Coal Availability of the Fort Union Formation in the Great Divide and Washakie Basins, South-Central Wyoming

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Cover photo: Lower Fort Union Formation coal beds on the eastern margin of the Great Divide Basin, Wyoming.

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ABSTRACT

The Paleocene Fort Union Formation in the eastern Greater Green River Basin of Wyoming contains extensive deposits of thick, subbituminous coal at relatively shallow depths. To determine the mineability of these coals in the Washakie and Great Divide basins, two sub-basins of the eastern Greater Green River Basin, Fort Union coal beds were correlated using a combination of coal bed outcrops and subsurface geophysical log data. Coal outcrops on the eastern side of the basins were correlated to exposures on the basins' western margins, establishing the spatial extent and thickness of more than 80 individual coal beds. Coal beds were combined into coal groups to account for regional name variations and approximate stratigraphic equivalence. The 12 thickest and most laterally extensive coal groups were modeled for areal distribution, bed thickness, and overburden thickness. The results were used to estimate original, economic, and available coal resources for the Washakie and Great Divide basins. Model results indicate 159.3 billion short tons (BT) of original coal, of which 89.1 BT are considered economic. Results also suggest approximately 82.3 BT of recoverable coal; of that, 3.5 BT is surface mineable, and the remaining 79.1 BT is potentially underground mineable.

INTRODUCTION

The Wyoming State Geological Survey (WSGS) completed an assessment of the available coal resources of the Paleocene Fort Union Formation in the eastern Greater Green River Basin (GGRB). Coal availability is defined as the volume of coal that can be economically extracted using current mining technology minus coal volumes restricted by land use regulations (Eggleston and others, 1990).

Although coal has been mined in the GGRB for more than 150 years, Fort Union Formation coal did not become a main target for production until the 1970s. Most mining activity has been located around the Rock Springs Uplift, and currently three mining operations produce coal from the Almond and Fort Union Formations along the eastern Rock Springs Uplift. In 2017, these three mining operations extracted 6.7 million short tons (MT) of coal along the eastern Rock Springs uplift from the Almond and Fort Union formations (Wyoming State Inspector of Mines, 2018).

This study estimates the volume of mineable coal within the Fort Union Formation in the Great Divide and Washakie basins (fig. 1) based on comprehensive correlations of Fort Union coal beds. The WSGS generated these new correlations using coal depth and thickness data obtained from surface mapping, subsurface geophysical logs from oil and gas boreholes, and mine exposures. Coal volume, thickness, and depth estimates contained in this

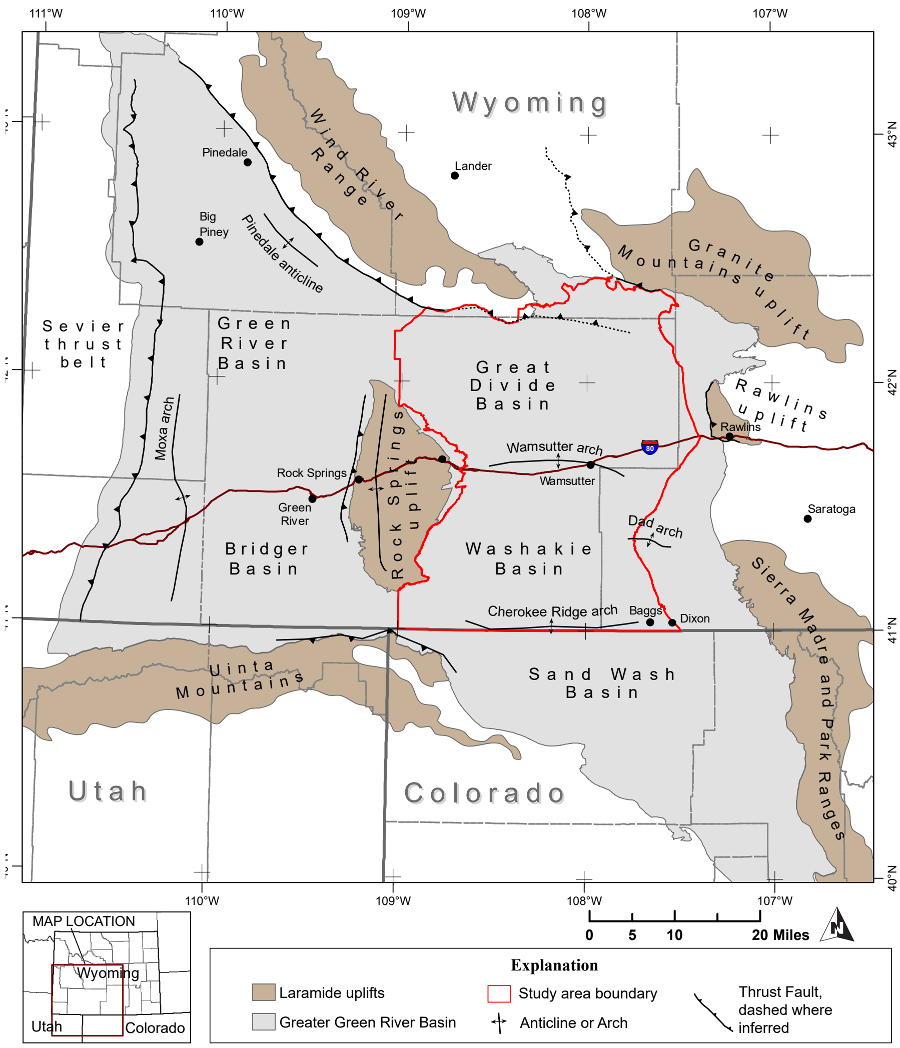

Figure 1. Location map of the Great Divide and Washakie basins study area within the Greater Green River Basin, (Southwestern Wyoming Province of the U.S. Geological Survey, 2003), Wyoming, Utah, and Colorado. Study area boundary in red. Modified from Lynds and Lichtner (2016).

coal resource assessment provide regulatory agencies, scientists, landowners, and energy industry representatives with the information required for a first-order assessment of the viability and potential impacts of future coal development.

COAL RESOURCES IN THE GREATER GREEN RIVER BASIN

Coal Mining

Historic

The occurrence of coal in the GGRB was first documented in the late 1840s by American surveyors. With the rise of the Overland Stage Route through southern Wyoming, coal was initially mined on a local scale to provide heat for stage stations and blacksmith shops along the trail (Gardner and Flores, 1989). Commercial coal mining in Wyoming began with the construction of the Union Pacific Railroad (UPRR) to supply coal to the steam-powered trains. In fact, the route of the new transcontinental rail line through southern Wyoming was influenced, in part, by the location of mineable coal deposits (Flores and Bader, 1999). In the past century and a half since commercial mining began in the eastern GGRB, coal was extracted from dozens of mines and prospects. The majority of activity was concentrated around the Rock Springs Uplift, although the Little Snake River coal field in the eastern Washakie Basin was also an area of historic activity (fig. 2). Most of the early mining in the GGRB targeted Cretaceous coal beds, but records indicate 17 historic mines within the Washakie and Great Divide basins that targeted Paleogene coals in the Fort Union and Wasatch formations.

Active

Three coal mines are currently active in the Washakie and Great Divide basins: Black Butte and Leucite Hills, Jim Bridger, and Bridger Underground (U.S. EIA, 2016).

The Black Butte and Leucite Hills mine (Black Butte) has supplied coals from the Fort Union, Lance, and Almond formations to the Jim Bridger Plant and other customers since 1979. The mine currently produces only from the Almond Formation and the Fort Union's "Black Rock" coal zone. This "Black Rock" coal zone contains the Leaf, Big Burn (Nuttal equivalent), Hail, Washout, and Little Valley (Lower Deadman equivalent) coal beds, in order of increasing depth. The Big Burn and Little Valley coals, up to 15 feet (ft) thick, are the thickest of the group. The Almond Formation coal produced at the mine is a high-volatile C bituminous coal, while the Fort Union Formation produces subbituminous B and C coals. The northern boundary of mineable coal for Black Butte is defined by a series of high-angle normal faults where the mineable coal beds are offset (Madden, 1989).

The Jim Bridger mine and Bridger Underground mine are part of the Bridger Mine Complex (Bridger), which supplies coal to the nearby Jim Bridger Plant, a mine-mouth, steam-turbine power station with a capacity of 2,120 megawatts (Jim Bridger Plant, 2011). Until 2004, the plant was supplied primarily by the Jim Bridger mine, which uses a combination of truck-shovel and highwall methods to mine from the Deadman coal zone in the Fort Union Formation. In 2004, PacifiCorp opened the Bridger Underground coal mine to supplement production at the surface mine. The underground mine is a longwall mining operation with an overburden depth of approximately 700 ft.

Coal Quality

Wyoming coal, including coal mined from the Black Butte and Bridger mines, has a competitive advantage over other state coal producers because the naturally occurring, low-sulfur coal is cheaper to burn without beneficiation or washing at power plants. Sale prices vary by coal quality, which affects the reserve value. Typically, the higher the gross calorific content and the lower the sulfur dioxide values, the higher the sale price (Luppens and others, 2015).

The U.S. Geological Survey (USGS) Coal Quality Database (COALQUAL; Bragg and others, 1998; Palmer and others, 2015) contains coal quality data from 47 Fort Union Formation samples obtained from the Great Divide and Washakie basins. These data show that the subbituminous Fort Union coals in this area have low sulfur concentrations, moderately low levels of ash, and moderate heat (gross calorific) values. Based in part on gross calorific values, apparent ranks of Fort Union coals in the eastern GGRB range from subbituminous A to C (ASTM D388, 2018). In general, gross calorific value content increases with depth. In the GGRB, subbituminous C coal (heating value, 19.3–22.1 MJ/kg [megajoules per kilogram]) occurs around the shallower basin margins. In contrast, subbituminous A coals (heating value, 24.4–26.7 MJ/kg) are found basinward at depths greater than 3,500 ft, making it uneconomic to mine. All of the Fort Union coals less than 3,500 ft deep are subbituminous in rank. Coal quality samples compiled by Jones (2010) indicate that the Deadman coal of the Fort Union Formation has an apparent rank of subbituminous B (heating value, 22.1–24.4 MJ/kg).

STUDY AREA

The 25,000-square-mile (mi^2) GGRB extends throughout southwestern Wyoming, northeastern Utah, and northwestern Colorado. The Wyoming portion of the GGRB is approximately 15,400 mi^2 in area. The GGRB is divided by the Rock Springs Uplift, separating the Green River and Bridger sub-basins to the west from the Great Divide and Washakie sub-basins to the east (fig. 1).

This report focuses on the area bounded by surface exposures of the base of the Fort Union Formation along the eastern and western margins of the Great Divide and Washakie basins, and from the Granite Mountains in the north to the Wyoming-Colorado state line.

The Great Divide and Washakie basins each exhibit unique surface features. Historically known as the Red Desert Basin, the Great Divide Basin is a topographic basin with interior drainage and is bounded on all sides by the Continental Divide. It is about 3,500 mi^2 in area (McCord, 1980) and is surrounded by the Rawlins Uplift to the east, the Granite Mountains to the north, the Wind River Range to the northwest, the Rock Springs Uplift to the west, and the Wamsutter Arch to the south.

The Washakie Basin is approximately 3,000 miles^2 in area (McCord, 1980; Tyler and others, 1995). Located south of the Great Divide Basin and the Wamsutter Arch, the Washakie Basin is bordered by the Cherokee Ridge Arch and Sand Wash Basin to the south, the Sierra Madre to the east, and the Rock Springs Uplift to the west.

Principal mineral resources in this area include natural gas, oil, coal, uranium (Veatch, 1907), oil shale, zeolites, and trona (McCord, 1980). Transportation corridors transect the GGRB, making these resources more attractive to mining—major petroleum pipelines, the UPRR, and U.S. Interstate Highway 80 (I-80) transect the basins west to east. Three coal-mining operations are near the railroad corridor at Point of Rocks, Wyoming. These mines account for about 2 percent of Wyoming's annual coal production.

General Geology

The Great Divide and Washakie basins are Laramide-aged structural and sedimentary basins flanked by Laramide uplifts (fig. 2). Phanerozoic sediments eroding from mountains that formed during the Sevier and Laramide orogenic events filled the basins (Blackstone, 1993). Near the end of the Mesozoic, the region became part of the Western Interior Foreland Basin and was submerged by the Western Interior Seaway. Transgressive-regressive cycles continued in the region through the end of the Cretaceous.

Structural development of the eastern GGRB began during the Campanian (Reynolds, 1976) and resumed during the Maastrichtian with a depocenter in the northeast part of the Great Divide Basin (Lynds and Lichtner, 2016). The Great Divide Basin is a northwest-trending, asymmetrical

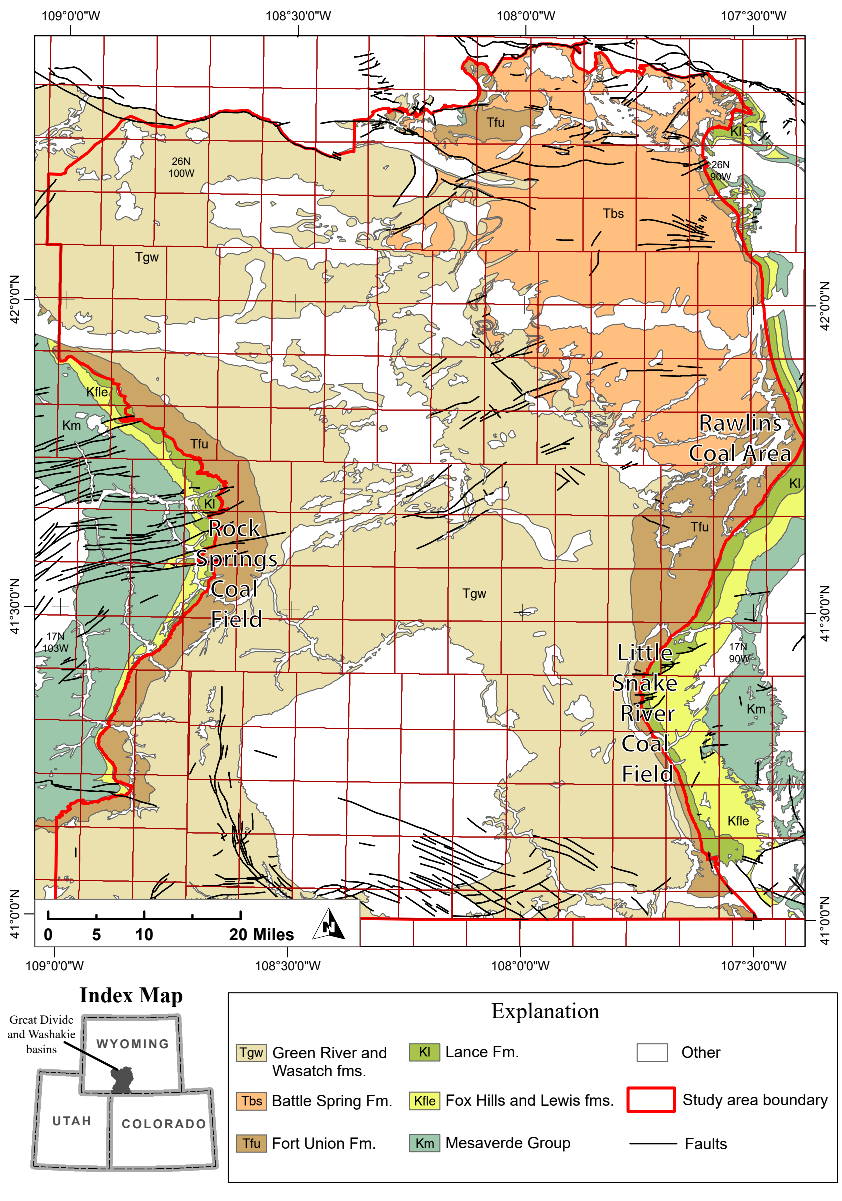

Figure 2. Geologic map of the Washakie and Great Divide basins (modified from Lynds and Lichtner, 2016). The study area boundary (in red) follows the Lance and Fort Union formations contact.

syncline with a steeper eastern limb and crystalline basement greater than 29,000 ft deep (22,000 ft below mean sea level [MSL]) in the synclinal axis. The Washakie Basin is also asymmetrical, with a steeper limb on the eastern side. Its axis trends north-northwest, and depth to basement rock is about 24,000 ft below the surface (17,000 ft below MSL; Blackstone, 1993).

Two large east–west-trending anticlines transect the study area. The Wamsutter Arch (fig. 1) is an anticline parallel to a trend of normal faults across the crest of the Rock Springs Uplift. Deformation along this arch has brought the basement to within 21,000 ft of the surface (Lynds and Lichtner, 2016). The Cherokee Ridge Arch is a fault-controlled anticline that separates the Washakie Basin from the Sand Wash Basin to the south.

Fort Union Formation

The Paleocene Fort Union Formation in the Great Divide and Washakie basins is formally divided into the uppermost Overland Member, the Blue Gap Member (Hettinger and Honey, 2005), and the lowermost China Butte Member (Honey and Hettinger, 2004; Hettinger and others, 2008; fig. 3). These names, used in previous studies for correlation across the Great Divide and Washakie basins (Lynds and Carroll, 2015; Lynds and Lichtner, 2016), are also used in this study. The coal-bearing Overland and China Butte members of the Fort Union Formation are the main focus of this report. The middle Blue Gap Member is not a focus of this study as it does not contain coal beds and is restricted to only the southeast portion of the study area.

The Fort Union Formation in the GGRB underlies the Eocene Wasatch and Battle Spring formations and overlies the Upper Cretaceous Lance Formation (fig. 3). The contact of the Fort Union Formation with the Wasatch and Battle Spring formations is unconformable in the Great Divide Basin (Pipiringos and Denson, 1970; Hettinger and others, 1991; Lynds and Carroll, 2015), while in the Washakie Basin, it occurs as both a conformable and unconformable contact (Mogensen, 1959; Honey and Hettinger, 1989).

The Fort Union Formation ranges in thickness from 1,500 to 1,600 ft along the southern margin of the Washakie Basin to approximately 5,200 ft in the northern part of the Great Divide Basin (Lynds and Lichtner, 2016). It is largely composed of sub-arkosic sandstone interbedded with siltstones, shales, and subbituminous coal (Carroll and others, 2015a, b) deposited in fluvial, paludal, and lacustrine environments (Lynds and Lichtner, 2016). Both the China Butte and Overland members of the Fort Union

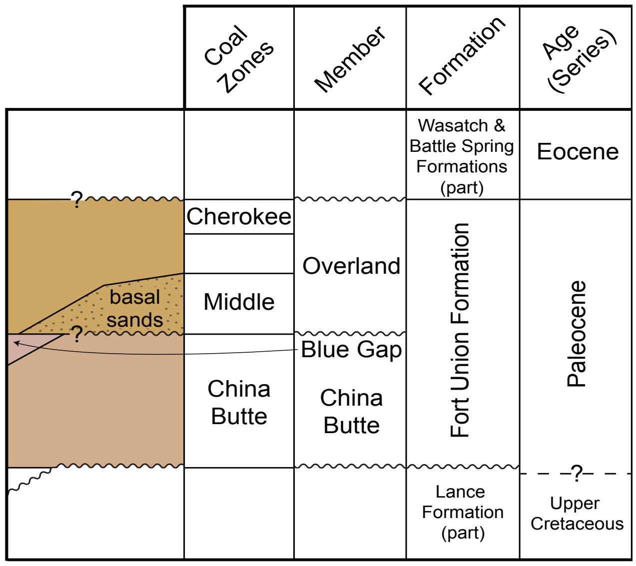

Figure 3. Stratigraphic chart of the Paleocene Fort Union Formation, members, and coal zones used in this study. Chart modified from Lynds and Lichtner (2016).

Formation are coal bearing, and they consist of numerous fining upward sequences that grade from medium- to fine-grained sandstone at the base, to siltstone, shale, and carbonaceous shale, with coal at the top of the sequence (Beaumont, 1979). These coals, correlative in zones, trend regionally for tens of miles across the study area.

Paleo-drainage patterns suggest two large fluvial systems in the Great Divide and Washakie basins during the Paleocene (Kirschbaum and others, 1994). Paleocene-aged rivers flowing northward from uplifts in central Colorado and southern Wyoming, and southeast-flowing rivers sourced along the Wind River Mountains, converged in the Great Divide Basin and flowed toward the east. These rivers deposited sands in successions that varied from braided to highly sinuous stream patterns (Flores, 2003).

Mountain building reshaped the landscape during the Paleocene, resulting in basin-wide shifts toward increasingly paludal settings. During this time, coal mires formed along lake margins and between river channels, resulting in the thick peat accumulations that became the coal deposits of the Fort Union Formation (Flores and others, 1997).

Post-depositional removal of the Fort Union Formation occurred on the northeastern side of the Great Divide Basin where the Eocene Battle Spring Formation excavated a trough into the upper part of the Fort Union Formation (Lynds and Carroll, 2015; Lynds and Lichtner, 2016).

Coal Stratigraphy

Overland Member Coals

The youngest Fort Union Formation coals are in the Cherokee coal zone of the upper Overland Member. Sanders (1974, 1975) and Edson (1979) originally described this coal zone as the upper coals of the Fort Union Formation. It was later renamed the Cherokee coal zone by Hettinger and others (1991). These coals are exposed in the eastern side of the study area but are not observed in outcrop on the western margin. The primary coal beds of this member include the upper, main, and lower Cherokee coals, and the Cow Butte and Horse Butte coals. The uppermost coals of the Cherokee coal zone are the Scotty Lake coals, which occur only in the subsurface in the northern part of the study area.

Within the basal sands of the lower Overland Member is the Middle coal zone. In this zone is a thick, contiguous coal bed referred to in this report as CB700, which serves as a reliable subsurface marker. Multiple coal beds that are thinner and less contiguous than CB700 are also identified in this coal zone, named Fort Union 13, Fort Union 14, Fort Union 15, Middle Fort Union, and Lower Middle Fort Union coal beds.

China Butte Member Coals

The China Butte Member contains an abundance of coal beds, some of which are the thickest and most laterally contiguous coals in the study area. The Deadman coal zone within this member contains important coal marker beds, including the Deadman, Big Red, Fillmore Ranch, and Baggs coal beds. These ubiquitous coals can be correlated over a large portion of the study area. The Deadman coal bed and its partings are exposed along the western margin of the study area, and are mined at the Black Butte and Bridger mines. The lower part of the Deadman coal zone correlates to the Little Valley coal beds south of the Black Butte Mine (Roehler, 1978a). Beneath the Deadman coal zone in the lower China Butte member are the Separation Creek, Riner, Olson Draw and Red Rim coals, which are fairly continuous throughout the study area.

METHODS

The Kentucky Geological Survey and the USGS in the late 1980s developed a methodology to assess coal availability for production. This assessment tool was first applied in a series of joint pilot studies in the central Appalachian region (Carter and Gardner, 1989; Eggleston and others, 1990). The methodology was adopted for this study.

This section describes the methods used to develop coal bed correlation charts, isopach and overburden maps, and calculate available coal resources. Coal beds were identified from and correlated between geophysical well logs. Data from interpretations of coal bed depth and thickness were then used in a geospatial data model to generate overburden and isopach maps, which were in turn used to model coal availability throughout the study area.

Resource Definitions

The USGS-U.S. Bureau of Mines coal resource classification system puts coal into reliability categories (fig. 4) based on the geologic probability of coal in-place and incorpo-

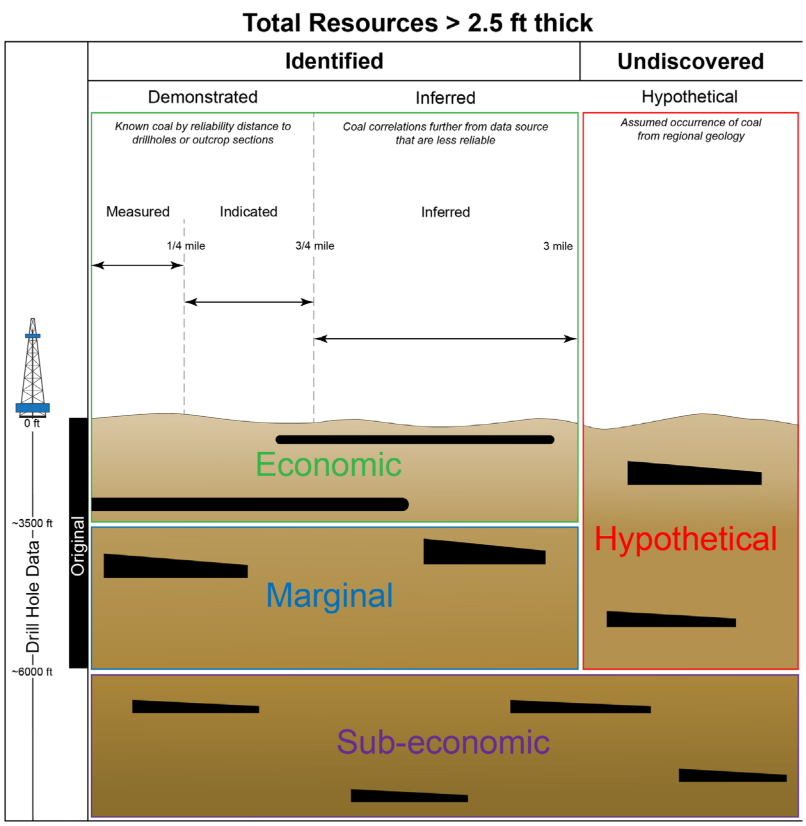

Figure 4. USGS-U.S. Bureau of Mines coal resource classification system. Coal beds are defined as measured, indicated, or inferred depending on distance from a reliability point. For this study, the economic coal depth was extended to 3,500 ft to reflect modern mining methods (Luppens and others, 2009). Modified from Wood and others (1983).

rates an assessment of the economic feasibility of recovery (Wood and others, 1983).

Coal resources are initially categorized based on the proximity from a borehole or outcrop, known as a reliability point. There is higher confidence, or reliability, in data near a borehole or outcrop observation than in data farther away (figs. 4 and 5). These categories extend outward from the reliability point in all directions, except for measured sections, in which case the categories are truncated at the edge of the coal outcrop. Reliability categories for *identified* coal include *measured coal* (0–0.25 mi from the point of measurement), *indicated coal* (0.25–0.75 mi), and *inferred coal* (0.75–3.0 mi; Wood and others, 1983). *Hypothetical coal* is coal that may exist outside the 3-mi radius of identified coal resources. Measured coal represents the area with the best-known reliable coal resource. Together, measured and indicated coal represent demonstrated coal, also known as the demonstrated reserve base (DRB), a category commonly used for coal assessments.

The second tier of coal classifications is based on the economic significance of the coal. The classification system was designed to quantify the total amount of coal in-place before mining begins, known as original resource, which combines economic and marginal identified coals (Wood and others, 1983). In this report, economic coals are coals that have a bed thickness of at least 2.5 ft (for subbituminous coal) and occur at depths less than 3,500 ft. Marginally economic coals are coals with a minimum bed thickness of 2.5 ft and occur at depths between 3,000 and 6,000 ft.

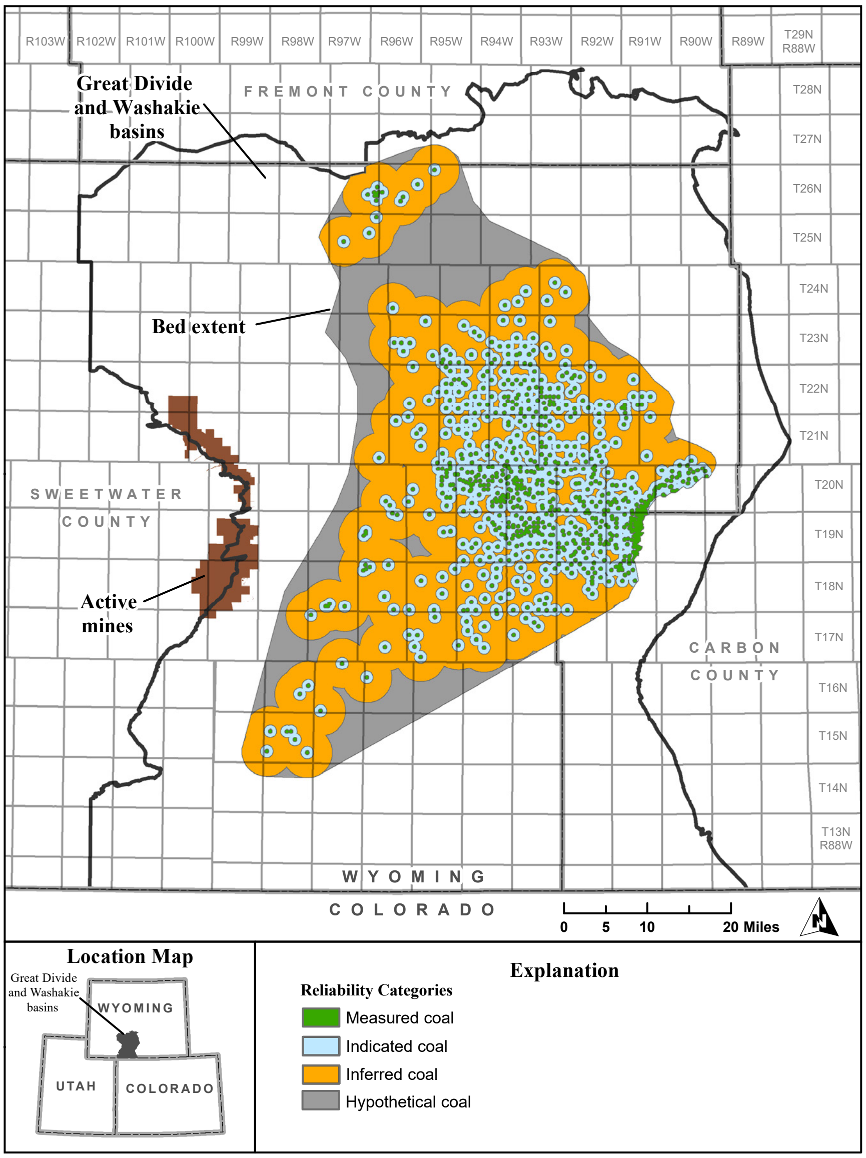

Figure 5. Example map showing reliability points and reliability categories for the Cherokee coal zone. Map includes coal bed areal extent and active coal mines.

Coal Bed Correlations

Coal bed correlations were developed using measured sections of surface and coal-mine exposures and geophysical log interpretations (reliability points; fig. 6). These data were incorporated from geologic maps, resource maps, and publications by Roehler (1973a–b; 1974, 1977a–d, 1978a–b, 1979a–b), Dames & Moore Co. (1978; 1979a–i), Danilchik (1978), Edson (1979), Madden (1989), Hettinger and Honey (2005; 2006), Hettinger and others (2008), Jones (2010), Jones and others (2011), Gregory and Bagdonas (2012), Carroll and others (2015b), Lynds and Carroll (2015), Lynds and others (2015), Carroll and others (2016), Gregory and others (2016), and Lynds and Lichtner (2016).

The lateral and vertical extents of the Fort Union coal beds in the subsurface were defined by correlating geophysical logs from hydrocarbon wells within an IHS Petra 4.2.11 relational database. Fort Union coal beds and zones were named using regional nomenclature from the USGS (Hettinger and others, 2008), with modifications by the authors and J. Haacke (written commun., 2014; 2018). Correlations and names of coal beds were assigned based on their stratigraphic position relative to formation contacts and coal bed partings. The Fillmore Ranch coal (of the Big Red coal group) was used as the main correlation control across the study area because it extends from north to south for more than 82 mi.

The stratigraphic well correlations used in this report are part of a larger dataset available through the USGS's National Coal Resources Data System. The Wyoming dataset can be accessed and downloaded from the WSGS website or the USGS website.

Isopach and Overburden Analysis

Coal bed thickness, bed extent, and overburden were modeled for 12 coal groups, selected based on average thickness and lateral coverage. Where applicable, coal beds with different regional names, but presumed stratigraphic equivalence, were included in each coal group. More than 5,000 points of surface and subsurface data were used for these resource calculations. Models were constructed and operated utilizing ESRI ArcGIS version 10.3.1 with an ArcInfo license, 3D Analyst and Spatial Analyst extensions, in Universal Transverse Mercator map projection, zone 13, and datum NAD83.

Bed extents were developed for each coal group using the 3-mi reliability area of the data extent, which was modified by outcrop information and manually adjusted based on known structural basin trends. A digital elevation model was used in calculating the surface locations of the wells, measured sections, and overburden thickness. Utilizing the bed extents, reliability points, and elevation model, the isopach and overburden models were created for each coal zone using a gridded interpolation. Structure contours were then created for visual analysis and the coal bed models used for coal availability calculations.

Coal Availability Assessment

Coal Resource and Reserve Calculations

Coal resources were calculated from the results of coal group isopach and extent modeling. Geometric calculation and overlay analysis were used to determine the area and volume of the total coal resource within each coal group bed extent. An average density factor for subbituminous coals of 1,770 tons per acre-foot (Wood and others, 1983) was used to convert the coal volumes to weight (short tons).

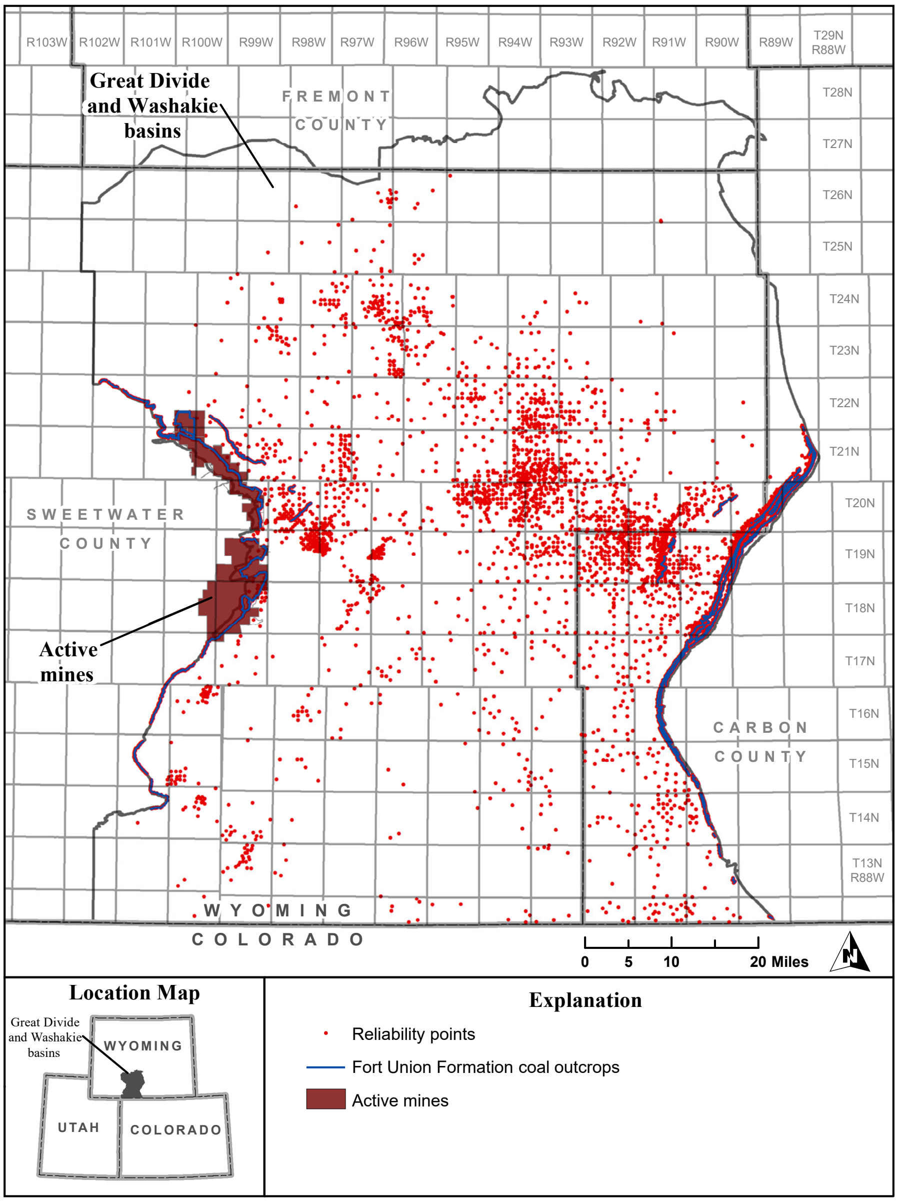

Figure 6. Map of the study area showing the distribution of reliability points for Fort Union coal beds, Fort Union coal bed outcrops, and active coal mines.

Resources in the modeled coal groups were classified as economic, marginal, sub-economic, or hypothetical (modified from Wood and others, 1983).

In this report, the depth to economic coal is extended to 3,500 ft to reflect improvements in mining technology (Luppens and others, 2009). Coal resources at depths between 3,500 ft and 6,000 ft below the surface are considered marginal. Coals deeper than 6,000 ft are classified as sub-economic to mine. Coals thinner than 2.5 ft thick were modeled and are included in the total resource model but are not included in the resource type categories (i.e. economic, marginal).

Further refinements were made to classifications to identify the potential mineability of coals using either surface or underground methods. Subsurface coal resources are extracted by shallow or deep underground mining techniques, depending on the depth of the coal. Shallow underground mineable coal beds are considered in this study to be greater than 5 ft thick and buried to depths of 500–2,000 ft; deep coals occur at depths between 2,000 and 3,500 ft. Coal groups were identified as measured, indicated, or inferred within the categories of surface-mineable or underground-mineable coal.

Volumes lost to land use, technological restrictions, and previous mining activity were subtracted from the economic coal calculated in each of the 12 modeled groups, producing the final calculation of recoverable coal for mining.

Restrictions to Mining

This resource analysis model takes into account land use and technological restrictions to mining (table 1, fig. 7). Restriction area data were obtained from the Bureau of Land Management, U.S. Department of Transportation, USGS, WSGS, Wyoming Department of Environmental Quality, U.S. Census Bureau, and Wyoming Oil and Gas Conservation Commission.

Mining exemptions are applied not only to the actual footprint of the exclusion, but also include a buffer distance mandated by state or federal regulation (table 1). For this

Table 1. Mining restrictions and buffer distances used for each exclusion. Modified from 43 Code of Federal Regulations (CFR) 3420.1–4 and 30 CFR 762.5.

Restriction category	Exclusion type	Buffer distance (ft)	Total width of right-of-way (ft)
Land use restrictions	Town, municipality	300	——
	Crucial stream corridors	100	——
	Alluvial valley floor	100	——
	Wilderness study areas	100	——
	Cemeteries	100	——
	Major highways	100	450
	Pipelines	100	——
	Dwellings, public buildings not in towns	300	——
	Railroads	100	600
	Gas processing plants	100	——
	Petroleum-produced water treatment plant	100	——
	Airports	300	——
	Lakes	100	——
Technological restrictions	Abandoned mines	200	——
	Faults	200	——
	Steeply dipping beds	50	——
	Active mine permit boundary	50	——
	Active underground mines	500	——

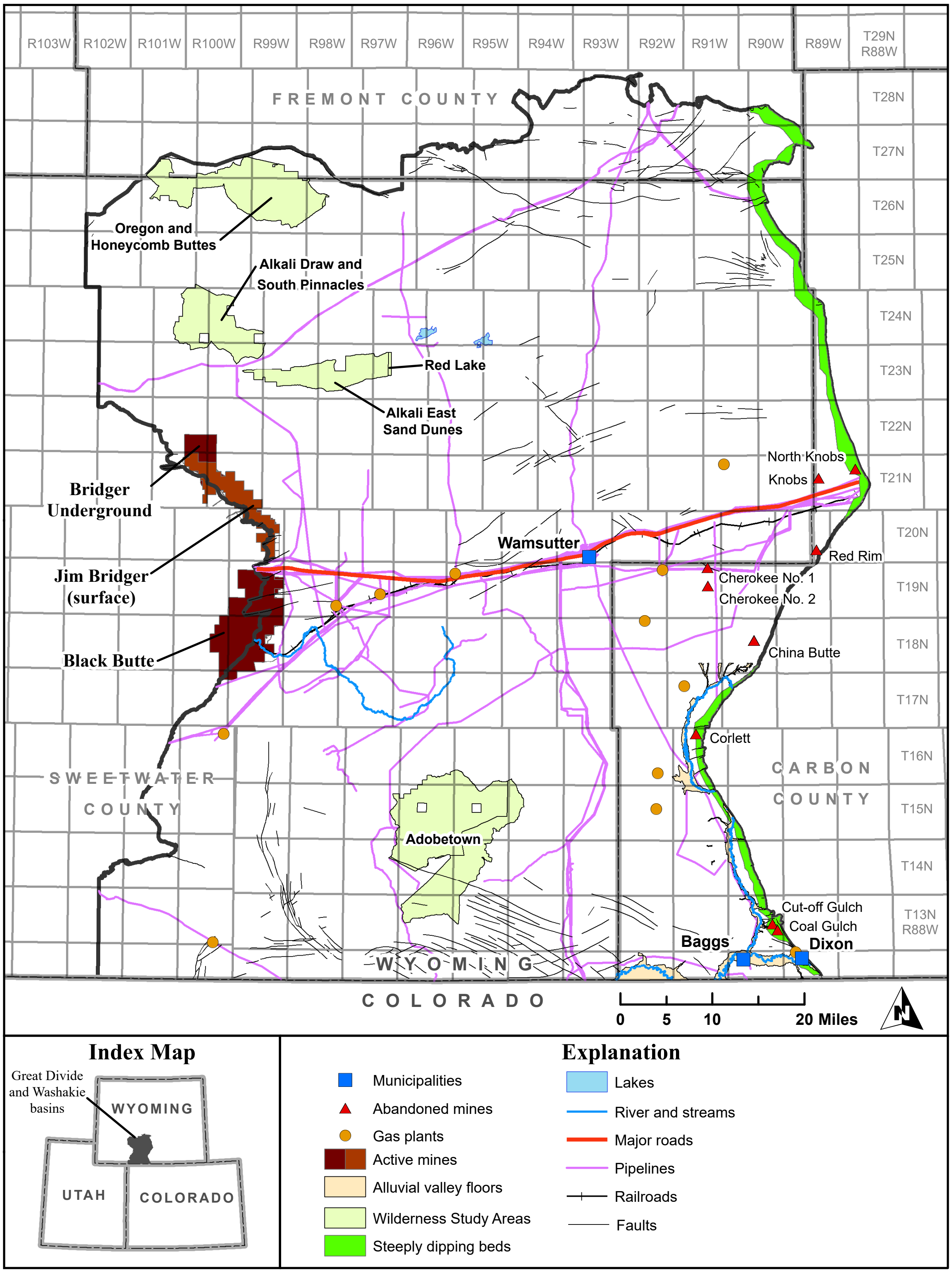

Figure 7. Map of land use and technological mining exclusion areas. Land use restrictions include I-80, UPRR corridor, major pipelines, natural gas processing plants, wilderness study areas, lakes, alluvial valley floors, and towns. Technological restrictions include steeply dipping beds, faults, and abandoned coal mines.

report, mining exclusions are considered vertical boundaries.

Land use restrictions limit mining to areas where operations will not interfere with vital infrastructure or harm vulnerable ecosystems. These include transportation, civic, and industrial infrastructure, in addition to riparian, lacustrine, and wilderness areas. Two examples of land use exclusions are the UPRR corridor, which cannot easily be relocated, or areas that cannot be easily reclaimed like the riparian areas along Muddy Creek.

Technological restrictions limit mining to areas where the coal can be safely extracted using present day mining technology. Regional faults (Love and others, 1993), steeply dipping bedding, and active or abandoned mines are considered to be technological exclusions (fig. 7). For both underground and surface mining, a dip of less than 5° is optimal for modern mining technology (Luppens and others, 2015). A dip of 20° or more can make coal mining very difficult, and areas with steeply dipping beds, for example along the Rawlins-Little Snake River coal field (Carroll and others, 2015b), were considered unmineable.

RESULTS AND DISCUSSION

Twelve coal groups were chosen for modeling from more than 100 individual coal beds identified in the study area. Detailed coal bed stratigraphic nomenclature charts were constructed for the Great Divide and Washakie basins using the regional coal correlations from this project (appendix).

Isopach and Overburden

Coal bed thicknesses and overburden in the 12 selected coal groups are shown in table 2, and a set of isopach and overburden maps are presented for each of the modeled coals (figs. 8–19). Where coals were considered too thin to mine (thinner than 2.5 ft), they are plotted on the isopach and overburden maps as white regions within the bed extent.

Cherokee Group

The Cherokee coal group includes the Cherokee coal bed and the equivalent Scotty Lake Main 2 coal bed (table 2), which occurs in the northwestern part of the study area. The Cherokee coal group is a subset of, and is not to be confused with, the Cherokee coal zone of the Overland Member referenced earlier and established by Hettinger and others (1991). The Cherokee coal group extends across the central part of the study area where the Overland Member is thickest (Lynds and Lichtner, 2016).

The correlated Cherokee coal group has an average thickness of 9 ft and in the northernmost Great Divide Basin reaches a maximum thickness of 49 ft (fig. 8). Depth to the top of this coal ranges from surface exposures on the eastern margin of the study area to more than 9,000 ft in the southernmost area of the coal's extent (fig. 8). The Cherokee coal group is shallowest near the Wamsutter Arch in the east-central portion of the study area and deepens to the north and south as it extends into the deeper parts of the Great Divide and Washakie basins. The Scotty Lake Main 2 coals in T. 26 N., R. 97 W. are very thick, but at depths greater than 3,500 ft they are too deep to mine.

Horse Butte Group

The Horse Butte coal group, composed of the Horse Butte coal, is correlative across the Great Divide and Washakie basins, and is exposed along both the eastern (Sanders, 1975; Edson, 1979) and western basin margins.

The average thickness of the Horse Butte coal group in the study area is 10 ft; maximum thickness is 23 ft in T. 22 N., R. 91 W. (fig. 9). Generally, the Horse Butte coal is thicker in the eastern part of its extent. The depth to the top of the Horse Butte coal ranges from surface exposures (T. 18 N., R. 99 W.) to more than 8,400 ft (T. 17 N., R. 99 W.; Roehler, 1977d) in the southwestern part of the study area (fig. 9).

CB700 Group

Informally named in this study, the CB700 coal group is the most regionally extensive Overland Member marker bed across the Great Divide Basin, occurring approximately 700 ft above the Big Red coal in the Middle coal zone. This thick, continuous coal is found primarily in the subsurface of the Great Divide Basin as well as in the northernmost Washakie Basin.

The average thickness of the CB700 coal group is 9 ft, and the maximum thickness is 21 ft (T. 23 N., R. 99 W.; fig. 10). The depth to the top of this coal ranges from 823 ft in T. 20 N., R. 99 W. to greater than 4,700 ft in T. 24 N., R. 96 W.

Upper Big Red Group

The Upper Big Red coal group includes the Upper Deadman and Upper Big Red coal beds. Correlatively the same, these two coals are the thickest splits off the Deadman coal zone exposed at the Bridger mines. The Upper Deadman coal at the Black Butte mine extends eastward for approximately 4 mi. It correlates to the Upper Big Red coal bed beyond that point.

Table 2. Modeled Fort Union coal groups in stratigraphic order, youngest to oldest. The thickest beds were selected for modeling each coal group. Although some beds may have different regional names, they are stratigraphically equivalent and were treated as a single coal bed for modeling purposes.

Modeled group	Correlated coal bed(s) used for model	Shallowest top (ft below ground level)	Deepest top (ft below ground level)	Average thickness (ft)	Maximum thickness (ft)	Number of point intercepts
Cherokee	Cherokee, Scotty Lake Main 2	0	9,000	9.3	49	1,058
Horse Butte	Horse Butte	0	8,420	9.9	22.7	1,107
CB700	CB700	823	4,767	9.2	21	927
Upper Big Red	Upper Big Red, Upper Deadman	0	6,872	8.7	34	495
Big Red	Big Red, Deadman, Fillmore Ranch, Baggs	0	12,400	10.8	46.2	1,683
Lower Big Red	Lower Big Red, Lower Deadman, Little Valley	0	10,125	7.6	24.3	586
Upper Little Valley	Upper Little Valley	0	4,800	4.3	16.4	113
Muddy Creek	Muddy Creek	0	13,600	6.8	32	1,438
Separation Creek B	Separation Creek B	0	10,000	6.1	26	793
Lower Riner	Lower Riner	0	9,400	7.5	39	900
Lower Olson Draw	Lower Olson Draw	0	7,135	5	26	307
Red Rim	Red Rim	0	14,415	6.2	43	964

The average thickness of the Upper Big Red coal group is 9 ft, reaching a maximum thickness of 34 ft in T. 21 N., R. 98 W. and T. 22 N., R. 100 W. (fig. 11). The majority of this coal is between 5 and 10 ft thick. Depth to the top of this coal group ranges from surface exposures in the southwestern part of the Great Divide Basin to more than 6,800 ft in the northern part of the study area (fig. 11).

Big Red Group

The Big Red coal group, the most laterally extensive coal of the Fort Union Formation, includes the correlated Deadman, Big Red, Baggs, and Fillmore Ranch coal beds. In the center of the study area, near the Wamsutter Arch, the Deadman coal correlates directly to the Big Red coal and to the Fillmore Ranch coal.

The Big Red coal group averages 11 ft thick, reaching a maximum thickness of 46 ft in the northwestern Great Divide Basin (T. 24 N., R. 98 W.; fig. 12). Depth to the top of this coal ranges from surface exposures on the eastern and western basin margins to 12,400 ft in the southwestern part of the study area (fig. 12).

Lower Big Red Group

The Lower Big Red coal group includes the Lower Deadman, Little Valley, and Lower Big Red coal beds.

The Lower Big Red coal group average thickness is 8 ft, and maximum thickness is 24 ft in T. 22 N., R. 98 W. (fig. 13). This coal group is thicker in the western part of the study area. The depth of the Lower Big Red coal group ranges from surface exposures to 10,250 ft in the southern part of the study area in T. 15 N., R. 99 W. (fig. 13).

Upper Little Valley Group

The Upper Little Valley coal group contains the Upper Little Valley coal. It is the least spatially extensive coal modeled and the only mineable coal resource in the southwest part of the study area. This coal is exposed in the Washakie Basin south of the Black Butte mine from T. 16 N., R. 101 W. to T. 12 N., R. 100 W. at the Colorado border.

The average thickness of this coal is 4 ft; the maximum thickness is 16 ft (fig. 14). The Upper Little Valley group ranges in depth from surface exposures to a maximum depth of 4,800 ft in T. 13 N., R. 99 W. (fig. 14).

Muddy Creek Group

The Muddy Creek coal group includes the Muddy Creek coal bed, which is pervasive throughout the eastern half of the study area in both the Great Divide and Washakie basins. It is exposed in the Rawlins coal area (T. 21 N., R. 89 W.) and in the Little Snake River coal field near Baggs (T. 12 N., R. 90 W.).

The average thickness of the Muddy Creek group is 7 ft and reaches a maximum thickness of 32 ft (fig. 15) in T. 22 N., R. 98 W. The depth to the top of this group ranges from surface exposures to 13,600 ft in T. 15 N., R. 97 W. (fig. 15).

Separation Creek B Group

The Separation Creek B coal group consists of the Separation Creek B coals, which occur stratigraphically beneath the Separation Creek 2 and above the Lower Separation Creek coals, and are approximately 150 ft beneath the Muddy Creek coal group. The Separation Creek B coal group extends from the northern Great Divide Basin southeast to the eastern edge of the study area. These coals crop out intermittently near Rawlins (T. 21 N., R. 89 W. to T. 19 N., R. 90 W.).

The average thickness of the Separation Creek B coal group is 6 ft, with a maximum thickness of 26 ft in T. 20 N., R. 93 W. (fig. 16). Depth ranges from surface exposures to 10,000 ft in T. 16 N., R. 96 W. (fig. 16).

Lower Riner Group

The Lower Riner coal group consists of the Lower Riner coal bed. This coal group occurs in the northern Washakie Basin and extends northeast across the Wamsutter Arch into the northern and eastern regions of the Great Divide Basin. Surface exposures are located between the Rawlins Uplift and Dad Arch on the eastern margin of the study area.

The average thickness of the Lower Riner group is 8 ft, reaching a maximum thickness of 39 ft in T. 20 N., R. 95 W. (fig. 17). The depth to the top of the Lower Riner group ranges from surface exposures to 9,400 ft at the southernmost part of its extent in the central part of the Washakie Basin (fig. 17).

Lower Olson Draw Group

The Lower Olson Draw coal group incorporates the Lower Olson Draw coal bed. These coals, part of the lower China Butte coal zone, occur in the Little Snake River coal field in the southeastern study area.

The average thickness of the Lower Olson Draw group is 5 ft, with a maximum thickness of 26 ft in T. 19 N., R. 93 W. (fig. 18). Depth to the top of the Lower Olson Draw group ranges from surface exposures on the southeastern margin of the study area to more than 7,100 ft in T. 13 N., R. 93 W (fig. 18).

Red Rim Group

The Red Rim coal group includes the Red Rim coal bed, one of the lowermost coals in the Fort Union Formation. This group extends from the Colorado border to the northern part of the Great Divide Basin, covering much of the eastern two-thirds of the study area. It is exposed intermittently along the entire Little Snake River coal field.

The average thickness of the Red Rim group is 6 ft, with a maximum thickness of 43 ft in T. 21 N., R. 90 W. where it dips 70° southwest (fig. 19). Depth to the top of the Red Rim coal group ranges from surface exposures to more than 14,000 ft in the southwestern portion of its extent (fig. 19).

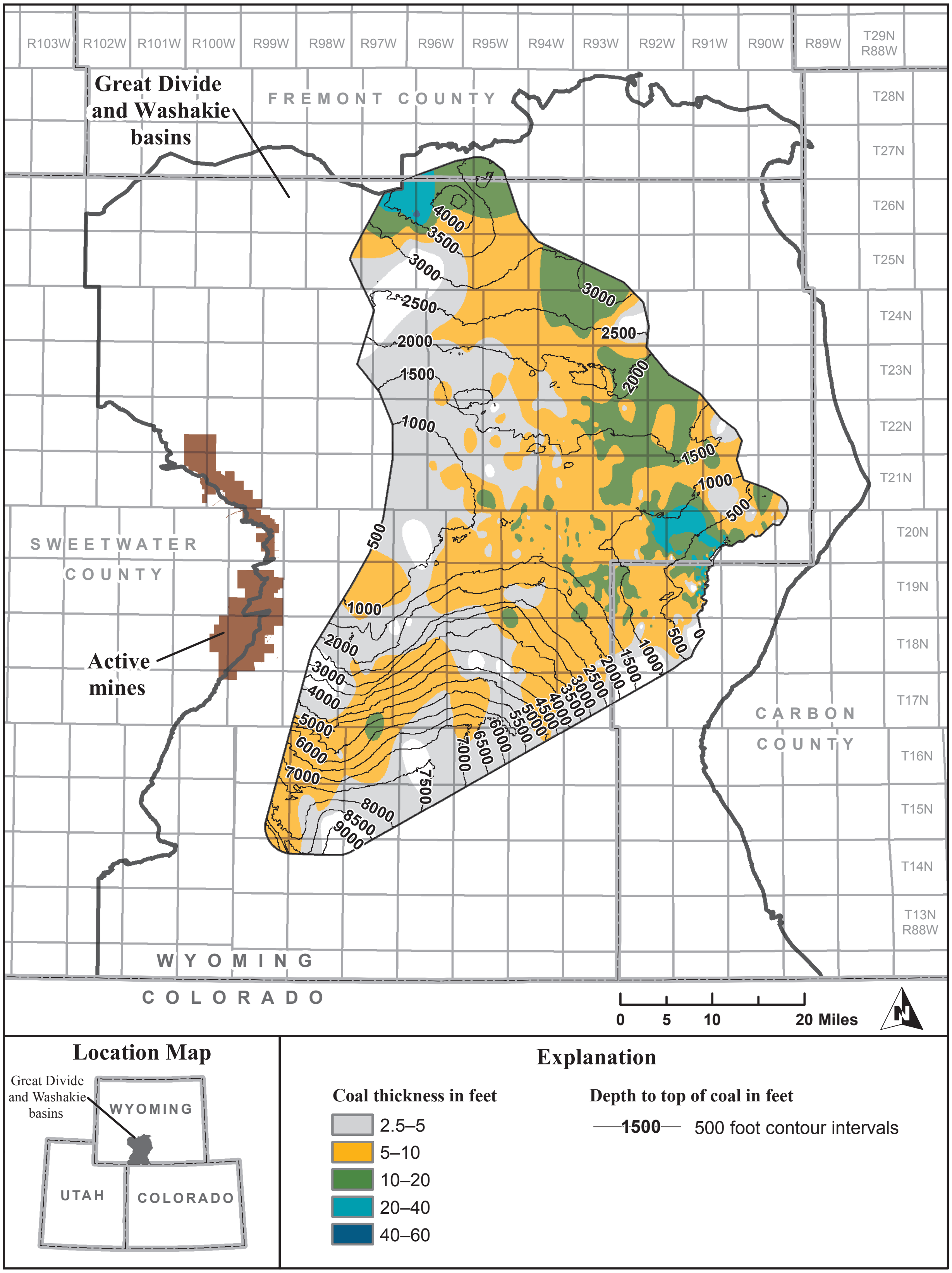

Figure 8. Isopach and overburden map for the Cherokee coal group, which includes the Cherokee and Scotty Lake Main 2 coal beds.

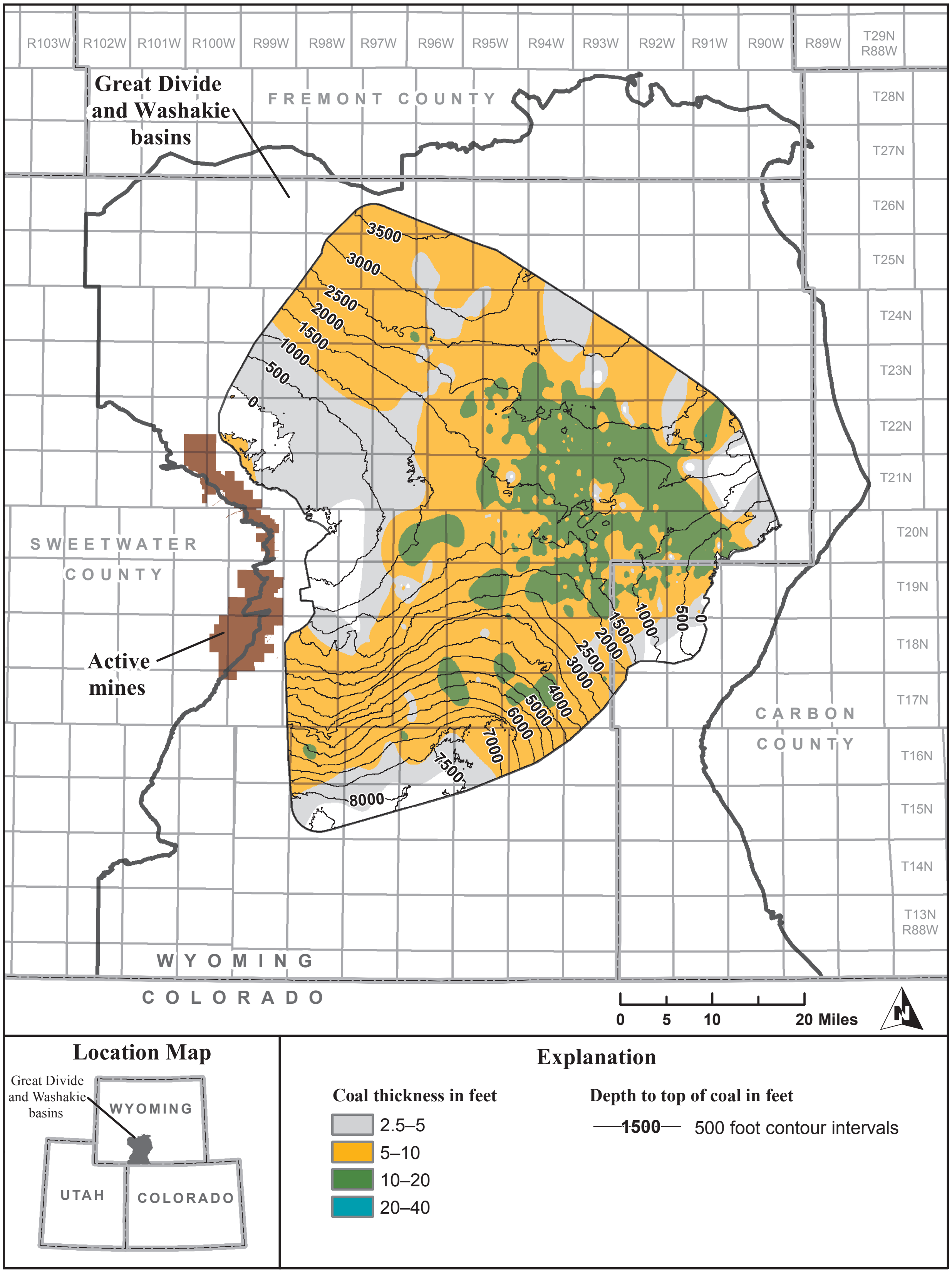

Figure 9. Isopach and overburden map for the Horse Butte coal group, which includes the Horse Butte coal bed.

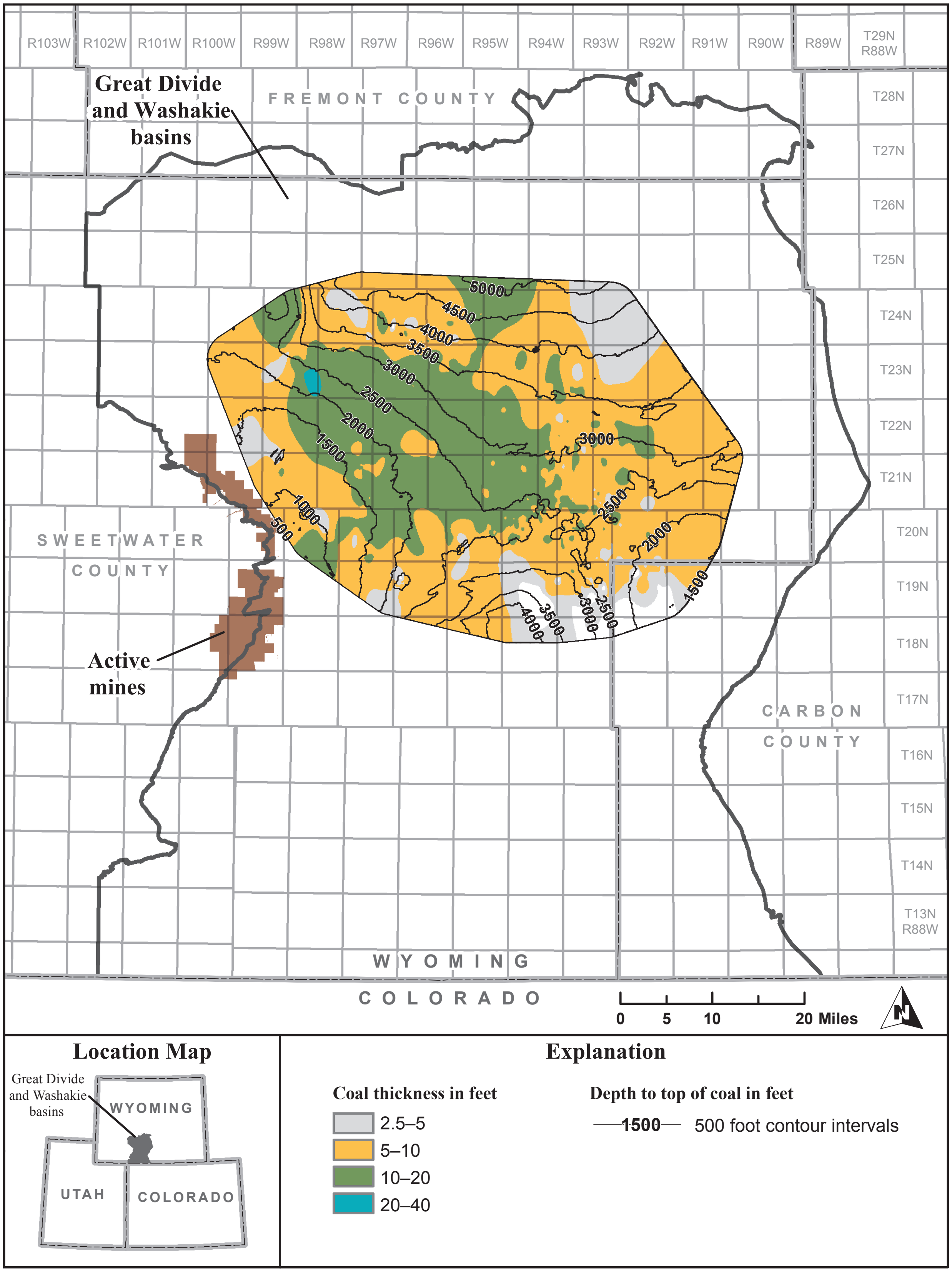

Figure 10. Isopach and overburden map for the CB700 coal group, which includes the CB700 coal bed.

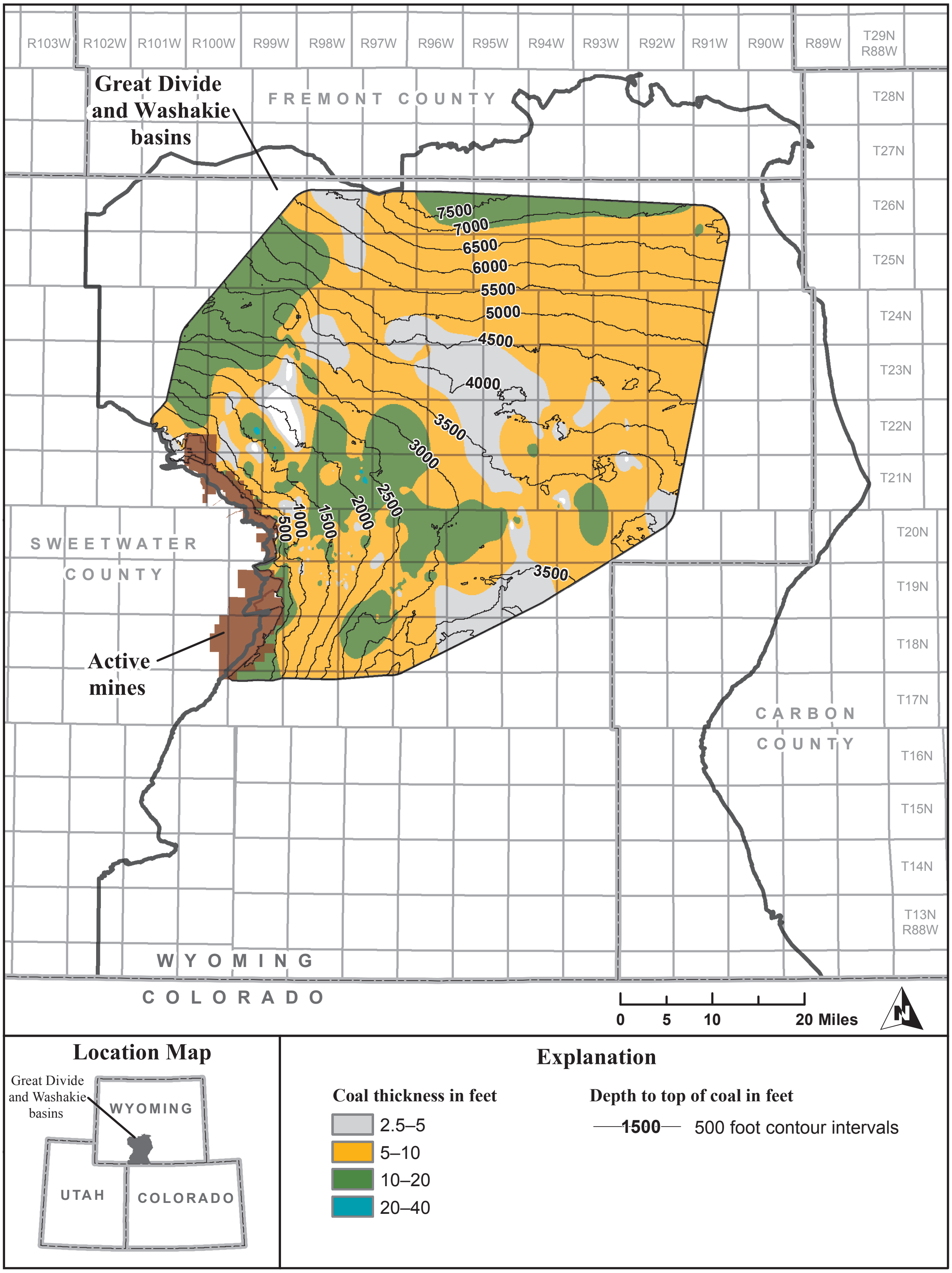

Figure 11. Isopach and overburden map for the Upper Big Red coal group, which includes the Upper Deadman and Upper Big Red coal beds.

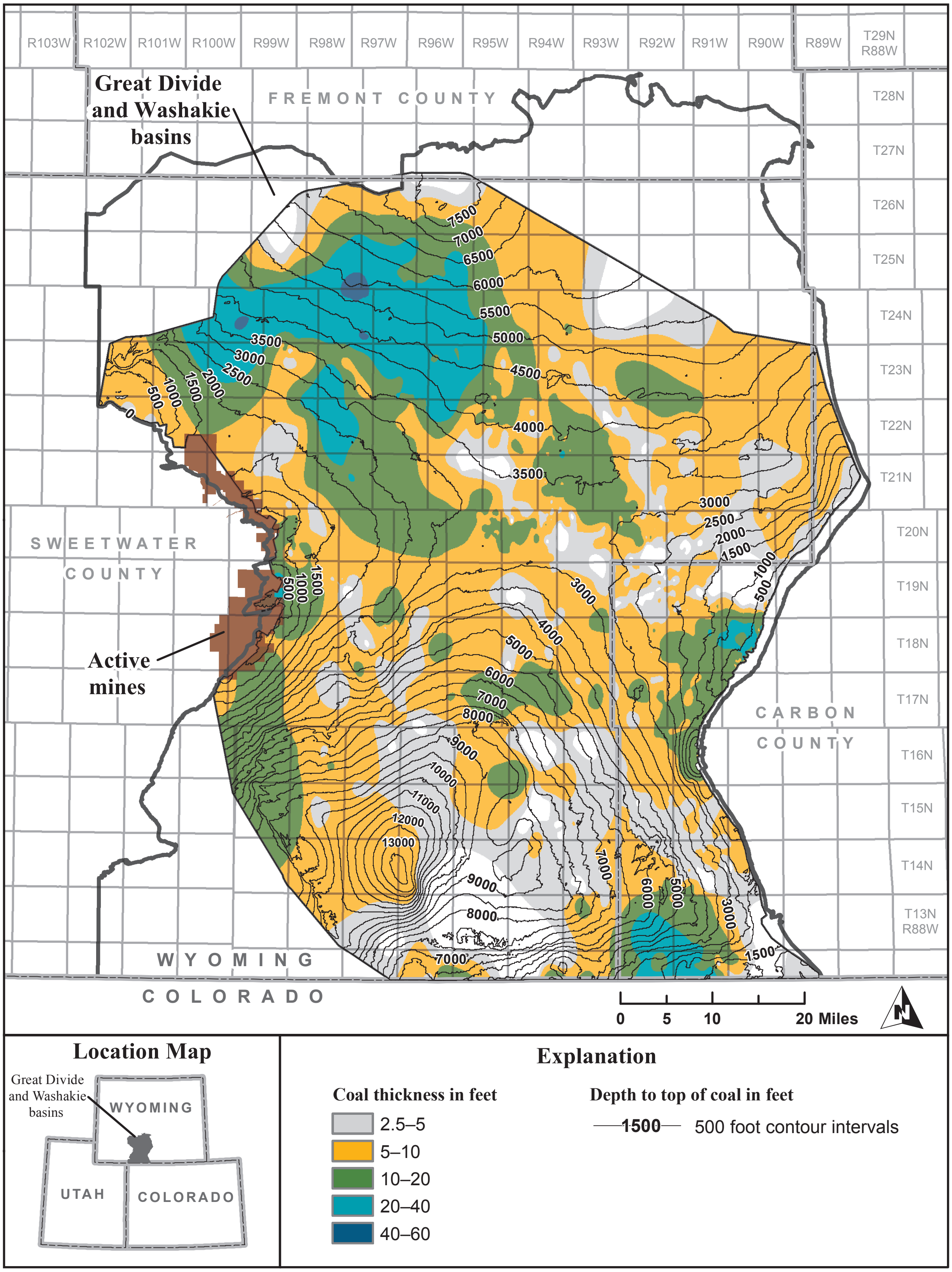

Figure 12. Isopach and overburden map for the Big Red coal group, which includes the Big Red, Deadman, Baggs, and Fillmore Ranch coal beds.

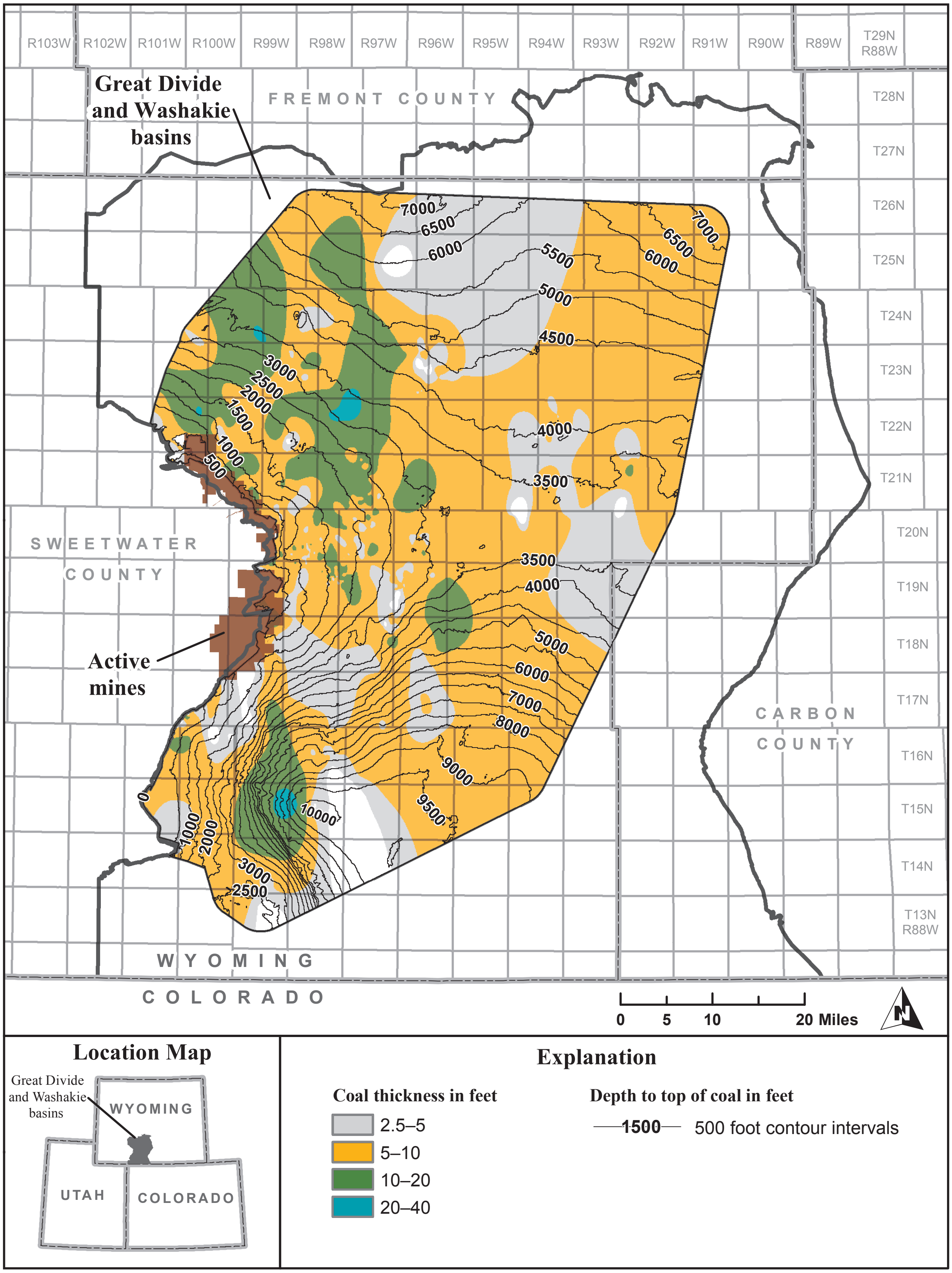

Figure 13. Isopach and overburden map for the Lower Big Red coal group, which includes the Lower Big Red, Lower Deadman, and Little Valley coal beds.

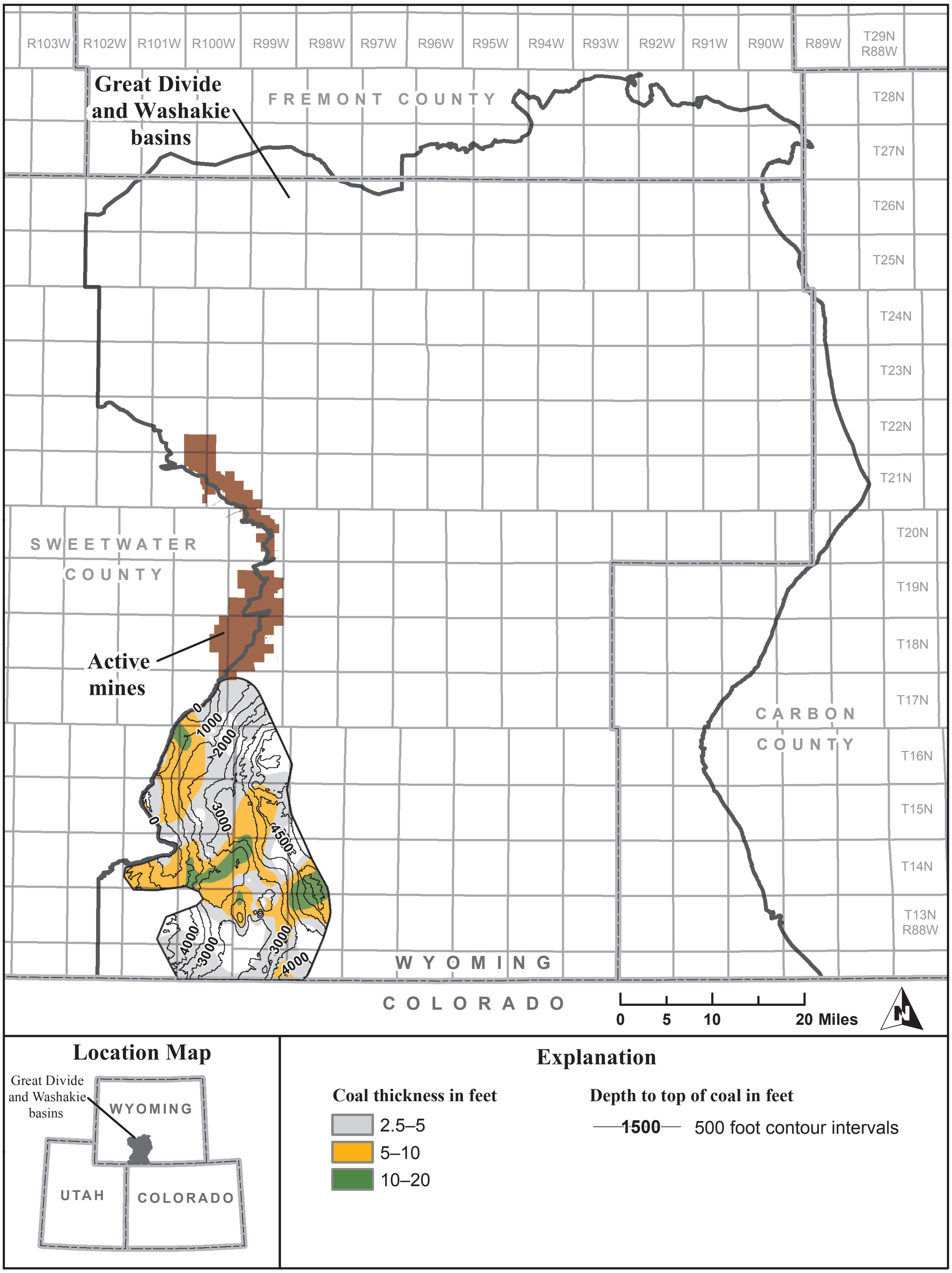

Figure 14. Isopach and overburden map for the Upper Little Valley coal group, which includes the Upper Little Valley coal bed.

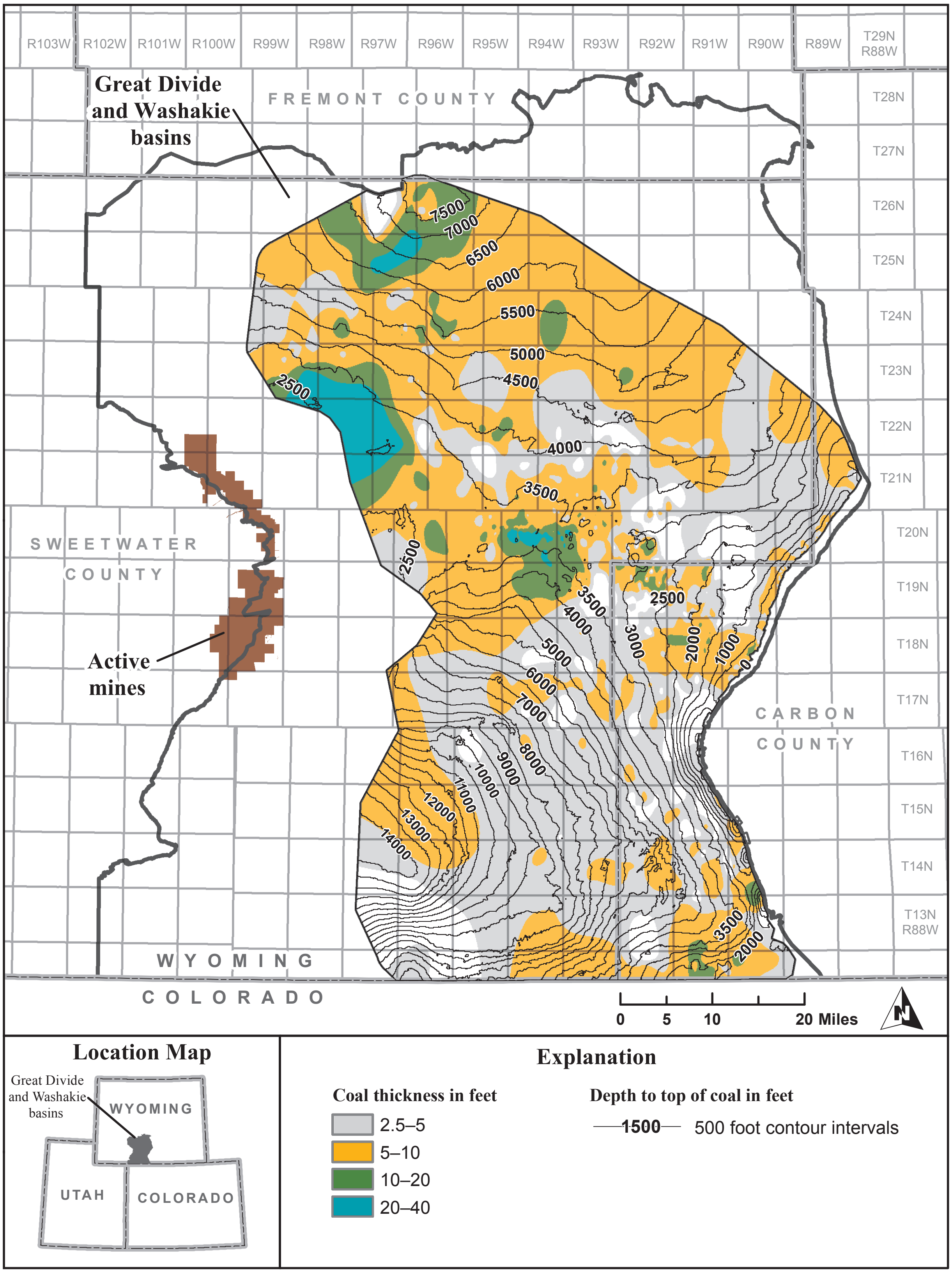

Figure 15. Isopach and overburden map for the Muddy Creek coal group, which includes the Muddy Creek coal bed.

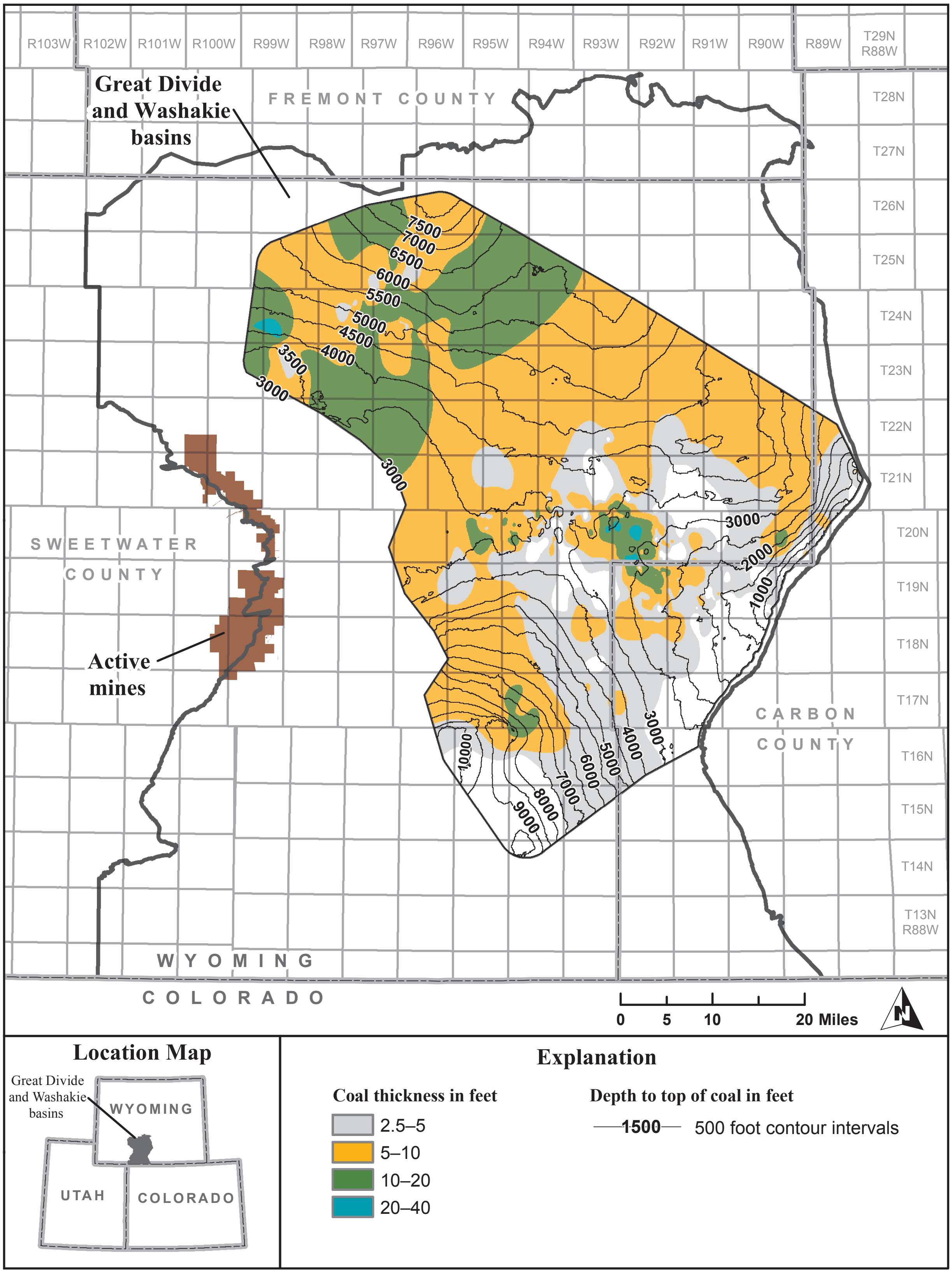

Figure 16. Isopach and overburden map for the Separation Creek B coal group, which includes the Separation Creek B coal bed.

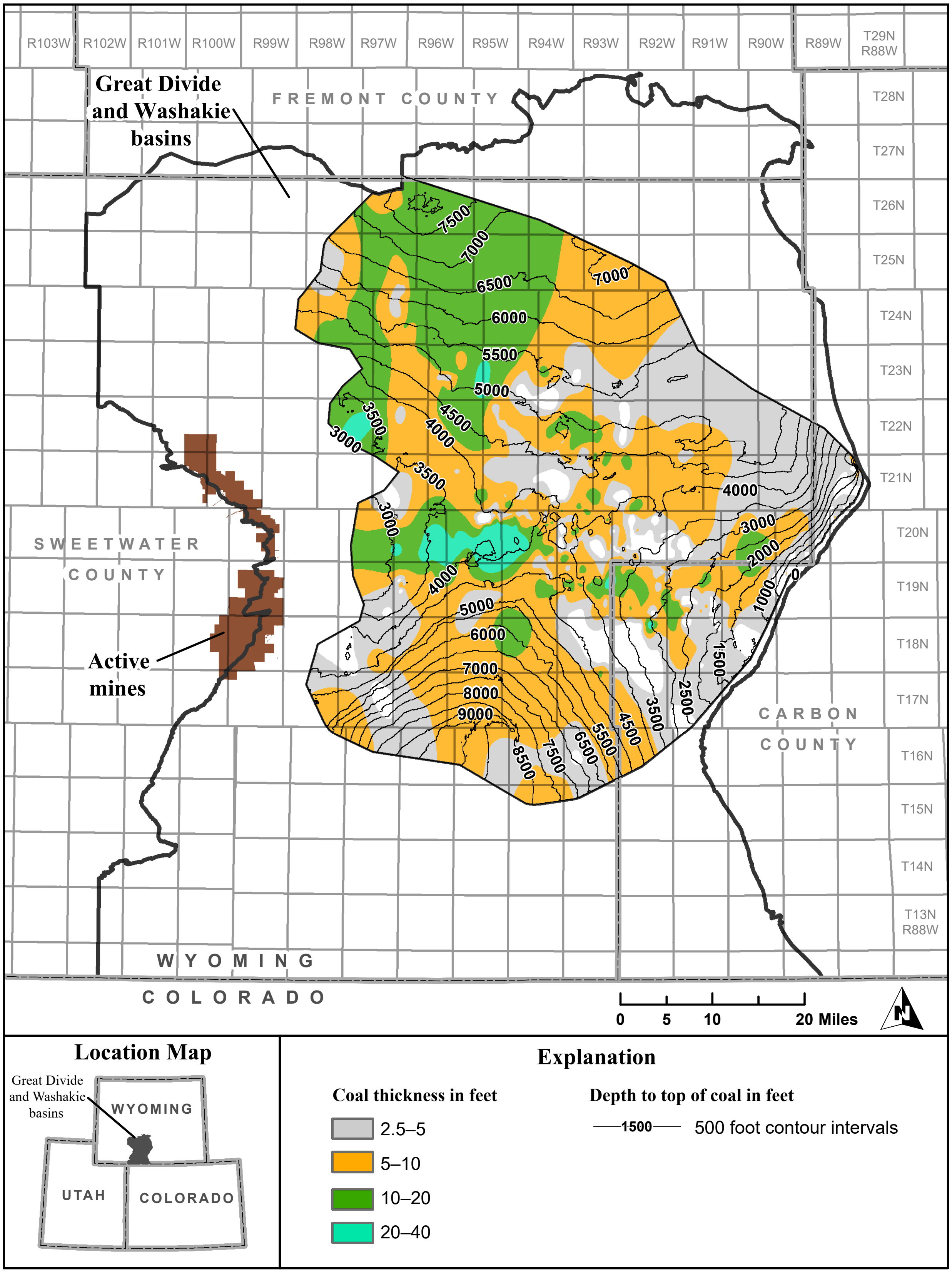

Figure 17. Isopach and overburden map for the Lower Riner coal group, which includes the Lower Riner coal bed.

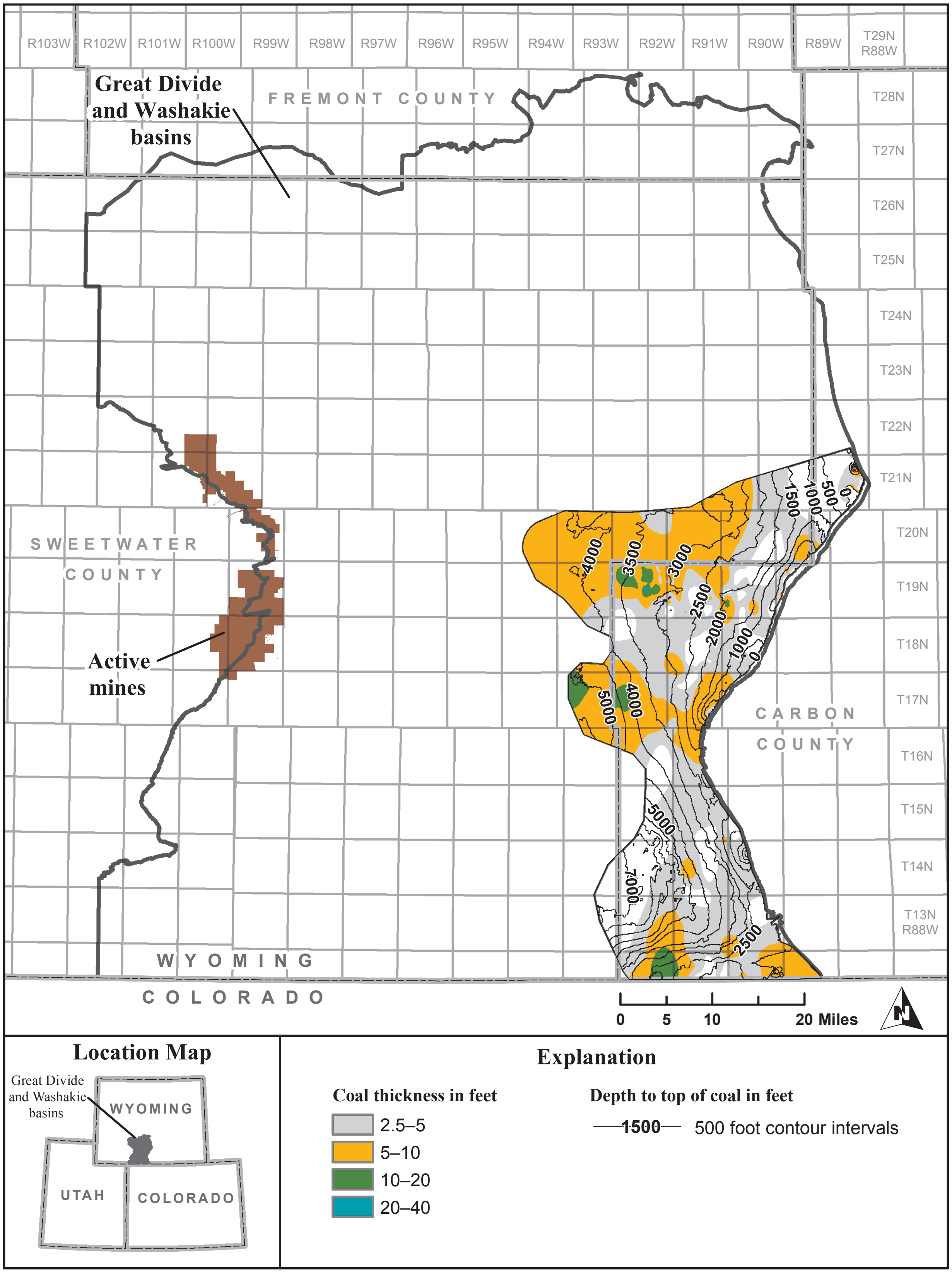

Figure 18. Isopach and overburden map for the Lower Olson Draw coal group, which includes the Lower Olson Draw coal bed.

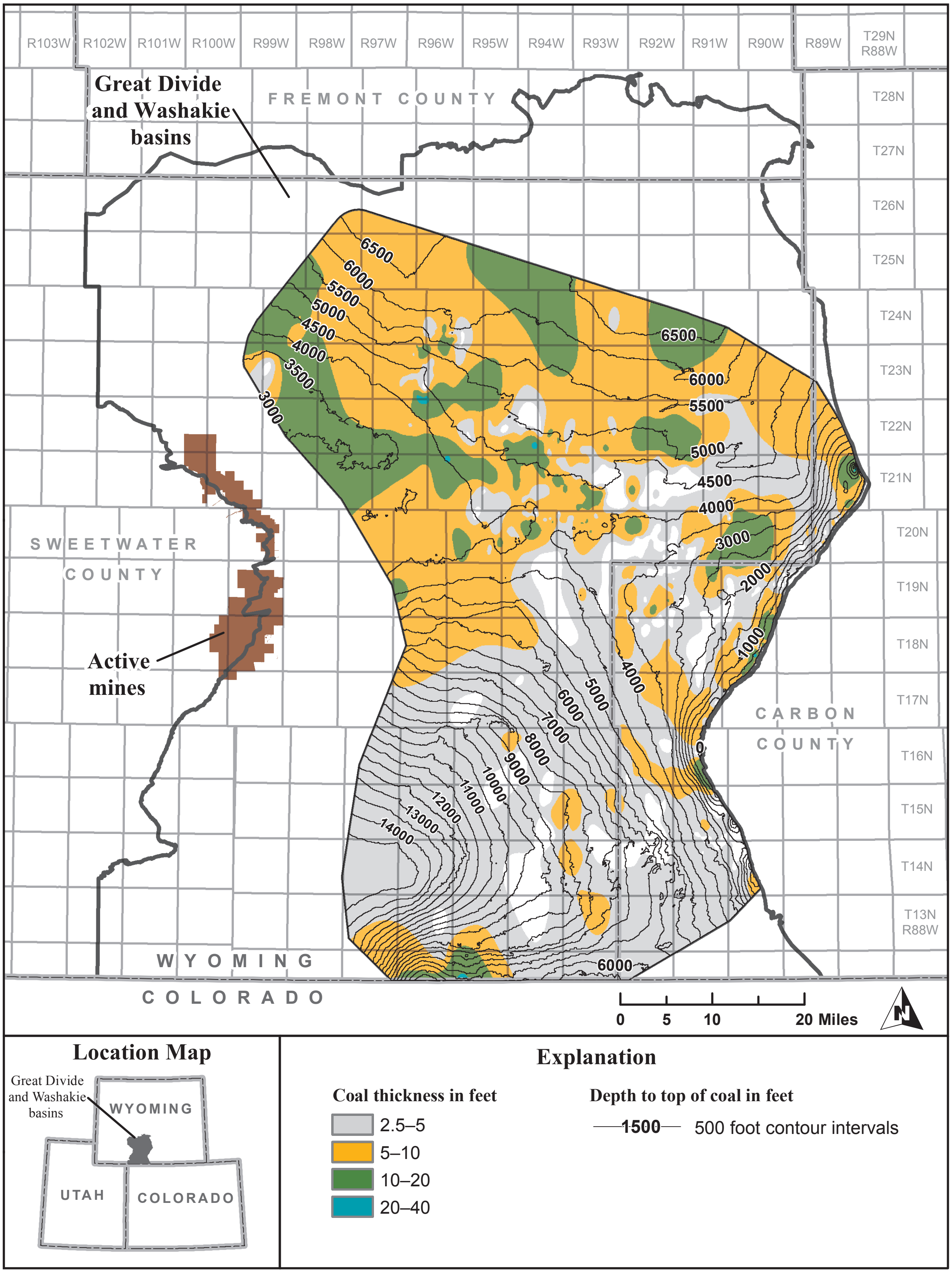

Figure 19. Isopach and overburden map for the Red Rim coal group, which includes the Red Rim coal bed.

Coal Resources

The 12 coal groups modeled are estimated to contain total coal resources of 256 billion tons (BT) regardless of bed thickness or depth of burial. Economic and marginal coals account for 89.1 and 70.2 BT, respectively (table 3), or 159.3 BT combined as original coal. The remaining coal resources are classified as hypothetical (47.0 BT), sub-economic (46.1 BT), or too thin to mine (3.9 BT).

Land use and technological restrictions render a total of 6.4 BT of coal resources unmineable (table 4). Most of the economic coal unavailable for mining runs along a corridor that includes I-80, the UPRR, and a gas pipeline network. This corridor parallels the east–west-trending Wamsutter Arch where the modeled coal groups are potentially mineable due to their relatively shallow depth of burial. Restrictions were subtracted from economic coal volumes to obtain an available coal resource of 82.7 BT, or nearly 93 percent of the economic coal in the Great Divide and Washakie basins.

Surface Mineable Coal

For this study, measured, indicated, and inferred coals that are up to 500 ft deep and more than 2.5 ft thick are considered surface mineable. The model data indicates that 3.5 BT of coal is surface mineable for the 12 modeled groups in the Great Divide and Washakie basins (table 5). Beds in the Cherokee (0.8 BT), Big Red (0.7 BT), Lower Big Red (0.5 BT), Upper Big Red (0.5 BT), and Horse Butte (0.5 BT) groups have the greatest tonnages available for surface mining.

All coal groups modeled had surface mineable coals, with the exception of the CB700 group, which is too deeply buried. However, the coal beds in Red Rim and Lower Riner groups are likely too thin or too steeply dipping to have high potential for future mining.

Underground Mineable Coal

The Horse Butte (7.5 BT), Cherokee (6.2 BT), Big Red (3.3 BT), CB700 (3.1 BT), and Lower Big Red (2.4 BT) coal groups have the highest potential for shallow underground mining (more than 5 ft thick and 500–2,000 ft deep; table 6). Most of the high potential for underground mining is located along the Wamsutter Arch and the edge of the Rock Springs Uplift in the western study area.

Results from this study estimate 49 BT of deep coals (more than 5 ft thick and 2,000–3,500 ft deep) could be extracted by deep underground mining methods. With the large amount of coal available to surface and shallow underground mining, this study did not investigate deep underground mining further.

Table 3. Calculated resources of economic, marginal, hypothetical, and sub-economic Fort Union coals modeled in the Washakie and Great Divide basins.

Modeled coal group	Economic (BT)	Marginal (BT)	Hypothetical (BT)	Sub-economic (BT)	Thin (<2.5 ft)
Cherokee	11.57	2.17	2.44	1.13	0.30
Horse Butte	13.18	2.08	3.26	1.22	0.28
CB700	12.97	2.53	2.08	0.00	0.08
Upper Big Red	8.70	3.09	6.65	3.35	0.03
Big Red	14.19	19.17	6.52	9.89	0.46
Lower Big Red	8.54	4.73	8.81	5.48	0.18
Upper Little Valley	1.67	0.55	0.15	0.00	0.19
Muddy Creek	7.26	7.81	3.49	6.73	0.59
Separation Creek B	2.92	5.90	6.23	3.73	0.56
Lower Riner	3.11	10.57	2.15	7.02	0.28
Lower Olson Draw	2.20	1.81	0.62	0.05	0.41
Red Rim	2.79	9.85	4.58	7.49	0.55
Total	**89.09**	**70.24**	**46.98**	**46.08**	**3.90**

Table 4. Economic, restricted, and available coal resources reported by coal group.

Modeled coal group	Economic resources (BT)	Land use and technological restrictions (BT)	Available resources (BT)
Cherokee	11.57	0.37	11.20
Horse Butte	13.18	0.40	12.78
CB700	12.97	0.89	12.08
Upper Big Red	8.70	0.71	7.99
Big Red	14.19	1.45	12.75
Lower Big Red	8.54	0.64	7.90
Upper Little Valley	1.67	0.03	1.64
Muddy Creek	7.26	0.82	6.43
Separation Creek B	2.92	0.23	2.69
Lower Riner	3.11	0.10	3.01
Lower Olson Draw	2.20	0.35	1.85
Red Rim	2.79	0.41	2.38
Total	**89.09**	**6.39**	**82.70**

Table 5. Measured, indicated, and inferred resources for surface mineable coals (depths <500 ft) for the 12 modeled coal groups.

Modeled coal group	Thickness 2.5–5 ft			Thickness >5 ft		
	Measured (BT)	Indicated (BT)	Inferred (BT)	Measured (BT)	Indicated (BT)	Inferred (BT)
Cherokee	0.01	0.02	0.01	0.28	0.35	0.12
Horse Butte	0.01	0.04	0.13	0.13	0.17	0.02
CB700	0.00	0.00	0.00	0.00	0.00	0.00
Upper Big Red	0.01	0.01	0.00	0.07	0.18	0.25
Big Red	0.03	0.02	0.00	0.17	0.28	0.18
Lower Big Red	0.01	0.02	0.04	0.07	0.15	0.24
Upper Little Valley	0.01	0.02	0.03	0.01	0.02	0.04
Muddy Creek	0.02	0.02	0.00	0.06	0.03	0.01
Separation Creek B	0.02	0.01	0.00	0.00	0.00	0.00
Lower Riner	0.01	0.01	0.00	0.00	0.00	0.00
Lower Olson Draw	0.01	0.01	0.02	0.01	0.02	0.02
Red Rim	0.01	0.01	0.00	0.06	0.03	0.01
Total Available	**0.14**	**0.19**	**0.24**	**0.86**	**1.23**	**0.88**

Table 6. Measured, indicated, and inferred resources for shallow underground mineable coals (depths 500–2,000 ft) for the 12 modeled coal groups.

Modeled coal group	Thickness 2.5–5 ft			Thickness >5 ft		
	Measured (BT)	Indicated (BT)	Inferred (BT)	Measured (BT)	Indicated (BT)	Inferred (BT)
Cherokee	0.06	0.30	0.86	0.88	3.05	2.25
Horse Butte	0.03	0.08	0.34	1.51	3.54	2.42
CB700	0.01	0.03	0.09	0.20	0.80	2.04
Upper Big Red	0.02	0.05	0.03	0.29	0.78	1.15
Big Red	0.02	0.08	0.18	0.36	1.23	1.74
Lower Big Red	0.02	0.07	0.17	0.32	0.82	1.25
Upper Little Valley	0.02	0.03	0.08	0.01	0.10	0.44
Muddy Creek	0.04	0.11	0.13	0.08	0.30	0.16
Separation Creek B	0.02	0.07	0.09	0.00	0.02	0.02
Lower Riner	0.01	0.06	0.15	0.00	0.02	0.16
Lower Olson Draw	0.01	0.05	0.13	0.02	0.06	0.08
Red Rim	0.02	0.07	0.09	0.03	0.16	0.24
Total Available	**0.28**	**1.00**	**2.35**	**3.70**	**10.87**	**11.94**

CONCLUSIONS

The Fort Union Formation of the Great Divide and Washakie basins contains an estimated 89.1 BT of economic coal resources for the 12 major coal groups assessed in this study (table 7). Of this, 82.7 BT are available coal resources. Approximately 0.4 BT of coal was mined from the Fort Union at the Black Butte and Bridger mines through 2017, leaving a recoverable coal tonnage of 82.3 BT.

The three coal groups with the largest overall amount of available coal are Horse Butte (8.4 BT), Cherokee (8.2 BT), and Big Red (4.3 BT). The greatest surface resources occur in the Cherokee (0.8 BT), Big Red (0.7 BT), and Lower Big Red (0.5 BT) coal groups. Shallow underground coals with the highest volume of total available coal resources are Horse Butte (7.9 BT), Cherokee (7.4 BT), and Big Red (3.6 BT) coal groups.

Table 7. Surface, shallow underground, deep underground and total values for original (economic plus marginal), economic, available, mined, recoverable, and Demonstrated Reserve Base resources calculated for all modeled coal groups together.

	Surface (BT)	Shallow underground (BT)	Deep underground (BT)	Total (BT)	Percent of original
Original	-	-	-	159.33	-
Economic	-	-	-	89.09	56%
Available	3.54	30.15	49.02	82.70	52%
Mined	0.37	0.04	-	0.40	0%
Recoverable	3.17	30.11	49.02	82.30	52%
Demonstrated Reserve Base (DRB)	2.42	14.58	17.78	34.77	22%

Comparison to Previous Assessments

Previous assessments of Fort Union coal in the Great Divide and Washakie basins were less comprehensive due to a lack of stratigraphic data required to calculate coal volumes. Historically, assessments were based on thickness measurements from coal outcrops, which were extrapolated into the subsurface with few constraints on depth or thickness. This resulted in generally lower estimated volumes than reported in this assessment.

Berryhill and others (1950) estimated 16 BT of original coal reserves in the Great Divide Basin, Little Snake River, and Rock Springs coal fields, which collectively extend west beyond the current study area.

Jones and Glass (1992) estimated the DRB of surface mineable coal resources in the Greater Green River Basin to be 1.8 BT. In contrast, this report estimates the DRB of surface coals at 2.4 BT in the eastern Greater Green River Basin alone.

McCord (1980) estimated 2 BT of original, in-place coal resources in the Fort Union and Lance formations in the Washakie Basin. Tyler and others (1995) estimated 316 BT of coal in the Fort Union at depths shallower than 6,000 ft in the Greater Green River Basin of Wyoming and Colorado, but did not assess the mineability of those resources.

Ellis and others (1999) estimated 2.7 BT of identified coal resources, of which 93 MT are measured resources, in the Deadman coal zone at the Black Butte coal field at depths shallower than 1,500 ft. This estimate from Ellis and others was obtained using a combination of outcrop and subsurface data, some of which originated from the Bridger Coal Company, and may represent a higher resolution dataset than the one used in this study.

Further Characterization

In this study, coal resources were assessed without considering surface- or mineral-right ownership, with the exception of the two active coal-mining leases. This regional study is not intended for determining coal resources for detailed mine planning, but is instead meant to be a general overview at the basin scale. Data users should conduct due diligence before applying coal resource calculations.

Continuous stratigraphic assumptions imply that certain coal beds can be mined over long distances. Flores and others (1997) describe Wyoming Fort Union coals as thick but discontinuous. For future mine planning, detailed economic studies should consider the discontinuous character of Fort Union coals, including coal bed pinch-outs and the potential presence of minor partings.

Future coal resource assessments in the Wasatch Formation, Lance Formation, and Mesaverde Group would complement the data presented in this study. Many of the geophysical logs used for this study also captured data from these formations.

With the increased interest in clean coal technologies, additional coal quality data could provide improved marketability for Greater Green River Basin coals. Additional heat value, sulfur, and ash content data may steer future development to target the highest-quality, cleanest-burning coals.

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Appendix

Table A1. Stratigraphic nomenclature of Fort Union coals as used in this report for the Great Divide Basin.

Great Divide Basin							
Fort Union Formation Coal Zones	**Southwest**	**Northwest**	**Southcentral**	**Northcentral**	**Southeast**	**Northeast**	**THIS STUDY Modeled Coal Groups**
Cherokee coal zone of the Overland Member		Upper Scotty Lake					
		Scotty Lake Main 1	Upper Cherokee		Upper Cherokee	Upper Cherokee	
		Scotty Lake Main 2	Cherokee		Cherokee	Cherokee	Cherokee
		Lower Scotty Lake	Lower Cherokee		Lower Cherokee	Lower Cherokee	
			Cow Butte		Cow Butte		
		Horse Butte	Horse Butte	Horse Butte	Horse Butte	Horse Butte	Horse Butte
	Nuttal	CB1200					
Middle coal zone of the Overland Member		CB700	CB700	CB700			CB700
	Fort Union 15						
					Middle Fort Union	Middle Fort Union	
	Fort Union 14						
		Lower Middle Fort Union	Lower Middle Fort Union				
	Fort Union 13						
China Butte coal zone of the China Butte Member	Fort Union 9						
	Fort Union 8						
	Fort Union 7						
		Chicken Springs	Chicken Springs	Chicken Springs	Chicken Springs		
		GU					
	Upper Deadman	Upper Big Red	Upper Big Red				Upper Big Red
	Deadman	Big Red	Big Red	Fillmore Ranch	Fillmore Ranch	Fillmore Ranch	Big Red
	Lower Deadman	Lower Big Red	Lower Big Red				Lower Big Red
				Fillmore Creek	Fillmore Creek	Fillmore Creek	
		Muddy Creek	Muddy Creek	Muddy Creek	Muddy Creek		Muddy Creek
	Fort Union 4						
	Upper Fort Union 3						
	Fort Union 3						
	Lower Fort Union 3						
					Separation Creek 1		
					Separation Creek 2		
		Separation Creek B	Separation Creek B	Separation Creek B	Separation Creek B		Separation Creek B
		Lower Separation Creek	Lower Separation Creek	Lower Separation Creek		Lower Separation Creek	
	Fort Union 2						
	Fort Union 1						
	Overland						
		Riner	Riner	Riner	Riner	Riner	
		Lower Riner	Lower Riner	Lower Riner	Lower Riner	Lower Riner	Lower Riner
					Olson Draw		
					Lower Olson Draw		Lower Olson Draw
					Hadsell Draw		
		Red Rim	Red Rim	Red Rim	Red Rim	Red Rim	Red Rim
		Daley Ranch	Daley Ranch	Daley Ranch		Daley Ranch	
						Continental Divide	

Table A2. Stratigraphic nomenclature of Fort Union coals as used in this report for the Washakie Basin.

Washakie Basin							
Fort Union Formation Coal Zones	**Southwest**	**Northwest**	**Southcentral**	**Northcentral**	**Southeast**	**Northeast**	**THIS STUDY Modeled Coal Groups**
Cherokee coal zone of the Overland Member		U. Cherokee		U. Cherokee		U. Cherokee	
	Cherokee (ltd)	Cherokee	Cherokee (ltd)	Cherokee		Cherokee	Cherokee
	L. Cherokee (ltd)	L. Cherokee/ Ft. Union_OVR_11	L. Cherokee (ltd)	L. Cherokee		L. Cherokee	
		Cow Butte/ Ft. Union_OVR_ 10		Cow Butte		Cow Butte	
	Horse Butte (ltd)	Horse Butte/ Ft. Union_OVR_9		Horse Butte		Horse Butte	Horse Butte
		Fort Union_OVR_ 8/Leaf					
	Big Burn	Fort Union_OVR_7/Big Burn					
Middle coal zone of the Overland Member		CB700/Fort Union_OVR_ 6/Hail		CB700		CB700	CB700
China Butte coal zone of the China Butte Member		Fort Union 9		Fort Union 9			
	Fort Union 8 (ltd)	Fort Union 8		Fort Union 8	Chicken Springs	Chicken Springs	
		Fort Union 7		Fort Union 7			
		Upper Deadman					Upper Big Red
		Deadman/Big Red	Fillmore Ranch	Fillmore Ranch/ Big Red	Fillmore Ranch/Baggs	Fillmore Ranch	Big Red
		Fort Union 5	Fillmore Creek (ltd)	Fillmore Creek		Fillmore Creek	
	U. Little Valley	U. Little Valley					Upper Little Valley
	Little Valley	Lower Deadman /Little Valley					Lower Big Red
				Upper Ft. Union 3			
	L. Little Valley	Fort Union 4/ Lower Little Valley					
			Muddy Creek	Muddy Creek	Muddy Creek	Muddy Creek	Muddy Creek
		(Upper) Ft. Union 3U					
	Fort Union 3 (ltd)	Fort Union 3		Fort Union 3	Fivemile Point		
		(Lower) Ft. Union 3L					
				Separation Creek (ltd)		Separation Creek	
				Separation Creek B		Separation Creek B	Separation Creek B
					Lower Separation Creek (ltd)	Lower Separation Creek	
		Fort Union 2	Wild Cow (ltd)	Wild Cow (ltd)	Wild Cow (ltd)	Wild Cow (ltd)	
		Fort Union 1	Riner (ltd)	Riner/Fort Union 1		Riner	
		Lower Riner		Lower Riner		Lower Riner	Lower Riner
				U. Olson Draw (ltd)		U. Olson Draw	
			Olson Draw	Olson Draw (ltd)	Olson Draw	Olson Draw	
					L. Olson Draw	L. Olson Draw	Lower Olson Draw
			Red Rim	Red Rim (ltd)	Red Rim	Red Rim	Red Rim
				Daley Ranch (ltd)		Daley Ranch	
						Continental Divide	

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