ESTIMATED RESOURCES OF NON-LEASED FEDERAL COAL, POWDER RIVER BASIN, MONTANA AND WYOMING

By

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INTRODUCTION

The 1976 Federal Coal Leasing Amendments Act (P.L. 94-377) and the 1976 Federal Land Policy and Management Act (P.L. 94-579) require that a comprehensive inventory of unleased Federal coal be made available to the public. The U.S. Geological Survey (USGS) responded in fiscal year 1977 by initiating a Coal Resource Occurrence/Coal Development Potential (CRO/CDP) map program to "determine the reserves of unleased Federal coal and to characterize for Federal land-use planning, the relative development potential of each leasable 40 acre tract" (Wayland, 1981, p. 543). The CRO/CDP map reports were to be compiled on 7.5-minute quadrangles using only publicly available data. Because of the need to meet time limitations of lease negotiations, most of the CRO/CDP work was to be done by consulting firms under contract; however, USGS geologists were to monitor each stage of completion.

For the Powder River Basin (Index map) the CRO/CDP program was officially completed by June 1982, when 243 of the 7.5-minute quadrangle reports contracted for had been placed on USGS open file. The results are summarized in Trent (1985) and also here in table 1; quadrangles involved are outlined on figure 1. Simultaneous use of table 1 and figure 1 allows the reader to locate and compare the large quantities of unleased, high development potential, strippable Federal coal. Each of the 243 CRO/CDP reports was reviewed prior to entering some of their data into the National Coal Resources Data System (NCRDS).

The CRO/CDP program for the Powder River Basin was restricted to estimating resources of unleased Federally owned coal contained in Tertiary coal beds more than 5 ft thick. Coal on Indian lands was not included in the estimates, and many quadrangles along the east and west margins of the basin (fig. 1) were not included in the CRO/CDP program. However, this report does include estimates of coal resources in seven 7.5-minute quadrangles near Sheridan, Wyo. (fig. 1) that were not included in the CRO/CDP program. USGS reports containing these estimates are listed in table 2 and in the references. Also available from other USGS reports are separate estimates of coal resources in many quadrangles that were included in the CRO/CDP program. These reports, listed in table 3, are also included in the references.

Acknowledgments

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GEOGRAPHIC SETTING

The Powder River Basin is a large north-northwest-trending topographic and structural basin in northeast Wyoming and southeastern Montana, between the Bighorn Mountains to the west, the Laramie Mountains to the south, and the Black Hills to the east (Index map). Northward, the Powder River Basin is separated from the Williston Basin by the Miles City arch (McGregor, 1972, p. 269). Coal-bearing rock underlies about 16,000 mi^2, of which there are nearly 10,000 mi^2 in Wyoming and 6,000 mi^2 in Montana. The northern part of the Powder River Basin includes virtually all of Powder River County and parts of Big Horn, Rosebud, and Custer Counties, Montana; the southern part of the basin includes all of Campbell County, as well as parts of Sheridan, Crook, Weston, Niobrara, Converse, Natrona, and Johnson Counties, Wyoming (Index map). The main drainages are north- and northeast-flowing tributaries of the Yellowstone River—Rosebud Creek, Tongue River, Powder River, and the Little Powder River. The central part of the basin in Wyoming is also traversed by the northeast-trending Belle Fourche River, which is a tributary to the Cheyenne River further east. The southern part of the basin is drained by streams that join the North Platte River, which then flows eastward to a junction with the Missouri River. The average elevation in the basin is 5,000 ft (McGregor, 1972, p. 270).

Land Use and Ownership

Before 1862, all land in the Powder River Basin was in the public domain, having been acquired by the United States as the result of the Louisiana Purchase in 1803. Congress passed Homestead Acts in 1862, 1909, and 1916 and other statutes to encourage settlement and convert much of this land to private ownership. Thus, millions of acres of public land were opened to entry and settlement. A homesteader retained the surface and mineral rights on his land if he acquired it before 1909. After certain "separation laws" were passed by Congress from 1907 to 1910, these rights were split, and the Federal government retained the mineral rights on lands sold thereafter. As a result, the Federal government has emerged as the largest holder of mineral rights in the Powder River Basin (U.S. Geological Survey, 1973).

Large acreages in the region, termed school lands, were transferred to state ownership. Specifically, sections 16 and 36 in every township were given to the States, with the stipulation that the income from these lands was to be used to support public education. The States control all surface and mineral rights in these areas.

Another significant land grant was given to the railroads in 1864 as an incentive to expand and open the area to commerce. Under this grant, title to all odd-numbered sections in an area 60 mi on each side of a railroad right-of-way was granted to the railroads traversing the area. Thus, Burlington Northern, Inc. (then Northern Pacific Railroad), shares the mineral rights about equally with the Federal government in part of the northern Powder River Basin around Colstrip, Mont.

Land ownership in the Powder River Basin is divided at present between the Federal government, State governments, the private sector, and the Crow and Northern Cheyenne Indians. Nearly 60 percent of the surface rights in the basin are privately owned, according to estimates using Bureau of Land Managment (BLM) land ownership maps for the region (U.S. Bureau of Land Managment, 1974-77). The Federal government controls about 27.5 percent of the basin, the States have jurisdiction over 7.5 percent, and the Indians own 5 percent. Mineral rights, on the other hand, are divided approximately as follows: 70 percent is controlled by the Federal government, 17.5 percent is privately owned, 7.5 percent is state owned, and 5 percent belongs to the Indians. Until about 10 years ago, Federal coal land could be leased more or less on demand, but currently all Federal coal leasing is on the basis of competitive auctions. All of the leased coal shown on the CRO/CDP reports was leased before competitive auctions were required by law.

About 87 percent of the basin is used for agricultural purposes, and roughly 90 percent of that area is rangeland suited for cattle and sheep grazing (U.S. Bureau of Land Management, 1981, p. 40). What farming there is consists mainly of dryland hay, both grass and alfalfa, or grain. Other land uses include mining, oil and gas production, transportation networks, national forests, Indian reservations, recreation areas, and urban areas.

GEOLOGIC SETTING

Stratigraphy

A thick sequence of sedimentary rocks and surficial deposits, whose ages range from Cambrian to Quaternary, unconformably overlie the Precambrian crystalline basement complex in the Powder River Basin. It has been estimated that as much as 18,000 ft of sedimentary rocks overlies the axial trough of the basin adjacent to the Bighorn and Laramie Mountains (McGregor, 1972, p. 269-270). The youngest rocks in the basin are coal-bearing Cretaceous and Tertiary strata. The outline of the Powder River Basin shown on the Index map and figure 1 of this report is at the boundary of the coal-bearing rocks of the Upper Cretaceous Mesaverde Formation (Glass, 1980, p. 99; Keefer, 1974). Many Tertiary coal beds are separated by variable rock sequences, ranging from thin shale beds to strata hundreds of feet thick that change from coarse sandstone or conglomerate to siltstone, claystone, and shale.

Cretaceous coal beds are interbedded in similar types of rock but are generally less than 10 ft thick and much less numerous. Because the Cretaceous coal beds are generally thin and mostly lie very deep in the basin, they are unimportant from a resource standpoint. No estimates of Cretaceous coal resources are presented in the CRO/CDP study.

The thickest and most important coal beds of the Powder River Basin are in the Paleocene Fort Union Formation and the Eocene Wasatch Formation. The Fort Union Formation is a prolific coal-bearing rock unit that ranges from 2,000 to 3,000 ft in thickness (Glass, 1980, p. 104). The thickest and most persistent coal beds are located at the top of the formation, in the 1,500- to 1,800-foot-thick Tongue River Member. Typically, the Tongue River Member consists of sandstone, siltstone, mudstone, shale, carbonaceous shale, and thick beds of coal (Kent and Berlage, 1980). The middle and lower members of the Fort Union Formation are, respectively, the Lebo Shale and the Tullock Member. The Lebo Shale comprises sandstone, claystone, shale, carbonaceous shale, and thin beds of coal. The Tullock Member is sandstone and silty shale, carbonaceous shale, and thin beds of coal (Kent and Berlage, 1980). The coal beds in the two lower members are not thick or widespread enough to be considered as important for coal resources (Glass, 1978, p. 20-21). Coals in the Tongue River Member are best developed in the northern and eastern parts of the Powder River Basin. Noteable are the 8 to 12 subbituminous coal beds cropping out along the Tongue River valley from Monarch, Wyo. to Decker, Mont. (Law and others, 1979) and in the Birney-Broadus coal field of Montana (Warren, 1959).

This report does not define stratigraphic boundaries in the Powder River Basin because there is considerable controversy about the correlation of coal beds and the position of the boundary between Paleocene and Eocene strata (Glass, 1978, p. 104-105). Some coal beds are assigned to different members of the Fort Union Formation because of lateral lithofacies changes. Therefore, with these problems in mind, I will present some properly referenced stratigraphic terminology. The Roland coal bed of Baker (1929) is considered to be the uppermost unit of the Fort Union Formation in some of the northern part of the Powder River Basin (Law and others, 1979; Olive, 1957). The thickest and economically most important coal bed in the Powder River Basin is the Wyodak-Anderson, which is from 50 to 100 feet thick in large areas. This coal bed, which has burned over many hundreds of acres, has been mapped for more than a hundred miles along the eastern side of the basin. Westward the Wyodak-Anderson splits into two or more beds, resulting in an expanded coal-bed nomenclature and correlation problems.

The Wasatch Formation, up to 2,000 ft thick and containing as many as eight thick persistent coal beds, overlies the Fort Union Formation. It crops out over much of the central part of the Powder River

Basin, mostly in Wyoming, and usually dips less than 4° toward the center of the basin. The thickest Wasatch coal is at Lake DeSmet on the west side of the basin north of Buffalo, Wyo. There the Healy coal bed locally exceeds 225 ft in thickness in drill holes (Mapel, 1959); it is the thickest coal bed described in Wyoming and probably in the United States. Another thick coal was found by drilling approximately midway between Buffalo and Gillette, Wyo. This deposit, with a maximum thickness of about 205 ft, is termed "Big George" and results from the coalescing of thinner coal beds of the Fort Union Formation (Bion H. Kent, USGS, oral commun., 1982). Generally, Wasatch coals are thickest and most persistent in the western and central parts of the basin (Glass, 1978, p. 21).

Structure

The Powder River Basin is a broad asymmetrical syncline whose axis trends north-northwest along its western side adjacent to the Bighorn Mountains (McGregor, 1972, pp. 269-270). In Montana, the structural axis trends northward through the Stroud Creek quadrangle (figure 1, Montana quadrangle 86) which is located in the trough of the basin (Mapel and others, 1978, p. 5). Most central and eastern parts of the Powder River Basin, including much of the area of this report, are situated along the homoclinal east limb of the fold where most beds dip westward at less than 2° and commonly less than 1°. In general, the Cretaceous rocks on the flanks of the basin dip more steeply than the nearly flat-lying Tertiary strata, except along the west and south flanks where locally Paleocene beds dip as much as 25° (Glass, 1978, p. 20). Although normal faults displace outcropping rocks in many parts of the basin, faults are relatively rare, except along the western margin particularly in southern Johnson County. Most faults in the Sussex area about 50 mi north of Casper, Wyo. trend northeastward and have maximum apparent vertical displacements of 300 to 400 ft.

COAL

The greatest long-term energy source in the Powder River Basin is immense quantities of low-sulfur subbituminous coal. Coal production from the Powder River Basin leads all other basins in the western United States; it is the principal reason that in 1984 Wyoming ranked third and Montana tenth in the nation after Kentucky (first) and West Virginia (second) in coal output (U.S. Department of Energy, 1985, p. 7-11). Preliminary coal production figures for 1985 indicate that Wyoming has displaced West Virginia as the second leading coal producing state with a total of 137.8 million short tons (U.S. Department of Energy, 1986, p. 67). There are six coal-fired electric powerplants at four localities in the Powder River Basin, having a total generating capacity of about 1,870 megawatts (Shifflett, 1982). Most coal mined in the Powder River Basin is sent to other steam-powered electric generating plants (Keefer and Schmidt, 1973) in the midwest and south-central United States (U.S. Bureau of Land Management, 1974, v. 1, p. 35). Only a minor part of the basin's coal production is consumed in the Powder River Basin powerplants.

Coal Production

Huge quantities of low-sulfur subbituminous coal have been strip mined from thick beds in the Powder River Basin of Montana and Wyoming. Annual production of coal from the Powder River Basin has been increasing steadily since the Organization of Petroleum Exporting Countries (OPEC) oil embargo in 1973, and the percentage of total U.S. production from the basin has also increased from 1.8 percent in 1973 to 18.9 percent in 1985 (table 5). Most of the increase of nearly 19 million short tons from 1978 to 1979 came from one new mine and expanded production at the other operating mines near Gillette in Campbell County, Wyoming. Campbell County by a wide margin is the first-ranked coal-producing county in the country, having produced 106.8 million short tons of subbituminous coal from 14 surface mines in 1984 (U.S. Department of Energy, 1985, pp. 7-11).

An in-depth study of world coal supply and production has been made by Mr. A.M. Clarke, of the British National Coal Board (written commun., 1983). Briefly, his research suggests that in projecting coal output for very large basins over long-term time intervals (15-20 years), the rates of production have a momentum of their own. The coal production rates continue on the same gradient regardless of fluctuations caused by ups and downs of business cycles, wars, labor problems, or changes in technology. He also believes that coal is a unique commodity because even though it is undergoing world-wide depletion, its long-term future price trend will be downward.

Future coal production from the Powder River Basin is projected to increase more slowly during the next few years because of a lessening of electric power requirements and business activity. Using the long-term coal production trends shown by table 5, I estimate that the total United States coal production will be about 1 billion short tons by 1990, and that about 230-250 million short tons of that total will be produced from the Powder River Basin. A more optimistic estimate has been published by Data Resources, Inc., a econometric forecasting service. Coal production from the Powder River Basin is projected by this firm to increase 14.4 percent in 1984 and in 1985, and they estimate that 409 million short tons of coal will be produced from the Powder River Basin in the year 2000 (Coal Week, 1984, p. 3).

Coal Rank and Quality

Most of the Powder River Basin coals are subbituminous in rank and low in sulfur; Btu values are relatively low, but the low sulfur content makes the coal a prized fuel because little or no cleaning is required to meet established emission standards. In general, these coals contain less than 0.5 percent sulfur, and ash content ranges from 5 to 8 percent.

Coal rank in the Powder River Basin of Montana ranges from lignite A along the eastern margin of the basin to subbituminous A, which predominates to the west (see table 6 for explanation of coal rank). Lignite underlies the northeastern part of the basin in a strip two to three quadrangles wide where the strata were less-deeply buried along the edge of the basin. This rather limited area of lower-rank coal is a southward extension of the Tertiary Fort Union lignite field in North Dakota and Montana (Trumbull, 1960). With few exceptions, the coal beds in this part of the basin are low in sulfur (less than 1 percent) and have low to moderate ash contents. Heating values determined from coal samples range from roughly 6,500 Btu/lb along the eastern side of the basin to about 9,500 Btu/lb in the vicinity of Decker, Mont. (Matson and Blumer, 1974, p. 13).

The rank of the thicker and more important coal beds in the Wyoming portion of the Powder River Basin varies from lignite A in the northeast to subbituminous C or B over much of the remaining basin area (Glass, 1978, p. 20). The subbituminous Tertiary coals have as-received moisture contents of 20 to 30 percent (mean value is 26.3 percent) and about equal percentages of volatile matter and fixed carbon. For the coal beds currently being mined in northeastern Wyoming, the sulfur content ranges from 0.45 to 0.6 percent, the mean value being 0.54 percent (Glass, 1978, p. 8). The ash content for coal sampled from the Wyoming part of the basin ranges from 4.4 to 11.4 percent—the mean value is 7.9 percent. The heat content values for coal samples from this part of the basin range from 7,550 to 8,700 Btu/lb, and the mean value is 8,300 BTU/lb (all values were determined on an as-received basis) (Glass, 1978, p. 8).

Generally coal beds in the northern Great Plains, including those in the Fort Union Formation of Montana and Wyoming, contain appreciably lesser amounts of most chemical elements of environmental concern than do coal beds in other areas of the United States (Hatch and Swanson, 1977, p. 147). Studies have shown that most Wyoming coals can be washed to reduce their ash contents to within suitable yield limits (Glass, 1978, p. 9). Also, most Wyoming coals are non-agglomerating and may be carbonized in fluidized systems (Glass, 1978, p. 12-13), although the end product—a lump char—is relatively weak.

CRO/CDP PROGRAM SPECIFICATIONS AND PRODUCTS

Primary objectives of the CRO/CDP map program were to classify and estimate coal resources on 7.5-minute quadrangles, according to tonnage categories of surface-minable coal, deep-minable coal, and in situ gasification coal. Relative development potentials (high, moderate, low) were to be calculated for both surface-mining and in situ gasification, to serve as guides for land-use planning by the BLM, and to help set priorities for leasing.

The Department of the Interior designated the Powder River Basin as one of the first priority areas for the initial resumption of general coal leasing. The Geologic Division of the USGS was one of the initial contractors for the Powder River Basin CRO/CDP program, and USGS geologists began work in 13 quadrangles of the Montana part of the basin (fig. 1).

Reserve base problem

Two USGS definitions for reserve base are used in this report. When the USGS geologists began work on the 13 quadrangles in Montana at the start of the CRO/CDP program, no formal contract specifications had been set. It was agreed that the reserve base should include subbituminous coal beds 60 in. or more thick that occur at depths to 1,000 ft, and that the stripping limit for surface-minable coal be 200 ft. These limits conformed to the accepted definition and criteria for the reserve base in standard use at that time, (U.S. Bureau of Mines and U.S. Geological Survey, 1976, p. B5) and now (Wood and others, 1983, pp. 29-30). However, when the USGS contract specialists and monitors later wrote the specifications for the private contractors, they changed the limiting depth criteria for surface-minable coal to 500 ft, and the criteria for reserve-base coal to a depth limit of 3,000 ft. Hereafter, the latter will be referred to as the reserve base and the former as the standard reserve base. Therefore, the standard reserve base definition applies only to the 13 quadrangle reports in Montana that were mapped by the USGS (fig. 1), while for the remaining 230 CRO/CDP reports in the Powder River Basin the reserve base is applicable.

Contract specifications

The coal resources inventoried in this program exist in a wide range of geologic conditions. So that the CRO/CDP maps and estimated resource figures would be consistent, it was necessary to standardize terms and conditions before bids for the work could be called for. USGS field and headquarters personnel had to make many difficult choices, as is evident in this selected list:

- 60 in. minimum coal bed thickness for all mining methods;
- 3,000 ft maximum limit of depth of burial for conventional underground mining methods;
- 200 ft stripping limit for a single coal bed less than 40 ft thick;
- 500 ft stripping limit for thicker beds or multiple beds;
- 0-15^{o} dip for conventional underground mining methods
- 15-90^{o} dip for in situ production, except in the Powder River Basin where all dips are very low
- 85 percent recovery of coal tonnages for surface mining
- 50 percent recovery of coal tonnages for conventional underground mining methods, but only for a maximum thickness of coal beds of 12 ft

Reliability categories based only on distance from data points are: Measured coal--0 to 0.25 mi; Indicated coal--0.25 to 0.75 mi; and Inferred coal--0.75 to 3 mi (fig. 2).

Coal Resource Occurrence maps

Each CRO/CDP report listed in table 4 and the pamphlet Appendix consists of a brief text and a group of maps (the average is about 20) of a 7.5-minute quadrangle. There is a general description of the CRO/CDP program in each text and a summary of the geology for each quadrangle. Included also, in addition to the classified coal resource tonnages for the quadrangle, are all available quality data for coal beds underlying the map area and a discussion of the coal development potential. The first of the maps (all have a planimetric township and range base) consists of three plates: plate 1, the Coal Data Map, showing basic geologic data including mapped coal beds with coal data points (coal thickness measurements) plotted along with mines and prospects, drill holes, and areas of burned coal; plate 2, the Boundary and Coal Data

Map, showing the area underlain by recoverable coal (the total tonnages of reserve base coal are listed by section), all non-Federal coal land, and the leased coal areas and plate 3, the Coal Data Sheet, which has a generalized geologic columnar section for the quadrangle, and at least one cross section derived from drill holes and(or) measured sections with the coal beds correlated where possible.

Two to five derivative coal bed maps were then prepared for each coal bed thick enough to be part of the reserve base category (60 in. +). These derivative maps include coal bed isopachs, structure contours, and overburden isopach and mining ratio maps; two additional maps also show the areal distribution of identified coal resources by section, and the total resources for each coal bed on a strippable and non-strippable basis.

The coal resources could have been calculated for other areas of interest, such as previously leased Federal and State lands and privately owned coal lands, because the coal resource occurrence maps show coal thickness information for all categories of land ownership except Indian lands. However, for this study only the unleased Federal coal was estimated so that leasing could proceed in approved areas according to a schedule. Before the estimation of coal resources could begin, a USGS monitor met with the contractor to select an applicable stripping limit and a mining recovery factor for each quadrangle, and to decide on any other limiting conditions. Thereafter, the contractor was only concerned with unleased Federal coal in known recoverable coal resource areas (KRCRA) boundaries within the quadrangle.

By definition, all coal that lies within a radius of 0.25 mi of a coal data point (a site where the thickness of coal was measured as shown in fig. 2) was classified as measured coal. The area surrounding the data point within a radius of 0.75 mi and beyond the measured coal area was classified as indicated coal. Lastly, the area around the data point circumscribed by a 3-mile radius and beyond the indicated coal was classified as inferred coal. The contractor drew the arcs around the coal data points and the areas made by the intersection of these arcs with the known boundary of unleased Federal coal permitted the calculation of measured, indicated, and inferred coal. Then the tonnage of in-place coal was calculated for each of these categories and plotted for each section of land. Separate tabulations were compiled for surface-minable and deep-minable coal.

Coal Development Potential maps

Coal development potential maps delineate areas that have high, moderate, and low coal development potential for surface mining, underground mining, and in situ gasification. Arbitrary standards for calculating development potential were devised by USGS personnel and incorporated into the contract specifications.

Coal Development Potential for surface mining.--The CDP for surface-minable coal is based upon the coal bed mining ratio value (MR), where

$$MR = \frac{\text{cubic yards of overburden}}{\text{short tons of recoverable coal.}}$$

Where MR = 0 to 10 the coal development potential is high, if MR = 10 to 15 the coal development potential is moderate, and if MR is greater than 15 the coal development potential is low. The coal development potential for surface mining is based only on a mining ratio applied to coal 5 ft or more thick to a depth of 500 ft (200 ft for the 13 quadrangles completed by the USGS geologists in Montana). The coal development potential classification for each tract of land is that of the highest classification of development potential for any one coal bed in the area.

Coal Development Potential for underground mining.--USGS personnel reached the decision that underground coal mining in the Powder River Basin was not economically feasible, mainly because of exceedingly thick coal beds and dangerous roof conditions, so contractors were not required to calculate the develpment potential for underground mining. For purposes of this report, however, all resources of underground coal that would otherwise be included in the reserve base are arbitrarily assigned a low coal development potential for underground mining.

Coal Development Potential for in situ gasification.--Subsurface coal beds in the Wyoming part of the Powder River Basin were evaluated for in situ gasification development potential on the basis of criteria as follows:

> Low development potential relates to: a) a total coal section less than 100 ft thick that lies 1,000 ft to 3,000 ft beneath the surface, or b) a coal bed or coal zone 5 ft or more thick that lies 500 ft to 1,000 ft beneath the surface; and to inclined beds whose dip is 15° to 35°.
>
> Moderate development potential is assigned to a total coal section from 100 to 200 ft thick and buried from 1,000 to 3,000 ft beneath the surface; and to inclined beds whose dip is 35° to 90°.
>
> High development potential involves 200 ft or more of total coal thickness buried from 1,000 to 3,000 ft; and the degree of dip of inclined beds is not applicable.

CDPs for in situ gasificaton of subsurface coal beds in the Montana part of the basin were not calculated.

Land-use planners, for whom the end products were designed, may find the data plates and derivative maps and reports generally instructive. The USGS will use the products as the starting point for further data collection and synthesis and for re-interpretation in light of new publicly available or proprietary information.

RESOURCE ESTIMATES OF UNLEASED FEDERAL COAL

Table 1 summarizes estimated resources of non-leased Federally-owned coal in the 243 quadrangles included in the CRO/CDP map program for the Powder River Basin, Montana and Wyoming. The grand total of these estimated reserve base coal resources (down to 3,000 ft depth of overburden and for beds 5 ft thick or greater) is approximately 775 billion short tons (table 1). Most of these coal resources, an estimated 633 billion short tons, are in Wyoming, where the basin is deeper and coal beds are more numerous and tend to be thicker than those in Montana.

About one-third (32 percent) of the area of each of the 243 quadrangles was not evaluated in this CRO/CDP map program, and therefore was not included in this estimate. Areas not evaluated in the 243 quadrangles include coal lands already leased, non-Federal coal lands, and Indian lands. Between 70 and 80 other 7.5-minute quadrangles were not evaluated in the Powder River Basin, nearly 44 of which are located in the Sheridan, Buffalo, and Lake DeSmet coal fields of Wyoming.

The geologic assurance or degree of reliability of the quadrangle coal resource estimates as suggested by the categories of measured, indicated, and inferred coal is available for the 108 quadrangles in Montana. Based upon the arithmetic means of the reliability measurements, 5 percent of the coal tonnages are measured, 25 percent are indicated, and 70 percent are inferred. I believe that the mean reliability measurements for the 135 quadrangles in Wyoming would approximate these results. This information may have been compiled by the contractor, IntraSearch Inc., but it was not presented in the quadrangle reports.

Reserve base coal estimates

The contractors were instructed by the USGS to classify all identified coal more than 5 ft thick to a depth of 3,000 ft. This does not follow the definition of the term reserve base as used by the U.S. Bureau of Mines and U.S. Geological Survey (1976) or Wood and others (1983, p. 29). Only the results presented in the 13 quadrangles in Montana by USGS geologists are in accord with the formal USGS definition of reserve base—that is, all identified coals 60 in. or more thick (for subbituminous coal) that occur to a depth of 1,000 ft. As discussed previously, all other quadrangles (230 quadrangles) includes all coal thicker than 30 in. to a depth of 3,000 ft in the reserve base category. Table 1 shows that there is an estimated quantity of nearly 200 billion short tons of non-leased Federal stripping coal alone in the evaluated part of the Powder River Basin.

Perhaps the most important products of the program are the CDP maps. The CDP depends on measurements of coal bed thickness and depth of overburden, computation of mining recovery factors, and the quality of the coal. A CDP map shows the parts or areas (as small as 40 acres) of that quadrangle according to the high, moderate, or low development potential of three classes of coal: 1) surface-minable or strippable coal; 2) underground-minable coal; and 3) in situ gasificaton coal.

For the Powder River Basin CRO/CDP program, however, USGS personnel judged all underground-minable coal to have low development potential, and the development potential of gasification coal was not determined for CRO/CDP quadrangles in Montana (see table 1). Strippable coal of high development potential represents the best of the coal resources in the Powder River Basin; tonnages of that class of coal are shown on the resource map (figure 1).

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APPENDIX

The following is a list by state of complete references for all of the 7.5-minute quadrangles shown on the accompanying sheet and listed in table 4. The scale for all the reports is 1:24,000.

MONTANA

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