Chapter IN

INTRODUCTION

By R.M. Flores and D.J. Nichols

in U.S. Geological Survey Professional Paper 1625-A

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PERSPECTIVES

The section entitled Perspectives is an Acrobat presentation that summarizes the rationale for the coal assessment study in the Northern Rocky Mountains and Great Plains region. The text and illustrations explain the “why,” “how,” and “where” of the assessment, and demonstrate the benefits to society. Click here to begin.

OBJECTIVES

The objectives of the coal resource assessment are to:

- Compile the information needed and assess selected coal beds and zones of the Fort Union Formation and its equivalent formations that are potentially minable in the next two or three decades.

- Identify clean and compliant coal that meets standards of the U.S. Environmental Protection Agency for sulfur, ash, and trace elements of environmental concern.

- Create a publicly available digital database of this coal that can be rapidly accessed and analyzed to provide information critical to decision-making by government, industry, and the public.

- Produce widely available digital products accessible in a variety of interpretive and interactive forms. (Please contact Romeo M. Flores at rflores@usgs.gov for more information.)

STRATEGY

The high quality of coal in selected Fort Union and equivalent coal beds and zones in the Northern Rocky Mountains and Great Plains region, in general, and in the Powder River Basin, in particular, makes it an important energy resource for continued development and expanded utilization within current and future environmental constraints. Our strategy to investigate and assess these important coal beds and zones is to create, manage, and analyze digital databases from which derivative digital products can be generated. Interpretive and interactive digital presentations and databases are provided in this report for users to utilize the data and metadata. Thus, this detailed investigation of these clean and compliant coal resources provides new and needed information for coal availability and recoverability, and for future mining development into the next century. The coal data and resource estimates provided in this report are also needed on a basinwide scale for potential coal-bed methane resource assessments.

BACKGROUND

- The Fort Union Formation (Paleocene) and equivalent rocks of Paleocene age in the Northern Rocky Mountains and Great Plains region contain 18 coal beds and zones that yielded more than 38 percent (383 million short tons) of the greater than 1 billion short tons of coal produced in the United States in 1998.

- Coal in the Fort Union Formation and equivalent rocks is a valuable resource because the coal beds and zones within these stratigraphic units are thick, and the coal is clean and compliant (low in ash, low in sulfur, and relatively low in concentrations of trace elements of environmental concern named in the Amendments to the 1990 Clean Air Act).

- The coal beds and zones in the Fort Union and equivalent rocks are targets for continued development and expanded utilization in the next 20-30 years.

- The coal in the Fort Union and equivalent rocks is in demand by as many as 144 electric power generation plants in 25 States of the conterminous United States, and also in foreign countries.

- Thus, Fort Union and equivalent coal will make an important contribution to the economic and industrial growth of the Nation, and its utilization deserves recognition and assessment.

GEOLOGIC SETTING

COAL GEOLOGY

- The Northern Rocky Mountains and Great Plains region of Wyoming, Montana, and North Dakota contains a vast expanse of the Fort Union Formation and equivalent Paleocene coal-bearing rocks (fig. IN-1).

- These coal-bearing rocks (fig. IN-2) exist from the surface down to a depth of about 6,000 ft in shallow basins, such as the Powder River, Williston, and Greater Great River Basins, and from the surface to a depth of 12,000 ft in deep basins such as the Hanna Basin.

- The apparent rank of Fort Union and equivalent coal ranges from lignite to subbituminous in the shallow basins and subbituminous to bituminous in deep basins.

- Deep basins were influenced more extensively by Tertiary Laramide deformation than were the shallow basins.

- Paleotectonic history and depositional settings (fig. IN-3) of the swamps in which this coal accumulated contributed to the high quality of the Fort Union and equivalent coal.

COAL STRATIGRAPHY

- The Fort Union Formation (fig. IN-4) is present in the Powder River, Williston, and Greater Green River Basins.

- Stratigraphically equivalent to the Fort Union Formation are coal-bearing rocks in the Ferris (fig. IN-5) and Hanna Formations in the Hanna and Carbon Basins of Wyoming.

- Major production of Fort Union coal in the Powder River Basin is from the Wyodak-Anderson (fig. IN-6), Rosebud, and equivalent coal beds and zones. These coal deposits, which range from 25 to 140 ft thick, produce from 25 mines more than 38 percent of the total U.S. coal production.

- The producing Fort Union coal beds and zones in the Williston Basin include the Beulah-Zap (fig. IN-7), Hagel, and Harmon coal beds and zones. These coal beds and zones range in thickness from 20 to 40 ft.

- Coal production in the Ferris and Hanna Formations in the Hanna Basin is from the Ferris Nos. 23, 25, 31, 50, and 65 coal beds and Hanna Nos. 77, 78, 79, and 81 coal beds, which are each as much as 36 ft thick.

- The producing Fort Union coal zone in the Greater Green River Basin is the Deadman coal zone (fig. IN-8), which has beds ranging from 2 to 33 ft thick.

BIOSTRATIGRAPHY

- Biostratigraphy uses fossils to determine age relations and correlations of coal deposits in the Northern Rocky Mountains and Great Plains region.

- The most common and most useful fossils in coal and coal-bearing rocks are microscopic spores and pollen grains of ancient plants. Thus, palynology (the study of plant microfossils) has been applied throughout the region to provide the biostratigraphic framework.

- Biostratigraphy based on fossil spores and pollen (fig. IN-9) is called palynostratigraphy.

- In the Northern Rocky Mountains and Great Plains, palynostratigraphic age determinations of the uplifts, basins, and coal deposits support interpretations of the evolution of the basins and the origin of Fort Union Formation and equivalent coal resources.

- The regional palynostratigraphic zonation divides the Paleocene into six biozones designated, from oldest to youngest, P1 through P6 (fig. IN-10). The biozones are defined by occurrences of species of the related genera *Momipites* and *Caryapollenites* and other species of fossil pollen.

- Palynostratigraphy is used to place all coal beds and zones in the assessment region in a stratigraphic framework (fig. IN-11).

- Palynostratigraphy is the basis of correlations of coal-bearing rocks between basins in the Northern Rocky Mountains and Great Plains region (fig. IN-12).

DEPOSITIONAL SETTINGS AND THEIR INFLUENCE ON COAL RESOURCES

About 55 to 60 million years ago when the Fort Union and equivalent coal-forming peat accumulated, the Northern Rocky Mountains and Great Plains region was primarily continental (Brown, 1958). Marine and coastal-plain environments were restricted to areas near the Cannonball Sea in what is now North Dakota and South Dakota. Areas west and southwest of the Cannonball Sea, in what is now Montana and Wyoming, were in constant change as a result of continuing uplift of mountain ranges and formation of basins between these uplifts. After a few million years had elapsed, river systems and their associated floodplains, lakes, and swamps formed a network of waterways and wetlands in the basins.

EARLY PALEOCENE

Large river systems (fig. IN-13) in what is now Montana and Wyoming generally flowed eastward and northeastward toward the Cannonball Sea (fig. IN-13) in what is now North Dakota and South Dakota (Flores, 1986). Coal-forming swamps or mires formed between river channels near the headwaters and downstream parts of river systems. Along the coast of the Cannonball Sea, delta, barrier, and tidal deposits (fig. IN-13) were formed (Flores, 1998).

MIDDLE PALEOCENE

Some of the large river systems changed to short, high-gradient streams as mountain building (fig. IN-14) continued to reshape the landscape. Coal-forming mires along river channels and associated lakes were widespread from the headwaters of the rivers to the coastal plain. The Cannonball Sea retreated northeastward, followed by an encroaching coastal plain where mires formed on abandoned delta, barrier, and tidal deposits.

LATE PALEOCENE

As mountain building continued, short, high-gradient drainage systems within developing basins were either ponded into lake systems (fig. IN-15) or flowed through the basins toward the seaway. Large coal-forming mires (fig. IN-15) developed in the basins between river channels and along lake margins. The extent and distribution of the swamps were controlled partly by the size and pattern of these networks of rivers and lakes, and partly by mountain-building activity. As a result, coal beds that formed from these swamps are generally discontinuous and lenticular. Many of the thick peat accumulations, which resulted in thick coal beds, developed in multiple, stacked, domed mires (fig. IN-15) that sheltered the peat from floods and burial by sediments. Coal beds in the Powder River Basin in excess of 200 ft thick reflect the repeated life cycle of swamp growth, demise, and rejuvenation over long periods of time within tectonically subsiding basins.

INFLUENCE OF DEPOSITIONAL ENVIRONMENTS

Depositional environments influence the thickness, shape or geometry, and distribution of Fort Union and equivalent coal. Generally, coal thickness depends on how long peat is permitted to accumulate within the swamp or mire. In this region, peat accumulation was primarily influenced by incursion of river sediments due to floods. Thus, how far the swamp was from river channels, how low or high was the topography of the mire, and the chemical and biological conditions existing in the mire determined the nature and duration of peat accumulation. Thick peat formed in chemically highly reduced, raised mires removed from river channels, with plant growth sustained by high rate of rainfall. The shape and distribution of coal beds are reflected by the location of the peat-forming swamps in the depositional environments. For example, peat-forming swamps between river channels formed lenticular shapes. Furthermore, when these river channels are abandoned, these discontinuous, lenticular, peat-forming swamps advanced and coalesced over channel deposits, forming a continuous bed.

The quality of coal (as demonstrated by sulfur, ash, and trace elements contents) is directly related to the depositional environment. For example, peat that accumulated in coastal swamps that were transgressed by brackish and marine water commonly produces coal that has a high sulfur content. Peat that accumulates in fluvial or continental areas far removed from marine influence produces coal that has a low sulfur content. Peat mires that are protected from sediment-carrying floods by raised topography produce coal that contains low amounts of ash or fine particulates. However, peat mires that are topographically low-lying and flooded by sediments produce coal high in ash and trace-element content.

COAL QUALITY

- Fort Union and equivalent Paleocene coal is considered clean, low contaminant-bearing, and compliant with the 1990 Clean Air Act Amendments.

- Coal in the Powder River and Williston Basins contains less sulfur and ash than coal produced from other regions in the conterminous United States, as shown in table IN-1 (arithmetic means for the Powder River Basin based on 279 samples; arithmetic means for the Williston Basin based on 281 samples).

- When sulfur values are compared on pounds of SO_2 per million Btu basis (table IN-2), Powder River Basin coal has the lowest mean content of SO_2 per million Btu of any coal in the conterminous United States.

- The quantity of trace elements of environmental concern named in the 1990 Clean Air Act Amendments (antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium, and uranium) is of increasing importance in meeting compliance standards.

- Powder River Basin coal has among the lowest concentrations of most of these elements when compared to coal from other coal-producing regions in the conterminous United States (table IN-3) on a whole-coal, remnant-moisture basis.

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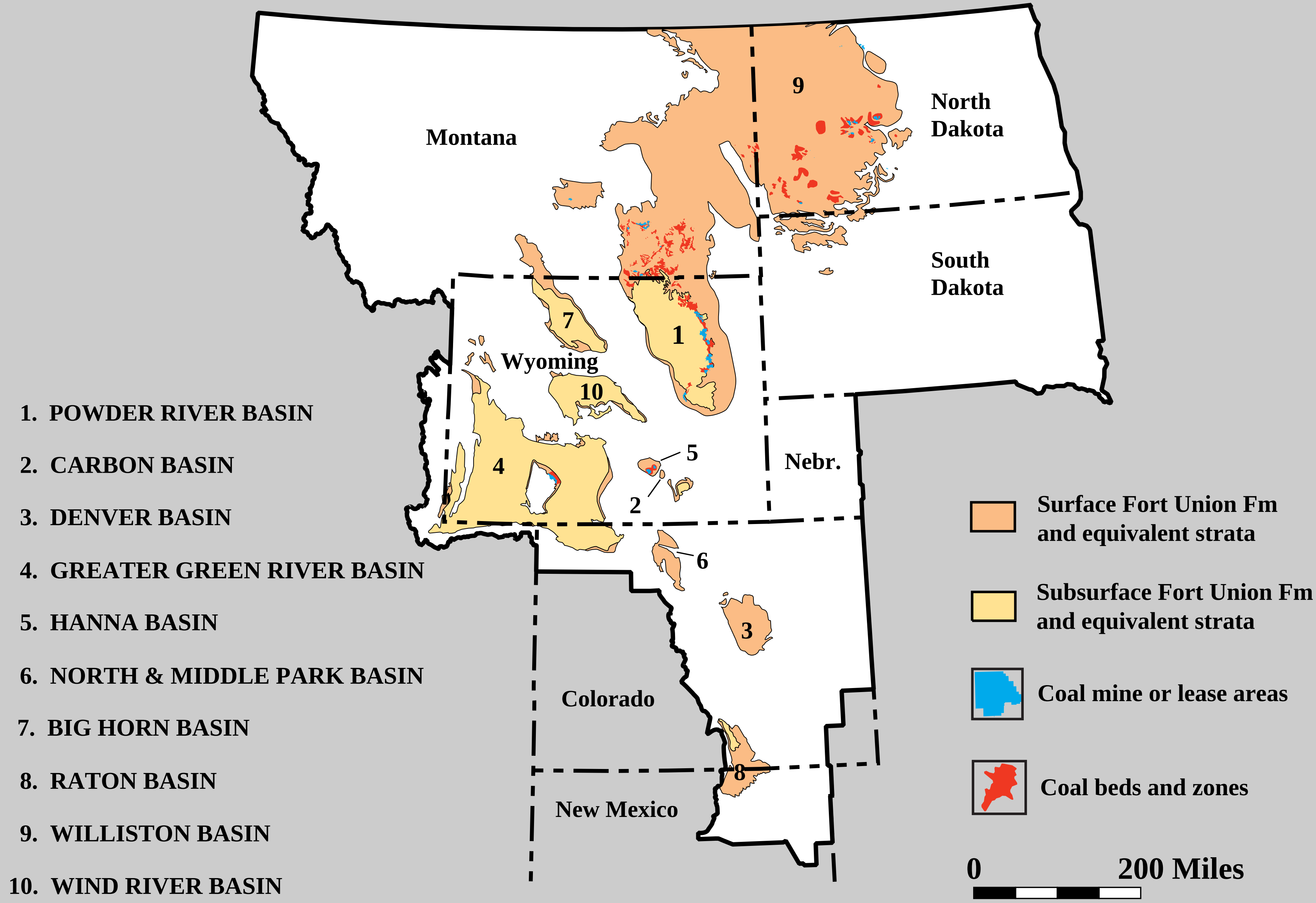

Figure IN-1. Index map of Northern Rocky Mountains and Great Plains region showing locations of sedimentary basins and distribution of Fort Union Formation and equivalent Paleocene strata and coal.

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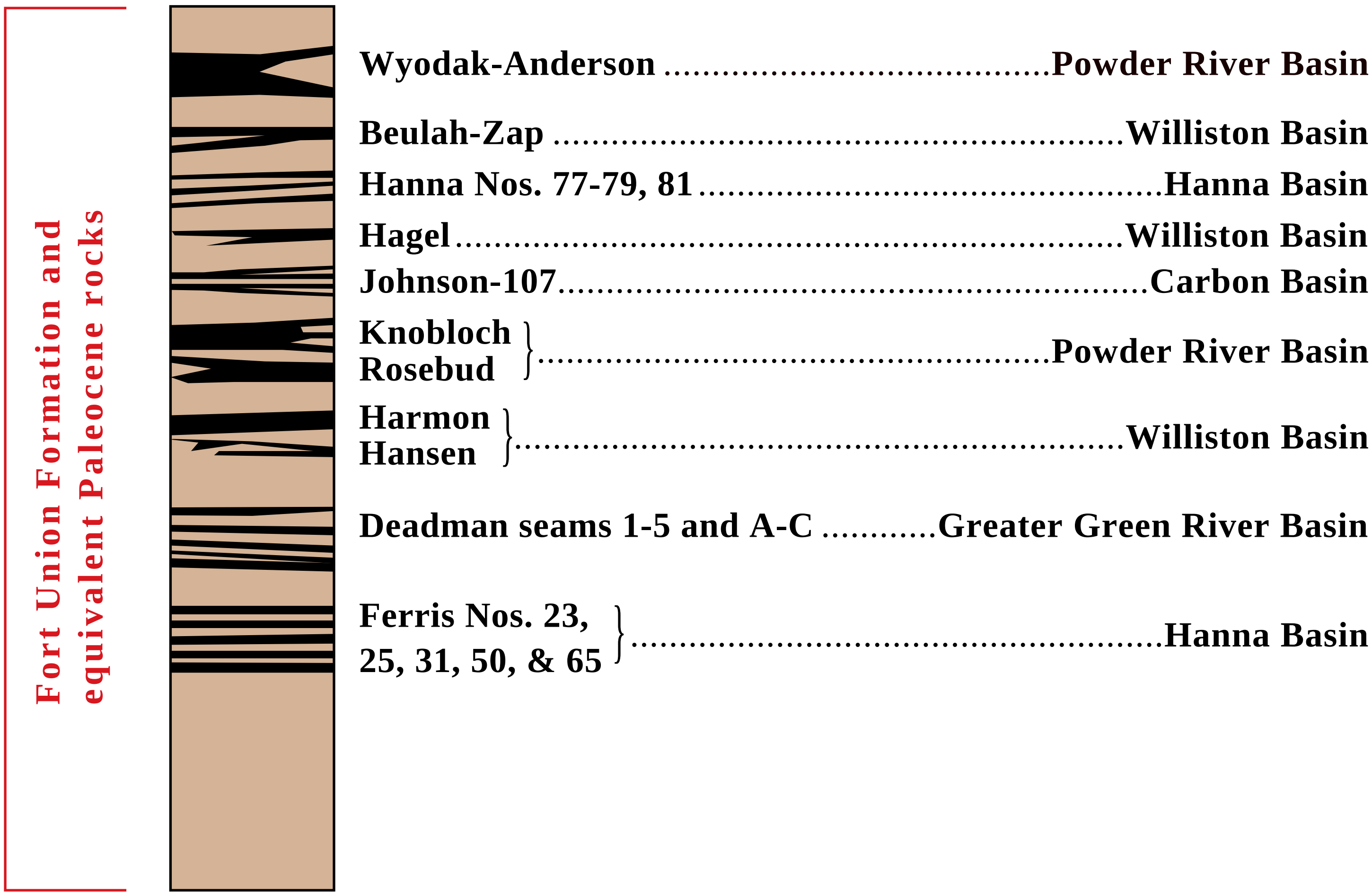

Figure IN-2. Composite stratigraphic section of coal-bearing Tertiary (Paleocene) rocks in the four major basins studied in the Northern Rocky Mountains and Great Plains region. The named coal beds and zones in the Fort Union Formation and equivalent rocks are covered in detail in this assessment.

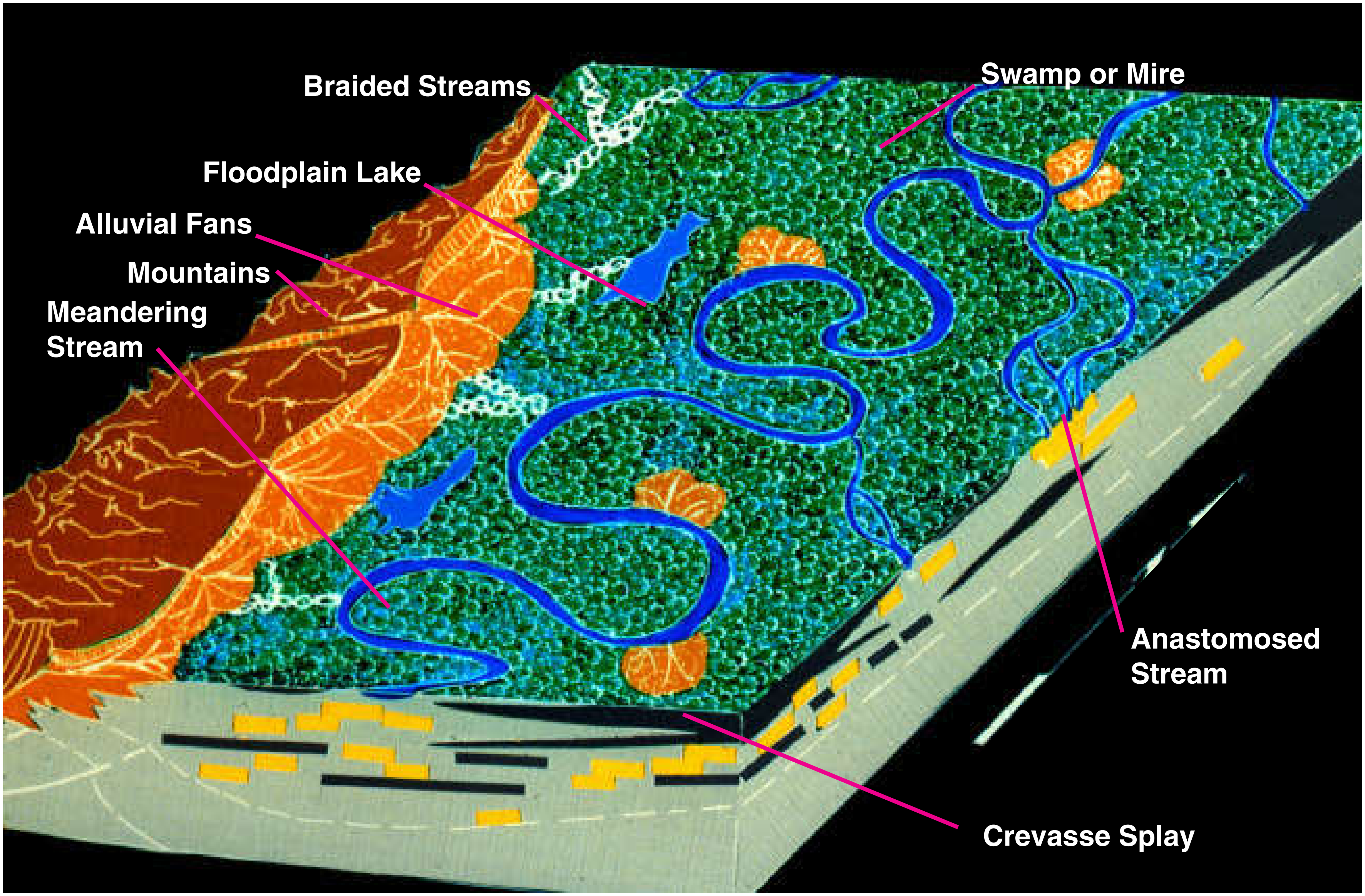

Figure IN-3. Fluvial depositional model.

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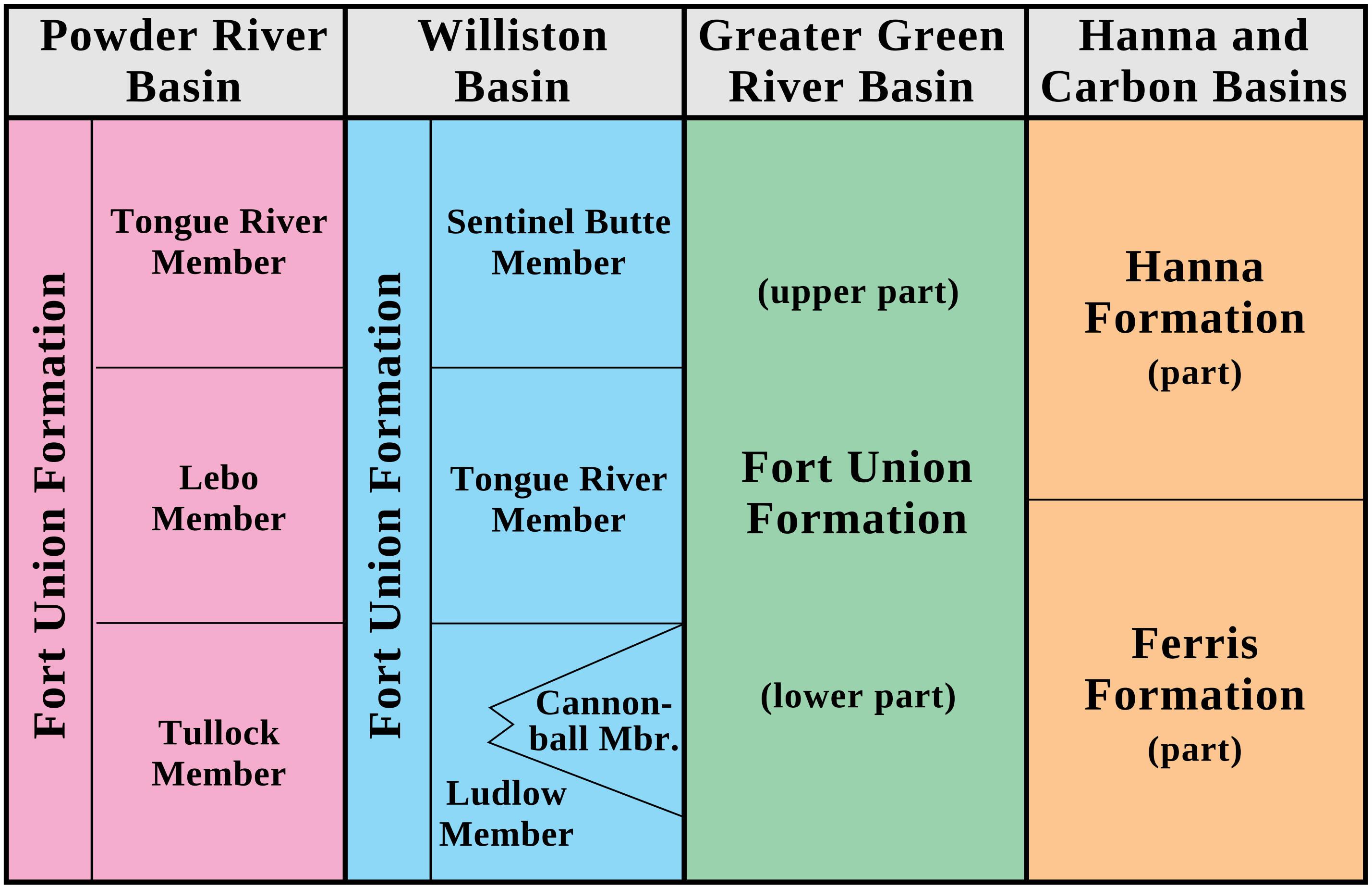

Figure IN-4. Stratigraphic nomenclature for the Paleocene of the Northern Rocky Mountains and Great Plains region.

Figure IN-5. Ferris coal beds.

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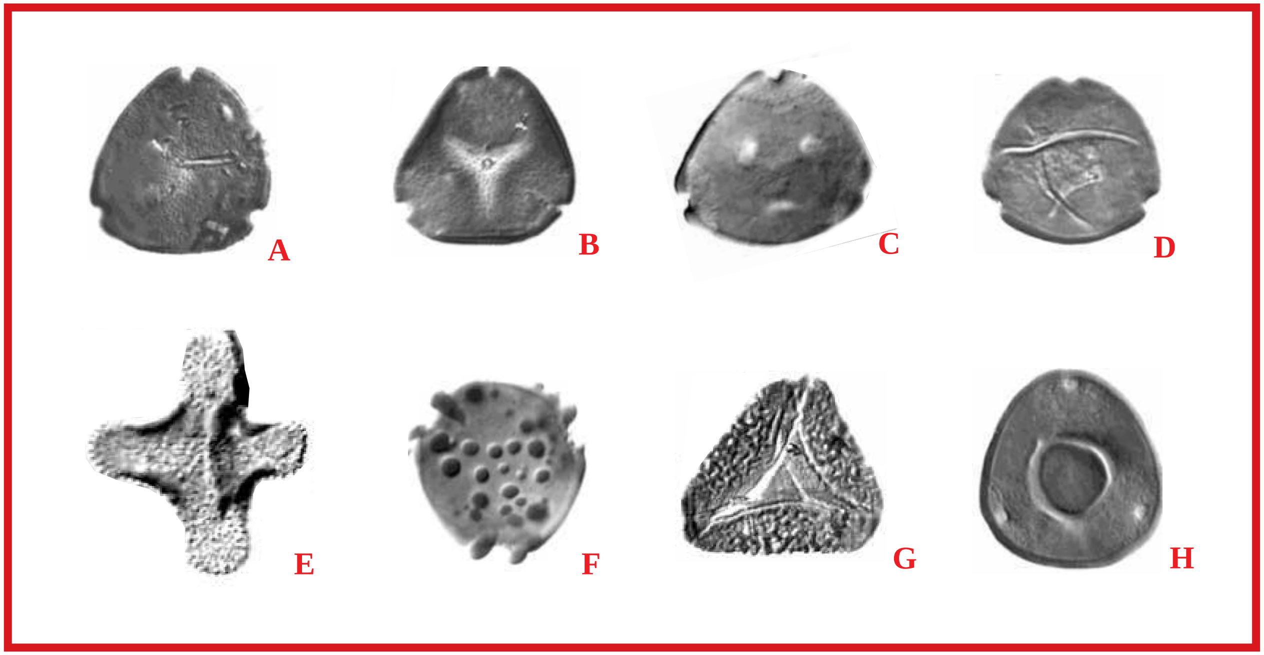
Figure IN-6. Wyodak-Anderson coal zone.

Figure IN-7. Beulah-Zap coal zone.

Figure IN-8. Deadman coal zone.



A - *Momipites wyomingensis*, B - *Momipites actinus*, C - *Momipites ventifluminis*, D - *Platycarya platycaryoides*, E - *Aquilapollenites spinulosus*, F - *Pistillipollenites mcgregorii*, G - *Insulapollenites rugulatus*, H - *Caryapollenites veripites*

Figure IN-9. Some key species of fossil pollen used in biostratigraphic zonation of the Paleocene and Eocene in the Rocky Mountain region.

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lower Eocene	*Platycarya platycaryoides*	
upper Paleocene	*Caryapollenites*	P6
		P5
middle Paleocene	*Momipites* species	P4
		P3
lower Paleocene		P2
		P1
Upper Cretaceous (part)	*Wodehouseia spinata* Assemblage	

Biozones are defined by the occurrences of fossil pollen and spores (palynostratigraphy). "P" biozones of the Paleocene are defined by species of the related fossil pollen genera *Momipites* and *Caryapollenites*.

Figure IN-10. Biostratigraphic (palynostratigraphic) zonation of the Paleocene and adjacent rocks in the Rocky Mountain region.

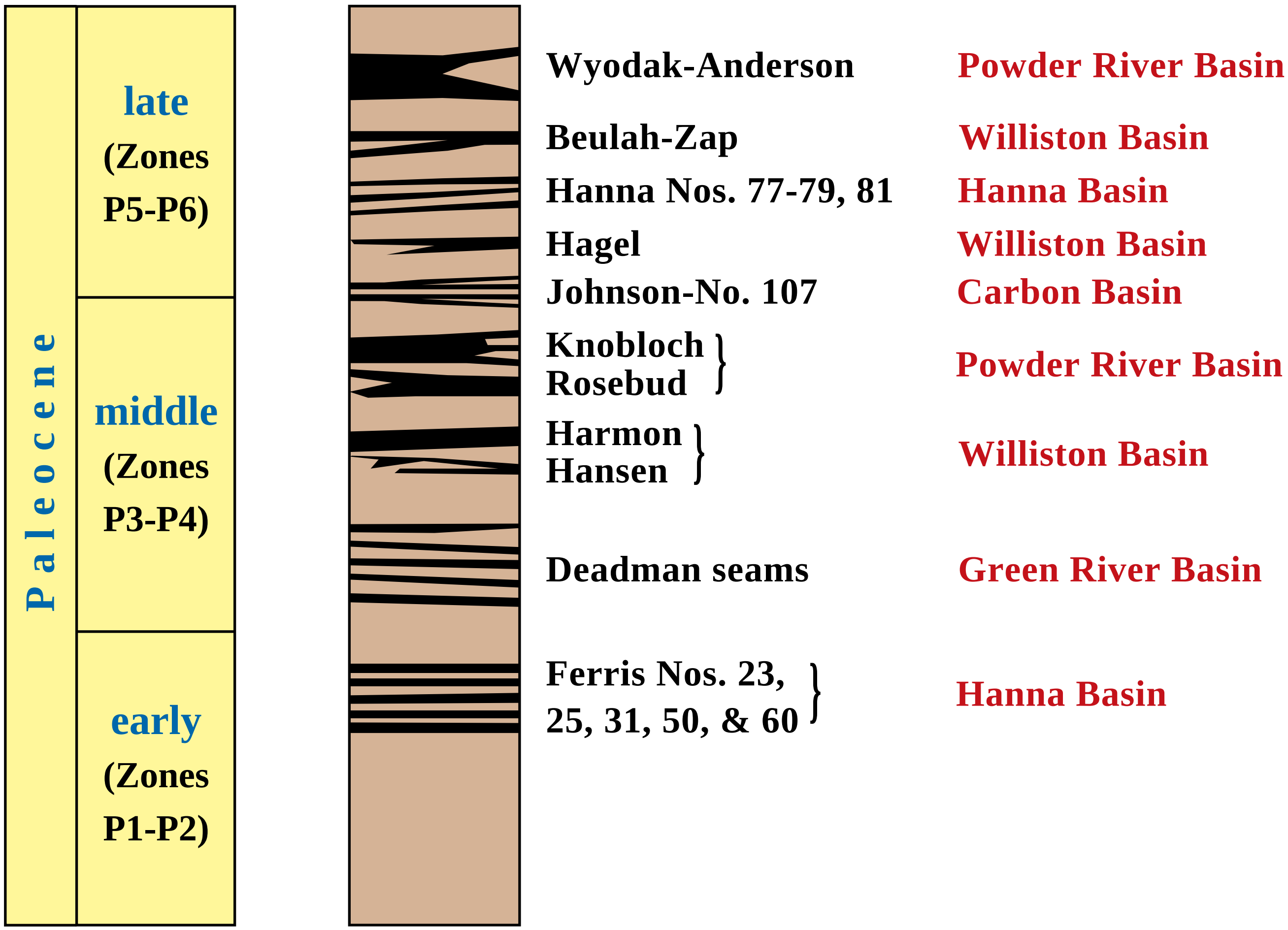

Figure IN-11. Composite stratigraphic section for the region showing the assessment units and age relationships based on palynology.

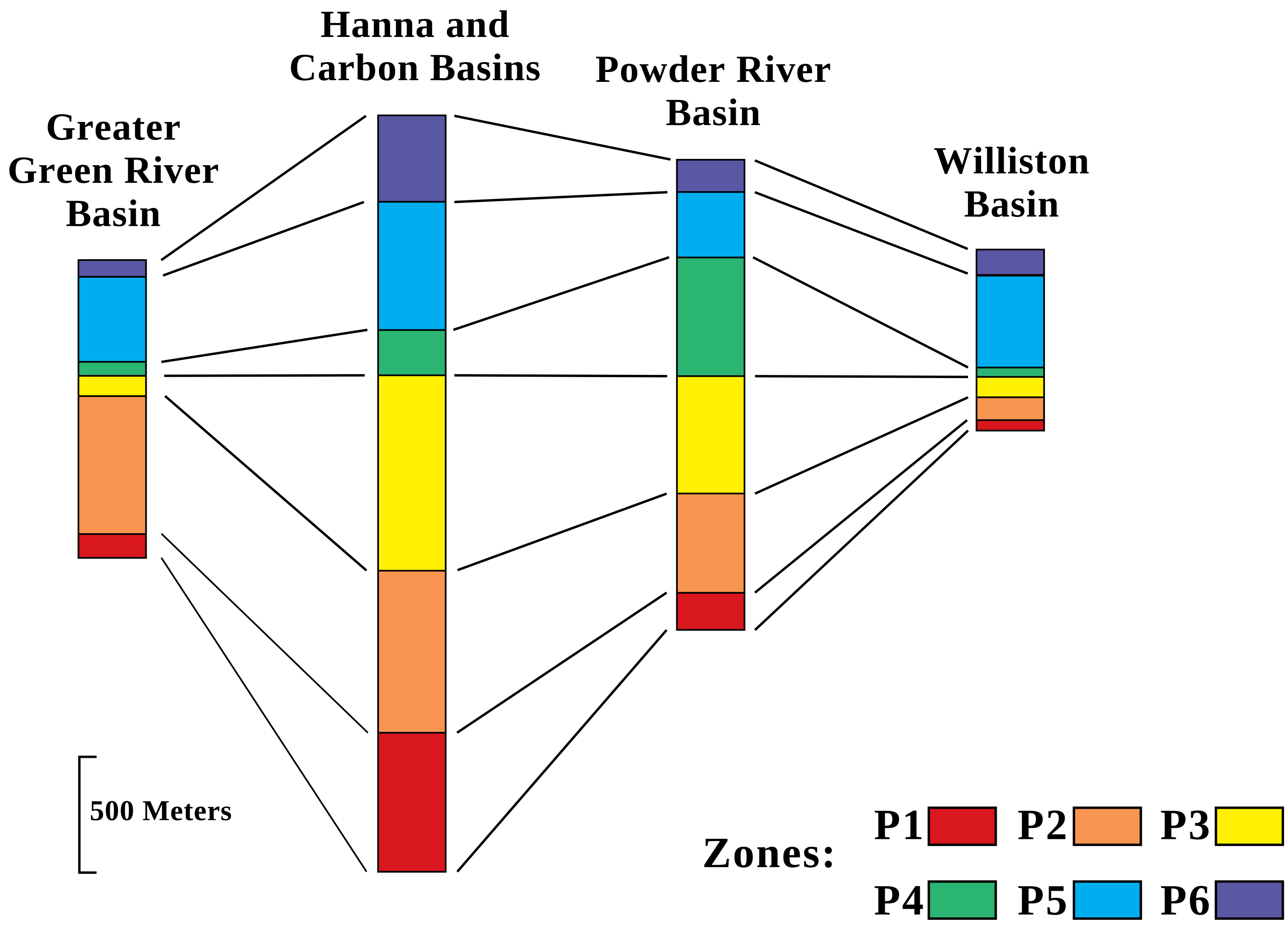

Figure IN-12. Composite correlation of Paleocene sections based on palynostratigraphy.

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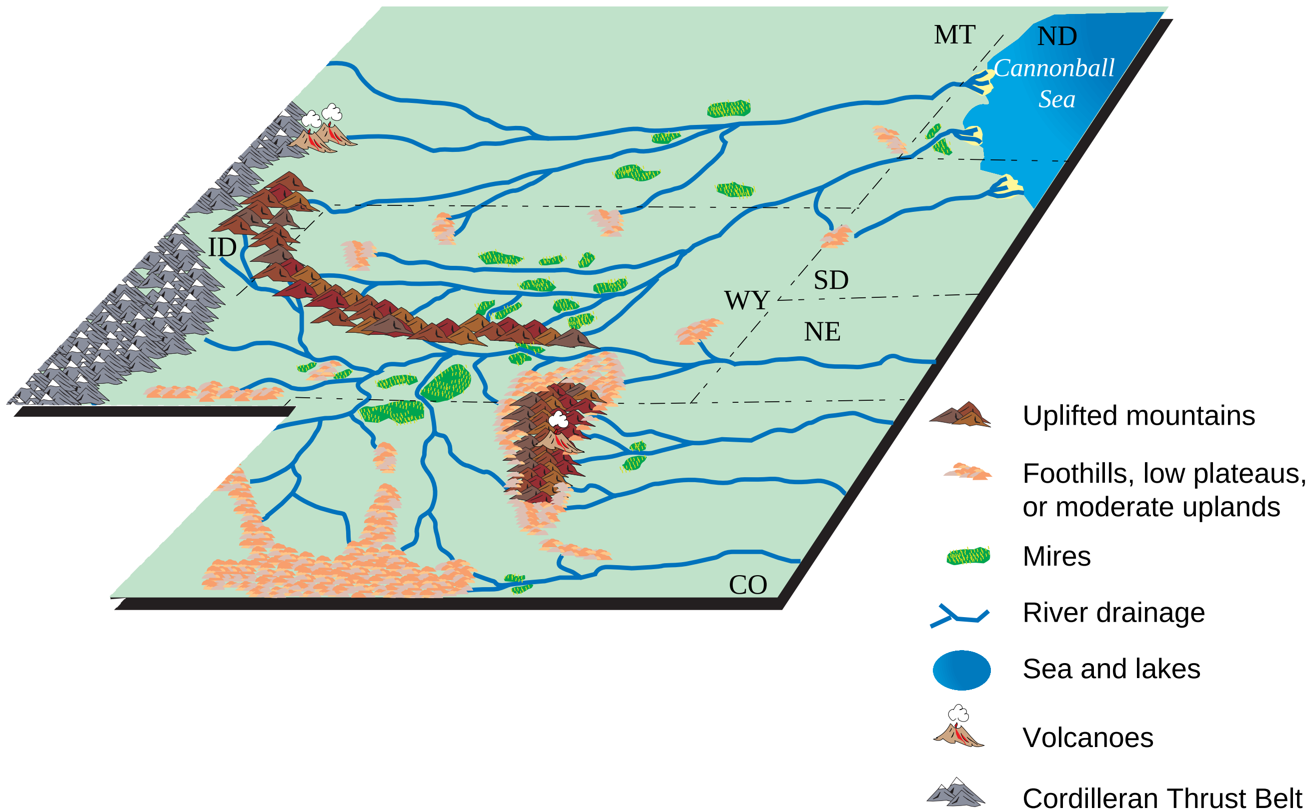

Figure IN-13. Physiographic diagram showing the region in early Paleocene time.

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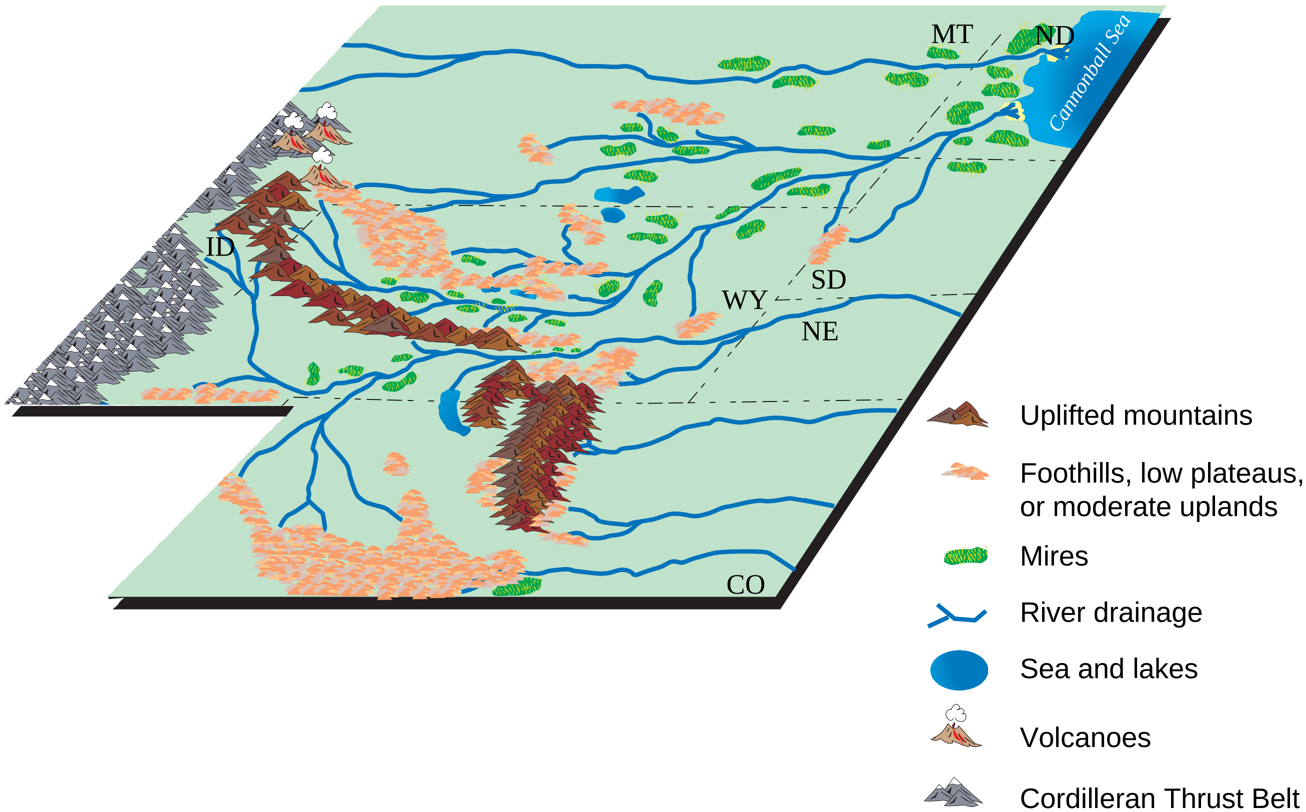

Figure IN-14. Physiographic diagram showing the region in middle Paleocene time.

Click on image to see animation.

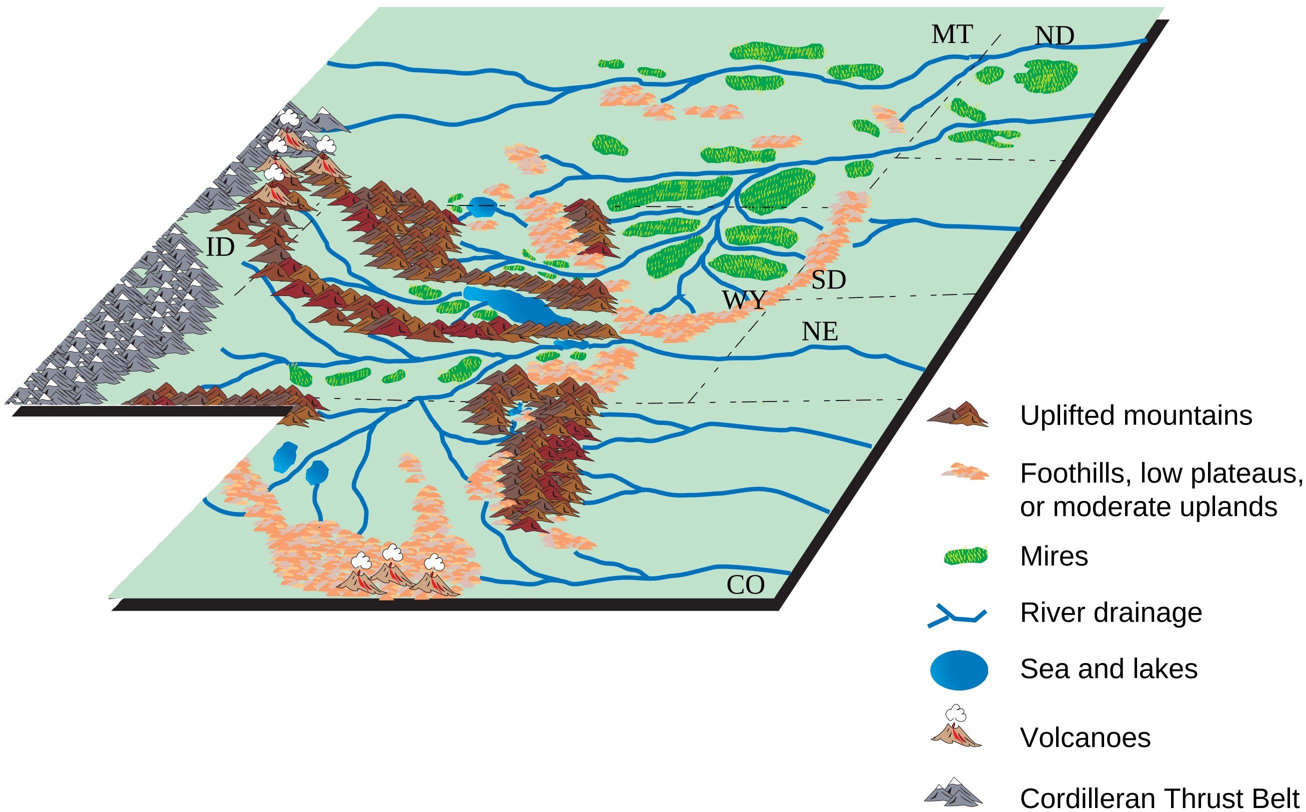

Figure IN-15. Physiographic diagram showing the region in late Paleocene time.

Click on image to see animation.

Table IN-1. Arithmetic means of heat-of-combustion (Btu/lb) and moisture, ash, and total sulfur contents (percent) of coal in the Powder River and Williston Basins compared to similar analyses from other coal-producing regions in the conterminous United States

Parameter	**Powder River Basin***	**Williston Basin**	**Colorado Plateau**	**Gulf Coast**	**Illinois Basin**	**Appalachian Basin**
Heat-of-combustion	8,220	6,510	10,020	6,780	11,600	12,710
Moisture	27.66	37.88	12.21	30.84	7.86	3.32
Ash	6.44	7.96	13.08	15.12	10.43	11.58
Total sulfur	0.48	0.84	0.83	1.09	3.55	2.14

* Only the Wyodak-Anderson coal zone is included in the Powder River Basin in this study. All data on an as-received basis.

Table IN-2. Arithmetic means of pounds of SO_2 per million Btu (SO_2/MMBtu) of coal in the Powder River and Williston Basins compared to similar analyses from other coal-producing regions in the conterminous United States

Parameter	**Powder River Basin***	**Williston Basin**	**Colorado Plateau**	**Gulf Coast**	**Illinois Basin**	**Appalachian Basin**
SO_2/MMBtu	1.2	2.5	1.5	2.1	5.0	3.4

* Only the Wyodak-Anderson coal zone is included in the Powder River Basin in this study. All data on an as-received basis.

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Table IN-3. Arithmetic means of concentrations of trace elements of environmental concern in parts per million in coal assessed in the Powder River and Williston Basins compared to similar analyses from other coal-producing regions in the conterminous United States

Parameter	Powder River Basin*	Williston Basin	Colorado Plateau	Gulf Coast	Illinois Basin	Appalachian Basin
Arsenic	2.6	9.1	3.1	5.1	10	22
Beryllium	0.54	0.73	1.6	2.3	1.5	2.4
Cadmium	0.21	0.08	0.11	0.22	2.6	0.10
Cobalt	1.9	2.9	2.2	4.7	4.8	6.7
Chromium	6.1	7.4	8.0	15	9.6	17
Mercury	0.13	0.14	0.095	0.20	0.11	0.19
Manganese	26.0	75.0	35	130	69	25
Nickel	4.6	4.3	5.9	12	15	16
Lead	3.0	3.5	9.2	8.8	27	8.9
Antimony	0.50	0.60	0.78	0.89	1.0	1.1
Selenium	1.1	0.74	1.5	5.0	2.0	3.4
Uranium	1.3	1.5	2.0	5.0	2.3	1.8

* Only the Wyodak-Anderson coal zone is included in the Powder River Basin in this study. All data on a whole-coal and remnant-moisture basis.

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Northern Rocky Mountains and Great Plains

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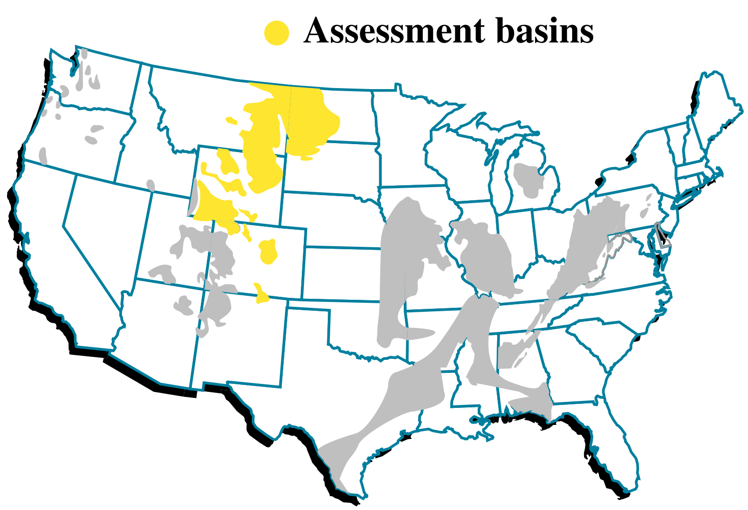
Perspectives

National Coal Resource Assessment

The USGS is assessing coal in the Northern Rocky Mountains and Great Plains



Why?

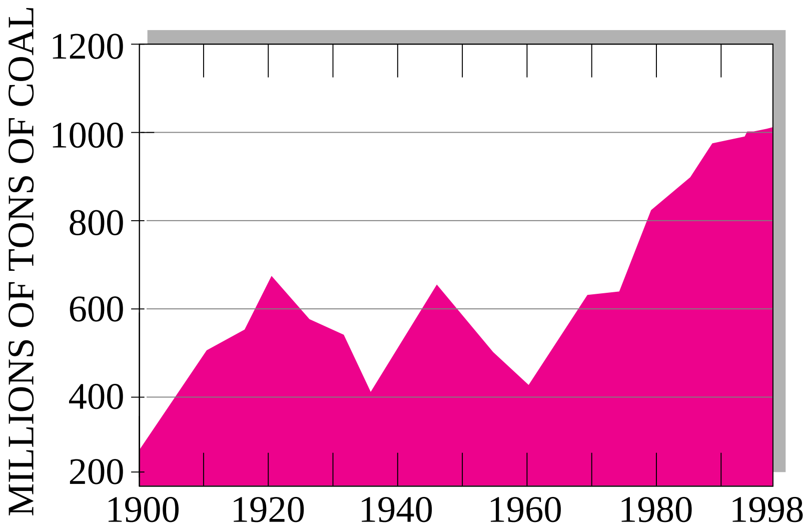
How?

Where?

What are benefits to society?

Click on an item for more information

Why? …three reasons:



(1) Utilization of coal is rising in the U.S., primarily because it is the least expensive fuel for electrical power generation

Click for more information

Source: modified from USGS Fact Sheet FS-157-96

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science for a changing world

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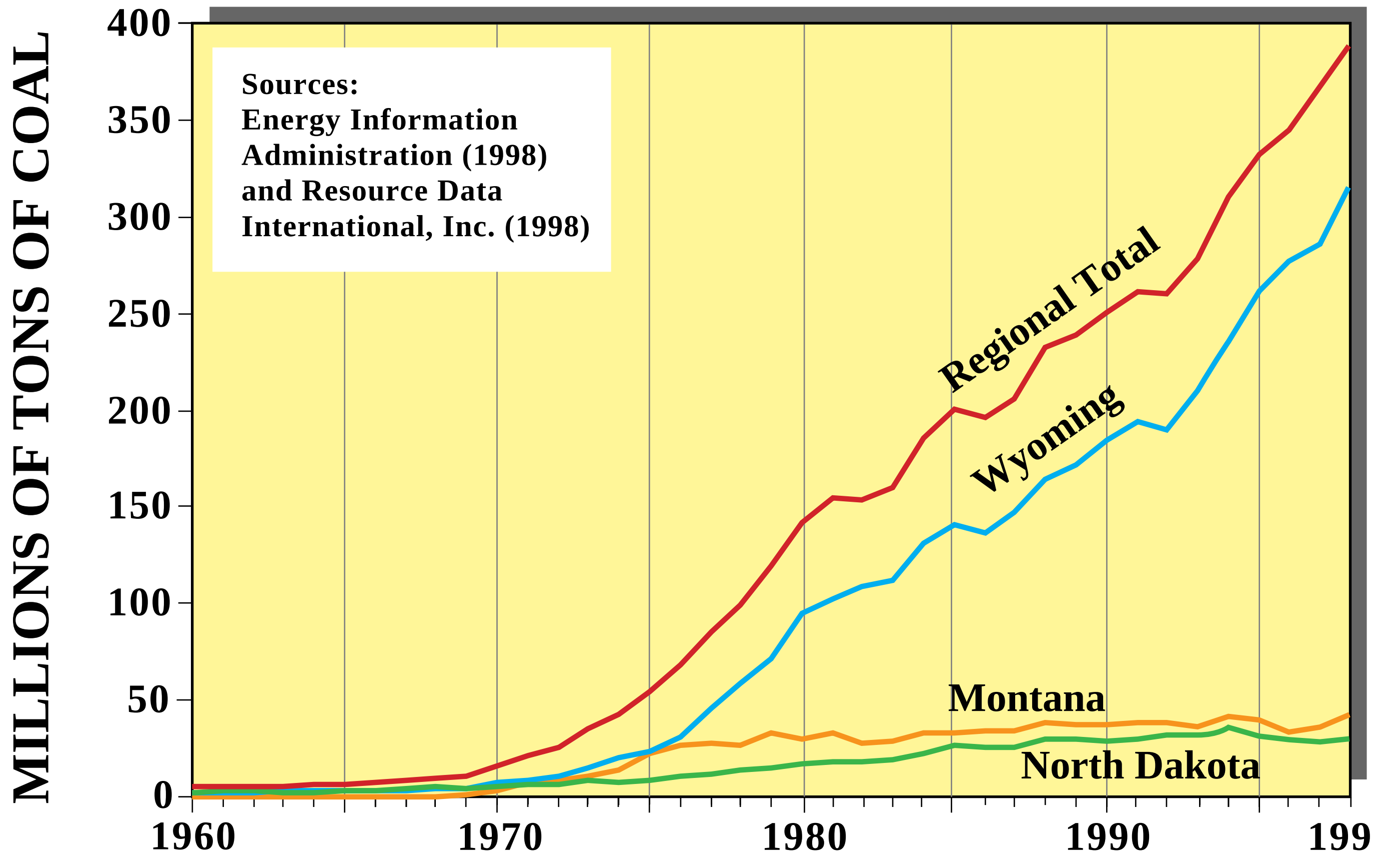

Much of the Nation's coal comes from Wyoming

About a third of the Nation's coal comes from this assessment region; more than a fourth comes from the Powder River Basin, Wyoming

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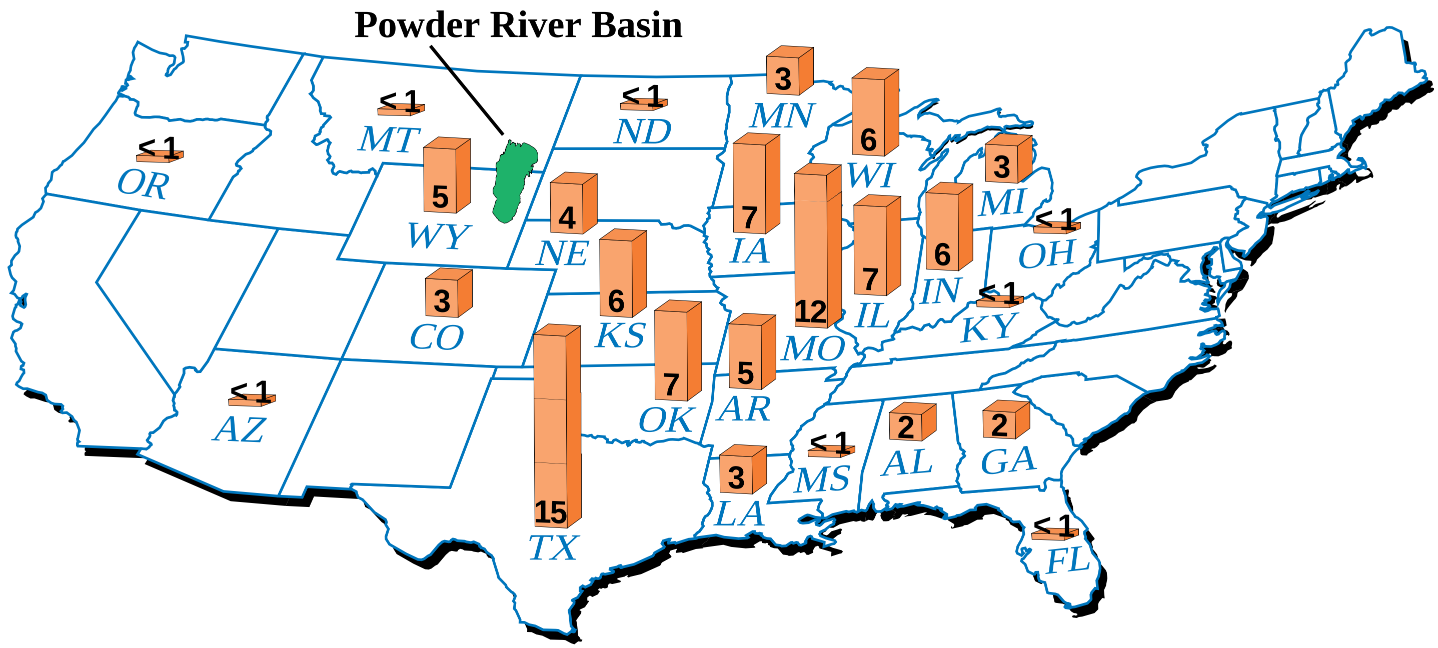

Where Powder River Basin coal goes

Sales of coal from the Powder River Basin to electric utilities in various states, shown as percentages of total production from the basin in 1998

Source: Resource Data International, Inc. (1998)

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Why? . . . *three reasons:*

(2) Increased demand for Powder River Basin coal is due to its clean compliant properties and inexpensive extraction methods

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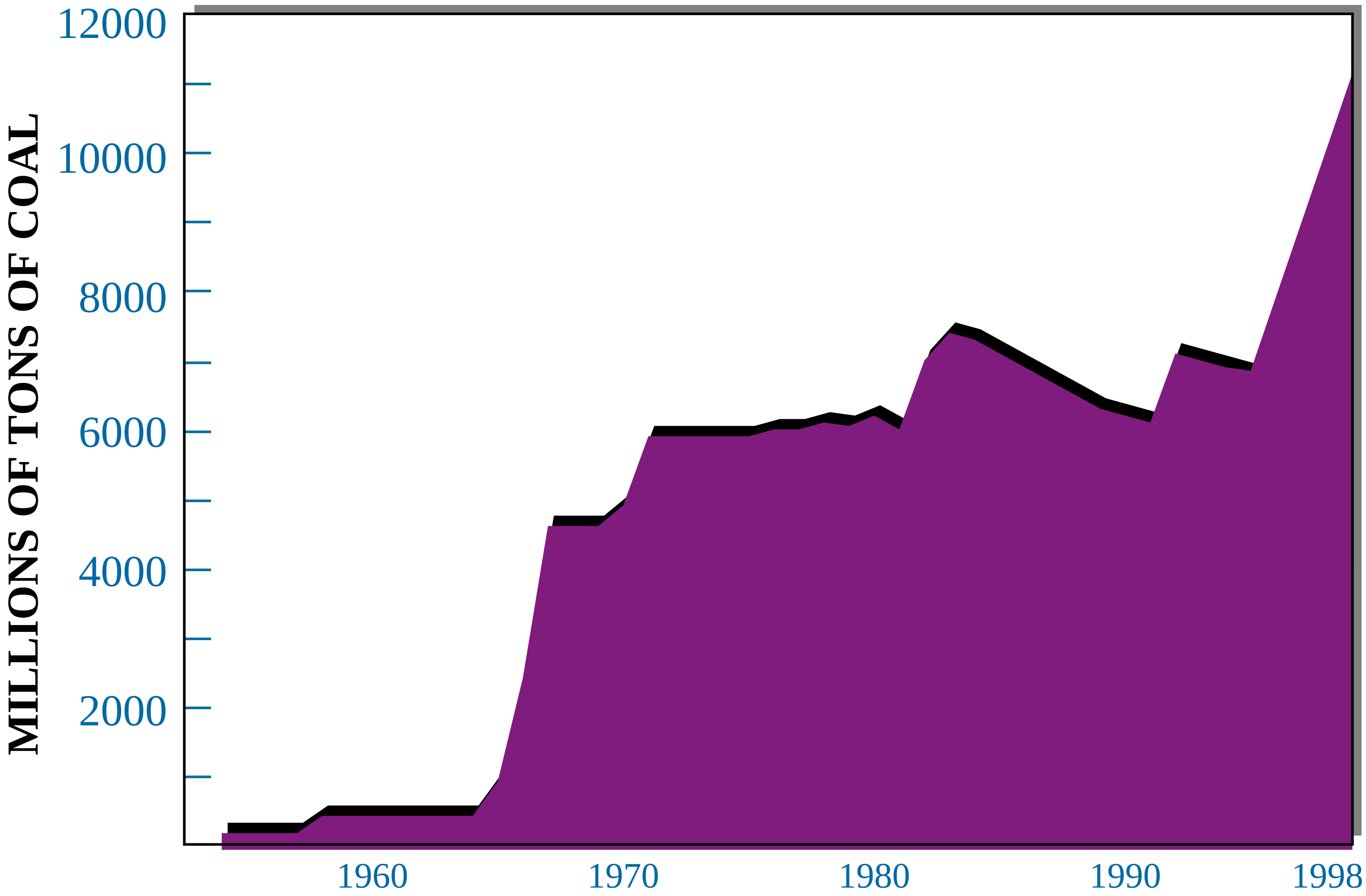

Amount of coal under lease, Powder River Basin, Wyoming

Data from Wyoming State Inspector of Mines and U.S. Bureau of Land Management

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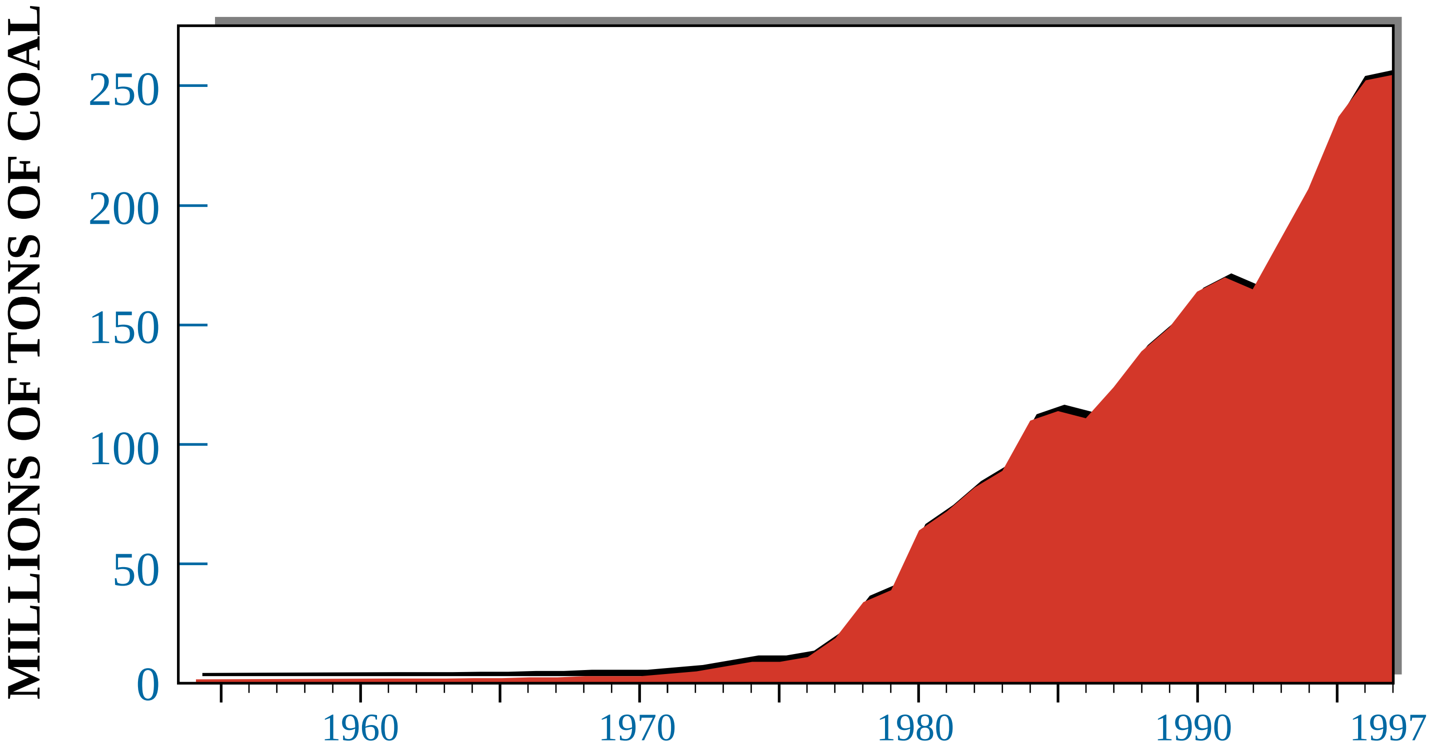

Annual coal production in Powder River Basin, Wyoming

Data from Wyoming State Inspector of Mines
and U.S. Bureau of Land Management

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Why? . . . *three reasons:*

(3) The supply of coal that is clean, compliant, and meets socio-economic and environmental restrictions is being depleted

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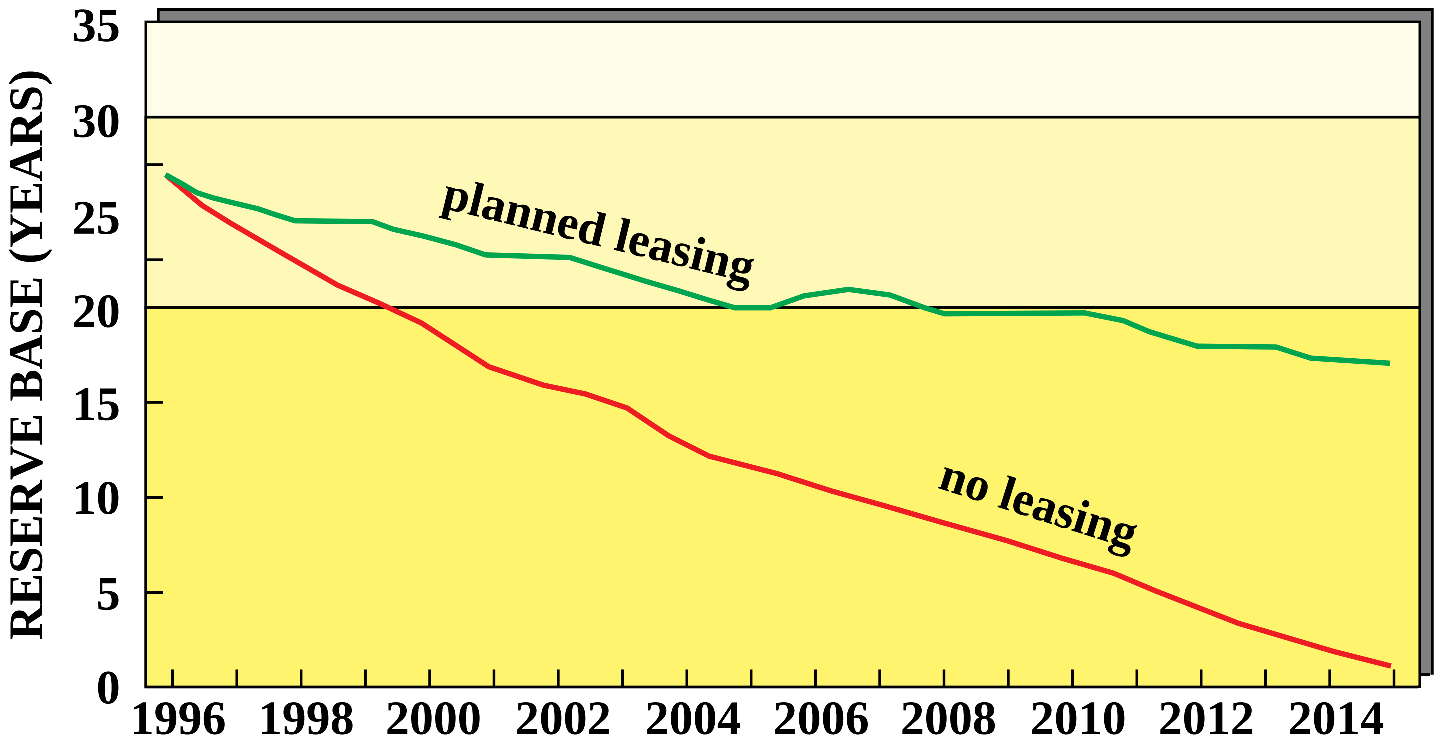
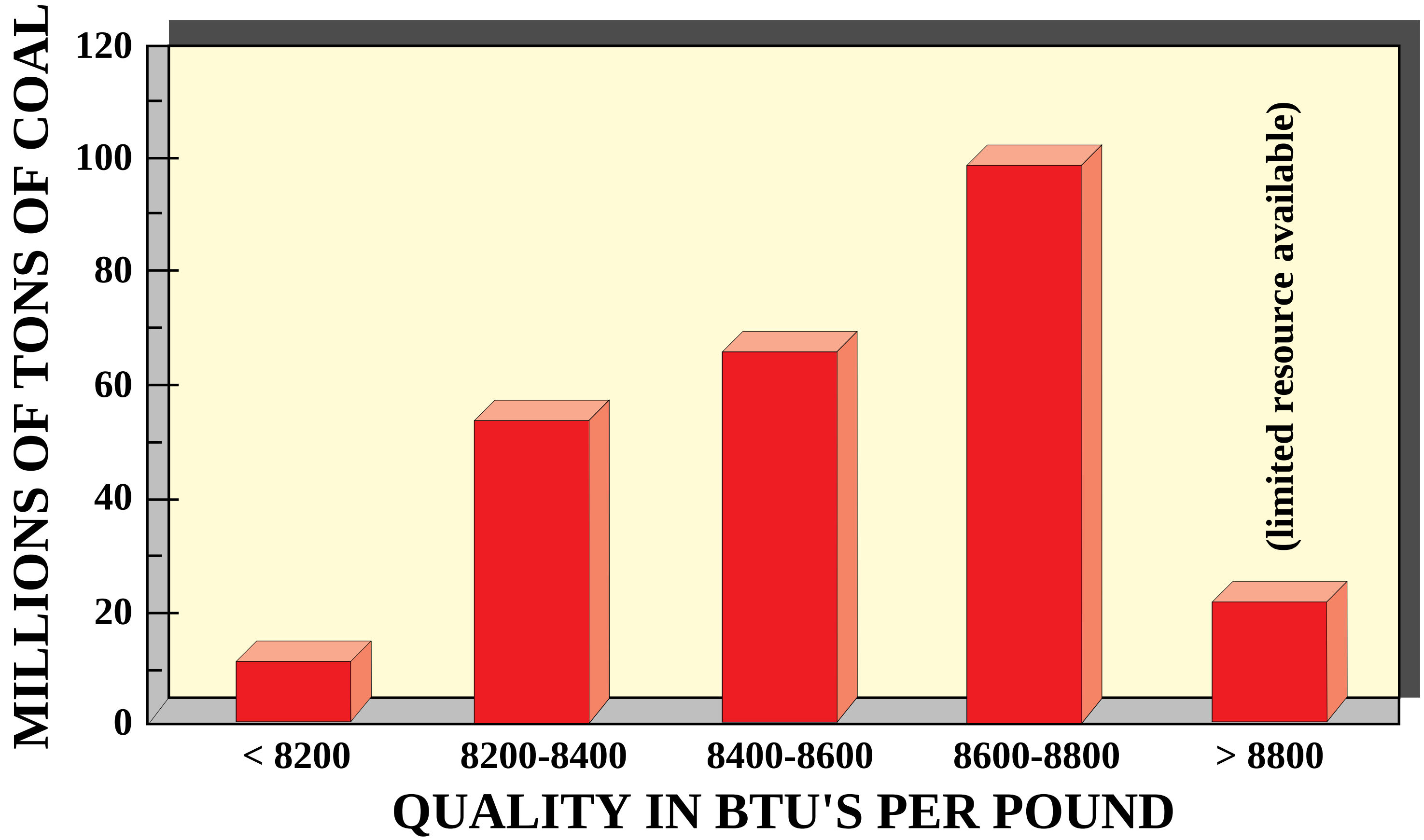


How much coal will be left in the next century?

Projected annual life of reserves in mining areas in Powder River Basin, Wyoming, based on a composite of coal and utility company forecasts

Forecast by U.S. Bureau of Land Management (1994)



High quality coal is selectively produced

Quantities produced according to thermal quality in the Powder River Basin, Wyoming, 1995

Data from U.S. Bureau of Land Management

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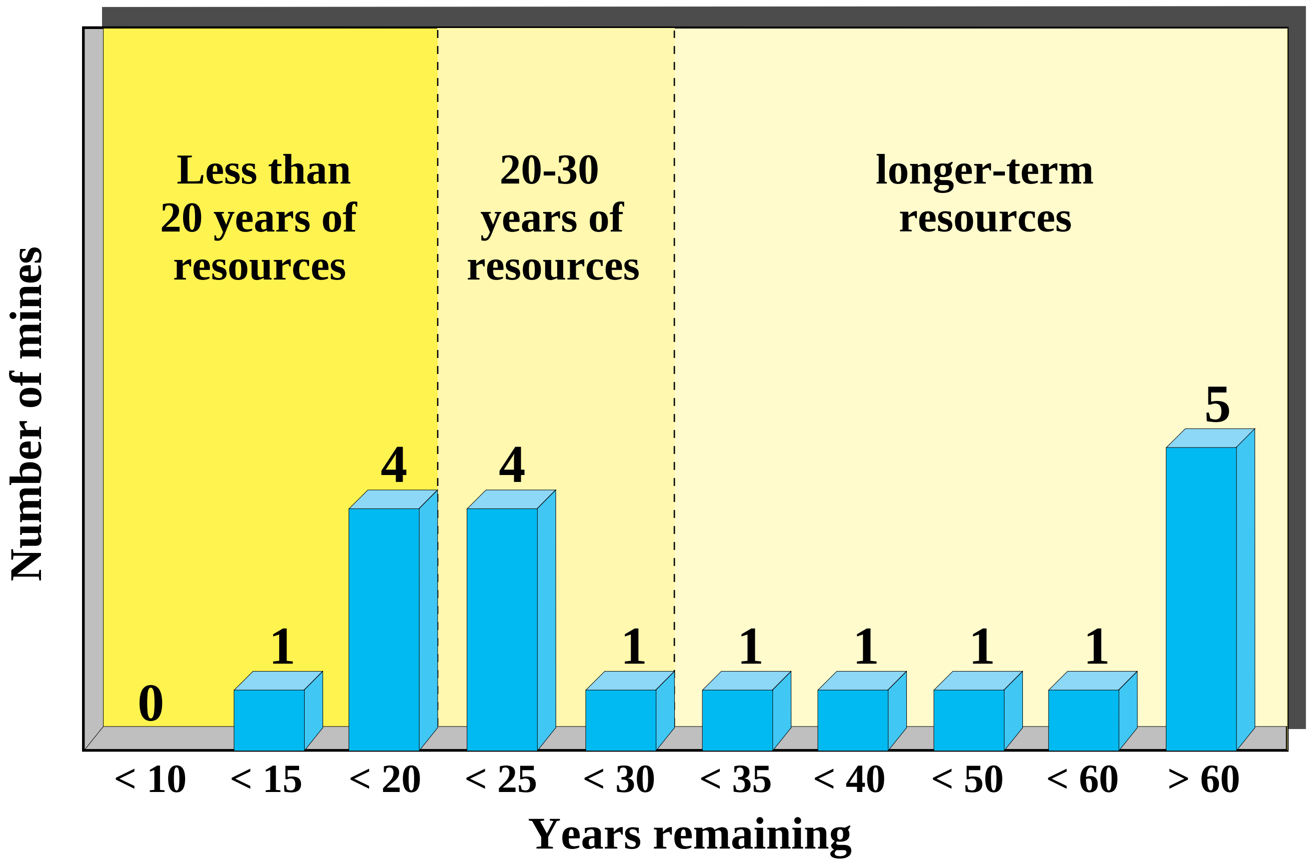

Years of life remaining for 19 coal mines in the southern Powder River Basin as of 1994

Data from U.S. Bureau of Land Management

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How? ... *three methods:*

(1) Collect data and create a modern digital coal database for public users

How? … *three methods:*

(2) Produce various digital products such as maps, text and graphics presentations, charts, and tables

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How? ... *three methods:*

(3) Estimate available coal resources and identify areas having deposits of clean and compliant coal

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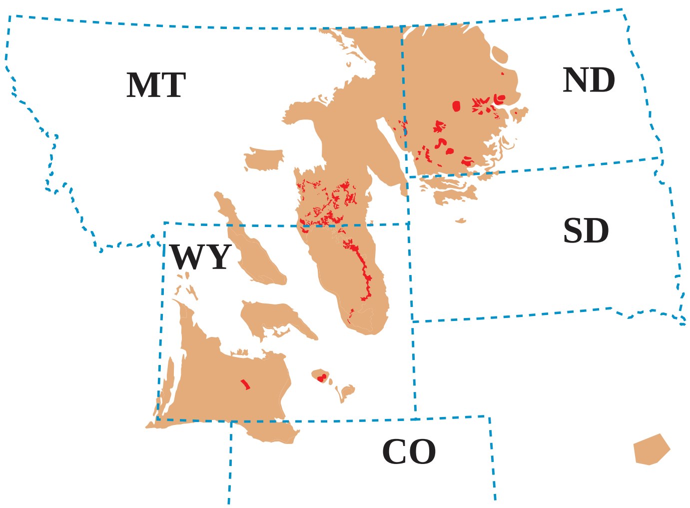
Where? … in the Northern Rocky Mountains and Great Plains

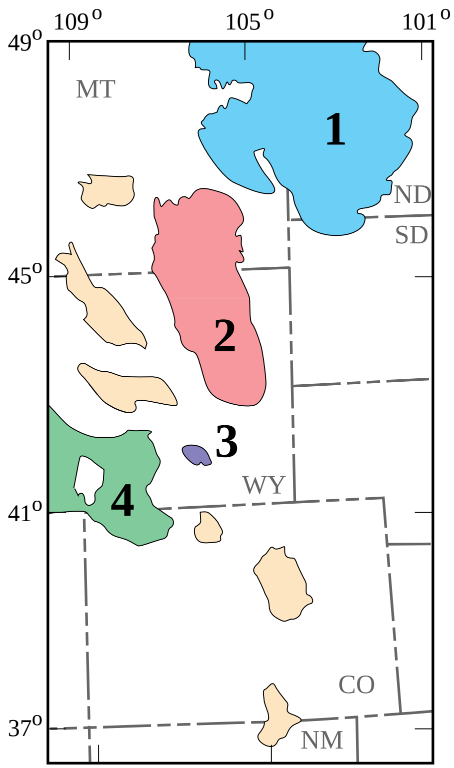


Coal exists in abundance in lower Tertiary rocks in the assessment region

Fort Union Formation and equivalents

Strippable coal

Where? ... in the Northern Rocky Mountains and Great Plains



Most clean compliant Tertiary coal is found in four basins in the assessment region

1. Williston Basin
2. Powder River Basin
3. Hanna and Carbon Basins
4. Greater Green River Basin

Other basins

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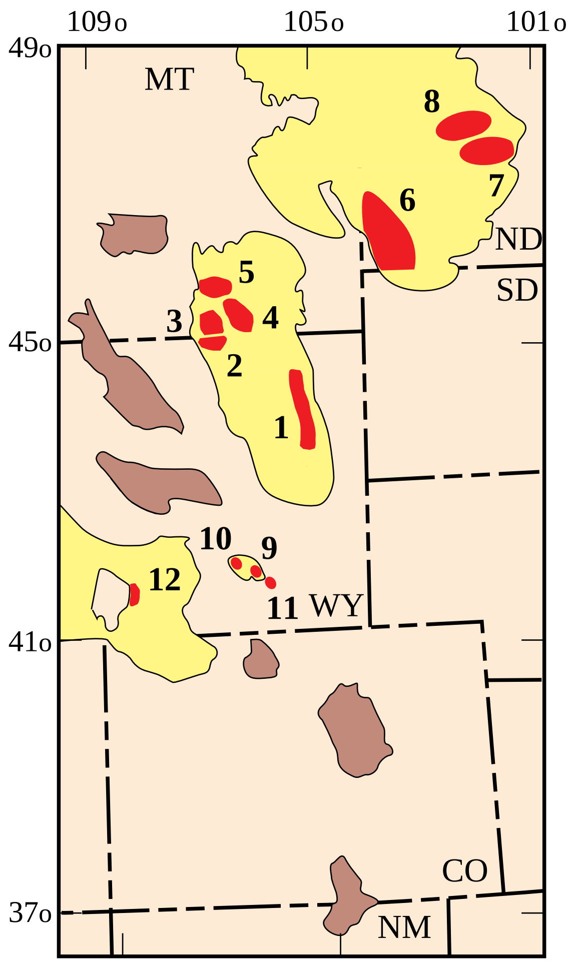
in the toolbar to return.

Where? ... in the Northern Rocky Mountains and Great Plains



Clean compliant coal currently is mined in 12 coalfields in four basins in the assessment region

1. **Gillette**
2. **Sheridan**
3. **Decker**
4. **Ashland**
5. **Colstrip**
6. **Bowman-Dickinson**
7. **Center-Falkirk**
8. **Beulah-Zap**
9. **Hanna**
10. **Ferris**
11. **South Carbon**
12. **Point of Rocks-Black Butte**

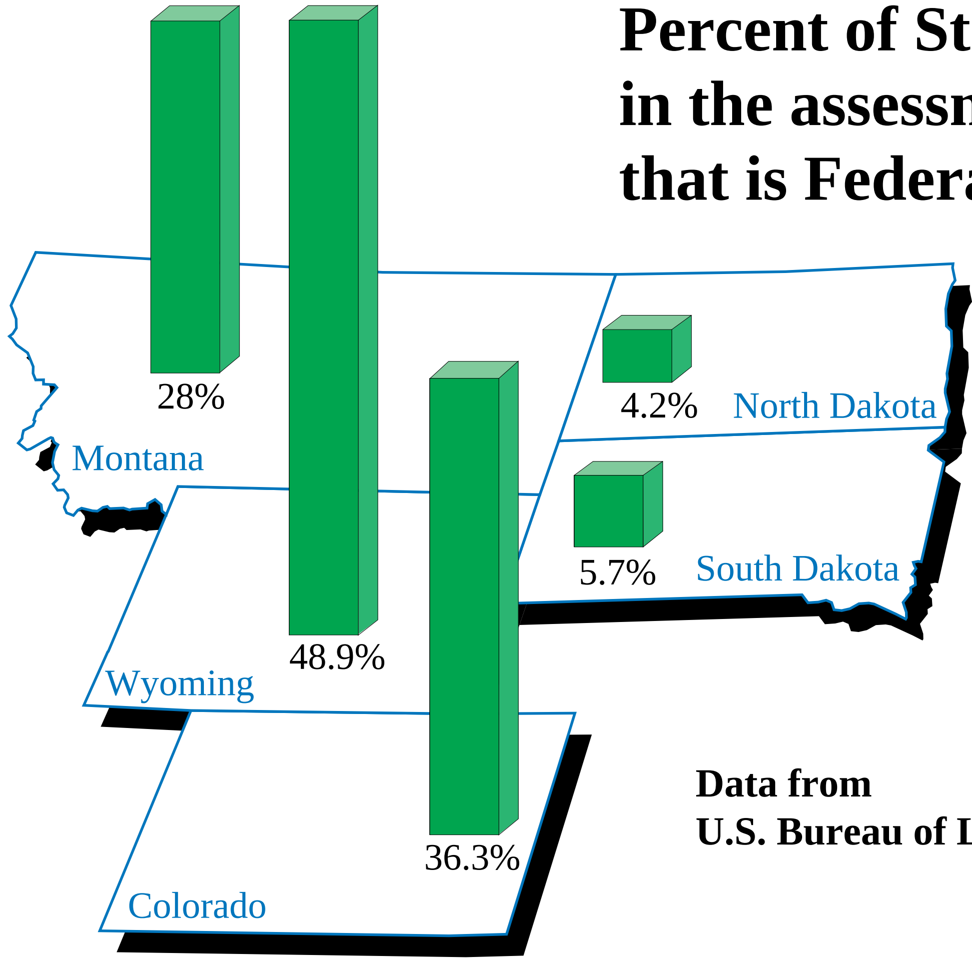
USGS
science for a changing world

Benefits to society:

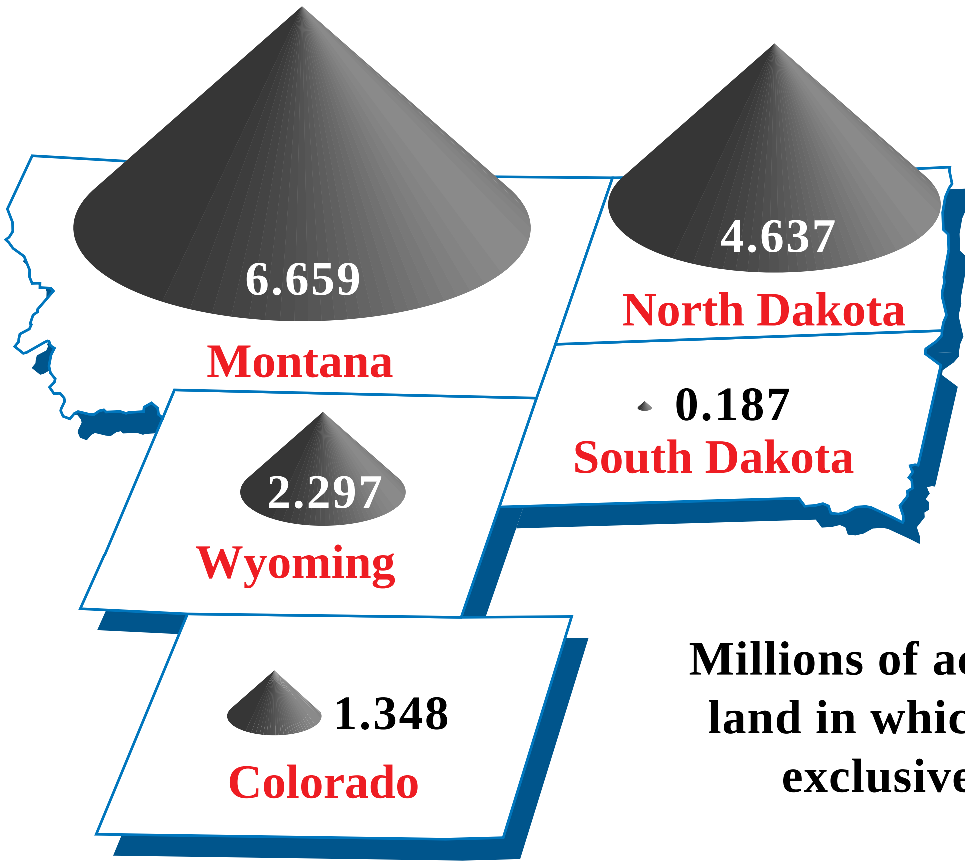
(1) Unbiased, publicly available data about the Nation's public lands and their energy resources

(2) More knowledgeable management of energy resources to strengthen local, State, and National economies

Percent of State acreage in the assessment region that is Federally owned



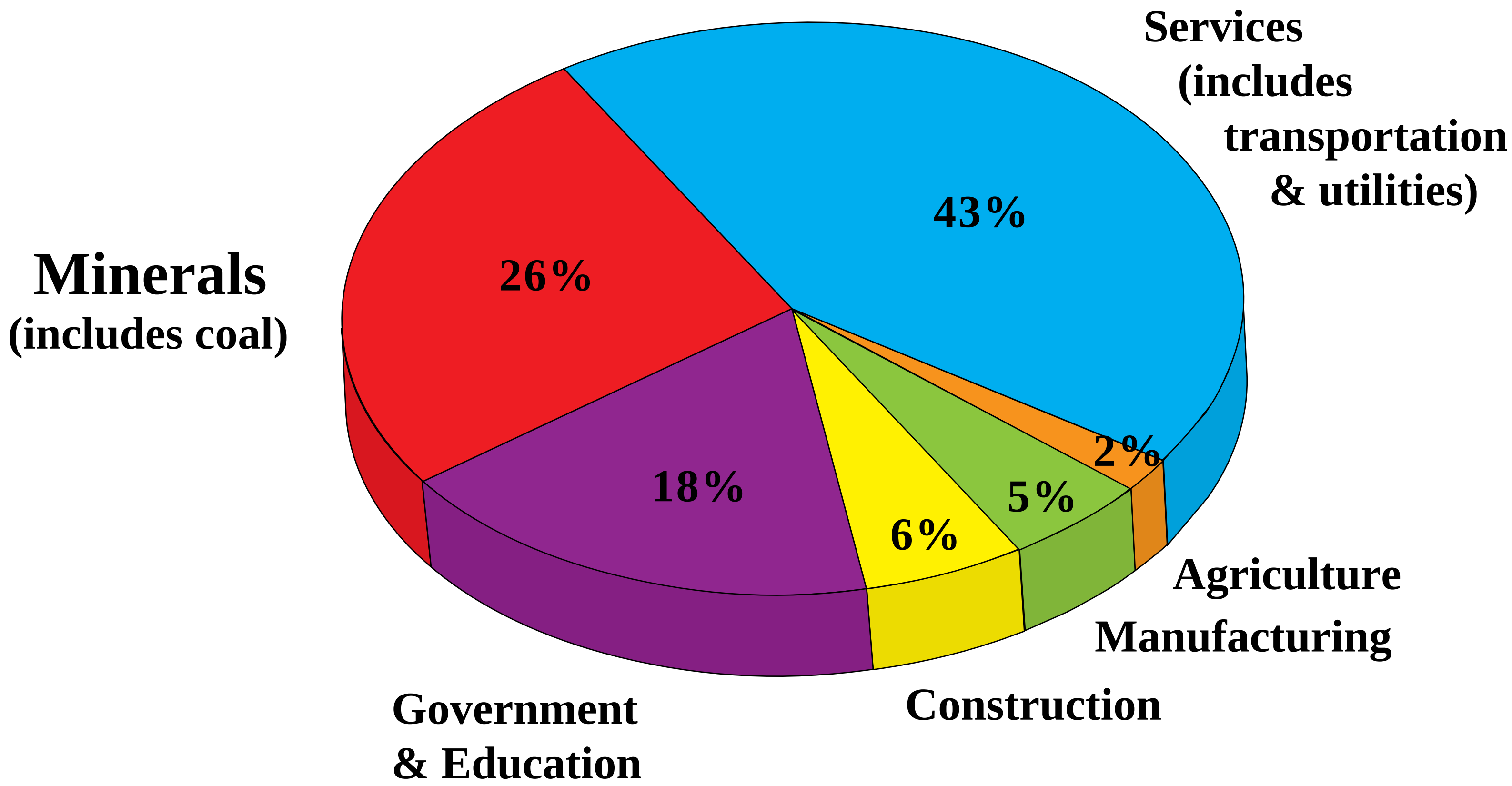
Data from
U.S. Bureau of Land Management



Millions of acres of non-Federal land in which the U.S. retains exclusive rights to coal

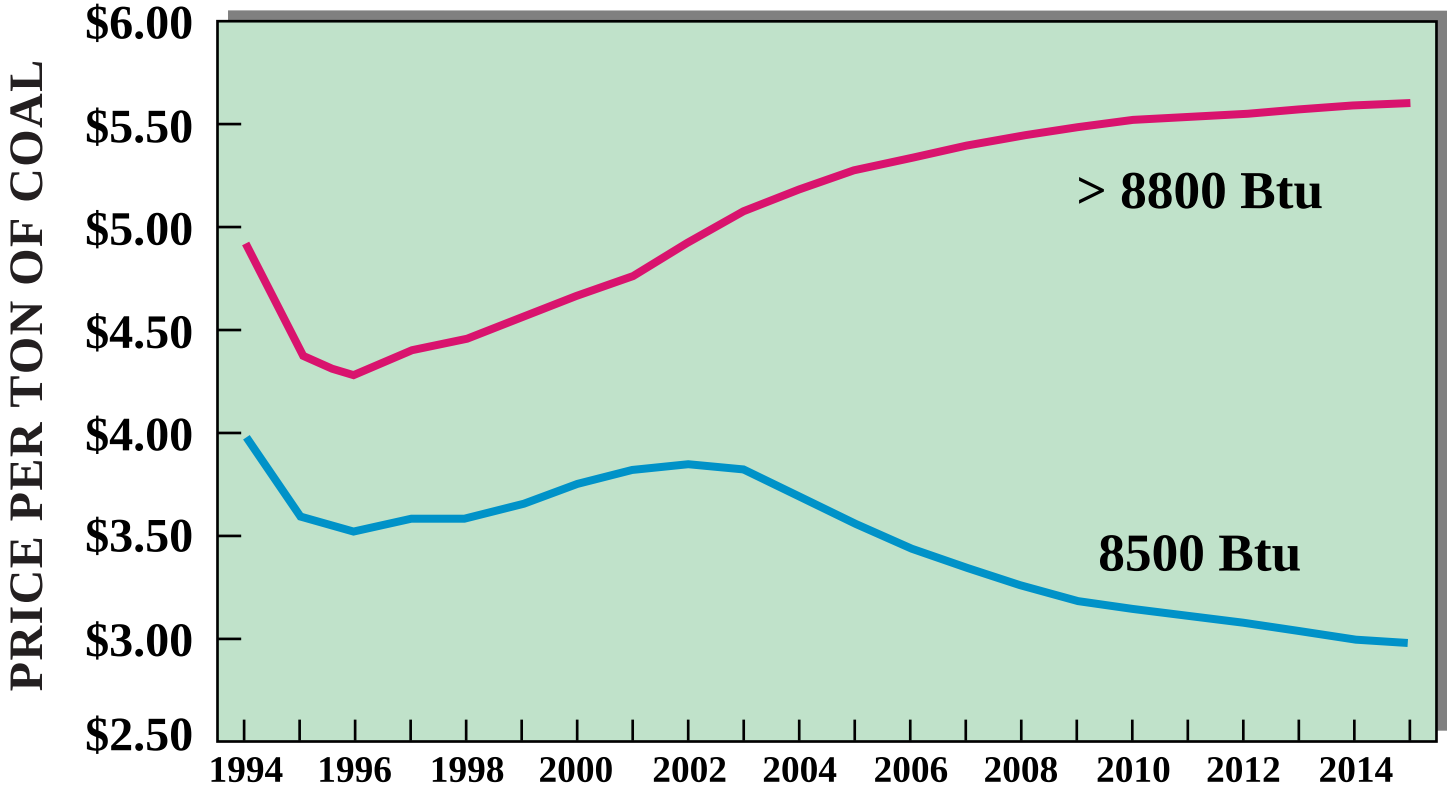
Patented acreage that has coal reserved to the U.S.

Data from U.S. Bureau of Land Management



Sources of income in northeastern Wyoming

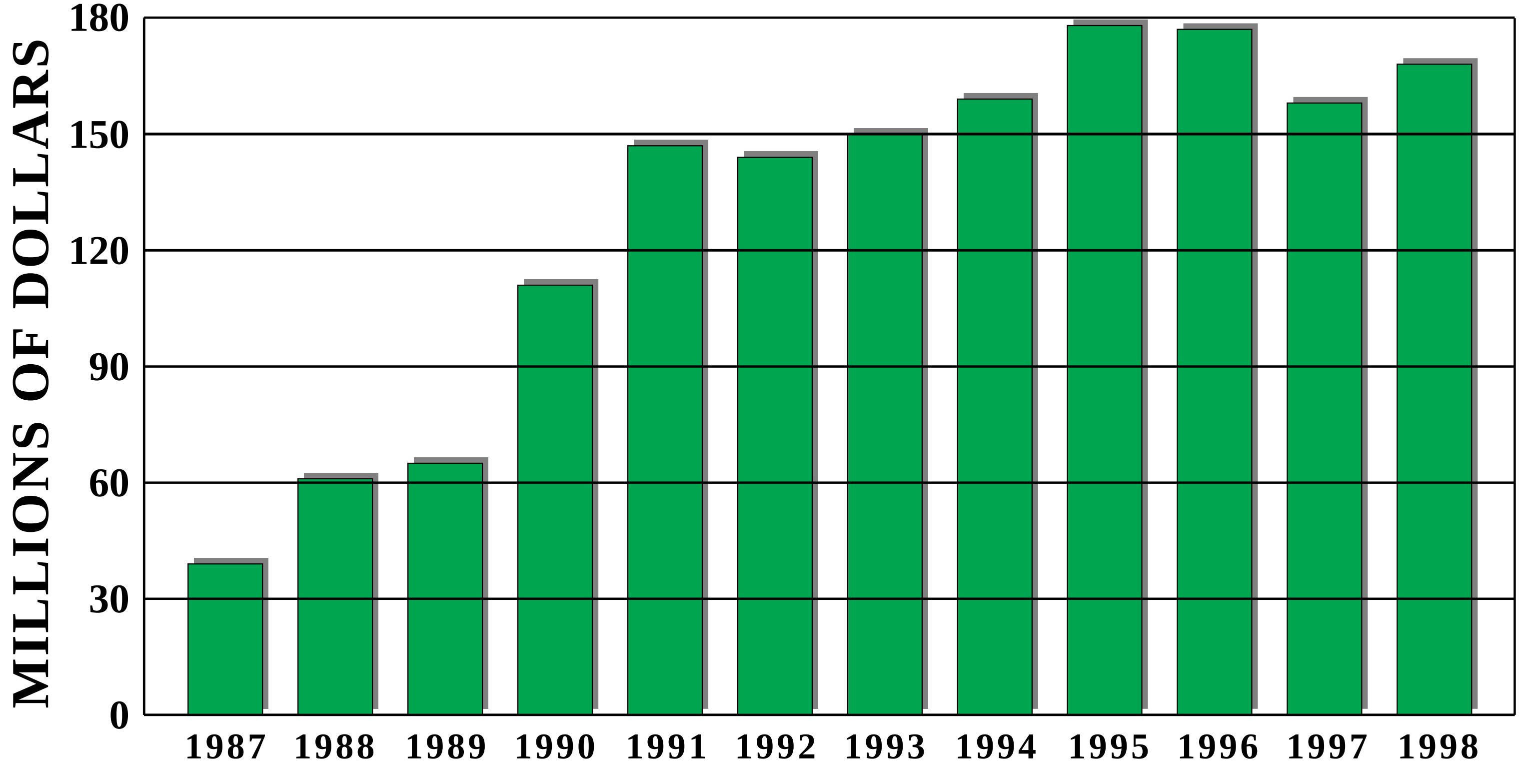
Data from U.S. Bureau of Land Management



Price of high-Btu coal is expected to increase

Powder River Basin price forecast in 1994 dollars per ton FOB

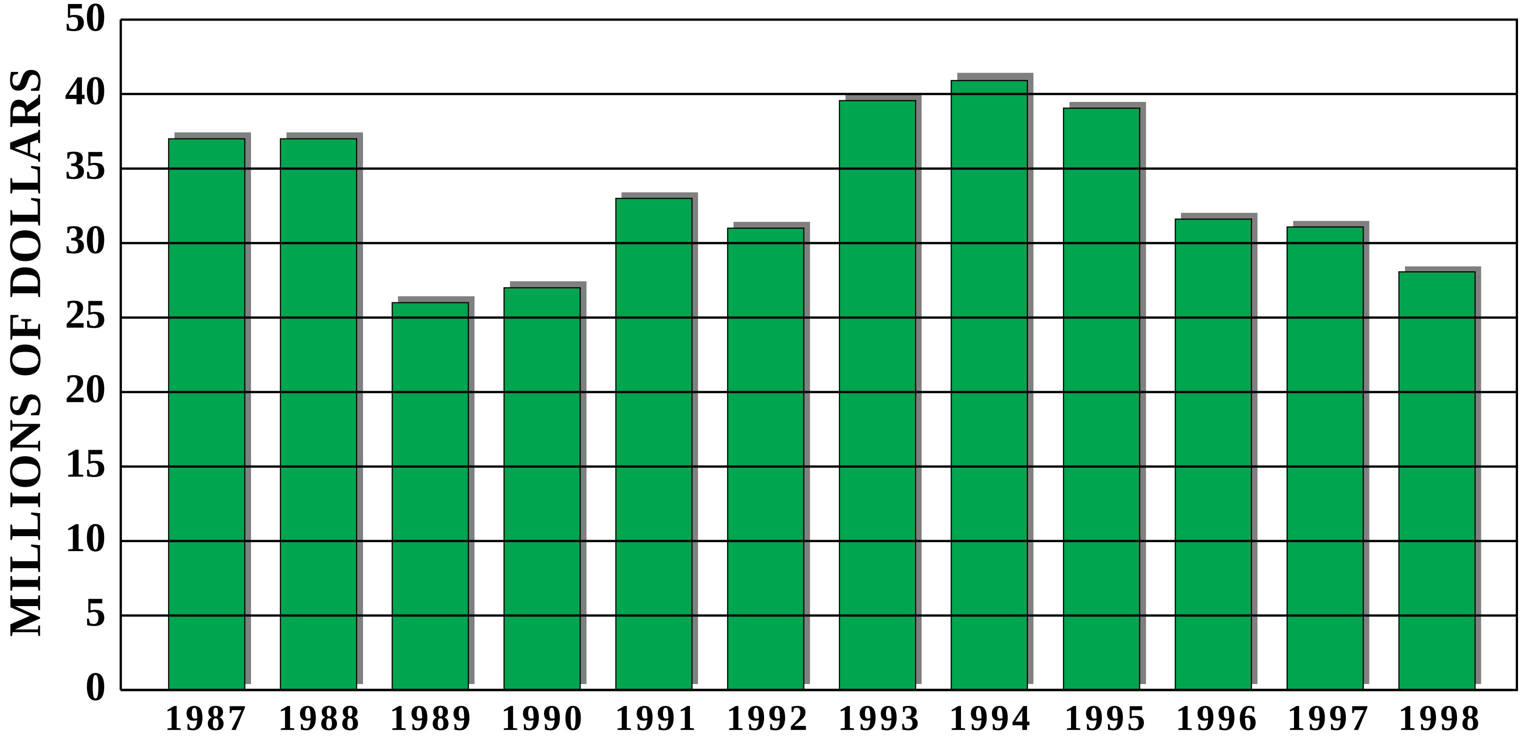
Source: Resource Data International, Inc. (1996)



Wyoming Federal coal royalty

About half of coal royalty income from Campbell and Converse Counties (Powder River Basin) was returned to the State of Wyoming

Data from U.S. Minerals Management Service



Montana Federal coal royalty

Income from Big Horn and Rosebud Counties (Powder River Basin)

Data from U.S. Minerals Management Service