THE AVAILABLE COAL RESOURCE FOR NINE 7.5-MINUTE QUADRANGLES IN THE SOUTHERN WASATCH PLATEAU COALFIELD, EMERY, SANPETE, AND SEVIER COUNTIES, UTAH

by

Jeffrey C. Quick, David E. Tabet, Brigitte P. Hucka, and Sharon I. Wakefield

SPECIAL STUDY 114
UTAH GEOLOGICAL SURVEY
a division of
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SUFCO mine surface facilities. Photo courtesy of SUFCO mine.

ISBN 1-55791-728-0

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Cover photos are of SUFCO mine in the Acord Lakes quadrangle. Photos by Michael Vanden Berg.

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ABSTRACT

A resource of about 2460 million tons of low-sulfur, low-mercury, bituminous coal is available for underground mining in the southern half of the Wasatch Plateau, Utah. This available coal resource is in beds that are more than 4 feet thick within the Cretaceous Blackhawk Formation, and excludes coal within the complexly faulted Joes Valley graben as well as coal made unavailable because of past mining (as of December 2000), technical limitations, or land-use restrictions. About half of the available coal is classified as a demonstrated resource (within 0.75 miles of a measurement location). Our data show that seven of the eleven coal beds identified in this study contain available coal; nearly 90% of this coal is in two of these beds, namely, the Acord Lakes coal bed and the Knight coal bed. We estimate that 670 million tons of the available coal resource can be recovered; this is sufficient to sustain current production from this area for more than 90 years.

INTRODUCTION

Since the 1870s, Utah coal mines have produced more than 800 million tons of coal. About 500 million tons of this coal came from mines in the Wasatch Plateau coalfield, of which 80 million tons came from the southern Wasatch Plateau study area. Despite the extensive past mining, the Wasatch Plateau remains Utah's most important coalfield, accounting for 80 to 90% of the state's coal production during the 1990s. Of the 27 million tons of Utah coal produced during 2000, nearly 23 million tons came from the Wasatch Plateau (Jahanbani, 2001).

How long can coal production from the Wasatch Plateau continue? This study provides an estimate of the amount and distribution of coal remaining in the southern half of the Wasatch Plateau coalfield. It complements an earlier study of the northern half of the Wasatch Plateau coalfield where a quantity over 1000 million tons of recoverable coal remains (Tabet and others 1999). These studies are part of a joint effort by the Utah Geological Survey (UGS) and the U.S. Geological Survey (USGS) to better define Utah's remaining coal resource (Tabet and others, 1999; Kirschbaum and others, 2000; Quick and others 2004).

We use a Geographic Information System (GIS) to identify the available coal resource in the southern half of the Wasatch Plateau coalfield. The available coal resource includes coal in beds more than 4 feet thick that remains after subtracting coal in mined-out areas as well as areas where current technical or land-use restrictions prohibit mining. Importantly, only part of the available coal resource identified in this study will be recovered by mining. Estimates of resource recovery in the Wasatch Plateau vary, but about 35% recovery of the in-ground coal resource is typical. Moreover, non-geologic factors such as coal price, land-use policy, and environmental regulation may affect future coal production.

Location and Geologic Setting

The study area covers most of the southern part of the Wasatch Plateau coalfield (figure 1), and includes parts of Emery, Sanpete, and Sevier Counties, Utah. Excluding shattered coal within the complexly faulted Joes Valley graben, we estimate the coal resource within nine, 7.5-minute quadrangles shown in figure 2. Two small towns, Emery and Ferron, are in the eastern part of study area. Both towns are served by State Highway 10, which runs southwest along the eastern edge of the study area. Interstate Highway 70 crosses the southern part of the coalfield through Salina Canyon. No railroads serve the area, and the nearest rail loadout is at least 30 miles away.

The coal beds mined in the Wasatch Plateau coalfield are in the 700- to 1100-foot-thick Upper Cretaceous Blackhawk Formation (Doelling, 1972). The Blackhawk Formation conformably overlies the Star Point Sandstone, and is unconformably overlain by the Castlegate Sandstone Member of the Price River Formation. These Cretaceous strata, as well as some younger Tertiary units, cap the highly dissected Wasatch Plateau. Most of the coal resource in the Wasatch Plateau coalfield is in the lower part of the Blackhawk Formation, which intertongues with the underlying Star Point Sandstone. Geologists at the USGS (Flores and others, 1979; Hayes and Sanchez, 1979, Sanchez and Hayes, 1979; Dubiel and others, 2000) show that this intertonguing controls the

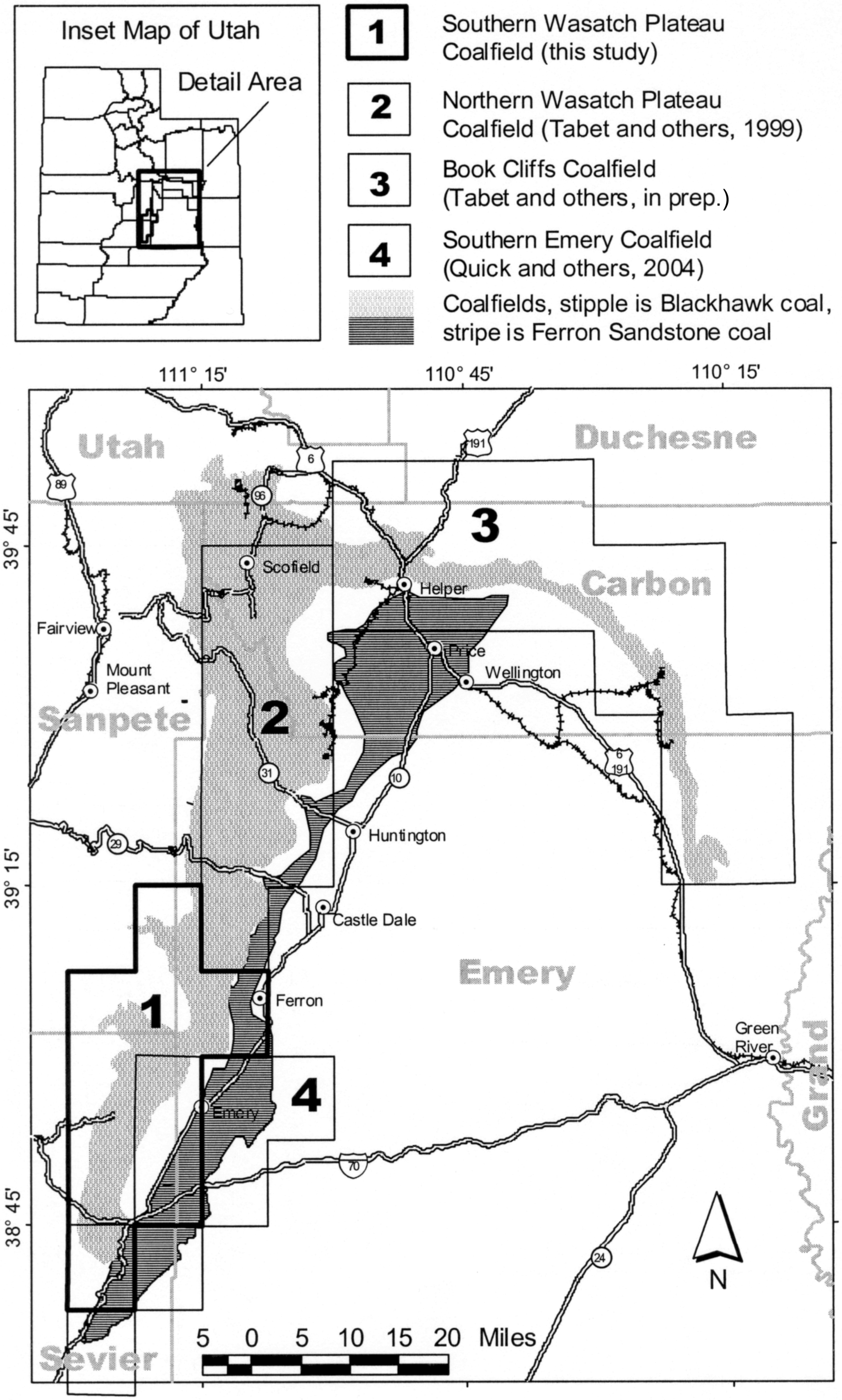

Figure 1. Location and geographic setting of the southern Wasatch Plateau study area. Similar studies have been completed for other central Utah coalfields.

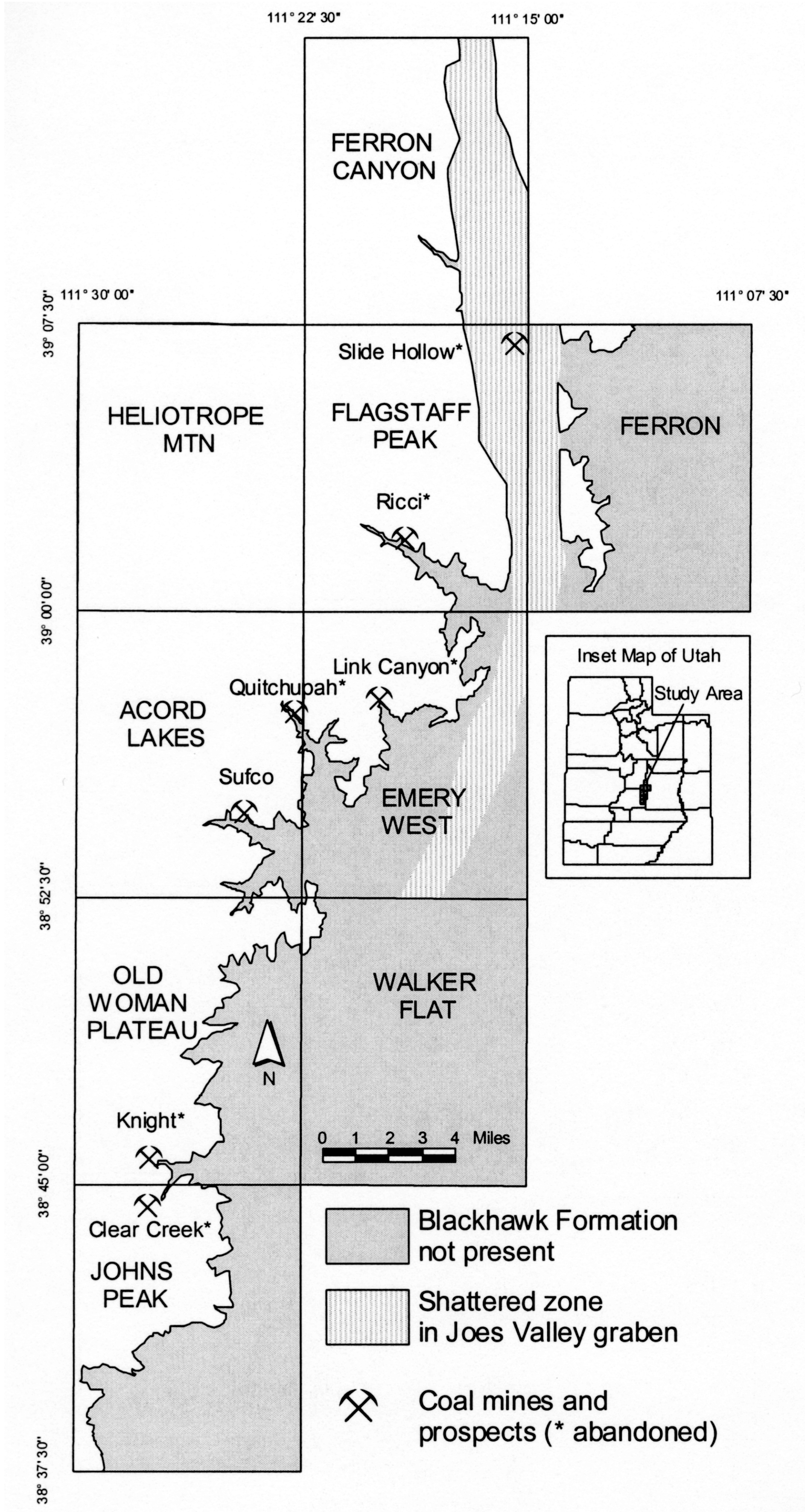

Figure 2. *Index map showing the nine 7.5-minute quadrangle study area and locations of active and abandoned coal mine portals and prospects, southern Wasatch Plateau, Utah.*

distribution and thickness of the coal beds.

The Wasatch Plateau is on the western flank of the San Rafael Swell, which typically dips by less than six degrees to the west or northwest. The strata of the Wasatch Plateau are broken by two north-trending grabens with displacements on the bounding faults of up to 1500 feet (Doelling, 1972). The Joes Valley graben is on the eastern side of the southern Wasatch Plateau (figure 2). The parallel Musinia graben is next to the western edge of the study area, and consequently is not shown on figure 2.

The principal coal beds of the study area are mainly in the lower half of the Blackhawk Formation (figure 3). In ascending order, these lower beds are named the Last Chance, Upper Last Chance, Knight, Acord Lakes, Axel Anderson, and Cottonwood according to fieldwork and mapping by the USGS (Marley and Flores, 1977; Hayes and Sanchez, 1979; Sanchez and Hayes, 1979; Blanchard, 1980; Ellis, 1981; Muldoon and others, 1981; Blanchard and Sanchez, 1982; Sanchez and others, 1983a, 1983b; Sanchez and Brown, 1983, 1987). A better understanding of the intertonguing of the Blackhawk and underlying Star Point Sandstone has improved coalbed correlations in the study area. Consequently, the bed names and correlations shown in figure 3 differ from those used by Spieker (1931).

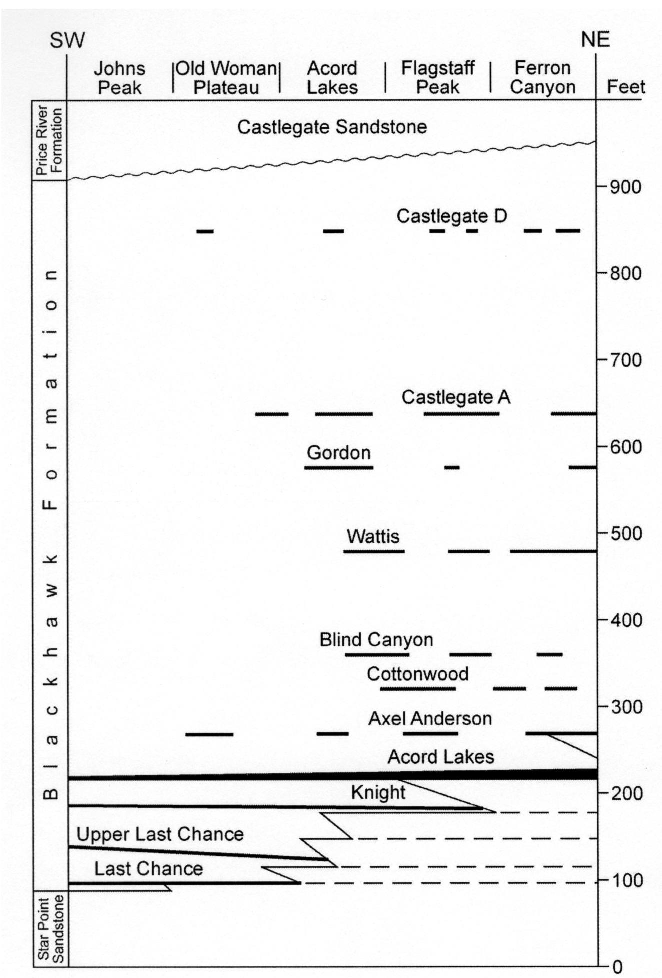

Figure 3. Idealized stratigraphic section showing 11 coal beds in the Blackhawk Formation, southern Wasatch Plateau, Utah. The thickness and distribution of the coal beds are based on drill-hole data for the quadrangles listed at the top of the figure; these attributes are more precisely shown on maps in appendix D.

Dubiel and others (2000) assigned color names to the major coal beds in the lower half of the Blackhawk Formation; their bed designations, with our names for the corresponding beds in parentheses, are purple (Last Chance), green (Upper Last Chance), red (Knight), and blue (Acord Lakes). We also identified some minor coal beds, which are stratigraphically above these major beds. These upper beds are better developed in the northern part of the Wasatch Plateau coalfield and include the Axel Anderson, Cottonwood, Blind Canyon, Wattis, Gordon, Castlegate A, and Castlegate D.

Mining History

By the end of 2003, 95.8 million tons of coal had been produced from the study area (figure 2), accounting for 11% of the cumulative 862 million tons of coal produced from Utah coalfields since 1870 (Brill and others, 2004). Coal production from the southern Wasatch Plateau has recently increased, rising from 13% of Utah's annual production in 1990 to over 30% in 2003.

Coal production from the southern Wasatch Plateau study area began in 1901 when the Quitchupah Creek mine began operations. The mine is located at the head of the North Fork of Quitchupah Canyon (Acord Lakes quadrangle) and produced about 6600 tons during intermittent activity until it closed in 1920 (Doelling, 1972). Although its beginnings are uncertain, the Slide Hollow mine was probably the second mine developed in the study area. The mine is located within the Joes Valley graben on the south side of Ferron Canyon in the Flagstaff Peak quadrangle. Spieker (1931) reported that the mine was abandoned during his visit in 1922, and consisted of a single 250-foot-long main entry with five rooms driven off to the side. The 8-foot-thick coal bed was partially burned near the entry, and abruptly thinned, possibly against a want or a fault. Based on Spieker's description, we estimate that the Slide Hollow mine produced 2000 tons of coal.

Several small mines and prospects apparently opened during the 1920s along drainages in the Johns Peak and Old Woman Plateau quadrangles. The Knight (or Ivie) mine and several small prospects worked the 4- to 8-foot-thick Knight coal bed along Ivie Creek in the Old Woman Plateau quadrangle. No mine maps or production figures are available, but mine permit records from the Utah Division of Oil Gas and Mining (UDOGM) suggest that the Knight mine produced 12,725 tons of coal during the 1920s, and an additional 124,393 tons between 1977 and June 1980 when the mine closed. Early developments also occurred in the 6- to 10-foot-thick parts of the Knight coal bed along Clear Creek in the northern part of the Johns Peak quadrangle. Spieker (1931) noted these prospects during his work in the area in 1922. No mine maps or production records are available for these developments, but field inspection by Doelling (1972) indicated that very little coal was mined.

Little or no mining activity occurred in the study area during the 1930s. However, the 1940s brought renewed activity to three areas in the southern Wasatch Plateau. In 1940, the Link Canyon mine opened in the Emery West quadrangle along the canyon for which it is named. This mine operated from 1940 to 1952 in the 8-foot-thick Upper Hiawatha bed (Acord Lakes bed in this report) and produced about 164,000 tons of coal (Doelling, 1972). In 1941, the Ricci (Crawford or Muddy Creek) mine opened in the Flagstaff Peak quadrangle along Muddy Canyon near the Sanpete-Sevier County line. According to U.S. Bureau of Mines records (unpublished data, 1953), the mine produced coal from the 8.5-foot-thick Muddy No. 1 bed (Acord Lakes bed in this report) and closed in February 1951 because of a mine fire. Doelling (1972, and unpublished data) estimated that the Ricci mine produced between 35,000 and 42,000 tons of coal.

The Southern Utah Fuel Company (SUFCO) mine opened in 1941. Its portal is in the Acord Lakes coal bed on the north side of Convulsion Canyon in the Acord Lakes quadrangle. The SUFCO mine has also been called the Convulsion Canyon, Hanson, or New Salina mine and is the only active mine in the study area. It began as a small room-and-pillar operation and is now the most productive longwall operation in Utah. During 2003, the SUFCO mine produced 7.1 million tons of coal, or 31% of Utah's annual coal production.

Past mining operations in the study area have largely worked in the Acord Lakes bed (Upper Hiawatha, Upper Ivie, or Blue) with lesser development of the Knight bed (Hiawatha, Ivie, or Red). Both beds retain the greatest potential for future mining in the study area.

DATA

Coal Assay Data

Analytical data for coal samples from the southern Wasatch Plateau coalfield indicate that most of the coal is high volatile C bituminous rank, with some high volatile B bituminous rank coal in the north and subbituminous A rank coal in the south (Doelling, 1972; Davis and Doelling, 1977; Hatch and others, 1979; Sanchez and Brown, 1983). The decrease of coal rank towards the south is illustrated in table 2, which shows coal analyses for four mines in the study area.

Spieker (1931) and Doelling (1972) observed that coals in the Blackhawk Formation have moderately high heating values (Btu/lb), low sulfur contents, and low ash values. Examination of a USGS database (Affolter, 2000) shows that coal from the southern Wasatch Plateau contains relatively low concentrations of elements of environmental concern such as antimony, arsenic, beryllium, cadmium, cobalt, mercury, manganese, sulfur, thorium, and uranium. Assay data for 51 coal samples from the southern Wasatch Plateau are presented in appendix A. These data show that on an as-received basis, coal in the study area averages 11,140 Btu/lb, 0.7% sulfur, and 8.4% ash.

Two universities collected and analyzed coal samples from the SUFCO mine. The Pennsylvania State University data are listed in an anonymous (1990) report and in reports by Davis and Glick (1993) and Scaroni and others (1999). Sommer and others (1991) report results from the University of Utah. Both universities show assay results similar to those reported by other workers, as well as results from less common assays such as petrographic composition, ash oxides, and trace elements.

Hucka and others (1997) report physical and petrographic data for Utah coal; their data for 58 coal samples from the southern Wasatch Plateau (vitrinite reflectance, maceral content, and density) are provided in appendix B. A correlation chart between vitrinite reflectance and ASTM rank classes (Davis, 1984) shows that the average 0.5% vitrinite re-

Table 1. *Cumulative production and location of active and inactive coal mines in the southern Wasatch Plateau, Utah (production in thousands of tons).*

Mine Name	Cadastral Location	Active Period	Production thru 2003 (thousand tons)
Quitchupah Creek	section 29, T. 21 S., R. 5 E.	1901 to 1920	7
Slide Hollow	section 4, T. 20 S., R. 6 E.	1917 to 1919*	2
Knight	section 34, T. 23 S., R. 4 E.	~1923, 1977-1980	137
Clear Creek	section 10, T. 24 S., R. 4 E.	~1922	<1
Link Canyon	section 26, T. 21 S., R. 5 E.	1940 to 1952	164
Ricci	section 35, T. 20 S., R. 5 E.	1941 to 1951	42
SUFCO	section 12, T. 22 S., R. 4 E.	1941 to present	95,226

Table 2. *Average proximate analyses for coal samples from four coal mines showing that rank decreases towards the south in the southern Wasatch Plateau study area (data from Doelling, 1972, and Dubiel and others, 2000).*

Mine Name	Location	Assay Data (as-received)						Apparent Rank[1]
		% Moisture	% Volatile Matter	% Fixed Carbon	% Ash	% Sulfur	Btu/lb	
Ricci	section 35, T.20 S., R.5 E.	8.4	39.1	45.2	7.3	0.5	11,922	hvCb
Link Canyon	section 26, T.21 S., R.5 E.	7.3	38.1	46.0	9.0	0.4	11,674	hvCb
SUFCO	section 12, T.22 S., R.4 E.	8.7	38.3	46.6	6.5	0.5	11,770	hvCb
Clear Creek	section 10, T.24 S., R.4 E.	13.4	36.2	43.8	6.7	0.6	10,570	subA

[1]ASTM (1990) rank codes: hvCb is high volatile C bituminous; sub A is subbituminous A

flectance value observed by Hucka and her co-workers is consistent with the typical high volatile C bituminous rank of these coals.

Coal in the Wasatch Plateau averages 81% vitrinite, 7% liptinite, and 12% inertinite (258 samples; Hucka and others, 1997). However, coal in the economically important Acord Lakes coal bed of the southern Wasatch Plateau study area has relatively abundant inertinite (average 20%, maximum 49%). Inertinite slightly increases greenhouse gas emissions from coal combustion (Quick and Brill, 2002), but also increases post-combustion mercury capture (Goodarzi, 2005). Although the Acord Lakes coal bed contains more intertinite than most U.S. coal (Waddell and others, 1978), it is not unusual compared to internationally traded coal (Coxhead, 1997).

Coal in the southern Wasatch Plateau study area has uniformly low methane gas content (Doelling and others, 1979; Smith, 1986). Twenty-six gas desorption measurements listed in appendix C range from 0 to 13 cubic feet per ton of coal, and average 3 cubic feet per ton. Low methane gas content improves mine safety and reduces ventilation costs.

Spatial Data

Spatial data used in this study are from varied sources. Digital maps of perennial streams, lakes, railroads, roads, pipelines, power lines, and municipalities are from the Utah Automated Geographic Reference Center (UAGRC). Digital elevation models (USGS, 30 meter grids) are also from the UAGRC Web site. The locations of exploration drill holes, outcrops, oil and gas wells, measured sections, and mined-out areas were hand-drawn on USGS 1:24,000-scale topographic maps and digitized using AUTOCAD© software. Faults were digitized from 1:24,000-scale USGS Coal Investigations Maps (Hayes and Sanchez, 1979; Sanchez and Hayes, 1979; Sanchez and Brown, 1983, 1987; Sanchez and others, 1983a, 1983b).

Mine maps used in this study are from the UDOGM and UGS files, and are current as of December 31, 2000. Although we lack maps for the Clear Creek, Slide Hollow, and Quitchupah Creek mines, these mines produced very little coal, so their absence has little effect on our resource calculations.

Most of the exploration drill-hole and outcrop records used in this report are from UGS files compiled over the past 20 years for the USGS National Coal Resources Data System (NCRDS). Many of these records are also included in tabulations by Davis and Doelling (1977), Blanchard and others (1977), Blanchard (1978), Blanchard and Lee (1978), Sanchez and Kubatz (1979), Sanchez (1980), Albee (1980, 1982), and Smith (1981). A few additional records are from the U.S. Bureau of Land Management. Although data for more than 1000 point locations are available, many of the data records are clustered in single locations. Such clustered data points add little additional information but substantially increase the data compilation effort. Accordingly, we selected 402 point locations (212 drill-hole and 190 outcrop records) to provide a uniform point distribution (figure 4). Note that our selection includes a few locations northwest of the study area, which were included to constrain our resource tabulations in this area.

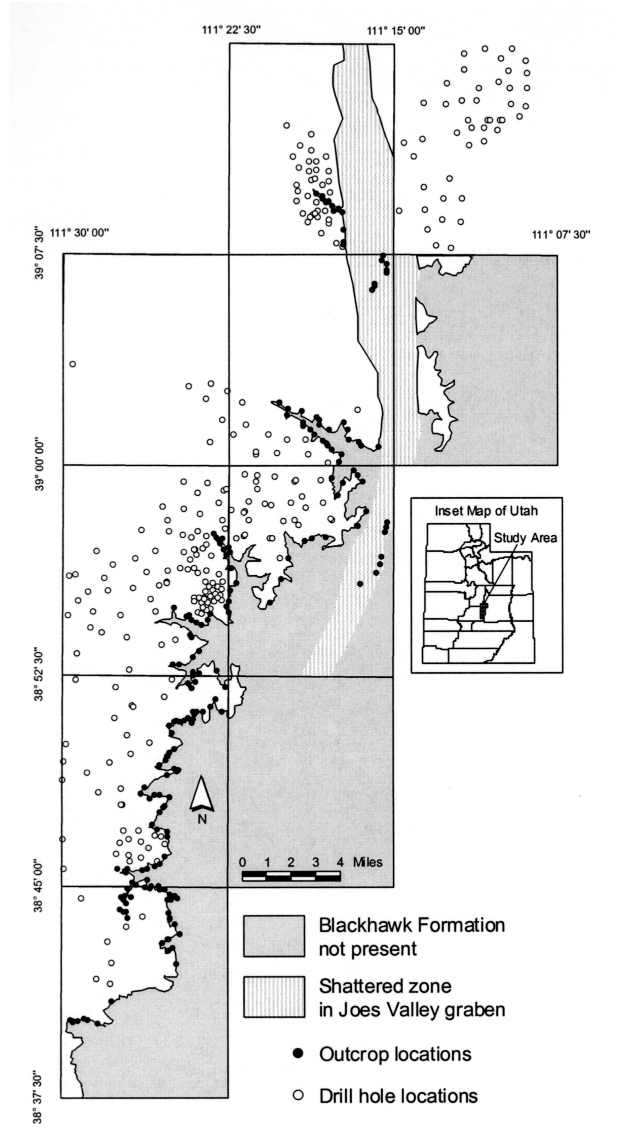

Figure 4. Locations of outcrop and drill-hole measurements used to estimate the coal resource in the southern Wasatch Plateau, Utah. Locations outside of the study area were used to constrain resource estimates for nearby parts of the study area.

We systematically entered the drill-hole and outcrop data into a spreadsheet. The spreadsheet includes values for coalbed thickness, elevation, and location coordinates; assigned bed names were verified by subsequent mapping. Values of zero thickness were assigned where coal beds are clearly missing at a given location; null values indicate that a coal bed may be present, but was not penetrated by the drill or observed at the surface. Bed thickness values are recorded to the nearest tenth of a foot; elevation values are recorded to the nearest whole foot.

METHODS USED TO CALCULATE COAL RESOURCE TONNAGE

Calculation of the coal resource tonnage requires three values: coalbed area, thickness, and density. We used ArcView (v.3.2)© GIS computer software to tabulate the areal extent of individual coal beds classified by 2-foot thickness intervals. Coalbed tonnage was calculated by considering the areal extent of the coal bed, the central value for each 2-foot thickness interval, and a coal density factor of 1800 tons per acre-foot of coal (Wood and others, 1983). For example, GIS analysis reveals 2590 acres where the available coal in the Upper Last Chance coal bed is between 4 and 6 feet thick. The spreadsheet calculation,

$$2590 \text{ acres} \times 5 \text{ feet coal} \times \frac{1800 \text{ tons coal}}{\text{acre - foot}} = 23.3 \times 10^6 \text{ tons coal}$$

shows 23.3 million tons of 4- to 6-foot-thick coal in the Upper Last Chance coal bed. Repeating this calculation for the remaining thickness intervals, and summing the results, indicates 47.9 million tons of available coal in the Upper Last Chance coal bed.

Creating Maps Using ArcView©

As noted above, most of the maps used in this study are from public collections like the UAGRC. However, some of the maps are newly created. This section describes how the newly created maps were made.

Maps showing coalbed thickness, elevation, and depth values, as well as associated interburden thickness, were created using ArcView© GIS software (Spatial Analyst extension v.1.1). This program includes mathematical functions that use drill-hole and outcrop data to calculate values for cells in a rectangular grid that is superimposed over the study area. All of our calculations are based on identically registered 30-meter grid cells (0.2224 acres), and NAD 27 Universal Transverse Mercator (UTM) zone 12 coordinates. Thickness (isopach) maps were made using a fourth-order, six-nearest-neighbor, inverse-distance function. Elevation (structure) maps were made using a tension, three-weighted, six-nearest-neighbor, spline function.

Coalbed Thickness Maps

We used coalbed thickness maps to calculate the areal extent of individual coal beds classified by 2-foot thickness intervals. Preliminary coalbed thickness maps were made using all 402 drill-hole and outcrop records shown on figure 2. These maps showed coal beds thinning towards the outcrop, as well as greater thickness variation near the outcrop. We attribute this outcome to coal oxidation and burning at the outcrop, which reduces the apparent coalbed thickness. Burning can also cause slumping of overlying sediments, which further reduces the apparent coalbed thickness at the outcrop. Thus, outcrop observations in central Utah are rarely representative of the amount of coal buried behind the outcrop. Moreover, the use of thickness values from burned or slumped coal outcrops results in the underestimation of coal resources. Accordingly, for our coalbed thickness maps, we used only those outcrop observations where the observed coalbed thickness is greater than that indicated by maps made exclusively from drill-hole data.

Coalbed Depth Maps

We used coalbed depth maps to identify areas where a coal bed is present at depths suitable for underground mining (between 100 and 3000 feet in this study). We made these maps by subtracting the coalbed elevation in the subsurface from the overlying topographic elevation. This calculation was done using coalbed elevation values from newly created coalbed structure maps and topographic elevation values from USGS digital elevation models.

Like our experience making coalbed thickness maps, our first attempts to make coalbed elevation (structure) maps also gave erroneous results. These maps sometimes showed adjacent coal beds intersecting in areas lacking point data observations, which is clearly not possible. Notably, these first maps were directly made using elevation values for the tops of the coal beds. We attribute these erroneous intersections to the proximity of adjacent coal beds (typically, 30 to 60 feet), the uncertain precision of the elevation data (±10 feet?), and the trend-dependent extrapolations in the spline mapping function that we used.

To avoid these errors, we used an indirect method to create the coalbed elevation maps. First, we made a structure map of the underlying Star Point Sandstone using elevation values listed for the sandstone. Next, we calculated the average vertical distance between the Star Point Sandstone and each individual coal bed. Coalbed elevation maps were made for each coal bed by adding its calculated average vertical distance to the Star Point Sandstone elevation map. Finally, we subtracted each coalbed elevation map from the topographic elevation map to create the depth maps used to identify the available coal resource.

Using the Star Point Sandstone as a datum to establish the elevation of each coal bed has several advantages. Unlike individual coal beds, the Star Point Sandstone is easily identified and present throughout the study area. Moreover, using a unique, uniform separation distance between the Star Point Sandstone and each overlying coal bed prevents the extrapolation errors noted above where coalbed elevation surfaces appear to intersect in the subsurface. Although our approach improves the accuracy of the derived depth maps it also has a disadvantage. Comparison of adjacent coalbed elevation maps made in this way does not show the subtle, but important, variation of interburden thickness between adjacent coal beds. Consequently, we used a different approach (described below) to create the coalbed interburden maps.

Interburden Thickness Maps

We use interburden thickness maps to identify areas where two otherwise-minable coal beds are separated by less than 40 feet of interburden. In such areas, only one of these beds can be safely recovered by underground mining. Given the limitations of our coalbed elevation maps (discussed above) we could not simply subtract adjacent coalbed elevation surfaces to create these maps. Instead, we created interburden thickness maps using the same inverse distance weighting function that we used to create the coalbed thickness maps. Interburden values applied to this function were necessarily limited to those locations where elevation and thickness values for adjacent coal beds were reported. The interburden values could then be calculated by subtracting the elevation of the top of the underlying bed from the elevation of the bottom of the overlying bed.

Resource Classification

The USGS (Wood and others, 1983; p.18-19) defines *reserves* as coal that can be "economically produced at the time of determination," whereas *resources* are broadly defined to include coal where economic extraction is "potentially feasible." In this study, we do not rigorously consider coal production costs, the percent of the in-ground coal that can be produced (the recovery factor), or other factors required to estimate coal reserves. Instead, we identify a subset of the original coal resource called the "available coal resource."

The original coal resource includes coal in beds more than one foot thick, which was present when mining began in the study area. The available coal resource is that part of the original coal resource remaining after subtraction of coal in areas affected by past mining, or where mining is prohibited because of current technical or land-use restrictions (Eggleston and others, 1990). Importantly, this definition recognizes that these restrictions vary from place to place, and may change in the future.

Restrictions to Mining

Restrictions to mining can be classified using two categories. Technical restrictions limit mining to areas where the coal can be safely recovered using current technology. Land-use restrictions limit mining to areas where mining will not harm existing human infrastructure or protected environmental assets. Table 3 lists the land-use and technical restrictions considered in this study together with associated buffers and restriction factors that we used to identify coal lost to these restrictions.

Technical Restrictions

Technical restrictions relate to local mining methods. Most Utah coal mines use continuous mining machines to develop mains and entries, and longwall mining machines for bulk coal production. These machines are designed for coal beds that are 6 to 14 feet thick. In other states, underground coal mines sometimes work beds as thin as 2 or 3 feet thick. However, this is only done where some special circumstance or use of the coal justifies a premium price. Moreover, underground mining of thinner beds in the eastern U.S. is also possible because these Carboniferous-age coal beds show uniform thickness over large areas. Cretaceous-age coal beds in central Utah show more thickness variation. Because Utah coal is sold mostly to power plants, rather than more lucrative specialty markets, beds less than 4 feet thick are rarely mined. Furthermore, even if a premium price is offered for Utah coal, mining these beds will be challenging since they are not uniformly thick over large areas like eastern U.S. coals. Given these circumstances, we use a 4-foot minimum thickness restriction to identify the technically minable coal resource.

Table 3. *Restrictions to mining in the southern Wasatch Plateau, Utah.*

Land-use restrictions [1]	**Buffer**
Power lines	100 feet on either side
Highways	100 feet on either side
Perennial streams	100 feet on either side
Lakes or reservoirs	100 feet around margin
Oil and gas wells	100-foot radius
Technical restrictions	**Factor**
Minimum bed thickness	4 feet
Maximum bed thickness	14 feet
Minimum depth	100 feet
Maximum depth	3000 feet
Minimum interburden	40 feet
Faults	50 feet on either side
Barrier for abandoned mines (included with mined-out coal)	50 feet around margin

[1] No railroads, radio towers, pipelines, towns, or residential houses are present in the coal-bearing part of the study area.

Although coal beds greater than 14 feet thick are actively mined in Utah, current mining methods can only recover up to a 14-foot-thick segment of the coal bed; the remaining coal is permanently lost in the gob pile behind the longwall. Accordingly, we use a maximum 14-foot thickness restriction.

Besides bed thickness, other technological restrictions include insufficient depth, excessive depth, insufficient interburden, and proximity to faults or abandoned mine workings. Shallow coal near the outcrop is often burned or oxidized coal and has no economic value; we use a 100-foot minimum burial depth restriction to exclude this low-quality coal. Utah mines have worked coal beds that are more than 2000 feet deep, and some are considering mining depths as great as 3000 feet; we use a 3000-foot maximum depth restriction to exclude this excessively deep coal. In areas where two thick coal beds are separated by less than 40 feet of interburden only one of these beds can be safely mined. Our 40-foot minimum interburden restriction is used to identify these areas, where coal in one of the adjacent coal beds is included in the available coal resource, but coal in the other bed is excluded. In these areas, we generally included the thicker bed in the available coal resource, but excluded the thinner of the two beds. To avoid unstable roof conditions and possible water infusions, most mines leave a 50-foot barrier near faults; in recognition of this practice we excluded coal within 50 feet of a fault. Regulations require coal operators to leave a barrier of 50 feet from abandoned coal mine workings to avoid potential ventilation or water infusion problems. Accordingly, we added a 50-foot buffer around the perimeter of abandoned coal mines to exclude this coal from the available coal resource.

Land-Use Restrictions

Most land-use restrictions related to coal mining are listed in federal and state regulations. These regulations are intended to protect surface features from damage that might result from subsidence associated with underground mining. Protected surface features in the southern Wasatch Plateau study area include power lines, highways, oil and gas wells, perennial streams, and lakes or reservoirs. Land-use restrictions that prohibit mining under railroads, radio towers, towns or residences, or pipelines are not considered because these features are not present in the study area.

Thickness Categories

Coalbed thickness categories used in this study are similar to those recommended by the USGS (Wood and others, 1983). We deviate slightly from the USGS classification to account for current Utah mining practice, which preferentially selects coal beds more than 6 feet thick. Table 4 compares the coalbed thickness categories used in this report with those recommended by Wood and others (1983).

Coal beds more than 4 feet thick are common in the Wasatch Plateau. Sometimes a named coal bed consists of several splits present in a 10- to 30-foot-thick interval. For this study, only the minable part of the coal bed is used to make coalbed thickness maps. Identifying the minable part of a coal bed is not always obvious where numerous partings, splits, or riders and sub-beds occur. Accordingly, we use some arbitrary but consistent rules to distinguish the minable part of a coal bed.

For our calculation of the minable coal resource, the thickness of the individual minable coal bed is truncated at partings one or more feet thick. This convention excludes riders and sub-beds sometimes associated with a thicker, minable interval. Note that a minable interval may include partings that are less than one foot thick if:

(a) the coal above or below a parting is at least twice the thickness of the included parting, and

(b) the included partings account for less than 20% of the minable coal thickness.

These distinctions were made (manually) when drill-hole records used for spatial analysis were compiled from drilling reports. Areas where thin partings are included in minable coal beds are small and not common in the study area.

Depth Categories

Table 5 compares the depth categories used in this report with those recommended by Wood and others (1983). We use a 0- to 100-foot depth category to identify shallow coal that is probably weathered or burned. Weathered or burned coal is not mined because it has a low heating value and is prone to slaking and spontaneous combustion during transport and storage.

The USGS (Wood and others, 1983) recommends a 0- to 500-foot depth category to identify coal that can be mined by open-pit methods. We do not include a 0- to 500-foot depth category because open-pit mines are unlikely in the study area. The shallow coal in the study area is typically near outcrops within near-vertical cliffs along the eastern edge of the Wasatch Plateau. Besides the poor quality of such coal due to weathering, land management agencies do not favor operations that might alter the prominent cliff face.

Reliability Categories

Our coal-resource tonnage estimates are derived from maps made using coal thickness measurements at specific locations (largely drill holes). Confidence in these maps, and derived tonnage estimates, is high in areas close to measurement locations and low in areas farther away from these measurement locations. Reliability categories indicate confidence in the derived tonnage estimates.

Three resource reliability categories (Wood and others, 1983) are used in this study. *Demonstrated* coal is within 0.75 miles of a measured thickness location. *Inferred* coal is between 0.75 and 3 miles of a measured thickness location. *Hypothetical* coal is more than 3 miles from a measured thickness location.

Table 4. *Coalbed thickness categories used in this report compared to those recommended by the USGS.*

This Report		USGS (Wood and others, 1983)	
feet	**inches**	**feet**	**inches**
1 to 2	12 to 24	1.2 to 2.3	14 to 28
2 to 4	24 to 48	2.3 to 3.5	28 to 42
4 to 6	48 to 72	3.5 to 7.0	42 to 84
6 to 10	72 to 120	7 to 14	84 to 168
10 to 14	120 to 168	+ 14	+ 168
+ 14	+ 168		

Table 5. *Depth categories used in this report compared to those recommended by the USGS.*

This Report	USGS (Wood and others, 1983)
0 to 100 feet	0 to 500 feet
100 to 1000 feet	500 to 1000 feet
1000 to 2000 feet	1000 to 2000 feet
2000 to 3000 feet	2000 to 3000 feet
3000 to 4000 feet	3000 to 6000 feet
4000 to 5000 feet	
+ 5000 feet	

RESOURCE CALCULATION RESULTS

The Original Coal Resource

The original coal resource includes coal in beds more than 1-foot-thick, which was present when mining began in the study area. GIS analysis shows 5700 million tons of original coal in 11 identified coal beds in the study area.

Two factors are important when considering the original coal tonnage. Coalbed thickness has obvious significance; coal in thin beds has little economic potential whereas coal in thick beds is potentially minable. Coalbed depth is also important. Deeply buried coal beds have little economic significance whereas coal at shallow to modest depths can potentially be mined.

Tons of Original Coal by Coalbed Thickness

Table 6 shows tonnage values according to thickness category for the 11 named coal beds in the study area. Over two-thirds of the 5700 million tons of original coal is from the Acord Lakes and Knight coal beds (2380 and 1450 million tons, respectively). These coal beds are also thick; 76% of the original Acord Lakes and Knight coal is in beds that are more than 6 feet thick. Conversely, table 6 shows that the other nine coal beds are relatively thin; 72% of this coal is in beds that are less than 4 feet thick. Thirty percent of the original coal in the southern Wasatch Plateau is in beds that are less than 4 feet thick. As explained above we do not consider this thin coal part of the minable resource. The importance of the Acord Lakes and Knight coal beds is even more evident given their contribution to the original coal resource in thick coal beds. These two coal beds account for 87% of the 3987 million tons of original coal that is more than 4 feet thick.

Tons of Original Coal by Coalbed Depth

Table 7 shows the distribution of the original coal resource by depth for coal beds that are more than 4 feet thick. Note that the Wattis, Castlegate A, and Castlegate D beds are not listed in table 7 since they are never more than 4 feet thick in the study area (table 6). About 78% of the coal more than 4 feet thick (3117 million tons) occurs at depths suitable for underground mining (between 100 and 3000 feet deep).

Calculation of the Available Coal Resource

The available coal resource includes that part of the original coal, in beds greater than 4 feet thick, that remains after subtraction of coal in areas affected by past mining as well as areas that cannot be mined due to technical or land-use restrictions.

Coal Lost to Past Mining

Mining can reduce the coal resource either directly or indirectly. Direct losses include the coal within the perimeter of underground coal mines. Indirect losses include the coal in beds above underground coal mines. Coal beds that are directly above underground coal mines have been undermined. We assume that undermining creates the potential for unstable floor and roof conditions in these overlying beds, which prevents the safe recovery of this coal. Note that a 50-foot buffer is used to expand the perimeter of abandoned mines for these calculations (table 3).

Table 8 shows a direct loss to mining of 170 million tons of coal in beds more than 4 feet thick. Nearly all of this coal is within the Acord Lakes coal bed. Undermining loss accounts for about 4 million tons, mostly from the Cottonwood bed. Together, the total coal resource lost to mining repre-

Table 6. *Original coal resource for 11 coal beds, by coalbed thickness, southern Wasatch Plateau, Utah (millions of tons).*

	COALBED THICKNESS							
COAL BED	**1 to 2 feet**	**2 to 4 feet**	**4 to 6 feet**	**6 to 10 feet**	**10 to 14 feet**	**> 14 feet**	**TOTAL (all coal)**	**TOTAL (thick coal)**
Castlegate D	42	49	0	0	0	0	91	0
Castlegate A	23	7	0	0	0	0	29	0
Gordon	14	17	8	0	0	0	39	8
Wattis	58	46	0	0	0	0	103	0
Blind Canyon	109	28	7	9	28	0	182	44
Cottonwood	137	167	43	35	0	0	382	78
Axel Anderson	87	151	315	10	0	0	564	326
Acord Lakes	24	154	265	1029	704	209	2384	2207
Knight	28	162	305	639	280	39	1454	1264
Upper Last Chance	59	210	27	29	0	0	325	56
Last Chance	90	50	4	0	0	0	145	4
TOTAL								
all coal	671	1041	975	1751	1013	248	5698	—
thick coal	—	—	975	1751	1013	248	—	3987
PERCENT								
all coal	12	18	17	31	18	4	100	—
thick coal	—	—	24	44	25	6	—	100

TOTAL values may differ from results obtained by summing rows or columns due to rounding.

Table 7. *Original coal resource in beds more than 4 feet thick, by depth below the surface, southern Wasatch Plateau, Utah (millions of tons).*

	DEPTH (feet)							
COAL BED	< 100	100 to 1000	1000 to 2000	2000 to 3000	3000 to 4000	4000 to 5000	> 5000	TOTAL
Gordon	0	2	6	0	0	0	0	8
Blind Canyon	0	8	36	0	0	0	0	44
Cottonwood	2	40	35	1	0	0	0	78
Axel Anderson	1	33	90	74	63	63	1	326
Acord Lakes	33	601	716	412	264	175	5	2207
Knight	16	309	479	222	125	109	4	1264
U. Last Chance	7	48	1	0	0	0	0	56
Last Chance	0	4	0	0	0	0	0	4
TOTAL	60	1045	1363	709	452	346	10	3986
PERCENT	2	26	34	18	11	9	0	100

TOTAL may differ from results obtained by summing rows or columns due to rounding.

Table 8. *Coal lost to mining and undermining of eight coal beds, by bed thickness, southern Wasatch Plateau, Utah (millions of tons).*

	THICKNESS CATEGORY						
COAL BED	4 to 6 feet	6 to10 feet	10 to 14 feet	> 14 feet	TOTAL LOST[2]	PERCENT LOST	REMAINING ORIGINAL COAL
Gordon	0	0	0	0	0	0	8
Blind Canyon	0	0	0	0	0	0	44
Cottonwood (undermined)	3	0	0	0	3	4	74
Axel Anderson	0	0	0	0	0	0	326
Acord Lakes (mined)	0	2	82	86	170	8	2037
Knight (mined)	<1[1]	<1[1]	0	0	<1[1]	<1	1264
Upper Last Chance	0	0	0	0	0	0	56
Last Chance	0	0	0	0	0	0	4
TOTAL LOST [2]	3	2	47	49	174		
PERCENT LOST	<1	<1	5	23		4	
TOTAL REMAINING	970	1749	931	162			3812

[1] Small mines and prospects have removed about 37,000 tons of 4- to 6-foot-thick coal, and 100,000 tons of 6- to 10-foot-thick coal from the Knight coal bed.
[2] TOTAL may differ from results obtained by summing rows or columns due to rounding.

sents about 4% of the original coal in beds more than 4 feet thick. More significantly, table 8 shows that 95% of the coal that has been mined from the southern Wasatch Plateau has come from beds more than 10 feet thick.

Coal Lost to Technical Restrictions

Technical restrictions to mining are listed in table 3. Table 9 shows that about one-third of the remaining minable coal (coal beds more than 4 feet thick not lost to mining) cannot be mined because of these technical restrictions. Note that a barrier around abandoned mines is listed as a technical restriction in table 3 but results for this restriction are not listed in table 9. The amount of coal lost to this restriction is trivial and included with the coal lost to mining as shown in table 9. Finally, note that a lost coal tonnage is individually tabulated for each restriction listed in table 9, but the net restricted coal is less than the sum of the individual restrictions. This is because the net restricted coal does not double-count coal in areas subject to more than one technical restriction.

Examination of table 9 shows two significant technical restrictions. Twenty percent (809 million tons) of the remaining original coal in beds more than 4 feet thick cannot be mined because it is more than 3000 feet deep. This is notable since none of the coal in the northern part of the Wasatch Plateau is more than 3000 feet deep (Tabet and others, 1999). Perhaps most surprising is the large amount of coal lost to insufficient interburden separation; 15% (576 million tons) of the otherwise minable coal in the southern Wasatch Plateau is lost to this restriction.

Less coal is lost to other technical restrictions. Coal less than 100 feet deep, about 59 million tons, is presumed burned or oxidized. A portion of 20 million tons of coal is lost in parts of the Acord Lakes and Knight coal beds that are more than 14 feet thick; this excessively thick coal cannot be recovered using current mining methods. A quantity of about 12 million tons of coal is adjacent to known faults and cannot be mined safely. Much more coal would have been lost to faulting had we included coal within the complexly faulted Joes Valley graben in our calculations. We excluded this coal because faults within the Joes Valley graben are so prevalent and closely spaced that any coal beds would be broken into numerous small blocks. The small size of these blocks makes economic extraction doubtful. Moreover, substantially more drill-hole records and further verification of outcrop observations are required to make useful coal resource maps of this structurally complex area.

Coal Lost to Land-Use Restrictions

Land-use restrictions exclude 58 million tons of coal (table 10), which represents about 2% of the technically minable coal resource in the study area. Nearly all of this lost coal (56 million tons) results from rules that prohibit mining under lakes and perennial streams. The direct effect of other land-use restrictions is trivial: about 2 million tons of coal lost because of rules that prohibit undermining of roads, power lines, or oil and gas wells. The remote, undeveloped character of the study area explains the small effect of these restrictions.

Arguably, land-use restrictions are less certain than technical restrictions. For example, some land-use restrictions can be mitigated (roads and power lines can be moved). The effects of other restrictions not considered in our study (such as surface rules that prohibit motorized vehicles) are less easily quantified, but can effectively reduce resource extraction where they limit placement of ventilation and emergency exit shafts, and decrease mine safety. Moreover, land-use restrictions are essentially defined by regulations; such regulations will probably change in the future.

THE AVAILABLE COAL RESOURCE

Of the 5698 million tons of original coal in the study area, the lost resource is 1712 million tons in beds that are too thin to mine, 174 million tons lost to past mining, 1291 million tons cannot be mined because of technical restrictions, and 58 million tons cannot be mined because of land-use regulations. This leaves an available coal resource of 2463 million tons, or 43% of the original coal resource.

Table 11 shows that 20% of the available coal resource (509 million tons) is in coal beds that are between 4 and 6 feet thick. Such relatively thin coal is rarely mined in Utah, where current economic considerations limit mining to coal beds that are more than 6 feet thick. Considering only the coal in beds that are more than 6 feet thick reduces the available coal resource to 1954 million tons.

About 48% of the available coal resource is demonstrated, 45% is inferred, and 7% is hypothetical. The reliability of the available coal resource according to coal bed and thickness category is shown in table 12.

Table 9. *Coal lost to technical restrictions for eight coal beds, southern Wasatch Plateau, Utah (millions of tons).*

COALBED	REMAINING ORIGINAL COAL	TECHNICAL RESTRICTIONS: *too shallow*	*too deep*	*too thick*	*insufficient interburden*	*near fault*	NET RESTRICTED COAL	TECHNICALLY MINABLE COAL
Gordon	8	0	0	0	0	0	0	8
Blind Canyon	44	0	0	0	0	1	1	43
Cottonwood	74	2	0	0	0	1	2	72
Axel Anderson	326	1	127	0	128	1	221	105
Acord Lakes	2037	32	444	15	177	4	666	1371
Knight	1264	16	238	5	267	2	390	874
U. Last Chance	56	7	0	0	0	3	8	48
Last Chance	4	0	0	0	4	1	4	0
TOTAL	3812	59	809	20	576	12	1291	2521
PERCENT RESTRICTED		2	21	<1	15	<1	34	

REMAINING ORIGINAL COAL is the coal in beds more than 4 feet thick that has not been lost to mining through 2000.

TECHNICAL RESTRICTIONS are individually tabulated for coal that is:

too shallow	less than 100 feet burial (weathered)
too deep	more than 3000 feet burial
too thick	part of a coal bed that is more than 14 feet thick
insufficient interburden	a coal bed more than 4 feet thick within 40 feet of a thicker or better coal bed
near fault	coal within 50 feet of a fault

NET RESTRICTED COAL is the total coal made unavailable due to technical restrictions; coal in areas subject to multiple restrictions is counted only once.

TOTAL values may differ from results obtained by summing columns due to rounding.

Table 10. *Coal lost to land-use restrictions for seven coal beds, southern Wasatch Plateau, Utah (millions of tons).*

COAL BED	TECHNICALLY MINABLE COAL	LAND-USE RESTRICTIONS: *Streams and lakes*	*Improved roads*	*Power lines*	*Oil wells*	NET RESTRICTED COAL	TOTAL AVAILABLE COAL
Gordon	8	0	0	0	0	0	8
Blind Canyon	43	<1	0	0	0	<1	43
Cottonwood	72	<1	0	0	0	<1	72
Axel Anderson	105	4	0	0	0	4	101
Acord Lakes	1371	29	<1	0	<1	29	1341
Knight	874	22	2	1	<1	24	850
U. Last Chance	48	0	0	0	<1	<1	48
TOTAL	2521	56	2	1	<1	58	2463
% RESTRICTED		2	<1	<1		2	

TECHNICALLY MINABLE COAL is coal in beds more than 4 feet thick that has not been lost to mining through 2000 and is not affected by technical restrictions.
NET RESTRICTED COAL does not double-count coal in areas subject to multiple land-use restrictions.
TOTAL values may differ from results obtained by summing rows or columns due to rounding.

Table 11. *The available coal resource for seven coal beds as of January 2001, by bed thickness, southern Wasatch Plateau, Utah (millions of tons).*

COAL BED	COALBED THICKNESS: 4 to 6 feet	6 to 10 feet	10 to 14 feet	> 14 feet	TOTAL AVAILABLE COAL
Gordon	8	0	0	0	8
Blind Canyon	6	8	28	0	43
Cottonwood	38	33	0	0	72
Axel Anderson	92	10	0	0	101
Acord Lakes	197	696	346	103	1341
Knight	145	407	264	33	850
U. Last Chance	23	25	0	0	48
TOTAL	509	1179	638	137	2463
PERCENT	21	48	26	6	

TOTAL may differ from results obtained by summing rows or columns due to rounding.

Table 12. *Reliability of the available coal resource for seven coal beds, by bed thickness, southern Wasatch Plateau, Utah (millions of tons).*

COAL BED	COALBED THICKNESS / Reliability: 4 to 6 feet			6 to 10 feet			10 to 14 feet			>14 feet			TOTAL
	Dem	*Inf*	*Hyp*	*Dem*	*Inf*	*Hyp*	*Dem*	*Inf*	*Hyp*	*Dem*	*Inf*	*Hyp*	
Gordon	8	0	0	0	0	0	0	0	0	0	0	0	8
Blind Canyon	3	3	0	0	8	0	0	27	1	0	0	0	43
Cottonwood	10	23	6	23	11	0	0	0	0	0	0	0	72
Axel Anderson	13	62	16	7	2	0	0	0	0	0	0	0	101
Acord Lakes	110	78	8	245	393	57	180	148	18	101	2	0	1341
Knight	112	29	4	209	174	25	109	131	25	27	6	0	850
U. Last Chance	12	11	0	13	11	1	0	0	0	0	0	0	48
TOTAL	269	206	34	497	599	83	288	306	44	129	8	0	2463
PERCENT	11	8	1	20	24	3	12	12	2	5	0	0	

Reliability category abbreviations: *Dem* is Demonstrated, *Inf* is Inferred, and *Hyp* is Hypothetical (after Wood and others 1983).
TOTAL may differ from results obtained by summing rows or columns due to rounding.

Comparison to Previous Resource Estimates

Besides the actual amount of in-ground coal, the size of the coal resource calculated for the southern Wasatch Plateau depends on the scope of the study and criteria used to identify the coal resource. For example, although Doelling (1972) used the same 3000-foot maximum depth restriction that we use, his resource estimate does not include coal in the Heliotrope Mountain quadrangle, whereas ours does. Although resource estimates by the USGS (Hayes and Sanchez, 1979; Sanchez and Hayes, 1979; Sanchez and Brown, 1983, 1987; Sanchez and others, 1983a, 1983b) included coal in all nine quadrangles that we examine, they excluded coal in beds between 2000 and 3000 feet deep, which we include in our estimate. A more recent USGS study (Dubiel and others, 2000) included coal up to 3000 feet deep, but used a minimum 3.5-foot bed thickness; we use a minimum 4-foot bed thickness. Despite these (and other) differences, coal resource tonnage estimates from earlier studies are compared with our results in table 13. Note that this comparison required that we combine resource estimates for demonstrated and inferred reliability categories into their parent, identified resource category (Wood and others, 1983). The sum of Doelling's Class I, Class II, and Class III resource categories is equivalent to the identified resource, whereas his Class IV resource category is equivalent to our hypothetical resource category.

Our calculations show 1320 million tons (70%) more coal than calculated by Doelling (1972). The difference is attributed to the greater number of exploration drill holes made available since Doelling's 1972 study. Because we use more inclusive criteria (footnote 4, table 13) than the USGS investigations of the late 1970s and 1980s (footnote 2, table 13), our estimates are correspondingly greater. Conversely, the most recent USGS study (Dubiel and others, 2000) calculated resources from a single map showing net coalbed thickness (all coal beds combined) rather than summing resources derived from maps of the minable portions of individual coal beds. The different calculation methods are probably the biggest reason why our resource estimate is less than that of Dubiel and others (2000).

Table 13. *Coal resource estimates from previous studies compared to results from this study, southern Wasatch Plateau, Utah (millions of tons).*

	Identified[5]	Hypothetical	Total
Doelling(1972)[1]	1543	314	1857
USGS (1979-87)[2]	720	NA	720
Dubiel and others (2000)[3]	4150	1438	5588
This study[4]	2966	212	3177

[1] Coal beds more than 4 feet thick and less than 3000 feet deep; excludes coal in the Heliotrope Mountain quadrangle.

[2] Coal beds more than 3.5 feet thick and less than 2000 feet deep; no hypothetical resource calculated, and only part of Heliotrope Mountain quadrangle considered.

[3] Coal beds more than 3.5 feet thick and less than 3000 feet deep; calculated from total net coal thickness rather than individual beds.

[4] Coal beds more than 4 feet thick and less than 3000 feet deep.

[5] Includes both the demonstrated and the inferred coal resource.

Finally, it is worth noting two differences between our study and earlier efforts. First, we estimate the coal resource for individual coal beds in the Blackhawk Formation. Second, we provide maps of these coal beds, which show where the available coal is located (appendix D).

Fragmentation of the Available Coal Resource

Fragmentation of the coal resource by mining activities reduces the amount of available coal that can be economically mined. Although not examined in this study, a related study of the northern Wasatch Plateau (Tabet and others, 1999) showed that small blocks of coal (fragments) are commonly left behind by previous mining operations. These fragments are common between old mine workings and the outcrop and are probably not large enough to be economically mined. For example, about 16% of the available coal resource in the Blind Canyon bed of the northern Wasatch Plateau is in isolated blocks that are less than 1000 acres (Tabet and others, 1999); this fragmented coal is unlikely to be mined. Qualitatively, coal beds in the southern Wasatch Plateau appear to be less fragmented than those in the northern Wasatch Plateau. Nonetheless, the example of the Blind Canyon bed indicates that only part of the available coal resource in the southern Wasatch Plateau will be mined. Engineering studies that examine the economics of mining variously sized blocks are needed to determine how much of this coal can be economically recovered.

DISCUSSION

Coal production records compiled by Jahanbani (2001) show that mines in the southern Wasatch Plateau produced 80 million tons of coal through 2000, whereas our calculations show a loss of 170 million tons to mining and undermining in this area. These observations suggest a 47% recovery factor. Undermining of higher coal beds is insignificant in the study area (4 million tons); subtracting undermined coal from the total coal disturbed by mining changes the recovery factor by less than one percent.

Studies by Doelling (1972) and Tabet and others (1999) indicated that mining in the northern Wasatch Plateau and Book Cliffs coalfields recover about 35% of the available coal, which is substantially less than the 47% recovery we observe for the southern Wasatch Plateau. We attribute the higher recovery factor for southern Wasatch Plateau to the use of efficient longwall mining methods in the study area. However, despite the inherent efficiency of longwall mining, this method is subject to more and increasingly stringent land-use restrictions. For example, older mining methods could more easily mine around restricted areas; longwall mines are less flexible since they require large intact blocks of coal. Consequently, larger amounts of coal are lost where longwall operations encounter restricted coal. Moreover, current land-use policies increasingly limit areas where mining is permitted. These factors suggest that the 47% recovery factor observed in the southern Wasatch Plateau cannot be sustained. Ultimate recovery of the available coal in the study area will probably be closer to the 35% recovery observed in other Utah coalfields.

A conservative estimate of how much coal is likely to be mined from the southern Wasatch Plateau in the near future would ignore coal in beds that are less than 6 feet thick. This would eliminate 509 million tons (21%) of the available coal resource identified in this report. Considering only this thicker coal, the maps of the Upper Last Chance and Axel Anderson beds (appendix D) show that these two beds have very small areas of thick coal. Consequently, by themselves, these two coal beds lack sufficient resources to support a large mining operation (and probably cannot be mined in combination with another thick bed). Thus, the 35 million tons of 6- to 10-foot-thick coal in these two beds is unlikely to be mined in the near future. Eliminating both the thinner and small resource areas from the remaining available coal lowers the total by 544 million tons to 1919 million tons of coal. This does not account for any further resource reductions for poor quality coal, coal at depths between 2500 and 3000 feet, or the possibility of more stringent land-use restrictions. If we assume a recovery factor of 35% for the 1919 million tons of available resources, then the recoverable coal in the southern Wasatch Plateau is about 670 million tons.

SUMMARY AND CONCLUSIONS

The southern Wasatch Plateau has 2463 million tons of available coal. About half of this coal is a demonstrated resource (within 0.75 miles of a drill-hole or outcrop measurement) and the rest is less reliably known. Eleven coal beds in the Cretaceous-age Blackhawk Formation are recognized; two beds (the Acord Lakes and the Knight coal beds) contain 90% of the available coal. This coal is too deeply buried for surface mining, but is suitable for underground mining. Coal quality data indicate a high volatile C bituminous rank over much of the study area, with rank increasing to the north. Coal sulfur and coal mercury contents, as well as in-ground coalbed methane, are exceptionally low.

Through 2003, coal mines recovered 80 million tons of coal from the study area. We conservatively estimate that 670 million tons of the remaining coal can be recovered. Assuming continued production of 7 million tons of coal per year, the resource is sufficient for more than 90 years of coal production.

ACKNOWLEDGMENTS

The U.S. Geological Survey partially funded this study under award number 01ERAG0008. We especially thank M. Devereux Carter and Timothy J. Rohrbacher (USGS) for helpful discussion and encouragement. The Utah State Office of the U.S. Bureau of Land Management helped us acquire recent drilling information. The Utah Division of Oil, Gas, and Mining provided access to annual reports from active coal mines and data on the location of active oil and gas wells, as well as guidance on land-use restrictions in the area. The Utah Automated Geographic Reference Center provided digital land grid, topographic, road, stream, and power line coverages for the study area.

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APPENDICES

APPENDIX A

Proximate Analyses for Coal Samples from the Southern Wasatch Plateau, Utah

				Assay Values[1]					
Quadrangle	Cadastral Location	Mine or Drill Hole	Bed Name	Moisture	VM	FC	Ash	Sulfur	Btu/lb
Flagstaff Pk.	01-20S-6E	BCR-1C1	Cottonwood	8.2	41.1	44.5	6.2	0.6	12061
Flagstaff Pk.	01-20S-6E	BCR-1C2	Axel Anderson	6.8	42.1	39.4	11.7	0.8	11397
Flagstaff Pk.	01-20S-6E	BCR-1C3	Acord Lakes(U)	8.4	36.8	42.2	12.6	0.7	10877
Flagstaff Pk.	01-20S-6E	BCR-1C4	Acord Lakes(U)	8.5	41.5	44.7	5.3	0.7	12143
Flagstaff Pk.	01-20S-6E	BCR-1C5	Acord Lakes(L)	8.4	39.5	42.8	9.3	1.6	11452
Flagstaff Pk.	33-20S-5E	MC-8-FP	Acord Lakes	6.9	37.6	46.7	8.8	1.5	11755
Flagstaff Pk.	33-20S-5E	MC-8-FP	Knight	7.9	38.7	47.7	5.7	0.8	11981
Flagstaff Pk.	35-20S-5E	Ricci	Acord Lakes	8.4	39.1	45.2	7.3	0.5	11922
Heliotrope Mtn	20-20S-5E	MC-74-HM	Axel Anderson	7.6	38.5	47.6	6.4	0.4	12144
Heliotrope Mtn	20-20S-5E	MC-74-HM	Acord Lakes	7.8	33.5	39.4	19.3	0.5	10047
Heliotrope Mtn	20-20S-5E	MC-74-HM	Knight	7.3	38.3	43.0	11.5	0.9	11322
Emery West	26-21S-5E	Link Cyn.	Acord Lakes	7.4	38.6	46.1	8.3	0.4	11770
Emery West	26-21S-5E	Link Cyn.	Acord Lakes	7.0	37.8	45.3	10.0	0.4	11570
Emery West	26-21S-5E	Link Cyn.	Acord Lakes	7.1	37.5	45.8	9.8	0.4	11590
Emery West	26-21S-5E	Link Cyn.	Acord Lakes	7.3	38.3	46.4	8.3	0.4	11730
Emery West	26-21S-5E	Link Cyn.	Acord Lakes	7.5	38.3	46.3	8.4	0.5	11710
Acord Lakes	13-21S-4E	MC-71-AL	Knight	7.3	39.0	44.9	8.8	0.9	11613
Acord Lakes	24-21S-4E	MC-18-AL	Rider	5.8	40.3	39.8	14.1	0.8	11094
Acord Lakes	24-21S-4E	MC-18-AL	Acord Lakes(U)	7.8	33.9	46.4	11.9	0.4	11246
Acord Lakes	24-21S-4E	MC-18-AL	Acord Lakes(L)	8.5	37.5	48.9	5.1	0.4	12080
Acord Lakes	24-21S-4E	MC-18-AL	Knight(U)	6.8	39.6	43.2	10.5	0.5	11553
Acord Lakes	24-21S-4E	MC-18-AL	Knight(U)	7.7	43.3	44.0	4.9	0.5	12313
Acord Lakes	24-21S-4E	MC-18-AL	Knight(L)	7.8	40.6	44.3	7.3	0.8	11867
Acord Lakes	24-21S-4E	MC-18-AL	Knight(L)	6.8	36.3	31.3	25.7	1.4	9073
Acord Lakes	34-21S-4E	MC-21-AL	Knight	6.5	36.9	41.1	15.5	0.9	10857
Acord Lakes	02-22S-4E	BCR-4	Knight	8.5	40.1	44.5	6.9	1.1	11705
Acord Lakes	04-22S-4E	CSC-32	Acord Lakes	6.8	NA	NA	15.9	0.5	10827
Acord Lakes	04-22S-4E	CSC-47	Acord Lakes	9.7	NA	NA	9.2	0.6	11305
Acord Lakes	05-22S-4E	CSC-19	Acord Lakes	6.6	NA	NA	15.0	0.4	10798
Acord Lakes	05-22S-4E	CSC-51	Acord Lakes	10.7	NA	NA	8.6	0.4	10744
Acord Lakes	08-22S-4E	CSC-44	Acord Lakes	7.3	NA	NA	12.8	0.4	11097
Acord Lakes	09-22S-4E	CSC-52	Acord Lakes	8.6	NA	NA	10.0	0.5	11305
Acord Lakes	12-22S-4E	SUFCO	Acord Lakes	5.6	37.9	50.4	6.1	0.4	12260
Acord Lakes	12-22S-4E	SUFCO	Acord Lakes	8.5	37.2	48.1	6.7	0.3	11760
Acord Lakes	12-22S-4E	SUFCO	Acord Lakes	8.2	36.2	48.8	7.1	0.5	11810
Acord Lakes	12-22S-4E	SUFCO	Acord Lakes	8.8	36.7	48.3	6.0	0.5	11840
Acord Lakes	12-22S-4E	SUFCO	Acord Lakes	10.4	37.7	46.4	5.9	0.5	11530
Acord Lakes	12-22S-4E	SUFCO	Acord Lakes	8.7	38.3	46.1	6.6	0.5	11790

Appendix A (continued)

Acord Lakes	12-22S-4E	SUFCO	Acord Lakes	8.6	39.0	45.5	6.6	0.5	11780
Acord Lakes	12-22S-4E	SUFCO	Acord Lakes	8.8	39.4	45.5	6.1	0.5	11900
Acord Lakes	12-22S-4E	SUFCO	Acord Lakes	9.5	40.6	43.3	7.1	0.6	11390
Acord Lakes	12-22S-4E	SUFCO	Acord Lakes	9.5	38.9	45.4	6.7	0.5	11740
Acord Lakes	12-22S-4E	SUFCO	Acord Lakes	9.3	39.7	45.1	6.3	0.4	11670
Acord Lakes	12-22S-4E	SUFCO	Acord Lakes	7.7	38.6	39.3	5.2	0.8	10630
Acord Lakes	17-22S-4E	CSC-14	Acord Lakes	7.7	NA	NA	8.0	0.5	11833
Johns Pk.	03-24S-4E	prospect	Knight	13.9	35.2	43.6	7.3	0.6	10540
Johns Pk.	10-24S-4E	Clear Crk.	Knight	12.9	37.2	43.9	6.0	0.6	10600
Johns Pk.	15-24S-4E	WP-7-1a	Acord Lakes(U)	13.1	32.0	39.2	15.7	0.8	9440
Johns Pk.	15-24S-4E	WP-7-1b	Acord Lakes(L)	9.3	26.8	30.4	33.5	0.6	7510
Johns Pk.	15-24S-4E	WP-7-2	U. Last Chance	11.9	34.6	44.8	8.7	2.3	10500
Johns Pk.	21-24S-4E	WP-8-1	Acord Lakes	13.7	25.6	26.3	34.4	0.6	6440
Johns Pk.	21-24S-4E	WP-8-2	U. Last Chance	13.0	28.3	29.1	29.6	0.5	7430

[1]Assay values on an as-received basis where, **Moist** is weight percent moisture, **VM** is weight percent volatile matter, **FC** is weight percent fixed carbon, and **Btu/lb** is gross British thermal units per pound (multiply by 0.002326 to convert to MJ/kg).

APPENDIX B

Vitrinite Reflectance, Group Maceral Content, and Density of Coal Samples from the Southern Wasatch Plateau, Utah

Quadrangle	Cadastral Location	Drill Hole or Mine Name	Coalbed Name	UGS ID	Ro max	Vit.	Lipt.	Inert.	Density (g/cc)
Acord Lakes	02-22S-04E	BCR-4	Acord Lakes	200	0.63	71	3	26	1.34
Acord Lakes	05-22S-05E	US-79-14	Acord Lakes	202	0.52	88	7	6	—
Acord Lakes	05-22S-05E	US-79-15	Acord Lakes	211	0.53	75	3	22	—
Acord Lakes	05-22S-05E	US-79-12	Acord Lakes	216	0.52	70	7	23	—
Acord Lakes	07-22S-05E	US-79-2	Acord Lakes	218	0.48	82	6	13	—
Acord Lakes	08-22S-05E	US-79-6	Acord Lakes	203	0.52	78	3	18	—
Acord Lakes	12-22S-04E	SUFCO	Acord Lakes	622.1	0.50	53	8	39	1.40
Acord Lakes	12-22S-04E	SUFCO	Acord Lakes	622.2	0.51	79	4	17	1.35
Acord Lakes	12-22S-04E	SUFCO	Acord Lakes	622.3	0.48	77	7	16	1.34
Acord Lakes	16-21S-05E	CH-83-6	Acord Lakes	686	0.47	92	5	4	1.33
Acord Lakes	24-21S-04E	MC-18-AL	Acord Lakes	219	0.57	68	3	28	1.34
Acord Lakes	25-21S-04E	US-81-4	Acord Lakes	308	0.51	71	11	18	1.33
Acord Lakes	25-21S-04E	DH 81-1	Acord Lakes	310	0.55	71	5	24	1.41
Acord Lakes	29-21S-04E	SUFCO	Acord Lakes	628	0.49	64	4	32	1.39
Acord Lakes	29-21S-04E	SUFCO	Acord Lakes	628.1	0.47	84	5	11	1.33
Acord Lakes	29-21S-04E	SUFCO	Acord Lakes	628.2	0.48	62	5	33	1.36
Acord Lakes	29-21S-04E	SUFCO	Acord Lakes	628.3	0.48	56	5	39	1.41
Acord Lakes	30-21S-05E	US-81-1	Acord Lakes	309	0.53	68	6	26	1.35
Acord Lakes	17-21S-05E	CH-84-9	Axel Anderson	697	0.53	76	7	17	1.42
Acord Lakes	02-22S-04E	BCR-4	Knight	228	0.53	89	5	7	1.32
Acord Lakes	13-21S-04E	MC-71-AL	Knight	282	0.61	86	5	9	1.32
Acord Lakes	17-21S-05E	CH-84-9	Knight	698	0.47	74	8	18	1.41
Acord Lakes	24-21S-04E	MC-18-AL	Knight	233	0.55	84	2	14	1.31
Acord Lakes	28-21S-04E	MC-109c/22	Knight	328	0.52	79	10	11	1.39
Acord Lakes	16-21S-05E	CH-83-6	unknown	684	0.49	84	7	9	1.31
Acord Lakes	16-21S-05E	CH-83-6	unknown	685	0.52	87	7	7	1.38
Acord Lakes	16-21S-05E	CH-83-6	unknown	687	NA	84	6	10	1.46
Emery West	14-21S-05E	CH-83-1	Acord Lakes	669	0.47	88	6	6	1.36
Emery West	21-21S-05E	BCR-3	Acord Lakes	212	0.56	45	6	49	1.38
Emery West	21-21S-05E	BCR-3	Acord Lakes	215	0.60	72	4	25	1.35
Emery West	24-21S-05E	CH-83-3	Acord Lakes	666	0.49	79	7	15	1.32
Emery West	14-21S-05E	CH-83-1	Axel Anderson	670	0.49	86	9	5	1.33
Emery West	21-21S-05E	CH-83-2	Axel Anderson	671	0.51	84	9	7	1.32
Emery West	22-21S-05E	CH-84-17	Axel Anderson	706	0.46	77	13	10	1.39
Emery West	28-21S-05E	CH-83-4	Axel Anderson	632	0.46	77	11	12	1.32
Emery West	14-21S-05E	CH-83-1	Knight	667	0.48	87	6	7	1.34
Emery West	14-21S-05E	CH-83-1	Knight	668	0.46	83	5	13	1.32
Emery West	22-21S-05E	CH-84-17	Knight	709	0.46	80	7	13	1.35
Emery West	23-21S-05E	CH-83-7	Knight	691	0.48	80	7	13	1.40
Emery West	24-21S-05E	CH-83-3	Knight	665	0.48	81	7	12	1.35

Appendix B (continued)

Emery West	28-21S-05E	CH-83-4	Knight	636	0.49	90	5	5	1.34
Emery West	22-21S-05E	CH-84-17	rider	707	0.45	87	7	6	1.38
Emery West	22-21S-05E	CH-84-17	rider	708	0.42	90	7	3	1.36
Emery West	23-21S-05E	CH-83-7	rider	690	0.47	76	8	16	1.46
Emery West	28-21S-05E	CH-83-4	rider	633	0.47	76	14	11	1.31
Emery West	28-21S-05E	CH-83-4	rider	634	0.48	90	4	6	1.35
Emery West	28-21S-05E	CH-83-4	rider	635	0.43	80	7	14	1.36
Ferron Canyon	14-19S-05E	FC-14-26	Acord Lakes	316	0.52	81	9	10	1.43
Flagstaff Peak	02-21S-05E	CH-83-8	Acord Lakes	693	0.51	71	7	22	1.38
Flagstaff Peak	10-21S-05E	CH-83-5	Acord Lakes	673	0.47	86	7	8	1.35
Flagstaff Peak	02-21S-05E	CH-83-8	Axel Anderson	692	0.53	76	8	16	1.34
Flagstaff Peak	10-21S-05E	CH-83-5	Axel Anderson	672	0.48	82	7	11	1.42
Flagstaff Peak	10-21S-05E	CH-83-5	Knight	674	0.43	89	5	6	1.37
Flagstaff Peak	10-21S-05E	CH-83-5	Knight	675	0.47	87	5	9	1.34
Heliotrope Mtn	20-20S-05E	MC-74-HM	Acord Lakes	280	0.62	83	5	12	1.34
Heliotrope Mtn	20-20S-05E	MC-74-HM	Axel Anderson	283	0.52	88	5	8	1.31
Heliotrope Mtn	20-20S-05E	MC-74-HM	Knight	281	0.56	83	7	10	1.35
Old Woman Plateau	27-22S-04E	DH-80-1	Knight	284	0.50	69	12	19	1.39

Notes: Data are from Hucka and others (1997). Some samples represent a partial bed thickness. **Ro max** is mean maximum reflectance of vitrinite. **Vit**., **Lipt**., and **Inert**. are volume percent vitrinite, liptinite, and inertinite, all on a mineral-free basis. **Density** was determined on air-dried coal using a helium pycnometer.

APPENDIX C

Gas Desorption Values for Coal Samples from the Southern Wasatch Plateau, Utah

Quadrangle	Cadastral Location	Drill Hole Name	Coalbed Name	Sample Number	Gas Content (cubic ft/ton)
Ferron Canyon	14-19S-5E	FC-14-26	Acord Lakes	316	6.7
Heliotrope Mtn	20-20S-5E	MC-74-HM	Axel Anderson	283	0.0
Heliotrope Mtn	20-20S-5E	MC-74-HM	Acord Lakes	280	0.0
Heliotrope Mtn	20-20S-5E	MC-74-HM	Knight	281	0.0
Flagstaff Peak	33-20S-5E	MC-8-FP	Acord Lakes	275	0.0
Flagstaff Peak	33-20S-5E	MC-8-FP	Knight	272	3.2
Flagstaff Peak	02-21S-5E	BCR-3	Acord Lakes	215	6.4
Flagstaff Peak	08-21S-5E	US-79-4	Acord Lakes	222	6.4
Acord Lakes	13-21S-4E	MC-71-AL	Knight	282	0.0
Acord Lakes	24-21S-4E	MC-18-AL	Acord Lakes	219	12.8
Acord Lakes	24-21S-4E	MC-18-AL	Knight	233	9.6
Acord Lakes	25-21S-4E	US-81-4	Acord Lakes	308	1.9
Acord Lakes	25-21S-4E	DH-81-1	Acord Lakes	310	0.0
Acord Lakes	30-21S-5E	US-81-1	Acord Lakes	309	0.0
Acord Lakes	02-22S-5E	BCR-3	Acord Lakes	212	0.0
Acord Lakes	02-22S-4E	BCR-4	Acord Lakes	200	3.2
Acord Lakes	02-22S-4E	BCR-4	Knight	228	0.0
Acord Lakes	05-22S-5E	US-79-12	Cottonwood	234	12.8
Acord Lakes	05-22S-5E	US-79-12	Acord Lakes	216	0.0
Acord Lakes	05-22S-5E	US-79-14	Acord Lakes	202	0.0
Acord Lakes	05-22S-5E	US-79-15	Acord Lakes	211	0.0
Acord Lakes	07-22S-5E	US-79-2	Acord Lakes	218	3.2
Acord Lakes	08-22S-5E	US-79-6	Acord Lakes	203	0.0
Old Woman Plateau	27-22S-4E	DH-80-1	Knight	284	0.0
Old Woman Plateau	22-23S-4E	USGS-13a	Knight	111	0.0
Old Woman Plateau	34-22S-4E	USGS-12a	Knight	112	0.0

Notes to table: Data modified from Doelling and others (1979) and Smith (1986). Most samples represent a partial bed thickness.

APPENDIX D

Available Coal Resource Tabulations and Associated Maps Showing the Location of the Available Coal, Southern Wasatch Plateau, Utah

Table D1. *Available coal resource in 11 coal beds, Blackhawk Formation, southern Wasatch Plateau, Utah (millions of tons).*

	Coalbed Thickness (feet)						
	1 to 2	**2 to 4**	**4 to 6**	**6 to 10**	**10 to 14**	**>14**	**Total**
Original coal	671	1041	975	1751	1013	248	5698
Technical restrictions							
too thin	671	1041	—	—	—	—	1712
too deep	124	131	209	343	257	0	1065
weathered	13	19	17	33	6	4	92
faulted	2	3	2	4	1	0	12
mined-out	0	0	<1	2	82	86	170
insufficient interburden exclusion	—	—	296	271	9	0	576
undermined	16	19	4	0	0	0	39
excessive thickness	—	—	—	—	—	106	106
net restrictions	671	1041	455	545	355	110	3177
Technically minable coal	0	0	520	1206	657	138	2521
Land-use restrictions							
streams and lakes	—	—	10	26	18	2	56
roads	—	—	<1	1	1	0	2
power lines	—	—	<1	<1	0	0	1
oil and gas wells	—	—	<1	<1	0	0	<1
net restrictions	—	—	11	27	19	2	58
Available coal resource	0	0	509	1179	638	137	2463
Reliability							
demonstrated	—	—	269	497	288	129	1182
inferred	—	—	206	599	306	8	1119
hypothetical	—	—	34	83	44	0	161

Notes to Table:
Original coal excludes riders and sub-beds where interburden is more than one foot thick, or 20% of bed thickness.
Dash (—) indicates that the restriction is not applicable.
Row and column totals may differ from those obtained by adding table values due to rounding.
Net restriction totals may differ from those obtained by adding column values since coal in areas subject to multiple restrictions is counted only once.

Table D2. Available coal resource in the Last Chance coal bed, Blackhawk Formation, southern Wasatch Plateau, Utah (millions of tons).

	Coalbed Thickness (feet)						
	1 to 2	**2 to 4**	**4 to 6**	**6 to 10**	**10 to 14**	**>14**	**Total**
Original coal	90.1	50.5	4.5	0.0	0.0	0.0	145.0
Technical restrictions							
too thin	90.1	50.5	—	—	—	—	140.6
too deep	34.7	0.0	0.0	—	—	—	34.7
weathered	1.1	3.1	0.1	—	—	—	4.4
faulted	0.2	0.7	0.1	—	—	—	1.0
mined-out	0.0	0.0	0.0	—	—	—	0.0
insufficient interburden exclusion	—	—	4.4	—	—	—	4.4
undermined	0.0	0.0	0.0	—	—	—	0.0
excessive thickness	—	—	—	—	—	—	0.0
net restrictions	90.1	50.5	4.4	—	—	—	145.0
Technically minable coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Land-use restrictions							
streams and lakes	—	—	—	—	—	—	—
roads	—	—	—	—	—	—	—
power lines	—	—	—	—	—	—	—
oil and gas wells	—	—	—	—	—	—	—
net restrictions	—	—	—	—	—	—	—
Available coal resource	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reliability							
demonstrated	—	—	—	—	—	—	—
inferred	—	—	—	—	—	—	—
hypothetical	—	—	—	—	—	—	—

Notes to Table:
Original coal excludes riders and sub-beds where interburden is more than one foot thick or 20% of bed thickness.
Dash (—) indicates that the restriction is not applicable.
Row and column totals may differ from those obtained by adding table values due to rounding.
Net restriction totals may differ from those obtained by adding column values since coal in areas subject to multiple restrictions is counted only once.

No map for Last Chance bed

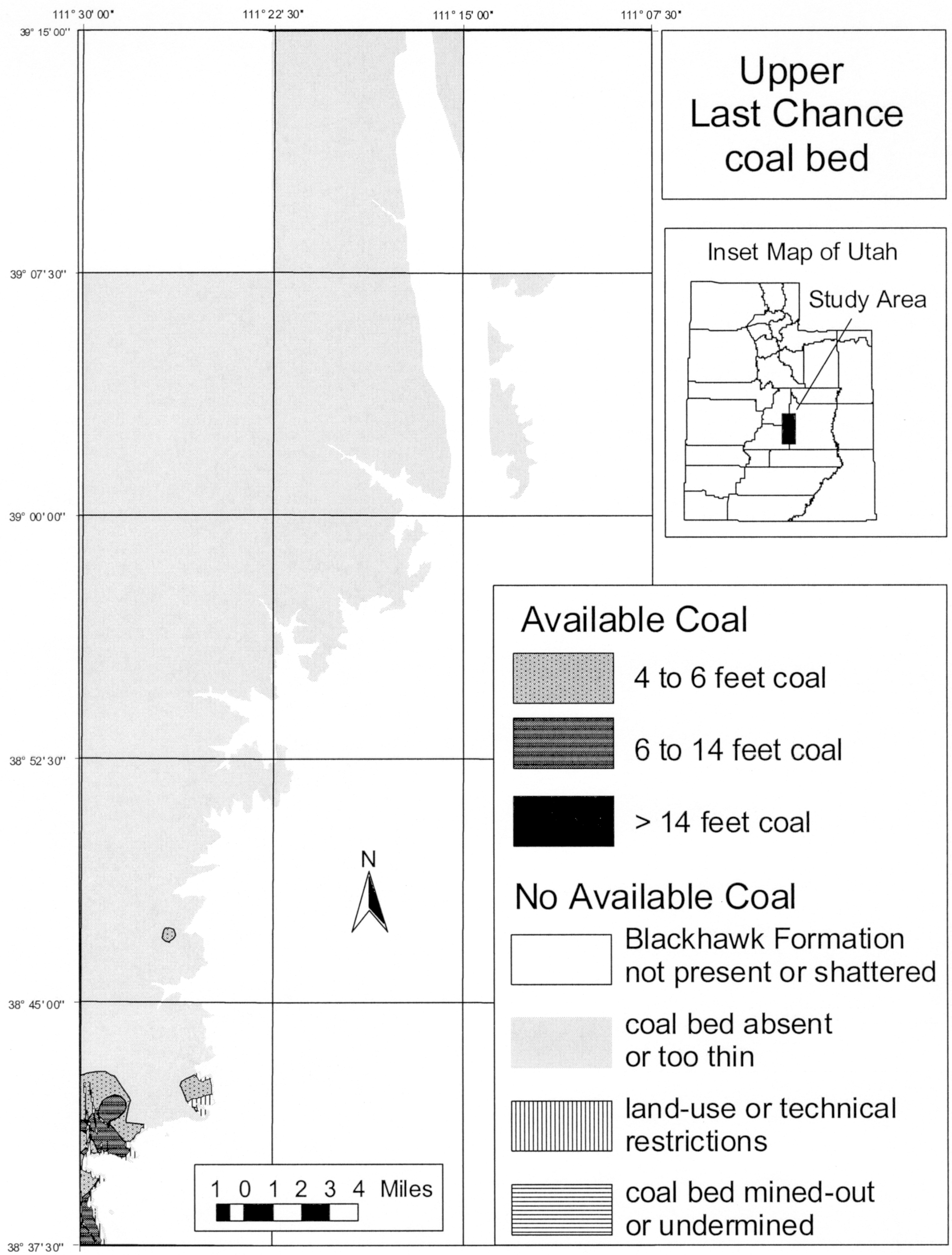

Figure D1. *Location of available coal resource for the Upper Last Chance coal bed, southern Wasatch Plateau, Utah.*

Table D3. *Available coal resource in the Upper Last Chance coal bed, Blackhawk Formation, southern Wasatch Plateau, Utah (millions of tons).*

	Coalbed Thickness (feet)						
	1 to 2	**2 to 4**	**4 to 6**	**6 to 10**	**10 to 14**	**>14**	**Total**
Original coal	59.0	209.8	26.7	29.0	0.0	0.0	324.5
Technical restrictions							
too thin	59.0	209.8	—	—	—	—	268.8
too deep	9.6	59.1	0.0	0.0	—	—	68.8
weathered	1.5	2.5	3.0	3.6	—	—	10.6
faulted	0.1	1.1	0.4	1.0	—	—	2.6
mined-out	0.0	0.0	0.0	0.0	—	—	0.0
insufficient interburden exclusion	—	—	0.0	0.0	—	—	0.0
undermined	0.0	0.0	0.0	0.0	—	—	0.0
excessive thickness	—	—	—	—	—	—	0.0
net restrictions	59.0	209.8	3.4	4.4	—	—	276.7
Technically minable coal	0.0	0.0	23.3	24.6	0.0	0.0	47.9
Land-use restrictions							
streams and lakes	—	—	0.0	0.0	—	—	0.0
roads	—	—	0.0	0.0	—	—	0.0
power lines	—	—	0.0	0.0	—	—	0.0
oil and gas wells	—	—	<0.1	0.0	—	—	<0.1
net restrictions	—	—	<0.1	<0.1	—	—	<0.1
Available coal resource	0.0	0.0	23.3	24.6	0.0	0.0	47.9
Reliability							
demonstrated	—	—	12.0	12.7	—	—	24.6
inferred	—	—	11.3	11.0	—	—	22.3
hypothetical	—	—	0.0	1.0	—	—	1.0

Notes to Table:
Original coal excludes riders and sub-beds where interburden is more than one foot thick or 20% of bed thickness.
Dots (—) indicate that the restriction is not applicable.
Row and column totals may differ from those obtained by adding table values due to rounding.
Net restriction totals may differ from those obtained by adding column values since coal in areas subject to multiple restrictions is counted only once.

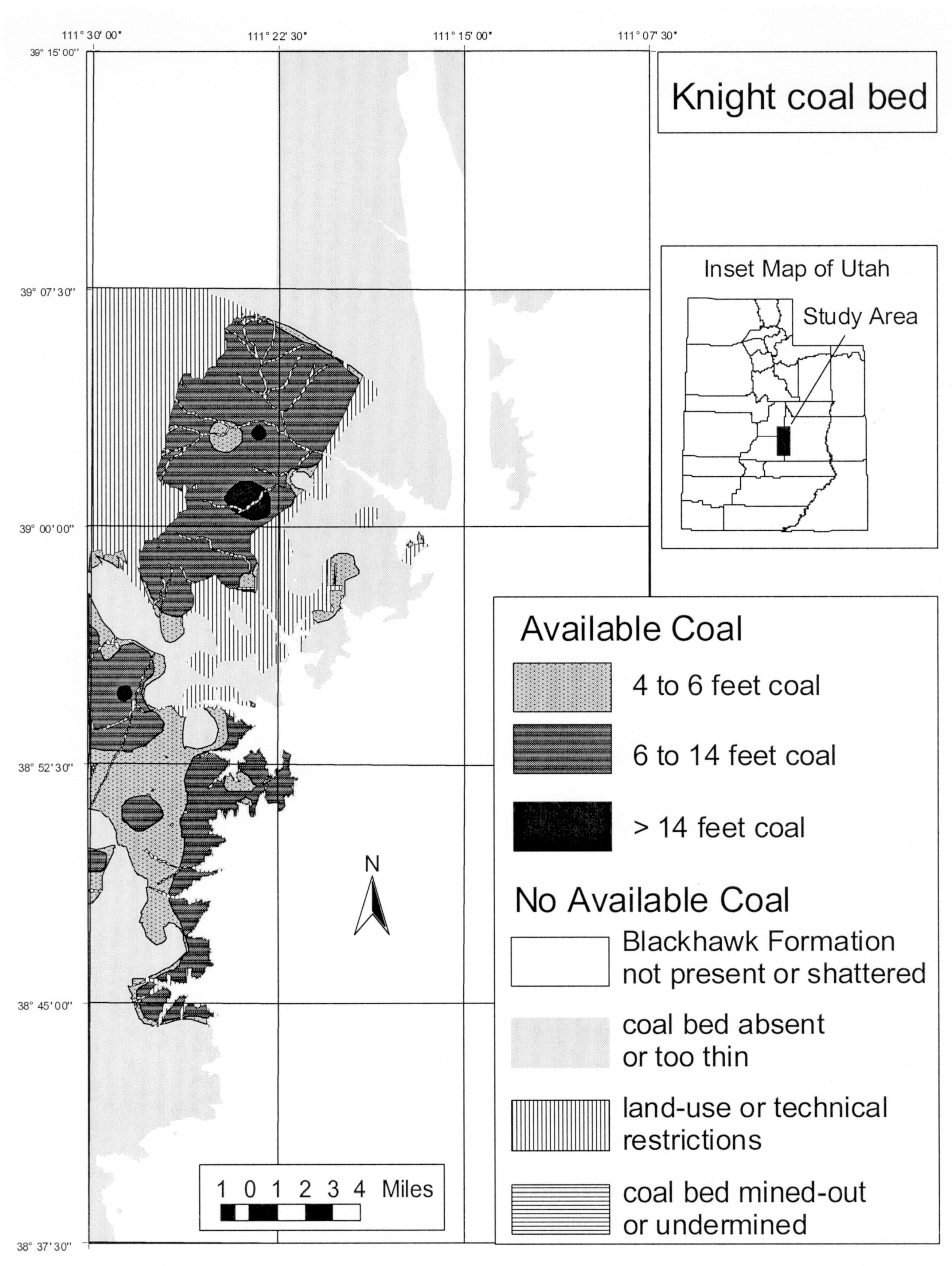

Figure D2. *Location of available coal resource for the Knight coal bed, southern Wasatch Plateau, Utah.*

Table D4. *Available coal resource in the Knight coal bed, Blackhawk Formation, southern Wasatch Plateau, Utah (millions of tons).*

	Coalbed Thickness (feet)						
	1 to 2	**2 to 4**	**4 to 6**	**6 to 10**	**10 to 14**	**>14**	**Total**
Original coal	28.4	161.9	304.7	639.1	280.5	39.2	1453.9
Technical restrictions							
too thin	28.4	161.9	—	—	—	—	190.4
too deep	0.1	2.6	71.2	164.6	2.0	<0.1	240.5
weathered	0.7	3.7	3.5	12.2	0.7	<0.1	20.8
faulted	0.1	0.2	0.5	1.1	0.5	<0.1	2.4
mined-out	0.0	0.0	0.0	0.1	0.0	0.0	0.1
insufficient interburden exclusion	—	—	116.8	149.3	1.1	<0.1	267.2
undermined	0.0	0.0	0.0	0.0	0.0	0.0	0.0
excessive thickness	—	—	—	—	—	4.7	4.7
net restrictions	28.4	161.9	157.5	223.0	4.9	4.7	580.5
Technically minable coal	0.0	0.0	147.2	416.1	275.5	34.6	873.4
Land-use restrictions							
streams and lakes	—	—	2.1	8.1	10.3	1.3	21.8
roads	—	—	0.1	0.6	0.8	0.0	1.5
power lines	—	—	0.5	0.1	0.0	0.0	0.6
oil and gas wells	—	—	<0.1	<0.1	0.0	0.0	<0.1
net restrictions	—	—	2.6	8.8	11.1	1.3	23.9
Available coal resource	0.0	0.0	144.6	407.3	264.4	33.2	849.5
Reliability							
demonstrated	—	—	112.4	208.8	108.4	27.3	456.8
inferred	—	—	28.5	173.6	130.7	6.0	338.8
hypothetical	—	—	3.7	24.9	25.3	0.0	53.9

Notes to Table:

Original coal excludes riders and sub-beds where interburden is more than one foot thick or 20% of bed thickness.
Dash (—) indicates that the restriction is not applicable.
Row and column totals may differ from those obtained by adding table values due to rounding.
Net restriction totals may differ from those obtained by adding column values since coal in areas subject to multiple restrictions is counted only once.

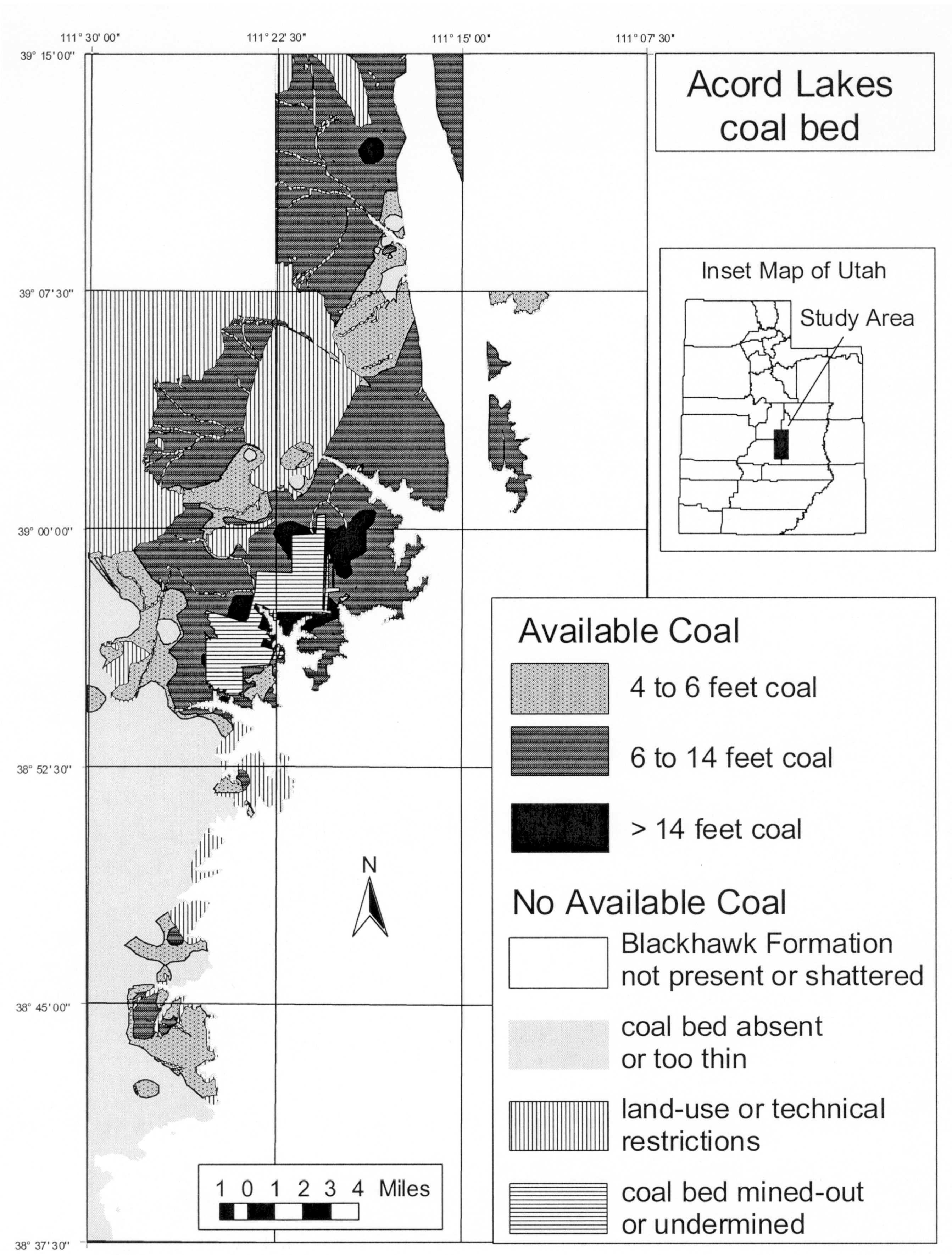

Figure D3. *Location of available coal resource for the Acord Lakes coal bed, southern Wasatch Plateau, Utah.*

Table D5. *Available coal resource in the Acord Lakes coal bed, Blackhawk Formation, southern Wasatch Plateau, Utah (millions of tons).*

	Coalbed Thickness (feet)					
	1 to 2	**2 to 4**	**4 to 6**	**6 to 10**	**10 to 14**	**>14**	**Total**
Original coal	23.7	154.0	265.1	1029.2	703.7	208.8	2384.4
Technical restrictions							
too thin	23.7	154.0		177.7			
too deep	0.0	0.0	10.6	178.5	255.1	0.0	444.1
weathered	1.3	2.5	7.1	16.4	5.2	4.4	37.0
faulted	0.2	0.7	1.0	1.4	0.7	0.0	4.0
mined-out	0.0	0.0	0.1	1.9	81.7	86.1	169.8
insufficient interburden exclusion	—	—	47.1	121.5	8.1	0.0	176.7
undermined	0.0	0.0	0.0	0.0	0.0	0.0	0.0
excessive thickness	—	—	—	—	—	101.6	101.6
net restrictions	23.7	154.0	64.1	316.5	350.5	105.0	1013.7
Technically minable coal	0.0	0.0	201.0	712.7	353.2	103.9	1370.7
Land-use restrictions							
streams and lakes	—	—	4.2	17.0	7.7	0.4	29.3
roads	—	—	0.1	0.1	<0.1	0.0	0.2
power lines	—	—	0.0	0.0	0.0	0.0	0.0
oil and gas wells	—	—	<0.1	<0.1	0.0	0.0	<0.1
net restrictions	—	—	4.2	17.1	7.7	0.4	29.5
Available coal resource	0.0	0.0	196.7	695.5	345.5	103.5	1341.2
Reliability							
demonstrated	—	—	110.4	245.1	180.0	101.5	637.1
inferred	—	—	78.3	393.2	147.9	2.0	621.4
hypothetical	—	—	8.0	57.2	17.6	0.0	82.8

Notes to Table:

Original coal excludes riders and sub-beds where interburden is more than one foot thick or 20% of bed thickness.
Dash (—) indicates that the restriction is not applicable.
Row and column totals may differ from those obtained by adding table values due to rounding.
Net restriction totals may differ from those obtained by adding column values since coal in areas subject to multiple restrictions is counted only once.

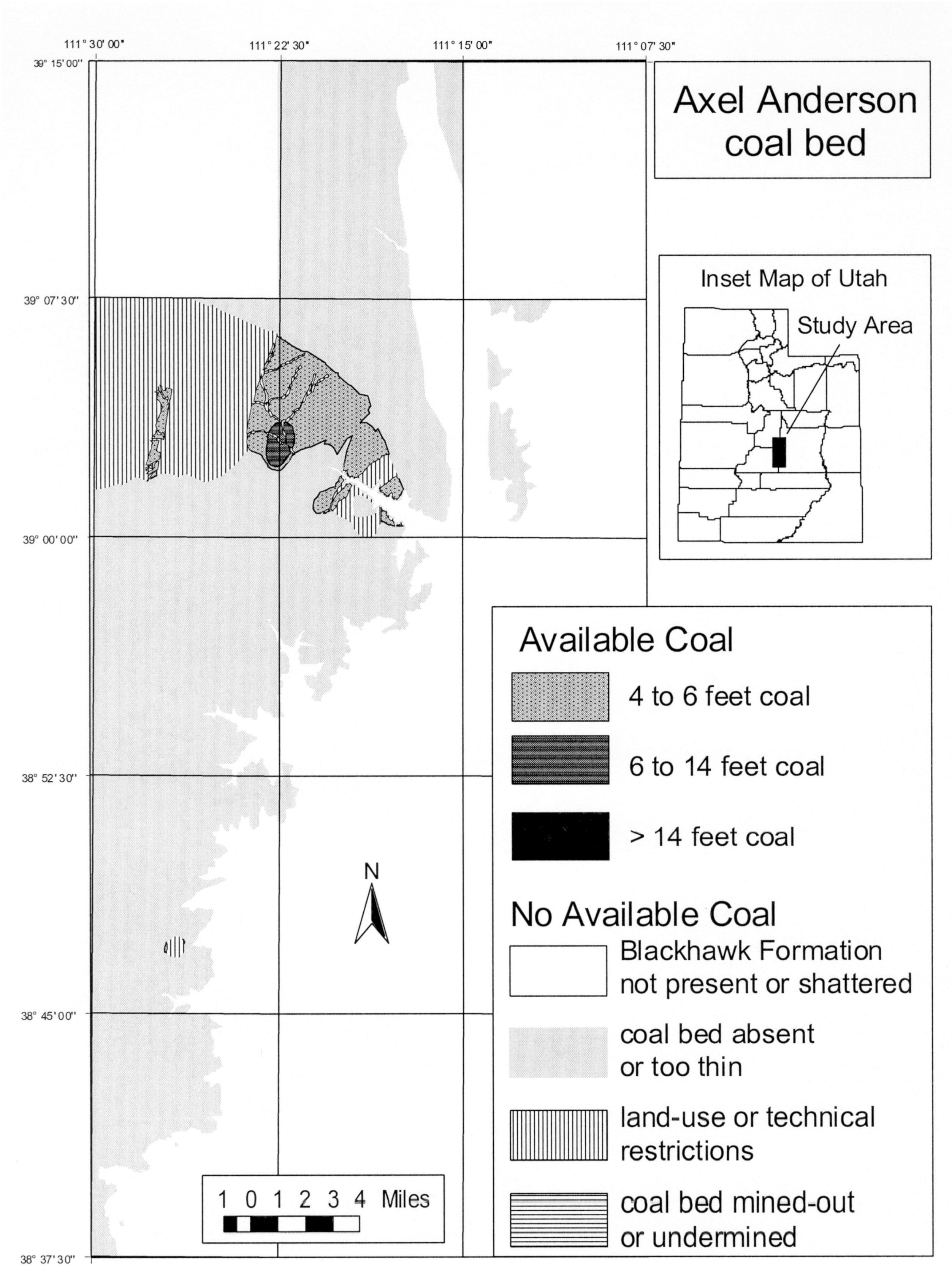

Figure D4. *Location of available coal resource for the Axel Anderson coal bed, southern Wasatch Plateau, Utah.*

Table D6. *Available coal resource in the Axel Anderson coal bed, Blackhawk Formation, southern Wasatch Plateau, Utah (millions of tons).*

	Coalbed Thickness (feet)						
	1 to 2	**2 to 4**	**4 to 6**	**6 to 10**	**10 to 14**	**>14**	**Total**
Original coal	87.3	150.8	315.3	10.2	0.0	0.0	563.6
Technical restrictions							
too thin	87.3	150.8	—	—	—	—	238.1
too deep	9.9	14.0	127.2	0.0	—	—	151.1
weathered	1.4	2.4	1.4	0.0	—	—	5.2
faulted	0.4	0.3	<0.1	0.0	—	—	0.6
mined-out	0.0	0.0	0.0	0.0	—	—	0.0
insufficient interburden exclusion	—	—	128.0	0.0	—	—	128.0
undermined	4.6	0.7	0.2	0.0	—	—	5.5
excessive thickness	—	—	—	—	—	—	0.0
net restrictions	87.3	150.8	220.1	0.0	—	—	458.2
Technically minable coal	0.0	0.0	95.2	10.2	0.0	0.0	105.4
Land-use restrictions							
streams and lakes	—	—	3.7	0.6	—	—	4.3
roads	—	—	0.0	0.0	—	—	0.0
power lines	—	—	0.0	0.0	—	—	0.0
oil and gas wells	—	—	0.0	0.0	—	—	0.0
net restrictions	—	—	3.7	0.6	—	—	4.3
Available coal resource	0.0	0.0	91.5	9.6	0.0	0.0	101.1
Reliability							
demonstrated	—	—	13.0	7.2	—	—	20.3
inferred	—	—	62.0	2.3	—	—	64.4
hypothetical	—	—	16.4	0.0	—	—	16.4

Notes to Table:

Original coal excludes riders and sub-beds where interburden is more than one foot thick or 20% of bed thickness.
Dash (—) indicates that the restriction is not applicable.
Row and column totals may differ from those obtained by adding table values due to rounding.
Net restriction totals may differ from those obtained by adding column values since coal in areas subject to multiple restrictions is counted only once.

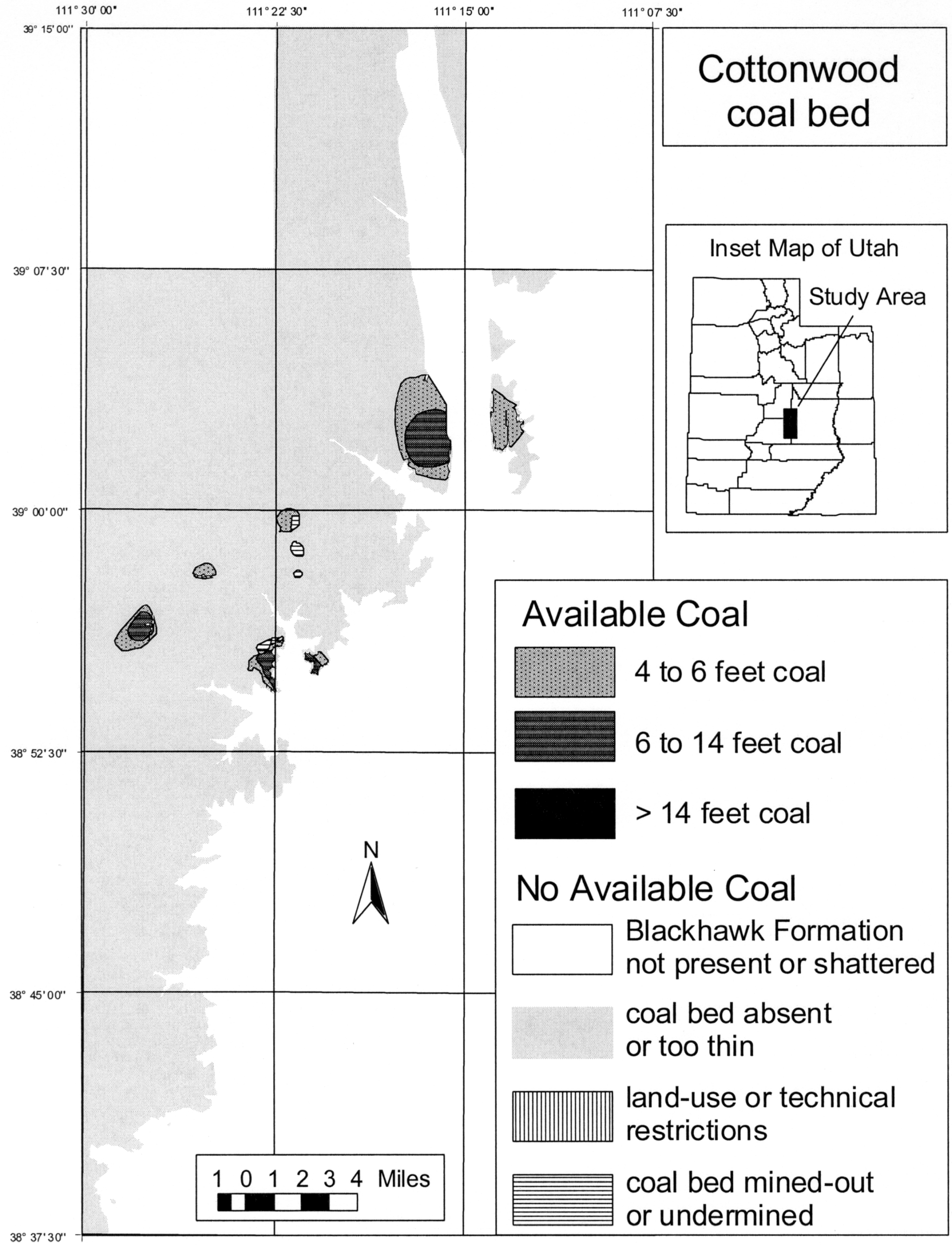

Figure D5. *Location of available coal resource for the Cottonwood coal bed, southern Wasatch Plateau, Utah.*

Table D7. *Available coal resource in the Cottonwood coal bed, Blackhawk Formation, southern Wasatch Plateau, Utah (millions of tons).*

	Coalbed Thickness (feet)						
	1 to 2	**2 to 4**	**4 to 6**	**6 to 10**	**10 to 14**	**>14**	**Total**
Original coal	137.4	166.9	43.3	34.6	0.0	0.0	382.2
Technical restrictions							
too thin	137.4	166.9	—	—	—	—	304.3
too deep	42.0	16.9	<0.1	<0.1	—	—	58.9
weathered	1.6	2.4	1.2	1.0	—	—	6.1
faulted	0.1	0.2	0.3	0.2	—	—	0.7
mined-out	0.0	0.0	0.0	0.0	—	—	0.0
insufficient interburden exclusion	—	—	0.0	0.0	—	—	0.0
undermined	4.9	12.1	3.2	<0.1	—	—	20.2
excessive thickness	—	—	—	—	—	—	0.0
net restrictions	137.4	166.9	4.6	1.1	—	—	310.1
Technically minable coal	0.0	0.0	38.6	33.5	0.0	0.0	72.2
Land-use restrictions							
streams and lakes	—	—	0.2	0.1	—	—	0.3
roads	—	—	0.0	0.0	—	—	0.0
power lines	—	—	0.0	0.0	—	—	0.0
oil and gas wells	—	—	0.0	0.0	—	—	0.0
net restrictions	—	—	0.2	0.1	—	—	0.3
Available coal resource	0.0	0.0	38.4	33.4	0.0	0.0	71.9
Reliability							
demonstrated	—	—	9.8	22.6	—	—	32.4
inferred	—	—	22.8	10.8	—	—	33.6
hypothetical	—	—	5.8	0.0	—	—	5.8

Notes to Table:

Original coal excludes riders and sub-beds where interburden is more than one foot thick or 20% of bed thickness.
Dash (—) indicates that the restriction is not applicable.
Row and column totals may differ from those obtained by adding table values due to rounding.
Net restriction totals may differ from those obtained by adding column values since coal in areas subject to multiple restrictions is counted only once.

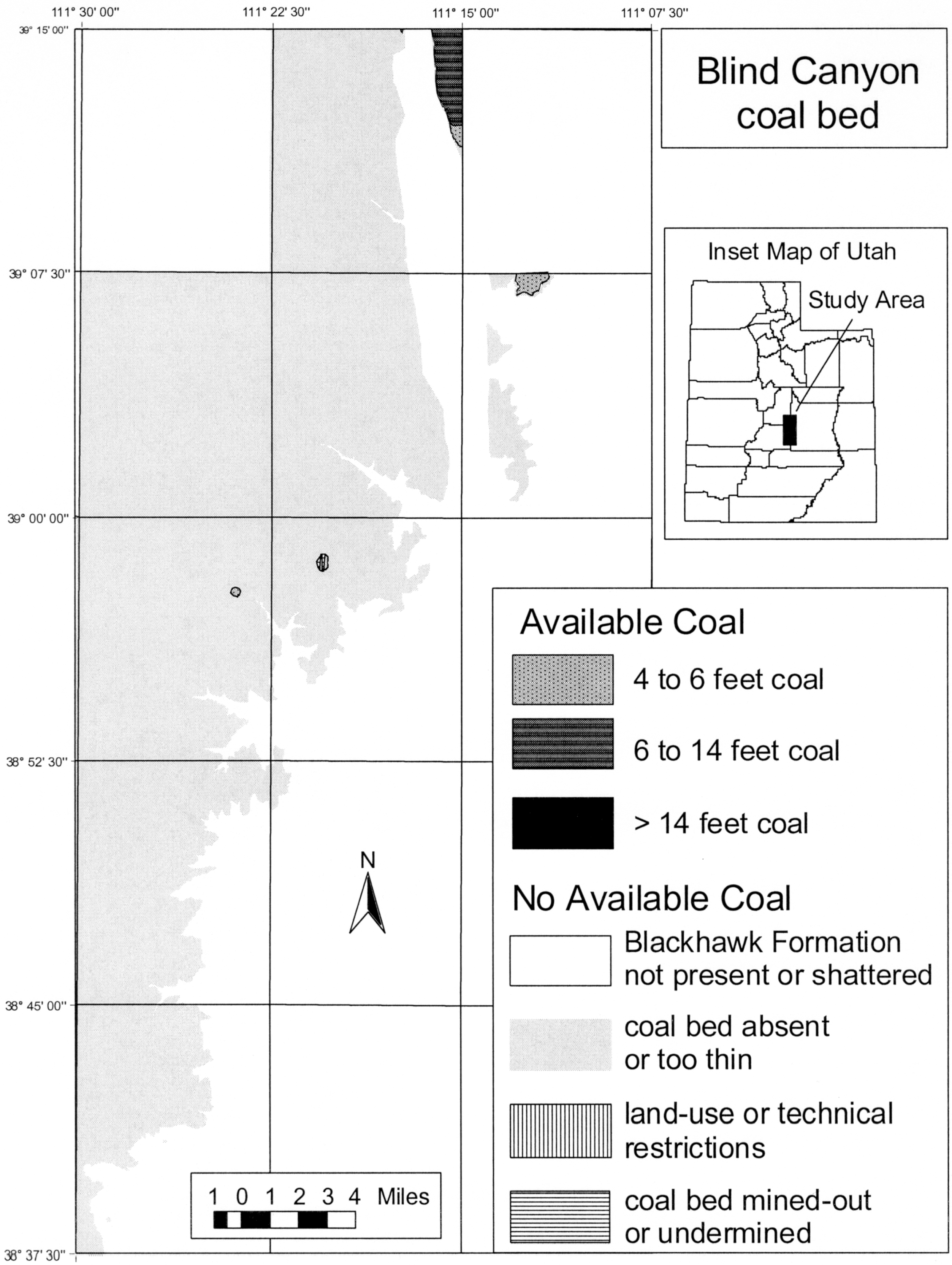

Figure D6. *Location of available coal resource for the Blind Canyon coal bed, southern Wasatch Plateau, Utah.*

Table D8. *Available coal resource in the Blind Canyon coal bed, Blackhawk Formation, southern Wasatch Plateau, Utah (millions of tons).*

	Coalbed Thickness (feet)						
	1 to 2	**2 to 4**	**4 to 6**	**6 to 10**	**10 to 14**	**>14**	**Total**
Original coal	108.9	28.5	7.2	8.6	28.3	0.0	181.5
Technical restrictions							
too thin	108.9	28.5	—	—	—	—	137.4
too deep	11.2	0.0	0.0	0.0	0.0	—	11.2
weathered	1.9	0.9	0.3	0.0	0.0	—	3.0
faulted	0.2	0.1	0.1	0.2	0.1	—	0.6
mined-out	0.0	0.0	0.0	0.0	0.0	—	0.0
insufficient interburden exclusion	—	—	0.0	0.0	0.0	—	0.0
undermined	5.3	5.9	0.5	0.0	0.0	—	11.7
excessive thickness	—	—	—	—	—	—	0.0
net restrictions	108.9	28.5	0.8	0.2	0.1	—	138.4
Technically minable coal	0.0	0.0	6.4	8.5	28.3	0.0	43.1
Land-use restrictions							
streams and lakes	—	—	<0.1	<0.1	0.0	—	<0.1
roads	—	—	0.0	0.0	0.0	—	0.0
power lines	—	—	0.0	0.0	0.0	—	0.0
oil and gas wells	—	—	0.0	0.0	0.0	—	0.0
net restrictions	—	—	<0.1	<0.1	0.0	—	<0.1
Available coal resource	0.0	0.0	6.4	8.4	28.3	0.0	43.1
Reliability							
demonstrated	—	—	3.4	0.0	0.0	—	3.4
inferred	—	—	2.9	8.1	27.3	—	38.3
hypothetical	—	—	0.1	0.3	1.0	—	1.4

Notes to Table:

Original coal excludes riders and sub-beds where interburden is more than one foot thick or 20% of bed thickness.
Dash (—) indicates that the restriction is not applicable.
Row and column totals may differ from those obtained by adding table values due to rounding.
Net restriction totals may differ from those obtained by adding column values since coal in areas subject to multiple restrictions is counted only once.

No map for Wattis bed

Table D9. *Available coal resource in the Wattis coal bed, Blackhawk Formation, southern Wasatch Plateau, Utah (millions of tons).*

	Coalbed Thickness (feet)						
	1 to 2	**2 to 4**	**4 to 6**	**6 to 10**	**10 to 14**	**>14**	**Total**
Original coal	57.6	45.6	0.0	0.0	0.0	0.0	103.2
Technical restrictions							
too thin	57.6	45.6	—	—	—	—	103.2
too deep	4.2	0.0	—	—	—	—	4.2
weathered	1.5	1.8	—	—	—	—	3.3
faulted	0.1	0.2	—	—	—	—	0.2
mined-out	0.0	0.0	—	—	—	—	0.0
insufficient interburden exclusion	—	—	—	—	—	—	0.0
undermined	0.9	0.4	—	—	—	—	1.3
excessive thickness	—	—	—	—	—	—	0.0
net restrictions	57.6	45.6	—	—	—	—	103.2
Technically minable coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Land-use restrictions							
streams and lakes	—	—	—	—	—	—	—
roads	—	—	—	—	—	—	—
power lines	—	—	—	—	—	—	—
oil and gas wells	—	—	—	—	—	—	—
net restrictions	—	—	—	—	—	—	—
Available coal resource	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reliability							
demonstrated	—	—	—	—	—	—	—
inferred	—	—	—	—	—	—	—
hypothetical	—	—	—	—	—	—	—

Notes to Table:

Original coal excludes riders and sub-beds where interburden is more than one foot thick or 20% of bed thickness.
Dash (—) indicates that the restriction is not applicable.
Row and column totals may differ from those obtained by adding table values due to rounding.
Net restriction totals may differ from those obtained by adding column values since coal in areas subject to multiple restrictions is counted only once.

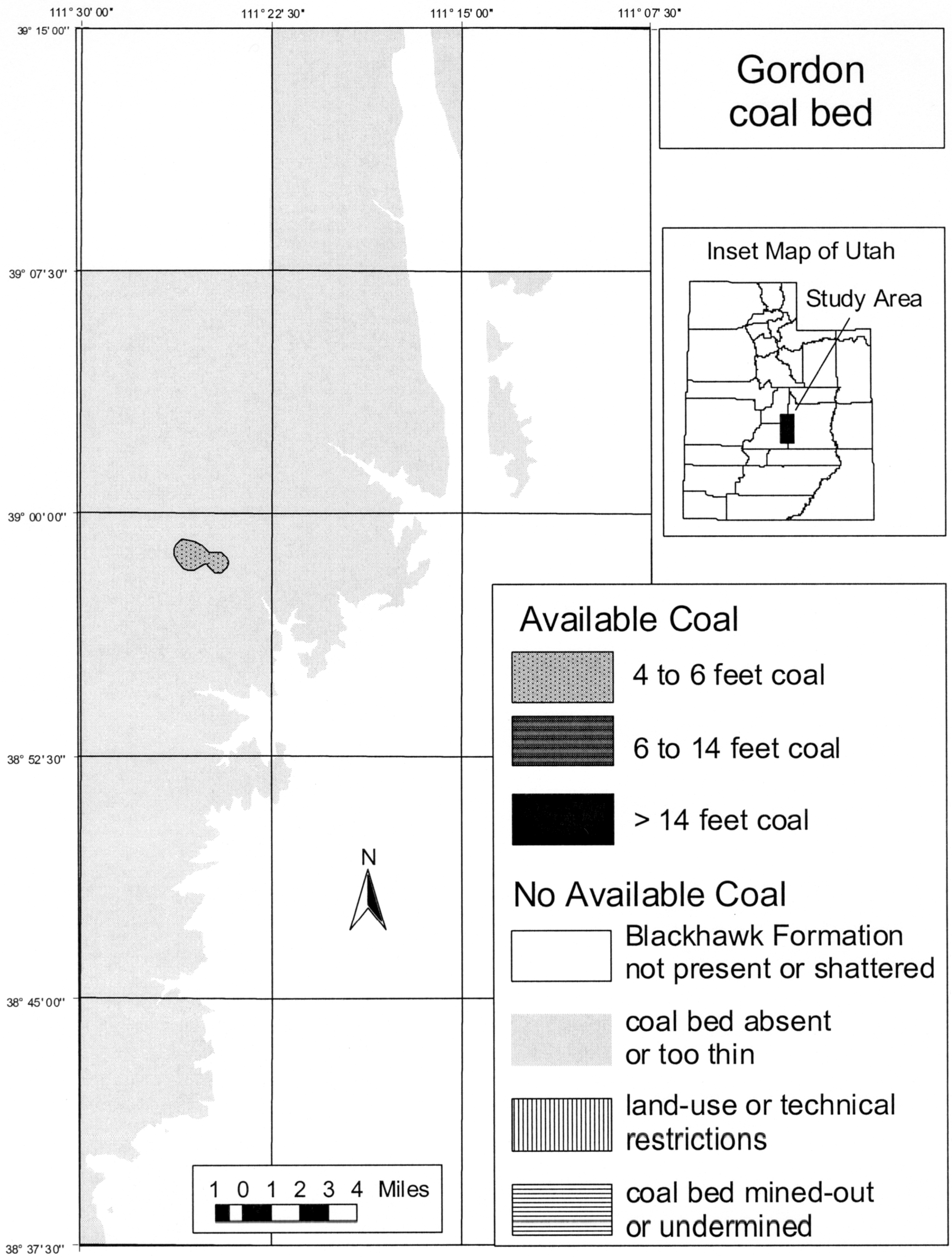

Figure D7. *Location of available coal resource for the Gordon coal bed, southern Wasatch Plateau, Utah.*

Table D10. *Available coal resource in the Gordon coal bed, Blackhawk Formation, southern Wasatch Plateau, Utah (millions of tons).*

	Coalbed Thickness (feet)						
	1 to 2	**2 to 4**	**4 to 6**	**6 to 10**	**10 to 14**	**>14**	**Total**
Original coal	13.8	17.4	8.2	0.0	0.0	0.0	39.4
Technical restrictions							
too thin	13.8	17.4	—	—	—	—	31.2
too deep	4.6	4.9	0.0	—	—	—	9.4
weathered	0.2	0.0	0.0	—	—	—	0.2
faulted	<0.1	<0.1	0.0	—	—	—	0.0
mined-out	0.0	0.0	0.0	—	—	—	0.0
insufficient interburden exclusion	—	—	0.0	—	—	—	0.0
undermined	0.0	0.0	0.0	—	—	—	0.0
excessive thickness	—	—	—	—	—	—	0.0
net restrictions	13.8	17.4	0.0	—	—	—	31.2
Technically minable coal	0.0	0.0	8.2	0.0	0.0	0.0	8.2
Land-use restrictions							
streams and lakes	—	—	0.0	—	—	—	0.0
roads	—	—	0.0	—	—	—	0.0
power lines	—	—	0.0	—	—	—	0.0
oil and gas wells	—	—	0.0	—	—	—	0.0
net restrictions	—	—	0.0	—	—	—	0.0
Available coal resource	0.0	0.0	8.2	0.0	0.0	0.0	8.2
Reliability							
demonstrated	—	—	7.8	—	—	—	7.8
inferred	—	—	0.4	—	—	—	0.4
hypothetical	—	—	0.0	—	—	—	0.0

Notes to Table:

Original coal excludes riders and sub-beds where interburden is more than one foot thick or 20% of bed thickness.
Dash (—) indicates that the restriction is not applicable.
Row and column totals may differ from those obtained by adding table values due to rounding.
Net restriction totals may differ from those obtained by adding column values since coal in areas subject to multiple restrictions is counted only once.

Table D11. *Available coal resource in the Castlegate A coal bed, Blackhawk Formation, southern Wasatch Plateau, Utah (millions of tons).*

	Coalbed Thickness (feet)						
	1 to 2	**2 to 4**	**4 to 6**	**6 to 10**	**10 to 14**	**>14**	**Total**
Original coal	22.9	6.6	0.0	0.0	0.0	0.0	29.5
Technical restrictions							
too thin	22.9	6.6	—	—	—	—	29.5
too deep	0.0	0.0	—	—	—	—	0.0
weathered	0.4	0.1	—	—	—	—	0.5
faulted	0.0	0.0	—	—	—	—	0.0
mined-out	0.0	0.0	—	—	—	—	0.0
insufficient interburden exclusion	—	—	—	—	—	—	0.0
undermined	0.4	<0.1	—	—	—	—	0.4
excessive thickness	—	—	—	—	—	—	0.0
net restrictions	22.9	6.6	—	—	—	—	29.5
Technically minable coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Land-use restrictions							
streams and lakes	—	—	—	—	—	—	—
roads	—	—	—	—	—	—	—
power lines	—	—	—	—	—	—	—
oil and gas wells	—	—	—	—	—	—	—
net restrictions	—	—	—	—	—	—	—
Available coal resource	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reliability							
demonstrated	—	—	—	—	—	—	—
inferred	—	—	—	—	—	—	—
hypothetical	—	—	—	—	—	—	—

Notes to Table:

Original coal excludes riders and sub-beds where interburden is more than one foot thick or 20% of bed thickness.
Dash (—) indicates that the restriction is not applicable.
Row and column totals may differ from those obtained by adding table values due to rounding.
Net restriction totals may differ from those obtained by adding column values since coal in areas subject to multiple restrictions is counted only once.

No map for Castlegate A bed

Table D12. *Available coal resource in the Castlegate D coal bed, Blackhawk Formation, southern Wasatch Plateau, Utah (millions of tons).*

	Coalbed Thickness (feet)						
	1 to 2	2 to 4	4 to 6	6 to 10	10 to 14	>14	Total
Original coal	41.8	49.0	0.0	0.0	0.0	0.0	90.8
Technical restrictions							
too thin	41.8	49.0	—	—	—	—	90.8
too deep	7.9	33.8	—	—	—	—	41.8
weathered	1.1	0.0	—	—	—	—	1.1
faulted	<0.1	0.0	—	—	—	—	<0.1
mined-out	0.0	0.0	—	—	—	—	0.0
insufficient interburden exclusion	—	—	—	—	—	—	0.0
undermined	0.3	0.0	—	—	—	—	0.3
excessive thickness	—	—	—	—	—	—	0.0
net restrictions	41.8	49.0	—	—	—	—	90.8
Technically minable coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Land-use restrictions							
streams and lakes	—	—	—	—	—	—	—
roads	—	—	—	—	—	—	—
power lines	—	—	—	—	—	—	—
oil and gas wells	—	—	—	—	—	—	—
net restrictions	—	—	—	—	—	—	—
Available coal resource	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reliability							
demonstrated	—	—	—	—	—	—	—
inferred	—	—	—	—	—	—	—
hypothetical	—	—	—	—	—	—	—

Notes to Table:

Original coal excludes riders and sub-beds where interburden is more than one foot thick or 20% of bed thickness.
Dash (—) indicates that the restriction is not applicable.
Row and column totals may differ from those obtained by adding table values due to rounding.
Net restriction totals may differ from those obtained by adding column values since coal in areas subject to multiple restrictions is counted only once.

No map for Castlegate D bed