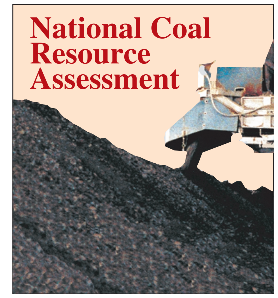
Chapter P

Geology and Resource Assessment of the Middle and Upper Coal Groups in the Yampa Coal Field, Northwestern Colorado



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Chapter P *of*

Geologic Assessment of Coal in the Colorado Plateau: Arizona, Colorado, New Mexico, and Utah

Edited by M.A. Kirschbaum, L.N.R. Roberts, *and* L.R.H. Biewick

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By Edward A. Johnson, Laura N.R. Roberts, Michael E. Brownfield, *and* Tracey J. Mercier

Abstract

The Yampa coal field is located in northwestern Colorado and covers about 520 mi^2 in parts of Moffat, Routt, and Rio Blanco Counties. Most of the coal is contained in the Upper Cretaceous Mesaverde Group. The Mesaverde is an eastward-tapering sedimentary wedge that contains a vertical succession of mixed marine and nonmarine rocks that were deposited along the western edge of the Late Cretaceous Western Interior Seaway in response to a constantly shifting shoreline. The Mesaverde is divided into two formations, the Iles in the lower part and the Williams Fork in the upper part. Included in the Iles is the Trout Creek Sandstone Member at the top of the formation, and included in the Williams Fork is the Twentymile Sandstone Member in the middle of the formation. Both of these sandstones are regressive shoreface deposits; each is transitional with an underlying interval of marine shale; and each is overlain by a thick interval of nonmarine rocks including fluvial sandstone, overbank sandstone and mudrock, and carbonaceous shale and coal.

Earlier workers defined coal in the Iles as the lower coal group, coal between the Trout Creek and the Twentymile as the middle coal group, and coal above the Twentymile as the upper coal group. The emphasis in this report is placed on the middle and upper coal groups because most of the economic coal is contained in the Williams Fork. To better define the occurrence of coal, four coal zones and three barren intervals are established in this report. The middle coal group contains the A coal zone, barren interval A, the B coal zone, and barren interval B, in ascending order. The upper coal group contains the C coal zone, barren interval C, and the D coal zone.

The A coal zone extends throughout the coal field and contains the maximum number of coal beds and the greatest amount of net coal. A regionally significant tonstein, the Yampa bed, is also present. All of the currently producing mines in the eastern part of the coal field extract coal from this zone. The B coal zone is only found in the central and western parts of the coal field and, other than supplying a few wagon mines, has never been an important source of coal. Also restricted to the central and western parts of the coal field, the C coal zone has the least economic potential of the four zones. This zone contains the least number of coal beds and the least amount of net coal of the four coal zones. The D coal zone extends throughout the coal field and is the second most economically important zone. The only currently producing mine in the western part of the coal field extracts coal from this zone.

Most of the coal in the Williams Fork has an apparent rank of high-volatile C bituminous. Ash yield is usually less than 10 percent, sulfur content is usually less than 1 percent, and the average caloric value is about 11,500 Btu/lb.

The Williams Fork contains an estimated remaining net-coal resource of about 76 billion short tons. Coal classified as identified makes up about 46 percent of the resource with the remainder classified as hypothetical. Most of the resource, about 80 percent, is contained in Moffat County. Although 93 percent of the resource underlies private surface, about 69 percent of the coal is owned by the Federal Government. Much of the coal is currently unavailable because of limits in mining technology, current economic conditions, or for various environmental reasons.

Introduction

Purpose and Scope

The assessment of coal in the Yampa coal field of northwest Colorado is part of the National Coal Resource Assessment initiated by the U.S. Geological Survey (USGS) in 1994. The goal of the National Assessment is to describe the distribution and calculate the resource potential of coal in selected areas of the United States. In the Rocky Mountain region, the Yampa coal field was selected because several large coal mines are currently extracting significant amounts of coal, a high percentage of the coal is federally owned, and the potential for subsurface accumulations of coal gases is high.

The assessment of the coal field was restricted to four coal zones, all within the Upper Cretaceous Williams Fork Formation. Areas of Federal and State coal leases were excluded in the assessment. Because a high percentage of the coal is publicly owned and managed by the Federal Government, no effort was made to exclude State or privately owned coal from the assessment. The report includes coal correlation charts, maps showing selected aspects of the coal distribution, and calculated coal resources. The resources reported represent minimum values but are far in excess of what can be economically mined.

Location

The Yampa coal field, covering 520 mi^2, is located in northwest Colorado and occupies parts of Routt and Moffat Counties and a very small part of Rio Blanco County (fig. 1). U.S. Highway 40 crosses the coal field on the north and connects the small communities of Milner and Lay, which more or less define the east-west limits of the coal field. More significant towns in the area, both along Highway 40, are Steamboat Springs, just east of the coal field, and Craig, in the western part of the coal field. The coal field is also crossed by the west-flowing Yampa River, which is located just south of the highway. Elevations in the coal field range from about 6,000 ft above sea level near Lay to slightly more than 9,800 ft at the top of Pilot Knob in the northeastern part of the coal field.

The coal field is comprised of three basic segments. Most of the coal is contained in a 47-mi-long, east-trending segment that extends from the town of Oak Creek on the east to near Lay on the west—this area is dominated by the Williams Fork Mountains. Almost all of the operating coal mines are within this segment. A second segment extends north for about 25 mi from the eastern end of the segment just described to a latitude about 18 mi north of the abandoned town of Mount Harris. Just south of Mount Harris, the segment contains an operating mine, but north of Mount Harris mining is hampered by steep structural dip. The third segment, isolated in the south-central part of the coal field, contains a considerable amount of coal but no operating mines.

Most of the land surface in the coal field is privately owned (fig. 2). The Federal Government controls only seven percent of the surface, and almost all of this is administered by the U.S. Bureau of Land Management (BLM). The State of Colorado controls an even smaller percentage of the surface.

Previous Geologic Studies

Coal in northwestern Colorado was first noted by Hayden (1877), and minor studies of the coal resources of the Yampa coal field began appearing as early as the 1880’s. The first notable investigation was published in the early 1900’s by Fenneman and Gale (1906b). Following this work, various reports on the coal resources were published, but two are particularity significant. Hancock (1925) investigated the coal resources in the western part of the coal field, and his report contains a geologic map at a scale of 1:62,500. Bass and others (1955) investigated the coal resources in the eastern part of the coal field, and their report contains a geologic map at the same scale. These two publications remain the primary sources of information on the geology of the coal field. During the mid-1970’s, Dames and Moore, under contract with the USGS, compiled a series of Coal Resource Occurrence and Coal Development Potential (CRO-CDP) 7.5′ quadrangle maps (table 1) that show all of the public surface and subsurface data on the coal field available at the time. During the mid-1970’s to early 1980’s, the USGS drilled more than 200 coal exploration holes in the coal field, and down-hole information obtained from the geophysical logs of these holes was the primary source of data used in the coal assessment (table 2). The Selected References section at the end of this report contains most of the significant publications pertaining to the coal field. A more comprehensive listing of reports published before 1984 is provided by Johnson and Brownfield (1984).

Previous and Current Mining Activity

According to Boreck and Murray (1979), 192 mines have operated in the Yampa coal field at one time or another. Small wagon mines provided coal from various beds in the Mesaverde Group for domestic use during the second half of the 19th century, but larger scale mining was hampered by a lack of adequate transportation. Following the arrival of the railroad in 1909 (Campbell, 1923), significant underground mines were established near Oak Creek and Mount Harris in the eastern part of the coal field. Most of the coal mined near Oak Creek was from the Upper Cretaceous Iles Formation, a unit not included in this assessment. In the Mount Harris area, the Utah Coal Company mined coal from the Williams Fork Formation south of the Yampa River and the Victor-American Fuel Company mined coal from the formation north of the river. Large strip mines were later established in the eastern part of the coal field that also extracted coal from the Williams Fork. The Edna mine was located about 3 mi north of Oak Creek, and the Energy mine was located in the southern part of Twentymile Park. Both of these mines have ceased operations and have been reclaimed.

Currently, only a few large mines operate in the coal field (fig. 1), and all of these extract coal from the Williams Fork. In the eastern part of the coal field, the Foidel Creek mine (underground) is located in the southern part of Twentymile Park, and the Seneca II-W and Yoast mines (both surface), are located several miles southwest of Mount Harris. A fourth mine, the Seneca II is located several miles south of Mount Harris but is mined out and is about to be reclaimed. Using three 1-mi-long longwall mining machines, the largest such system in the world, the Foidel Creek mine set a monthly coal production world record in 1996 of just more than 1 million

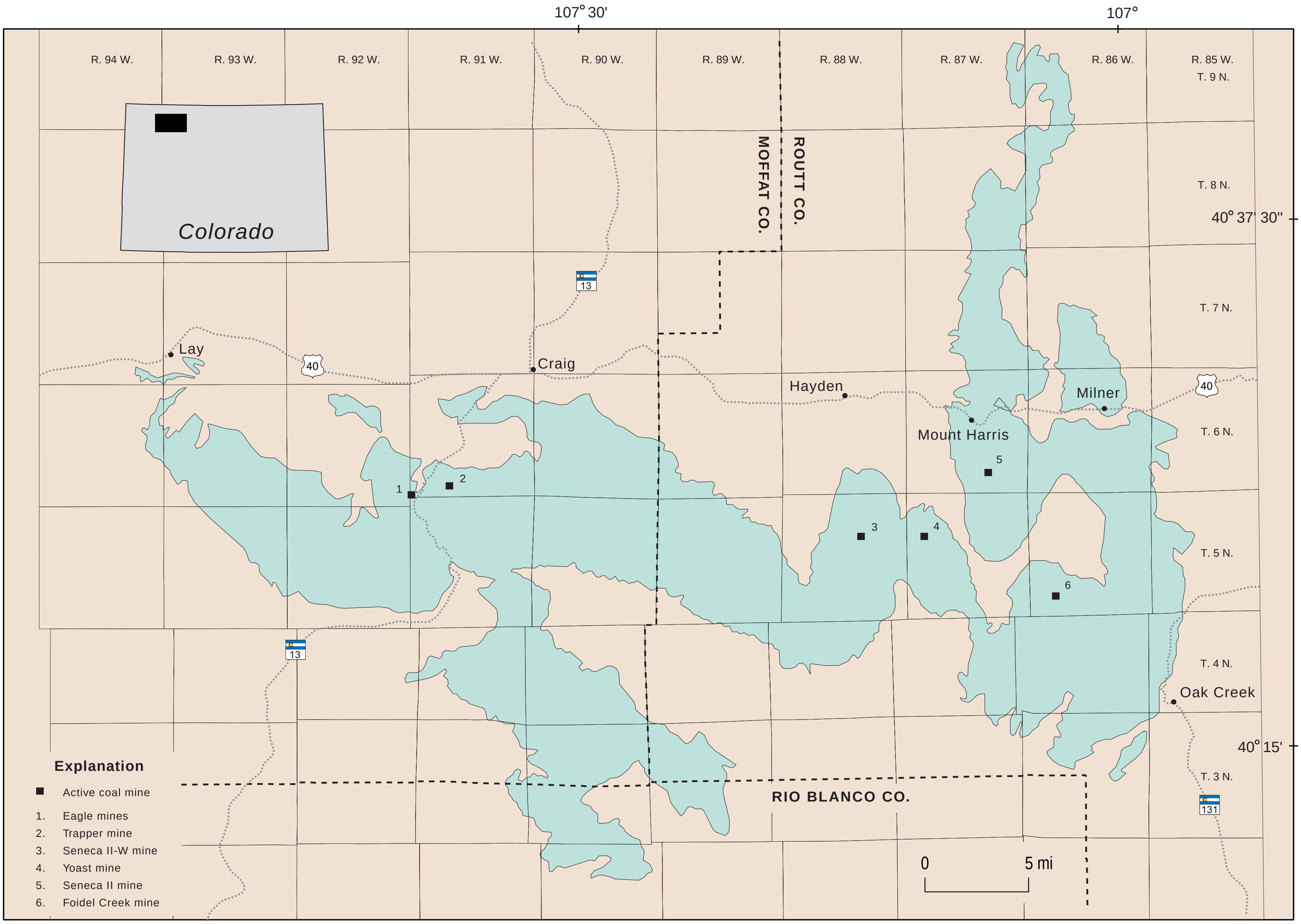

Figure 1. Location of the Yampa coal field, Moffat, Rio Blanco, and Routt Counties, Colorado. The outcrop of the Mesaverde Group (shaded in gray) delineates the boundaries of the coal field. Approximate locations of existing coal mines are shown.

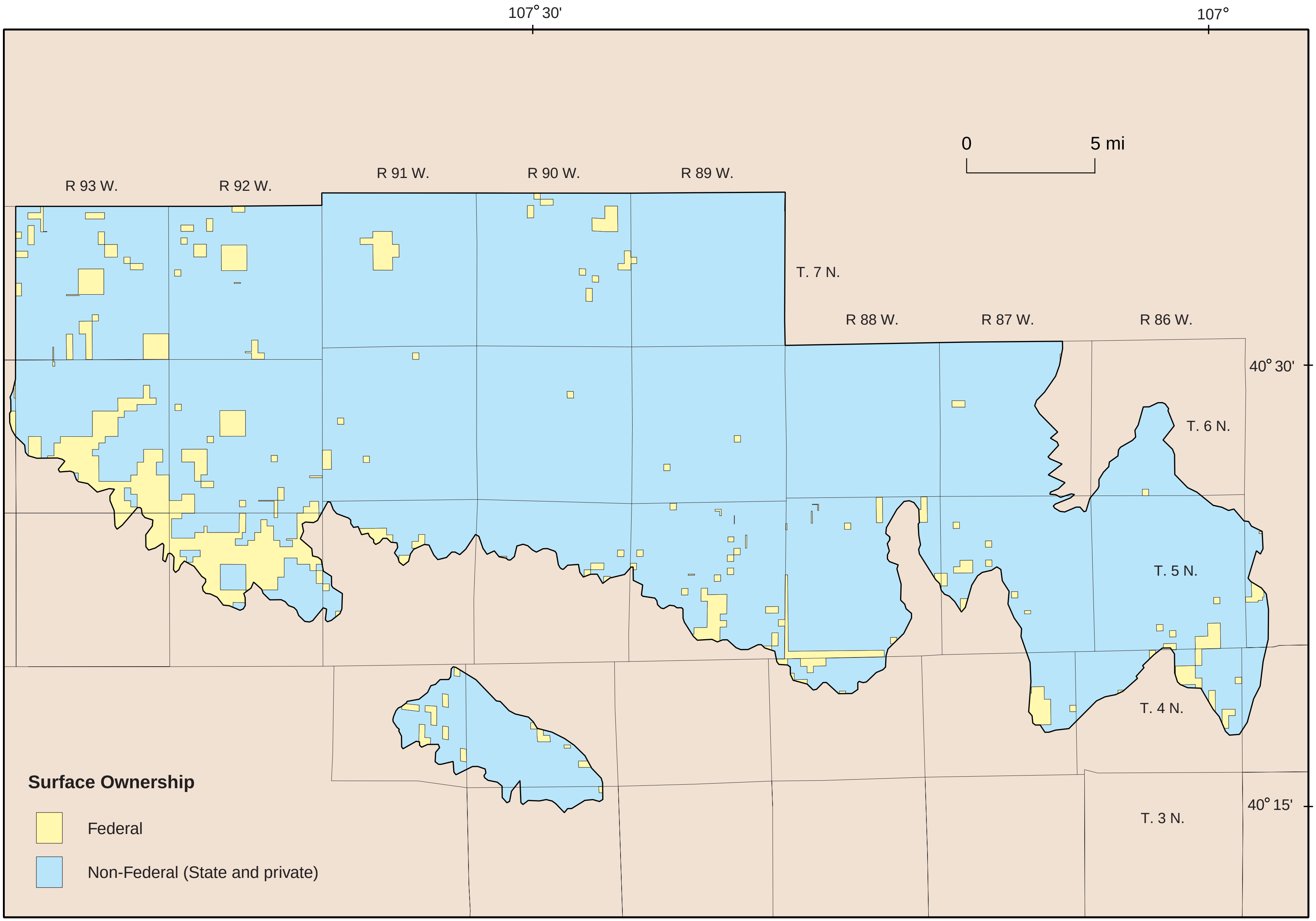

Figure 2. Federal and non-Federal land surface ownership in the Yampa coal field. This outline of the coal field represents the maximum resource polygon used in the coal assessment (see definition in Coal Resource section in text).

Table 1. List of Coal Resource Occurrence and Coal Development Potential (CRO-CDP) 7.5′ quadrangle maps available for the Yampa coal field.

Quadrangle	USGS Open-File Report number	Dames and Moore reference (see Selected References)
Breeze Mountain	79-1393	1979g
Castor Gulch	79-820	1979n
Cow Creek	78-629	1978d
Craig	78-627	1978c
Dunckley	79-813	1979j
Hamilton	79-628	1979b
Hayden	79-825	1979p
Hayden Gulch	79-1395	1979s
Hooker Mountain	78-626	1978b
Horse Gulch	79-882	1979i
Juniper Hot Springs	79-881	1979h
Lay	79-877	1979d
Lay SE	79-878	1979e
Milner	79-815	1979l
Monument Butte	79-281	1979a
Mount Harris	79-821	1979o
Oak Creek	79-818	1979m
Pagoda	79-1394	1979n
Pine Ridge	79-876	1979c
Ralph White Lake	79-880	1979g
Rattlesnake Butte	79-1396	1979t
Rock Springs Gulch	79-876	1979f
Round Bottom	79-814	1979k
Wolf Mountain	78-624	1978a

Table 2. U. S. Geological Survey Open-File Reports, by 7.5′ quadrangle, containing bore-hole geophysical logs of coal exploration drill holes used in the assessment of the Yampa coal field.

Quadrangle	Author	USGS Open-File Report number
Breeze Mountain	Prost (1977)	OF 77-155
	Brownfield (1978b)	OF 78-365
	Johnson and Hook (1985b)	OF 85-43
Castor Gulch	Johnson and Hook (1985b)	OF 85-43
Cow Creek	Brownfield (1978b)	OF 78-365
	Bronson (1979)	OF 79-1593
Hamilton	Meyer (1977)	OF 77-118
	Meyer (1978)	OF 78-366
	Meyer and Brown (1982)	OF 82-475
Hayden	Brownfield (1976)	OF 76-817
	Prost (1977)	OF 77-155
	Brownfield (1978b)	OF 78-365
	Johnson and Hook (1985b)	OF 85-43
Hayden Gulch	Prost (1977)	OF 77-155
	Brownfield (1978b)	OF 78-365
	Johnson and Hook (1985b)	OF 85-43
Horse Gulch	Brownfield (1976)	OF 76-817
	Johnson (1978)	OF 78-229
	Meyer (1978)	OF 78-366
	Johnson and Hook (1985a)	OF 85-37
	Johnson and Hook (1985b)	OF 85-43
Juniper Hot Springs	Johnson and Hook (1985a)	OF 85-37
	Johnson and Hook (1985b)	OF 85-43
Lay	Muller (1976)	OF 76-383
	Brownfield (1978b)	OF 78-365
Milner	Brownfield (1978b)	OF 78-365
Monument Butte	Johnson and Brown (1979)	OF 79-328
Oak Creek	Brownfield (1978b)	OF 78-365
Pagoda	Meyer (1977)	OF 77-118
	Meyer (1978)	OF 78-366
	Meyer and Brown (1982)	OF 82-475
Rattlesnake Butte	Brownfield (1978a)	OF 78-364
	Brownfield (1978b)	OF 78-365
	Stevenson (1978)	OF 78-1048
Round Bottom	Johnson (1978)	OF 78-229
	Johnson and Brown (1979)	OF 79-328
	Johnson and Hook (1985a)	OF 85-37
	Johnson and Hook (1985b)	OF 85-43

short tons (Eakins and Coates, 1998; Fiscor, 1998). In the western part of the coal field, the Trapper mine (surface), is located about 5 mi south of Craig, and the Eagle No. 5 mine (underground) and the Eagle No. 9 mine (surface) are both located about 12 mi southwest of Craig. The Eagle mines are temporarily closed. For the year 1997, the coal field produced 10.9 million short tons of coal, accounting for about 40 percent of Colorado's total coal production (Resource Data International, 1998). The cumulative coal production for the Yampa coal field, from 1864 through 1997, is 266.19 million short tons (Tremain and others, 1996; Resource Data International, 1998).

Two mine-mouth power plants produce electricity in the coal field: the Craig station, located about 4 mi south-southwest of Craig, and the Hayden station, located about 5 mi east-southeast of Hayden. According to plant personnel, the Craig station is owned by Tri State Generation and Transmission Association, Inc. This three-unit power plant has a net capacity of 1,264 megawatts (the largest capacity in Colorado) and features state-of-the-art environmental controls. The first unit was completed in 1979, the second in 1980, and the third in 1984. Most coal burned at the plant comes from the Trapper mine, located about 3 mi to the south-southeast, and a small amount comes from the Colowyo mine, located about 18 mi to the southwest in the northern part of the Danforth Hills coal field. The Hayden station is owned by Public Service of Colorado, PacificCorp, and Salt River Project. According to plant personnel, this two-unit power plant has a net capacity of 446 megawatts. The first unit was completed in 1965, and the second unit was completed in 1976. All of the coal burned at the plant comes from the Seneca II-W and Yoast mines and, until recently, from the Seneca II mine. The Seneca II-W and Yoast mines are located about 1 mi to the south, and the Seneca II is located about 1 mi to the southeast.

Methods Used in the Assessment

Almost all of the basic data used in the assessment were derived from published geologic reports and maps and from information obtained from coal-exploration drilling conducted by the USGS. Data in this assessment are reported in customary inch-pound units because the metric system is not currently used by the coal industry in the United States. Readers wishing to convert measurements to the International System of units (SI) can use the conversion factors in Appendix 1. All resource values are reported in short tons. In order to assess the coal resources, digital files were created of various geologic and geographic information within the area. Drill-hole data were stored and correlated using a StratiFact (GRG Corp.) stratigraphic database manager. Structure data and coal-zone-thickness data were obtained from the database and integrated with digital elevation data to digitally generate the positions of coal-zone outcrop lines. These outcrop lines were then used to define the boundary of assessment polygons for the individual coal zones within the coal field. Coal-bed-thickness data stored in the database were filtered using a computer program developed by the USGS to determine net coal bed thickness. Spatial data were stored, manipulated, and analyzed in a geographic information system (GIS) using ARC/INFO software (Environmental Systems Research Institute, Inc.). The spatial data that required gridding for the generation of structure contour and isopach maps were processed using EarthVision (Dynamic Graphics, Inc.). Contour lines generated in EarthVision (EV) were then converted into ARC/INFO coverages using a program called ISMARC (provided by the Illinois Geological Survey) and an Arc Macro Language (AML) called "convert-ism." Integrating the various coverages in EV allowed for the characterization of coal distribution and calculation of coal resources within a variety of geologic and geographic parameters. The methodology for reporting estimated coal resources is from Wood and others (1983) and is described in detail in the Coal Resources section in this report. All products from this assessment are available in digital form so that GIS technology can be used to manipulate and display the coal-resource information.

Lithologic Data

Most of the subsurface information used in the assessment came from 162 of the 225 coal exploration holes drilled in the Yampa coal field by the USGS between 1975 and 1985 (table 2). The bore-hole geophysical logs of these drill holes were provided by the Craig District Office of the BLM. In addition, the geophysical logs of 13 oil and gas exploration drill holes, which are publicly available, were used in the assessment. The locations of all 175 public drill holes are shown on figure 3, and information about these drill holes is given in Appendix 2. In addition, information from 81 proprietary coal exploration drill holes where provided by the Craig District Office of the BLM for limited use in the assessment. Several coal companies released the geophysical logs of a few specific drill holes for use in the assessment, and nine of these holes appear in cross sections on plate 1. Most of the locations for these drill holes were determined by computer digitization, but a small number were determined by hand using a Gerber scale.

Coal could usually be identified on the geophysical logs of coal exploration drill holes with a high degree of certainty because the curves for natural gamma and gamma gamma density were of good quality. Major sandstone bodies were picked from the curves of natural gamma, spontaneous potential, and single-point resistance, and a tonstein (altered volcanic ash) unit was picked using the single-point resistance curve. For a comprehensive discussion of how coal is identified on geophysical logs, consult Wood and others (1983, p. 60–65). On the geophysical logs of oil and gas exploration drill holes, coal and the tonstein unit were picked using the gamma ray and resistivity curves, and major sandstone bodies were picked using the spontaneous potential and resistivity curves. No attempt was made to identify minor sandstone bodies or argillaceous units. Because the geophysical logs were of several scales and varying quality, lithologic units were measured to the nearest foot in order to insure uniformity. However, coal beds in some of the proprietary data were measured to the nearest tenth of a foot.

Stratigraphic Data

Regional stratigraphic cross sections of the study interval were constructed using public subsurface data and, in several cases, priority data released by coal companies (pl. 1, figs. B, C, and D) . The number of coal beds encountered by any single drill hole that penetrated most of the study interval ranges from as few as four on the east side of the Yampa coal field to more than 50 on the west side of the coal field. Thus, correlating coal beds becomes more difficult from east to west simply because of the increased number of beds. Adding to this complexity, the depositional nature of the study interval is such that individual coal beds have varying thickness and limited lateral extent, which often makes correlating a single bed difficult if not impossible. However, grouping coal beds by zones eliminates these difficulties. Four coal zones are recognized in the coal field, and these zones are discussed in the text and displayed on the cross sections, and resource values are reported according to these subdivisions.

Cartographic Data

Geographic boundaries were imported as ARC/INFO coverages from existing public domain databases. Surface topography was obtained from a 1:250,000-scale digital elevation model (DEM) constructed by the USGS. County lines were obtained from 1:100,000-scale topologically interrogated geographic encoding and referencing (TIGER) files produced

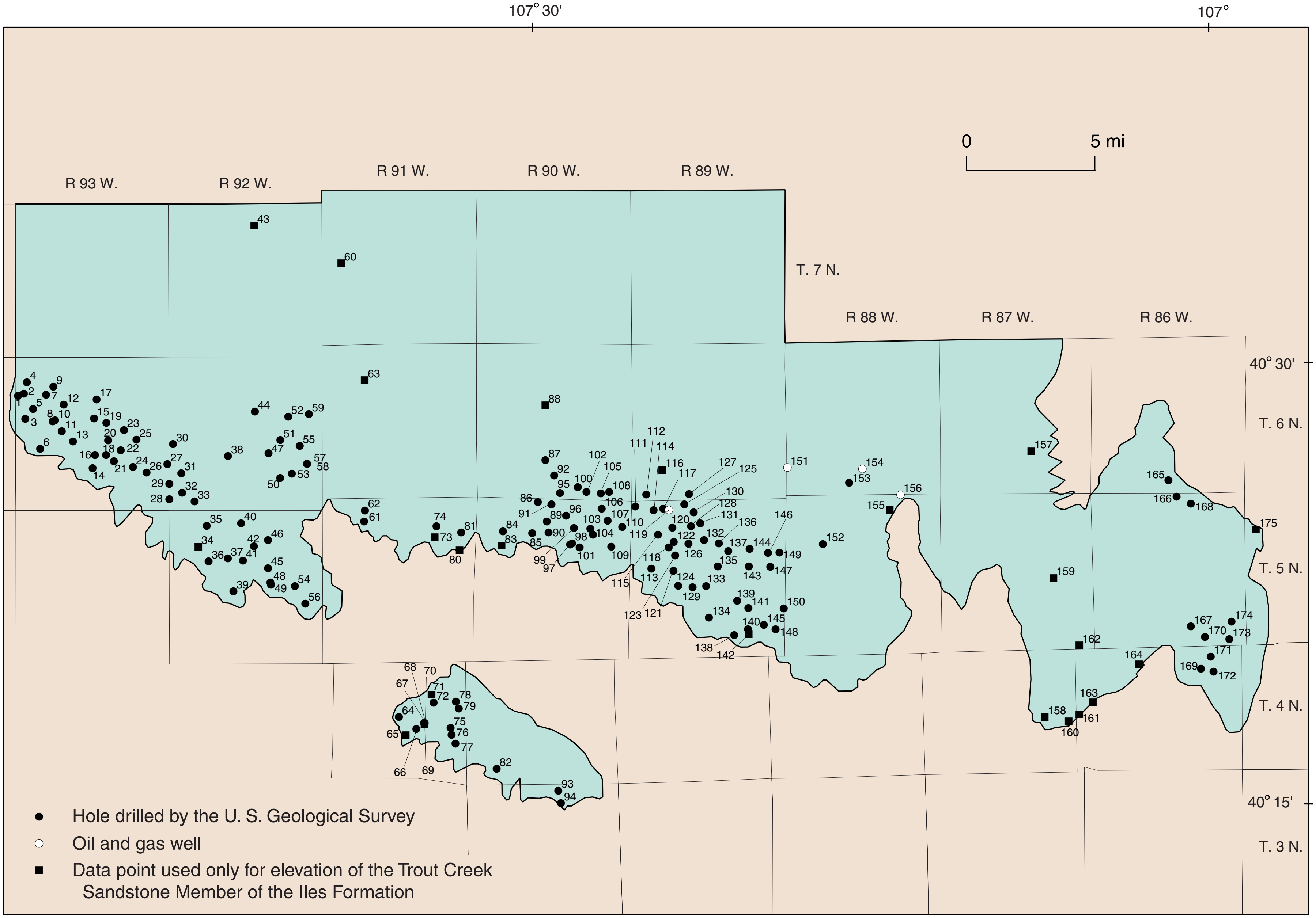

Figure 3. Location of Yampa coal field public data points used for the coal assessment. Data points are identified by map number in Appendix 2.

by the U.S. Bureau of the Census in 1990. Areas of surface and mineral ownership were obtained from 1:24,000-scale digital compilations provided by the Craig District Office of the BLM. Maps showing areas of active and inactive coal leases were also obtained from the Craig District Office BLM, confirmed by the Colorado State Office of the BLM, and digitized. Digital maps generated from ARC/INFO coverages of geologic features include stratigraphic boundaries, faults, fold axes, and strike and dip measurements. These geologic data were digitized by Green (1992) from the 1:500,000-scale geologic map of Colorado compiled by Tweto (1979). That part of the geologic map of Colorado covering the Yampa coal field was compiled from the 1:250,000-scale geologic map of the Craig 1°×2° quadrangle, also compiled by Tweto (1976), which is based on 1:62,500-scale geologic maps by Hancock (1925) and Bass and others (1955). Figure 4 shows the 7.5′ quadrangle map coverage for the coal field. Appendix 7 contains the ArcView project that was used for the coal resource assessment, and Appendix 8 contains the stratigraphic database that was used in the assessment.

Acknowledgments

We would like to thank Janet Hook, Robert Ernst, and Jerry Strahan of the Craig District Office of the BLM for supplying geophysical logs of coal exploration drill holes and maps showing active and inactive coal leases, and Matt McColm of the Colorado State Office of the BLM for confirming the lease maps. In addition, several mining companies granted permission for us to use selected priority data in our assessment, and we here extend our appreciation for this consideration. We also would like to thank USGS employees Ron Affolter for contributing coal-quality data, Laura Biewick for providing GIS support, Dorsey Blake for computer programming support, and Gary Stricker for computer programming support. USGS contract employees Tim Gognat, Jon Haacke, Al Heinrich, Tracey Mercier, and Marin Popov are acknowledged for their technical support. And last, we would like to thank USGS employees Mark Kirschbaum and Bob Hettinger for their peer reviews of the manuscript, and Rick Scott for his editorial work.

Geologic Setting

Cretaceous Paleogeography

During the Cretaceous Period, a large, north-trending epicontinental seaway, the Western Interior Seaway, occupied what is now central North America (fig. 5). The seaway stretched from Mexico to Alaska, and, in what is now the central part of the United States, the width of the seaway extended from western Colorado to eastern Nebraska. A stable cratonic platform bordered the seaway on the east, and the tectonically active Sevier orogenic belt bordered the seaway on the west. Sediments moving eastward from the highlands were deposited along the fluctuating shoreline, resulting in a complex package of Cretaceous sedimentary formations.

General Stratigraphy of Cretaceous Sedimentary Rocks in Northwestern Colorado

In ascending order, the Cretaceous lithostratigraphic units in northwestern Colorado are as follows: Lower Cretaceous Cedar Mountain Formation and Dakota Sandstone, Upper Cretaceous Mancos Shale, Mesaverde Group (Iles Formation and Williams Fork Formation), Lewis Shale, Fox Hills Sandstone, and Lance Formation. The Dakota Sandstone overlies the Upper Jurassic Morrison Formation, and a major unconformity separates the Lance Formation from the overlying Paleocene Fort Union Formation. The oldest Cretaceous unit exposed in the vicinity of the Yampa coal field is the Dakota, which crops out on the west side of Steamboat Springs about 6 mi east of the coal field, and near Juniper Hot Springs about 3 mi west of the coal field. The youngest Cretaceous unit exposed the vicinity of the coal field is the Lance Formation, which forms low hills just north of the coal field.

Mesaverde Group in the Yampa Coal Field

Holmes (1877) applied the named Mesaverde Group to a thick interval of sandstone, mudrock (siltstone, mudstone, shale, and claystone), and coal in southwestern Colorado. Fenneman and Gale (1906b) noted a similar interval of rocks in the Yampa coal field and extended the name Mesaverde into northwestern Colorado. Based on lithologic comparison, their correlation was correct. However, it is now known that the Mesaverde in northwestern Colorado is slightly younger than the Mesaverde in southwestern Colorado (Cobban and Reeside, 1952). Fenneman and Gale lowered the Mesaverde to formation status and included in it two regional sandstones, which they named the Trout Creek Sandstone and the Twentymile Sandstone Members. In addition, they noted that coal in the Mesaverde could be described as occurring in either a lower, a middle, or an upper coal group. The lower group contains all the coal below the Trout Creek, the middle group contains all the coal between the Trout Creek and the Twentymile, and the upper group contains all of the coal above the Twentymile.

Hancock (1925), working in the western part of the coal field, raised the Mesaverde back to group status and subdivided it into the Iles Formation and overlying Williams Fork Formation, and defined the Trout Creek as a member at the top of the Iles and the Twentymile as a member more or less in the middle of the Williams Fork. Bass and others (1955) later extended these names into the eastern part of the coal field. Masters (1966) introduced the name Mount Harris member for the lower part of those rocks between the Trout Creek

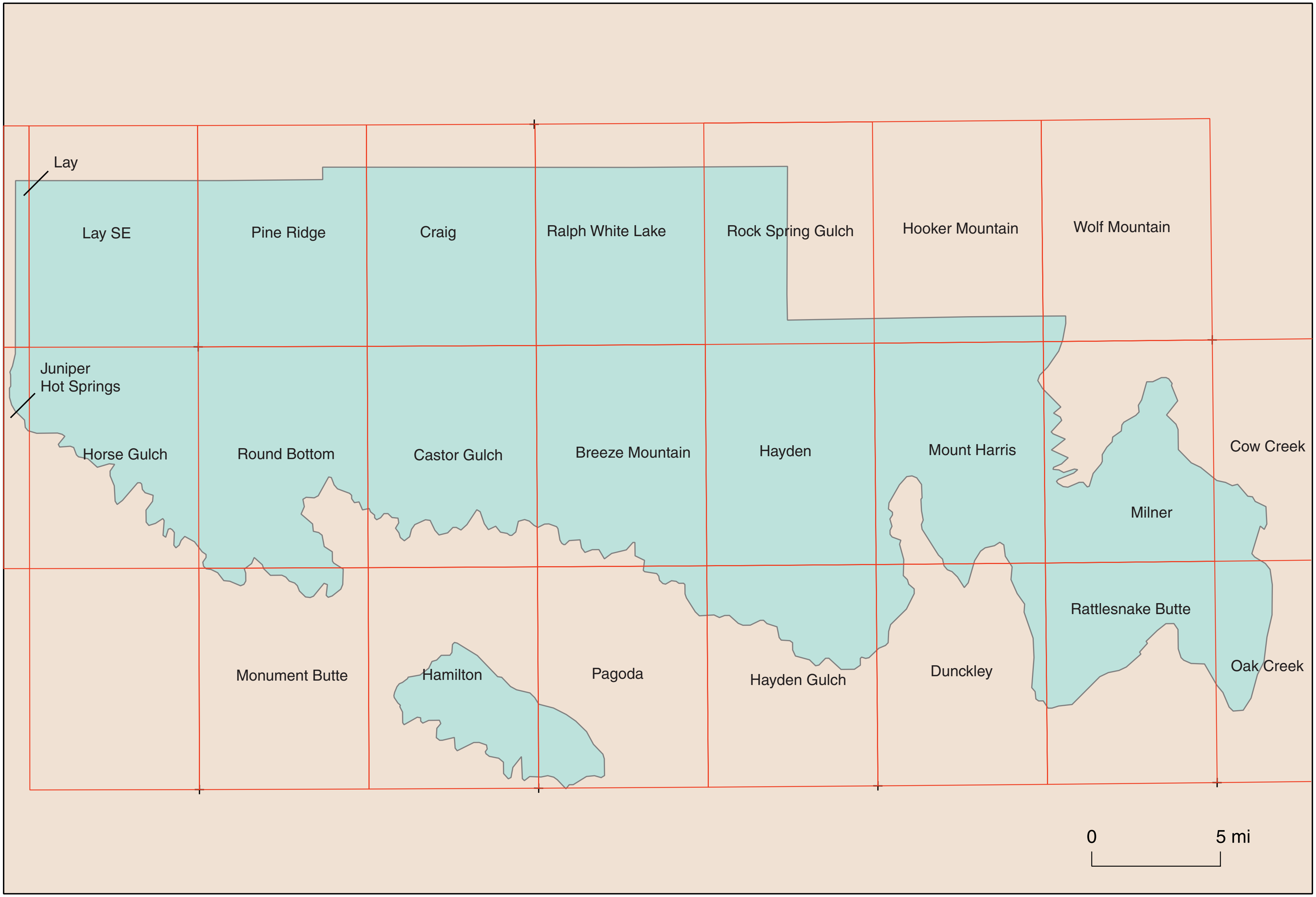

Figure 4. Index map of 7.5′ quadrangles, Yampa coal field.

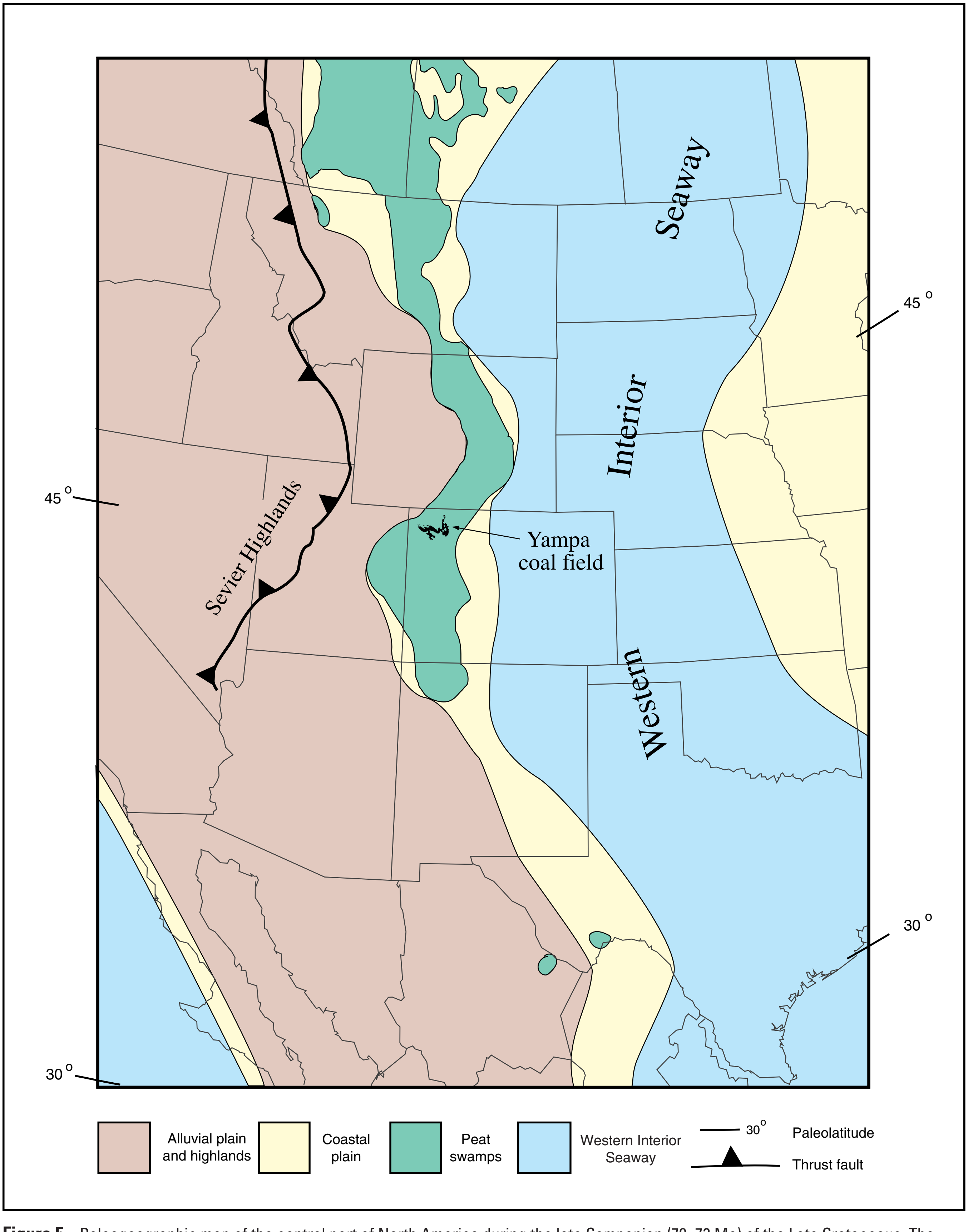

Figure 5. Paleogeographic map of the central part of North America during the late Campanian (79–72 Ma) of the Late Cretaceous. The Yampa coal field is shown in relation to the western shoreline, coastal plain, and peat swamps associated with the Western Interior Seaway. Modified from Roberts and Kirschbaum (1995).

and the Twentymile, and reintroduced an earlier name, Holderness member, for those rocks in the Williams Fork above the Twentymile; neither of these names are used today.

In northwest Colorado, the Mesaverde (fig. 6) comprises an eastward-thinning, wedge-shaped package of marine and nonmarine rocks that overlies and intertongues with the Mancos Shale, which contains *Baculities perplexus* in its upper part, and underlies and intertongues with the Lewis Shale, which contains *Baculities clinolobatus (*Izett and others, 1971). Toward the east, the Mesaverde presumably pinches out into marine rocks of the Upper Cretaceous Pierre Shale, but evidence of this transition was lost to erosion when the Park Range was uplifted during the Tertiary. Toward the west, the Mesaverde becomes increasingly more nonmarine to the point that, in central Utah, equivalent strata are composed almost exclusively of conglomerate.

Detailed Stratigraphy of the Upper Cretaceous (Upper Campanian) Williams Fork Formation in the Yampa Coal Field

The Williams Fork Formation was named by Hancock (1925) for coal-bearing strata in the upper part of the Mesaverde Group in the western part of the Yampa coal field (fig. 7). These rocks are well exposed along the Williams Fork River and in the Williams Fork Mountains.

Mudrock is the most common lithology in the Williams Fork, followed by sandstone and lesser amounts of carbonaceous shale and coal. The mudrock occurs in various shades of brownish gray, is finely laminated, and usually contains varying amounts of carbonaceous debris. Fossil root traces are common. The sandstone is calcareous and appears light gray on fresh surfaces but typically weathers yellowish gray. The rock is composed of moderately well sorted, surrounded to subangular grains of quartz, chert, feldspar, and dark rock fragments that give fresh surfaces a salt-and-pepper appearance. Sandstone bodies include: (1) relatively thin, ripple-laminated sandstones that can be traced laterally, (2) relatively thick, trough cross-stratified sandstones that are lenticular, and (3) relatively massive, cliff-forming sandstones of regional extent. In comparison to the other two types of sandstone bodies, regional sandstones are better sorted and contain a higher percentage of quartz grains, and the grains are more rounded. The carbonaceous shale is black on fresh surfaces and medium to dark brown on weathered surfaces. This lithology commonly grades laterally into coal. Coal occurs in thin to thick, lenticular beds that commonly pinch out or split laterally along strike. In some areas, the coal has burned, and the rocks directly adjacent to the burned bed are baked to a distinctive brick-red color.

Except for the thicker sandstone bodies, rocks in the Williams Fork Formation are poorly exposed throughout the coal field. The formation rests conformably on the top of the Trout Creek Sandstone Member of the Iles Formation. Because the Trout Creek is usually well exposed, identifying the lower contact of the Williams Fork is relatively easy. The upper contact of the Williams Fork with the overlying Lewis Shale is also conformable, but identifying this contact can be more difficult. In the western part of the coal field, the uppermost part of the Williams Fork is characterized by three, vertically stacked, thick sandstone bodies, and this juxtaposition of sandstone in the Williams Fork and shale in the Lewis makes identifying the contact possible. However, in the eastern part of the coal field, these sand bodies are absent, and mudrock in the Williams Fork abuts shale in the Lewis. Here, identifying the contact can be very difficult.

In the western part of the coal field, Hancock (1925) reported that the Williams Fork is approximately 1,600 ft thick, and Johnson (1987) reported the formation to be approximately 1,880 ft thick in the Round Bottom quadrangle southwest of Craig. In the eastern part of the coal field, Bass and others (1955) reported the formation to range from 1,600 ft thick near Mount Harris to nearly 2,000 ft thick at the western margin of their study area. Only four drill holes used in the assessment penetrate the entire Williams Fork, and all four are located in the western part of the coal field. From the geophysical logs of these holes, the thickness of the formation averages 1,915 ft.

North of the coal field, a regional cross section by Roehler and Hansen (1989), which extends from the vicinity of Mount Harris, Colo., north-northwest to Cow Creek in the eastern Washakie Basin in southern Wyoming, shows that the Williams Fork is roughly equivalent to the uppermost part of the Allen Ridge Formation, the Pine Ridge Sandstone, and the Almond Formation. Northwest of the coal field, a regional cross section by Roehler (1987), which extends from the vicinity of Mount Harris, Colo., northwest to Rock Springs, Wyo., shows that the Williams Fork is roughly equivalent to the upper part of the Ericson Sandstone and the Almond Formation. West of the coal field, the term Williams Fork Formation is used to the vicinity of Pinyon Ridge, about 27 mi northwest of Meeker, Colo. (Hail, 1974). South of the coal field, the term Williams Fork is used to the vicinity of Coal Basin, just east of Redstone, Colo., about 66 mi southeast of Meeker (Collins, 1976).

In the pages that follow, thickness ranges are cited for sandstone units and for other stratigraphic intervals, and the reader will note considerable variability in these values. Some of this variability is natural, resulting from lateral changes in depositional facies. But three other factors can cause variability. First, measuring stratigraphic sections in the field is difficult because the rocks are almost always poorly exposed. Even determining the thickness of regional sandstone units is problematic because the lower contact is usually gradational. Second, because of the poor exposure, the presence of normal faults can go undetected, and these faults have a tendency to thicken stratigraphic section. Third, the Williams Fork is composed of a variety of lithologies, and these units can change thickness over short distances. Because each lithology compacts differently, the thickness of a given stratigraphic interval can vary considerably.

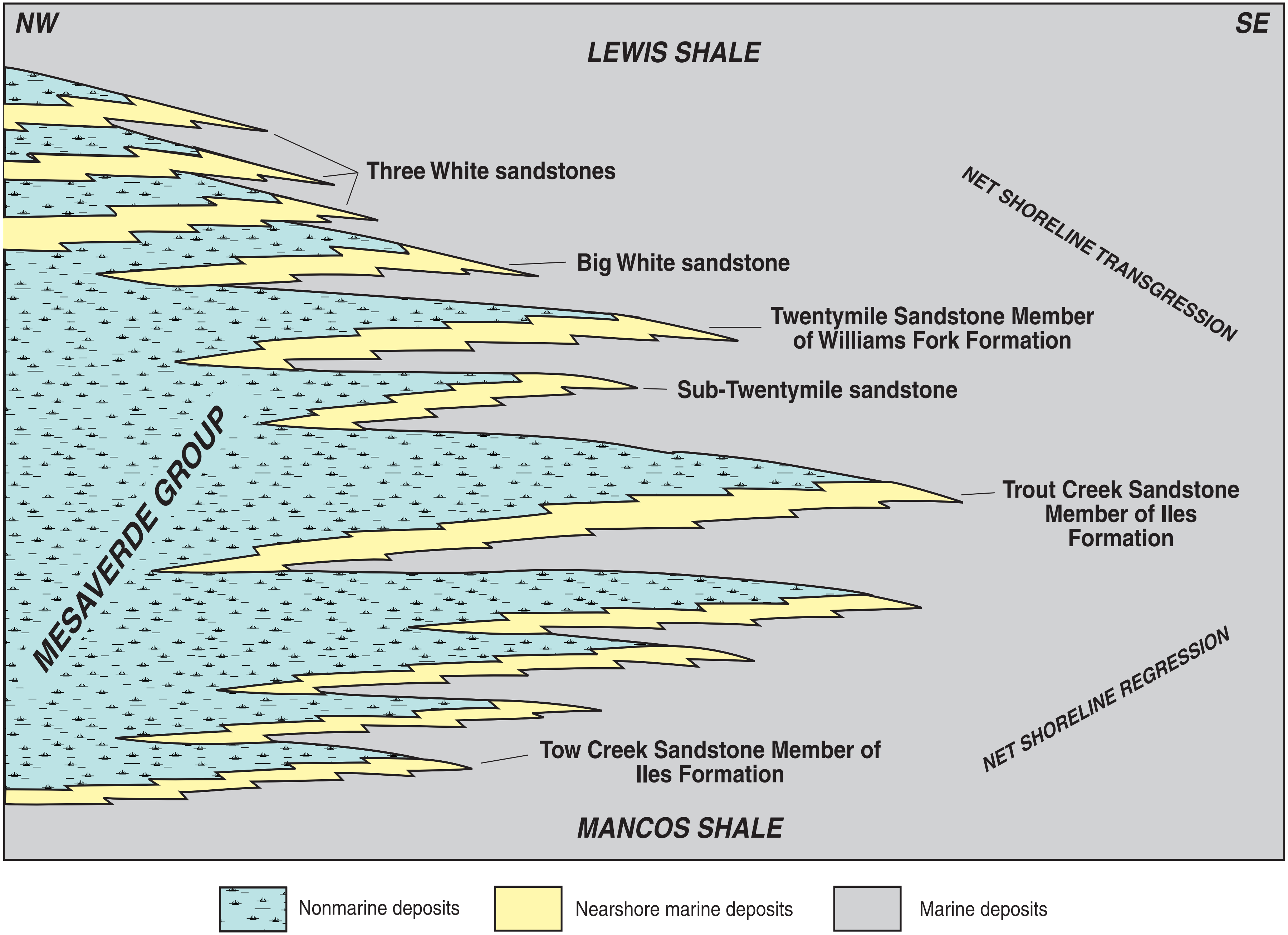

Figure 6. Generalized northwest-southeast cross section of the Mesaverde Group in the Yampa coal field showing the stratigraphic positions of major sandstone units. Modified from Seipman (1985).

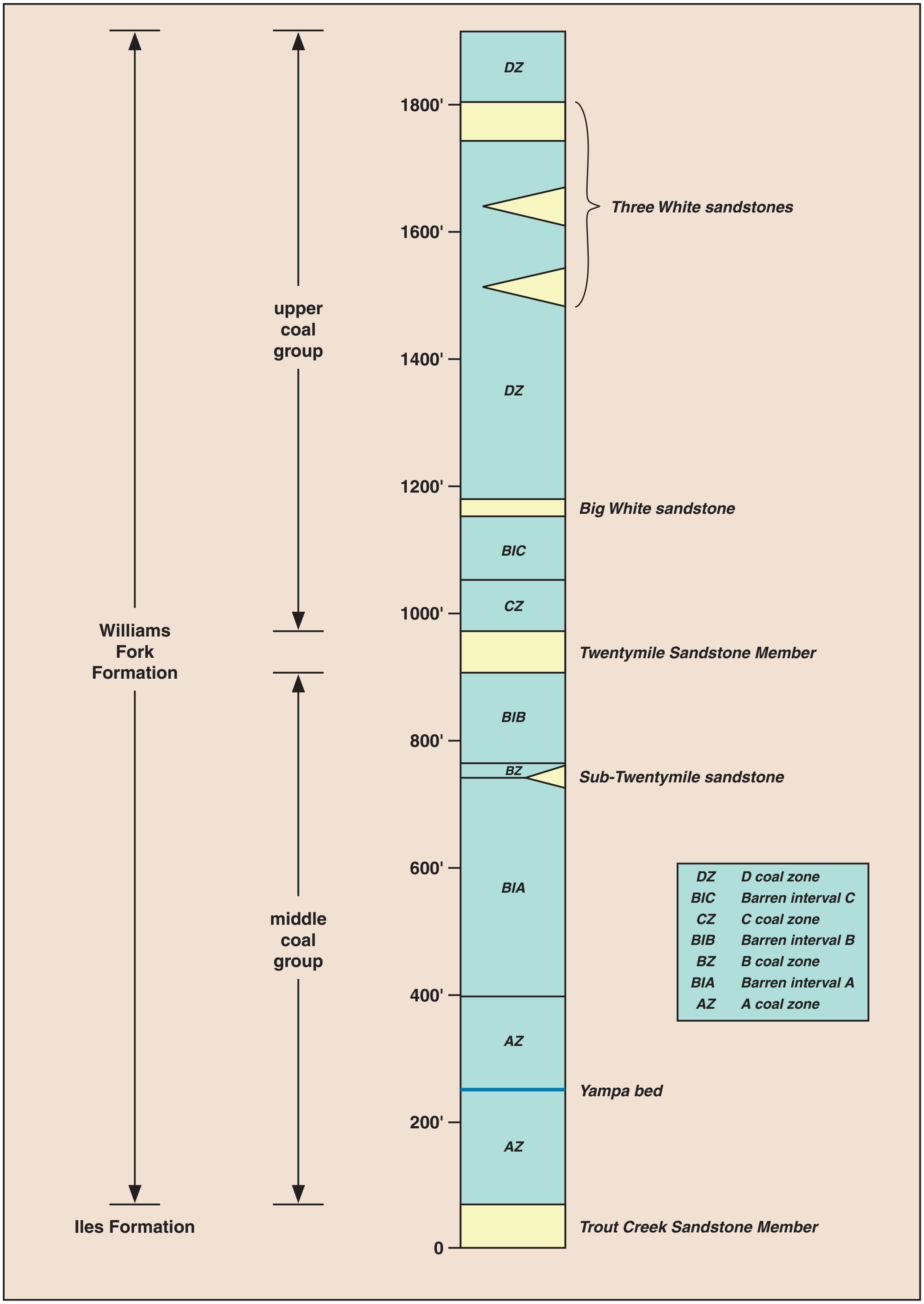

Figure 7. Stratigraphic column for the Williams Fork Formation in the Yampa coal field showing the stratigraphic positions of major sandstone units, coal zones, and barren intervals.

Trout Creek Sandstone Member (Iles Formation)

The Trout Creek Sandstone Member of the Iles Formation was named by Fenneman and Gale (1906b) for exposures along Trout Creek in the eastern part of the Yampa coal field. Although the Trout Creek lies just below the Williams Fork Formation, it is discussed in this report because it is a significant lithostratigraphic unit in the region. The Trout Creek is an impressive, cliff-forming unit of regional extent. Sandstone in the Trout Creek is very fine to medium grained and moderately well sorted, and the rocks become coarser grained and better sorted upward in the unit. The rock is almost white on fresh surfaces but weathers light yellowish gray. Bedding thickness ranges from thin to thick, with thickness increasing upward in the unit. Although the unit is best described as massive, especially in its upper part, hummocky and large-scale trough cross-stratification are commonly observed. Marine trace fossils and the large bivalve *Inoceramus* sp. are locally present. The Trout Creek transitionally overlies an interval of marine shale containing *Exiteloceras jenneyi (*Izett and others, 1971) and is overlain by coal-bearing, nonmarine rocks. At many places a coal bed sits directly on the top of the Trout Creek. Fenneman and Gale (1906b) and Bass and others (1955) reported the Trout Creek to be about 100 ft thick in the eastern part of the coal field, and Johnson (1987) reported that, in the subsurface of the Round Bottom 7.5′ quadrangle in the western part of the coal field, the unit ranges from 67 to 79 ft thick. Siepman (1985), in his regional study of the unit, found that it ranges from 140 ft thick near Mount Harris to 31 ft thick at Middle Creek in the eastern part of the coal field. Based on information compiled during the assessment, the thickness of the unit ranges from 28 to 145 ft, with an average thickness of about 67 ft. Toward the northwest, the Trout Creek pinches out in the subsurface of the Sand Wash Basin (Siepman, 1985; Roehler, 1987). Toward the southwest, the Trout Creek is well exposed in the Danforth Hills (Hancock and Eby, 1930), and, 25 mi to the west in the Pinyon Ridge area, the unit is present in the 7.5′ Rough Gulch quadrangle (Hail, 1974). The Trout Creek pinches out west of Pinyon Ridge, but its nonmarine equivalent might be present in the western half of the Rangely 7.5′ quadrangle (Cullins, 1971). Toward the south, the Trout Creek is equivalent to the Rollins Sandstone Member of the Iles Formation in the southern Piceance Basin of west-central Colorado (Collins, 1976).

Yampa Bed

Brownfield and Johnson (1986) introduced the informal term “Yampa bed” for a regionally significant tonstein (altered volcanic ash) in the lower part of the Williams Fork Formation in the middle part of the A coal zone (fig. 7; pl. 1, figs. C and D). Where rarely exposed on the surface or observed in drill core, the unit is seen to be a grayish-white, structureless claystone that weathers blocky. Typically, the unit is sandwiched between two coal beds, and both the lower and upper contacts are sharp. In the subsurface, the unit becomes an important regional marker bed that is easily identified on the geophysical logs of coal and oil and gas exploration drill holes. In the case of coal exploration logs, the unit displays low natural gamma and very low single-point resistance. Based on information compiled during the assessment, the thickness of the Yampa bed ranges from less than 1 ft to 6 ft thick, but the unit can be absent locally. The average thickness of the unit is about 3 ft. In the western and central parts of the Yampa coal field, the unit lies between 113 and 259 ft above the top of the Trout Creek Sandstone Member, with an average value of 178 ft. However, in the eastern part of the coal field, the Trout Creek rises stratigraphically, and, in this area, the stratigraphic separation is less than 20 ft—on some geophysical logs, the Yampa bed appears to rest directly on the Trout Creek (pl. 1, fig. C). The Yampa bed has also been identified in the Danforth Hills and in the subsurface of the Sand Wash Basin.

Sub-Twentymile Sandstone

The informal term “sub-Twentymile sandstone” was introduced by Kiteley (1983) for a sandstone unit that lies about 150 ft below the base of the Twentymile Sandstone Member of the Williams Fork Formation in the east-central part of the Yampa coal field (fig. 7; pl. 1, fig. C). Most of what is known about this unit comes from the subsurface, but it probably has many physical characteristics in common with the Trout Creek and Twentymile Sandstone Members. Based on information compiled during the assessment, the unit averages about 30 ft in thickness, contains one to three sandstone bodies, and is overlain by the B coal zone. Masters (1966) defined an informal sandstone unit, the Hayden Gulch sandstone, at this same stratigraphic level, and this sandstone is undoubtedly equivalent to the sub-Twentymile. Siepman (1985) recognized the sub-Twentymile and included it at the top of his sub-Twentymile unit. The sub-Twentymile sandstone pinches out toward the east, and it loses its distinctiveness toward the west by splitting into a number of smaller sandstone bodies, but the overlying B coal zone continues through the western part of the coal field.

Twentymile Sandstone Member of the Williams Fork Formation

The Twentymile Sandstone Member of the Williams Fork Formation was named by Fenneman and Gale (1906b) for exposures in Twentymile Park in the eastern part of the Yampa coal field. Based on information compiled during the assessment, the stratigraphic distance between the top of the Trout Creek Sandstone and the base of the Twentymile ranges from 575 to 1,091 ft, with an average of about 839 ft. Thickness values greater than 1,000 ft occur on the eastern side of the coal field, presumably because of a thickening of the marine shale under the Twentymile. The Twentymile typically forms distinctive cliffs of yellowish-gray-weathering sandstone. Lithologically, the Twentymile is very similar to the Trout Creek. Grain size ranges from very fine to medium, and the fragments are moderately well sorted. The rocks are light gray on fresh surfaces and become coarser grained and better sorted in the upward direction. Bed thickness also increases upward. Hummocky and large-scale trough cross-stratification are commonly observed, as are marine trace fossils. Unlike the Trout Creek, the Twentymile often consists of two to three individual sandstone bodies separated by finer grained material. The Twentymile transitionally overlies a thick interval of marine shale containing *Baculities reesidei* (Izett and others, 1971) and is overlain by coal-bearing, nonmarine rocks. At many places a coal bed sits directly on the top of the Twentymile. Bass and others (1955) reported that the Twentymile is about 100 to 200 ft thick in the eastern part of the coal field. Siepman (1985) reported that the unit ranges from 184 ft thick in Fish Creek Canyon in the eastern part of the coal field to 28 ft thick at Duffy Mountain in the western part of the coal field. Based on information compiled during the assessment, the thickness of the Twentymile ranges from 12 to 133 ft, with an average thickness of about 63 ft. Although the thickness varies, in general, values less than 30 ft tend to occur in the western part of the coal field, and values greater than 100 ft tend to occur in the eastern part of the coal field. The Twentymile is less laterally extensive than the Trout Creek. It begins to loose its identity on the western edge of the coal field and is known to pinch out toward the northwest in the subsurface of the Sand Wash Basin (Siepman, 1985). Moreover, the Twentymile is not present to the southwest in the Danforth Hills.

Big White Sandstone

The informal term “Big White sandstone” was introduced by W.R. Grace and Company for a poorly exposed sandstone that lies above the Twentymile Sandstone Member in the central part of the Yampa coal field. In the western part of the coal field, a somewhat discontinuous sandstone is present at the same stratigraphic level as the Big White, and in the Round Bottom 7.5′ quadrangle Johnson (1987) referred to it as the unnamed upper sandstone member of the Williams Fork Formation. Several geologists with the USGS who have worked in the area refer to this informal unit as the Fuhr Gulch sandstone. In the eastern part of the coal field, another sandstone is present at the same stratigraphic level as the Big White, and this informal unit was indirectly defined as the Fish Creek sandstone by Campbell (1923) in his description of the overlying Fish Creek coal bed. With little doubt, all three sandstones are equivalent and represent a poorly exposed, regional unit (fig. 7; pl. 1, figs. B and E). Little is known about the physical characteristics of the Big White. However, Johnson (1987), in his discussion of the unnamed upper sandstone member of the Williams Fork in the Round Bottom 7.5′ quadrangle, describes the unit at the mouth of Fuhr Gulch as a light-gray-weathering, very fine to fine-grained sandstone. Here, the unit is 39 ft thick and lies about 200 ft above the Twentymile. Based on information compiled during the assessment, the stratigraphic distance between the top of the Twentymile and the base of the Big White (or its lateral equivalents) ranges from 90 to 248 ft, with an average value of about 179 ft. The thickness of the unit ranges from 5 to 54 ft, with an average value of about 31 ft.

Three White Sandstones

In the western part of the Yampa coal field, the upper part of the Williams Fork Formation contains three, thick, conspicuous sandstone bodies that are informally referred to by several geologists with the USGS who have worked in the area as the “Three White sandstones” (fig. 7; pl. 1, fig. B). Lithologically, the three sandstones resemble the Twentymile Sandstone Member in almost every detail. In addition, each sandstone overlies a thin interval of finer grained rocks of possible marine affinity and each sandstone is overlain by nonmarine rocks that are usually coal bearing. In some places, a coal bed lies directing on the sandstone. Each of the three sandstones is 50 to 60 ft thick, but exceptions are common. Where best exposed along the Yampa River southwest of Craig (T. 6 N., R. 91 W., secs. 19 and 30), the base of the lower sandstone lies about 310 ft above the top of the Big White sandstone—the stratigraphic distance between the base of the lower sandstone and the top of the upper sandstone is about 320 ft—and the base of the Lewis Shale lies about 115 ft above the top of the upper sandstone. Toward the west, the lower and middle sandstones pinch out, but the upper sandstone continues to the edge of the coal field. Toward the east, the three sandstones continue for several miles east of the Yampa River, but, farther east, the sandstones are difficult to identify on the surface. In the subsurface, evidence of their existence is lacking because all of the coal exploration drill holes were spudded stratigraphically below the expected level of the lower sandstone. It should be mentioned that, where the Three White sandstones are well exposed along the Yampa River, another thick sandstone body exists at the very top of the Williams Fork in sharp contact with the Lewis. This so-called sub-Lewis sandstone is less distinct than those below, and it lacks many of the characteristics shared by the other three. Moreover, it is difficult to trace laterally both on the surface and in the subsurface. On the western edge of the coal field, a single coal bed appears in the subsurface high above the stratigraphic level of the highest coal associated with the upper sandstone, and this coal bed might lie above the sub-Lewis sandstone. If this is true, then the sub-Lewis sandstone is probably a poorly developed fourth sandstone in the series.

Depositional Environments Represented in the Williams Fork Formation

During the Late Cretaceous, the western edge of the Western Interior Seaway was continually modified by sediment influx from tectonically active areas to the west. According to Haun and Weimer (1960), as much as 11,000 vertical feet of sediment were deposited in the seaway during this time. In what is now northwestern Colorado, this western tectonism is referred to as the Sevier orogenic belt, and periods of increased tectonic activity can be related to periods of increased sediment progradation. Because of the interplay between sediment progradation (regression) and marine flooding (transgression), the position of the shoreline fluctuated back and forth with time. Depositional dip was toward the southeast and depositional strike rotated from northeast trending to northwest trending during deposition of the Williams Fork Formation (Zapp and Cobban, 1960).

The sediments deposited in northwestern Colorado during this time are now contained in the Iles and Williams Fork Formations of the Mesaverde Group (fig. 6). Masters (1966) recognized three large-scale, regressive cycles in the Mesaverde: (1) from the base of the Iles to the base of the marine shale underlying the Trout Creek Sandstone Member, (2) from the base of the Trout Creek to the base of the marine shale underlying the Twentymile Sandstone Member, and (3) from the base of the Twentymile Sandstone to the top of the Williams Fork. In each cycle, the top of the coal-bearing package and the base of the overlying marine shale are separated by a transgressive disconformity. In general, the Iles represents a net shoreline regression and the Williams Fork represents a net shoreline transgression. However, in detail, the Williams Fork shows evidence of several shoreline fluctuations, as evidenced by the vertical juxtaposition of the formation’s three major depositional settings: offshore marine, nearshore marine, and fluvial.

Offshore Marine Mudrock

The westward-thinning tongues of mudrock that directly underlie the Trout Creek and Twentymile Sandstones Members were deposited on an open-marine shelf, as evidenced by the presence of marine body fossils and deep-marine trace fossils. Most likely, this same environment is represented in the strata that directly underlie the sub-Twentymile sandstone in the eastern part of the coal field, and a somewhat shallower marine environment is probably represented in the strata that directly underlie the Three White sandstones in the western part of the coal field. The characteristics of the strata that directly underlie the Big White sandstone are poorly known, but it is quite possible that these rocks are also marine.

Nearshore Marine Sandstone

The sandstones contained in the Trout Creek Sandstone Member, sub-Twentymile sandstone, Twentymile Sandstone Member, Big White sandstone, and in the Three White sandstones were deposited in a nearshore marine environment. This conclusion is supported by an upward increase in grain size and an upward increase in bed thickness, hummocky cross-stratification followed upward by trough cross-stratification, and the occurrence of shallow-marine trace fossils, especially *Ophiomorpha*. Relatively complete stratigraphic sections of the Trout Creek and Twentymile reveal that the units are composed of a basal transitional part, deposited below wave base, and an overlying shoreface part, deposited above wave base but below low tide level. Some exposures also contain a higher foreshore part, deposited between low- and high-tide levels—some rare exposures are capped by a backshore part, deposited above high-tide level. Many workers, most recently Seipman (1985), believe that the Trout Creek and Twentymile were deposited along a wave-dominated, deltaic strand plain and barrier-island system in a microtidal setting.

Nonmarine Deposits

The strata that directly overly the nearshore marine sandstones probably accumulated in lagoonal settings, whereas all of the higher strata most likely accumulated as fluvial deposits on a coastal plain that sloped gently seaward with little topographic relief. Two main fluvial environments are represented in the coastal-plain system: channel and overbank. Lenticular, fining-upward sandstone bodies represent the active channel fill of high-sinuosity streams, and the much more subtle lenticular bodies of mudrock represent abandoned-channel fill. Interbedded strata deposited in the overbank environment include: (1) intervals of very fine grained sandstone and mudrock representing levee deposits, (2) intervals of mudrock containing abundant fossil root traces representing flood-plain deposits, and (3) tabular bodies of ripple-laminated, fine- to very fine grained sandstone representing splay deposits. Coal beds positioned on or just above the nearshore marine sandstones perhaps represent peat that accumulated in lagoons that separated barrier islands from the mainland. Coal beds positioned higher in the stratigraphic section probably represent peat that accumulated in swamps that existed in interchannel areas on the coastal plain. The nonmarine successions that overlie the Trout Creek Sandstone Member, sub-Twentymile sandstone, Twentymile Sandstone Member, and the Big White sandstone each consist of a lower coal-bearing part (coal zone) and an overlying part that does not contain coal (barren interval). Most likely, the coal-bearing part represents an environment low on the coastal plain where the gradient was at its lowest and the water table was at its highest. The overlying part that does not contain coal is marine in its upper portion, especially in the eastern part of the Yampa coal field, but the nonmarine lower portion perhaps represents an environment higher on the coastal plain where conditions did not favor the formation of swamps.

Brief History of the Deposition of the Mesaverde Group in the Yampa Coal Field

Prior to the deposition of the Mesaverde Group (fig. 6), the western shoreline of the Western Interior Seaway was positioned about 75 mi west of what is now the Yampa coal field (Zapp and Cobban, 1960), and, in the area of the coal field, marine mud—now contained in the Mancos Shale—was accumulating. The lowest unit of the Mesaverde, the Tow Creek Sandstone Member of the Iles Formation (Crawford and others, 1920), was deposited when a major eastward migration of the sea moved the shoreline to the area of the coal field, and nearshore marine sand was deposited over marine mud. As the shoreline continued to move eastward beyond the coal field, nonmarine rocks now contained in the main body of the Iles were deposited over the Tow Creek, and this part of the Iles contains some coal. The depositional history of the main body of the Iles is not well documented, but several minor oscillations of the shoreline occurred during this time, and rocks representing these events are now contained in this part of the formation (Kiteley, 1980). Toward the end of Iles time, the shoreline moved westward back across the coal field, flooding the area with seawater, and marine mud was deposited over the nonmarine sediments. This event is now recorded in the marine shale that directly underlies the Trout Creek Sandstone Member of the Iles. At the very end of Iles time, the shoreline again moved eastward to the area of the coal field and the nearshore marine sand of the Trout Creek was deposited (Siepman, 1985).

The first phase of Williams Fork deposition occurred as the shoreline continued to move eastward beyond the coal field: nonmarine sediments accumulated just behind the beach or low on the coastal plain, and this interval now contains coal (A coal zone). Following this, sediments were probably deposited higher on the coastal plain, and this higher interval lacks coal (lower part of barren interval A). On the eastern side of the coal field, a minor westward shift of the shoreline caused an interval of marine mud to be deposited, followed by a minor eastward shift of the shoreline that allowed nearshore marine sand to be deposited—these two events are now represented by rocks contained in the sub-Twentymile sandstone and its underlying marine shale (upper part of barren interval A). As the shoreline continued to move eastward, nonmarine sediments accumulated above the sub-Twentymile, and this interval now contains coal (B coal zone). The nonmarine rocks directly above this interval lack coal (lower part of barren interval B). Finally, the shoreline again moved westward back across the coal field, flooding the area with seawater, and marine mud was deposited over the nonmarine sediments. This mud is now represented by the marine shale (upper part of barren interval B) that lies directly under the Twentymile Sandstone Member of the Williams Fork.

The last phase of Williams Fork deposition occurred when the shoreline again moved eastward across the area of the coal field, and the nearshore marine sand and overlying nonmarine rocks now contained in the Twentymile and upper part of the Williams Fork were deposited. As occurred earlier, the first nonmarine sediments were deposited just behind the beach or low on the coastal plain, and this interval now contains coal (C coal zone). In the interval above, coal is not present because the sediments were probably deposited higher on the coastal plain (barren interval C). At this point, the depositional history of the Williams Fork becomes obscure. What is known is that (1) a significant sandstone, the Big White sandstone, was deposited more or less across the entire coal field, and (2) the interval overlying the sandstone contains coal (D coal zone). Most likely, the Big White represents another couplet of shoreline shifts and subtle marine characteristics that will eventually be described in the unit, and the rocks directly below the sandstone will prove to have a marine affinity. The depositional history at the close of Williams Fork time is more clear. A major westward migration of the sea caused the area to be covered by seawater, and marine mud was deposited, which is now contained in the Lewis Shale. This signaled the end of Mesaverde deposition in northwestern Colorado. However, the event was interrupted at least three times by minor oscillations of the shoreline, during which time the Three White sandstones and their associated rocks were deposited.

Post-Mancos Shale Regional Cretaceous Stratigraphy in Northwestern Colorado

The Cretaceous formations above the Mesaverde Group in the area of the western Williams Fork Mountains (the Lewis Shale, Fox Hills Sandstone, and Lance Formation) have not been recognized to the southwest in the Danforth Hills (fig. 8). Moreover, the thickness of strata assigned to the Williams Fork Formation increases from 1,900 ft in the Williams Fork Mountains to 4,775 ft in the Danforth Hills. The depositional conditions that lead to this conundrum have been pondered by geologists for many years. West of the Danforth Hills, in the vicinity of Rangely, Colo., the post-Mancos Shale stratigraphic section is much thinner, suggesting that Tertiary erosion has removed a significant amount of Cretaceous rock. Because much of the post-Mancos depositional history has been lost to erosion in this area, solving the riddle must rely on evidence obtained from the Williams Fork Mountains and Danforth Hills.

Part of the solution involves the Axial Basin anticline, the structural feature that separates the southeastern part of the Sand Wash Basin, including the Williams Fork Mountains,

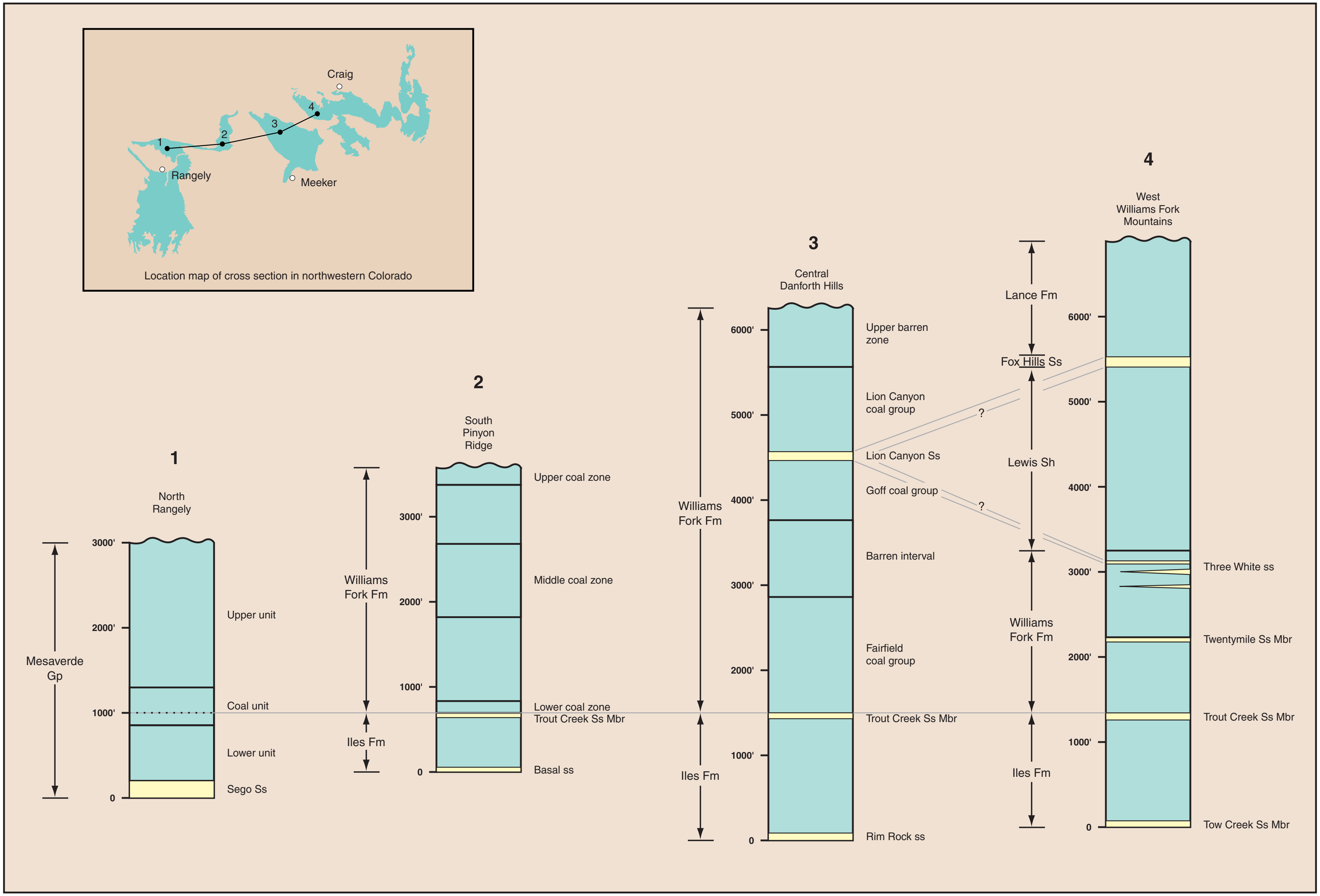

Figure 8. Generalized regional cross section of the Mesaverde Group and younger Cretaceous formations in northwestern Colorado. No horizontal scale implied.

from the northeastern part of the Piceance Basin, including the Danforth Hills. This feature is probably related to an underlying weakness in the crust, and tectonic activity in this area could possibly date from the Precambrian (Stone, 1986). If the area of the present-day Axial Basin was active during the Late Cretaceous, it is fair to assume that the shape of the western coastline of the Western Interior Seaway was modified in response to the tectonism and that the Late Cretaceous depositional history in this small area is somehow unique. Presumably, sometime during the late Tertiary, the area of the Axial Basin was uplifted above the surrounding terrain, and the post-Mancos rocks were subjected to differential erosion. As a result, the soft shales of the Mancos were exposed in the core of the fold, and continued erosion of these rocks has resulted in the topographic depression (or basin) seen today. Because the post-Mancos rocks have been lost to erosion, the complete depositional history of this area will never be known. Indeed, it will never be known if any post-Mancos rocks were even deposited.

The first geologist to publish his thoughts on the subject was Gale (1910), who postulated that either the Lewis, Fox Hills, and Lance were never deposited in the area of the Danforth Hills, or they were deposited but subsequently removed by Tertiary erosion. Sears (1925), and later Masters (1959), thought that a regional facies change could explain both the absence of these units as well as the increased thickness of the Williams Fork Formation. Both workers suggested that the Lewis sea did not transgress into the area of the Danforth Hills, and therefore no marine shale was deposited. If this is true, then the thick shale unit (Lewis Shale) that separates and defines the top of the Williams Fork Formation from the base of the overlying Cretaceous units (Fox Hills and Lance) in the Williams Fork Mountains is simply not present in the Danforth Hills. Thus, rocks equivalent to the Fox Hills and Lance are actually present in the Danforth Hills but remain unidentified in the upper part of the Williams Fork Formation. By this hypothesis, the Lion Canyon Sandstone Member of the Williams Fork Formation in the Danforth Hills, known to contain brackish-water bivalves, might represent deposition at, or near, the locality of maximum transgression of the Lewis sea. The Lion Canyon might therefore be a retrogradational and progradational stack of nearshore marine sandstones that includes equivalents of the Three White sandstones in the upper part of the Williams Fork Formation and the Fox Hills Sandstone, respectively, in the Williams Fork Mountains.

In conclusion, the coal in the upper part of the Williams Fork Formation in the Danforth Hills, the Lion Canyon coal group, is possibly equivalent to coal in the Lance in the Williams Fork Mountains, and the Mesaverde Group coal in the Rangely area is probably equivalent to the Fairfield coal group of the Williams Fork Formation in the Danforth Hills.

Post-Cretaceous Deformational History of Northwestern Colorado

Near the end of the Cretaceous, the Western Interior Seaway withdrew from what is now northwestern Colorado, and marine and coastal-plain deposition ceased. This event was followed closely by compressional tectonism associated with the onset of the Laramide orogeny. In northwestern Colorado, the Lance and older rocks were folded, mildly uplifted, and eroded, and the peneplain that resulted is now represented by a regional unconformity. As the orogeny intensified in earliest Tertiary, the Park Range was uplifted and eroded and a thin veneer of gravel spread westward as an alluvial fan over the erosional surface. This deposit now forms the basal conglomerate of the Paleocene Fort Union Formation. With the uplift of the Park Range and other Laramide structures, the ancestral Sand Wash Basin was defined, and all Tertiary formations younger than the Fort Union are finer grained and show lateral facies changes consistent with deposition in a slowly subsiding basin. During the middle and late Tertiary, extensional tectonism resulted in numerous normal faults and volcanism in the region. The various volcanic features and deposits located northwest of Steamboat Springs are Miocene in age.

Structural Features of the Yampa Coal Field

The Yampa coal field occupies the southeastern corner of the Sand Wash Basin (Tweto, 1976), and this is reflected in the gross regional structure of the coal field (fig. 9). In the western and central parts of the coal field, the structural dip is toward the north, but farther to the east, the regional structure swings counterclockwise until, in the northeastern part of the coal field, north of Mount Harris, the dip is toward the west. Another regional structure of significance in the area of the coal field is the northwest-trending Axial Basin anticline. This structure borders the coal field on the southwest and defines the boundary between the Sand Wash Basin on the north and the Piceance Basin on the south. According to Stone (1986), this fold is a minor part of a much larger tectonic structure that extends from the Uinta Mountains in northeastern Utah to the Eagle Basin in north-central Colorado. The anticlinal nature of the fold, as seen on Stone's cross sections, results from the doming of strata above a southwest-vergent thrust fault. Although movement along this regional trend might date from the Precambrian, the current Axial Basin anticline probably formed during the Laramide orogeny at the same time that smaller, subparallel folds were forming toward the north in the coal field.

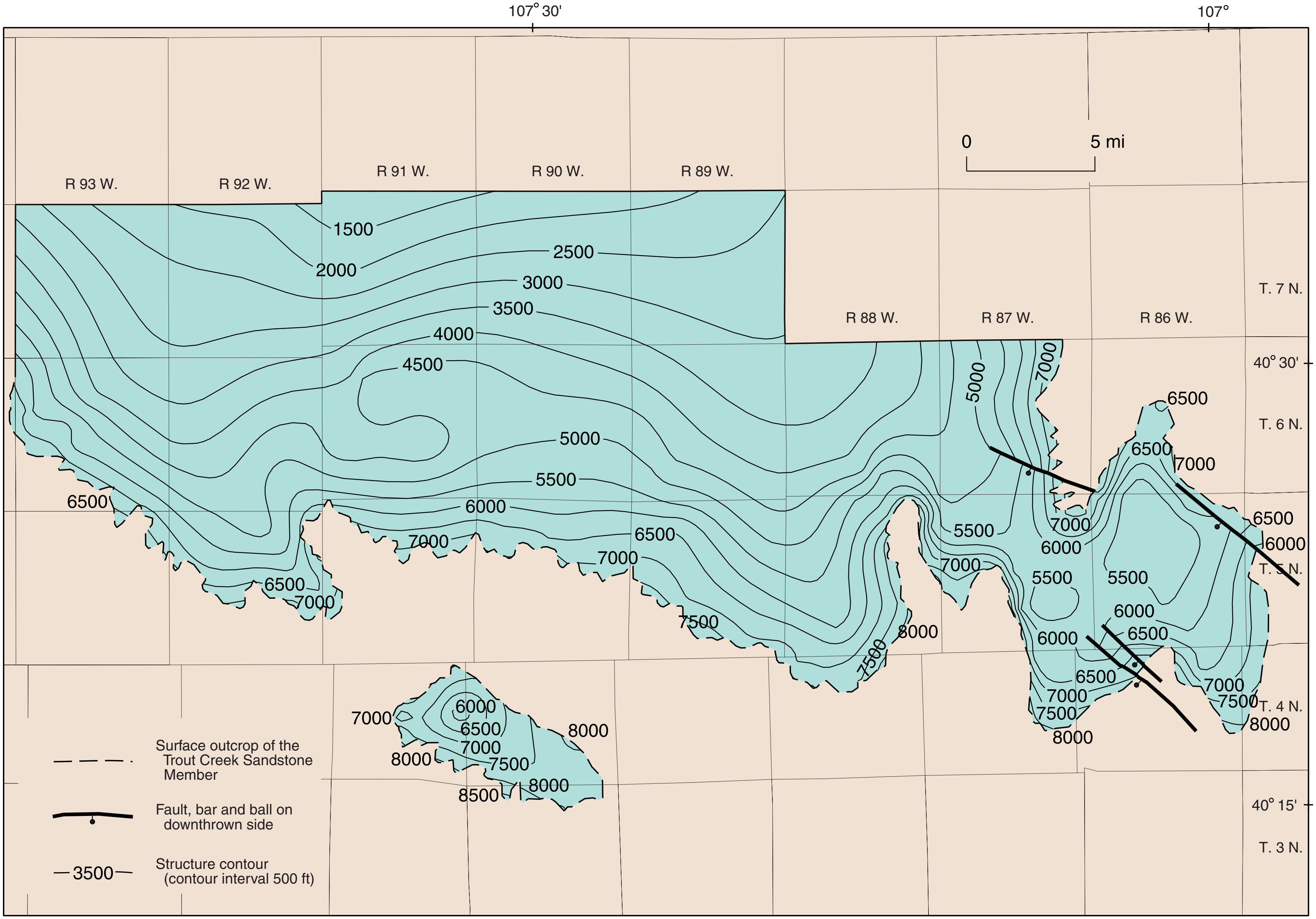

Figure 9. Structure contour map drawn on top of the Trout Creek Sandstone Member of the Iles Formation, Yampa coal field. Surface outcrop of the Trout Creek modified after the 1:250,000-scale geologic map of the Craig 1°×2° quadrangle compiled by Tweto (1976). Contours generated from surface elevations and subsurface elevations contained in the public data base used in the coal assessment. Only those faults known to offset the top of the Trout Creek are shown.

Folding in the coal field occurred after deposition of the Lance Formation but before deposition of the Fort Union Formation (Tweto, 1976). In general, folds within the coal field can be grouped into a western group and an eastern group (fig. 10). On the east side of the coal field, south and east of Hayden, the fold axes trend north-northwest and north-northeast and plunge in a southerly direction. These folds are asymmetrical, with their axial planes inclined in a westerly direction. Starting from the west, the more significant folds are the Sage Creek anticline, the Fish Creek anticline, the Twentymile Park syncline, and the Tow Creek anticline. The Twentymile syncline is doubly plunging, and a structural basin containing Lewis Shale accounts for the broad open area, or park, south of Milner. On the western side of the coal field, south and west of Craig, fold axes trend and plunge toward the northwest. Most of the folds are also asymmetrical, with their axial planes inclined toward the northeast. Starting from the west, the more significant folds are the Round Bottom syncline, the Williams Fork anticline, the Big Bottom syncline, and the Breeze Mountain–Buck Peak anticline.

South of the western part of the coal field, folds trend and plunge toward the northwest and are asymmetrical with their axial planes inclined toward the northeast, thus following the structural pattern in the western part of the coal field. The dominant fold in this area is the Hart syncline. This structure is bounded on the north by the Beaver Creek anticline and on the south by the Seely anticline. The axes of these folds trend northwest, but the axis of the Hart syncline and the Seely anticline eventually veer westward. The Hart syncline is a doubly plunging structure, and the resistant Trout Creek Sandstone Member holds up the fold as a topographic high with a depressed basin in its center.

Faulting in northwestern Colorado commenced sometime in the middle or late Tertiary, and, in the Sand Wash Basin, units as young as the Miocene Browns Park Formation have been displaced (Tweto, 1976). Undoubtedly, faulting continued into the Quaternary, and the region still experiences rare, mild earthquakes. Most of the faults in the coal field are high-angle normal faults that trend northwest (fig. 10). Displacements are down to the northeast or southwest, and horst-and-graben structures are common. Overall, faulting has not disrupted the gross structure of the coal field to any significant degree.

Coal Assessment

On the map “Coal Fields of the Conterminous United States” (Tully, 1996), the Yampa coal field is shown to be in the southeastern corner of the Green River Region of the Rocky Mountain Province. Both Cretaceous- and Paleocene-age coal occur in this area, but only the coal in the Mesaverde Group is of economic significance at this time. Of the three coal groups in the Mesaverde, as defined by Fenneman and Gale (1906b), only the middle and upper groups in the Williams Fork Formation were considered in this assessment. Several large mines are currently extracting coal from these two groups, and future coal leasing and subsequent mining will most likely be restricted to coal in these two groups. The lower coal group, which comprises the coal in the Iles Formation, was not considered in this assessment because the coal is currently subeconomic. Notable closed mines in the Iles include the Pinnacle mine, located about 1 mi southeast of Oak Creek; the Bear River mine, located about 1 mi northeast of Mount Harris; and the Sun and Rice mines, located in Hayden Gulch in the south-central part of the coal field.

The Lance Formation contains a minor amount of coal, notably the 3- to 10-ft-thick Lorella bed, positioned about 50 ft above the base of the formation, and the 10- to 14-ft-thick Kimberley bed, positioned about in the middle of the formation (Bass and others, 1955). There is also a significant amount of coal in Fort Union Formation, notably the Seymour bed in the upper part of the formation—this bed can be as thick as 17 ft. There is currently no interest in extracting coal from either of these formations, and therefore they were not included in this assessment.

During deposition of the Williams Fork, the area that is now northwestern Colorado was at a latitude of about 42 degrees north (Roberts and Kirschbaum, 1995) and had a humid, subtropical climate. This favorable climate, coupled with a high water table characteristic of a lower-coastal-plain depositional setting, facilitated the development of a complex network of peat swamps that were interspersed with fine-grained siliciclastic sediments. Because of this complexity, coal in the Williams Fork is widely distributed, both vertically and horizontally, and coal beds commonly pinch out or split laterally over relatively short distances, making regional correlations of individual beds difficult. Correlation problems are made more difficult because each mine in the western and central parts of the coal field has developed their own bed nomenclature. This is not the case on the eastern side of the coal field, where there are only three major coal beds and their names are in common use by all of the mining companies.

Coal Distribution

Based on regional cross sections (pl. 1, figs. B, C, and D), coal in the Williams Fork Formation can be grouped into four zones, two in the middle coal group and two in the upper coal group (fig. 7). These zones are defined in terms of the regional sandstone units in the formation and three barren intervals that can be traced throughout the coal field. Local variations in thickness for coal zones and barren intervals can result from differing compaction ratios of the varying non-coal lithologies. In analyzing a particular coal zone or barren interval, only those drill holes that were commenced above the zone or interval and completed below the zone or interval where used. This criteria insured that only complete stratigraphic sections were used.

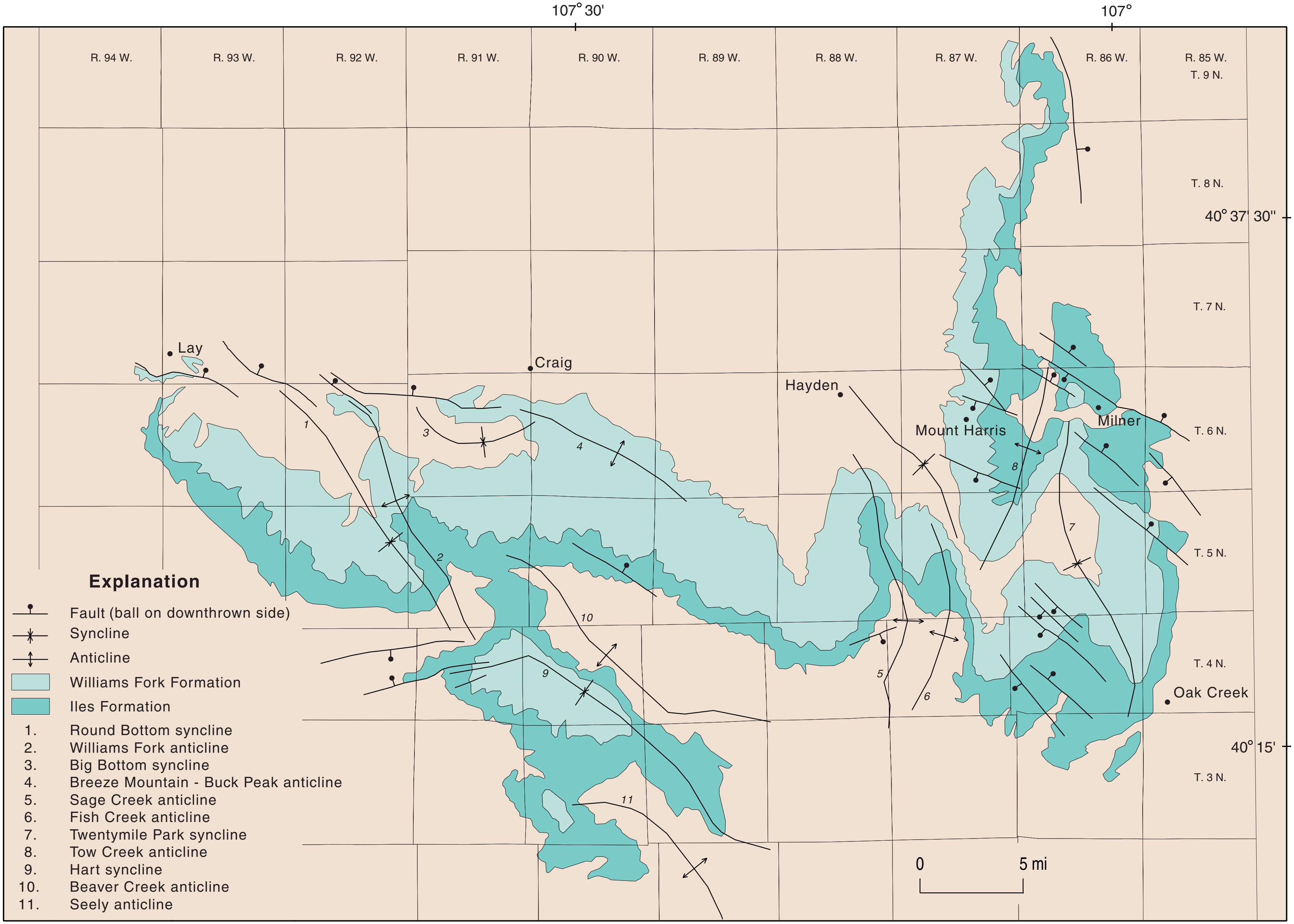

Figure 10. Generalized geology of the Yampa coal field showing the Iles and Williams Fork Formations and major folds and faults. Modified after the 1:250,000-scale geologic map of the Craig 1°×2° quadrangle compiled by Tweto (1976).

A Coal Zone

The A coal zone is defined as the interval that extends from the top of the Trout Creek Sandstone Member to the top of the first coal bed below barren interval A. In the eastern and central parts of the coal field, the coal zone is quite distinct, but in the western part of the coal field, barren interval A is much thinner (pl. 1, fig. C)—in this area separating the A and B coal zones can be problematic. The Yampa bed is positioned more or less in the middle of the A coal zone in the western and central parts of the coal field, but, along the eastern margin of the coal field, the Yampa bed drops stratigraphically and in some places appears to set almost on top of the Trout Creek. Based on information compiled during the assessment, the thickness of the interval between the base of the lowest coal bed to the top of the highest coal bed ranges from 202 to 463 ft, and averages about 350 ft. This interval excludes a variable thickness of rock that lies above the Trout Creek and below the lowest coal bed.

Based on drill-hole data collected during the assessment, the A coal zone contains the most coal beds and has the greatest net thickness of coal of the four coal zones in the Williams Fork Formation. The number of coal beds increases from east to west. On the eastern side of the coal field, in the Rattlesnake Butte, Milner, and Oak Creek 7.5′ quadrangles (fig. 4), the number of coal beds ranges from four to nine, with an average of five. On the western side of the coal field, in the Horse Gulch and Round Bottom 7.5′ quadrangles, the number of coal beds ranges from eight to 23, with an average of 14. The net thickness of coal also increases from east to west (fig. 11). On the eastern side of the coal field, in the Rattlesnake Butte, Milner, and Oak Creek 7.5′ quadrangles, the net thickness of coal ranges from 20 to 27 ft, with an average of 24 ft. On the western side of the coal field, in the Horse Gulch and Round Bottom 7.5′ quadrangles, the net thickness of coal ranges from 31 to 97 ft, with an average of 66 ft. In the Hart syncline (fig. 10), south of the main area of the coal field, the average number of beds, 13, is similar to the average for the western part of the coal field. However, the net thickness of coal, 87 ft, exceeds the average for the western part of the coal field. Figure 11 also shows a trend of net coal greater than 80 ft that extends in a northwesterly direction from the western half of the Hart syncline. The thickest single coal bed in the A coal zone encountered during the assessment, measuring 33 ft, was penetrated by drill hole H-32-H (data point 82, fig. 3; pl. 1, fig. D) in the southeastern part of this trend, and the Eagle No. 5 mine (fig. 1) extracts coal from a thick coal bed in the northwestern part of the trend.

In the eastern part of the coal field, the A coal zone maintains its regional thickness, but the coal zone contains only three major coal beds: the Wolf Creek, Wadge, and Lennox, in ascending order (pl. 1, fig. C). These names were probably established prior to 1900 because the names were in common use by the time they were first mentioned in print in 1906 (Fenneman and Gale, 1906b). Although the term bed is always used when discussing these coals, they almost always comprise several beds. Thus, the term “sub coal zone” seems more appropriate and is informally used in this report. Based on 18 geophysical logs of widely spaced drill holes in this part of the coal field, the following information is typical of the sub zones.

The stratigraphic distance between the top of the Trout Creek Sandstone Member and the base of the Wolf Creek sub coal zone ranges from 33 to 76 ft, with an average value of about 54 ft. The thickness of the sub zone ranges from 12 to 42 ft, with an average value of about 22 ft. The sub zone always comprises two to four coal beds, with the number of beds increasing toward the southeast. The beds range in thickness from less than 1 ft to 15 ft, and the stratigraphic position of the thinnest and thickest beds within the sub zone appears to be random. The stratigraphic distance between the top of the Wolf Creek sub coal zone and the base of the Wadge sub coal zone ranges from 122 to 145 ft, with an average value of about 132 ft. The thickness of the sub zone ranges from 11 to 34 ft, with an average value of about 23 ft. The sub zone always comprises two to three coal beds ranging in thickness from less than 1 ft to 11 ft. Where the sub zone contains two beds, the upper bed is always the thickest, averaging about 8 ft. The lower bed lies an average of 9 ft below the upper bed and averages about 2 ft thick. Toward the southeast edge of the coal field, the sub zone locally picks up a third bed as a rider above the other two. This bed lies an average of about 11 ft above the upper bed and averages about 2 ft thick . The stratigraphic distance between the top of the Wadge sub coal zone and the base Lennox sub coal zone ranges from 40 to 58 ft, with an average value of about 51 ft. This sub zone typically consists of a single coal bed, ranging in thickness from less than 1 ft to 4 ft, with an average thickness of about 2 ft. Toward the southeast edge of the coal field, a rider bed locally appears about 4 ft below the main bed, and this bed averages about 1 ft thick. One local coal company has defined a coal bed positioned between and the Wolf Creek and Wadge sub coal zones as the Sage Creek coal bed. This bed might be equivalent to a higher-than-normal Wolf Creek bed or a lower-than-normal Wadge bed.

The number of coal beds in the A coal zone increases in the central part of the coal field. In this area, Bass and others (1955) defined three coal zones, F, G, and H, which are included in the A coal zone used in this assessment. Bass’ terms are seldom used today. In the western part of the coal field, the A coal zone contains many coal beds. Here, the Eagle and Trapper mines have both developed their own nomenclatures for individual beds. These names are not used in this assessment because they are difficult to use beyond the mine property.

The A coal zone is the most economically important coal zone in the coal field, especially in the eastern part. Currently, the Foidel Creek mine (fig. 1), Seneca II-W mine, and Yoast mine extract coal from the Wadge sub coal zone. When active, the Seneca II extracted coal from both the Wolf Creek and Wadge sub coal zones. Two earlier mines, now closed, extracted coal from the A coal zone. The Edna mine extracted

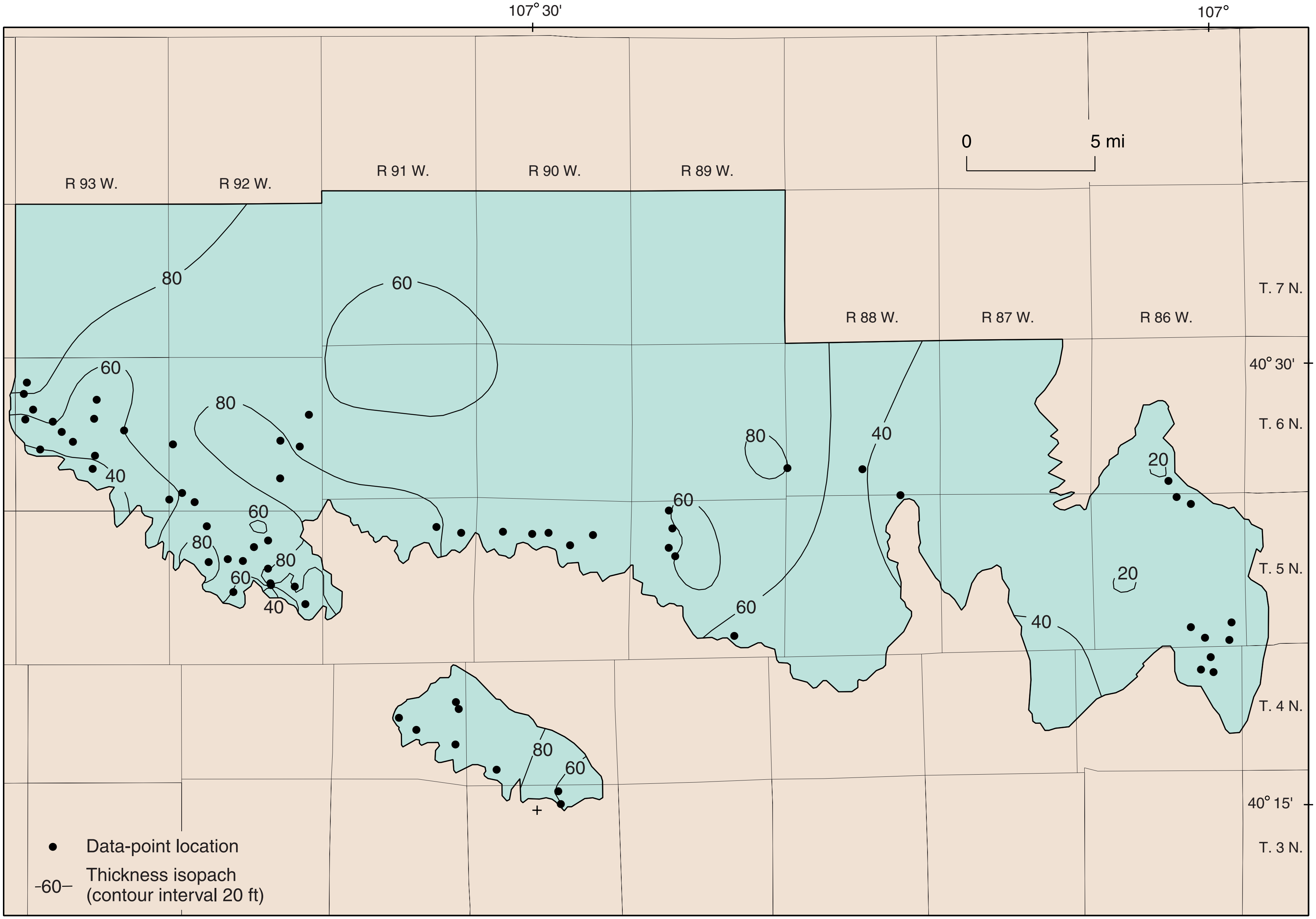

Figure 11. Isopach map of net coal in beds equal to or greater than 1.2 ft thick covering the surface and subsurface extent of the A coal zone, Yampa coal field. Outline is the resource polygon for the A coal zone.

coal from the Wadge sub coal zone, and the Energy mine extracted coal from the Wadge and, where feasible, the Lennox sub coal zones. The only active mine working the A coal zone in the western part of the coal field is the Eagle No. 5 mine, which extracts coal from the F and E coal beds, as defined by Eagle nomenclature.

Barren Interval A

Barren interval A is defined as the interval that extends from the top of the highest coal bed in the A coal zone to the bottom of the lowest coal bed in the B coal zone. The interval contains a variety of fluvial units including thick to thin interval of mudrock and sandstone. In the eastern part of the coal field, the upper part of the barren interval also contains the sub-Twentymile sandstone and, possibly, an underlying marine shale unit. In the western part of the coal field, in the southern part of the Round Bottom 7.5′ quadrangle, the lower part of the barren interval contains a prominent sandstone referred to as the unnamed lower sandstone member of the Williams Fork Formation by Johnson (1987). Geologists working at the Eagle No. 5 mine, where the sandstone is well exposed just above the mine portal, refer to the unit as the middle sandstone, in reference to its position midway between the Trout Creek Sandstone and the Twentymile Sandstone Members. The base of the sandstone lies about 380 ft above the top of the Trout Creek, and the unit averages 48 ft in thickness (Johnson, 1987). To the west of this area, the sandstone splits into several thinner units, and, to the east, the sandstone climbs stratigraphically and then pinches out. In the eastern part of the coal field, in the Milner and Rattlesnake Butte 7.5′ quadrangles, the B coal zone is missing and barren interval A is defined as extending up to the base of the Twentymile. Here, barren interval A averages about 721 ft thick. In the central part of the coal field, in the Castor Gulch, Breeze Mountain, and Hayden Gulch 7.5′ quadrangles, the B coal zone is present and begins to thicken toward the west. As a result, the barren interval thins in that direction, and, in this area, its thickness ranges from 271 ft to 485 ft and averages about 358 ft. In the western part of the coal field, in the Horse Gulch and Round Bottom 7.5′ quadrangles, the B coal zone continues to thicken and the barren interval continues to thin, ranging from 40 ft to 260 ft and averaging about 116 ft.

B Coal Zone

The B coal zone is defined as the interval that extends from the bottom of the first coal bed above barren interval A to the top of the first coal bed below barren interval B. The coal zone is not present in the eastern part of the coal field (pl. 1, fig. C). In the central part of the coal field, the coal zone is quite distinct, but in the western part of the coal field barren interval A is much thinner, and here separating the A and B coal zones can be problematic. The thickness of the B coal zone, where present, ranges from 1 ft to 460 ft, with an average thickness of about 91 ft.

Of the four coal zones in the Williams Fork Formation, the B coal zone displays the most dramatic east-to-west increase in the number of coal beds and in the net thickness of coal (fig. 12). In the central part of the coal field, in the Breeze Mountain 7.5′ quadrangle, the number of coal beds ranges from one to three, with an average of about one. On the western side of the coal field, in the Horse Gulch 7.5′ quadrangle, the number of coal beds ranges from two to 15, with an average of about seven. In the central part of the coal field in the Breeze Mountain 7.5′ quadrangle, the net thickness of coal ranges from 3 to 15 ft, with an average thickness of about 7 ft. On the western side of the coal field, in the Horse Gulch 7.5′ quadrangle, the net thickness of coal ranges from 13 to 77 ft, with an average of about 33 ft. The number of coal beds and the total thickness of coal continues to decrease toward the east, and the zone probably pinches out somewhere east of the north-central part of the Hayden Gulch 7.5′ quadrangle. The thickest coal bed in the coal zone encountered during the assessment, 29 ft, was penetrated by drill hole Rb-1-81 in the northern part of the Round Bottom 7.5′ quadrangle (data point 59, fig. 3).

In the central part of the coal field, the I and J coal beds of Bass and others (1955) are within the B coal zone. In the western part of the coal field, the Hart bed, a term used by both the Eagle and Trapper mines, is within the B coal zone. Two small mines have also extracted coal from the B coal zone. In the central part of the coal field, the J bed was mined at the Searcy mine in Searcy Gulch and about a mile to the east at the Jim Dunn mine in Peck Gulch.

Barren Interval B

Barren interval B is defined as the interval that extends from the top of the highest coal bed in the B coal zone to the bottom of the Twentymile Sandstone Member. The lowest part of the interval contains a variety of fluvial units, but most of the interval is dominated by marine shale that underlies the Twentymile. In the eastern part of the coal field where the B coal zone is missing, barren interval B does not exist and barren interval A extends up to the bottom of the Twentymile. In the central part of the of coal field, where the B coal zone is present, the thickness of barren interval B ranges from 82 to 315 ft, with an average of about 162 ft. The thickness of the interval in the western part of the coal field, in the area of the Horse Gulch 7.5′ quadrangle, ranges from 4 to 133 ft, with an average of about 45 ft. The westward thinning of the interval is the result of a thinning of the B coal zone coupled with decrease in the amount of marine shale under the Twentymile.

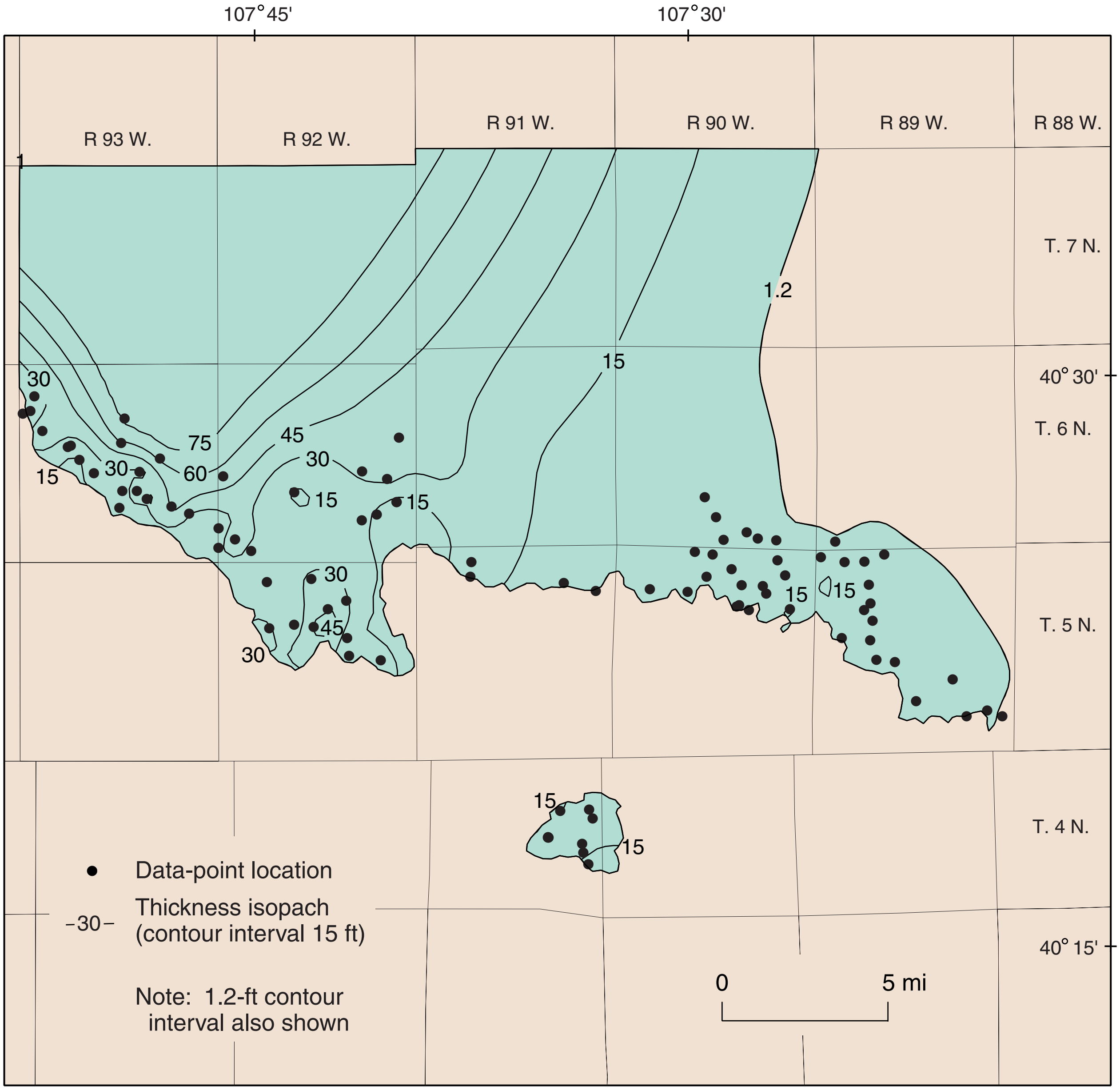

Figure 12. Isopach map of net coal in beds equal to or greater than 1.2 ft thick covering the surface and subsurface extent of the B coal zone, Yampa coal field. Outline is the resource polygon for the B coal zone.

C Coal Zone

The C coal zone is defined as the interval that extends from the top of the Twentymile Sandstone Member to the top of the first coal bed below barren interval C. The coal zone is not present in the eastern part of the coal field. The thickness of the interval between the base of the lowest coal bed and the top of the highest coal bed ranges from 2 ft to 145 ft, with an average of about 82 ft. This interval excludes a variable thickness of rock that lies above the Twentymile and below the lowest coal bed in the C coal zone.

The C coal zone is the least economically significant of the four coal zones. The number of coal beds and the net thickness of coal (fig. 13) increases toward the west in the same fashion as the B coal zone, only less dramatically. In the central part of the coal field, in the Breeze Mountain 7.5′ quadrangle, the number of coal beds ranges from one to six, with an average of about three. On the western side of the coal field, in the Horse Gulch and Round Bottom 7.5′ quadrangles, the number of coal beds ranges from two to eight, with and average of about four. In the central part of the coal field, in the Breeze Mountain 7.5′ quadrangle, the net thickness of coal ranges from 2 to 12 ft, with an average of about 8 ft. On the western side of the coal field, in the Horse Gulch and Round Bottom 7.5′ quadrangles, the net thickness of coal ranges from 4 to 27 ft, with an average of about 14 ft. The thickest single coal bed in the coal zone encountered during the assessment, 10 ft, was penetrated by drill hole E-16-HG (data point 33, fig. 3) on the eastern edge of the Horse Gulch 7.5′ quadrangle. East of the Breeze Mountain 7.5′ quadrangle, the number of coal beds and the net thickness of coal decreases, and the zone probably pinches out somewhere east of the north-central part of the Hayden Gulch 7.5′ quadrangle. Interestingly, in the westernmost part of the coal field, the net thickness of coal starts to decrease toward the west (fig. 13). This phenomena might be related to the thinning of the Twentymile as the unit becomes more fluvial toward the west.

In the central part of the coal field, the C coal zone contains the K coal bed of Bass and others (1955). In the western part of the coal field, both the Eagle and Trapper mines have developed their own unique nomenclature for coal beds in the C coal zone. These names are not used in this assessment because they are difficult to use beyond the mine property. Other than occasional wagon mines, coal has never been extracted from the C coal zone.

Barren Interval C

Barren interval C is defined as the interval that extends from the top of the highest coal bed in the C coal zone to the bottom of the Big White sandstone, or its stratigraphic equivalents. In areas where the Big White is missing, the top of barren interval B is placed at the bottom of the lowest coal bed in the D coal zone. Most of the interval comprises a variety of fluvial units, but if the Big White sandstone is marine, as is postulated in this report, then any marine rocks that might underlie the sandstone would be included at the top of barren interval B. The thickness of the interval where the Big White is present ranges from 29 to 183 ft, with an average thickness of about 79 ft. In areas where the Big White is absent, the interval is about 20 ft thicker than its regional average. On the eastern side of the coal field, in areas where the C coal zone is missing, the bottom of the interval is defined as the top of the Twentymile Sandstone Member.

D Coal Zone

The D coal zone is defined as the interval that extends from the top of the Big White sandstone, or its stratigraphic equivalents, to the top of the Williams Fork Formation. In areas where the Big White is missing, the base is defined at the bottom of the first coal bed above barren interval C. In the western part of the coal field, the coal zone includes the Three White sandstones in the upper part of the Williams Fork. The thickness of the interval that extends from the base of the lowest coal bed to the top of the highest coal bed ranges from 4 ft to 815 ft, with an average of about 355 ft. This interval excludes rock that lies above the Big White sandstone, where present, and below the lowest coal bed in the coal zone. In the eastern part of the coal field, the Lewis Shale rests directly on the only coal bed assigned to the D coal zone. The interval between the top of the highest coal bed in the coal zone and the top of the Williams Fork ranges from 0 ft in the eastern part of the coal field to 277 ft in the western part of the coal field. The wide range in thickness is explained by the fact that the Lewis climbs stratigraphically toward the west, allowing for a thicker section of the Williams Fork.

The D coal zone is the second most economically important coal zone in the Williams Fork, especially in the western part of the coal field. The number of coal beds and the net thickness of coal (fig. 14) increases toward the west in the same fashion as the B and C coal zones. In the east-central part of the coal field, in the Hayden 7.5′ quadrangle, the number of coal beds ranges from one to seven, with an average of about four. On the western side of the coal field, in the Horse Gulch and Round Bottom 7.5′ quadrangles, the number of coal beds ranges from seven to 16, with an average of about 12. In the east-central part of the coal field, in the Hayden 7.5′ quadrangle, the net thickness of coal ranges from 4 to 22 ft, with an average of about 14 ft. On the western side of the coal field, in the Horse Gulch and Round Bottom 7.5′ quadrangles, the net thickness of coal ranges from 24 to 52 ft, with an average of about 38 ft. East of the Hayden 7.5′ quadrangle, the number of coal beds and the net thickness of coal continues to decrease to the point where the coal zone contains only one coal bed. The thickest single coal bed in the coal zone encountered during this assessment, 14 ft, was penetrated by drill hole H-36-H (data point 79, fig. 3) in the central part of the Hamilton 7.5′ quadrangle. In the eastern part of the coal field, only the Fish Creek coal bed (Campbell, 1923) is present

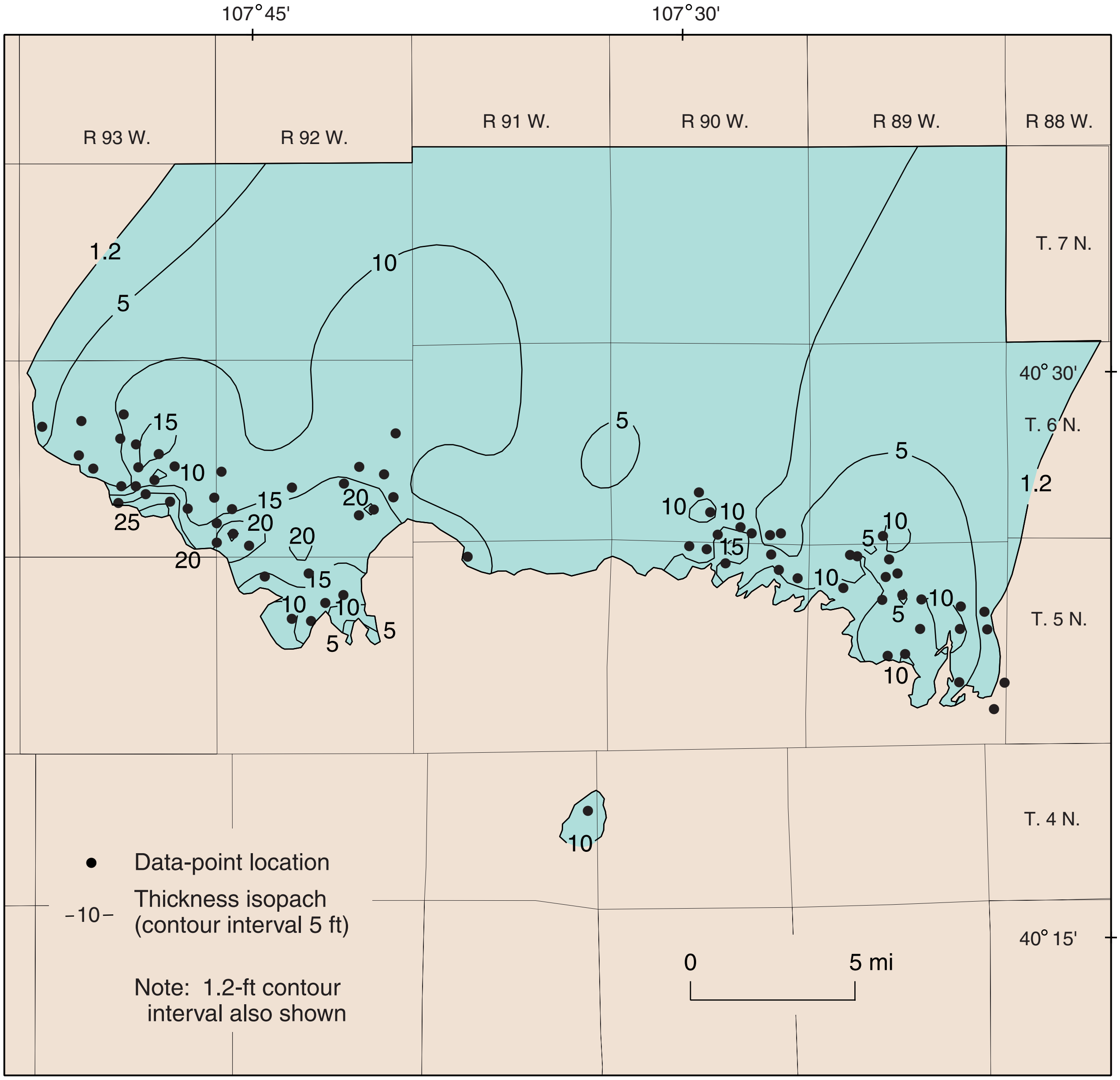

Figure 13. Isopach map of net coal in beds equal to or greater than 1.2 ft thick covering the surface and subsurface extent of the C coal zone, Yampa coal field. Outline is the resource polygon for the C coal zone.

in the D coal zone (pl. 1, fig. B). Bass and others (1955) did not mention the Fish Creek, but their Dry Creek coal bed in the east-central part of the coal field is at about the same stratigraphic level as the Fish Creek, and the two coal beds might be equivalent. In the central part of the coal field, the D coal zone contains the L, M, N, O, P, R, and S coal beds of Bass and others (1955). The coal beds mined in this area at the Carey and Sleepy Cat mines (Bass and others, 1955) are probably within the D coal zone. In the western part of the coal field, the Eagle and Trapper mines have both developed their own nomenclature for individual beds in the D zone, although Eagle's nomenclature is similar to that used by Bass and others in the central part of the coal field. The names used by the Eagle and Trapper mines are not used in the assessment because they are difficult to use beyond the mine property. In the eastern part of the coal field, the Fish Creek coal bed was mined, where economically feasible, at the now-abandoned Energy mine. In the central part of the coal field, coal from the D zone was mined at the Carey and Sleepy Cat mines (underground). In the western part of the coal field, the Trapper mine extracts coal from the R, Q, M, L, I, and H beds, as defined by Trapper's nomenclature. In this same area, the Eagle No. 9 mine extracts coal from the P bed, as defined by Eagle's nomenclature.

Coal Quality

Most Cretaceous coal in the Yampa coal field is noncoking, high-volatile C bituminous, but some subbituminous A, B, and C is reported. Rare anthracite is also present adjacent to certain Tertiary igneous intrusions in the northeastern part of the coal field (Bass and others, 1955). Coal analyses from the eastern part of the coal field, on an as-received basis, return average values of 9.4 percent moisture, 41.1 percent volatile matter, 51.8 percent fixed carbon, 6.9 percent ash yield, 0.9 percent sulfur content, and an average caloric value of 11,580 Btu/lb. Coal analyses from the western part of the coal field, on an as-received basis, return average values of 11.6 percent moisture, 42.0 percent volatile matter, 53.8 percent fixed carbon, 4.3 percent ash yield, 0.3 percent sulfur content, and an average caloric value of 11,500 Btu/lb (Speltz, 1976).

Summarizing coal analyses contained in a USGS database of specific coal beds in the A coal zone in the eastern part of the coal field (R.H. Affolter, written commun., 1999), the Wolf Creek bed has average as-received values of 10.90 percent ash yield and 0.72 percent sulfur content, and an average caloric value of 10,769 Btu/lb. The Wadge bed has average values of 7.97 percent ash yield and 0.58 percent sulfur content, and an average caloric value of 11,192 Btu/lb. The Lennox bed has average values of 6.73 percent ash yield, 2.64 percent sulfur content, and an average caloric value of 11,422 Btu/lb. Little information is available on the quality of coal in the A coal zone in the western part of the coal field, but as-received data provided by personnel at the Eagle No. 5 mine to Zook and Tremain (1997) lists Eagle's F bed as subbituminous B, with a range for ash yield between 4.99 and 10.36 percent and a range for sulfur content between 0.46 to 0.57 percent. The caloric value is reported to range between 10,377 and 11,567 Btu/lb, and the coal is a mixture of subbituminous A, B, and C, and high-volatile bituminous C. The only other coal zone that is presently being mined in the coal field is the D zone in the western part of the coal field. According to personnel at the Trapper mine, the eight beds currently being extracted are a mixture of subbituminous A, B, and C, and high-volatile bituminous C. Average, as-received values for all of the beds mined during September 1998 are ash yield 7.05 percent and sulfur content 0.40 percent, with a caloric value of 9,931 Btu/lb.

Coal Resources

In essence, coal resources are calculated by multiplying thickness by areal extent to acquire volume, and then multiplying this value by density to obtain tonnage. However, in detail the process of calculating resources is quite involved. Because of the poor quality of many of the geophysical logs used in this assessment, the thickness of coal beds penetrated by public drill holes was measured only to the nearest foot. However, some proprietary databases used in the assessment have coal beds measured to the nearest tenth of a foot. Following the methodology of Wood and others (1983), non-coal partings within a coal bed that did not exceed the thickness of the coal layer directly above or below were deleted for the purpose of resource calculations. To accomplish this, a computer program developed by the USGS was used to delete the parting and combine the adjacent parts of coal beds. In selecting data for use in resource calculations, only those drill holes that penetrated the entire thickness of a given coal zone were used. That is, holes that were commenced below the top of the zone or were completed above the bottom of the zone were not used.

The maximum polygon used in calculating coal resources (e.g., fig. 2) was constructed using the outcrop of the top of the Trout Creek Sandstone Member of the Iles Formation as the west, south, and east sides, and arbitrary township lines on the north side. The west side of the northern boundary was drawn along the top of T. 7 N., and the east side of the boundary was drawn along the top of T. 6 N. North of this line, subsurface data are sparse but the Williams Fork Formation is undoubtedly deeper than 6,000 ft, which is the economic cut-off suggested by Wood and others (1983). This resource polygon includes all areas traditionally included in the coal field (e.g., fig. 1) except for the north-trending extension in the eastern part of the coal field. This northeastern part of the coal field was terminated against the T. 6 N. line because, to the north, the exact location of the Trout Creek Member is somewhat uncertain and because the steep geologic structure (fig. 9) would probably preclude mining. The maximum resource polygon covers about 630 mi^2 (fig. 2), whereas the area of the coal field based on the surface exposure of the Mesaverde

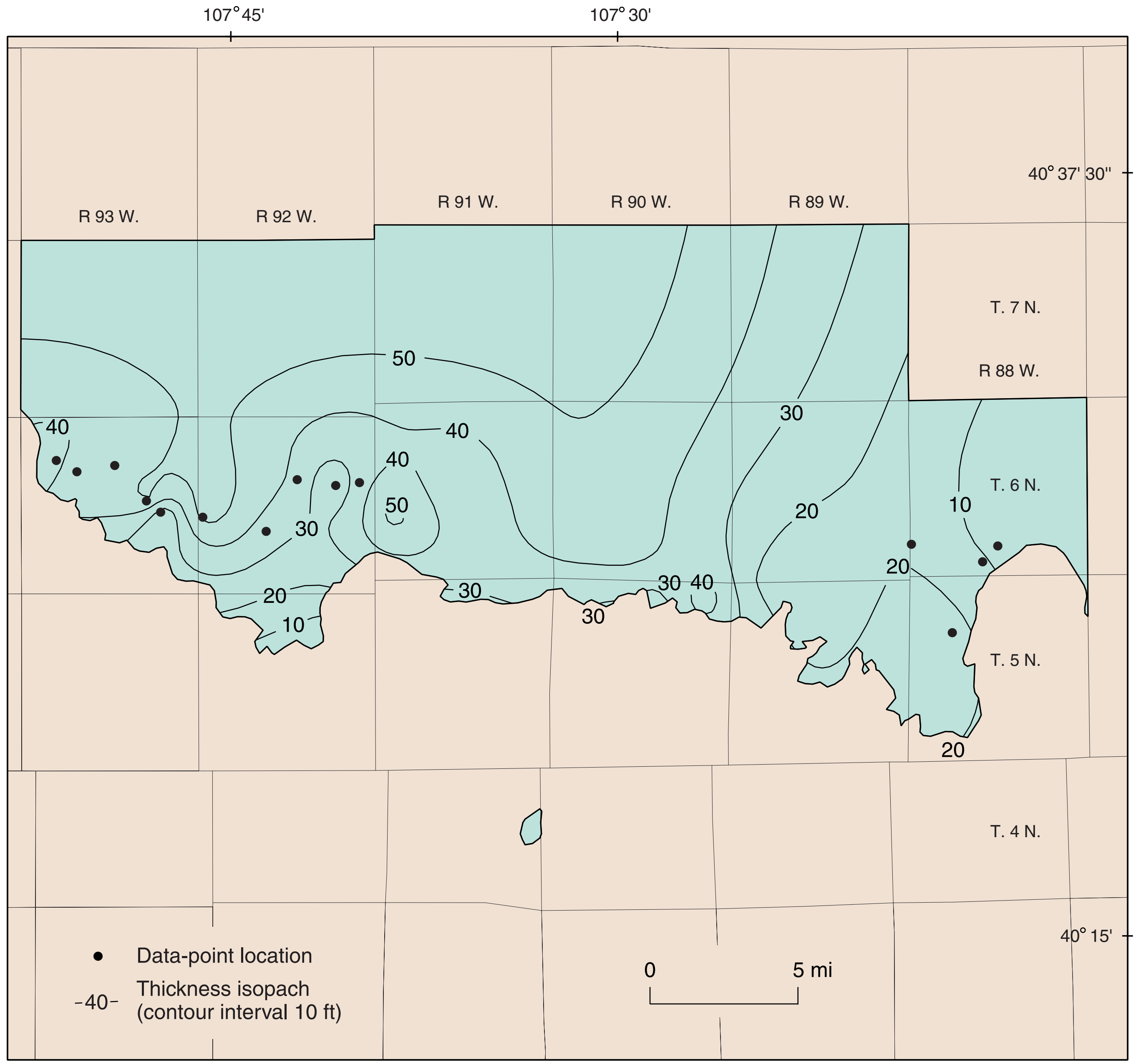

Figure 14. Isopach map of net coal in beds equal to or greater than 1.2 ft thick covering the surface and subsurface extent of the D coal zone, Yampa coal field. Outline is the resource polygon for the D coal zone.

Group covers only 520 mi^2 (fig. 1). This difference results from (1) the polygon not including the Iles Formation, and (2) the polygon extending north of the north-dipping stratigraphic top of the Williams Fork into areas where the formation is not exposed at the surface. It should be noted that the coal-bearing Lance and Fort Union Formations could be included in a broader definition of the coal field, but, traditionally, only the Mesaverde is taken into account. For each of the four coal zones, areas covered by active coal leases (provided by the BLM), or areas known to have been mined out (provided by the Colorado Geological Survey), were eliminated from resource calculations. In regard to coal leases, if the company had a specific bed under lease then the entire zone containing the bed was eliminated. In those cases where the company had all of the coal under lease, all four zones where eliminated.

Using the methodology of Wood and others (1983), coal tonnages were calculated by multiplying the estimated volume of coal by the average density. The volume of coal is the product of net-coal thickness and areal extent. The areal extent of the A and B coal zones was determined by utilizing structure contours drawn on top of the Trout Creek (fig. 9), the base elevation of the zone above the Trout Creek, and the 1:250,000-scale digital elevation model (DEM) constructed by the USGS. In the case of the C and D coal zones, structure contours drawn on top of the Twentymile Sandstone Member of the Williams Fork were used. Where a coal zone is partly eroded, calculations were stopped at the zero overburden line. An average apparent rank of bituminous coal was used, based on published analyses and discussions with mine personnel. The average density of bituminous coal is 1.32 g/cm^3 or 1,800 short tons per acre foot, as recommended by Wood and others (1983). Resources are reported as net coal, which is the sum of all coal beds equal to or greater than 1.2 ft thick. Beds thinner than this were considered uneconomic by Wood and others. Following Wood and others, resources are reported in reliability categories of identified or hypothetical, based on the distance that the resource was calculated from a data point. Resources reported as identified are located within a 3-mi radius of a data point and have a higher degree of geologic assurance, and those reported as hypothetical are located beyond a 3-mi radius and have a lower degree of geologic assurance. Included within the identified reliability category are the measured, indicated, and inferred categories, but these subdivisions were not used in this assessment. Maximum overburden was determined by subtracting the elevations at the base of each coal zone from the surface elevations imported from the DEM. Resources are reported in maximum overburden categories of 0–500 ft; 500–1,000 ft; 1,000–2, 000 ft; 2,000–3,000 ft; and greater that 3,000 ft. Nowhere in the resource polygon does the maximum overburden exceed 6,000 ft. These categories were generated by integrating the maximum overburden and net-coal isopach maps of each coal zone. In order to better understand the distribution of coal, maps were constructed for each coal zone that show net coal in five net-thickness categories: 1.2–2.3 ft, 2.3–3.5 ft, 3.5–7.0 ft, 7.0–14.0 ft, and greater that 14.0 ft. Only the B and C coal zones have entries in all five net-thickness categories. The D coal zone has only three of the five categories because nowhere in the coal field is the net-coal thickness less than 3.5 ft, and the A coal zone has only one of the five because nowhere in the coal field is the net-coal thickness less than 14.0 ft. The coal resource for each of the four coal zones is reported in tables for areas within Moffat and Routt Counties, and for each 7.5′ quadrangle and for each township (Appendix 3, Appendix 4, Appendix 5, and Appendix 6).

Coal resource numbers cited in the assessment have been rounded to two significant figures. It is extremely important to keep this in mind when examining the numbers provided in Appendixes 3, 4, 5, and 6 of this report because totals might not equal the sum of their components in any particular column because of independent rounding. The actual procedures used to generate the resource numbers in this assessment are extensive and complex. Those interested in these details should refer to Roberts and others (1998) and Roberts and Biewick (1999).

The reader should be aware that certain systematic errors can significantly influence final resource estimates for a given coal field. Errors in preparing the raw data include the difficulty in differentiating between coal and carbonaceous shale on some geophysical logs, and the fact that bed thickness when determined from the geophysical curves can vary depending on whether the midpoint or the inflection point is used (the midpoint was used in this assessment). Another source of error is introduced by using a single coal rank to represent an entire coal field, and then accepting an average density for that rank. But the biggest source of error occurs during the actual calculation of the resources. The computer program assumes that a given coal bed is continuous between data points and that any change in thickness is uniform. Because of the nature of Cretaceous coals in the Rocky Mountains, this is rarely the case, and considerable error is probably introduced because of this assumption.

A Coal Zone

The A coal zone contains an estimated 42 billion short tons of net coal in beds equal to or greater than 1.2 ft thick (Appendix 3a). Of this, about half is classified as identified and the other half hypothetical. Resources in net-coal thickness categories are not listed in Appendix 3a, nor is a figure of coal-thickness categories provided because net coal in the A zone is everywhere greater than 14 ft thick. Resources in maximum overburden categories are listed in Appendix 3a and shown on figure 15. Moffat County contains about 70 percent of the A coal zone resource, with the remaining amount in Routt County, (Appendix 3a). Private land overlies about 93 percent the of the A-zone coal, but about 67 percent of the A-zone coal is owned by the Federal Government (Appendixes 3b and 3c). Resources for the A coal zone are listed for each 7.5′ quadrangle and for each township in the coal field (Appendixes 3d and 3e).

The A coal zone contains more coal than the other three zones combined. Much of this coal underlies Moffat County, but the only mine in the area that recently extracted A-zone coal is currently closed. Nevertheless, the western part of the coal field will probably witness increased exploration, leasing, and development of this resource in the future. The eastern part of the coal field in Routt County contains a lesser volume of A-zone coal, but two significant beds, the Wolf Creek and Wadge, are currently being extracted from three mines. Because these mines are already established, this part of the coal field is likely to produce most of the A-zone coal, at least in the short term.

B Coal Zone

The B coal zone contains an estimated 13 billion short tons of net coal in beds equal to or greater than 1.2 ft thick (Appendix 4a). Of this, about 40 percent is classified as identified, with the remaining amount being hypothetical. Resources in net-coal thickness categories are listed in Appendix 4a and shown on figure 16. Resources in maximum overburden categories are listed in Appendix 4a and shown on figure 17. Moffat County contains almost all of the B coal zone resource (Appendix 4a). Private land overlies about 85 percent of the B-zone coal, but about 75 percent of the B-zone coal is owned by the Federal Government (Appendixes 4b and 4c). Resources for the B coal zone are listed for each 7.5′ quadrangle and for each township in the coal field (Appendixes 4d and 4e).

Although the B coal zone contains only a moderate amount of coal, which is limited to the western part of the coal field, several beds in the coal zone are thick and laterally extensive. Perhaps the most promising area for development is the Hart syncline (fig. 10) where bed thickness commonly exceeds 20 ft and overburden is relatively thin (fig. 17). Unfortunately, the deposit is confined to a small area, which limits the amount of coal that can ultimately be extracted.

C Coal Zone

The C coal zone contains an estimated 3.7 billion short tons of net coal in beds equal to or greater than 1.2 ft thick (Appendix 5a). Of this, about half is classified as identified and the other half hypothetical. Resources in net-coal thickness categories are listed in Appendix 5a and shown on figure 18. Resources in maximum overburden categories are listed in Appendix 5a and shown on figure 19. Moffat County contains about 86 percent of the C coal zone resource, with the remaining amount in Routt County (Appendix 5a). Private land overlies about 92 percent the of the C-zone coal, but about 73 percent of the C-zone coal is owned by the Federal Government (Appendixes 5b and 5c). Resources for the C coal zone are listed for each 7.5′ quadrangle and for each township in the coal field (Appendixes 5d and 5e).

The C coal zone contains substantially less coal than any of the other three zones. Although it does contains some locally thick coal beds, the zone should not be considered an economic entity for the foreseeable future. The coal zone was only included to complete the coal assessment of the Williams Fork Formation.

D Coal Zone

The D coal zone contains an estimated 17 billion short tons of net coal in beds equal to or greater than 1.2 ft thick (Appendix 6a). Of this, about 40 percent is classified as identified, with the remaining amount being hypothetical. Resources in net-coal thickness categories are listed in Appendix 6a and shown on figure 20. Resources in maximum overburden categories are listed in Appendix 6a and shown on figure 21. Moffat County contains about 88 percent of the D coal zone resource, with the remaining amount in Routt County (Appendix 6a). Private land overlies nearly 100 percent the of the D-zone coal, but about 70 percent of the D-zone coal is owned by the Federal Government (Appendixes 6b and 6c). Resources for the D coal zone are listed for each 7.5′ quadrangle and for each township in the coal field (Appendixes 6c and 6d).

The D coal zone is the second most productive coal zone in the coal field, although it contains only about one-third of the coal present in the A coal zone. Most of the D-zone coal underlies Moffat County, and the only operating mine in the area extracts coal from this zone. With little doubt, most coal exploration, leasing, and development in the western part of the coal field will continue to be from this coal zone. Although D-zone coal in the eastern part of the coal field, the Fish Creek bed, has been mined in the past, its thinness and high sulfur content make it uneconomic.

Restrictions to Coal Availability

Certain technical restrictions limit the mining of coal underground (T. J. Rohrbacher, oral commun., 1999). The three main issues are coal-bed thickness, bed inclination, and bed depth. Under current mining practices, coal beds thinner than about 2 ft cannot be recovered. And, no more than 14 ft of coal can usually be recovered from a bed of any thickness. Hypothetically, all of a 14 ft bed can be recovered, but only 14 ft of a 20 ft bed can be recovered. Underground mining is most effective where the bed is inclined less than 6 degrees and is very difficult where the bed is inclined greater that 12 degrees. And finally, underground mining rarely takes place deeper than 3,000 ft. Restrictions that limit surface mining are more economic than technical. Under current conditions, stripping ratios (overburden to coal) should be less than 10:1 in order to insure a profit.

Land-use restrictions can limit coal availability. For example, coal resources that underlie cultural features such

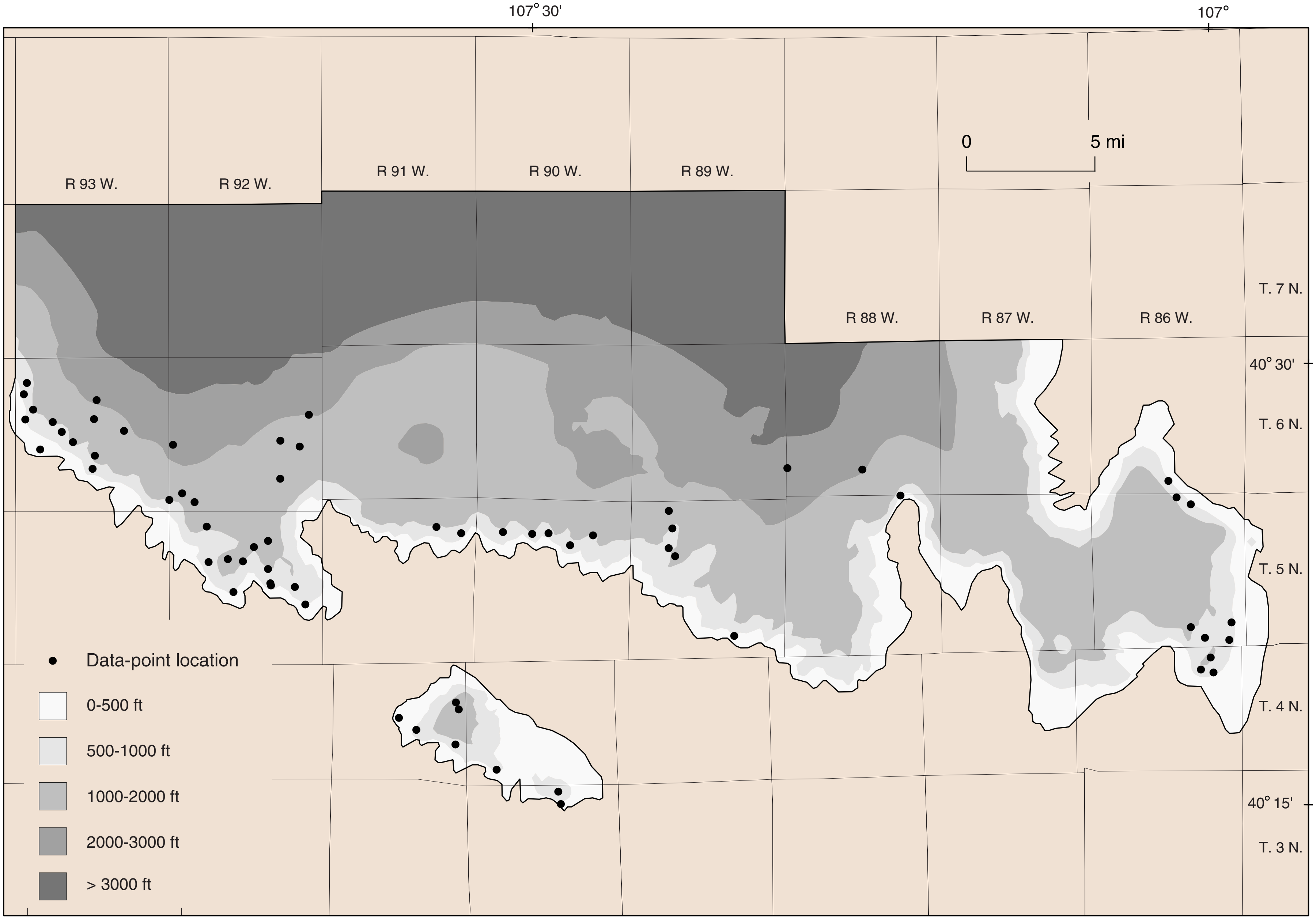

Figure 15. Isopach map of maximum overburden to the base of the A coal zone, Yampa coal field.

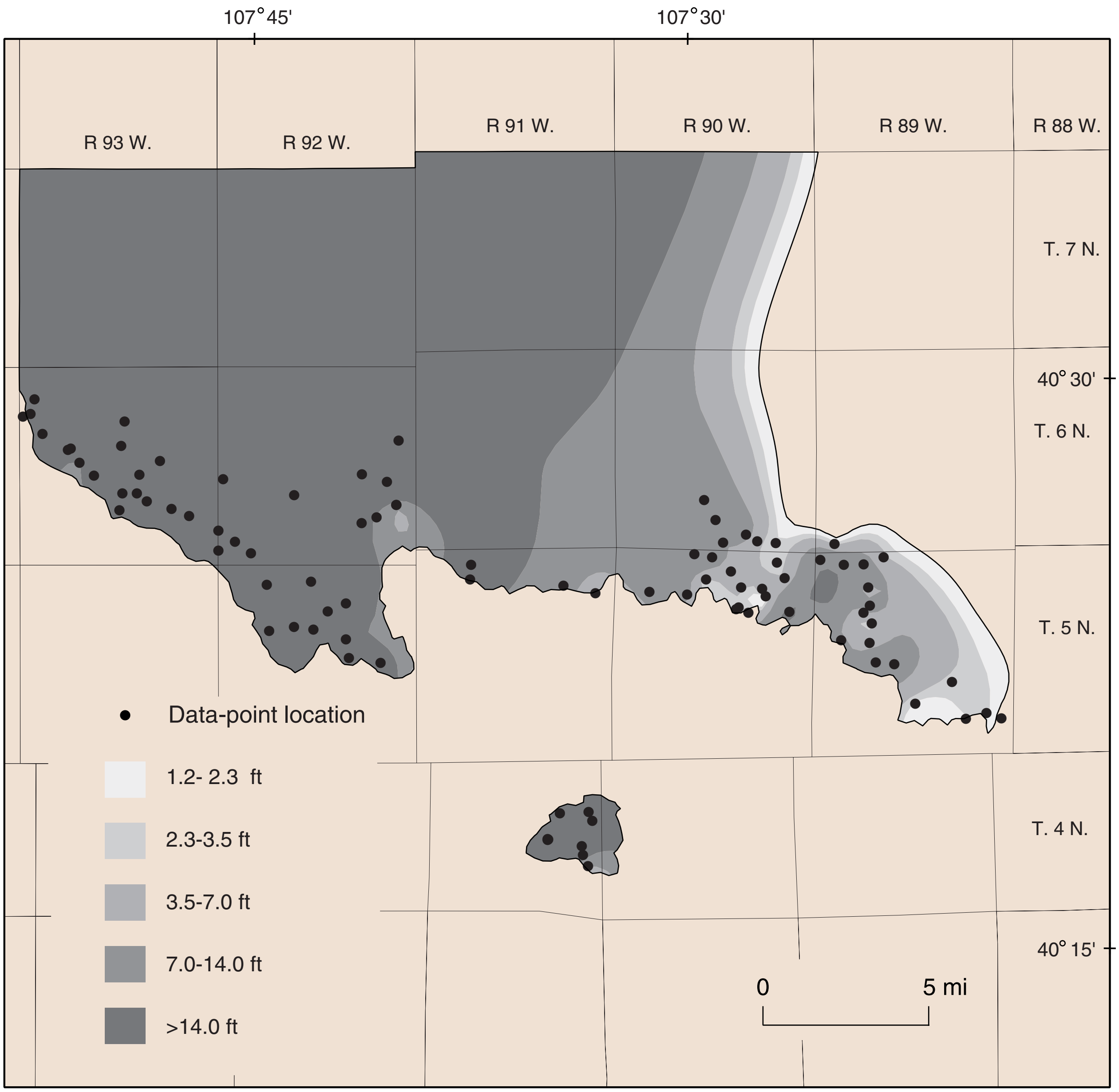

Figure 16. Net-coal thickness categories for the B coal zone, Yampa coal field.

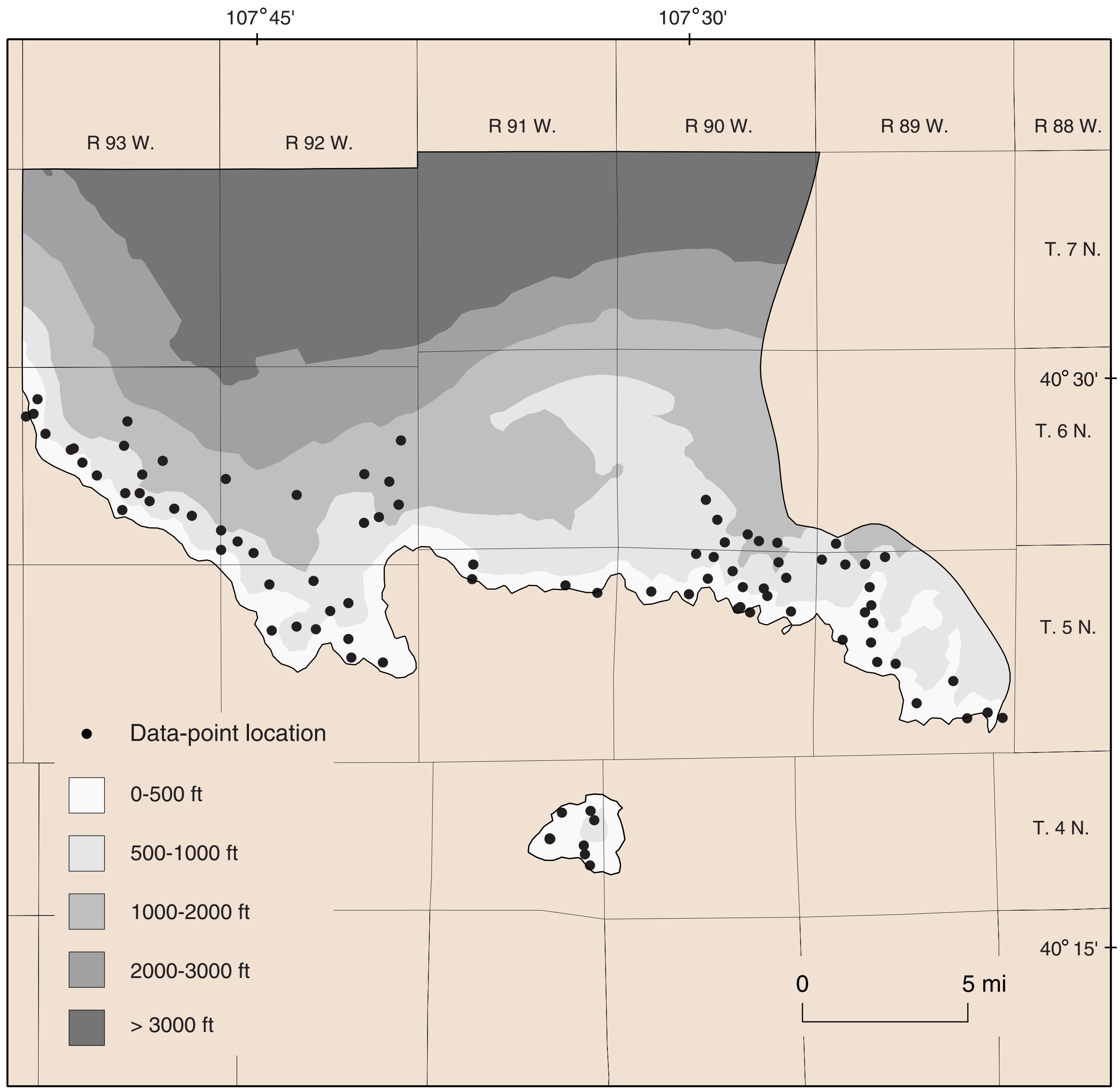

Figure 17. Isopach map of maximum overburden to the base of the B coal zone, Yampa coal field.

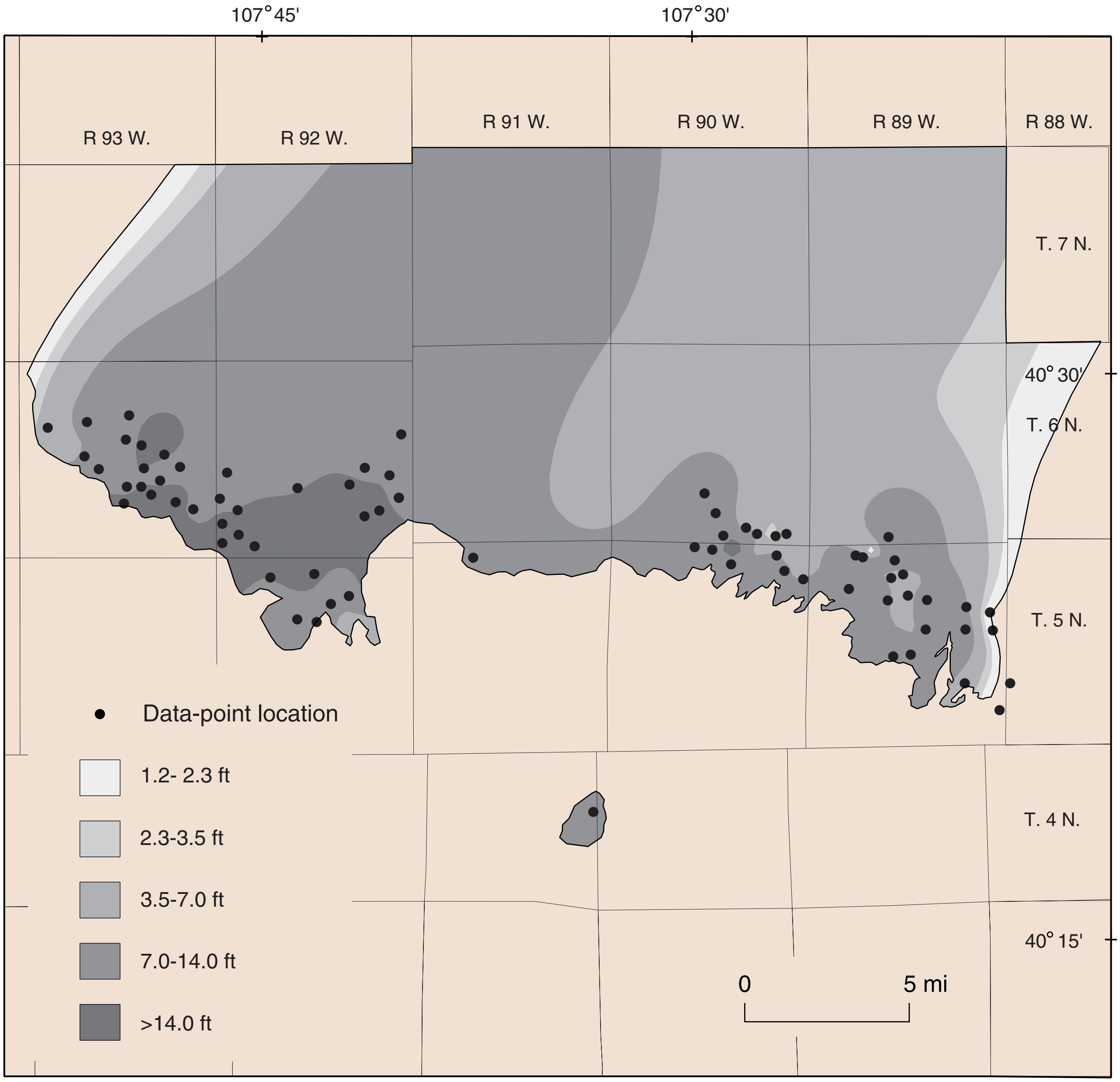

Figure 18. Net-coal thickness categories for the C coal zone, Yampa coal field.

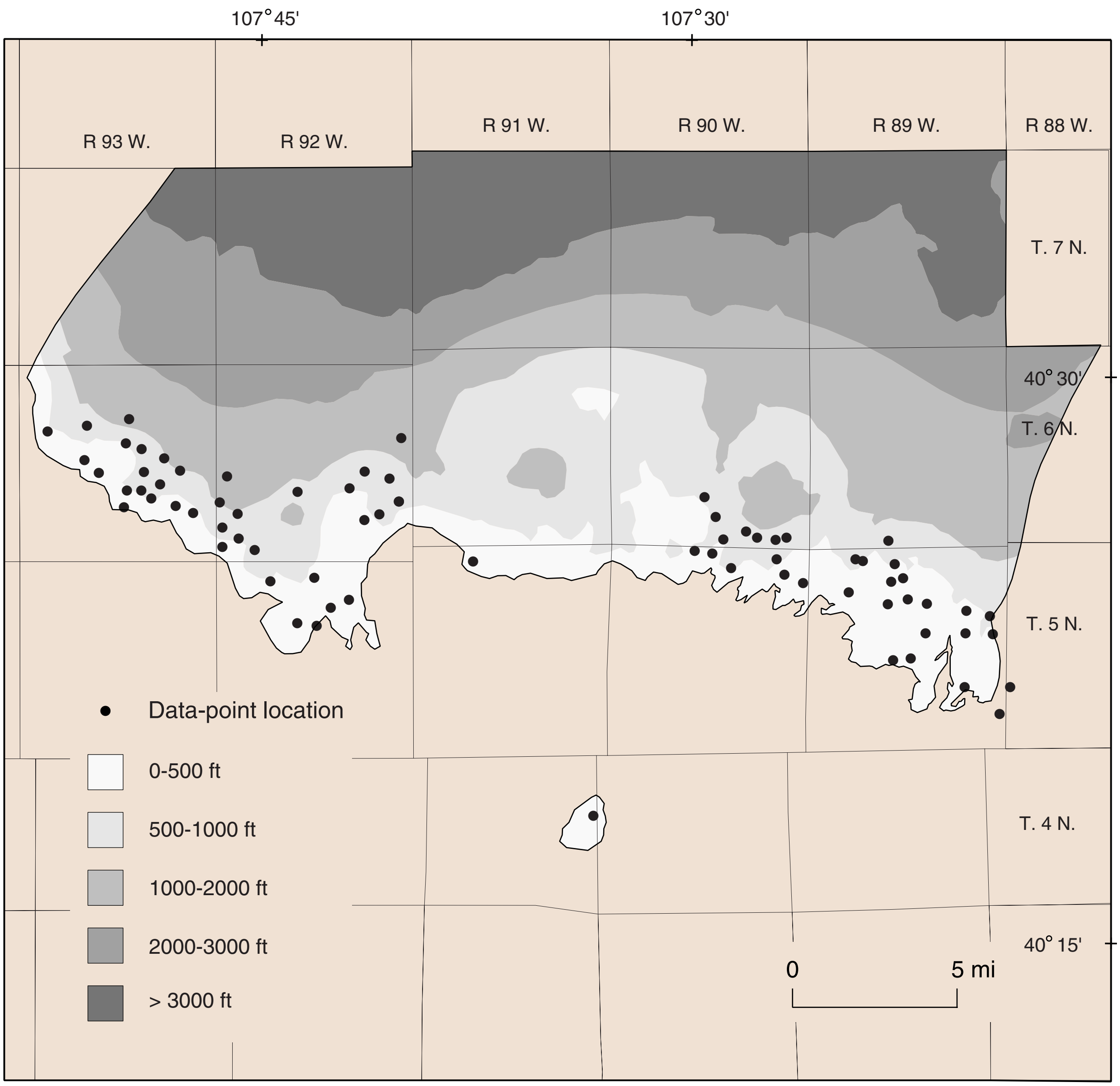

Figure 19. Isopach map of maximum overburden to the base of the C coal zone, Yampa coal field.

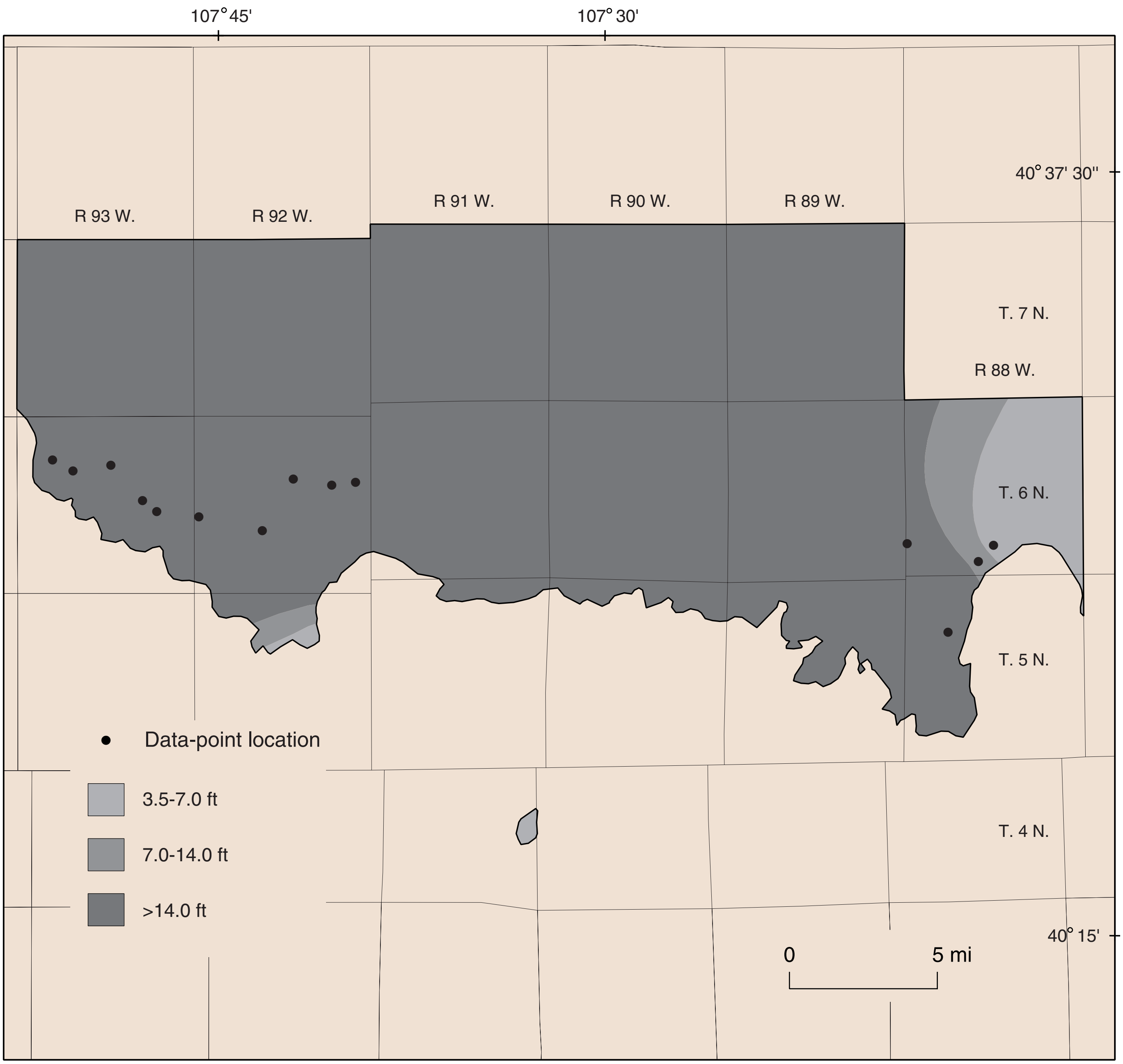

Figure 20. Net-coal thickness categories for the D coal zone, Yampa coal field.

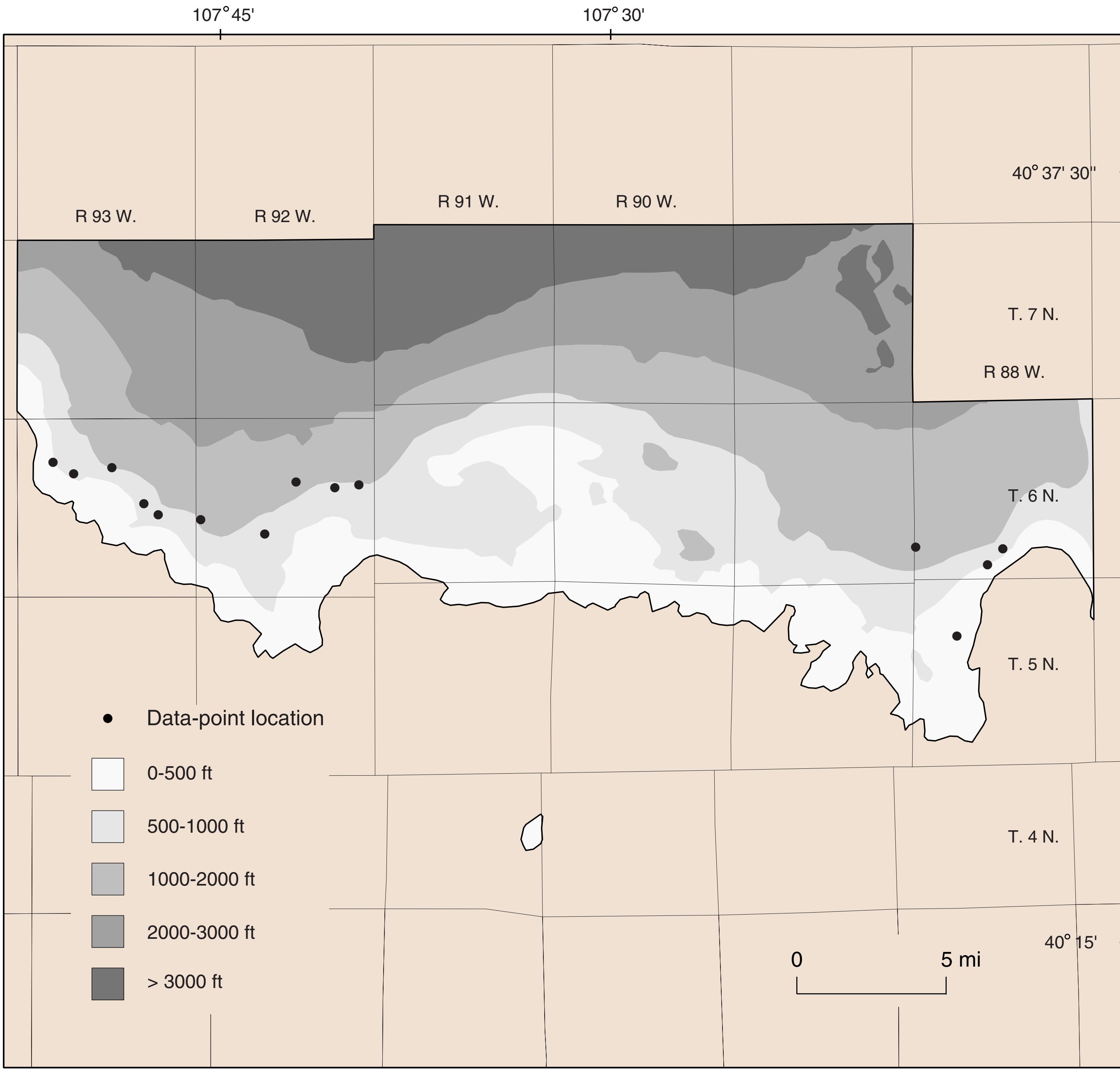

Figure 21. Isopach map of maximum overburden to the base of the D coal zone, Yampa coal field.

as towns and highways are unavailable for extraction. Environmental restrictions can also limit coal availability. For example, coal resources adjacent to a wildlife habitat such as raptor nests might not be available for extraction. Air and water quality are always issues of concern in areas where coal is either mined or burned, and, in the case of the Yampa coal field, both of are occurring. There is always the possibility that future increases in coal production and utilization in this region might be limited because of these issues. For example, in the past few years the burning of coal in the Yampa Valley has caused some concern in regard to acid rain in the nearby Routt National Forest. Although this and other environmental problems could be lessened by mitigation, they still might limit the amount of coal that can be ultimately recovered.

Summary of Coal Resources

The Yampa coal field contains an estimated net coal resource of about 76 billion short tons in beds equal to or greater than 1.2 ft. This is more coal than the combined resources of northwest Colorado's other two coal fields, the Danforth Hills north of Meeker and the Lower White River north of Rangely. Coal classified as identified makes up about 46 percent, with the remaining 54 percent classified as hypothetical. Most of the hypothetical coal lies deep below the ground surface in the northern part of the maximum resource polygon (fig. 2).

Although there is a significant amount of coal in the coal field, this figure should be regarded with caution because it does not reflect geologic, land-use, and environmental restrictions that might limit coal availability. For example, of the 76 billion short tons, about 48 percent is under more than 3,000 ft of overburden and thus is unavailable for underground mining. In addition, coal beds that dip more than 12 degrees are unavailable for underground mining at any depth, and such resources in the vicinity of the Sage Creek, Fish Creek, and Tow Creek anticlines (fig. 10) are considerable. But even more significant, about 90 percent of the coal is under more than 500 ft of overburden and is thus unavailable for surface mining. In addition, the coal in beds greater than 14 ft thick would be left behind in underground mines and subeconomic coal beds would be wasted during surface mining. An estimate of the amount of coal that would be subtracted from the net-coal resource for land-use and environmental concerns would require a detailed coal availability study of the entire coal field, but suffice it to say that the deduction would be significant. To conclude, only a small percentage of the 76 billion short tons of the net-coal resource could be recovered.

Moffat County contains about 80 percent of the net-coal resource in the coal field. This is of interest to the county because future mining operations would undoubtedly contribute significantly to the tax base. About 93 percent of the total net-coal resource in the coal field underlies private surface. This is of interest to land owners because, as new mines are developed, compensation for loss of acreage and for disturbance would provide vital income at a time when farming is not as profitable as it once was. About 69 percent of the net-coal resource is owned by the Federal Government (fig. 22). This is important to the Nation because royalties paid on coal leases provide a source of revenue to the Government.

The future of coal mining in northwestern Colorado appears bright. The industry will continue to support the local economy by providing jobs and by purchasing goods and services from local suppliers. However, during the next decade most of the coal produced in the coal field will come from areas presently under lease and from coal mines already in existence. The A coal zone will continue to dominate production in the eastern part of the field, and the D coal zone will continue to dominate in the western part of the coal field. Coal mining in the Yampa coal field, combined with coal mining in the Danforth Hills and Lower White River coal fields, will remain an important social and economic factor in this region of Colorado well into the 21st century.

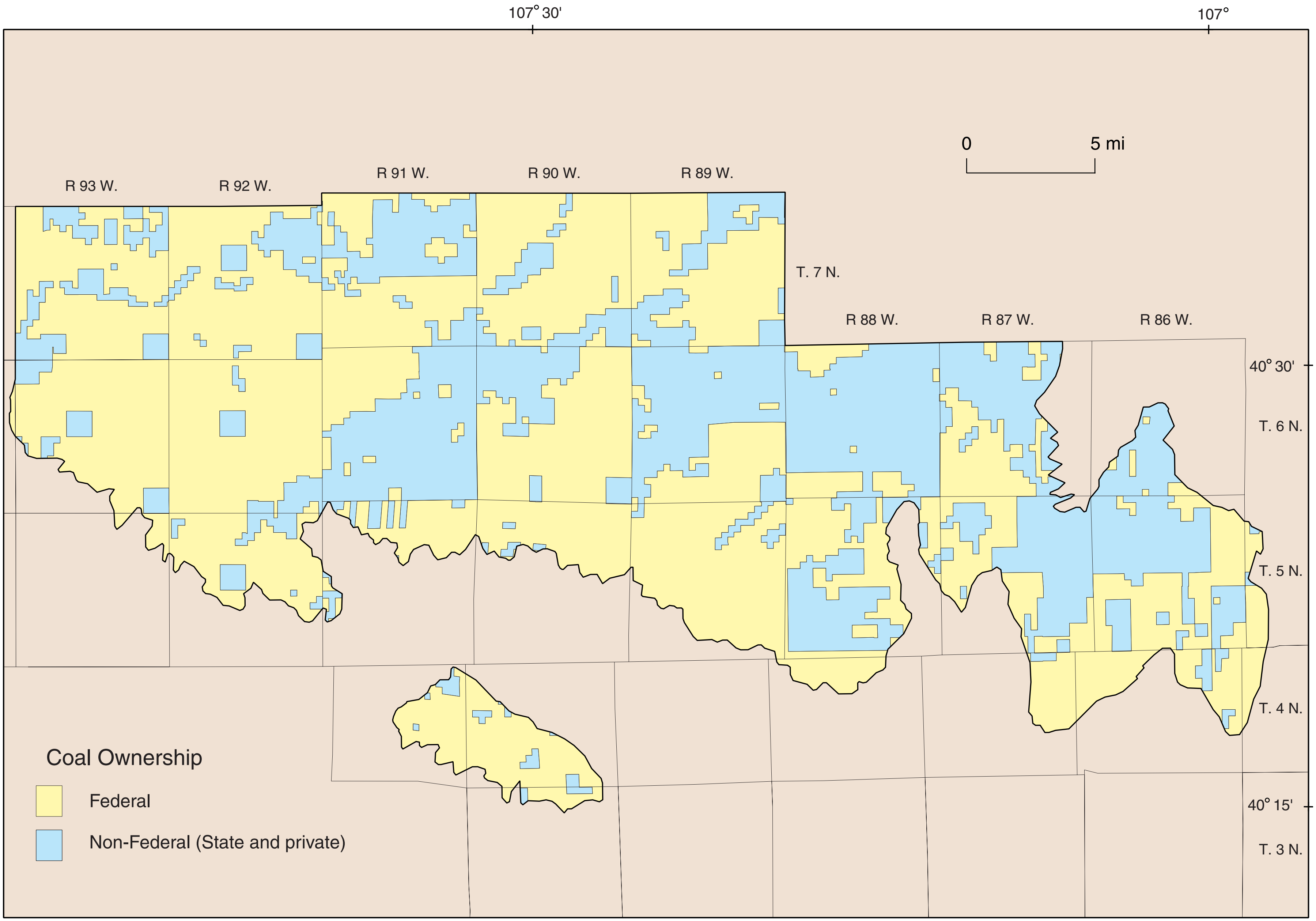

Figure 22. Federal and non-Federal coal ownership in the Yampa coal field.

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Appendix 1—Metric Conversion Factors

Metric conversion factors.

Customary inch-pound units	SI conversion
acre	4,046.87 square meters
acre-foot	1,233.49 cubic meters
British thermal unit (Btu)	1,005.056 joules
British thermal unit / pound (Btu / lb)	2,326 joules / kilogram
foot (ft)	0.3048 meters
inch (in)	0.0254 meters
mile (mi)	1.609 kilometers
pound (lb)	0.4536 kilograms
short ton (ton)	0.9072 metric tons
short tons / acre-foot	0.7355 kilograms / cubic meter
square mile (mi^2)	2.59 square kilometers

Appendix 2—Information on Publicly Available Exploration Drill Holes Used in this Report

Map no.	Point ID	Source	Longitude	Latitude	Section	Township	Range	Surface elevation (ft)	Total depth (ft)	Top of Trout Creek Sandstone elev. (ft)	A coal zone Total coal (ft)	A coal zone # beds	B coal zone Total coal (ft)	B coal zone # beds	C coal zone Total coal (ft)	C coal zone # beds	D coal zone Total coal (ft)	D coal zone # beds
1	JHS-1-81C	85-37	-107.88328	40.48542	7	T6N	R93W	6,450	632				17	3				
2	R-1-JHS	85-43	-107.87895	40.48659	7	T6N	R93W	6,440	742	5,765	78	23	13	2				
3	R-2-JHS	85-43	-107.87787	40.47223	18	T6N	R93W	6,494	961	5,882	54	10						
4	Y-4	76-383	-107.87664	40.49306	6	T6N	R93W	6,418	740	5,716	90	15	22	5				
5	Y-18-HG	76-817	-107.87208	40.47783	18	T6N	R93W	6,565	1,200	5,420	69	18	41	8	4	2		
6	Y-13-HG	76-817	-107.86686	40.45519	19	T6N	R93W	6,575	496	6,213	40	12						
7	HG-6-85	Fed Reg only	-107.86250	40.48583	8	T6N	R93W	6,645	1,355								38	14
8	HG-5-85	Fed Reg only	-107.85750	40.47083	17	T6N	R93W	6,635	1,195	5,517	62	13	23	6				
9	Y-17-HG	76-817	-107.85706	40.49042	8	T6N	R93W	6,640	950									
10	HG-5-85C	Fed Reg only	-107.85583	40.47139	17	T6N	R93W	6,635	950				20	5				
11	Y-14-HG	76-817	-107.85086	40.46514	17	T6N	R93W	6,640	938	5,867	48	8	14	3	7	3		
12	R-15-HG	85-37	-107.84934	40.48031	8	T6N	R93W	6,620	1,520						8	3	44	16
13	R-18-HG	85-43	-107.84255	40.45944	21	T6N	R93W	6,715	1,420	5,413	52	12	23	4	9	3		
14	R-1-HG	78-366	-107.82802	40.44422	27	T6N	R93W	6,775	1,089	5,800	31	9	24	3	21	4		
15	R-17-HG	85-43	-107.82688	40.47250	15	T6N	R93W	6,290	1,500	4,829	49	12	58	14	9	4		
16	R-2-HG	78-366	-107.82630	40.45163	22	T6N	R93W	6,650	1,250	5,440	45	14	18	3	7	2		
17	HG-1-81	85-37	-107.82494	40.48325	10	T6N	R94W	6,371	2,300	4,156	45	10	77	11	11	4	41	12
18	Y-16-HG	76-817	-107.81797	40.45161	22	T6N	R93W	6,680	1,000				44	11	13	4		
19	Y-15-HG	76-817	-107.81781	40.47000	15	T6N	R93W	6,120	800						14	5		
20	R-3-HG	78-366	-107.81644	40.45992	22	T6N	R93W	6,350	967				25	6	15	6		
21	R-6-HG	78-366	-107.81225	40.44813	27	T6N	R93W	6,615	1,184				28	5	20	4		
22	R-5-HG	78-366	-107.80714	40.45433	23	T6N	R93W	6,460	928						9	2		
23	R-16-HG	85-37	-107.80467	40.46579	14	T6N	R93W	6,320	1,947	4,476	60	19	64	15	17	6	49	15
24	R-7-HG	78-366	-107.79813	40.44477	26	T6N	R93W	6,370	1,183				48	8	26	6		
25	R-4-HG	78-366	-107.79553	40.46033	23	T6N	R93W	6,410	1,066						11	4	25	9
26	R-8-HG	78-366	-107.78801	40.44167	25	T6N	R93W	6,242	1,256				31	9	12	5		
27	R-9-HG	78-366	-107.77263	40.44640	25	T6N	R93W	6,438	1,106						12	3		
28	R-12-HG	78-366	-107.77124	40.42660	31	T6N	R92W	6,518	1,285		57	10	27	7	20	6		
29	R-13-HG	78-366	-107.77117	40.43518	30	T6N	R92W	6,445	915				20	8	17	3		
30	HG-2-81	85-37	-107.76842	40.45783	19	T6N	R92W	6,200	2,247	4,050	75	15	54	15	11	2	52	10
31	R-10-HG	78-366	-107.76233	40.44133	30	T6N	R92W	6,420	1,102						13	3		
32	R-11-HG	78-366	-107.76175	40.43034	31	T6N	R92W	6,355	1,501	4,936	61	16	39	9	27	8		
33	E-16-HG	78-229	-107.75253	40.42523	32	T6N	R92W	6,320	1,380	4,964	66	11	27	8	21	6		
34	E-5-RDB	78-229	-107.74986	40.39961	8	T5N	R92W	6,100	440	5,716								
35	E-4-RDB	78-229	-107.74353	40.41148	5	T5N	R92W	6,660	1,406	5,318	69	16	20	6	14	4		
36	MC-1	85-43	-107.74225	40.39131	8	T5N	R92W	6,760	1,002	5,875	97	17	33	4				
37	MC-2	85-43	-107.72803	40.39286	9	T5N	R92W	6,710	1,300	5,692	67	14	18	3	8	2		
38	RB-3-81	85-37	-107.72769	40.45083	21	T6N	R92W	6,195	2,319				14	4	13	5	35	10
39	E-24-MB	79-328	-107.72397	40.37421	21	T5N	R92W	7,165	580	6,675	59	13						
40	E-2-RDB	78-229	-107.71812	40.41287	4	T5N	R92W	6,290	1,415				32	6	19	5		
41	MC-3	85-43	-107.71686	40.39172	9	T5N	R92W	6,840	1,380	5,758	67	16	46	5	15	5		
42	E-21-RDB	79-328	-107.70864	40.39967	10	T5N	R92W	6,500	1,320	5,312	73	15	42	6	10	3		
43	1USADOROUGH	O&G	-107.70770	40.58140	3	T7N	R92W	6,767	4,810	2,069								
44	E-8-RDB	78-229	-107.70766	40.47614	15	T6N	R92W	6,560	1,000								37	12
45	E-6-RDB	78-229	-107.69828	40.38735	15	T5N	R92W	7,010	1,046	6,030	79	14	23	2				
46	I.U.-1	85-43	-107.69814	40.40322	10	T5N	R92W	6,410	1,359	5,142	80.1	18	33.5	4	16.5	4		
47	E-11-RDB	78-229	-107.69759	40.45241	22	T6N	R92W	6,380	860						17	5		
48	ILES MTN #2	85-43	-107.69658	40.37919	14	T5N	R92W	7,300	995	6,328	95	16	25	5				
49	I.U.-3	85-43	-107.69614	40.37800	15	T5N	R92W	7,300	900	6,507	55	13						
50	BRG-3	85-43	-107.68903	40.43839	26	T6N	R92W	6,445	1,500	5,201	93	14	18	5	18	6		
51	BRG-1	85-43	-107.68878	40.45983	23	T6N	R92W	6,460	1,763	4,759	84	17	33	5	10	3		
52	E-26-RDB	79-328	-107.68291	40.47312	14	T6N	R92W	6,365	943								24	7

Map no.	Point ID	Source	Longitude	Latitude	Section	Township	Range	Surface elevation (ft)	Total depth (ft)	Top of Trout Creek Sandstone elev. (ft)	A coal zone Total coal (ft)	A coal zone # beds	B coal zone Total coal (ft)	B coal zone # beds	C coal zone Total coal (ft)	C coal zone # beds	D coal zone Total coal (ft)	D coal zone # beds
53	E-13-RDB	78-229	-107.68043	40.44091	26	T6N	R92W	6,720	961				13	4	21	7		
54	E-22-RDB	79-328	-107.67847	40.37714	14	T5N	R92W	7,410	1,120	6,488	82	15	24	3				
55	BRG-2	85-43	-107.67445	40.45651	24	T6N	R92W	6,370	1,810	4,788	74	17	33	5	13	5		
56	E-25-MB	79-328	-107.67069	40.36721	24	T5N	R92W	7,480	700	6,896	73	11						
57	E-12-RDB	78-229	-107.66910	40.44640	25	T6N	R92W	6,610	1,400				11	3	11	4		
58	RB-2-81C	85-37	-107.66906	40.44640	25	T6N	R92W	6,600	1,480				9	2	13	5		
59	RB-1-81	85-37	-107.66760	40.47453	13	T6N	R92W	6,382	2,070	4,402	65	11	31	2	14	4	35	10
60	1GOVT	O&G	-107.64320	40.55990	18	T7N	R91W	6,980	5,180	1,824								
61	CG-1	85-43	-107.62697	40.41352	5	T5N	R91W	7,270	1,105				19	5				
62	E-1-RDB	78-229	-107.62631	40.41989	5	T5N	R91W	7,090	1,106				17	4	11	3		
63	1 BILSING	O&G	-107.62611	40.49361	8	T6N	R91W	6,338	1,730	4,648								
64	H-40-H	82-475	-107.60181	40.30272	22	T4N	R91W	7,235	631	6,724	89	19						
65	H-21-P	77-118	-107.59682	40.29234	27	T4N	R91W	7,895	400	7,626								
66	H-34-H	78-366	-107.58900	40.29585	27	T4N	R91W	7,725	520	7,305	96	12						
67	C-1C-H	82-475	-107.58315	40.29916	23	T4N	R91W	7,615	884				23	2				
68	H-12-P	77-118	-107.58312	40.29945	23	T4N	R91W	7,615	380				23	2				
69	C-1A-H	82-475	-107.58296	40.29840	23	T4N	R91W	7,615	875	7,052								
70	C-1-H	82-475	-107.58284	40.29922	23	T4N	R91W	7,610	906				22	2				
71	H-22-P	77-118	-107.57758	40.31530	14	T4N	R91W	7,592	500	7,333								
72	H-14-P	77-118	-107.57603	40.31077	14	T4N	R91W	7,695	280				15	2				
73	CG-4	85-43	-107.57476	40.40440	11	T5N	R91W	7,240	500	6,877								
74	CG-3	85-43	-107.57339	40.41067	2	T5N	R91W	7,460	1,035	6,495	85	9	9	2				
75	H-26-P	77-118	-107.56361	40.29630	24	T4N	R91W	7,785	460				23	2				
76	H-20-P	77-118	-107.56294	40.29247	25	T4N	R91W	7,870	480				21	2				
77	H-33-H	78-366	-107.56007	40.28749	25	T4N	R91W	8,060	1,005	7,201	99	13	6	2				
78	H-35-H	78-366	-107.55956	40.31138	13	T4N	R91W	7,262	1,300	6,202	106	15	22	2				
79	H-36-H	82-475	-107.55753	40.30741	24	T4N	R91W	7,350	1,825	5,772	97	12	20	2	11	3		
80	CG-6	85-43	-107.55637	40.39696	12	T5N	R91W	7,610	800	7,419								
81	CG-5	85-43	-107.55509	40.40712	12	T5N	R91W	7,680	895	6,865	66	11	5	2				
82	H-32-H	78-366	-107.52975	40.27303	32	T4N	R90W	8,135	631	7,666	94	12						
83	CG-7	85-43	-107.52518	40.39954	8	T5N	R90W	7,565	920	7,092								
84	CG-8	85-43	-107.52413	40.40765	8	T5N	R90W	7,565	1,000	6,661	76	17	8	2				
85	CG-9	85-43	-107.50250	40.40642	9	T5N	R90W	7,445	940	6,637	66	16	8	2				
86	BM-37	78-365	-107.49822	40.42408	4	T5N	R90W	7,320	980				12	1	9.5	3		
87	BM-59	85-43	-107.49239	40.44783	28	T6N	R90W	6,895	1,000				11	2	9	5		
88	1-16 STATE	O&G	-107.49222	40.47889	16	T6N	R90W	6,478	1,866	4,618								
89	BM-20	77-155	-107.49158	40.41308	4	T5N	R90W	7,060	580				3	1				
90	BM-19	77-155	-107.49039	40.40686	9	T5N	R90W	6,970	569	6,419	61.8	17						
91	BM-36	78-365	-107.48806	40.42278	4	T5N	R90W	7,480	1,000				10.5	2	7.5	2		
92	BM-58	85-43	-107.48597	40.43906	33	T6N	R90W	6,945	1,000				11	2	11	6		
93	H-41-P	82-475	-107.48422	40.26056	3	T3N	R90W	8,270	960	7,531	58	12						
94	H-31-P	78-366	-107.48239	40.25342	3	T3N	R90W	8,442	950	7,967	61	8						
95	BM-53	85-43	-107.48169	40.42914	34	T6N	R90W	7,340	1,500				6.5	1	10	4		
96	BM-50	85-43	-107.47725	40.41639	3	T5N	R90W	7,640	715				5	1	6.5	2		
97	BM-49	85-43	-107.47444	40.39992	10	T5N	R90W	7,485	960	6,617	72	16	4	1				
98	BM-17	77-155	-107.47303	40.40061	10	T5N	R90W	7,480	580				2.5	1				
99	BM-18	77-155	-107.47147	40.40933	10	T5N	R90W	7,280	580				8.3	3				
100	BM-54	85-43	-107.46847	40.43250	34	T6N	R90W	7,330	1,040				9	3	7.5	3		
101	BM-16	77-155	-107.46744	40.39828	11	T5N	R90W	7,540	560				5	1				
102	BM-34	78-365	-107.46211	40.42967	35	T6N	R90W	7,480	840				4	1	9	3		
103	BM-39	78-365	-107.45942	40.40883	11	T5N	R90W	7,760	760				5	2				
104	BM-48	85-43	-107.45744	40.40547	11	T5N	R90W	7,360	1,180	6,480	62.5	15	0	0				

Map no.	Point ID	Source	Longitude	Latitude	Section	Township	Range	Surface elevation (ft)	Total depth (ft)	Top of Trout Creek Sandstone elev. (ft)	A coal zone Total coal (ft)	A coal zone # beds	B coal zone Total coal (ft)	B coal zone # beds	C coal zone Total coal (ft)	C coal zone # beds	D coal zone Total coal (ft)	D coal zone # beds
105	BM-44	78-365	-107.45147	40.42875	35	T6N	R90W	7,440	880				2.5	1	2	1		
106	BM-31	78-365	-107.45089	40.42017	2	T5N	R90W	7,680	820				3	1	7	3		
107	BM-38	78-365	-107.44650	40.41336	1	T5N	R90W	7,700	820				4	1	10	4		
108	BM-33	78-365	-107.44519	40.42964	36	T6N	R90W	7,320	640						5	2		
109	BM-14	77-155	-107.44394	40.39856	12	T5N	R90W	7,480	580				15.5	1				
110	BM-13	77-155	-107.43569	40.40967	1	T5N	R90W	7,800	545						6.5	2		
111	BM-30	78-365	-107.42600	40.42128	6	T5N	R89W	7,150	885				13	1				
112	BM-29	78-365	-107.41775	40.42814	31	T6N	R89W	6,960	600				3	1				
113	BM-22	77-155	-107.41431	40.38594	18	T5N	R89W	7,925	580				7.5	1				
114	BM-12	77-155	-107.41247	40.41906	6	T5N	R89W	7,160	580				12	1				
115	BM-10	77-155	-107.40933	40.40528	8	T5N	R89W	7,830	440						10.5	3		
116	1 LYONS	O&G	-107.40583	40.44194	29	T6N	R89W	6,751	2,104	4,743								
117	BM-28	77-155	-107.40531	40.41992	5	T5N	R89W	7,550	580						9.5	5		
118	BM-46	85-43	-107.40144	40.39800	8	T5N	R89W	7,640	1,180	6,740	61.5	11	5	1				
119	HAY COAL 22-4	O&G	-107.40111	40.41917	4	T5N	R89W	7,345	1,675	5,725	61	9	10	1	8	2		
120	BM-45	85-43	-107.39858	40.40906	8	T5N	R89W	7,300	1,005	6,406	66	14	6	1				
121	BM-23	77-155	-107.39803	40.38472	17	T5N	R89W	7,850	580				6	1				
122	BM-06	77-155	-107.39772	40.40100	8	T5N	R89W	7,520	581				10	1				
123	BM-40	78-365	-107.39667	40.39328	17	T5N	R89W	7,740	1,040	6,763	60	13	3	1				
124	BM-24	78-365	-107.39458	40.37622	20	T5N	R89W	7,830	720				9	1				
125	BM-03	77-155	-107.38966	40.42230	4	T5N	R89W	6,950	580				4	1				
126	BM-25	77-155	-107.38683	40.39997	9	T5N	R89W	7,830	500						9	3		
127	BM-01	77-155	-107.38622	40.42806	33	T6N	R89W	6,840	570						10	4		
128	BM-26	77-155	-107.38478	40.40997	4	T5N	R89W	7,520	580						6	2		
129	BM-42	78-365	-107.38397	40.37522	21	T5N	R89W	7,900	800				10	2	9	4		
130	BM-27	77-155	-107.38272	40.41772	4	T5N	R89W	7,370	580						8	4		
131	BM-02	77-155	-107.37795	40.41149	4	T5N	R89W	7,415	580						6	1		
132	BM-43	78-365	-107.37525	40.40203	9	T5N	R89W	7,300	560						4	2		
133	HAY-8	78-365	-107.37382	40.37597	21	T5N	R89W	7,770	780						10	2		
134	HAYG-11	78-365	-107.37203	40.35797	27	T5N	R89W	7,900	800				2	1				
135	HAY-9	78-365	-107.36511	40.38699	15	T5N	R89W	7,400	800						7	3		
136	HAY-4	77-155	-107.36424	40.39999	10	T5N	R89W	7,660	580						10	3		
137	HAY-3	77-155	-107.35735	40.39557	10	T5N	R89W	6,900	523									
138	HAYG-14	85-43	-107.35329	40.34792	35	T5N	R89W	7,805	600	7,278	59	15						
139	HAYG-10	78-365	-107.35095	40.36745	23	T5N	R89W	7,320	800				3	1				
140	HAYG-4	77-155	-107.34315	40.35119	26	T5N	R89W	7,660	560				2	1				
141	HAYG-6	77-155	-107.34277	40.36319	26	T5N	R89W	7,960	578						6	2		
142	HAYG-12	78-365	-107.34264	40.34849	35	T5N	R89W	7,320	710	6,991								
143	HAY-2	77-155	-107.34211	40.38684	14	T5N	R89W	7,300	580						12	3		
144	HAY-5	77-155	-107.34148	40.39677	11	T5N	R89W	6,850	578						9	4		
145	HAYG-3	77-155	-107.33135	40.35369	25	T5N	R89W	7,270	560				3	1				
146	HAY-11	85-43	-107.32789	40.39437	13	T5N	R89W	6,890	760						2	1		
147	HAY-7	78-365	-107.32629	40.38649	13	T5N	R89W	7,000	753						2	1		
148	HAYG-15A	85-43	-107.32275	40.35119	25	T5N	R89W	7,920	1,460				0	0	0	0		
149	HAY-6A	77-155	-107.31944	40.39465	13	T5N	R89W	6,820	551									
150	HAYG-9	78-365	-107.31656	40.36300	25	T5N	R89W	7,700	770						0	0		
151	BRESH 14-30	O&G	-107.31306	40.44278	30	T6N	R88W	6,514	2,638	3,944	80	11					19.1	4
152	Y-25-H	76-817	-107.28722	40.39922	8	T6N	R88W	6,800	619								22	7
153	Y-22-H	76-817	-107.26739	40.43378	33	T6N	R88W	7,528	540								12	5
154	DCU 0-28-6-88-N	O&G	-107.25750	40.44167	28	T6N	R88W	6,517	2,152	4,443	42	10					4	1
155	DCU 12-2 HD	O&G	-107.23750	40.41833	2	T5N	R88W	7,443	1,060	6,443								
156	FCU 3-2	O&G	-107.22942	40.42681	2	T5N	R88W	7,225	930	6,375	30	6						

Map no.	Point ID	Source	Longitude	Latitude	Section	Township	Range	Surface elevation (ft)	Total depth (ft)	Top of Trout Creek Sandstone elev. (ft)	A coal zone		B coal zone		C coal zone		D coal zone	
											Total coal (ft)	# beds	Total coal (ft)	# beds	Total coal (ft)	# beds	Total coal (ft)	# beds
157	GRACE 1-27	O&G	-107.13222	40.45083	27	T6N	R87W	6,819	678	6,181								
158	RB-22	78-1048	-107.12411	40.30019	23	T4N	R87W	7,930	315	7,643								
159	JOSE ROCHE 23-5	O&G	-107.11667	40.37889	23	T5N	R87W	6,863	1,475	5,460								
160	RB-20	78-1048	-107.10644	40.29750	23	T4N	R87W	8,040	255	7,813								
161	RB-19	78-1048	-107.09849	40.30148	19	T4N	R86W	7,920	215	7,723								
162	FCU 6-36	O&G	-107.09806	40.34056	3	T5N	R87W	7,050	1,420	5,755								
163	RB-18	78-1048	-107.08832	40.30811	19	T4N	R86W	7,746	315	7,456								
164	RB-17	78-1048	-107.05394	40.32948	9	T4N	R86W	7,620	335	7,297								
165	M-3	78-365	-107.03078	40.43356	34	T6N	R86W	6,860	1,000	6,151	21	4						
166	M-4	78-365	-107.02483	40.42433	3	T5N	R86W	6,670	1,005	5,906	30	4						
167	RB-14	78-365	-107.01531	40.35067	34	T5N	R86W	7,140	1,230	5,917	23	6						
168	M-5	78-365	-107.01433	40.42028	3	T5N	R86W	6,640	807	6,290	21	5						
169	RB-12	78-365	-107.00822	40.32658	11	T4N	R86W	7,540	1,185	6,471	23	5						
170	RB-15	78-365	-107.00494	40.34450	35	T5N	R86W	7,560	1,250	6,394	25	6						
171	RB-13	78-365	-107.00089	40.33346	11	T4N	R86W	7,460	1,130	6,399	21	5						
172	OC-1	78-365	-106.99892	40.32492	14	T4N	R86W	7,280	775	6,624	26	5						
173	OC-2	78-365	-106.98694	40.34314	36	T5N	R86W	7,070	776	6,480	20	6						
174	OC-3	78-365	-106.98517	40.35303	36	T5N	R86W	7,070	717	6,476	27	9						
175	CC-1	78-365	-106.96639	40.40506	7	T5N	R85W	6,720	700	6,356								

Appendix 3—Estimated Remaining Coal Resources in the A Coal Zone, Williams Fork Formation, Yampa Coal Field

Appendix 3a. Estimated coal resources (in millions of short tons) in beds 1.2 ft thick or greater, by county, as expressed in reliability and maximum overburden categories. Resources in net-coal thickness categories are not listed in Appendix 3a, nor is a figure of coal-thickness categories provided because net coal in the A zone is everywhere greater than 14 ft. Does not include mined-out areas or areas where A-zone coal is included in an active coal lease. Totals might not equal the sum of their components in any particular column because of independent rounding.

County	Reliability	Maximum overburden (ft)					Total
		0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	
Moffat	Identified	2,500	2,100	6,300	2,500	610	14,000
	Hypothetical	0	12	1,100	2,700	11,000	15,000
Moffat Total		2,500	2,100	7,400	5,200	11,000	29,000
Routt	Identified	900	1,100	3,100	2,000	410	7,400
	Hypothetical	370	320	1,200	1,400	2,900	6,100
Routt Total		1,300	1,400	4,300	3,300	3,300	14,000
Total		**3,800**	**3,500**	**12,000**	**8,500**	**15,000**	**42,000**

Appendix 3b. Estimated coal resources in maximum overburden categories by surface ownership. Non-Federal surface includes State and private.

Surface owner	Maximum overburden (ft)					Total
	0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	
Federal	800	700	670	350	720	3,200
Non-Federal	3,000	2,800	11,000	8,200	14,000	39,000
Total	**3,800**	**3,500**	**12,000**	**8,500**	**15,000**	**42,000**

Appendix 3c. Estimated coal resources in maximum overburden categories by coal ownership. Non-Federal coal includes State and private.

Coal owner	Maximum overburden (ft)					Total
	0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	
Federal	3,300	2,700	6,700	5,400	10,000	28,000
Non-Federal	470	820	5,000	3,100	4,600	14,000
Total	**3,800**	**3,500**	**12,000**	**8,500**	**15,000**	**42,000**

Appendix 3d. Estimated coal resources in maximum overburden categories by 7.5′ quadrangle.

7.5′ quadrangle	Maximum overburden (ft) 0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	Total
Breeze Mountain	180	470	1,700	1,600	0.25	3,900
Castor Gulch	250	200	2,200	150	0	2,800
Cow Creek	78	41	14	0	0	130
Craig	0	0	300	740	2,200	3,200
Dunckley	170	62	59	0	0	290
Hamilton	950	530	260	0	0	1,700
Hayden	0	73	1,300	1,800	890	4,100
Hayden Gulch	220	410	550	0	0	1,200
Hooker Mountain	13	9	99	140	0	260
Horse Gulch	340	260	900	750	130	2,400
Juniper Hot Springs	84	59	0	0	0	140
Lay	0	45	180	140	73	440
Lay SE	0	0.91	310	970	3,100	4,400
Milner	220	110	460	0	0	790
Monument Butte	170	40	0	0	0	210
Mount Harris	120	130	780	390	0	1,400
Oak Creek	200	59	2.6	0	0	260
Pagoda	450	120	0	0	0	570
Pine Ridge	0	0	0	190	3,200	3,400
Ralph White Lake	0	0	11	720	2,900	3,600
Rattlesnake Butte	78	180	320	0	0	580
Rock Spring Gulch	0	0	0	21	2,000	2,000
Round Bottom	250	720	2,200	1,000	140	4,300
Wolf Mountain	24	0	0	0	0	24
Total	**3,800**	**3,500**	**12,000**	**8,500**	**15,000**	**42,000**

Appendix 3e. Estimated coal resources in overburden categories by township.

Township	Maximum overburden (ft)					Total
	0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	
3N 90W	110	48	0	0	0	160
4N 85W	53	0	0	0	0	53
4N 86W	120	90	26	0	0	230
4N 87W	91	47	53	0	0	190
4N 88W	110	110	0.13	0	0	220
4N 90W	810	330	72	0	0	1,200
4N 91W	380	220	190	0	0	780
5N 85W	79	1.9	0	0	0	81
5N 86W	100	180	410	0	0	700
5N 87W	100	130	610	0	0	840
5N 88W	140	220	950	52	0	1,400
5N 89W	250	530	1,200	98	0	2,100
5N 90W	210	280	390	0	0	890
5N 91W	270	140	87	0	0	510
5N 92W	390	660	450	0	0	1,500
5N 93W	91	0.51	0	0	0	91
6N 86W	100	43	33	0	0	180
6N 87W	120	48	380	75	0	620
6N 88W	0.85	11	250	1,100	620	2,000
6N 89W	0	0	330	1,900	770	3,000
6N 90W	0	0	1,500	1,000	0	2,500
6N 91W	1.4	62	2,100	450	8.6	2,600
6N 92W	39	74	1,400	1,200	410	3,100
6N 93W	200	280	790	580	110	2,000
6N 94W	26	0	0	0	0	26
7N 89W	0	0	0	29	2,900	2,900
7N 90W	0	0	0.2	550	2,200	2,800
7N 91W	0	0	4	380	2,200	2,600
7N 92W	0	0	0	13	3,000	3,000
7N 93W	0	18	420	1,000	2,400	3,900
Total	**3,800**	**3,500**	**12,000**	**8,500**	**15,000**	**42,000**

Appendix 4—Estimated Remaining Coal Resources in the B Coal Zone, Williams Fork Formation, Yampa Coal Field

Appendix 4a. Estimated coal resources (in millions of short tons) in beds 1.2 ft thick or greater, by county, as expressed in reliability, net-coal thickness, and maximum overburden categories. Does not include mined-out areas or areas where B-zone coal is included in an active coal lease. Totals might not equal the sum of their components in any particular column because of independent rounding.

County	Reliability	0-500 ft maximum overburden Net-coal thickness category 1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0	>14.0	0-500 Total	500-1,000 ft maximum overburden Net-coal thickness category 1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0	>14.0	500-1,000 Total
Moffat	Identified	0.54	2.1	9	57	390	450	0.25	2.1	14	210	740	960
	Hypothetical	0	0	0	0	0	0	0	0	0	16	1.6	18
Moffat Total		0.54	2.1	9	57	390	450	0.25	2.1	14	220	740	980
Routt	Identified	2.5	4.3	17	27	0.39	51	3.5	7.2	19	29	10	70
Routt Total		2.5	4.3	17	27	0.39	51	3.5	7.2	19	29	10	70
Total		**3.1**	**6.5**	**26**	**84**	**390**	**510**	**3.8**	**9.3**	**33**	**250**	**750**	**1000**

County	Reliability	1,000-2,000 ft maximum overburden Net-coal thickness category 1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0	>14.0	1,000-2,000 Total	2,000-3,000 ft maximum overburden Net-coal thickness category 1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0	>14.0	2,000-3,000 Total
Moffat	Identified	5.9	7.6	27	83	1,800	2,000	0	0	0	0	1,500	1,500
	Hypothetical	2.2	2.8	14	50	340	410	1.8	2.8	13	47	1,500	1,500
Moffat Total		8.1	10	41	130	2,200	2,400	1.8	2.8	13	47	3,000	3,000
Routt	Identified	0.9	0.77	1.8	1.4	0	4.8	0	0	0	0	0	0
Routt Total		0.9	0.77	1.8	1.4	0	4.8	0	0	0	0	0	0
Total		**9**	**11**	**43**	**130**	**2,200**	**2,400**	**1.8**	**2.8**	**13**	**47**	**3,000**	**3,000**

County	Reliability	>3,000 ft maximum overburden Net-coal thickness category 1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0	>14.0	>3,000 Total	Total
Moffat	Identified	0	0	0	0	79	79	4,900
	Hypothetical	3.2	4.8	22	62	5,600	5,700	7,700
Moffat Total		3.2	4.8	22	62	5,700	5,800	13,000
Routt	Identified	0	0	0	0	0	0	130
Routt Total		0	0	0	0	0	0	130
Total		**3.2**	**4.8**	**22**	**62**	**5,700**	**5,800**	**13,000**

Appendix 4b. Estimated coal resources in maximum overburden categories by surface ownership. Non-Federal surface includes State and private.

Surface owner	Maximum overburden (ft)					Total
	0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	
Federal	190	200	200	260	410	1,300
Non-Federal	320	850	2,200	2,800	5,400	11,000
Total	**510**	**1,000**	**2,400**	**3,000**	**5,800**	**13,000**

Appendix 4c. Estimated coal resources in maximum overburden categories by coal ownership. Non-Federal coal includes State and private.

Coal owner	Maximum overburden (ft)					Total
	0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	
Federal	410	660	1,800	2,800	4,000	9,700
Non-Federal	91	390	590	260	1,700	3,100
Total	**510**	**1,000**	**2,400**	**3,000**	**5,800**	**13,000**

Appendix 4d. Estimated coal resources in maximum overburden categories by 7.5′ quadrangle.

7.5′ Quadrangle	Maximum overburden (ft)					Total
	0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	
Breeze Mountain	53	110	79	0	0	250
Castor Gulch	18	260	260	0	0	540
Craig	0	5.8	210	300	930	1,400
Hamilton	86	15	0	0	0	100
Hayden	4.6	13	0.02	0	0	18
Hayden Gulch	7	6.6	0	0	0	14
Horse Gulch	110	270	740	500	2.1	1,600
Juniper Hot Springs	15	0	0	0	0	15
Lay	12	37	87	99	0	230
Lay SE	0.35	29	370	1,300	2,000	3,700
Monument Butte	5.8	0	0	0	0	5.8
Pagoda	7.1	0.36	0	0	0	7.4
Pine Ridge	0	0	6.2	380	2,800	3,200
Ralph White Lake	0	0	14	33	91	140
Round Bottom	190	290	610	430	0	1,500
Total	**510**	**1,000**	**2,400**	**3,000**	**5,800**	**13,000**

Appendix 4e. Estimated coal resources in maximum overburden categories by township.

Township	Maximum overburden (ft)					Total
	0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	
4N 90W	21	1.6	0	0	0	22
4N 91W	65	13	0	0	0	79
5N 89W	51	66	1.4	0	0	120
5N 90W	30	35	1.7	0	0	66
5N 91W	13	11	0	0	0	24
5N 92W	190	180	2.3	0	0	380
5N 93W	0.35	0	0	0	0	0.35
6N 89W	0	3	3.4	0	0	6.4
6N 90W	0	130	120	0	0	250
6N 91W	9.6	180	570	93	0	850
6N 92W	11	130	510	750	45	1,500
6N 93W	110	240	680	450	7.1	1,500
7N 89W	0	0	0	0	0.06	0.06
7N 90W	0	0	34	110	250	390
7N 91W	0	0	54	270	1,400	1,700
7N 92W	0	0	0	110	2,800	2,900
7N 93W	5.2	55	400	1,200	1,300	3,000
Total	**510**	**1,000**	**2,400**	**3,000**	**5,800**	**13,000**

Appendix 5—Estimated Remaining Coal Resources in the C Coal Zone, Williams Fork Formation, Yampa Coal Field

Appendix 5a. Estimated coal resources (in millions of short tons) in beds 1.2 ft thick or greater, by county as expressed in reliability, net-coal thickness, and maximum overburden categories. Does not include mined-out areas or areas where C-zone coal is included in an active coal lease. Totals might not equal the sum of their components in any particular column because of independent rounding.

		0-500 ft maximum overburden Net-coal thickness category					0-500 Total	500-1,000 ft maximum overburden Net-coal thickness category					500-1,000 Total
County	Reliability	1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0	>14.0		1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0	>14.0	
Moffat	Identified	1.1	1.9	29	200	180	410	1.7	2.5	130	300	170	610
	Hypothetical	0	0	0	0.87	0	0.87	0.26	0	26	7.6	0	34
Moffat Total		1.1	1.9	29	210	180	410	2	2.5	150	310	170	640
Routt	Identified	1	1.3	22	130	0	150	1.1	1.3	32	35	0	70
	Hypothetical	0	0	0	0	0	0	0	0	2.1	0	0	2.1
Routt Total		1	1.3	22	130	0	150	1.1	1.3	34	35	0	72
Total		**2.1**	**3.3**	**52**	**330**	**180**	**570**	**3.1**	**3.8**	**190**	**350**	**170**	**710**

		1,000-2,000 ft maximum overburden Net-coal thickness category					1,000-2,000 Total	2,000-3,000 ft maximum overburden Net-coal thickness category				2,000-3,000 Total
County	Reliability	1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0	>14.0		1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0	
Moffat	Identified	0.08	1.2	47	400	24	470	0	0	3.3	110	120
	Hypothetical	5	4.4	110	57	0	170	9	11	200	350	570
Moffat Total		5	5.6	150	460	24	640	9	11	200	470	690
Routt	Identified	1	1.9	45	13	0	61	0	0	0	0	0
	Hypothetical	6.4	16	69	0	0	91	8.8	21	65	0	95
Routt Total		7.4	18	110	13	0	150	8.8	21	65	0	95
Total		**12**	**23**	**270**	**470**	**24**	**800**	**18**	**32**	**270**	**470**	**780**

		>3,000 ft maximum overburden Net-coal thickness category				>3,000 Total	Total
County	Reliability	1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0		
Moffat	Identified	0	0	0	0	0	1,600
	Hypothetical	10	14	240	550	810	1,600
Moffat Total		10	14	240	550	810	3,200
Routt	Identified	0	0	0	0	0	280
	Hypothetical	0	2	67	0	70	260
Routt Total		0	2	67	0	70	540
Total		**10**	**16**	**300**	**550**	**880**	**3,700**

Appendix 5b. Estimated coal resources in maximum overburden categories by surface ownership. Non-Federal surface includes State and private.

Surface owner	Maximum overburden (ft) 0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	Total
Federal	130	39	44	32	51	300
Non-Federal	430	670	760	750	830	3,400
Total	**570**	**710**	**800**	**780**	**880**	**3,700**

Appendix 5c. Estimated coal resources in maximum overburden categories by coal ownership. Non-Federal coal includes State and private.

Coal owner	Maximum overburden (ft) 0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	Total
Federal	430	460	600	630	560	2,700
Non-Federal	130	250	200	160	300	1,000
Total	**570**	**710**	**800**	**780**	**880**	**3,700**

Appendix 5d. Estimated coal resources in maximum overburden categories by 7.5′ quadrangle.

7.5′ quadrangle	Maximum overburden (ft) 0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	Total
Breeze Mountain	120	130	100	0	0	360
Castor Gulch	49	200	19	0	0	270
Craig	0	34	110	130	240	510
Hamilton	20	0	0	0	0	20
Hayden	56	31	76	14	0	180
Hayden Gulch	21	0	0	0	0	21
Horse Gulch	120	100	150	19	0	390
Juniper Hot Springs	0.66	0	0	0	0	0.66
Lay	0.42	0	0	0	0	0.42
Lay SE	0.89	5.7	46	200	67	320
Pagoda	2.6	0	0	0	0	2.6
Pine Ridge	0	0	27	210	370	600
Ralph White Lake	0	1.7	74	140	130	350
Rock Spring Gulch	0	0	0.82	51	73	120
Round Bottom	180	200	200	25	0	600
Total	**570**	**710**	**800**	**780**	**880**	**3,700**

Appendix 5e. Estimated coal resources in maximum overburden categories by township.

Township	Maximum overburden (ft)					Total
	0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	
4N 90W	3.6	0	0	0	0	3.6
4N 91W	16	0	0	0	0	16
5N 88W	0	0.2	0.24	0	0	0.44
5N 89W	150	29	1.3	0	0	180
5N 90W	42	11	0	0	0	54
5N 91W	9	0	0	0	0	9
5N 92W	100	19	0	0	0	120
6N 88W	0	0	5.8	12	0	18
6N 89W	0.96	43	140	22	0	210
6N 90W	27	140	71	0	0	240
6N 91W	35	210	100	4.9	0	360
6N 92W	87	170	210	71	0	540
6N 93W	93	75	120	19	0	300
7N 89W	0	0	5.1	99	120	220
7N 90W	0	0	62	120	140	320
7N 91W	0	0	53	110	290	460
7N 92W	0	0	0	190	290	480
7N 93W	0.27	3.8	32	130	35	200
Total	**570**	**710**	**800**	**780**	**880**	**3,700**

Appendix 6—Estimated Remaining Coal Resources in the D Coal Zone, Williams Fork Formation, Yampa Coal Field

Appendix 6a. Estimated coal resources (in millions of short tons) in beds 1.2 ft thick or greater, by county as expressed in reliability, net-coal coal thickness, and maximum overburden categories. Does not include mined-out areas or areas where D-zone coal is included in an active coal lease. Totals might not equal the sum of their components in any particular column because of independent rounding.

County	Reliability	0-500 ft maximum overburden Net-coal thickness category 3.5-7.0	7.0-14.0	>14.0	0-500 Total	500-1,000 ft maximum overburden Net-coal thickness category 3.5-7.0	7.0-14.0	>14.0	500-1,000 Total
Moffat	Identified	4.5	21	1,900	1,900	0	0	1,900	1,900
	Hypothetical	0	0	33	33	0	0	690	690
Moffat Total		4.5	21	1,900	2,000	0	0	2,600	2,600
Routt	Identified	12	5.4	450	460	17	6.6	320	350
	Hypothetical	1.1	0	92	93	7	0	47	54
Routt Total		13	5.4	540	560	24	6.6	370	400
Total		**18**	**26**	**2,500**	**2,500**	**24**	**6.6**	**2,900**	**3,000**

County	Reliability	1,000-2,000 ft maximum overburden Net-coal thickness category 3.5-7.0	7.0-14.0	>14.0	1,000-2,000 Total	2,000-3,000 ft maximum overburden Net-coal thickness category 7.0-14.0	>14.0	2,000-3,000 Total
Moffat	Identified	0	0	1,500	1,500	0	400	400
	Hypothetical	0	0	1,600	1,600	0	3,500	3,500
Moffat Total		0	0	3,100	3,100	0	3,900	3,900
Routt	Identified	20	50	280	350	0	0	0
	Hypothetical	34	45	500	580	7.6	620	620
Routt Total		53	94	780	930	7.6	620	620
Total		**53**	**94**	**3,900**	**4,000**	**7.6**	**4,500**	**4,500**

County	Reliability	>3,000 ft maximum overburden Net-coal thickness category >14.0	>3000 Total	Total
Moffat	Identified	0	0	5,700
	Hypothetical	3,400	3,400	9,100
Moffat Total		3,400	3,400	15,000
Routt	Identified	0	0	1,200
	Hypothetical	150	150	1,500
Routt Total		150	150	2,700
Total		**3,500**	**3,500**	**17,000**

Appendix 6b. Estimated coal resources in maximum overburden categories by surface ownership. Non-Federal surface includes State and private.

Surface owner	Maximum overburden (ft)					Total
	0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	
Federal	190	88	210	190	250	930
Non-Federal	2,300	2,900	3,800	4,300	3,300	17,000
Total	**2,500**	**3,000**	**4,000**	**4,500**	**3,500**	**17,000**

Appendix 6c. Estimated coal resources in maximum overburden categories by coal ownership. Non-Federal coal includes State and private.

Coal Owner	Maximum overburden (ft)					Total
	0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	
Federal	1,500	1,700	2,800	3,500	2,300	12,000
Non-Federal	1,000	1,300	1,200	960	1,200	5,700
Total	**2,500**	**3,000**	**4,000**	**4,500**	**3,500**	**17,000**

Appendix 6d. Estimated coal resources in maximum overburden categories by 7.5′ quadrangle.

7.5′ quadrangle	Maximum overburden (ft)					Total
	0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	
Breeze Mountain	410	780	310	0	0	1,500
Castor Gulch	880	580	0	0	0	1,500
Craig	21	310	610	690	1,000	2,700
Hamilton	19	0	0	0	0	19
Hayden	310	190	480	0	0	980
Hayden Gulch	110	0	0	0	0	110
Hooker Mountain	0	2	11	0	0	13
Horse Gulch	370	290	520	26	0	1,200
Lay	49	34	67	33	0	180
Lay SE	33	120	640	1,300	340	2,400
Mount Harris	12	19	22	0	0	53
Pagoda	0.25	0	0	0	0	0.25
Pine Ridge	0	0	150	960	1,400	2,500
Ralph White Lake	0	44	610	940	630	2,200
Rock Spring Gulch	0	0	42	510	160	710
Round Bottom	310	570	530	23	0	1,400
Total	**2,500**	**3,000**	**4,000**	**4,500**	**3,500**	**17,000**

Appendix 6e. Estimated coal resources in maximum overburden categories by township.

Township	Maximum overburden (ft)					Total
	0-500	500-1,000	1,000-2,000	2,000-3,000	>3,000	
4N 90W	0.02	0	0	0	0	0.02
4N 91W	19	0	0	0	0	19
5N 88W	240	36	0	0	0	270
5N 89W	280	73	0	0	0	350
5N 90W	140	0	0	0	0	140
5N 91W	7.1	0	0	0	0	7.1
5N 92W	73	5.3	0	0	0	78
6N 88W	20	53	230	25	0	330
6N 89W	23	240	620	50	0	930
6N 90W	540	890	250	0	0	1,700
6N 91W	550	850	190	4.6	0	1,600
6N 92W	220	370	700	150	0	1,500
6N 93W	340	260	410	28	0	1,000
7N 89W	0	0	81	830	400	1,300
7N 90W	0	14	550	830	640	2,000
7N 91W	0	28	330	540	1,200	2,100
7N 92W	0	0	13	1,000	1,100	2,100
7N 93W	67	140	620	1,000	210	2,100
8N 90W	0	0	0	0	0.14	0.14
Total	**2,500**	**3,000**	**4,000**	**4,500**	**3,500**	**17,000**

Appendix 7—ArcView Project for the Yampa Coal Field, Northwestern Colorado

The digital files used for the coal resource assessment of the Yampa coal field are presented as views in the ArcView project.

The ArcView project and the digital files are stored on both discs of this CD-ROM set—Appendix 7 of chapter P resides on both discs. Persons who do not have ArcView 3.1 may query the data by means of the ArcView Data Publisher on disc 1. Persons who do have ArcView 3.1 may utilize the full functionality of the software by accessing the data that reside on disc 2. An explanation of the ArcView project and data library—and how to get started using the software—is given by Biewick and Mercier (chap. D, this CD-ROM). Metadata for all digital files are also accessible through the ArcView project.

Appendix 8—Stratigraphic Database for the Yampa Coal Field, Northwestern Colorado

Appendix 8 contains the database used to asses coal resources in the middle and upper coal groups in the Yampa coal field. The location, lithologic, and stratigraphic data are available in ASCII format, DBF, and Excel spreadsheet files on disc 2 of this CD-ROM.

Click on image below to bring up high-resolution image of plate 1.

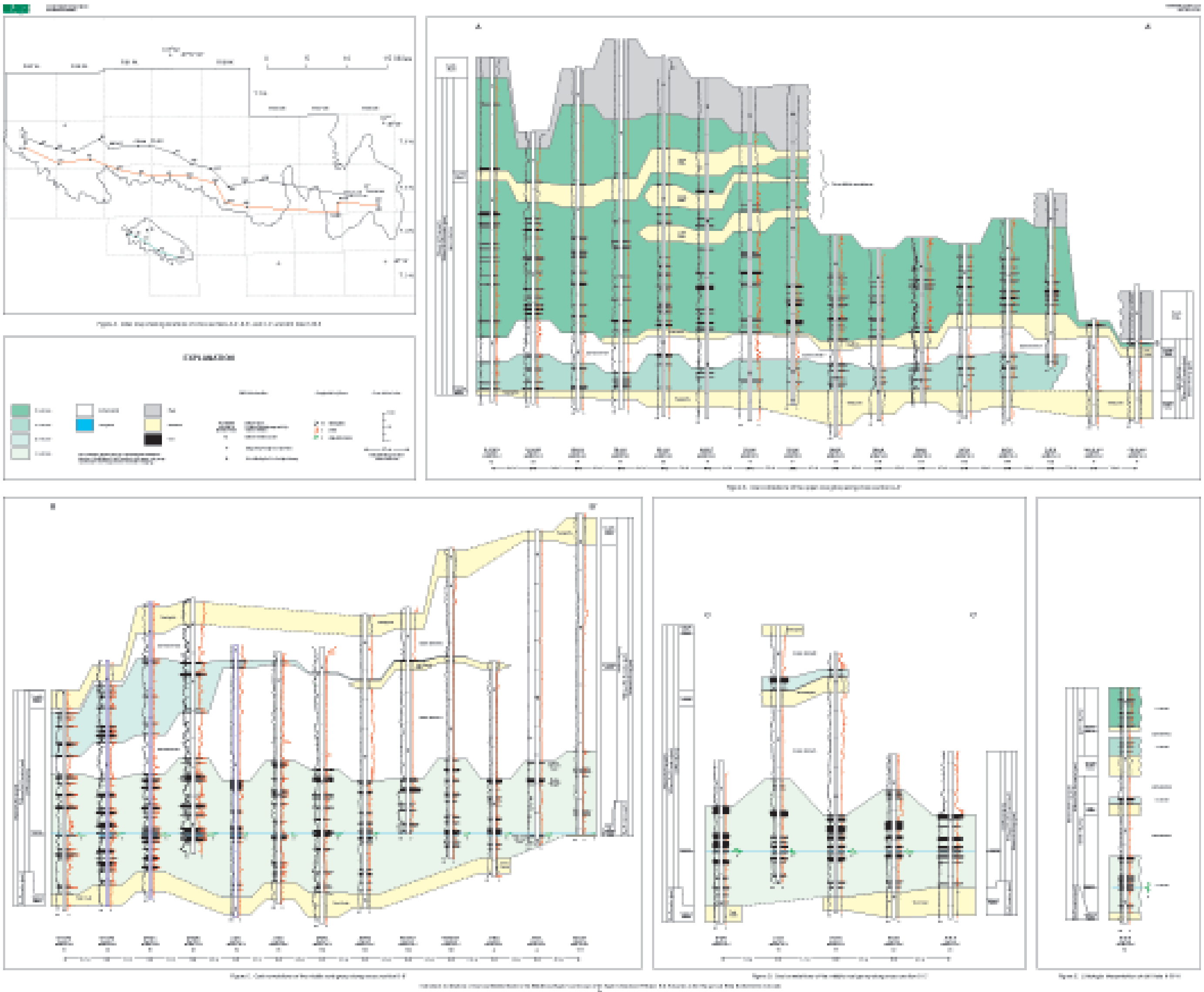
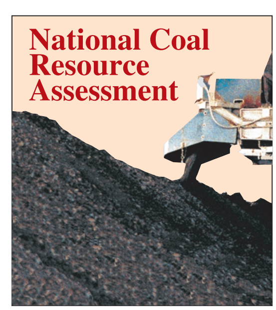


Plate 1. Subsurface correlations of coal and related rocks in the middle and upper coal groups of the Upper Cretaceous Williams Fork Formation in the Yampa coal field, northwestern Colorado.



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