2	2.9	3.2
	Mean	0.61	0.46	2.1	0.64

FACTORS AFFECTING EXTRACTION OF COAL RESOURCES

There are many factors that can affect the availability of coal for mining. The three general groups of factors or considerations in Powder River Basin coal development are: legal unsuitability criteria, land-use conflicts, and technological factors. Table 7 shows a listing of the factors under each of these groups. It is important to note that not every factor included in table 7 affects development within the Gillette coal field.

Table 7. List of factors that can restrict coal mining

Legal unsuitability criteria from Federal Coal Management Regulations (43 CFR 3461.5)
Federal Land Systems
Rights of way and easements (railroad)
Dwellings, roads, cemeteries, and public buildings
Wilderness study areas
Lands with outstanding scenic quality
Lands used for scientific study
Historic lands and sites
Natural areas
Critical habitat for threatened or endangered plant and animal species
State listed threatened or endangered species
Bald or golden eagle nests
Bald and golden eagle roost and concentration areas
Federal lands containing active falcon cliff nesting site
Habitat for migratory bird species
Fish and wildlife habitat for resident species
Floodplains
Municipal watersheds
National resource waters
Alluvial valley floors
State or Indian Tribe criteria
Land-use conflicts
Towns
Pipeline
Oil and gas development (a land-use restriction for surface mining)
Gas plant
Power lines
Gravel pits
Archaeological areas
Surface and coal ownership issues
Wetlands

Table 7 continued.

Technological factors
Coal quality
Overburden geochemistry
Overburden thickness (coal too deep)
Mined-out areas or limit of coal
Surface subsidence over abandoned mines
Active mines
Abandoned mines
Clinkered areas
Coal beds too close together
Coal beds too thin (coal beds less than 2.5 ft thick were considered too thin to mine)
Coal beds too thick (for underground mining)
Coal bed discontinuities
Roof or floor problems
Barrier pillars
Oil and gas development (technological restriction for underground mining)
Coalbed methane development

The coal leasing unsuitability criteria are listed in the Code of Federal Regulations, Title 43 Subpart 3461 (43 CFR 3461) (Office of the Federal Register, 2000). These 20 specific legal criteria are used to determine if an area can be mined by surface mining methods. The 43 CFR 3461 regulations are issued under the authority of, and implement several major provisions of, Public Law 95-87, which is part of the Surface Mining Control and Reclamation Act of 1977 (30 U.S.C. 1201 et seq.) (1977). The 20 unsuitability criteria involve consideration of scenic areas, natural and historic values, wildlife, flood plains, alluvial valley floors, and other special values (U.S. Bureau of Land Management, 1984).

Restrictions to mining vary with location and local land-management regulations. Thus, different study areas can have different mining restrictions and availability considerations. This report reflects our assumptions concerning restrictions to mining, which are based on local practices in the Powder River Basin, and specifically to those practices within the Gillette coal field. In addition, the BLM in Casper, Wyoming, provided guidance concerning restrictions to mining and the distances to be buffered around specific features, as well as files delineating many of the features and the buffer distances around the features that we used for our study. Because required buffer distances can change from year to year, all of the distances that we used were conservative in that we selected buffer distances that were considered to be the maximum amount that might be required by future regulations. A more detailed determination of restrictions and other availability considerations would be necessary as part of leasing and mine-planning phases of property development.

The following is a detailed discussion of the various restrictions to mining that we used for this investigation. Figure 20 shows the areas within the Gillette coal field where the restrictions were applied to limit the areas in which coal resources were calculated.

<u>CITIES</u>: The municipalities of Gillette and Wright are located within the Gillette coal field and are permanent restrictions to mining. For this study, a 300-ft restriction buffer was placed around the city limits of Gillette and the town of Wright.

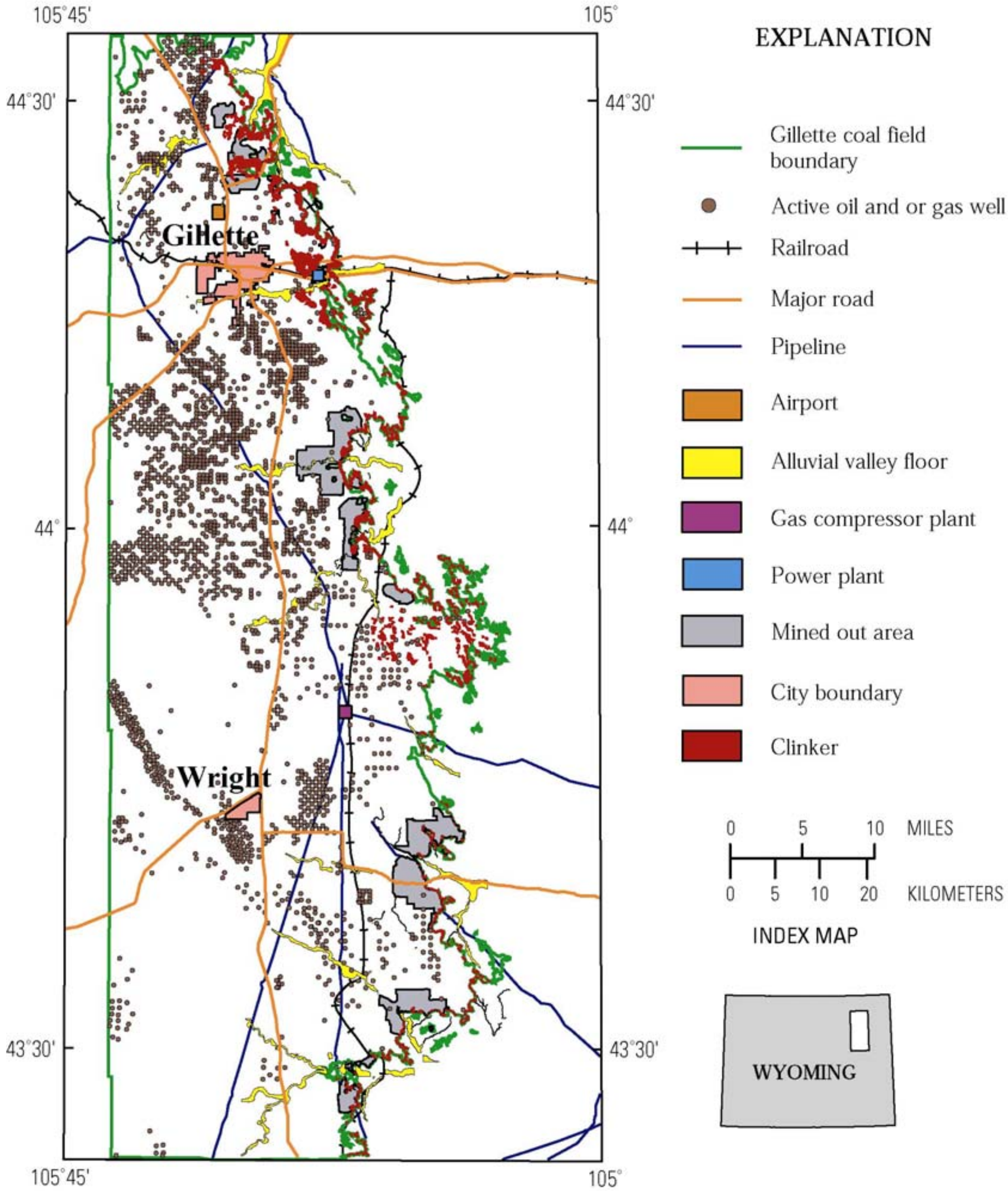

Figure 20. Map showing some features that can restrict the area to be mined.

ROADS: County roads (mostly gravel) cross many areas throughout the Gillette coal field. It is assumed that these roads could be fairly easily relocated to allow mining to proceed; therefore, these roads are not considered restrictions to mining. However, a number of State and U.S. highways, including an interstate highway, are also present within the study area. Although it is possible that some or all of these highways could also be relocated to allow for mining, we consider them to be restrictions to coal mining for assessment purposes. They are shown on figures 19 and 20 with a buffer; the State highways, including buffers on each side, are 220 ft wide. Interstate Highway 90, including its buffers on each side, is 270 ft across.

RAILROADS: There are two main railroad lines within the Gillette coal field, as well as a number of spur lines that serve the existing coal mines. Because the spur lines can be expected to be moved as the mining operations proceed, these spur lines are not considered to represent restrictions to mining. It is conceivable that the main lines of the existing rail routes could also be relocated to allow mining to proceed, once the appropriate agreements and permits were acquired. However, for the purposes of this study, we have assumed that these main rail lines would not be moved, and we consider them, and the 300 ft buffer along each side of them, to be restrictions to coal mining.

PIPELINES: There is a network of underground oil and gas pipelines throughout the Gillette coal field. Probably most, if not all, of these pipelines would be moved so that surface mining could proceed; however, moving and restoring them would represent an added economic consideration to mining. For this study, we have considered only the major pipelines to be restrictions to mining. The pipeline restrictions include a 100 ft buffer along each side of the pipelines.

AIRPORT: About two miles north of Gillette lies the Campbell County airport. We believe it unlikely that this facility would be relocated to allow for surface mining on the land, so the airport grounds, along with a 300-ft-wide buffer, are determined to be a permanent restriction to mining.

POWER PLANTS: Electrical power-generating facilities of the Wyodak Plant and the Neil Simpson Plant lie a few miles to the east of Gillette, near the coal outcrop boundary of the Gillette coal field. The area occupied by these installations, as well as a 100-ft buffer, are shown in figure19; this land is a permanent restriction for coal mining.

HILIGHT GAS PLANT: The plant, located approximately 7 miles to the northeast of Wright, connects to several major pipelines for gas and crude oil, as well as to a pipeline for gas-processing-plant products. This installation, with a 100-ft buffer, is considered a restriction to coal mining.

OIL AND OIL-RELATED GAS WELLS: As of July 2000, there were more than 2,300 active producing wells within the Gillette coal field; these wells include those in the study area's two major oil and gas fields – Hilight and Kitty. How land-use conflicts between coal mining and the oil and gas field development would be resolved will depend on economic conditions, regulations, and negotiations between oil developers and coal developers. Perhaps an area around a major cluster of active wells would be eliminated from mining activities until these wells are no longer actively producing. On the other hand, mining activities might proceed around individual active wells that are given a buffer zone. Conversely, specific wells might be plugged and then re-established after mining. For this study, we have buffered around each active well (300-ft-buffer radius) and consider these areas as restrictions to mining.

ALLUVIAL VALLEY FLOORS: All areas within the coal field identified as alluvial valley floors by the Bureau of Land Management, where mining would interrupt, discontinue, or preclude farming, are unsuitable for surface coal mining, thus are deemed to be restrictions.

AREAS OF CLINKER: There are many areas along the coal outcrop, some areas as much as several miles down dip from the coal outcrop, where coal has burned in-place and produced overlying clinker. Because coal beneath areas containing clinker is either burned or compromised in quality, we considered these areas to be restrictions to mining. The eastern limit of the coal, for this study, was drawn so that most areas along the coal outcrop that contain clinker are excluded from consideration for resource assessment.

The following detailed discussions address other potential mining restrictions that also need to be considered. Although not deemed by us to represent restrictions to mining in the study area, they likely would represent limitations to mining within other areas.

COALBED METHANE WELLS AND PIPELINES: The rapid growth in coalbed methane production within the Gillette coal field, particularly during the last five years, has resulted in the placement of thousands of wells, along with their accompanying pipeline infrastructure, throughout the study area. Designating all of these wells and their extensive gas delivery systems as being restrictive to mining, would effectively exclude most of the coal field from resource consideration. As stated previously in the section on other energy commodities in the Gillette coal field, the expected lifetime of a coalbed methane well producing from a single coal bed is 10 to 12 years. For the purpose of this study, we have assumed that the coal within any part of the study area will be mined after the coalbed methane operations have ceased operating in that area. Therefore, we have not designated any coalbed methane facilities as representing a restriction to mining.

FEDERAL LAND SYSTEMS: There are no Federal lands systems that are unsuitable for coal leasing in the Gillette coal field. The study area does contain a part of the Thunder Basin National Grassland, a large area in northeastern Wyoming that includes scattered Federal lands under the jurisdiction of the U.S. Forest Service, although it is not part of a National Forest. The same unsuitability criteria and land-use considerations discussed in this report apply to coal mining on the Thunder Basin National Grassland. Where the mineral ownership there is Federal, the BLM develops the coal-leasing and mining stipulations in conjunction and cooperation with the U.S. Forest Service. Federal surface management areas and Federal subsurface coal ownership are shown in figure 21.

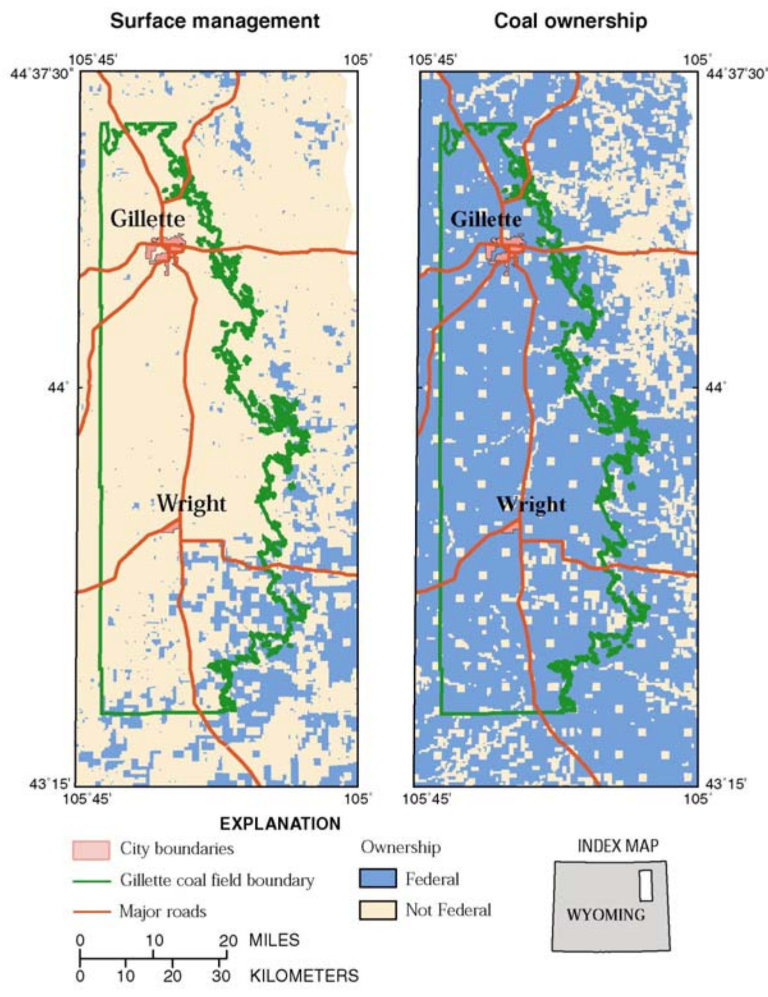

Figure 21. Map showing coal ownership in and around the Gillette coal field.

POWER LINES: The authors expect that all power lines within the study area could be fairly easily moved to accommodate surface mining operations. Thus, power lines are not considered a restriction to mining in the area of the Gillette coal field.

RIVERS, STREAMS, AND LAKES: The Belle Fourche River is the most significant body of flowing water within the Gillette coal field. However, throughout its course within the coal field, it is a shallow, slow moving, meandering stream, as is the case with all of the other larger creeks in the study area. Surface mining operations could temporarily relocate the courses of these streams and then return them to their pre-mining locations during mine reclamation. Only the parts of the watercourses that have been designated by the BLM as alluvial valley floors would need to be preserved with no modification. There are no major lakes present within the Gillette coal field; the shallow lakes and small ponds that do exist could either be temporarily moved during mining or simply reformed after the mining operations ceased.

DWELLINGS AND BUILDINGS: Individual dwellings and buildings that exist within the Gillette coal field, outside of the incorporated areas of Gillette and Wright, are not considered to represent restrictions to mining. These individual structures could probably be purchased by a coal company, which could then move or destroy them in order to proceed with mining.

RAPTOR SITES: In the proposed final environmental impact statement for the Buffalo Resource Area (U.S. Bureau of Land Management, 1985), golden eagle sites (with one-mile buffers) were identified as unsuitable for mining. However, currently these and other raptor sites are considered open to leasing and coal mining, pending further study; the mining effects at the sites could probably be mitigated. Because raptor sites are not considered to be a permanent restriction to mining, they were not excluded in this study.

ARCHAEOLOGICAL AREAS: No major archaeological areas that would prevent mining are known in the study area. There are several minor archaeological sites and also several minor historic sites within the Gillette coal field. A mitigation plan would be developed before coal mining disturbed these areas; therefore, coal within these known sites was not excluded from this resource study.

In some cases, an area that was originally declared unsuitable for coal mining could have a mitigation measure developed to the extent that would permit mining. Economic analyses by the coal developer would help to determine whether costs for mitigation would preclude mining.

Coal quality was not considered to be a restriction when determining the economically recoverable coal resources. The quality of a coal can be a factor in its marketability because government regulations prevent the use of coal containing potentially hazardous environmental pollutants at coal-fired power plants. The regulatory standard for sulfur dioxide emissions from coal-fired power plants restricts the amount of SO_2 per million Btu that can be released into the air to 1.2 pounds. In the Gillette coal field, the coal is relatively low in total sulfur content and almost all of the minable coal contains sulfur content and Btu values that equate to less than the standards set for SO_2 emissions from power plants.

STUDY METHODOLOGY

Data Collection, Correlation, and Preparation

The methodology for calculating economically recoverable coal resources for assessed coal beds in the Gillette coal field involved several phases. The first phase involved the compilation and correlation of data and the delineation of coal-mining units and areas of restrictions, including: (1) acquisition of coal stratigraphic and analytical data, and their transfer into a point-data management system; (2) correlation and grouping of coal and parting into coal beds, or mining units; (3) transference of point-source, line, and polygon data to a geographic information system (GIS); and (4) conversion of point-source, line, and polygon data into vector coverages and/or raster grids using the GIS program. The second phase was to calculate the original coal resources, previously mined resources, restricted coal resources, and coal resources available for mining. The third phase was to calculate recoverable coal tonnages, determine a mine model for the study area, and finally, apply a cost model to the recoverable resource to determine how much of the resource could be produced at a profit.

Our study involved compilation of three types of data. The first was point-source data consisting of stratigraphic and coal quality information. As noted earlier, in the section titled Coal Bed Correlations, we used stratigraphic interpretations and representative coal quality data from a USGS open-file report by Flores and others (1999). Point-source geologic data were initially processed using StratiFact software (GRG Corporation, 1996) to store, manipulate, and graphically display cross sections throughout the study area. Where Kent and others (1980) or Pierce and others (1990) contained correlations of coal beds for the same drill holes used in this report we used their coal bed names as a basis for our correlations. We correlated individual coal beds and grouped the coal beds and partings into mining units using StratiFact visualization. Coal beds and partings were grouped into mining units by assigning coal bed designations to the appropriate lithologic units. Then, coal-mining unit data were exported using StratiFact (GRG Corporation, 1996), and brought into ArcView (Environmental Systems Research Institute, 2001a).

We devised a system of identifying and naming these coal intervals that would be modeled for mining. As previously noted, it was difficult to correlate individual coal beds across the whole study area. Data for some drill holes indicated a thick coal bed with no partings, but data for nearby holes indicated the same coal with partings that separate the thick coal into several coal beds. If we had applied strictest coal-correlation conventions, each of those parts of the single thick coal might have a separate name. In that case we would have a mixture of small extents of multiple, thin coal beds and small extents of single, thick coal beds across the study area. Such a distribution would not be feasible for coal-extraction modeling.

To avoid this problem, we grouped coal beds and partings together in intervals that were representative of the five coal beds being modeled. In each interval, we verified that total parting was less than 50 percent of the entire thickness; in most cases, total parting was much less than 50 percent. By the use of this system, we could accommodate the variation in coal stratigraphy over our 1,500-sq-mi-study area, and also accommodate differences in geophysical-log interpretation that may have existed in our original data set. The five coal intervals represented reasonable groupings of coal and partings in our view, hence were considered to be the mining units.

The second data type that we used consisted of polygon or line data that delineated the surface extent of clinker and other areas that pose restrictions to mining, and areas of Federal, State and private coal ownership. The BLM provided many of these data in digital format. The digital line data was processed using one or more GIS computer programs. Some of the BLM data could be directly imported into ArcView for processing, whereas other data required prior manipulation with ArcInfo (Environmental Systems Research Institute, 2001b) before importation into ArcView.

The third type of data was the digital elevation model (DEM), which is a digital file produced by the National Mapping Division of the USGS that represents the surface topography as a grid, or raster file. The DEM is used to calculate overburden thickness by subtracting the raster values of the elevation of the top of the Upper Wyodak coal bed from the DEM surface-elevation raster values. Figure 15 shows overburden thickness above the Upper Wyodak coal, which is the thickest and most pervasive coal bed assessed for this study. The overburden thickness for the Wyodak coal bed was used in combination with the parting thicknesses to calculate stripping ratio of rock (overburden plus parting thickness) to total coal (total coal thickness of all five assessed beds). The calculation and application of the stripping ratios is discussed in more detail in the next section of this report.

Coal Resource Calculation

The point, line, and raster data, which included information on the coal-mining units, areas restricted from mining, coal ownership, and overburden, were combined in ArcView. ArcView's program extension, Spatial Analyst, was used to create raster grids of the thickness of each of the coal-mining units and to delineate the area in which the mining units could be modeled for each type of resource category. Areas in which coal mining would be restricted were also converted to raster data.

Resource categories were discussed earlier in this report, but the following discussion explains how the restrictions were applied in ArcView using the Spatial Analyst extension. Resource tonnages were derived by first calculating the volume of each mining unit and coal ownership category in acre-ft. This volume was then multiplied by a conversion factor for subbituminous coal of 1,770 short tons per acre-ft. **Original resources** were calculated for each of the coal-mining units for each of the coal ownership categories with no limitations or restrictions applied. **Remaining resources** were calculated for each mining unit and coal ownership category, using the volume of original resources minus the volume of coal that had been previously mined. The volume of coal plus partings in areas that would be restricted from mining (the unavailable resources) were then calculated for each of the mining units and coal ownership categories and those volumes were subtracted from the remaining resources to determine the **available resources**. Table 8 shows the results of coal resource calculations for the original, previously mined, remaining, restricted (unavailable), and available coal tonnages, reported by coal-mining unit and coal ownership categories.

As the next step, we developed preliminary extraction scenarios (mine models) that would be used in COALVAL (Plis and others, 1993; Suffredini and others, 1994) to determine the resources in each coal-mining unit. The **recoverable resource** is the available resource minus the amount of coal that would be lost through various mining methods. We used a mining loss of 10 percent for coal-mining units in the Gillette coal field (table 8). This is the standard amount of coal loss that is applied in the COALVAL for a truck and shovel mining operation. The recoverable resources include coal plus parting material.

Table 8. Original coal resources, previously mined resources, unavailable resources, available resources, mining losses, and recoverable resources of assessed coal-mining units in the Gillette coal field, reported in millions of short tons and by coal ownership category. These resource tonnages include coal plus parting material. Columns may not total because of independent rounding.

Coal unit	Coal ownership	Original resources	Percent that is parting material	Previously mined resources	Remaining resources	Unavailable resources[2]	Available resources	Mining losses on available resources	Recoverable resources	Percent of original resource
Wyodak rider	Federal	7,484.3	2.4	15.2	7,469.1	406.2	7,062.9	706.3	6,356.6	84.9
	State	377.4	2.6	.2	377.2	26.1	351.1	35.1	316.0	83.7
	Private	184.2	7.4	4.0	180.2	33.3	146.9	14.7	132.2	71.8
	Total	**8,045.9**	**2.5**	**19.4**	**8,026.5**	**465.5**	**7,561.0**	**756.1**	**6,804.9**	**84.6**
Upper Wyodak	Federal	94,859.7	6.0	3,765.5	91,094.2	7,142.1	83,952.1	8,395.2	75,556.9	79.7
	State	5,294.1	6.5	204.9	5,089.2	487.7	4,601.5	460.2	4,141.3	78.2
	Private	2,305.4	6.8	186.5	2,118.9	440.0	1,678.9	167.9	1,511.0	65.5
	Total	**102,459.2**	**6.0**	**4,156.9**	**98,302.3**	**8,069.7**	**90,232.6**	**9,023.3**	**81,209.3**	**79.4**
Canyon	Federal	873.2	1.2	0	873.2	161.6	711.6	71.2	640.4	73.3
	State	13.1	0.2	0	13.1	4.9	8.2	.8	7.4	56.4
	Private	15.4	0	0	15.4	3.2	12.2	1.2	11.0	71.2
	Total	**901.6**	**1.1**	**0**	**901.6**	**169.7**	**731.9**	**73.2**	**658.7**	**73.1**
Lower Wyodak/ Werner	Federal	20,637.7	11.2	137.7	20,500.0	1,526.9	18,973.1	1,897.3	17,075.8	82.7
	State	1,038.8	11.4	4.1	1,034.7	82.7	952.0	95.2	856.8	82.5
	Private	577.7	12.5	.9	576.8	119.1	457.7	45.8	411.9	71.3
	Total	**22,254.2**	**11.2**	**142.7**	**22,111.5**	**1,728.6**	**20,382.9**	**2,038.3**	**18,344.6**	**82.4**
Gates/ Kennedy	Federal	2,312.5	12.9	0	2,312.5	96.7	2,215.8	221.6	1,994.2	86.2
	State	136.0	12.6	0	136.0	5.9	130.1	13.0	117.1	86.1
	Private	34.5	15.8	0	34.5	.9	33.6	3.4	30.2	87.5
	Total	**2,483.0**	**12.9**	**0**	**2,483.0**	**103.5**	**2,379.5**	**238.0**	**2,141.5**	**86.2**
All assessed coal beds	Federal	126,167.5	6.7	3,918.4	122,249.1	9,333.4	112,915.7	11,291.6	101,624.1	80.5
	State	6,859.4	7.1	209.2	6,650.2	607.3	6,042.9	604.3	5,438.6	79.3
	Private	3,117.1	8.0	191.4	2,925.7	596.5	2,329.2	232.9	2,096.3	67.3
	Grand total	**136,143.9**	**6.8**	**4,319.0**	**131,825.0**	**10,537.2**	**121,287.8**	**12,128.8**	**109,159.0**	**80.2**

[2] Mining restricted by municipalities, State and Federal highways, railroad main lines, major oil and gas pipelines, an airport, power plants, the Hilight gas plant, active oil and oil-related gas wells, alluvial valley floors, and clinkered areas.

COALVAL is a coal property-evaluation software package developed by the U.S. Bureau of Mines. We used this software because it could efficiently handle the large quantity of cost data associated with our study. COALVAL has the capability to evaluate as many as 25 coal seams, each to be mined with as many as seven different mining methods. The software package produces summary spreadsheets that list the cost per clean ton of coal to mine the resources ("free on board" or f.o.b. cost at load-out) for each property, seam, and mining method. COALVAL performs discounted cash flow-rate of return (DCF-ROR) analyses. The DCF-ROR is defined as the rate of return that makes the present worth of future generated cash flow over the life of a project equal to the present worth of all after-tax investments (Barnes, 1980, p. 137). For this study we updated the DCF-ROR using year 2001 cost indices to calculate the costs of coal production.

Mining cost models include assumptions on recovery factors and production costs for specific mining methods. For this investigation of assessed coal in the Gillette coal field, we assumed that all mining, for the foreseeable future, would be limited to surface methods using truck and shovel operations. Furthermore, we assumed that this mining would be restricted to the five coal-mining units discussed earlier. Mining costs were based on the application of mining equipment and personnel assumptions for a super large mining operation.

Economic coal resource analysis was performed on the basis of "*waste rock*-to-*coal* ratio" for all coal-mining units combined (fig. 22). The waste-to-rock-ratio is calculated using the total thickness of all rock material (including overburden, interburden, and partings) and the total thickness of all coal at a given location. The stripping ratio is only used in this study to calculate economic coal resources. The same stripping ratio is applied to all of the assessed coal beds, because it is assumed that when mining proceeds, all five coal beds will be mined. The stripping ratio was gridded using the lateral extent of each coal assessment unit as a grid boundary, to reflect the abrupt change in coal thickness that would occur with more or fewer coal beds being mined. The cost to produce coal is directly related to the amount of rock material that must be moved in mining, and the relation between the amount of rock material to be moved and the amount of coal that will be produced. Using the stripping ratio, instead of determining the

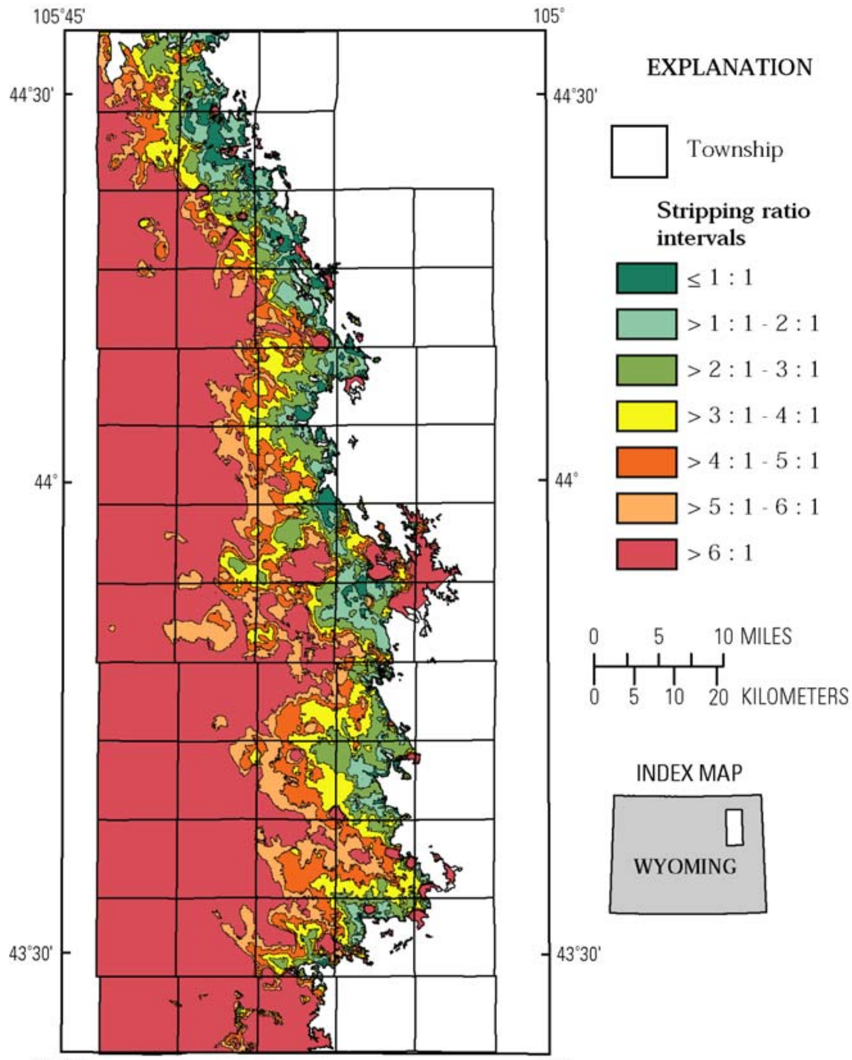

Figure 22. Map showing the ratios of waste rock to coal (stripping ratio). Waste rock includes the thickness of overburden above the uppermost coal bed, thickness of all interburden, and thickness of partings. Coal includes the thickness of all coal in the coal in the mining units.

resources only on the basis of coal-bed thickness, allowed us to directly correlate mining costs to the amount of rock material that would have to be removed to mine the coal beds. The stripping ratio is one of several variables that were used to determine the cost of coal production. Table 9 shows the economic coal resources for each of the assessed coal beds reported by stripping ratio.

Table 9. Recoverable resources of assessed coal-mining units in the Gillette coal field reported by stripping ratio (waste rock to coal). Resources are reported in millions of short tons and include coal plus parting material.

Coal-mining unit	Recoverable resources in millions of short tons reported by stripping ratio						
	≤ 1:1	>1:1- 2:1	>2:1- 3:1	>3:1- 4:1	>4:1- 5:1	>5:1- 6:1	All stripping ratios
Wyodak rider	31	86	272	650	1,066	1,652	6,804
Upper Wyodak	1,419	5,529	11,148	18,239	26,056	35,215	81,210
Canyon	0	0	2	25	86	177	659
Lower Wyodak/Werner	279	1,389	2,696	4,165	5,637	7,442	18,345
Gates/Kennedy	0	0	0	0	9	107	2,141
All mining units	1,729	7,004	14,118	23,079	32,854	44,593	109,159

Tonnage of economically recoverable coal will necessarily vary with changes in coal prices and production costs. Cost factors for determining economically recoverable resources from recoverable resource estimates are described by Rohrbacher and others (1993), Suffredini and others (1994), Doney (2000), and Western Mine Engineering (2000). COALVAL uses specific mining scenarios to determine coal production costs; the software calculates the operating costs associated with mining, using a specific mine model. The program then calculates the amount of coal in each bed that is available for different production cost ranges.

For the purpose of this report we determined that a coal resource was economic for development if the cost of coal production was less than or equal to the current market value (sales price on a per-ton basis, free-on-board (f.o.b.) cost at load-out). Therefore, the amount of coal that is economic at a production cost of $3.00 would have a sales price of $3.00 or more. In our study, we calculated economically recoverable resources for the following sales price levels: $3.00 per ton, $4.00 per ton, $5.00 per ton, $6.00 per ton, and $7.00 per ton. All tonnages of economic coal resources are reported for coal only. No parting material is included in the economic coal resources.

The over-the-counter assessment for Powder River Basin coal at the mine load-out (f.o.b. cost) for February 2002 was $5.35 per ton for coal with a calorific value of 8,400 Btu and total sulfur content of less than 0.35 percent and $6.20 per ton for coal with a heat value of 8,800 Btu and a total sulfur content of less than 0.35 percent (McGraw Hill, Co., 2002). The mean calorific value of all assessed coal in this study, based on our coal quality data set, is 8,554 Btu with mean total sulfur content of 0.46 percent. Because the economic coal resources we report do not include parting material, which would lower Btu and increase total sulfur content, we considered current market value for the economic coal resources to be about $6.00 per ton. Table 10 shows the results of the economic coal resource calculations.

It is important to note that in the Gillette coal field, the majority of the land surface is privately owned and the majority of the coal is federally owned (fig. 21). The ownership of the coal is an important aspect of coal resources in the coal field, as the BLM permits leasing for development of federally owned coal. The development of Federal coal in Wyoming contributed over $107,000,000 in royalties to the state in the year 2000 (U.S. Minerals Management Service, 2001). Knowledge of the volume of Federal coal is also important in determining National energy policy and in making land-use decisions. We believe that it is important to know the volume of Federal coal resources, as well as the resources that are owned by State and private interests. Consequently, we calculated coal resources for Federal, State, and private coal ownership and these results are shown on tables 8 and 10.

Table 10. Economically recoverable coal resources of all assessed coal (no parting material included) in the Gillette coal field, Powder River Basin, Wyoming. For the purpose of this report, coal is considered to be economic if the cost of production is less than or equal to the sales price. February 2002 over-the-counter assessment (projected sales price) for coal from the Powder River Basin was between $5.35 and $6.20 per ton (McGraw Hill Co., 2002). All tonnage values are reported in millions of short tons.

Coal ownership	Economically recoverable resources at $3.00 per ton sales price	Percent of original resource	Economically recoverable resources at $4.00 per ton sales price	Percent of original resource	Economically recoverable resources at $5.00 per ton sales price	Percent of original resource	Economically recoverable resources at $6.00 per ton sales price	Percent of original resource	Economically recoverable resources at $7.00 per ton sales price	Percent of original resource
Federal	1,526	1.2	6,462	5.1	13,089	10.4	21,273	16.9	41,471	32.9
State	132	1.9	418	6.1	794	11.6	1,341	19.6	2,318	33.8
Private	71	2.3	123	3.9	235	7.5	465	14.9	807	25.9
Grand total	**1,729**	**1.3**	**7,003**	**5.1**	**14,118**	**10.4**	**23,079**	**17.0**	**44,596**	**32.8**

RESULTS

The five coal units that we studied in the Gillette coal field (Wyodak rider, Upper Wyodak, Canyon, Lower Wyodak/Werner, and Gates/Kennedy) contain slightly more than 136.1 bst of total **original** coal resources. The percentage of each of the coal units that make up the total original coal resource in the Gillette coal field is shown on figure 23. About 89 percent, or nearly 121.3 billion tons of the original coal resource within these coal units, are considered **available** for development in the Gillette coal field (fig. 24).

If these 121.3 billion available tons were to be completely developed for mining, approximately 12.1 billion tons of coal could be expected to be lost in the mining process, resulting in an extractable resource of 109.2 billion tons (80 percent of original in-place resource). Because we assumed that the mined coal would not need washing, there would be no processing losses. Thus, this extractable resource is also the **recoverable** resource. Table 8 summarizes the original resources, previously mined resources, unavailable resources, available resources, mining losses, and recoverable resources for the study area. It should be noted that the original, available, and recoverable resource tonnages include about 9 bst of parting material, which are not included in the economic coal resource tonnage.

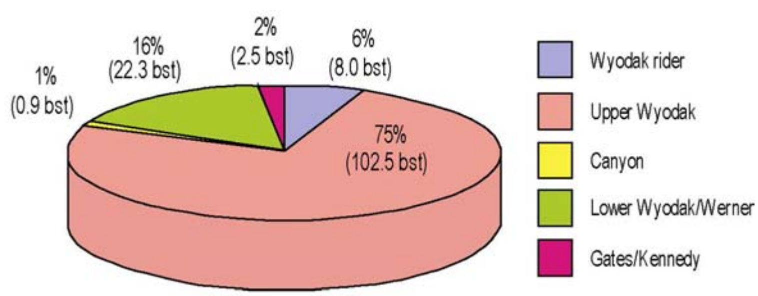

Figure 23. Pie chart showing proportions of the Wyodak rider, Upper Wyodak, Canyon, Lower Wyodak/Werner, and Gates/Kennedy coal mining units that together compose the original coal resource in the Gillette coal field. Values in parenthesis are the original coal resource for each coal mining unit reported in billions of short tons (bst). The total original coal resource for all units combined is 136 bst.

The recoverable resources were then evaluated with cost models to determine the amount of economically recoverable resources for different stripping ratios (table 9) and at five sales-price levels (table 10). Our modeling determined that only coal resources with a rock-to-coal ratio of 4:1 or less (equivalent to a production cost of $5.79 or less per ton) are currently **economically recoverable**. This category of economically recoverable coal represents 17 percent (23.1 billion tons) of the original resource, as shown graphically in figures 24 and 25. A rock-to-coal ratio of 3:1 or less resulted in a production cost of $4.68 or less per ton and represents about 10 percent (14.1 billion tons) of the original resource as economically recoverable. The amount of economically recoverable coal is significantly smaller at a rock-to-coal ratio of 2:1 or less (equivalent to a production cost of $3.53 or less per ton) and represents only about 5 percent (7.0 billion tons) of the original resource. For a rock-to-coal ratio of 1:1 or less (equivalent to a production cost of $2.70 or less), the amount of economically recoverable coal is estimated to be just over 1 percent (1.7 billion tons) of the original resource.

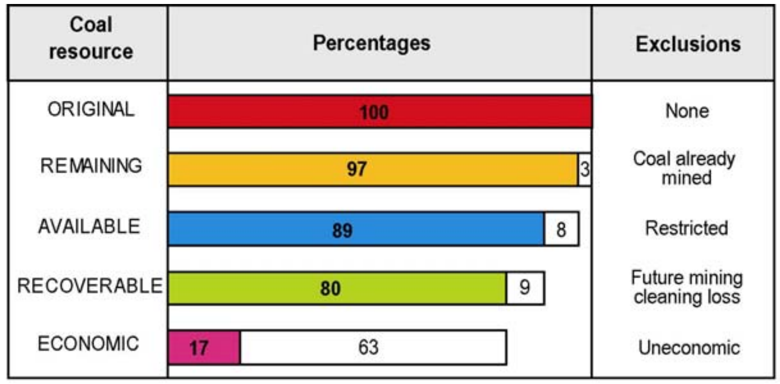

Figure 24. Gillette coal field coal resource analysis results for the five coal mining units combined. Percentages of combined five coal units. Percent of original shownin red, percnt of previous resource category shown in white.

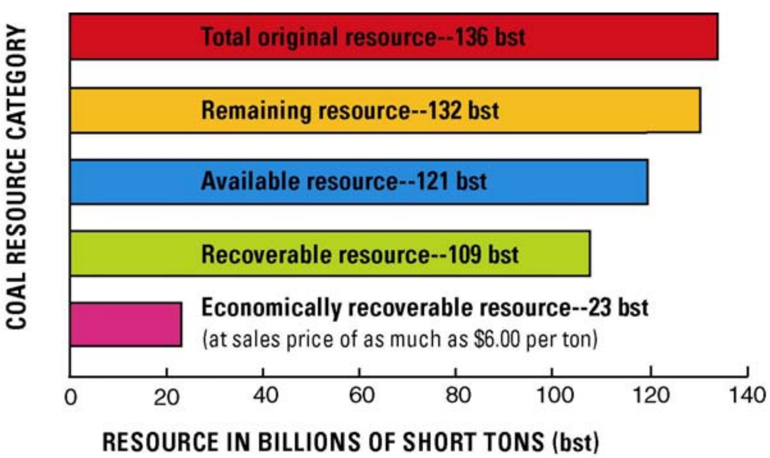

Figure 25 Bar graph showing resources in different resource categories for the combined five coal beds in the Gillette coal field study.

Although coal resources with a rock-to-coal ratio in excess of 4:1 are not presently economically recoverable, significant amounts of additional coal could become profitable in the future if the sales price for the coal increased by just $1.00 per ton. For instance, at a rock-to-coal ratio of 6:1 or less (equivalent to a production cost of $6.91 or less per ton), 44.6 bst (33 percent) of the original coal resource would be economically recoverable.

Table 10 also shows the amount of economically recoverable Federal, State, and private coal at various coal sales-price levels. At a production cost of $6.00 or less per ton (sales price of $6.00), for example, 17 percent (21.3 bst) of the Federal coal, 20 percent (1.3 bst) of the State coal, and 15 percent (0.5 bst) of the private coal within the coal field are economically recoverable.

CONCLUSIONS

Results of the economic assessment of extractable coal resources in the Gillette coal field, Wyoming, indicate that there is a total of 136 billion standard tons of original coal resources for the five coal units assessed (fig. 25). Of these original coal resources, 89 percent (121 bst) of the coal resource is available and 80 percent (109 bst) is recoverable. Most importantly, only 17 percent (23 bst) of the original coal resource is economically recoverable at a sales price of $6.00 a ton. This amount of economic resource would change, depending on changes in current market prices, as shown in table 9.

There are several reasons for the relatively high percentage of available, recoverable, and economically recoverable coal within the Gillette coal field. There are few land-use and technological restrictions—mining in the Gillette coal field occurs in areas that are largely undeveloped and contain few population centers. The area is suited for surface mining because topography is relatively flat, and there are numerous thick, gently dipping, relatively shallow coal beds. The use of large-scale, efficient, surface-mining methods contributes to the significant amount of recoverable and economically recoverable coal. A network of railroad lines already exists to transport coal from the mines.

Several other studies of extractable coal by the U.S. Geological Survey have estimated original, recoverable, and economic coal resources for various areas. Results of recent studies for the Northern Wasatch Plateau coal field of Utah, the Somerset coal field of Colorado, the Bisti coal field of New Mexico (DST and Associates, 2002, personal communication) and the Hilight 7.5-minute quadrangle, which is within the Gillette coal field (Molnia and others, 1999; Osmonson and others, 2000), are shown in figure 26. The Hilight 7.5-minute quadrangle (fig. 4) encompasses about 52 sq mi within the southern part of the Gillette coal field.

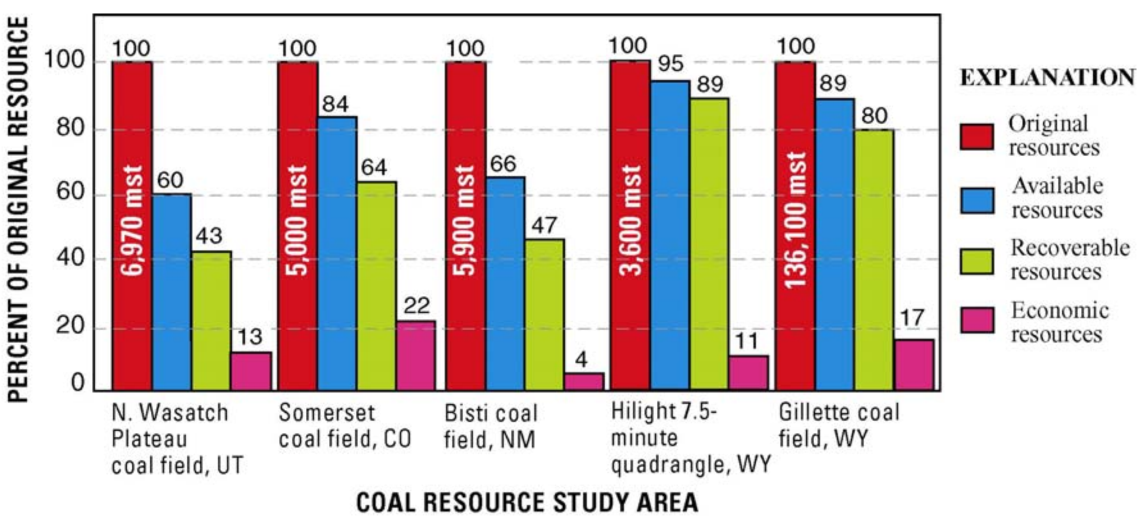

Figure 26. Histogram showing differences in the amounts of original, available, recoverable, and economic coal resources calculated for recent studies by the U.S. Geological Survey (Molnia and others, 1999, Osmonson and others, 2000, DST and Associates, 2002, personal communication).

This study covers the same area as the study by Ellis and others (1999), but a larger stratigraphic interval. Ellis and others (1999) reported a total of 110 bst of coal in the Wyodak-Anderson coal zone within the Gillette coal field, whereas the available resource tonnage (121 bst) in our study includes two additional coal beds and parting material. The available resource tonnage decreases to 112 bst if we exclude the parting material, to more closely match the criteria used by Ellis and others (1999). Our estimate would be even lower had we excluded all coal that is under lease, as did Ellis and others (1999).

Calculations of original and available coal resources add to the general body of knowledge regarding possible energy sources; however, these large coal resource estimates can be misleading. As shown in this report, the coal resource that is economically extractable is significantly less than the original or available coal resources. Additionally, this difference varies from one study area to the next. It is important to consider specific factors that can limit the amount of coal that could be produced within each study area. The calculation of economically extractable coal resources from coal units within specified areas, for different market values, provides useful data to developers and planners to determine the life of energy resources and to make informed land-use decisions.

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