Preliminary Report on Coal Resources of the Wyodak-Anderson Coal Zone, Powder River Basin, Wyoming and Montana

By Margaret S. Ellis, Gregory L. Gunther, Romeo M. Flores, Allan M. Ochs, Gary D. Stricker, Steven B. Roberts, Thomas T. Taber, Lisa R. Bader, and John H. Schuenemeyer

U.S. GEOLOGICAL SURVEY OPEN-FILE REPORT 98-0789-A

Online Edition

Table of Contents

TABLES

ABSTRACT

The National Coal Resource Assessment (NCRA) project by the U.S. Geological Survey is designed to assess US coal with the greatest potential for development in the next 20 to 30 years. Coal in the Wyodak-Anderson (WA) coal zone in the Powder River Basin of Wyoming and Montana is plentiful, clean, and compliant with EPA emissions standards. This coal is considered to be very desirable for development for use in electric power generation.

The purpose of this NCRA study was to compile all available data relating to the Wyodak-Anderson coal, correlate the beds that make up the WA coal zone, create digital files pertaining to the study area and the WA coal, and produce a variety of reports on various aspects of the assessed coal unit. This report contains preliminary calculations of coal resources for the WA coal zone and is one of many products of the NCRA study.

Coal resource calculations in this report were produced using both public and confidential data from many sources. The data was manipulated using a variety of commercially available software programs and several custom programs. A general description of the steps involved in producing the resource calculations is described in this report.

INTRODUCTION

The Powder River Basin is in the central part of the Northern Rocky Mountains and Great Plains Region, in Wyoming and Montana (figure 1). The Wyodak-Anderson coal zone in the Powder River Basin is being studied as part of the U.S. Geological Survey National Coal Resource Assessment, a study of coals with the highest potential for development within the next 20 to 30 years. The assessment is driven by the need for clean compliant energy sources. More than 30% of the Nation's 1997 total coal production of 1.09 billion short tons (EIA, 1998) was produced from 14 Tertiary coal beds and zones in the Northern Rocky Mountains and Great Plains region. Tertiary coals that we are studying within this region are from the Powder River, Williston, Hanna and Carbon Basins, and the Greater Green River Basin (figure 2).

In the northern Rocky Mountain and Great Plains Region, coal production has been from mines primarily in Wyoming, Montana, and North Dakota (figure 3). The highest coal production in the Region is from the Wyoming part of the Powder River Basin, from the Wyodak-Anderson coal zone.

According to figures from the Energy Information Administration (EIA, 1998) the total coal production for 1997 from the Northern Rocky Mountains and Great Plains Region (all coal produced in Wyoming, Montana and North Dakota) was 350 million short tons. Of the total 280 million short tons from Wyoming, 41 million short tons from Montana, and 29 million short tons from North Dakota. Total coal production from Wyoming accounted for approximately 26% of total national coal production for 1997 (EIA, 1998). Based on 1996 consumption rates, the Energy Information Agency projected that most of the low-sulfur and low ash coals in the Nation will be produced from Fort Union Formation coals in the Wyodak-Anderson coal zone.

ACKNOWLEDGMENTS

The authors would like to acknowledge the efforts of agencies and individuals for their contributions to this study. Data were compiled from many different sources. Much of the data was obtained from the U.S. Geological Survey (USGS) National Coal Resources Data System (NCRDS), the Office of Surface Mining, the Bureau of Land Management, the Wyoming Geological Survey, and the Montana Bureau of Mines and Geology. Individual workers who supplied and correlated data for the Wyodak-Anderson coal zone include Daniel Vogler (Wyoming Geological Survey), Edith Wilde (Montana Bureau of Mines and Geology), and Peter Warwick, Ronald Johnson, Frances Wahl Pierce, and Carol Molnia (USGS). Some other agencies and companies supplied information for this study,

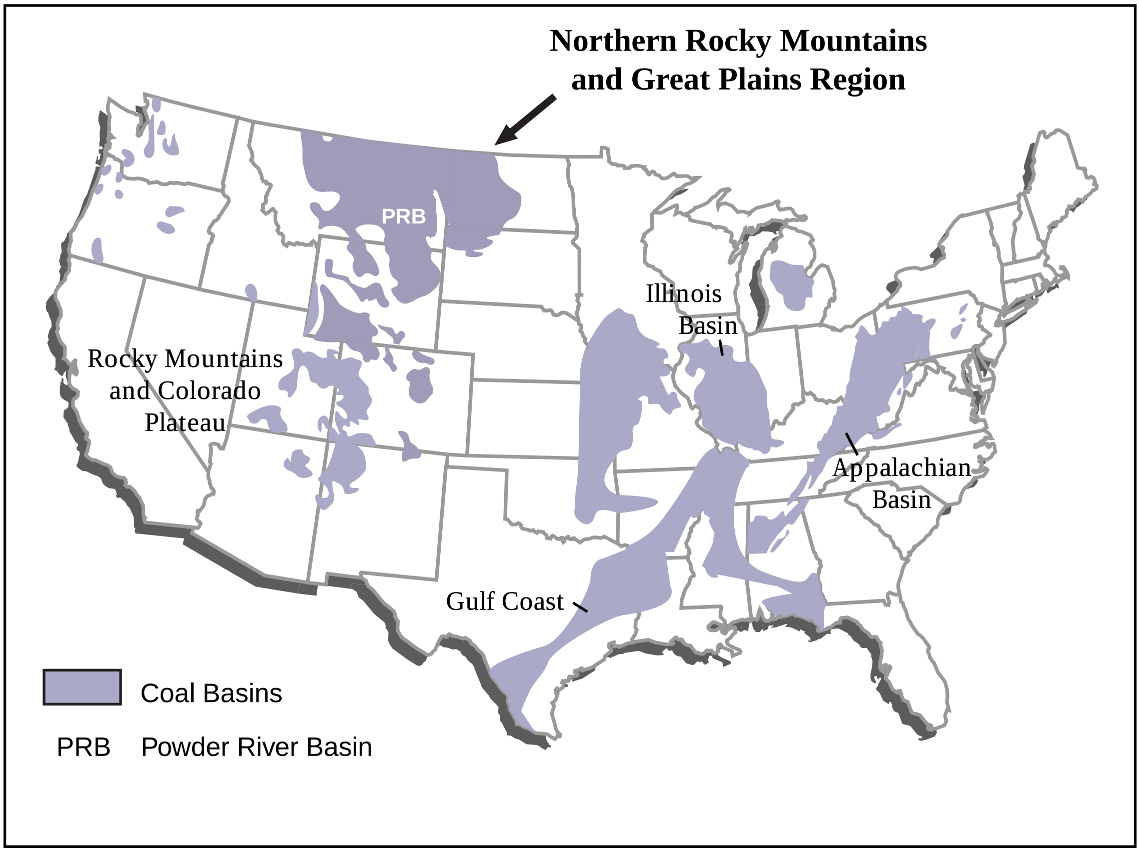

Figure 1. Coal Regions in the National Coal Resource Assessment.

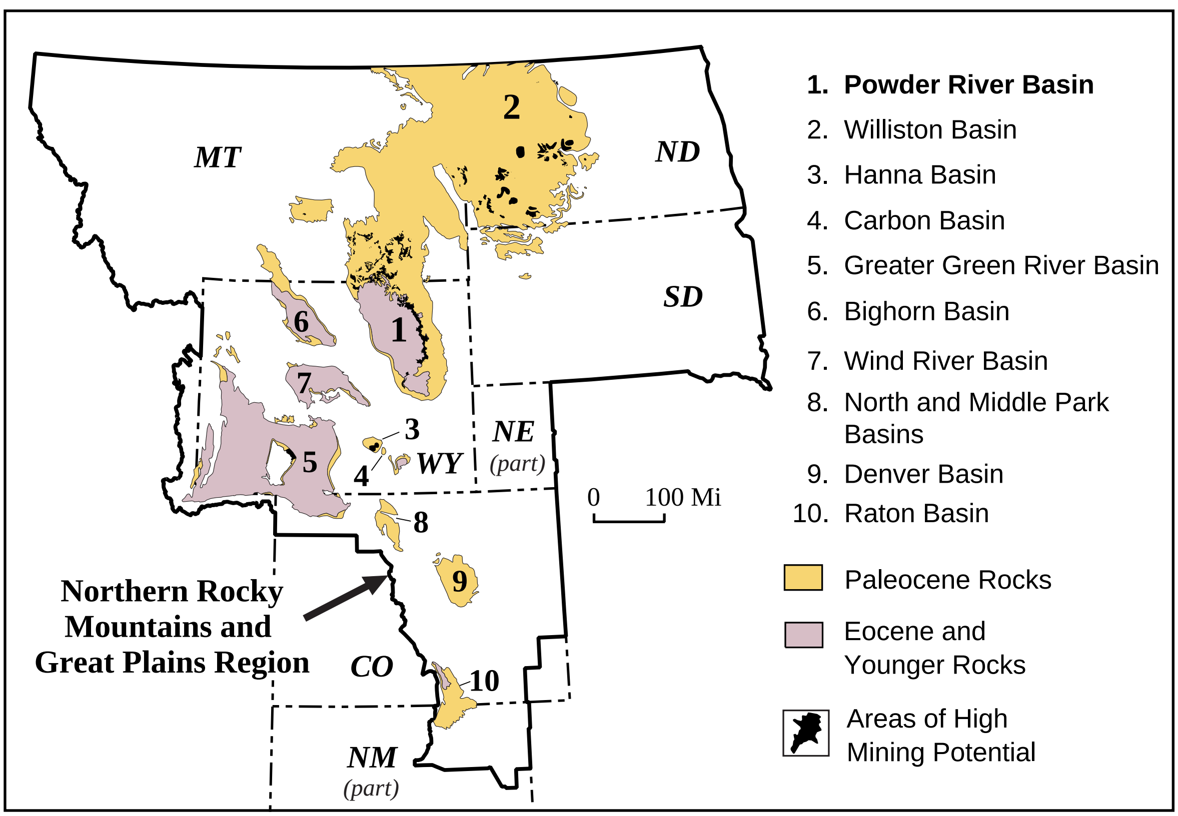

Figure 2. Northern Rocky Mountains and Great Plains Region basemap.

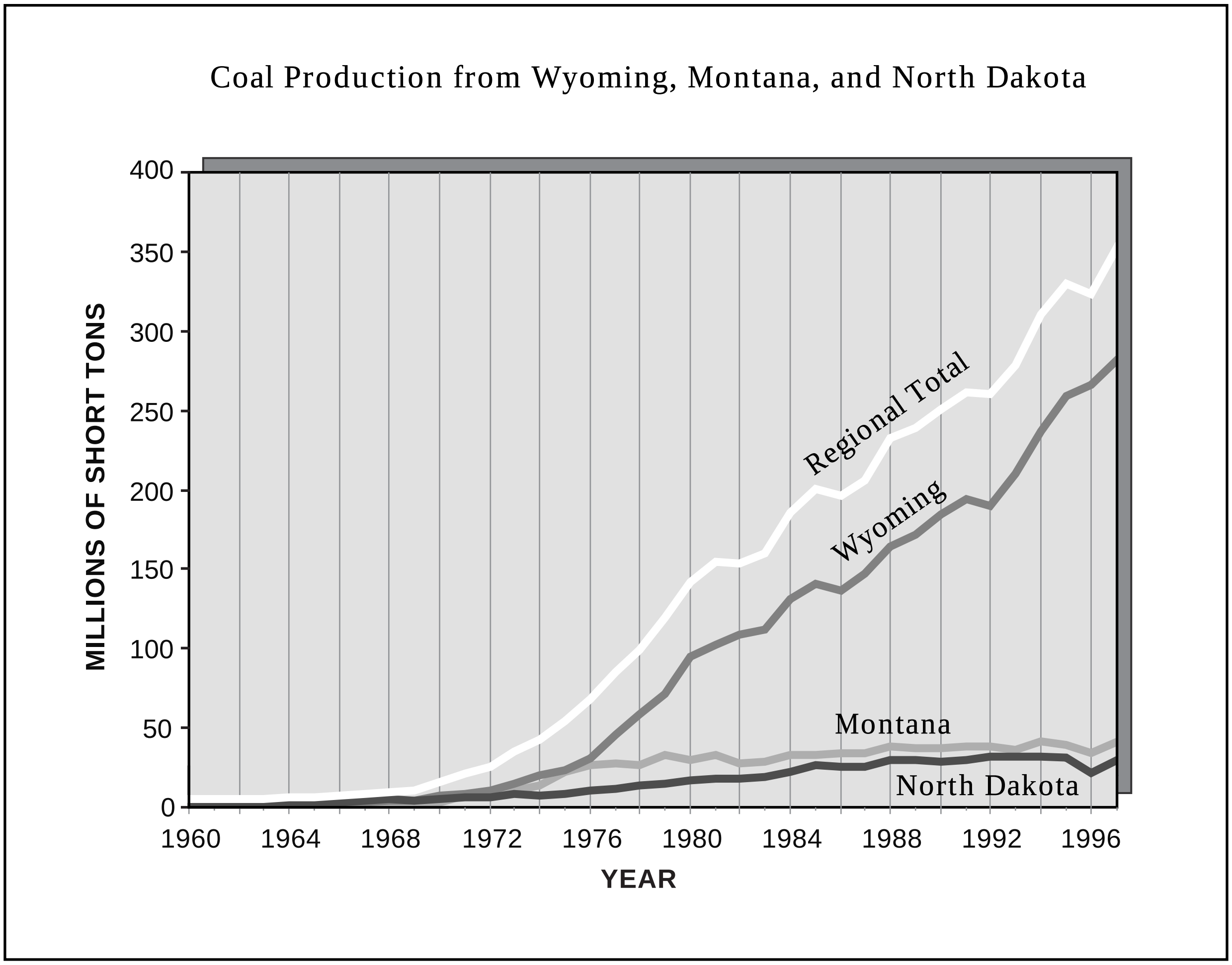

Figure 3. Coal production from 1960 through 1997 from all coal in Wyoming, Montana, and North Dakota. (Data from Energy Information Administration (EIA), 1998).

but regrettably cannot be acknowledged due to the proprietary status of the data. Additional workers that entered data into our data set include Gerald Forney, Timothy Gognat, James Hunsicker, Gregory Rossi, Scott Kinney, and Kathy Yates. In addition to the contributions of Gregory Gunther and Thomas Taber, digital data were also produced by Gregory Rossi, Scott Kinney, and Paul Hagen.

Custom programs used in various steps of the coal resource methodology were written and supplied by Colin Treworgy of the Illinois State Geological Survey, and by Dorsey Blake and Gary Stricker of the U.S. Geological Survey. Finally, we would like to thank Timothy Rohrbacher, Carol Molnia, and Kathy Varnes of the U.S. Geological Survey for their critical review and helpful suggestions to improve this manuscript.

POWDER RIVER BASIN GEOLOGY

The Wyodak-Anderson coals occur in the upper part of the Paleocene Fort Union Formation in the Powder River Basin of Wyoming and Montana. The Fort Union Formation crops out along the margin of the basin, and is overlain by exposures of the Eocene Wasatch Formation in the central part of the basin.

The Powder River Basin is an asymmetrical structural basin with an axis that trends northwest to southeast along the far western part of the basin. Along the western margin of the basin Fort Union rocks dip an average 20-25° to the east, and along the eastern margin of the basin the rocks have an average dip of 2-5° to the west. The Powder River Basin covers more than 12,000 square miles and the Fort Union Formation is more than 6,000 ft thick in the deepest part (axis) of the basin.

The basin is bounded to the west by the Bighorn Uplift, to the southwest and south by the Casper Arch, Laramie Mountains, and Hartville Uplift, and to the east by the Black Hills Uplift. The Miles City Arch and the Cedar Creek Anticline to the north essentially separate the Powder River Basin from the Williston Basin.

DEPOSITIONAL ENVIRONMENTS OF WYODAK-ANDERSON COALS

The Powder River Basin evolved from an open to a partially enclosed structural basin from early to late Paleocene time (Flores, 1986). The basin drained to the northeast through interconnected flow-through fluvial pathways. Early through late Paleocene coal in the Powder River Basin is in the Fort Union Formation and developed in raised mires. Major coal accumulation took place during the late Paleocene. In the late Paleocene, paleoenvironments included converging and diverging drainage patterns, and mire development. The drainage patterns were changed by the influence of meandering, anastomosed and braided streams, and associated floodplain environments. There were extensive accumulations of peat in the late Paleocene (figure 4). These accumulations occurred in peat swamps adjacent to fluvial drainages, and formed the Wyodak-Anderson coals.

The Wyodak-Anderson coal zone contains net coal (total thickness of all coals greater than 2.5 ft thick) that is more than 200 ft thick. The entire zone is more than 600 ft thick (measured from the top of the uppermost coal to the base of the lowermost coal). It consists of as many as six coal beds. The coal beds average 25 ft in thickness, and are separated by clastic sedimentary rocks ranging from a few feet to 150 ft in thickness. The Wyodak-Anderson coal beds merge into a single coal bed as much as 202 ft thick in the west-central part of the basin and as much as 120 ft thick in the eastern part of the basin.

The vertical and lateral stratigraphic variations of the coals in the Powder River are caused by autocyclic depositional processes represented by fluvial channel sandstones and associated flood plain deposits formed adjacent to peat swamps. The coal beds merge, split and pinch out over short distances. Most of the coals formed as thick, discontinuous pod-like coal beds that were split continually by converging and diverging fluvial channels. The west-east trending cross-section in figure

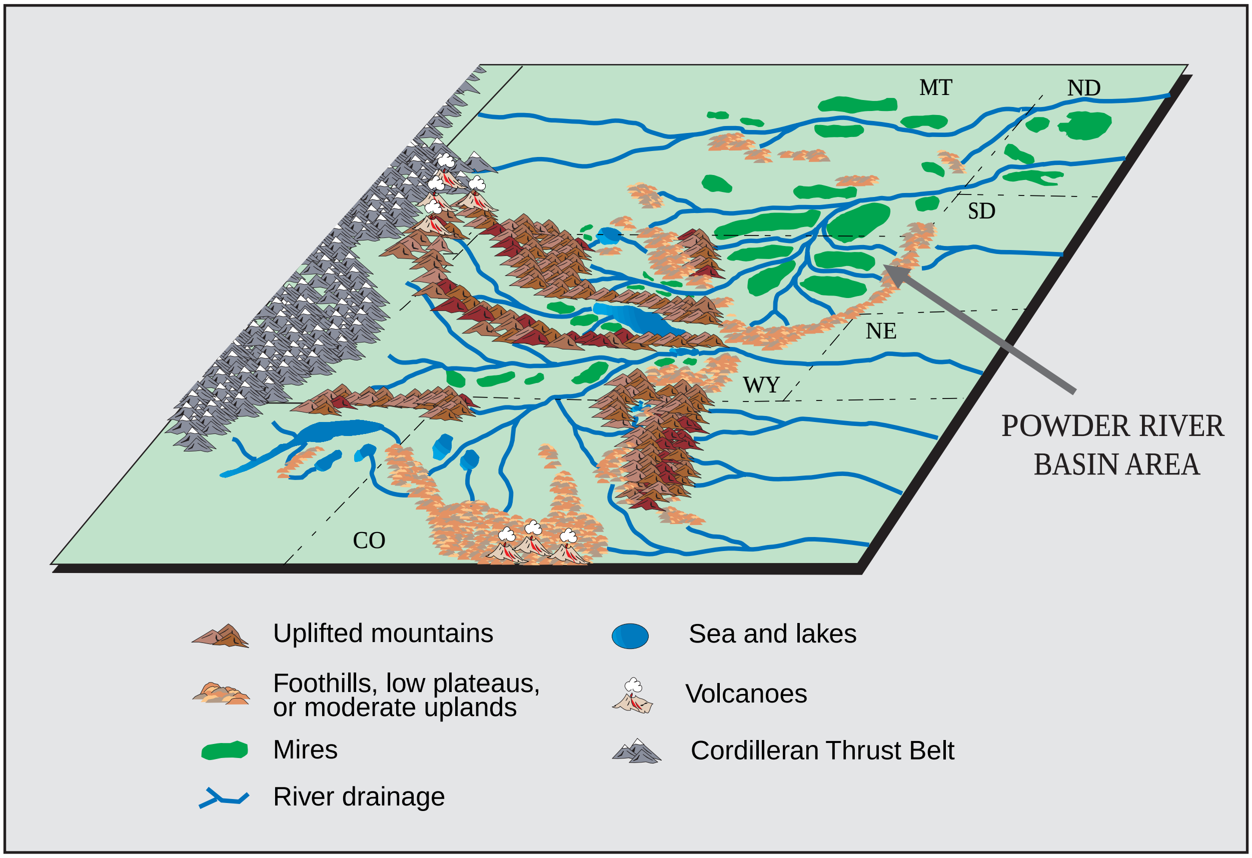

Figure 4. Late Paleocene paleoenvironments. The lateral extent of the upper Fort Union Formation and age equivalent coals are indicated by areas of peat accumulation in raised and low-lying mires, shown in dark green.

5 shows the merging, splitting, and pinching-out of many of the Wyodak-Anderson coal beds. The figure also shows increased thickness of detrital deposits to the west and the cutting of the coal beds by fluvial channel sands. This cross-section is located 13 miles north of Gillette, Wyoming.

Depositional setting controls the thickness and lateral continuity of the Wyodak-Anderson coals. The depositional environments of the Fort Union Formation rocks (Flores, 1986) were mainly fluvial systems consisting of braided, meandering, and anastomosing streams in the basin center and alluvial fans along the western basin margin. Coals accumulated in peat mires or swamps formed as topogenous (low-lying) and raised (domed) bogs in fluvial floodplains, abandoned fluvial channels, and interchannel environments. Thick coals accumulated in raised bogs, well above drainage level, that were sustained by high rainfall in tropical to subtropical (mean annual temperature of 20° C; annual precipitation rate of more than 90.55 in.) climate conditions (Nichols and others, 1989).

WYODAK-ANDERSON COAL QUALITY

Powder River Basin coals are generally considered to be clean and compliant. Arithmetic mean values of the Wyodak-Anderson coal analyses indicate that the coal contains low percentages of ash and total sulfur and is compliant with EPA standards for pounds of SO_2 per million Btu/lb. According to Wood and others (1983) the standard for low ash yield is from 0-8 weight percent, and low total sulfur content is from 0-1 weight percent (on an as-received basis). The current Environmental Protection Agency (EPA) emissions standard, for Phase I compliance is SO_2 less than or equal to 2.5 pounds per million Btu. After the year 2000, the EPA standard for Phase II requires that SO_2 emissions from electrical generation facilities not exceed 1.2 pounds per million Btu.

The Wyodak-Anderson coal beds in the Powder River Basin generally contain less sulfur and ash than coals produced from other regions in the conterminous United States. As part of our resource study, we studied coal quality in the Wyodak-Anderson coal zone using weighted averages, based on the thickness of the coal samples used for the analyses, for each of the coal quality parameters at each data point location. The means of these weighted averages are total sulfur yield of 0.47 weight percent and ash content of 6.4 weight percent (n=300) (table 1). The range of total sulfur in Wyodak-Anderson coal beds is from 0.06 to 2.4 weight percent and the range of ash is from 2.9 to 25 weight percent. Sulfur is reported as the forms of organic, pyritic, and sulfate. Sulfur content varies from 0.06 to 1.2 weight percent for organic sulfur, from 0.01 to 0.77 weight percent for pyritic sulfur, and from 0.01 to 0.39 weight percent for sulfate. The pyritic and sulfate forms are contained in minerals (e.g., pyrite, marcasite, and anhydrite) that occur in cleats or as discrete particles in the coal. The organic form of sulfur is part of the organic structure of the coal macerals.

Pounds of SO_2 per million Btu for the Wyodak-Anderson coals range from 0.14 to 7.9 with a mean of 1.2. By comparison, according to the 1998 CoalDat database (Resource Data International, Inc., 1998), average coal quality of Wyodak-Anderson coal supplied to electrical power plants in 1997 was 5.2 percent ash, 0.32 percent total sulfur, 0.79 pounds of SO_2 per million Btu, and 8,700 Btu/lb.

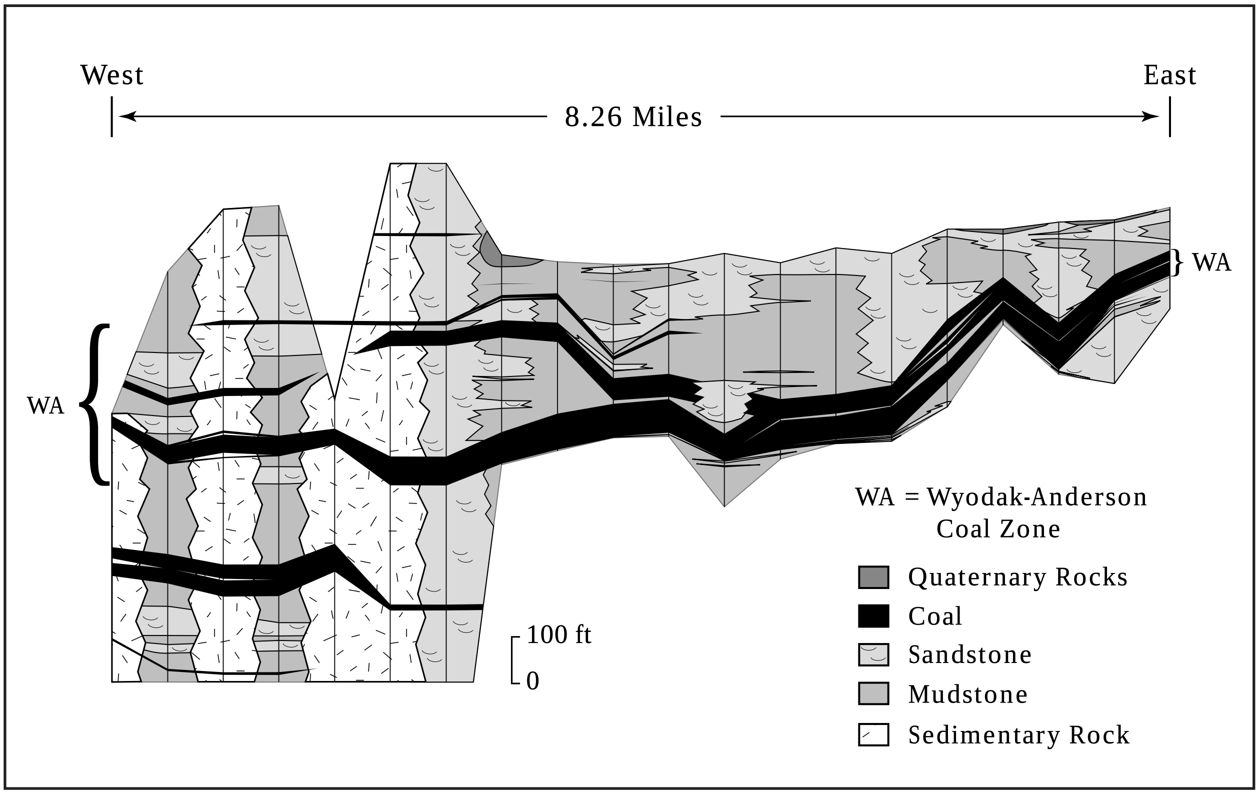

Figure 5. Cross section showing the lateral variation of Wyodak-Anderson coal beds.

Table 1. Wyodak-Anderson coal quality and geochemistry in the Powder River Basin. Statistics were run on our coal quality/geochemistry data set using weighted average values (weighted on bed thickness where several sample analyses were available at a given location). Analyses are on an as-received basis (*= weight percent, $lbSO_2/mmBtu$ = pounds SO_2 per million Btu, and MmmfBtu = moist, mineral-matter free Btu/lb).

POWDER RIVER BASIN, WYODAK-ANDERSON COAL ZONE					
Parameter	Number of Samples (n)	Mean	Minimum	Maximum	Standard Deviation
Gross Calorific Value (Btu/lb)	277	8220	3736	9950	817
Moisture*	300	28	15	42	3.97
Ash*	279	6.4	2.9	25	3.37
Total Sulfur*	279	0.47	0.06	2.4	0.35
$LbSO_2/mmBtu$	277	1.2	0.14	7.9	1.09
MmmfBtu	277	8819	4576	10563	745
Volatile Matter*	105	30.1	24	36	2.03
Fixed Carbon*	105	36	20.3	45	3.77
Organic Sulfur*	71	0.25	0.060	1.2	0.16
Pyritic Sulfur*	67	0.10	0.010	0.77	0.13
Sulfate*	58	0.040	0.010	0.39	0.07

PREVIOUS STUDIES OF COAL RESOURCES IN THE POWDER RIVER BASIN

There have been a number of publications that included coal assessment and coal resource calculations for coals in the Powder River Basin, Wyoming and Montana. Several of the publications consisted of general geologic studies of the basin area that included either coal resource tonnages in tables, or showed the distribution of coal resources by state, basin, or strippable coal status. These publications include Averitt (1975), Berryhill and others (1950), Combo and others (1949, 1978), and Smith and others (1972).

A number of publications report coal resources for all coals in the Powder River Basin. Gary Glass (1997) sites several sources for coal resource calculations. He reports that the remaining identified resources in the Powder River Basin are 110 billion short tons (modified from Berryhill, and others, 1950) with identified resources that include coal that is >2.5 ft in thickness and under less than 3000 ft of overburden. To further refine this number, he reports a reserve base of 45.5 billion short tons of coal in the Powder River Basin, Wyoming. Of this total, 22.6 billion were deemed to be recoverable through underground mining, and 22.9 billion short tons were considered surface minable. In that report the reserve base for all coal in Wyoming is reported at 55.9 billion short tons. Richard Jones and Gary Glass (1991) reported demonstrated reserves of strippable coal in the Powder River Basin in Wyoming as 23.7 billion short tons. In a more detailed study, Smith and others (1966) (Glass, 1996) reported 17.5 billion short tons of strippable Wyodak coal in the Wyoming portion of the Powder River Basin.

Additional detailed studies of coal resources in the area of the Powder River Basin include a series of 243 7.5-minute quadrangle map studies of coal resources for non-leased Federal coal. These reports were produced as part of a CRO/CDP (Coal Resource Occurrence/Coal Development Potential) project by the U.S. Geological Survey. This series of maps, authored by many different workers, is referenced and synopsized in Trent (1986) and in Roberts (1998). Other more specific studies include those by Ayers (1986), Barnum (1975), Culbertson and others (1978), Glenn (1979), Mapel (1959), and Molnia and others (1997). These publications are valuable sources of information on coal resources in the Powder River Basin. They report coal resource calculations for areas that range from a single 7.5-minute quadrangle to portions of 24 7.5-minute quadrangles.

In this study, we have drawn information from both published and unpublished sources to provide information on the coal resources for all of the coal beds in they Wyodak-Anderson coal zone throughout the Powder River Basin study area. The study provides an overview of this assessment unit and a consistently correlated data set for the basin area that is available for future investigations.

NATIONAL COAL RESOURCE ASSESSMENT UNITS

In each of the Tertiary basins studied for the National Coal Resource Assessment (NCRA) there are from 1 to 3 study areas containing coals that were studied as assessment units. Assessment units consist either as distinct individual beds, or as related coal beds that have been combined and studied as coal zones. The assessment units for the Northern Rocky Mountains and Great Plains Region are shown in figure 6. This figure shows the relative age of the coals (the time of peat accumulation) with age correlation based on palynological biozone analyses by Doug Nichols of the U.S. Geological Survey (Stricker and others, 1998 and Flores and others, 1996).

The major assessment unit for our study of the coals in the Powder River Basin is the Late Paleocene Wyodak-Anderson coal and stratigraphically equivalent coal beds. This unit is referred to as the Wyodak-Anderson coal zone. Due to the vertical and lateral stratigraphic variations of coal beds within the Wyodak-Anderson coals it was determined that the assessment of individual beds was impractical. Coal beds included in the zone are (from north to south) the Anderson, Dietz, Canyon, Smith, Swartz, Werner, Wyodak, Sussex, School, and Badger. The coals being assessed consisted of from 1 to 6 beds at each data point location. The data set that we compiled consists of approximately 6,200 data points.

In addition to the regional study of Wyodak-Anderson coals in the Powder River Basin, local studies of the Wyodak-Anderson coals in the Sheridan and Gillette coal fields in Wyoming are also being conducted by the authors. National Coal Resource Assessment studies in the Montana part of the Powder River Basin are being conducted by Steven B. Roberts. These studies include the Anderson-Canyon coal in the Decker coal field, which is included in the Wyodak-Anderson coal zone; the Rosebud-Robinson coal in the Colstrip coal field; and the Knobloch coal in the Ashland coal field.

METHODOLOGY

Overview

The general procedure for our study consisted of a number of crucial steps. The first step was to define the coal unit to be assessed and determine the lateral extent of the coal. Next we established coal resource reporting categories so that we knew what data were essential to be included in our data sets. We then compiled and correlated the lithologic data for the rock and the coal beds in our coal zone. The correlated data were edited and downloaded from our relational database. These data were modified to produce an ASCII file for use in creating coal thickness and overburden grids, and isopach maps. Maps of coal thickness and overburden were then combined with other layers of

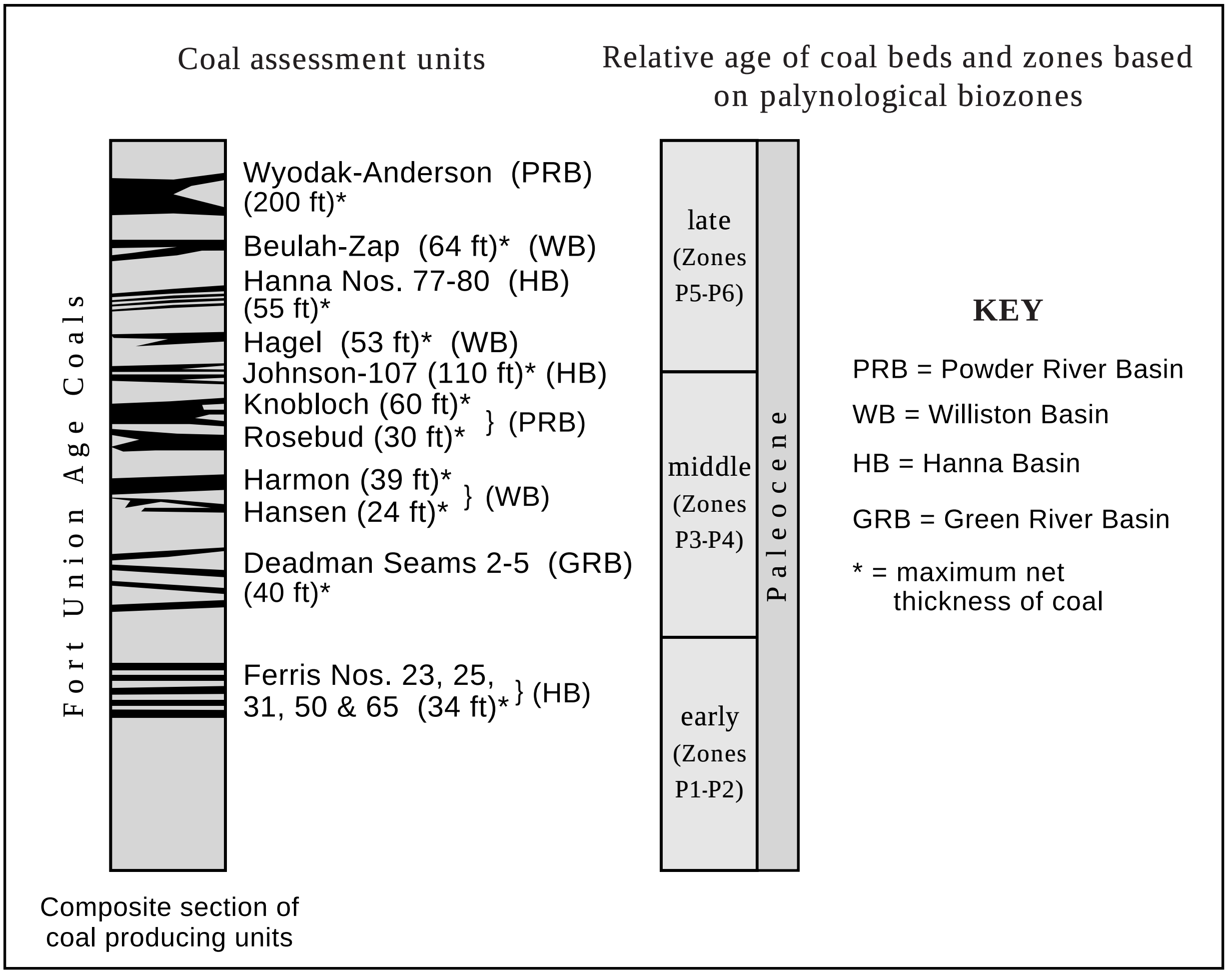

Figure 6. Relative age correlation of coal assessment units in the Northern Rocky Mountains and Great Plains Region.

spatial data containing information needed for creating coal resource reports. The digital file (polygon union coverage) containing all of the necessary information was used in conjunction with the coal thickness grid information to calculate the tonnage of coal resources in each polygon. The information from the volumetrics report was combined with the attributes from the union coverage and resource tables were created for different reporting parameters.

Resource Reporting Categories

Standardized reporting criteria were mandated for the National Coal Resource Assessment. Mandatory and optional reporting categories have been established in U.S. Geological Survey Circular 891 (Wood and others, 1983). The following reporting categories are mandatory for reporting coal resources for surface minable lignite and subbituminous coal:

1. Overburden thickness of 0-100 ft, 100-200 ft, 200-500 ft, and >500 ft;
2. Net coal thickness of 2.5-5 ft, 5-10 ft, 10-20 ft, 20-40 ft, and >40 ft;
3. Reliability categories (areas based on distance from a data point) of measured (0-1/4 mi), indicated (1/4-3/4 mi), inferred (3/4-3 mi), and hypothetical (>3 mi).

Additional coal resource reporting categories used in this study are state, county, 7.5-minute quadrangle map, and Federal coal and surface ownership.

Defining the Assessment Unit and Correlating Stratigraphy

The Wyodak-Anderson assessment unit is a coal zone. Beds included in the zone (from north to south) are the Anderson, Dietz, Canyon, Smith, Schwartz, Werner, Wyodak, Sussex, School, and Badger (table 2) The coal zone extends from the top of the uppermost coal bed to the base of the lowermost coal bed. The total thickness of the coal zone includes the rock within the interval. The net coal thickness in the zone is the sum of all of the coal beds greater than or equal to 2.5 ft thick.

For consistency of stratigraphic correlations, a stratigraphic column was prepared establishing nomenclature for the coal zone and for the rocks above and below the zone. The standardized stratigraphic column was used for editing and labeling spreadsheet data, and for establishing the organization of stratigraphic units in our relational database. Information from the standardized stratigraphic column was entered in the relational database and used to define primary zones and sub-zones.

Table 2. Stratigraphic column showing nomenclature used for the correlation of the Wyodak-Anderson coal zone. The relative age and approximate stratigraphic relationships of the coal beds are shown. The boxes for the coal beds are not proportional.

<table>
<tr><th rowspan="2">Age</th><th rowspan="2">Formation</th><th rowspan="2">StratiFact Nomenclature</th><th>Northwest</th><th>Northeast and north-central</th><th>East</th><th>South</th></tr>
<tr><th colspan="4">Coal Bed Names</th></tr>
<tr><td>Eocene</td><td>Wasatch Formation</td><td rowspan="2">Above Wyodak-Anderson coal zone</td><td colspan="4" rowspan="2"></td></tr>
<tr><td rowspan="7">Late Paleocene</td><td>Wasatch-Fort Union?</td></tr>
<tr><td rowspan="5">upper Fort Union Formation (Tfu)</td><td rowspan="5">Wyodak-Anderson coal zone</td><td></td><td>Smith (WY) Swartz</td><td rowspan="5">Wyodak-Anderson</td><td>Badger</td></tr>
<tr><td>Anderson (Dietz 1)</td><td>Anderson</td><td>School</td></tr>
<tr><td>Dietz 2
Dietz 3</td><td></td><td rowspan="3"></td></tr>
<tr><td rowspan="2">Canyon (Monarch)</td><td>Canyon</td></tr>
<tr><td>Werner (WY)</td></tr>
<tr><td>Tfu undifferentiated</td><td>Below Wyodak-Anderson coal zone</td><td colspan="4"></td></tr>
</table>

Compiling and Correlating the Data

The study began with the compilation of all stratigraphic and geochemical data for the assessment unit. Sources of the data included federal and state agencies (e.g., U.S. Geological Survey, Bureau of Land Management, Office of Surface Mining, State geological surveys, and State Departments of Environmental Quality), industry (mining companies), and private (individual geologists) sources. Much of the industry and private data are proprietary and will not be released to the public. Some of the data acquired existed on computer files in spreadsheet format, however, much of the data had to be hand entered from paper copy onto spreadsheets using commercially available computer software.

Information on the spreadsheets was checked, edited, and supplemented to conform to standardized column names and data entries. As the data sets from various sources were completed, the files were loaded into our relational database (StratiFact (GRG Corp., 1996)). In the relational database, standardized stratigraphic nomenclature was used to define the top and base of the coal zone, and the units above and below the zone at each data point throughout the study area. Standardized lithologic nomenclature was also established and applied to the rock and coal units in the data set. The final Powder River Basin data set contains 6,216 data points, of these 3,013 points are from oil and gas exploratory drilling, 3,178 are from coal exploratory drilling, and 25 points are measured sections. The Wyodak-Anderson data set contains 5,169 data point locations that contain Wyodak-Anderson coal, 897 of which contain confidential information.

When the data set was in its final form we downloaded selected information from StratiFact in ASCII format. The data dump consisted of one line of data for each coal unit within the coal zone.

There were therefore, multiple entries at each data point location. Data included; point ID, sequence number, drill hole depth, surface elevation, depth to the top of the uppermost coal, depth to the base of the lowermost coal, elevation of the top of the coal, elevation of the base of the coal, coal thickness, decimal latitude, and decimal longitude. The downloaded information also included two rows of information that synopsize the information for just the coal in the zone (ZY) and for all of coal zone (ZZ). An example of the data included in the ASCII file for one data point location is shown in table 3.

Table 3. StratiFact data output. The table shows sample StratiFact output for one location, WT108, from the Powder River Basin, Wyoming. The entry for the ZY sequence number represents the coal data only, and the entry for the ZZ sequence number represents the data for the entire coal zone.

DBS Number	Point ID	Sequence Number	Drill Hole Depth	Surface Elevation (ft)	Top Depth (ft)	Bottom Depth (ft)	Top Elevation (ft)	Bottom Elevation (ft)	Coal Thickness (ft)	Latitude (decimal degrees)	Longitude (decimal degrees)
036I	WT108	01	430.0	4146.0	28.0	32.0	4118.0	4114.0	4.0	44.8257	105.5934
036I	WT108	02	430.0	4146.0	36.0	58.0	4110.0	4088.0	22.0	44.8257	105.5934
036I	WT108	03	430.0	4146.0	219.0	221.0	3927.0	3925.0	2.0	44.8257	105.5934
036I	WT108	04	430.0	4146.0	224.0	234.0	3922.0	3912.0	10.0	44.8257	105.5934
036I	WT108	05	430.0	4146.0	304.0	322.0	3842.0	3824.0	18.0	44.8257	105.5934
036I	WT108	06	430.0	4146.0	400.0	403.0	3746.0	3743.0	3.0	44.8257	105.5934
036I	WT108	ZY	430.0	4146.0	28.0	403.0	4118.0	3743.0	59.0	44.8257	105.5934
036I	WT108	ZZ	430.0	4146.0	28.0	403.0	4118.0	3743.0	375.0	44.8257	105.5934

Preparing Data for Computer Modeling

The StratiFact data dump is used as input for a parting/split computer program, which modifies the data so that it consists of one line of data for each data point location. The program determines whether a rock unit between two coal units is a parting in a coal bed or if the rock unit splits two separate coal beds, as defined by Wood and others (1983, p. 36). This information is important when summing the net coal thickness of the coal. Coal units are combined to form a single coal bed if the thickness of rock between them is thinner than the coal on either side. If the rock is thinner it is considered to be a parting and if it is thicker it is considered to be a split. After the program calculates the thickness of coal in each coal bed it must determine if the coal beds are greater than minimum thickness requirement for calculating coal resources, which is 2.5 ft for lignite and subbituminous coal (Wood and others, 1983, p. 34). Data is interpreted by the program as shown in table 4, which represents an intermediate step in the program processing.

Table 4. Internal matrix showing the interpretation of our data using the parting/split program. It calculates rock thickness between coals and determines whether the rock unit is a parting in the coal or if it splits two coal beds.

Point ID	Drill Hole Depth	Surface Elevation (ft)	Top Depth (ft)	Base Depth (ft)	Top Elevation (ft)	Base Elevation (ft)	Unit Thickness (ft)	Latitude (decimal degrees)	Longitude (decimal degrees)	Lithology Type	Parting or Split
WT108	430.0	4146.0	28.0	32.0	4118.0	4114.0	4.0	44.8257	105.5934	Coal	
WT108	430.0	4146.0	32.0	36.0	4114.0	4110.0	4.0	44.8257	105.5934	Rock	Parting
WT108	430.0	4146.0	36.0	58.0	4110.0	4088.0	22.0	44.8257	105.5934	Coal	
WT108	430.0	4146.0	58.0	219.0	4088.0	3927.0	161.0	44.8257	105.5934	Rock	Split
WT108	430.0	4146.0	219.0	221.0	3927.0	3925.0	2.0	44.8257	105.5934	Coal	
WT108	430.0	4146.0	221.0	224.0	3925.0	3922.0	3.0	44.8257	105.5934	Rock	Split
WT108	430.0	4146.0	224.0	234.0	3922.0	3912.0	10.0	44.8257	105.5934	Coal	
WT108	430.0	4146.0	234.0	304.0	3912.0	3842.0	70.0	44.8257	105.5934	Rock	Split
WT108	430.0	4146.0	304.0	322.0	3842.0	3824.0	18.0	44.8257	105.5934	Coal	
WT108	430.0	4146.0	322.0	400.0	3824.0	3746.0	78.0	44.8257	105.5934	Rock	Split
WT108	430.0	4146.0	400.0	403.0	3746.0	3743.0	3.0	44.8257	105.5934	Coal	

To determine the net coal thickness for the coal at a single location the parting/split program sums coal bed thickness of only the coal beds that are greater than minimum coal thickness requirements. The program outputs a single line of data for each location with net coal thickness and location parameters. Also included in the data output is the number of coal beds that were utilized in calculating the net coal thickness. Figure 7 and table 5 show how the program interpreted the original data, and the output for data point WT108.

A negative sign is assigned to the coal thickness if the drill hole was prematurely terminated. The drill hole was inferred to be terminated if the base of the final unit is equal to the total depth of the drill hole, indicating that the data may not be complete for the entire coal zone. A negative sign on the net coal thickness allows for special handling within the isopach gridding option in EarthVision (Dynamic Graphics, Inc., 1997). The example shown in table 5 is not a terminated drill hole.

Table 5. Example of data output file from parting/split program for data point WT108.

Point ID	Drill Hole Depth (ft)	Surface Elevation (ft)	Top Coal Depth (ft)	Bottom Coal Depth (ft)	Top Coal Elevation (ft)	Bottom Coal Elevation (ft)	Original Coal Thickness (ft)	Latitude (decimal degrees)	Longitud e (decimal degrees)	Calculated Net Coal Thickness (ft)	Number of Coal Beds
WT108	430.0	4146.0	28.0	403.0	4118.0	3743.0	59.0	44.8257	105.5934	57.0	5

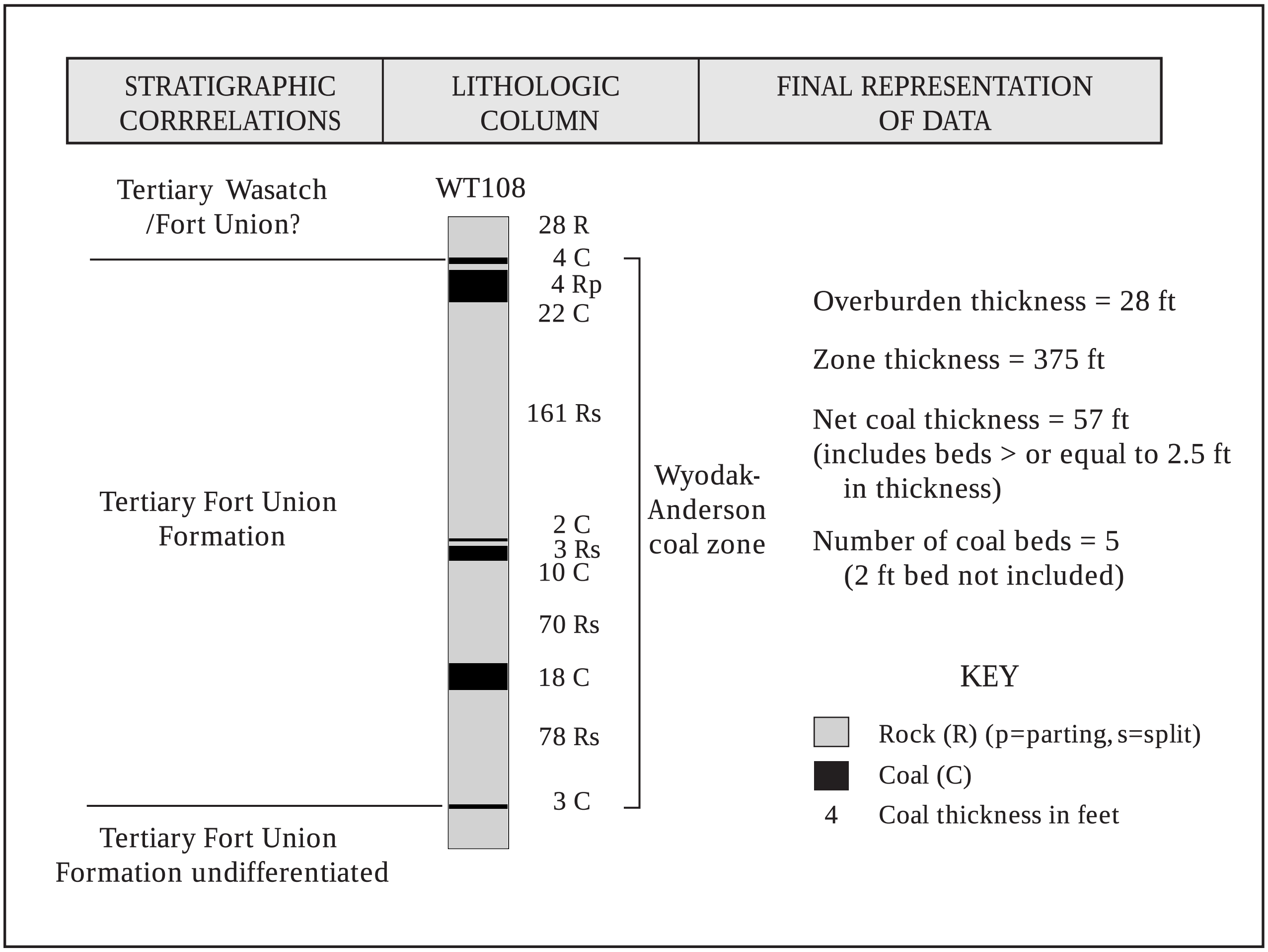

Figure 7. Graphic showing the interpretation of Stratifact data to be used for computer modeling.

Creating Layered Spatial Data (ARC/INFO coverages)

To calculate coal resources using computerized methods, a number of computer software programs were used. For our study we created and managed layered spatial information using ARC/INFO (ESRI, 1998), ArcView (ESRI, 1998), and EarthVision (Dynamic Graphics, Inc., 1997) software. All of the layers of information were created as ARC/INFO point or polygon coverages and were limited to a lateral extent just outside of the Powder River Basin area.

For the study of the Wyodak-Anderson coal zone the coverages are in Lambert Conformal Conic projection, Clark 1866, with first standard parallel of 33 degrees, second standard parallel of 45 degrees, and Central Meridian of 106 degrees (the approximate center of the Powder River Basin). We used an origin for the projection of 0 degrees and false northing and false easting of 0. The projection parameters used were selected considering the scale at which the information would be displayed and the lateral extent of the digital information. The layers of data used for the resource study include: State boundaries, counties, the Powder River Basin boundary defined by the contact of Tertiary and Cretaceous age rocks (Ross and others, 1955, and Love and Christiansen, 1985), tribal lands for the Northern Cheyenne and Crow Indian Reservations (Biewick and others, 1998), areas of mapped Wyodak-Anderson clinker (Boyd and Van Ploeg, 1997, Heffern and others, 1993, Heffern, 1998, and Kanizay, 1978), and Wyodak-Anderson mine and lease boundaries, shown in figure 8; the Wyodak-Anderson study limit defined by the lateral extent of the Wyodak-Anderson coal and 7.5-minute quadrangles maps in the study area, shown in figure 9 and indexed in tables 6 and 7; point locations and reliability categories, (public data only) shown in figure 10; Federal coal and surface ownership (Biewick and others, 1997) shown in figure 11; net coal thickness, shown in figure 12; digital elevation model (DEM), represented by a shaded relief map shown in figure 13; and overburden isopach map, shown in figure 14. Additional information on the spatial data (coverages) used for the Wyodak-Anderson study can be found in Ellis and others (in press).

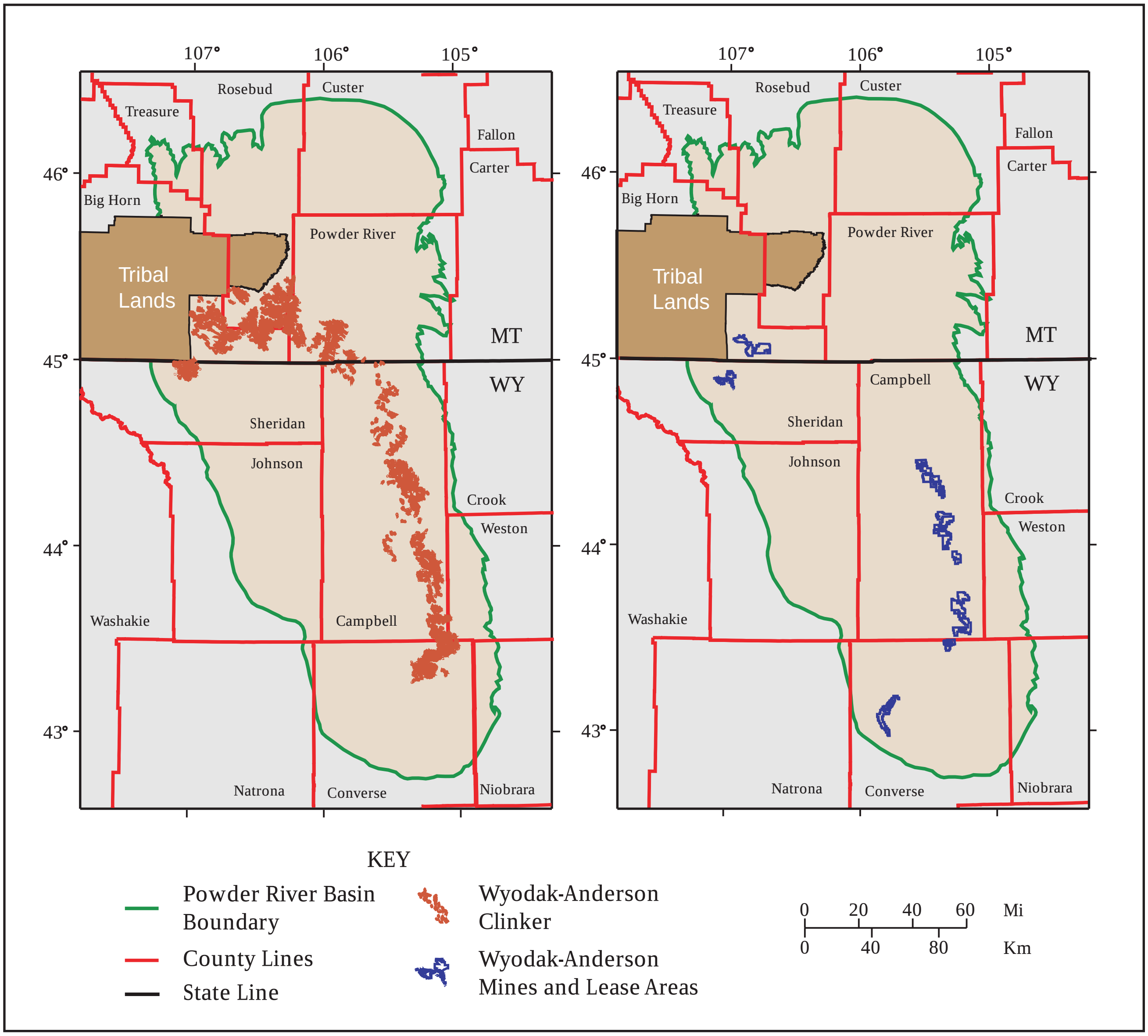

Figure 8. Graphic showing information from coverages of the Montana/Wyoming state boundary, counties, the Powder River Basin boundary, tribal lands, clinker, and mine and lease boundaries. The mines shown are only those that contain Wyodak-Anderson coal.

Table 6. Numeric key to 7.5-minute quadrangle maps in the study area. Locations are shown in figure 9 and coal resources are reported by 7.5-minute quadrangle in table 11.

Number	7.5-minute Quadrangle Map	Number	7.5-minute Quadrangle Map
1	COOK CREEK BUTTE	57	HOMESTEAD DRAW
2	CLUBFOOT CREEK	58	ROCKY BUTTE
3	BIRNEY DAY SCHOOL	59	HULTZ DRAW
4	GREEN CREEK	60	SHERIDAN
5	KING MOUNTAIN	61	WYARNO
6	THREEMILE BUTTES	62	JONES DRAW
7	SONNETTE	63	S R SPRINGS
8	SPRING CREEK RANCH	64	SHULER DRAW
9	KIRBY	65	GARDNER GULCH
10	TAINTOR DESERT	66	FAWN DRAW
11	BIRNEY SW	67	CABIN CREEK SE
12	BIRNEY	68	KLINE DRAW
13	BROWNS MOUNTAIN	69	RESERVOIR CREEK
14	POKER JIM BUTTE	70	HOMESTEAD DRAW SW
15	FORT HOWES	71	WHITE TAIL BUTTE
16	GOODSPEED BUTTE	72	ROCKY BUTTE SW
17	PHILLIPS BUTTE	73	BEAVER CREEK HILLS
18	HODSDON FLATS	74	BIG HORN
19	BAR V RANCH NE	75	BUFFALO RUN CREEK
20	HALF MOON HILL	76	VERONA
21	TONGUE RIVER DAM	77	ULM
22	SPRING GULCH	78	CLEARMONT
23	LACEY GULCH	79	LEITER
24	STROUD CREEK	80	ARVADA
25	HAMILTON DRAW	81	ARVADA NE
26	OTTER	82	LAREY DRAW
27	REANUS CONE	83	SPOTTED HORSE
28	SAYLE	84	RECLUSE
29	BLOOM CREEK	85	PITCH DRAW
30	LITTLE BEAR CREEK	86	OLIVER DRAW
31	BAR V RANCH	87	STORY
32	PEARL SCHOOL	88	BANNER
33	DECKER	89	HORSE HILL
34	HOLMES RANCH	90	UCROSS
35	PINE BUTTE SCHOOL	91	JULIO DRAW
36	FORKS RANCH	92	ARPAN BUTTE
37	QUIETUS	93	JEWELL DRAW
38	BEAR CREEK SCHOOL	94	LARIAT
39	SAYLE HALL	95	CROTON
40	BRADSHAW CREEK	96	TRUMAN DRAW
41	MOORHEAD	97	WILDCAT
42	THREE BAR RANCH	98	CALF CREEK
43	BAY HORSE	99	WESTON SW
44	RANCHESTER	100	STONE MOUNTAIN
45	MONARCH	101	LAKE DE SMET WEST
46	ACME	102	LAKE DE SMET EAST
47	BAR N DRAW	103	BUFFALO NE
48	CEDAR CANYON	104	FREDRICK DRAW
49	O T O RANCH	105	FLOATE DRAW
50	ROUNDUP DRAW	106	MITCHELL DRAW
51	BOX ELDER DRAW	107	LIVINGSTON DRAW
52	CABIN CREEK NW	108	ECHETA
53	CABIN CREEK NE	109	TWENTYMILE BUTTE
54	BLACK DRAW	110	ORIVA NW
55	DEAD HORSE LAKE	111	RAWHIDE SCHOOL
56	CORRAL CREEK	112	MOYER SPRINGS

Table 6. Continued.

Number	7.5-minute Quadrangle Map	Number	7.5-minute Quadrangle Map
113	NORTH RIDGE	171	GREASEWOOD RESERVOIR
114	BUFFALO	172	ROCKY BUTTE GULCH
115	BUFFALO SE	173	RENO JUNCTION
116	PINE GULCH	174	HILIGHT
117	BEAR DRAW	175	OPEN A RANCH
118	SOMERVILLE FLATS WEST	176	KAYCEE NE
119	SOMERVILLE FLATS EAST	177	FIGURE 8 RESERVOIR
120	CARR DRAW	178	SUSSEX
121	JEFFERS DRAW	179	HOUSE CREEK
122	ORIVA	180	DRY FORK RANCH
123	GILLETTE WEST	181	ROLLING PIN RANCH
124	GILLETTE EAST	182	SOUTH BUTTE
125	FORTIN DRAW	183	BAKER SPRING
126	KLONDIKE RANCH	184	RATTLESNAKE DRAW
127	T A RANCH	185	LITTLE THUNDER RESERVOIR
128	TA RANCH NE	186	RENO RESERVOIR
129	CRAZY WOMAN RANCH	187	PINEY CANYON NW
130	PLOESSERS DRAW	188	LINCH
131	JUNIPER DRAW	189	TAYLOR RANCH
132	LASKIE DRAW	190	ARTESIAN DRAW
133	MORGAN DRAW	191	PINE TREE
134	SCOTT DAM	192	TURNERCREST
135	FOUR BAR J RANCH	193	RENO FLATS
136	APPEL BUTTE	194	TECKLA SW
137	THE GAP	195	TECKLA
138	COYOTE DRAW	196	PINEY CANYON SW
139	COON TRACK CREEK	197	SAWMILL CANYON
140	PURDY RESERVOIR	198	ROSS
141	TRABING	199	ROSS FLAT
142	BROWN RANCH	200	MACKEN DRAW
143	BOON	201	COAL DRAW NORTH
144	BOWMAN FLAT	202	BETTY RESERVOIR
145	NEGRO BUTTE	203	DUGOUT CREEK NORTH
146	BOGIE DRAW	204	COAL BANK DRAW
147	DOUBLE TANKS	205	GILLAM DRAW EAST
148	PLEASANTDALE	206	MARSH DRAW
149	SCAPER RESERVOIR	207	THOMPSON DRAW
150	THE GAP SW	208	BEAR CREEK
151	SADDLE HORSE BUTTE	209	COAL DRAW SOUTH
152	ANTELOPE DRAW	210	ALTA CREEK
153	ELAINE DRAW	211	DUGOUT CREEK SOUTH
154	PROVENCE RANCH	212	SEVEN L CREEK EAST
155	HOE RANCH	213	FLY DRAW
156	THE NIPPLE	214	SOUTH FORK RESERVOIR
157	FATS DRAW	215	SUICIDE HILL
158	WAGS PINNACLE	216	RED HILL
159	PEPSSON DRAW	217	PATSY DRAW
160	THREEMILE CREEK RESERVOIR	218	BEAUCHAMP RESERVOIR
161	EAGLE ROCK	219	GUMBO HILL
162	NEIL BUTTE	220	COAL HILL
163	ROUGH CREEK	221	HOLDUP HOLLOW
164	DRY CREEK RESERVOIR	222	WHIPPLE HOLLOW
165	FOURMILE RESERVOIR	223	BOBBY DRAW
166	SOLDIER CREEK	224	GLENROCK NW
167	FORT RENO	225	HYLTON RANCH
168	FORT RENO SE	226	LEUENBERGER RANCH
169	NORTH BUTTE	227	GILBERT LAKE
170	SAVAGETON		

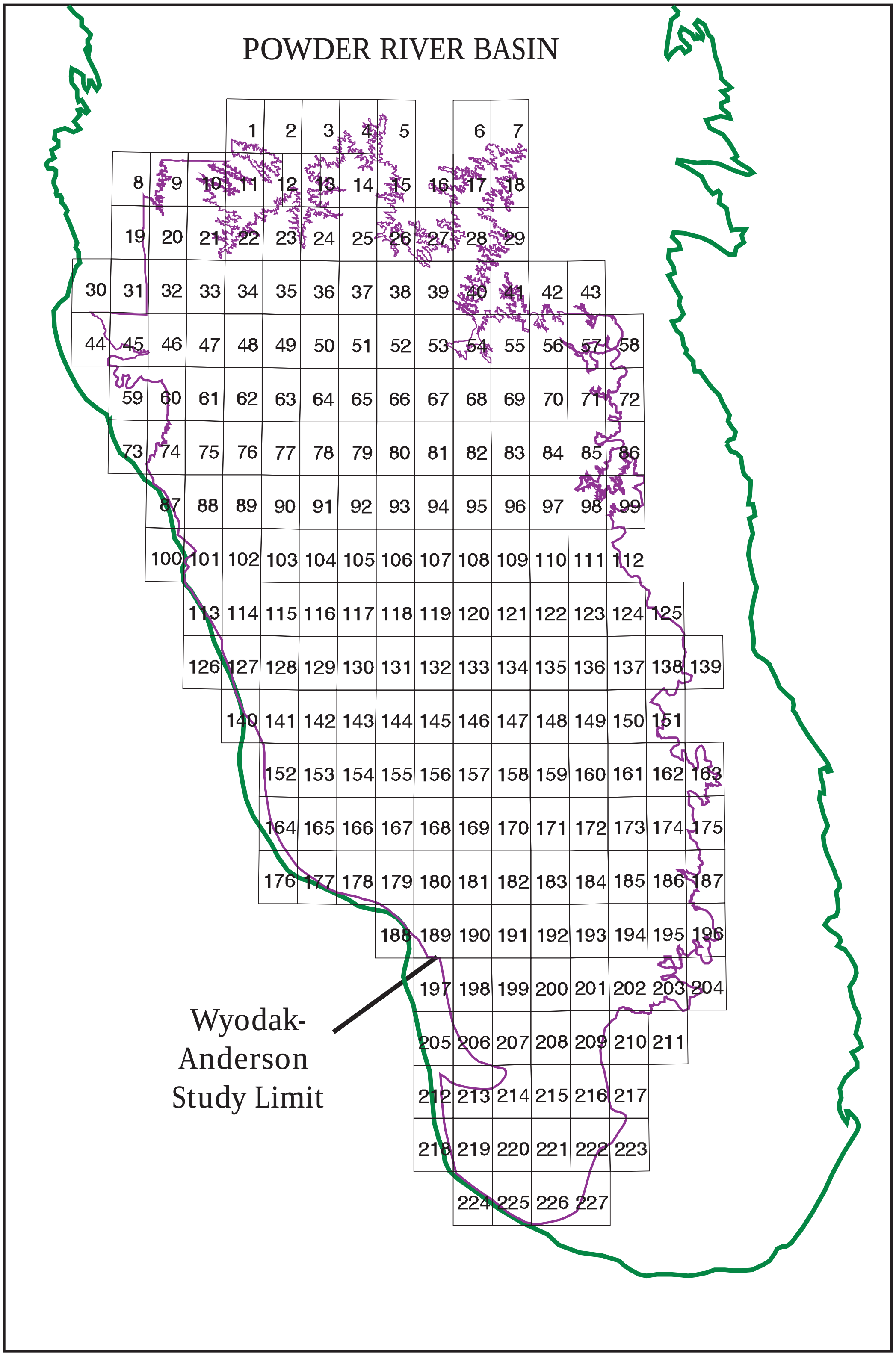

Figure 9. Index map showing 7.5-minute quadrangle maps in the study area.

Table 7. Alphabetic key to 7.5-minute quadrangle maps in the study area. Locations are shown in figure 9 and coal resources are reported by 7.5-minute quadrangle in table 11.

7.5-minute Quadrangle Map	Number	7.5-minute Quadrangle Map	Number
ACME	46	DRY CREEK RESERVOIR	164
ALTA CREEK	210	DRY FORK RANCH	180
ANTELOPE DRAW	152	DUGOUT CREEK NORTH	203
APPEL BUTTE	136	DUGOUT CREEK SOUTH	211
ARPAN BUTTE	92	EAGLE ROCK	161
ARTESIAN DRAW	190	ECHETA	108
ARVADA	80	ELAINE DRAW	153
ARVADA NE	81	FATS DRAW	157
BAKER SPRING	183	FAWN DRAW	66
BANNER	88	FIGURE 8 RESERVOIR	177
BAR N DRAW	47	FLOATE DRAW	105
BAR V RANCH	31	FLY DRAW	213
BAR V RANCH NE	19	FORKS RANCH	36
BAY HORSE	43	FORT HOWES	15
BEAR CREEK	208	FORT RENO	167
BEAR CREEK SCHOOL	38	FORT RENO SE	168
BEAR DRAW	117	FORTIN DRAW	125
BEAUCHAMP RESERVOIR	218	FOUR BAR J RANCH	135
BEAVER CREEK HILLS	73	FOURMILE RESERVOIR	165
BETTY RESERVOIR	202	FREDRICK DRAW	104
BIG HORN	74	GARDNER GULCH	65
BIRNEY	12	GILBERT LAKE	227
BIRNEY DAY SCHOOL	3	GILLAM DRAW EAST	205
BIRNEY SW	11	GILLETTE EAST	124
BLACK DRAW	54	GILLETTE WEST	123
BLOOM CREEK	29	GLENROCK NW	224
BOBBY DRAW	223	GOODSPEED BUTTE	16
BOGIE DRAW	146	GREASEWOOD RESERVOIR	171
BOON	143	GREEN CREEK	4
BOWMAN FLAT	144	GUMBO HILL	219
BOX ELDER DRAW	51	HALF MOON HILL	20
BRADSHAW CREEK	40	HAMILTON DRAW	25
BROWN RANCH	142	HILIGHT	174
BROWNS MOUNTAIN	13	HODSDON FLATS	18
BUFFALO	114	HOE RANCH	155
BUFFALO NE	103	HOLDUP HOLLOW	221
BUFFALO RUN CREEK	75	HOLMES RANCH	34
BUFFALO SE	115	HOMESTEAD DRAW	57
CABIN CREEK NE	53	HOMESTEAD DRAW SW	70
CABIN CREEK NW	52	HORSE HILL	89
CABIN CREEK SE	67	HOUSE CREEK	179
CALF CREEK	98	HULTZ DRAW	59
CARR DRAW	120	HYLTON RANCH	225
CEDAR CANYON	48	JEFFERS DRAW	121
CLEARMONT	78	JEWELL DRAW	93
CLUBFOOT CREEK	2	JONES DRAW	62
COAL BANK DRAW	204	JULIO DRAW	91
COAL DRAW NORTH	201	JUNIPER DRAW	131
COAL DRAW SOUTH	209	KAYCEE NE	176
COAL HILL	220	KING MOUNTAIN	5
COOK CREEK BUTTE	1	KIRBY	9
COON TRACK CREEK	139	KLINE DRAW	68
CORRAL CREEK	56	KLONDIKE RANCH	126
COYOTE DRAW	138	LACEY GULCH	23
CRAZY WOMAN RANCH	129	LAKE DE SMET EAST	102
CROTON	95	LAKE DE SMET WEST	101
DEAD HORSE LAKE	55	LAREY DRAW	82
DECKER	33	LARIAT	94
DOUBLE TANKS	147	LASKIE DRAW	132

Table 7. Continued.

7.5-minute Quadrangle Map	Number	7.5-minute Quadrangle Map	Number
LEITER	79	ROUGH CREEK	163
LEUENBERGER RANCH	226	ROUNDUP DRAW	50
LINCH	188	S R SPRINGS	63
LITTLE BEAR CREEK	30	SADDLE HORSE BUTTE	151
LITTLE THUNDER RESERVOIR	185	SAVAGETON	170
LIVINGSTON DRAW	107	SAWMILL CANYON	197
MACKEN DRAW	200	SAYLE	28
MARSH DRAW	206	SAYLE HALL	39
MITCHELL DRAW	106	SCAPER RESERVOIR	149
MONARCH	45	SCOTT DAM	134
MOORHEAD	41	SEVEN L CREEK EAST	212
MORGAN DRAW	133	SHERIDAN	60
MOYER SPRINGS	112	SHULER DRAW	64
NEGRO BUTTE	145	SOLDIER CREEK	166
NEIL BUTTE	162	SOMERVILLE FLATS EAST	119
NORTH BUTTE	169	SOMERVILLE FLATS WEST	118
NORTH RIDGE	113	SONNETTE	7
O T O RANCH	49	SOUTH BUTTE	182
OLIVER DRAW	86	SOUTH FORK RESERVOIR	214
OPEN A RANCH	175	SPOTTED HORSE	83
ORIVA	122	SPRING CREEK RANCH	8
ORIVA NW	110	SPRING GULCH	22
OTTER	26	STONE MOUNTAIN	100
PATSY DRAW	217	STORY	87
PEARL SCHOOL	32	STROUD CREEK	24
PEPSSON DRAW	159	SUICIDE HILL	215
PHILLIPS BUTTE	17	SUSSEX	178
PINE BUTTE SCHOOL	35	T A RANCH	127
PINE GULCH	116	TA RANCH NE	128
PINE TREE	191	TAINTOR DESERT	10
PINEY CANYON NW	187	TAYLOR RANCH	189
PINEY CANYON SW	196	TECKLA	195
PITCH DRAW	85	TECKLA SW	194
PLEASANTDALE	148	THE GAP	137
PLOESSERS DRAW	130	THE GAP SW	150
POKER JIM BUTTE	14	THE NIPPLE	156
PROVENCE RANCH	154	THOMPSON DRAW	207
PURDY RESERVOIR	140	THREE BAR RANCH	42
QUIETUS	37	THREEMILE BUTTES	6
RANCHESTER	44	THREEMILE CREEK RESERVOIR	160
RATTLESNAKE DRAW	184	TONGUE RIVER DAM	21
RAWHIDE SCHOOL	111	TRABING	141
REANUS CONE	27	TRUMAN DRAW	96
RECLUSE	84	TURNERCREST	192
RED HILL	216	TWENTYMILE BUTTE	109
RENO FLATS	193	UCROSS	90
RENO JUNCTION	173	ULM	77
RENO RESERVOIR	186	VERONA	76
RESERVOIR CREEK	69	WAGS PINNACLE	158
ROCKY BUTTE	58	WESTON SW	99
ROCKY BUTTE GULCH	172	WHIPPLE HOLLOW	222
ROCKY BUTTE SW	72	WHITE TAIL BUTTE	71
ROLLING PIN RANCH	181	WILDCAT	97
ROSS	198	WYARNO	61
ROSS FLAT	199		

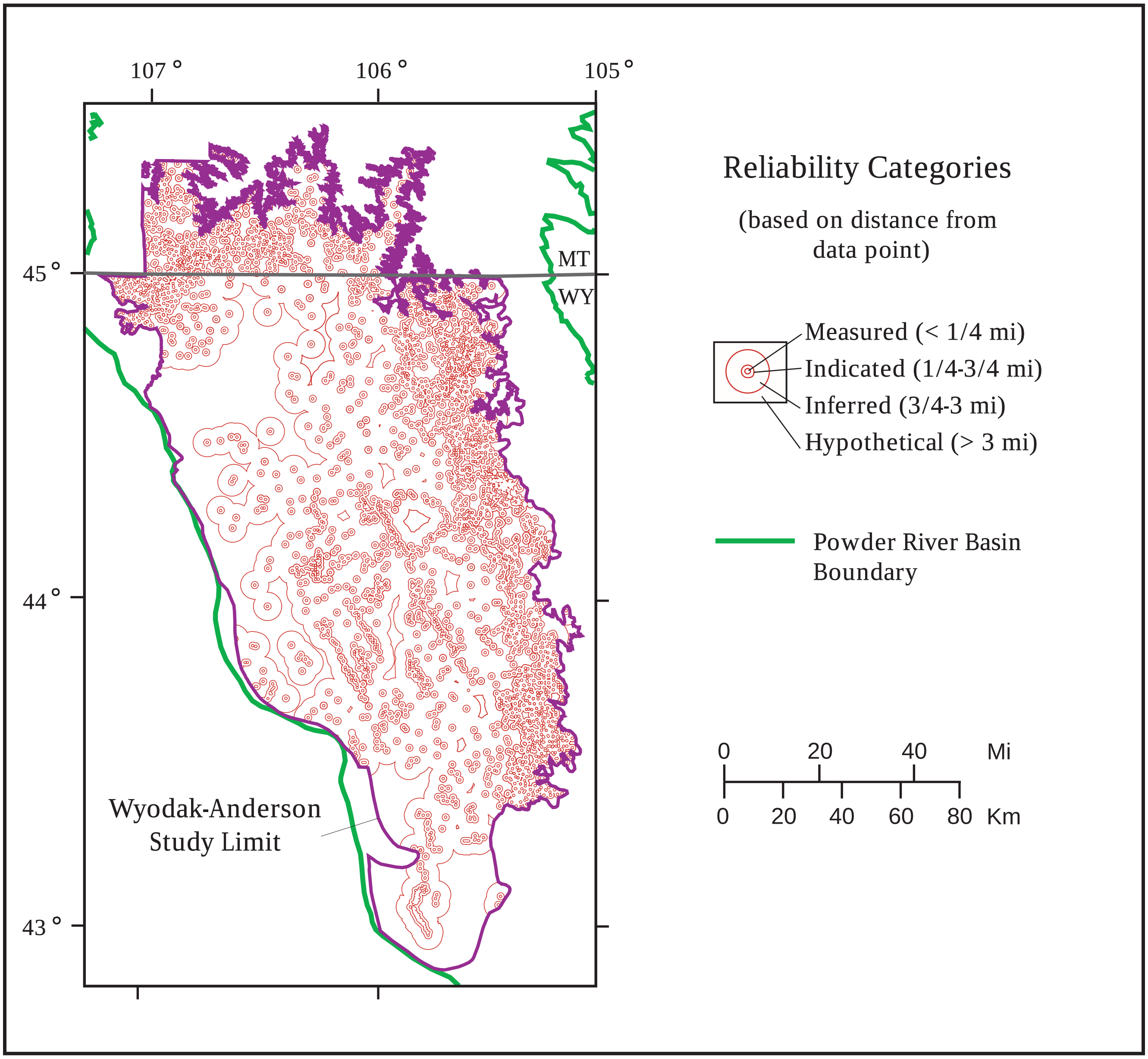

Figure 10. Map showing reliability categories. Only the circles drawn around non-confidential (public) data points are shown on this map.

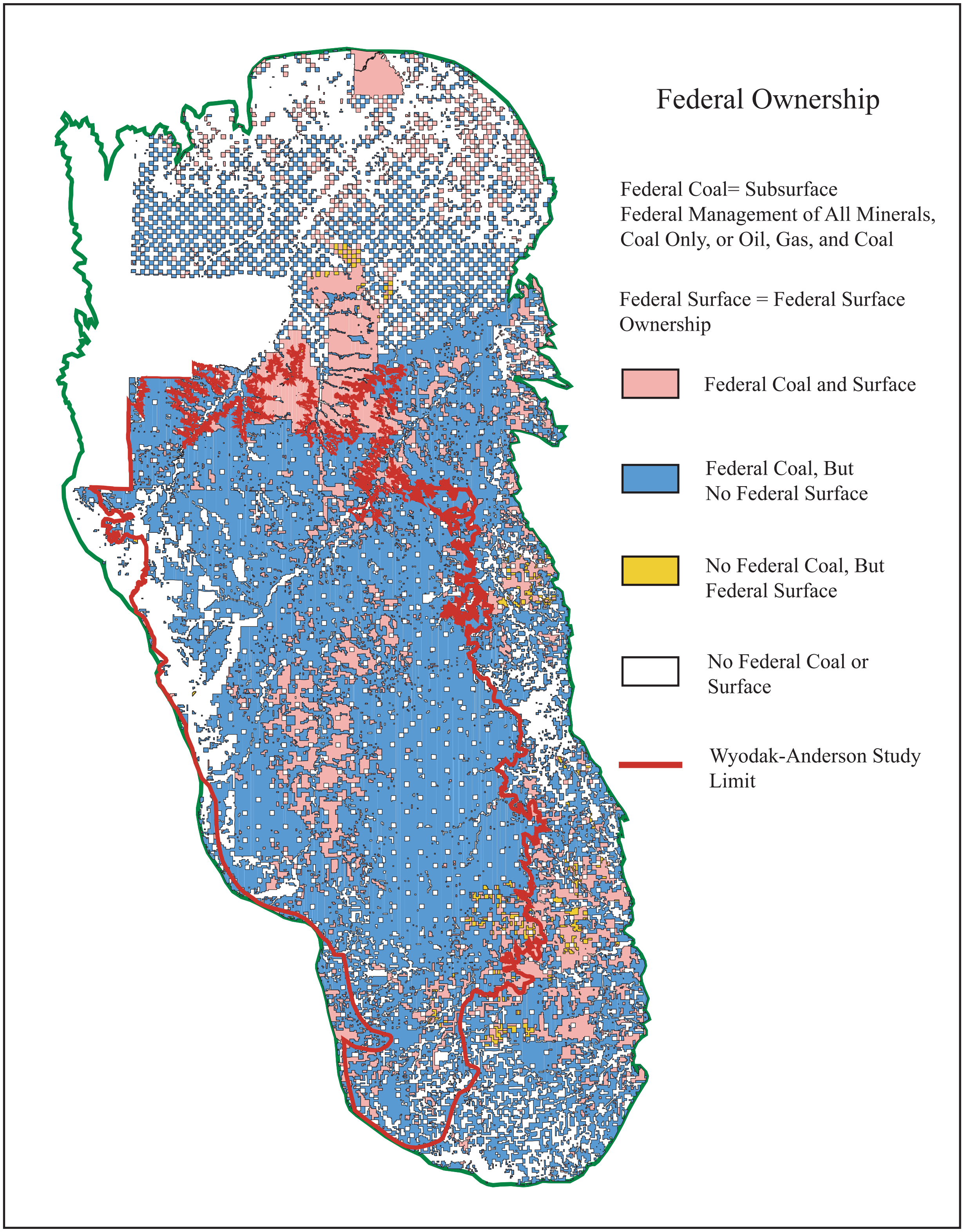

Figure 11. Map showing Federal coal ownership categories.

Gridding and Modeling Net Coal Thickness and Overburden

The gridding and modeling of net coal and overburden thickness data were performed using EarthVision (Dynamic Graphics, Inc., 1997) software. Data files were brought into EarthVision (EV) in fixed ASCII format, with locations given in decimal latitude and longitude. The data fields and projection were defined (as geographic, with a central meridian of Longitude 106 degrees west). The file was then projected to Lambert Conformal conic, Clarke 1886, with first standard parallel of 33 degrees, second standard parallel of 45 degrees, and central meridian of 106 degrees (the approximate center of the basin). The origin of the projection is 0 degrees with 0 false northing and 0 false easting.

To accurately grid the net coal thickness, the data set was augmented to include interpretive points. This was necessary because the isopach map contours were extrapolated throughout the study area using the existing data set and the distribution of data did not include information on where the coal pinched-out (depositional “want” areas) or was eroded away (erosional want areas). These additional data were taken from published and unpublished mapping. In extensive areas where the coal pinched-out along the Wyodak-Anderson boundary, portions of the polygon file (the locations of the nodes) were assigned coal thickness values of 0 and added to the data set. Other data were hand digitized and added to the data set.

The grid for net coal thickness was created using the EV isopach gridding option. This option considers terminated data (negative sign in front of the net coal thickness) as "greater than" values when assigning the net coal thickness values to the grid nodes. The Wyodak-Anderson data set included data from 714 drill holes that terminated before the Wyodak-Anderson coal zone was completely penetrated (therefore, the data may not represent all of the coal in the Wyodak-Anderson coal zone). Grids were created using 4 multiple data points (the program looks at the 4 closest points to determine the grid values), with a coal thickness z range from .1 to 285 ft (actual data ranged from –87 to 284 ft), and extrapolated to cover the full extent of the study area.

Several different grid spacings were tested to determine which grids were most accurate and appropriate for our purposes. There were several criteria for choosing the correct grids to use for graphic output, creating the net coal isopach coverage, and calculating coal resources. It was important to choose a grid that used as many of the data points in the data set as possible and that had a relatively small absolute Z grid error (shown in the grid report). The grid must also have fine enough grid spacing to produce an acceptable level of detail for graphics and the calculation of volumetrics.

The EV method of calculating volumetrics uses grid nodes and subgrid nodes from EarthVision for coal thickness information in conjunction with the area of the polygons from the ARC/INFO (ESRI, 1998) union coverage. Therefore, the grid we used for calculating coal resources had to be fine enough to have at least one grid node value within each polygon. Because we were considering the necessity of having at least one grid node within each polygon, we chose grid spacing that was indicated by the distance between nodes measured in meters. The default EV grid spacing was 3,520 X 3,606 meters, which was very coarse and created a grid that only used 2,800 out of 5,346 points and had an average absolute z error of about 4%, which is quite high. We tested several other grid spacings and determined that the best grid spacing to use for the union coverage and for the calculation of coal resources was 300 X 300 meters. This grid spacing used 5,261 out of 5,346 points and had an absolute z error of .5%.

The coal thickness isopach map was created in EarthVision and is shown in figure 12. The isopach map for use in the ARC/INFO union coverage was produced in the EV visualization module and saved as an ASCII file. The ASCII file was modified using a custom program, ismarc, and generated into a polygon coverage in ARC/INFO using an Arc Macro Language (AML) that was supplied to us from the Illinois State Geological Survey. This AML clips the isopach map to the study area and assigns thickness values to each polygon that is the average of the value of the isopach lines on either side of the polygon.

The overburden for the Wyodak-Anderson coal zone is the thickness of rock above the uppermost coal in the coal zone, and therefore represents minimum overburden. The overburden isopach grid was created by subtracting the grid for the top of the coal zone (grid spacing of 500 X 500

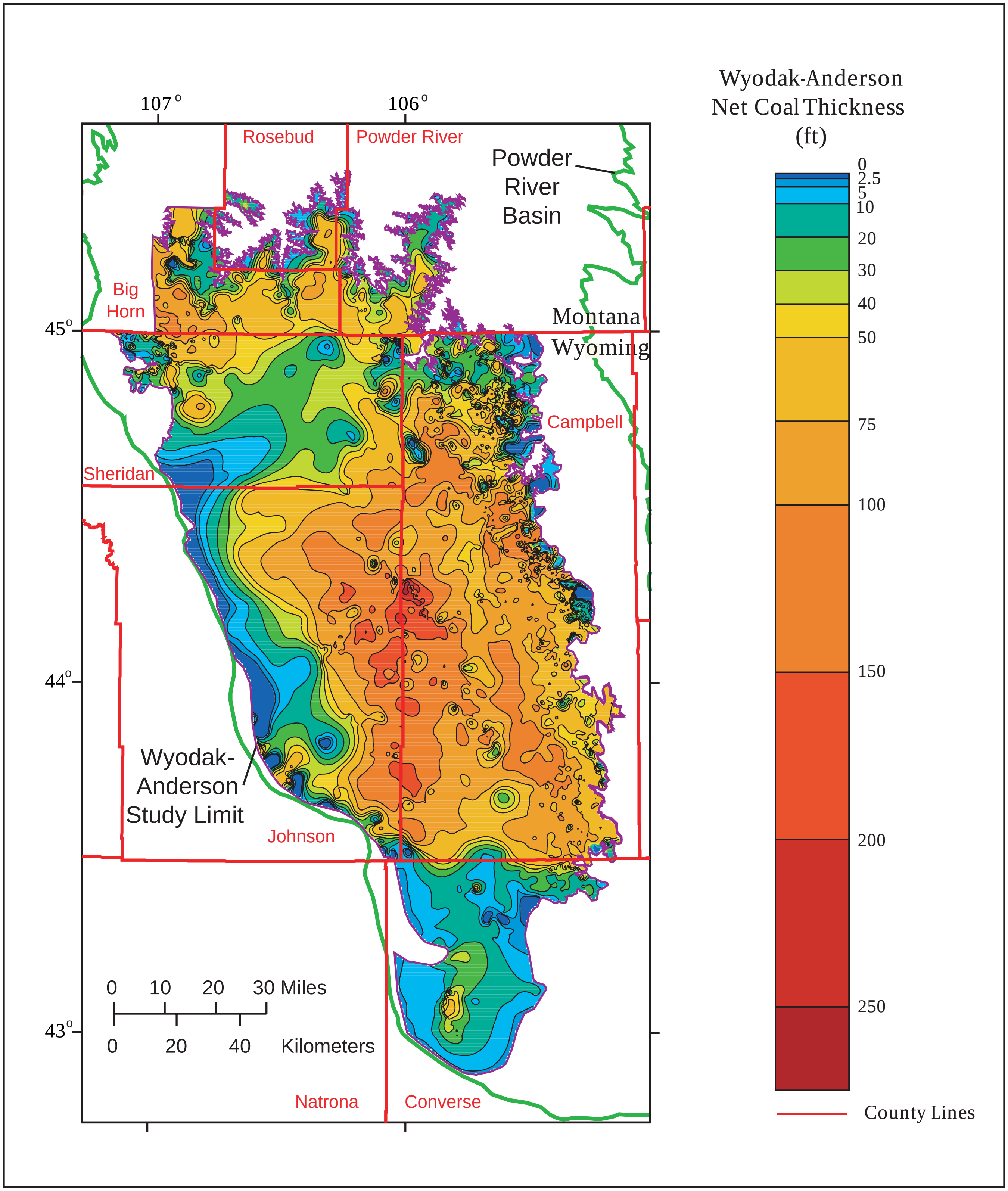

Figure 12. Net coal isopach map.

meters) from the grid for the digital elevation model (DEM) which represents a detailed topographic surface (grid spacing of 500 X 500 meters). The shaded relief map in figure 13 indicates the topography generated from the digital elevation model. The overburden isopach map (figure 14) was created in EarthVision and was generated into a polygon coverage in ARC/INFO using the same procedure and programs as described for the generation of the net coal thickness polygon coverage.

Creating the ARC/INFO Union Coverage

Spatial information for use in the study of the coal resources for the Wyodak-Anderson coal zone were created and manipulated as ARC/INFO polygon and point coverages. The coverages were created by importing or digitizing data, projecting all of the coverages to a standard projection, editing and cleaning the coverages, generalizing the data where necessary, assigning attributes to the polygons or points, and clipping the coverages to the appropriate study extent.

The coverages were combined (unioned) to create an ARC/INFO union coverage with many different attributes for each polygon. Because some of the coverages had similar boundaries that came from different sources, extra polygons (or slivers) had to be edited out of the union coverage. This was accomplished by eliminating polygons that had an area of less than 20,000 square meters and manually editing (dissolving) additional problematic polygons.

Calculating Volumetrics

Volumetrics were calculated using a combination of EarthVision and ARC/INFO products. The union coverage was imported into EarthVision, and labels were assigned to the polygons based on polygon ID. The coverage was saved as a polygon file and the projection of the file was defined. In EarthVision utilities, volumetrics were calculated with the layered volumetrics option using the ARC/INFO union coverage polygon, the unclipped 300 X 300-meter net coal thickness grid, and a conversion factor of 1770 short tons per acre-ft for subbituminous coal. The results of the calculation of short tons of coal in each polygon are given in the EarthVision volumetrics report. The volumetrics report was modified using a custom program, evrpt, which striped-off the file header and added a calculated field containing coal thickness (calculated from EarthVision positive area and the short tons in each polygon.) An example of the file output is shown in table 8.

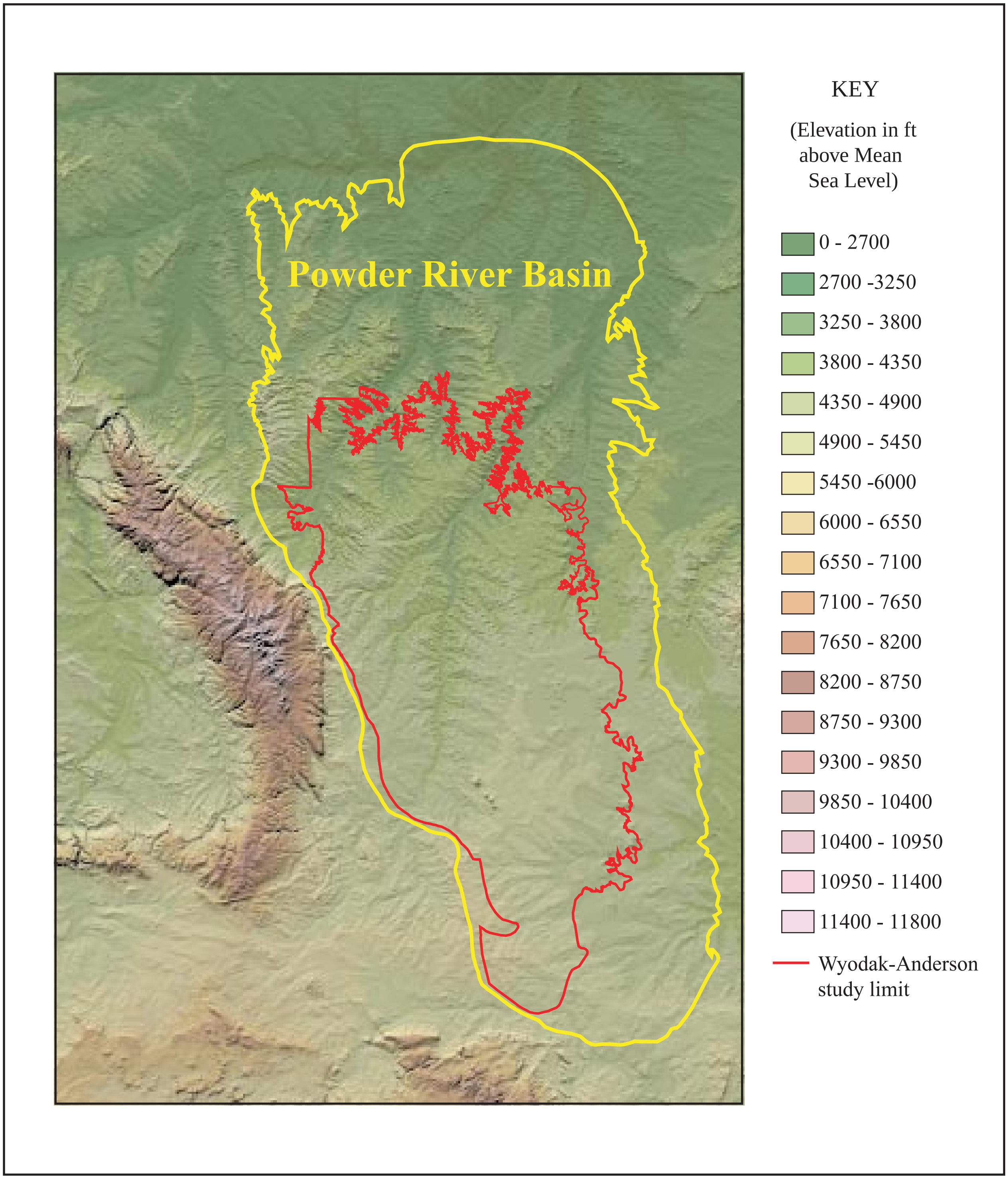

Figure 13. A shaded relief map generated from the Digital Elevation Model (DEM).

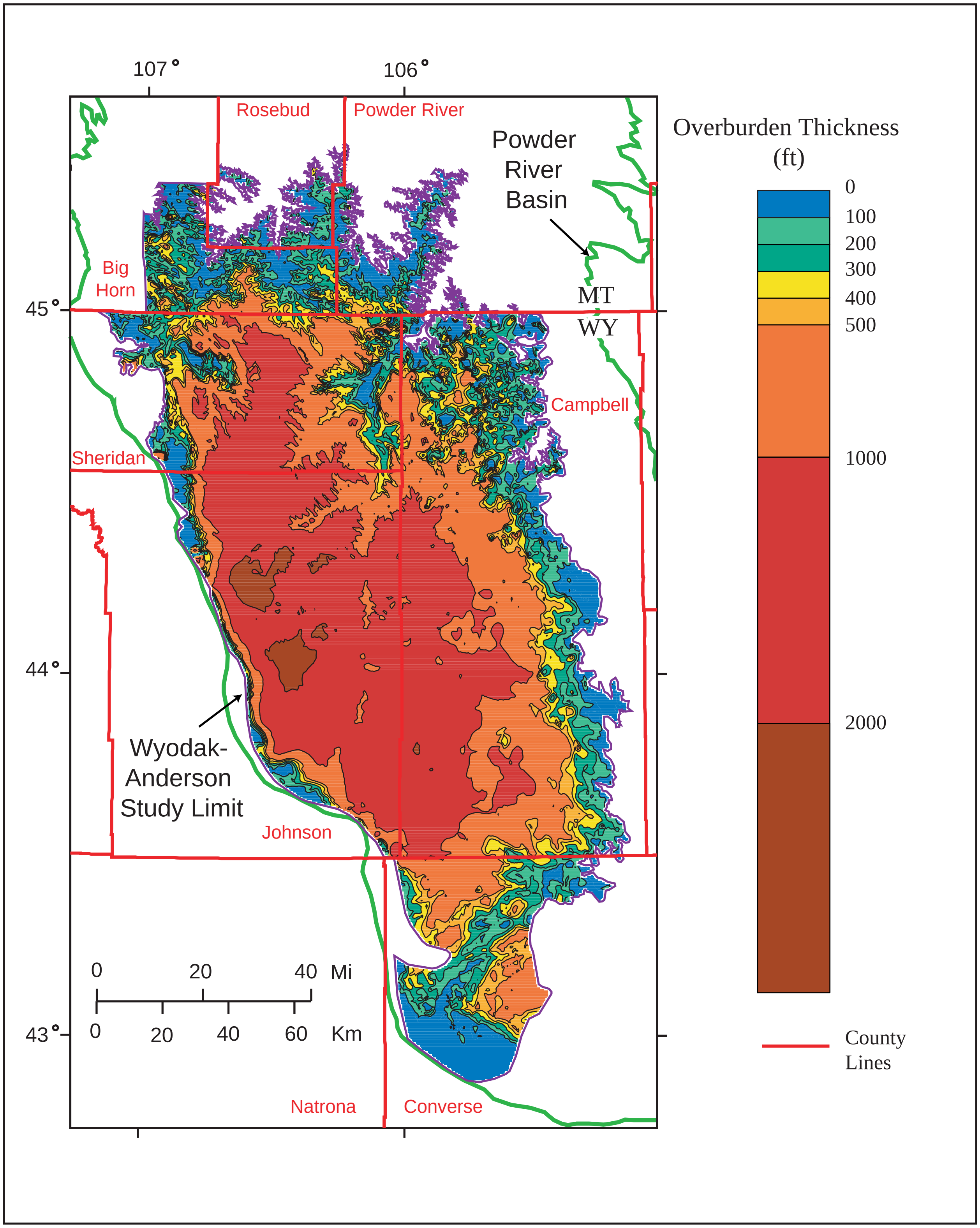

Figure 14. Overburden isopach map showing polygons for reporting categories.

Table 8. Example of information output from the EarthVision volumetrics report after it has been modified by the evrpt program.

Polygon ID	Short Tons	EV Positive Area (square meters)	EV Coal Thickness (ft)
2	998,838	197,200.2	11.6
3	308,697	58,976.1	12
4	444,720	87,232.6	11.7
5	619,674	119,618.2	11.8
6	313,039	62,791	11.4
7	145,275	28,581.8	11.6
8	358,032	70,026.8	11.7
9	318,819	64,151.8	11.4
10	1,969,375	401,293	11.2
11	1,025,328	205,536.2	11.4
12	270,140	55,757.8	11.1
13	132,878	26,525.4	11.5
14	4,840,237	928,079.3	11.9
15	443,408	87,635.1	11.6
16	934,074	201,994.8	10.6
17	720,379	132,345.6	12.4
18	718,352	150,964.6	10.9

Creating Resource Tables

Information from the modified EarthVision Volumetrics report and the ARC/INFO union coverage polygon attribute tables were combined to create coal resource tables. This merging of information was based on the polygon ID. This merging of data can be accomplished in ArcView (ESRI, 1998) or in spreadsheet or relational database software. For this study, we imported the polygon attribute table and the volumetrics report in ASCII format into Excel spreadsheet software. The files were merged, additional fields were calculated (e.g., millions of short tons and acres), and text fields were added (so that the categories in our resource tables would print in the proper order). Polygons containing lease and mine areas, clinker, and net coal less than 2.5 ft thick were then deleted. The polygons in Wyodak-Anderson (WA) mine and lease areas and in areas containing WA clinker were removed because we did not have enough detailed information to determine how much WA coal remained in those areas. Coal less than 2.5 ft in thickness was deleted because it is not included in standard resource reporting categories.

Coal resources tables were produced using pivot tables in Excel. The following tables (tables 9 through 12) show coal resources for the Wyodak-Anderson coal zone reported on various parameters. All coal tonnages are reported in millions of short tons and with two significant figures.

Table 9. Wyodak-Anderson coal resources reported by state and county. Resources are shown in millions of short tons (MST) and with two significant figures. Zeros (0) indicate that no coal resources were calculated within those categories. The table does not include coal resources in mine or lease areas, areas containing Wyodak-Anderson clinker, or areas containing coal less than 2.5 ft thick. County outlines are shown on figure 8.

State	County	Total (MST)
Montana	BIG HORN	29,000
	POWDER RIVER	11,000
	ROSEBUD	2,800
Montana Total		42,000
Wyoming	CAMPBELL	280,000
	CONVERSE	15,000
	JOHNSON	160,000
	SHERIDAN	52,000
Wyoming Total		510,000
Grand Total (MST)		550,000

Table 10. Wyodak-Anderson coal resources reported by state and by Federal coal and Federal surface ownership categories. Resources are shown in millions of short tons (MST) and with 2 significant figures. The table does not include coal resources in mine or lease areas, areas containing Wyodak-Anderson clinker, or areas containing coal less than 2.5 ft thick. Federal ownership categories are shown on figure 11.

State	Federal Ownership	Total (MST)
Montana	No Federal coal ownership or Federal surface ownership	3,900
	No Federal coal ownership, but Federal surface ownership	2.9
	Federal coal ownership, but no Federal surface ownership	32,000
	Federal coal ownership and Federal surface ownership	6,700
	Total Federal coal in Montana	39,000
Montana Total		42,000
Wyoming	No Federal coal or Federal surface ownership	64,000
	No Federal coal ownership, but Federal surface ownership	1,900
	Federal coal ownership, but no Federal surface ownership	360,000
	Federal coal and Federal surface ownership	79,000
	Total Federal coal in Wyoming	440,000
Wyoming Total		510,000
Grand Total (MST)		550,000

Table 11. Wyodak-Anderson coal resources reported by state and 7.5-minute quadrangle map area. Resources are shown in millions of short tons (MST) and with 2 significant figures. The table does not include coal resources in mine or lease areas, areas containing Wyodak-Anderson clinker, or areas containing coal less than 2.5 ft thick. The index map showing locations of the 7.5-minute quadrangles is on figure 9 and the numeric and alphabetized keys are shown on tables 6 and 7.

State	7.5-minute Quadrangle Map	Numeric Key	Total (MST)
Montana	ACME	46	160
	BAR N DRAW	47	150
	BAR V RANCH	31	320
	BAR V RANCH NE	19	740
	BAY HORSE	43	2.1
	BEAR CREEK SCHOOL	38	2,700
	BIRNEY	12	74
	BIRNEY DAY SCHOOL	3	2.2
	BIRNEY SW	11	130
	BLACK DRAW	54	51
	BLOOM CREEK	29	65
	BOX ELDER DRAW	51	89
	BRADSHAW CREEK	40	1,100
	BROWNS MOUNTAIN	13	60
	CABIN CREEK NE	53	150
	CABIN CREEK NW	52	150
	CEDAR CANYON	48	130
	CLUBFOOT CREEK	2	2.4
	COOK CREEK BUTTE	1	81
	DECKER	33	1,900
	FORKS RANCH	36	2,700
	FORT HOWES	15	160
	GOODSPEED BUTTE	16	43
	GREEN CREEK	4	56
	HALF MOON HILL	20	1,600
	HAMILTON DRAW	25	2,400
	HODSDON FLATS	18	210
	HOLMES RANCH	34	2,700
	KING MOUNTAIN	5	22
	KIRBY	9	1,700
	LACEY GULCH	23	1,100
	MONARCH	45	1.2
	MOORHEAD	41	43
	O T O RANCH	49	140
	OTTER	26	630
	PEARL SCHOOL	32	4,600
	PHILLIPS BUTTE	17	600
	PINE BUTTE SCHOOL	35	3,400

Table 11. Continued on next page.

Table 11. Continued.

State	7.5-minute Quadrangle Map	Numeric Key	Total (MST)
Montana	POKER JIM BUTTE	14	1,000
	QUIETUS	37	3,500
	REANUS CONE	27	360
	ROUNDUP DRAW	50	110
	SAYLE	28	1,100
	SAYLE HALL	39	2,600
	SONNETTE	7	46
	SPRING CREEK RANCH	8	47
	SPRING GULCH	22	790
	STROUD CREEK	24	1,000
	TAINTOR DESERT	10	1,100
	THREE BAR RANCH	42	39
	THREEMILE BUTTES	6	3.4
	TONGUE RIVER DAM	21	250
Montana Total			42,000
Wyoming	ACME	46	2,700
	ALTA CREEK	210	6.0
	ANTELOPE DRAW	152	59
	APPEL BUTTE	136	5,000
	ARPAN BUTTE	92	2,800
	ARTESIAN DRAW	190	4,600
	ARVADA	80	2,200
	ARVADA NE	81	3,700
	BAKER SPRING	183	4,200
	BANNER	88	93
	BAR N DRAW	47	2,900
	BAY HORSE	43	0.25
	BEAR CREEK	208	680
	BEAR DRAW	117	6,700
	BEAUCHAMP RESERVOIR	218	29
	BETTY RESERVOIR	202	1,700
	BIG HORN	74	520
	BLACK DRAW	54	1,200
	BOBBY DRAW	223	67
	BOGIE DRAW	146	6,900
	BOON	143	3,400
	BOWMAN FLAT	144	7,000
	BOX ELDER DRAW	51	1,200
	BROWN RANCH	142	750
	BUFFALO	114	1600
	BUFFALO NE	103	3,300
	BUFFALO RUN CREEK	75	880
	BUFFALO SE	115	3,900
	CABIN CREEK NE	53	1,400

Table 11. Continued on next page.

Table 11. Continued.

State	7.5-minute Quadrangle Map	Numeric Key	Total (MST)
Wyoming	CABIN CREEK NW	52	2,500
	CABIN CREEK SE	67	2,400
	CALF CREEK	98	3,400
	CARR DRAW	120	7,800
	CEDAR CANYON	48	2,700
	CLEARMONT	78	1,500
	COAL BANK DRAW	204	64
	COAL DRAW NORTH	201	1,200
	COAL DRAW SOUTH	209	230
	COAL HILL	220	1,300
	COON TRACK CREEK	139	51
	CORRAL CREEK	56	1,600
	COYOTE DRAW	138	1,400
	CRAZY WOMAN RANCH	129	2,700
	CROTON	95	6,200
	DEAD HORSE LAKE	55	1,300
	DOUBLE TANKS	147	7,500
	DRY CREEK RESERVOIR	164	570
	DRY FORK RANCH	180	7,300
	DUGOUT CREEK NORTH	203	840
	DUGOUT CREEK SOUTH	211	2.7
	EAGLE ROCK	161	4,200
	ECHETA	108	4,900
	ELAINE DRAW	153	620
	FATS DRAW	157	7,300
	FAWN DRAW	66	2,600
	FIGURE 8 RESERVOIR	177	670
	FLOATE DRAW	105	5,900
	FLY DRAW	213	250
	FORT RENO	167	3,600
	FORT RENO SE	168	7,600
	FORTIN DRAW	125	390
	FOUR BAR J RANCH	135	4,600
	FOURMILE RESERVOIR	165	2,000
	FREDRICK DRAW	104	4,500
	GARDNER GULCH	65	2,000
	GILBERT LAKE	227	80
	GILLAM DRAW EAST	205	1.1
	GILLETTE EAST	124	2,400
	GILLETTE WEST	123	4,900
	GLENROCK NW	224	96
	GREASEWOOD RESERVOIR	171	4,700
	GUMBO HILL	219	390
	HILIGHT	174	3,500
	HOE RANCH	155	4,600

Table 11. Continued on next page.

Table 11. Continued.

State	7.5-minute Quadrangle Map	Numeric Key	Total (MST)
Wyoming	HOLDUP HOLLOW	221	770
	HOMESTEAD DRAW	57	480
	HOMESTEAD DRAW SW	70	2,700
	HORSE HILL	89	1,100
	HOUSE CREEK	179	4,700
	HULTZ DRAW	59	240
	HYLTON RANCH	225	590
	JEFFERS DRAW	121	4,500
	JEWELL DRAW	93	3,900
	JONES DRAW	62	1,700
	JULIO DRAW	91	2,800
	JUNIPER DRAW	131	7,900
	KAYCEE NE	176	110
	KLINE DRAW	68	3,200
	LAKE DE SMET EAST	102	2,200
	LAKE DE SMET WEST	101	380
	LAREY DRAW	82	3,800
	LARIAT	94	5,200
	LASKIE DRAW	132	9,500
	LEITER	79	1,600
	LEUENBERGER RANCH	226	480
	LINCH	188	390
	LITTLE BEAR CREEK	30	1.2
	LITTLE THUNDER RESERVOIR	185	5,700
	LIVINGSTON DRAW	107	5,700
	MACKEN DRAW	200	670
	MARSH DRAW	206	330
	MITCHELL DRAW	106	6,000
	MONARCH	45	690
	MOORHEAD	41	1.8
	MORGAN DRAW	133	9,700
	MOYER SPRINGS	112	530
	NEGRO BUTTE	145	9,200
	NEIL BUTTE	162	2,200
	NORTH BUTTE	169	8,000
	NORTH RIDGE	113	78
	O T O RANCH	49	2,200
	OLIVER DRAW	86	36
	OPEN A RANCH	175	430
	ORIVA	122	4,400
	ORIVA NW	110	5,100
	PATSY DRAW	217	33
	PEPSSON DRAW	159	5,500
	PINE GULCH	116	5,100
	PINE TREE	191	4,200

Table 11. Continued on next page.

Table 11. Continued.

State	7.5-minute Quadrangle Map	Numeric Key	Total (MST)
Wyoming	PINEY CANYON NW	187	110
	PINEY CANYON SW	196	520
	PITCH DRAW	85	1,100
	PLEASANTDALE	148	5,300
	PLOESSERS DRAW	130	5,700
	PROVENCE RANCH	154	2,000
	PURDY RESERVOIR	140	35
	RANCHESTER	44	180
	RATTLESNAKE DRAW	184	4,000
	RAWHIDE SCHOOL	111	4,300
	RECLUSE	84	3,400
	RED HILL	216	630
	RENO FLATS	193	4,300
	RENO JUNCTION	173	6,000
	RENO RESERVOIR	186	3,100
	RESERVOIR CREEK	69	2,600
	ROCKY BUTTE	58	100
	ROCKY BUTTE GULCH	172	6,200
	ROCKY BUTTE SW	72	240
	ROLLING PIN RANCH	181	7,000
	ROSS	198	770
	ROSS FLAT	199	1,200
	ROUGH CREEK	163	1,500
	ROUNDUP DRAW	50	1,500
	S R SPRINGS	63	1,300
	SADDLE HORSE BUTTE	151	370
	SAVAGETON	170	5,600
	SAWMILL CANYON	197	33
	SCAPER RESERVOIR	149	5,900
	SCOTT DAM	134	5,600
	SEVEN L CREEK EAST	212	59
	SHERIDAN	60	1,100
	SHULER DRAW	64	1,500
	SOLDIER CREEK	166	1,100
	SOMERVILLE FLATS EAST	119	6,800
	SOMERVILLE FLATS WEST	118	7,300
	SOUTH BUTTE	182	5,300
	SOUTH FORK RESERVOIR	214	900
	SPOTTED HORSE	83	5,400
	STORY	87	7.5
	SUICIDE HILL	215	1,100
	SUSSEX	178	1,900
	T A RANCH	127	310
	TA RANCH NE	128	1,400
	TAYLOR RANCH	189	2,600

Table 11. Continued on next page.

Table 11. Continued.

State	7.5-minute Quadrangle Map	Numeric Key	Total (MST)
Wyoming	TECKLA	195	3,700
	TECKLA SW	194	4,800
	THE GAP	137	3,800
	THE GAP SW	150	3,200
	THE NIPPLE	156	7,300
	THOMPSON DRAW	207	720
	THREE BAR RANCH	42	1.2
	THREEMILE CREEK RESERVOIR	160	6,400
	TRABING	21	450
	TRUMAN DRAW	96	6,200
	TURNERCREST	192	2,900
	TWENTYMILE BUTTE	109	4,600
	UCROSS	90	2,700
	ULM	77	710
	VERONA	76	630
	WAGS PINNACLE	158	5,800
	WESTON SW	99	100
	WHIPPLE HOLLOW	222	400
	WHITE TAIL BUTTE	71	1,500
	WILDCAT	97	4,100
	WYARNO	61	2,700
WY Total			510,000
Grand Total (MST)			550,000

Table 12. Wyodak-Anderson coal resources reported by state, county, and overburden, net coal thickness, and reliability categories. Resources are shown in millions of short tons (MST) and with two significant figures. Zeros (0) indicate that no coal resources were calculated within those categories. The table does not include coal resources in mine or lease areas, areas containing Wyodak-Anderson clinker, or areas containing coal less than 2.5 ft thick. County outlines are shown on figure 8.

State	County	Overburden Thickness	Net Coal Thickness	Reliability Categories (distance from data point) Measured (<1/4 mi)	Indicated (1/4-3/4 mi)	Inferred (3/4-3 mi)	Hypothetical (>3 mi)	Grand Total (MST)
Montana	BIG HORN	0-100 ft	2.5-5 ft	0	0.35	2.3	0	2.7
			5-10 ft	0.26	0.20	10	0	10
			10-20 ft	21	54	79	0	150
			20-40 ft	120	420	240	0	780
			>40 ft	650	2,100	1,100	0	3,900
		0-100 ft Total		790	2,600	1,500	0	4,900
		100-200 ft	2.5-5 ft	0	0.29	0.76	0	1.0
			5-10 ft	0	1.9	6.6	0	8.4
			10-20 ft	11	41	36	0	89
			20-40 ft	92	350	220	0	670
			>40 ft	1,000	3,200	1,400	0	5,700
		100-200 ft Total		1,100	3,600	1,700	0	6,400
		200-500 ft	2.5-5 ft	0.14	0.40	0.07	0	0.61
			5-10 ft	0	4.1	0.55	0	4.6
			10-20 ft	2.9	28	64	0	95
			20-40 ft	27	140	430	0	600
			>40 ft	1,500	7,300	5,100	0	14,000
		200-500 ft Total		1,500	7,500	5,600	0	15,000
		>500 ft	2.5-5 ft	0	0.25	0	0	0.25
			5-10 ft	0.75	1.2	0	0	2.0
			10-20 ft	0.95	0.15	0	0	1.1
			20-40 ft	3.4	1.1	0	0	4.5
			>40 ft	190	1,100	1,400	0	2,700
		>500 ft Total		200	1,100	1,400	0	2,700
	BIG HORN Total			3,600	15,000	10,000	0	29,000
	POWDER RIVER	0-100 ft	2.5-5 ft	0.42	1	19	4.1	25
			5-10 ft	2.3	15	110	13	140
			10-20 ft	59	260	450	32	800
			20-40 ft	220	930	670	93	1,900
			>40 ft	200	730	760	40	1,700
		0-100 ft Total		490	1,900	2,000	180	4,600
		100-200 ft	2.5-5 ft	0	0	3.8	0.52	4.3
			5-10 ft	0.55	6.6	39	4.3	51
			10-20 ft	2.0	47	140	14	200
			20-40 ft	30	180	370	50	630
			>40 ft	130	730	730	7.1	1,600
		100-200 ft Total		160	970	1,300	75	2,500

Table 12. Continued on next page

Table 12. Continued

State	County	Overburden Thickness	Net Coal Thickness	Reliability Categories (distance from data point) Measured (<1/4 mi)	Indicated (1/4-3/4 mi)	Inferred (3/4-3 mi)	Hypothetical (>3 mi)	Grand Total (MST)
Montana	POWDER RIVER	200-500 ft	2.5-5 ft	0	0	0.7	0	0.70
			5-10 ft	0	2.0	8.9	1.4	12
			10-20 ft	0	3.4	27	9.2	40
			20-40 ft	9.5	88	180	24	300
			>40 ft	200	1,100	2,200	0	3,500
		200-500 ft Total		210	1,100	2,400	34	3,800
		>500 ft	>40 ft	0	0.53	0	0	0.53
		>500 ft Total		0	0.53	0	0	0.53
	POWDER RIVER Total			860	4,100	5,700	290	11,000
	ROSEBUD	0-100 ft	2.5-5 ft	0.38	0.47	6.3	1.5	8.6
			5-10 ft	11	31	66	30	140
			20-40 ft	29	120	180	0	320
			>40 ft	62	330	220	0	610
		0-100 ft Total		120	590	610	56	1,400
		100-200 ft	2.5-5 ft	0	0.46	4.2	0.094	4.8
			5-10 ft	2.4	15	24	8.3	50
			10-20 ft	7.2	34	79	16	140
			20-40 ft	9.4	89	110	0	210
			>40 ft	75	340	340	0	750
		100-200 ft Total		94	470	560	25	1,200
		200-500 ft	2.5-5 ft	0	0	0.61	0	0.61
			5-10 ft	0.097	6.2	9.6	4.0	20
			10-20 ft	0	20	61	7.0	89
			20-40 ft	3.4	3.9	19	0	26
			>40 ft	11	82	27	0	120
		200-500 ft Total		15	110	120	11	250
	ROSEBUD Total			230	1,200	1,300	92	2,800
Montana Total				4,700	20,000	17,000	380	42,000
Wyoming	CAMPBELL	0-100 ft	2.5-5 ft	3.6	9.6	57	12	83
			5-10 ft	24	36	83	33	180
			10-20 ft	140	140	300	32	620
			20-40 ft	380	780	1,100	0	2,300
			>40 ft	1,900	4,400	2,900	420	9,600
		0-100 ft Total		2,500	5,300	4,500	490	13,000
		100-200 ft	2.5-5 ft	1.1	5.4	14	0.58	21
			5-10 ft	6.9	32	31	5.6	76
			10-20 ft	55	180	140	2.7	380
			20-40 ft	290	880	660	3.3	1,800
			>40 ft	3,200	6,800	1,800	0	12,000
		100-200 ft Total		3,500	7,900	2,600	12	14,000
		200-500 ft	2.5-5 ft	3.5	9.5	5.3	0.73	19
			5-10 ft	31	49	23	0.96	100
			10-20 ft	120	360	200	0	680
			20-40 ft	540	1,400	830	0	2,800
			>40 ft	9,300	29,000	11,000	20	49,000
		200-500 ft Total		10,000	30,000	12,000	22	52,000

Table 12. Continued on next page.

Table 12. Continued.

State	County	Overburden Thickness	Net Coal Thickness	Reliability Categories (distance from data point) Measured (<1/4 mi)	Indicated (1/4-3/4 mi)	Inferred (3/4-3 mi)	Hypothetical (>3 mi)	Grand Total (MST)
Wyoming	CAMPBELL	>500 ft	2.5-5 ft	0.25	3.8	9.0	0	13
			5-10 ft	2.3	18	59	0	79
			10-20 ft	1.3	37	160	0	200
			20-40 ft	120	390	1,400	49	1900
			>40 ft	13,000	57,000	120,000	6,900	200,000
		>500 ft Total		13,000	58,000	130,000	6,900	200,000
	CAMPBELL Total			29,000	100,000	140,000	7,500	280,000
	CONVERSE	0-100 ft	2.5-5 ft	0.10	0.36	1.8	190	200
			5-10 ft	1.6	21	80	620	720
			10-20 ft	41	280	570	380	1,300
			20-40 ft	92	440	650	22	1,200
			>40 ft	46	100	280	0	430
		0-100 ft Total		180	850	1,600	1,200	3,800
		100-200 ft	2.5-5 ft	0.33	1.1	15	30	46
			5-10 ft	1.4	17	89	120	230
			10-20 ft	47	230	370	54	700
			20-40 ft	76	360	440	88	960
			>40 ft	65	270	100	0	440
		100-200 ft Total		190	880	1,000	300	2,400
		200-500 ft	2.5-5 ft	1.6	7.3	92	92	190
			5-10 ft	20	97	290	710	1,100
			10-20 ft	70	350	960	530	1,900
			20-40 ft	41	260	730	230	1,200
			>40 ft	150	480	230	0	860
		200-500 ft Total		280	1,200	2,300	1,600	5,300
		>500 ft	2.5-5 ft	2.3	14	16	2.4	35
			5-10 ft	20	120	430	430	1,000
			10-20 ft	22	150	590	1,000	1,800
			20-40 ft	1.3	20	350	340	710
			>40 ft	0	0	190	0	190
		>500 ft Total		45	300	1,600	1,800	3,700
	CONVERSE Total			700	3,200	6,500	4,900	15,000
	JOHNSON	0-100 ft	2.5-5 ft	0	2.3	3.3	10	16
			5-10 ft	0	5.6	13	9.9	28
			10-20 ft	5.4	15	52	26	99
			20-40 ft	33	62	42	10	150
			>40 ft	32	82	150	0	270
		0-100 ft Total		71	170	260	56	560
		100-200 ft	2.5-5 ft	0	2.3	2.0	10	15
			5-10 ft	0	4.0	4.3	12	20
			10-20 ft	2.0	5.3	17	8.5	33
			20-40 ft	9.2	42	100	7.9	160
			>40 ft	30	130	220	0	380
		100-200 ft Total		41	180	350	39	610

Table 12. Continued on next page

Table 12. Continued

State	County	Overburden Thickness	Net Coal Thickness	Reliability Categories (distance from data point) Measured (<1/4 mi)	Indicated (1/4-3/4 mi)	Inferred (3/4-3 mi)	Hypothetical (>3 mi)	Grand Total (MST)
Wyoming	JOHNSON	200-500 ft	2.5-5 ft	0	2.9	4.7	36	44
			5-10 ft	0.036	7.0	17	85	110
			10-20 ft	5.6	25	74	38	140
			20-40 ft	23	72	440	23	560
			>40 ft	32	310	1,300	16	1,600
		200-500 ft Total		61	410	1,800	200	2,500
		>500 ft	2.5-5 ft	1.6	6.6	33	88	130
			5-10 ft	5.7	49	500	420	970
			10-20 ft	20	130	1,500	1,200	2,900
			20-40 ft	85	620	5,000	3,200	9,000
		>500 ft	>40 ft	6,800	32,000	96,000	7,700	140,000
		>500 ft Total		6,900	33,000	100,000	13,000	160,000
	JOHNSON Total			7,100	34,000	110,000	13,000	160,000
	SHERIDAN	0-100 ft	2.5-5 ft	0.053	8.2	2.2	22	33
			5-10 ft	12	40	11	37	100
			10-20 ft	36	170	120	40	370
			20-40 ft	45	230	420	5.5	700
			>40 ft	100	350	740	0	1,200
		0-100 ft Total		200	790	1,300	110	2,400
		100-200 ft	2.5-5 ft	1.4	4.1	2.0	15	23
			5-10 ft	4.6	11	14	51	81
			10-20 ft	22	62	90	54	230
			20-40 ft	98	410	660	46	1,200
			>40 ft	290	620	850	81	1,800
		100-200 ft Total		420	1,100	1,600	250	3,400
		200-500 ft	2.5-5 ft	1.4	8.1	7.6	16	33
			5-10 ft	6.7	23	20	49	98
			10-20 ft	34	160	530	180	910
			20-40 ft	260	1,100	3,400	370	5,100
			>40 ft	840	3,700	6,500	220	11,000
		200-500 ft Total		1,100	4,900	11,000	840	17,000
		>500 ft	2.5-5 ft	0.51	3.0	4.7	87	95
			5-10 ft	4.9	33	73	580	690
			10-20 ft	23	140	760	1,600	2,500
			20-40 ft	120	790	7,800	5,200	14,000
			>40 ft	310	1,800	8,600	1,300	12,000
		>500 ft Total		450	2,700	17,000	8,700	29,000
	SHERIDAN Total			2,200	9,600	31,000	9,900	52,000
WY Total				39,000	150,000	290,000	35,000	510,000
Grand Total (MST)				44,000	170,000	300,000	36,000	550,000

Confidence Interval Estimation Procedure

A confidence interval is a statistic designed to capture uncertainty associated with a point estimate. In this study we computed 90-percent confidence intervals on the volume of coal in the Wyodak-Anderson coal zone in the measured, indicated, inferred, and hypothetical categories.

The three main potential sources of error exist that might bias the confidence interval are preferential sampling, measurement errors, and model fitting. The probabilistic interpretation of a confidence interval is based upon a random sample, which does not occur in this situation, as there is preferential sampling in those areas deemed to be minable. Measurement error can be caused by an error in recording the coal bed thickness or in the definition of coverage areas. Modeling fitting variability and bias result from the choice of models and fitting procedures.

Confidence limits for coal resources of the Wyodak-Anderson coal zone were calculated by Jack Schuenemeyer and Helen Power using a data set containing net coal measurements from 4,462 locations (only data from those locations that contained Wyodak-Anderson coal (no 0 values) and were representative of the entire coal zone (no terminated holes)). The confidence limits were derived through a complex series of steps. These steps included modeling coal thickness trends and removing the trends using a nonparametric regression algorithm loess; using residual thickness to compute a semivariogram and fitting the semivariogram to an exponential model to determine measurement error; calculating standard deviations of coal thickness from the variogram model; compensating for differences in point density by calculating a pseudo n within each reliability category and calculating the variability of volume for each of the reliability categories; and calculating the volumes of Wyodak-Anderson coal at a 90-percent confidence interval with measurement error. Some of the parameters used and results of the confidence limit calculations are shown in tables 13 and 14. A detailed description of the methodology used is given in Schuenemeyer and Power (1998), and in Ellis and others, 1998.

Table 13. Data used for computation of confidence intervals within reliability categories for the Wyodak-Anderson coal zone. Rows may not sum due to independent rounding.

Parameter	Reliability Category				Entire Area
	Measured	Indicated	Inferred	Hypothetical	
Area (in square meters)	1,488,759,443	5,670,020,546	11,140,313,431	3,612,068,158	21,911,161,578
Percent of area	7	26	51	16	100
Acres	367,880	1,401,092	2,752,831	892,561	5,414,365
SD (Standard deviation (in ft) from variogram model)	18.38	22.78	26.67	26.89	
Acre feet (Acres x SD)	6,759,910	31,921,428	73,423,804	24,000,492	
Volume standard deviation (MST)	227	1,634	10,675	43,028	55,564
Pseudo n (Minimum number of points in the area)	2,928	1,239	152	1	

Table 14. Estimates of uncertainty for the Wyodak-Anderson coal with measurement error. Resource calculations are in millions of short tons (MST) with four significant figures. Rows may not sum due to independent rounding.

Parameter	Reliability Category				Entire Area
	Measured	Indicated	Inferred	Hypothetical	
Volume (in millions of short tons (MST))	43,670	167,700	303,700	35,610	550,700
Lower 90% confidence bound (MST)	43,300	165,000	286,100	0	459,300
Upper 90% confidence bound (MST)	44,050	170,400	321,200	106,400	642,100

CONCLUSION

The coal resources for the Wyodak-Anderson coal zone are approximately 550,000 million short tons with a lower confidence limit (at the 90-percent confidence interval) of 460,000 million short tons and an upper confidence limit (at the 90-percent confidence interval) of 640,000 million short tons. These calculations represent net coal (all coal beds greater or equal to 2.5 ft in thickness added together at each data point) and does not include coal in mine or lease areas, within areas of mapped clinker, or areas where coal thickness was extrapolated to be less than 2.5 feet in thickness. All coal was considered to be subbituminous in apparent rank, with a conversion factor of 1,770 short tons per acre-foot.

This report represents one aspect of the National Coal Resource Assessment for the Wyodak-Anderson coal zone. The production of comprehensive stratigraphic and coal quality data sets containing detailed correlations, digital data in the form of layered and attributed spatial data, and other reports on various aspects of this study, which will be available to the public, add a new dimension to future investigations.

SELECTED REFERENCES

Averitt, Paul, 1975, Coal resources of the United States, January 1, 1974: U.S. Geological Survey Bulletin 1412, 131 p.

Ayers, W.B., Jr., 1986, Coal resources of the Tongue River Member of the Fort Union Formation (Paleocene), Powder River Basin, Wyoming and Montana: Geological Survey of Wyoming Report of Investigations No. 35, 22 p.

Barnum, Bruce E., 1975, Geologic map and coal resources of the Ranchester quadrangle, Sheridan County, Wyoming and Big Horn County, Montana: U.S. Geological Survey Coal Investigations Map C-75, scale 1:24,000.

Berryhill, H.L. Jr., Brown, D.M., Brown, A., and Taylor, D.A., 1950, Coal resources of Wyoming: U.S. Geological Survey Circular 81, 78 p.

Biewick, Laura R.H., Urbanowski, Shayne R., Cain, Sheila, and Neasloney, Larry, 1998, Land status and Federal mineral ownership in the Powder River Basin, Wyoming and Montana: a digital data set for geographic information systems, U.S. Geological Survey Open-File Report 98-108, coverage scale 1:100,000.

Boyd, Cynthia S., and Van Ploeg, Alan J., 1997, Geologic map of the Gillette 30' X 60' quadrangle, Campbell, Crook, and Weston Counties, northeastern Wyoming: Wyoming State Geological Survey Map Series 49, scale 1:100,000.

Combo, J.X., Brown, D.M., Pulver, H.F., and Taylor, D.A., 1949, Coal resources of Montana: U.S. Geological Survey Circular 53, 28 p.

Combo, J.X., Holmes, C.N., and Christner, H.R., 1978, Map showing the coal resources of Montana: U.S. Geological Survey Coal Investigations Map C-2.

Culbertson, W.C., Hatch, J.R., and Affolter, R.H., 1978, Geology and coal resources of the Hanging Woman Creek Study area, Big Horn and Powder River Counties, Montana: U.S. Geological Survey Open-File Report 78-506. p. 1-37.

Dynamic Graphics, Incorporated, 1997, EarthVision, v.4.

Ellis, M.S., Gunther, G.L., Flores, R.M., Stricker, G.D., Ochs, A.M., and Schuenemeyer, J.H., in press, Preliminary report on the methodology for calculating coal resources in the Wyodak-Anderson coal zone, Powder River Basin, Wyoming and Montana: U.S. Geological Survey Open-File Report 98-789B.

Energy Information Administration (EIA), 1996, Energy Information Administration Annual Energy Outlook 1996, reference cast forecast, National Energy Modeling System run AEO96B, D101995C.

Energy Information Administration (EIA), 1998, Energy Information Administration Coal Industry Annual 1997: Department of Energy, DOE/EIA-0584 (97).

ESRI- Environmental Systems Research Institute, Inc., 1998, ARC/INFO, v. 7.1.1.

ESRI- Environmental Systems Research Institute, Inc., 1998, ArcView, v.3.0a.

Flores, R.M., 1986, Styles of coal deposition in Tertiary alluvial deposits, Powder River Basin, Montana and Wyoming: Geological Society of America Special Paper 210, p. 79-102.

Flores, R.M., and Roberts, S.B., 1996, Drainage network evolution during Paleocene Laramide structural partitioning of the northern Rockies: Geological Society of America Abstract with Programs, Denver, CO, p. A372.

Flores, R.M., Nichols, D.J., Perry, W.J., Jr., Ellis, M.S., Roberts, S.B., and Stricker, G.D., 1996, Rocky Mountain Paleocene Coal Basins: U.S. Geological Survey Energy Team Fact Sheet (poster).

Glass, G.B., 1996, Coal update: Wyoming Geological Survey Wyoming Geo-notes no. 51, August 1996, p. 25-38.

Glass, G.B., 1998, Coal resources of the Powder River Basin, *in*, Guidebook to Coal Geology of the Powder River Basin: Wyoming Geological Survey Information Circular no. 14, p. 97-131.

Glenn, M., 1979, Coal resources and coal quality of Pumpkin Creek EMIRA site, Powder River County, Montana: U.S. Geological Survey Open-File Report 79-589.

GRG Corporation, 1996, StratiFact, relational database software, v. 4.5.

Heffern, Edward L., Coates, Donald A., Whiteman, Jason, and Ellis, Margaret S., 1993, Geologic map showing distribution of clinker in the Tertiary Fort Union and Wasatch Formations, Northern Powder River Basin, Montana, U.S. Geological Survey Coal Investigations Map C-142, scale 1:175,000.

Heffern, Edward L., 1998, personal communication (unpublished mapping at scales of 1:24,000 and 1:100,000.)

Jones, Richard, and Glass G., 1991, Demonstrated reserve base of coal in Wyoming as of January 1, 1991: Wyoming Geological Survey Open-File Report 92-4.

Kanizay, S.P., 1978, Preliminary geologic map of the Sheridan area, northwestern Powder River Basin, Wyoming, U.S. Geological Survey Miscellaneous Field Studies Map MF-1043, scale 1:50,000.

Love, J.D., and Christensen, A.C., 1985, Geologic map of Wyoming: U.S. Geological Survey, scale 1:500,000.

Mapel, W.J., 1959, Geology and coal resources of the Buffalo-Lake de Smet area, Johnson and Sheridan Counties, Wyoming: U.S. Geological Survey Bulletin 1078, 148 p.

Molnia, C.L., Biewick, L.R.H., Blake, Dorsey, Tewalt, S.J., Carter, M.D., and Gaskill, Charlie, 1997, Coal availability in the Hilight quadrangle, Powder River Basin, Wyoming: a prototype study in a western coal field: U.S. Geological Survey Open-File Report 97-469, 21 p.

Nichols, D.J., Wolfe, J.A., and Pocknall, D.T., 1989, Tertiary and Cretaceous coals in the Rocky Mountains region: 28th International Geological Congress Field Trip Guidebook T132, p. 28-33, and 57-60.

Resource Data International, Inc., 1998, COALdat database, version 4.1 comprehensive data set, Software and data set available from Resource Data International, Inc., 1320 Pearl Street, Suite 300, Boulder, Colorado, 80302.

Roberts, R.L., Biewick, L.R.H, Molnia, C.L.1998, Federal Coal in the United States: U.S. Geological Survey Fact Sheet FS-12-98 (Internet access at http://energy.cr.usgs.gov/fedland/FS12-98/part5.html).

Ross, C.P., Andrews, D.A., and Witkind, I.J., 1955, Geologic map of Montana: U.S. Geological Survey and Montana Bureau of Mines and Geology, scale 1:500,000.

Schuenemeyer, J.H., and Power, H., 1998, An uncertainty estimation procedure for U.S. coal resources: 15th Annual International Pittsburgh Coal Conference CD-ROM, 13 p.

Smith, J.B., Ayler, M.F., Knox, C.C., and Pollard, B.C., 1972, Strippable coal resources of Wyoming: U.S. Department of the Interior Information Circular 8538, U.S. Bureau of Mines.

Stricker, G.D., Ellis, M.S., Flores, R.M., and Bader, L.R., 1998, Coal in the Northern Rocky Mountains and Great Plains Region—Clean, Compliant, and Available: Fifteenth Annual International Pittsburgh Coal Conference Proceedings, CD-ROM, 9 p.

Trent, V.A., 1986, Estimated resources of non-leased Federal coal, Powder River Basin, Montana and Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map MF-1887, scale 1:500,000.

Wood, Gordon H. Jr., Kehn, Thomas M., Carter, M. Devereux, and Culbertson, William C., 1983, Coal resource classification system of the U.S. Geological Survey: U.S. Geological Survey Circular 891, 65 p.