U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Assessment of the Distribution and Resources of Coal in the Deserado Coal Area, Lower White River Coal Field, Northern Piceance Basin, Colorado

by

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CONTENTS

FIGURES

TABLES

METRIC CONVERSION FACTORS

Data in this volume are reported in customary inch-pound units because the metric system is not currently in use by the coal industry of the United States. Readers wishing to convert measurements to the International System of units (SI) may use the following factors:

U.S. customary unit	SI conversion
Acre	= 4,046.87 square meters
Acre-foot	= 1,233.49 cubic meters
British thermal unit (Btu)	= 1,055.056 joules
Btu/lb	= 2,326 joules per kilogram
Foot (ft)	= 0.3048 meters
Inch (in.)	= 0.0254 meters
Mile (mi)	= 1.609 kilometers
Pound (lb)	= 0.4536 kilograms
Short ton (ton)	= 0.9072 metric tons
Square miles (mi^2)	= 2.59 square kilometers
Ton/acre-foot	= 0.7355 kilograms per cubic meter

EXECUTIVE SUMMARY

Assessment of the coal resources of the Deserado coal area, Lower White River coal field, Colorado is part of the U. S. Geological Survey's (USGS) "National Coal Resource Assessment" (NCRA), a five year program to identify and characterize the coal deposits that could potentially provide fuel for the Nation's coal needs during the first few decades of the twenty-first century. For the NCRA, the Nation was divided into regions. Teams of geoscientists, with knowledge about each region, are developing coal data bases and spatial data on land use to assess the coal resources in each region. Five major coal-producing regions of the United States being assessed are: (1) the Appalachian Basin; (2) the Illinois Basin; (3) the Gulf of Mexico Coastal Plain; (4) the Powder River Basin and Northern Great Plains; and (5) the Rocky Mountains and Colorado Plateau. Six priority regions were designated in the Rocky Mountains and Colorado Plateau Region because of their current coal production and potential for future development. The Lower White River coal field is part of the northwest Colorado priority region.

The coal quantities reported for this study are considered resources only and represent, as accurately as the data will allow, the total net-coal in beds greater than 1.2 feet thick. The coal resources are reported as "identified" following the classification of the USGS (Wood and others, 1983). Coal beds in the Deserado coal area, Lower White River coal field are contained in the Upper Cretaceous Mesaverde Group and are laterally discontinuous when compared to many other coal-bearing regions in the United States. The coal within the study area is considered to be low sulfur (0.55 percent) and has an apparent rank of high-volatile C bituminous.

The Deserado coal area contains an estimated original coal resource of about 440 million short tons with more than 80 percent of the total coal resource contained in two coal zones. The coal resources estimated for this study do not include the area inside the Deserado Logical Mining Unit. Although the study area contains a significant coal resource, the resource figure does not reflect economic, land-use, environmental, technological, and geologic constraints that may affect the availability and recovery of the coal. Within the Deserado coal area the recoverable coal will be reduced because the two major zones are close together and contain partings and splits that restrict mining. Currently the coal is being mined in the study area by long-wall methods from both zones. Coal can be bypassed due to long-wall mining methods related to adjacent coal beds and reduced thickness from partings and splits. Although these factors will reduce the amount of coal that could be recovered, the amount of recoverable coal was not estimated.

INTRODUCTION

Purpose and scope

The assessment of the distribution and resources of the coal in the Lower White River Coal Field of northwest Colorado is part of the United States Geological Survey's National Coal Assessment project that was initiated in 1994. The goal of the National Assessment project is to characterize the resource potential and quality of coal for priority areas in the United States that will be utilized for the next few decades. The Lower White River coal field, in Garfield, Moffat, and Rio Blanco counties Colorado (fig. 1), is one of the priority areas within the Rocky Mountain Coal Province (Tully, 1996). Because of the need to restrict the resource potential to a 10 to 20 year window, only the northern part of the Lower White River coal field was assessed for this study and was designated the Deserado coal area (figs. 2 and 3). The study area was determined by analyzing current mining activity and Federal coal ownership within the Lower White River coal field. Only one operating mine, the Deserado Mine, is present in the study area and there has been no interest in developing new mines in the Lower White River coal field. The coal within the study area is mostly owned by the U. S. Government.

The assessment of the Deserado coal area is based on data from geologic mapping, outcrop measurements, and drilling that has been conducted in the study area since the early 1900's (Gale, 1910). The deposits of coal are contained in the Coal and Upper units of the Upper Cretaceous Mesaverde Group (figs. 4 and 5). The data was stored digitally and manipulated in a Geographic Information System (GIS) to calculate coal resources within a variety of spatial parameters that were deemed useful for land-use planning and potential mining. Total net-coal resources for the Coal unit and net-coal resources for two major coal zones are reported for the Deserado coal area. The Deserado Logical Mining Unit (includes all Federal and State coal leases and private coal) were excluded in this study.

Methods

In order to assess the coal resources of the Deserado coal area, we created digital files for various geologic features within the study area. The drill hole data are stored and correlated in a stratigraphic data base and graphics software package called StratiFact (GRG Corporation). The drill-hole data was then analyzed by a U. S. Geological Survey program to determine the net thickness of coal using the methodology of Wood and others (1983). The spatial data are stored, analyzed, and manipulated in a Geographic Information System using ARC/INFO software developed by Environmental Systems Research Institute, Inc. Spatial data that required gridding for the generation of contour and isopach maps were processed using ARC/INFO (Environmental Systems Research Institute, Inc.) and Earth Vision (Dynamic Graphics, Inc.) software. Integrating the various coverages allowed us to calculate coal resources and characterize the coal distribution within a variety of geologic and geographical parameters using Earth Vision software. The methodology for estimating coal resources is from Wood and others (1983) and is reported in detail in the Coal Resource section.

Geologic maps

Digital maps generated from ARC/INFO coverages for geologic features include the locations of stratigraphic boundaries, faults, fold axes, and points where strata are inclined at various ranges of dip. Data from the State geologic map of Colorado (Tweto, 1979 and the digital version, Green, 1992) were used to generate digital maps using ARC/INFO. The State geologic map in the Deserado area was compiled from 1:250,000 scale geologic maps (Tweto, 1975 and Rowley and others, 1979), and published at a scale of 1:500,000. The generalized geologic map for this report (fig. 2) was compiled at 1:100,000 scale and was modified using outcrop data from 1:24,000 scale-geologic maps by Barnum and Garrigues (1980), Garrigues and Barnum (1980), and Barnum and Hail (1996).

Geographical boundaries

Geographical boundaries were imported as ARC/INFO coverages from existing public data bases. Township boundaries were digitized from the Rangely NE and Cactus Reservoir 7.5 minute quadrangles. Areas of surface and mineral ownership were obtained from 1:24,000-scale digital compilations from the Craig District Office, U. S. Bureau of

Land Management. County and State lines were obtained from 1:100,000-scale Topologically Interrogated Geographic Encoding and Referencing (TIGER) files produced by the U. S. Bureau of the Census in 1990. Surface topography was obtained from 1:24,000 Digital Elevation Model files for the Rangely NE and Cactus Reservoir 7.5 minute quadrangles. Coal lease and mine plan data maps were obtained from the U. S. Bureau of Land Management and digitized.

Location

The Lower White River coal field is located in the northwest part of Colorado and occupies parts of Garfield, Moffat and Rio Blanco counties (fig. 1). The coal field is located in the northern part of the Piceance Basin, which is part of the Uinta Region of the Rocky Mountain Coal Province (Tully, 1996). In this study, the area of interest is restricted to the northern part of the Lower White River coal field and is referred to as the Deserado coal area where there is active coal mining (figs. 2 and 3). The Deserado coal area is located north of Rangely, Colorado and south of the Dinosaur National Monument.

Previous geologic studies and mining activity

The U. S. Geological Survey conducted investigations to study the geology and to assess the regions containing coal, oil and gas, and oil shale resources since the early 1900's. Gale (1910) was the first to investigate the coal resources in northern part of the Lower White River coal field. Cullins (1968, 1969, 1971) mapped portions of the Lower White River coal field near the town of Rangely. The Deserado coal study area was mapped by Barnum and Garrigues (1980) and Garrigues and Barnum

Figure 1. Location map for the Lower White River, Danforth Hills, and Yampa coal fields, northern Piceance Basin, Moffat, Rio Blanco, and Routt Counties, Colorado.

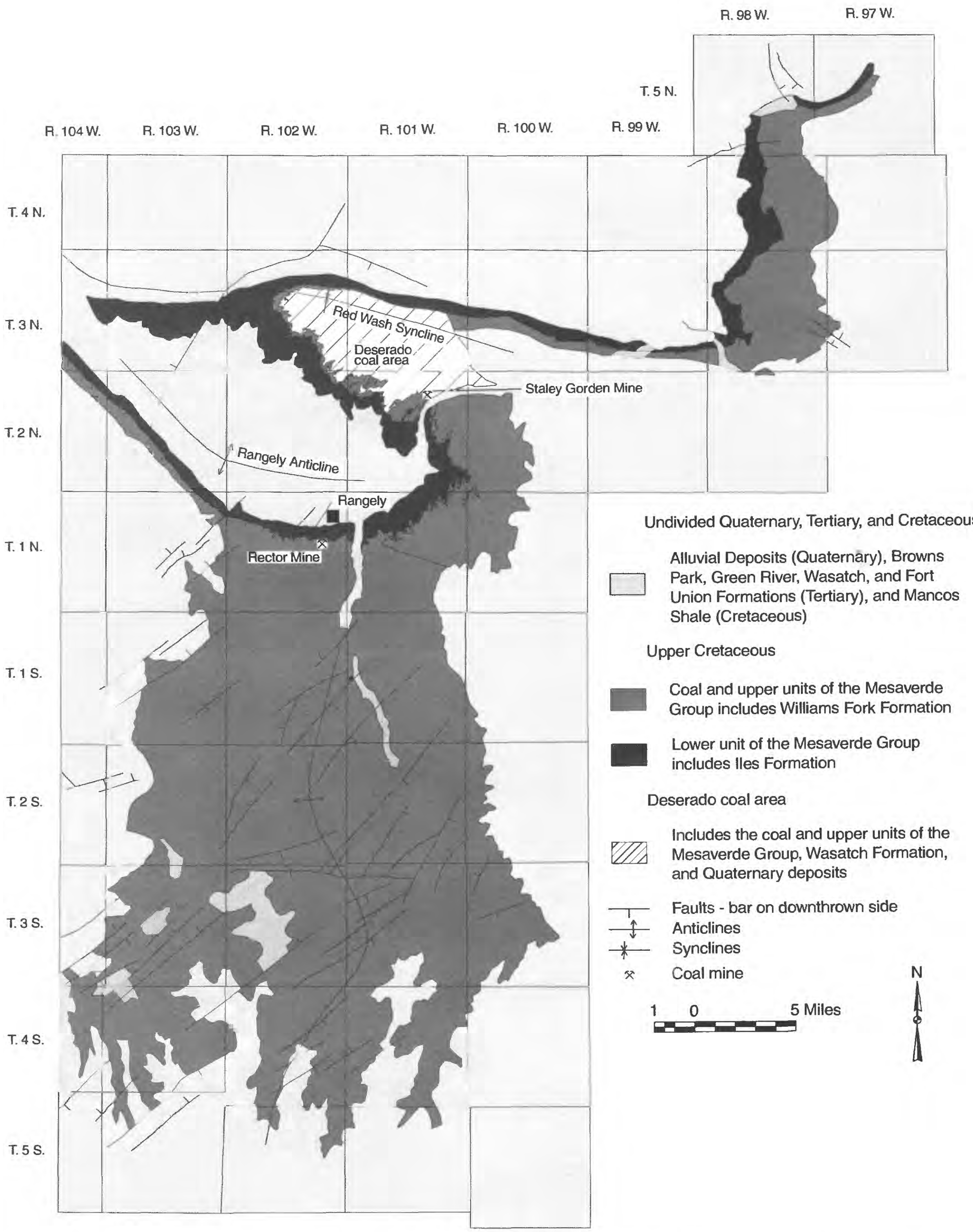

Figure 2. Generalized geologic map of the Lower White River coal field showing Deserado coal area, Garfield, Moffat, and Rio Blanco Counties, Colorado. Modified after Barnum and Garrigues (1980), Garrigues and Barnum (1980), and Tweto (1979).

Table 1. Locations of coal-exploration holes drilled by the U. S. Geological Survey, in 1976, in the Lower White River coal field. Also shown for the holes are elevations and drilling and logging depths. (All measurements are in feet; to convert feet to meters, multiply by 0.3048)

Drill hole No.	Location	Surface Elevation	Depth Drilled	Depth Logged
LW-1-CR	SE1/4SE1/4SE1/4 Sec. 15, T.3 N., R. 101 W.	5,700	300	290
LW-3-CR	NE1/4NE1/4SW1/4 Sec. 33, T.3 N., R. 101 W.	5,800	520	519
LW-4-CR	SW1/4SE1/4NE1/4 Sec. 34, T.3 N., R. 101 W.	5,710	1,120	1,115
LW- 7-CR	NW1/4SW1/4NW1/4 Sec. 18, T.2 N., R. 100 W.	5,630	920	918
LW-8-CR	NW1/4SE1/4NW1/4Sec. 19, T. 2 N., R. 100 W.	5,830	940	925
LW-24-CR	SW1/4SE1/4NE1/4 Sec. 11, T. 2 N., R. 101 W.	5,330	280	279
LW-12-GD	SE1/4NW1/4SE1/4 Sec. 31, T. 2 N., R. 100 W.	6,150	640	614
LW-13-GD	NW1/4SE1/4NE1/4 Sec. 7, T. 1 N., R. 100 W.	5,900	620	610
LW-14-GD	SW1/4NE1/4SW1/4 Sec. 1, T. 1 N., R. 101 W.	6,530	500	500
LW-15-GD	NE1/4NW1/4NW1/4, Sec. 11, T. 1 N., R. 101W.	6,420	380	380
LW-16-GD	SW1/4NE1/4NW1/4 Sec. 14, T. 1 N., R. 101 W.	5,700	420	420
LW-17-GD	SW1/4SW1/4NW1/4; Sec. 16, T. 1 N., R. 101 W	5,840	260	256
LW-18-GD	NE1/4SE1/4NE1/4 Sec. 20, T. 1 N., R. 101 W.	5,964	460	459
LW-18B-GD	NE1/4SE1/4SW1/4 Sec. 21, T. 1 N., R. 101 W.	5,910	400	393
LW-19-GD	NW1/4NE1/4NE1/4 Sec. 32, T. 1 N., R. 101 W.	6,020	480	476
LW-25-GD	SW1/4SW1/4NW1/4 Sec. 30, T. 2 N., R. 100 W.	6,090	640	636
LW-2A-RN	NW1/4NW1/4NW1/4 Sec. 6, T. 2 N., R. 101 W.	6,365	400	400
LW-9A-RN	NW1/4NW1/4NW1/4 Sec. 25, T. 3 N., R. 102 W.	6,005	400	366
LW-21-RN	SW1/4SE1/4SW1/4 Sec. 15, T. 3 N., R. 102 W	6,051	400	400
LW-22-RN	NE1/4NW1/4NW1/4 Sec. 14, T. 3 N., R. 102 W.	6,073	360	350
LW-23-RN	NE1/4NW1/4NW1/4 Sec. 18, T. 3 N., R. 101 W.	5,815	320	318
LW-26-RN	SE1/4NE1/4NE1/4 Sec. 36, T. 3 N., R. 102 W.	6,174	400	397
LW-10-DC	SE1/4SE1/4SE1/4 Sec. 21, T. 3 N. R. 100 W.	5,950	480	445

(1980). Other mapping in the Lower White River coal field was conducted by Hail (1974), Hail and Barnum (1993), and Barnum and Hail (1996).

During the late 1800's and early 1900's, several mines produced coal in the Lower White River coal field for local consumption (Gale, 1910). In addition to local heating uses, some of the coal was used to provide fuel for drilling wells in the early days of the Rangely oil field. Gale (1910) sampled and reported analyses of coal from the Rector mine, southwest of the Deserado coal study area. Within the study area, the Staley Gordon Mine produced an unknown amount of coal from the main coal zone of the Coal unit of the Mesaverde Group (fig. 5).

Coal is presently mined by underground methods in the Lower White River coal field at the

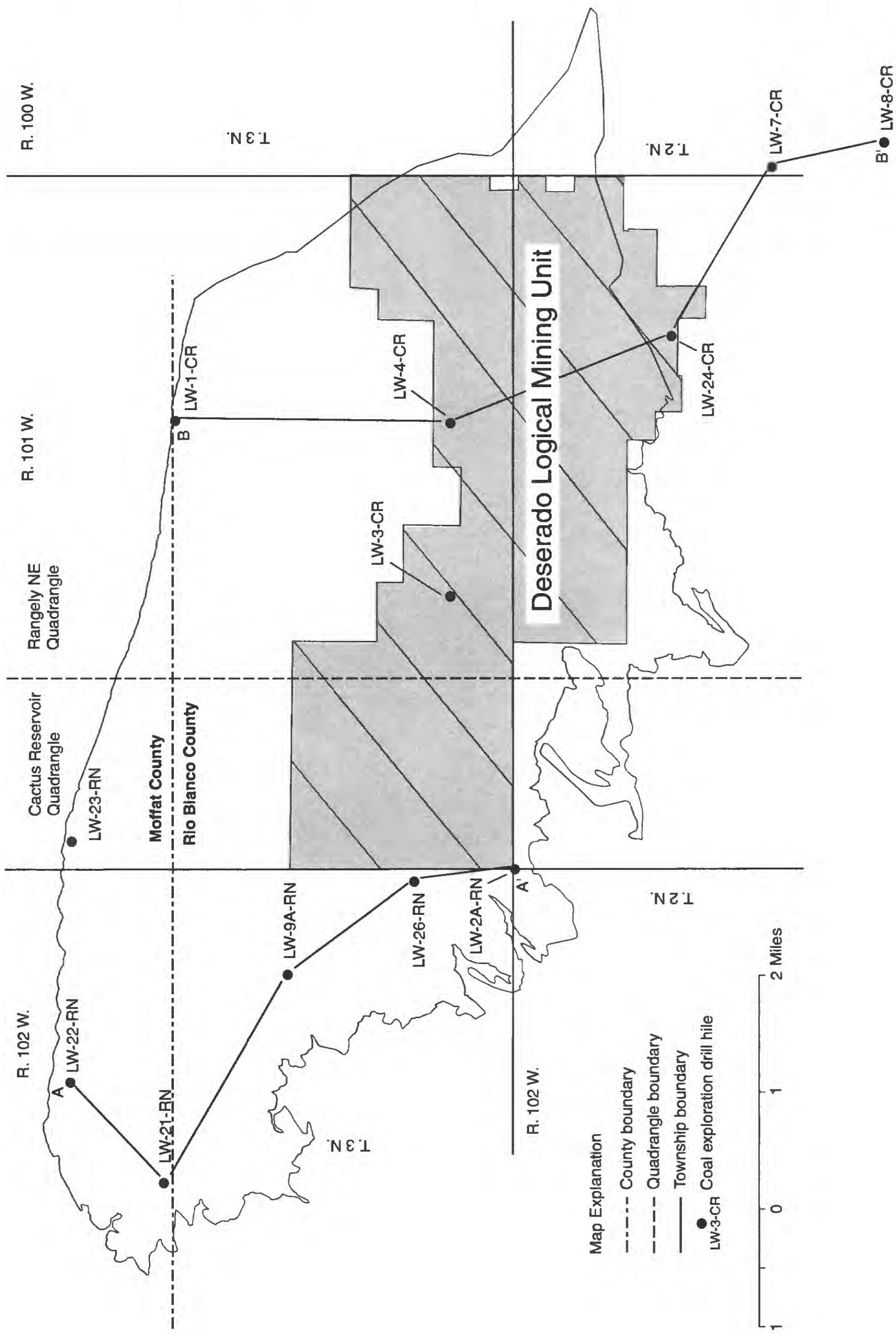

Figure 3. Index map showing location of U. S. Geological Survey drill holes and cross sections in the Deserado coal area, the outcrop of the coal marker sands, and the Deserado Logical Mining Unit, Lower White River coal field, Colorado.

Deserado Mine operated by Western Fuels, Inc. Coal from the Deserado Mine is transported over a dedicated electric railroad to the Deseret Generation and Transmission power plant in northeastern Utah. Coal production averaged 1.44 million tons per year from 1989 to 1994 (Resource Data International, Inc., 1998). All the coal produced in the Deserado Mine, or presently projected for future production, is within the Coal unit of the Mesaverde Group.

Geophysical logs

The borehole geophysical logs used in this study, supplied by the Bureau of Land Management (BLM) and the U. S. Geological Survey (USGS), were generally of good quality and contained natural gamma and density traces. Twenty-three exploratory holes were drilled during the summer of 1976 in the Lower White River coal field by the U. S. Geological Survey (Garrigues, 1976 and Garrigues and others, 1977). Ten of the 23 holes were drilled in the

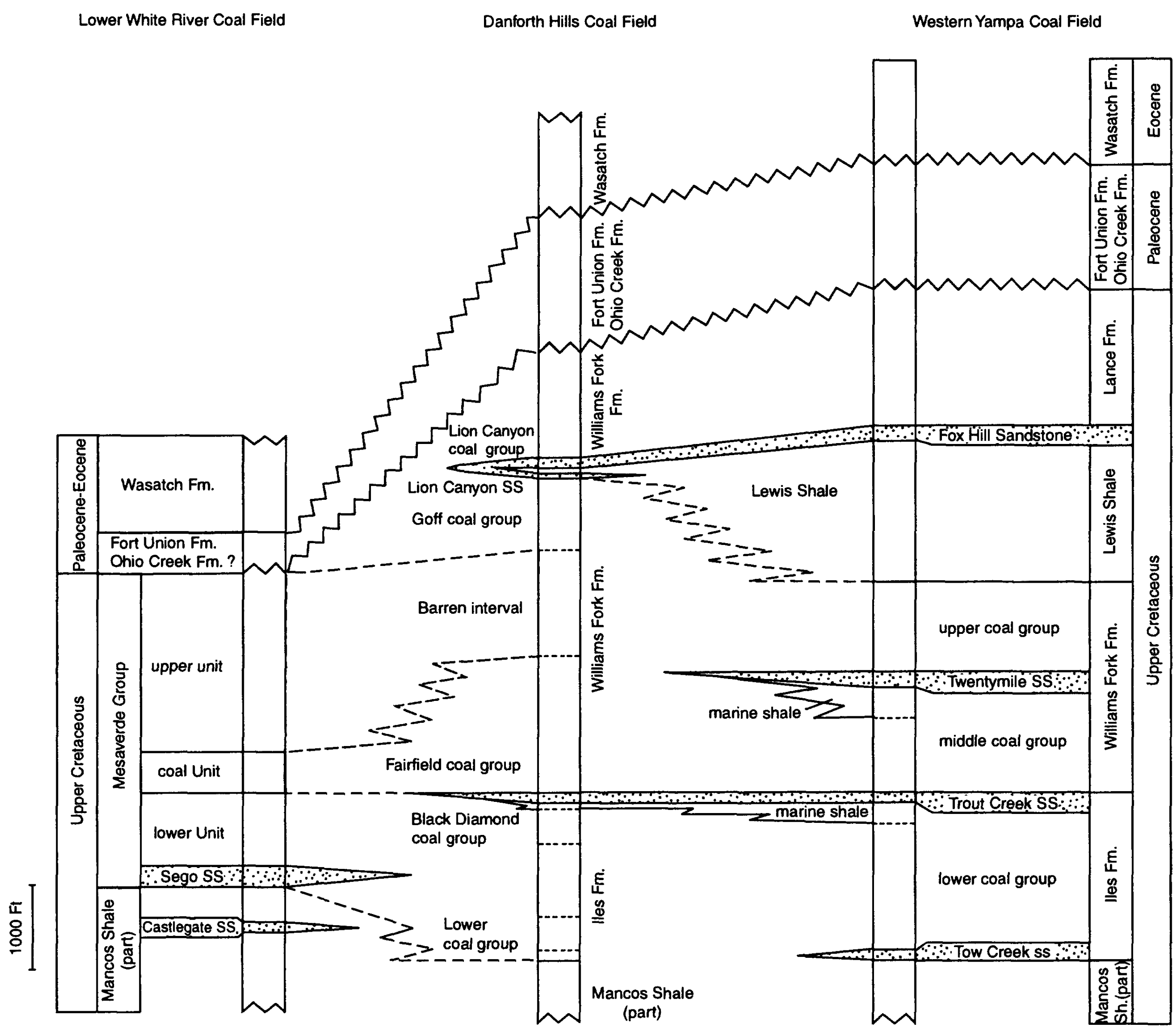

Figure 4. Generalized regional cross section for part of the Upper Cretaceous and Tertiary rocks in the Lower White River, Danforth Hills, and Yampa coal fields, northwest Colorado. Modified after Brownfield and Johnson (1984).

Deserado coal study area (fig. 3). Location and depth information about these holes is summarized in Table 1. The remainder of the geophysical logs used in the study are proprietary and were obtained over a 15 year drilling period by several different operators and organizations, often at different scales. The proprietary well log data were supplied by the BLM. Coal and other lithologic units could usually be interpreted from the logs with a high degree of certainty because good natural gamma and density traces were available. The logs allowed the lithologic contacts to be estimated to the nearest one half foot. A few of the older and poorer quality logs allowed interpretations only to the nearest foot. A few of the most recent, well-calibrated logs allowed unit picks to the nearest one tenth of a foot.

As is true of most coal correlation studies, the degree of certainty varies with distance, local stratigraphy, presence of stratigraphic markers, and log quality. In areas of high drill-hole density it is likely that a coal bed is continuous within a coal zone between selected drill holes. In areas of low drill-hole density it is unlikely that a coal bed at the same stratigraphic horizon is continuous within the coal zone between drill holes. Despite these problems, the lithologic and stratigraphic log interpretations were accurately correlated across the study area.

Acknowledgments

We thank the U. S. Bureau of Land Management, Craig District Office, for supplying coal exploration drill-hole data, land use and coal ownership, coal lease, and logical mining unit data for the study area. We want to thank Ronald Affolter for providing coal quality data for the study area. We thank Laura Biewick for providing computer and technical assistance.

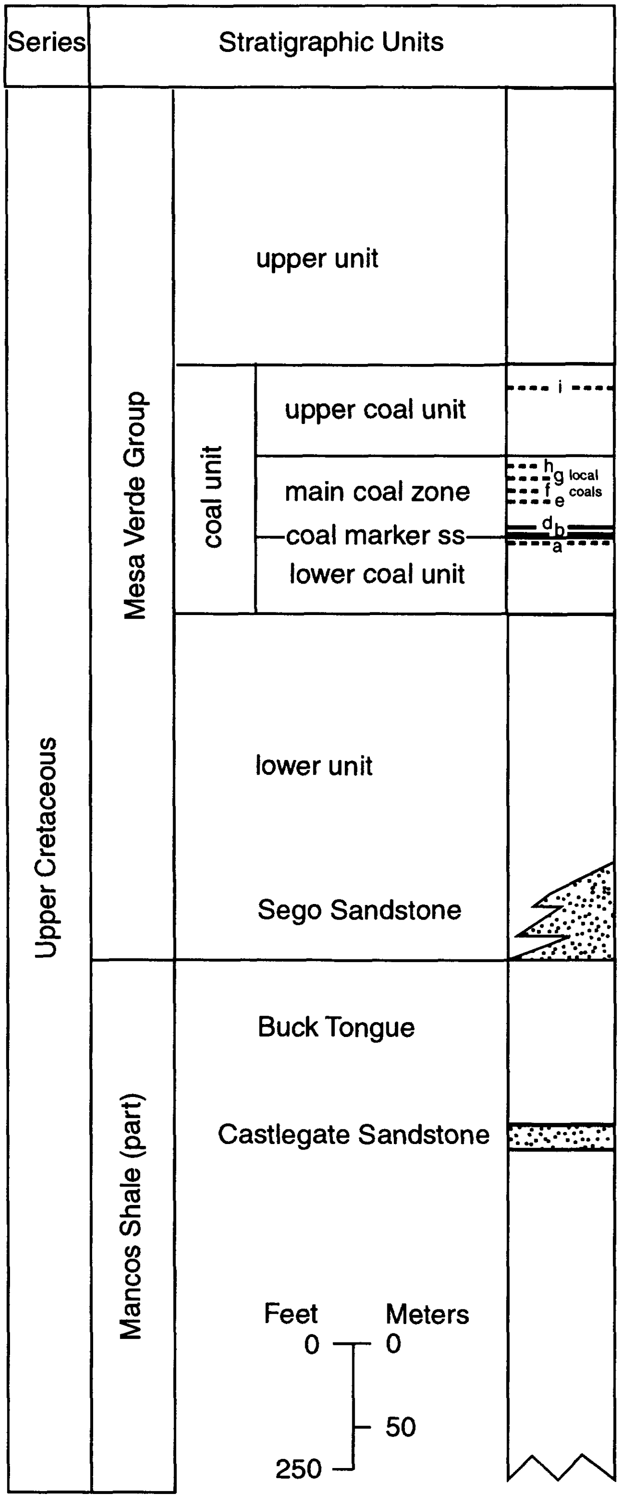

Figure 5. Generalized stratigraphic column for a portion of the Upper Cretaceous rocks for the Deserado coal area, Lower White River coal field, Colorado. Shown the major divisions of the coal unit of the Mesaverde Group and the Western Fuels, Inc. coal zone names. Coal beds and coal marker sands not drawn to scale. Named sandstones stippled. Modified after Barnum and Garrigues (1980).

GEOLOGIC SETTING

Stratigraphy of the Cretaceous and Tertiary Strata of the Lower White River coal field

A generalized stratigraphic column for a portion of the Upper Cretaceous rocks of northwest Colorado including the Lower White River coal field is shown in figure 4 and a columnar section for the Deserado coal area in shown in figure 5. The Lower and Upper Cretaceous Mancos Shale has a maximum thickness of 5,100 feet (1570 m) within and adjacent to the Lower White River coal field and outcrops north and south of the Deserado coal area and north and west of Rangely, Colorado (fig. 2). Only the upper part of the unit is shown in the stratigraphic columns. All the coal-bearing units considered in this study are included in the Mesaverde Group of Late Cretaceous age. Within the Deserado coal area the Mesaverde Group is approximately 5000 feet (1500 m) thick and composed of a thick succession of mostly non-marine sediments which overlie the marine Mancos Shale. The Mesaverde Group has been divided into three formation-equivalent stratigraphic units (fig. 5) by the U. S. Geological Survey (Barnum and Garrigues, 1980). These three units are designated the lower unit, coal unit, and upper unit (fig. 5). The lower unit is roughly equivalent to the Iles Formation of the Danforth Hills coal field about 60 miles to the east of the study area and averages 690 feet (210 m.) thick. The coal unit and upper unit are generally equivalent to the Williams Fork Formation of the Danforth Hills and average about 2130 feet (650 m.) thick (fig. 4). The coal unit was subdivided into the lower and upper coal units and the main coal zone in this report. The top of the lower coal unit is marked by persistent sandstone beds mapped as the "coal marker sands" by Barnum and Garrigues (1980).

Overlying the Cretaceous Mesaverde Group within the Deserado coal area is a Tertiary section of fluvial and lacustrine sediments assigned to the Wasatch and Fort Union? Formations of Paleocene and Eocene age (fig. 4). This section has been divided into the lower member and the main body of the Wasatch Formation by Barnum and Garrigues (1980). The lower member consists of shale, mudstone, thin, persistent, light-brown sandstone interbeds, carbonaceous shale with coally lenses, and local lenses of brown clay-pebble conglomerate. Locally a white, massive, clay-cemented basal sandstone, possible equivalent to the Ohio Creek Formation, is present (Barnum and Garrigues, 1980). The lower member is about 360 feet (110 m) thick and probably at least partially correlative with the Fort Union Formation about 10 miles east of the study area (Hail, 1974, Hail and Barnum, 1993). Approximately 980 feet (300 m) of the main body is exposed in the study area. The main body consists of lacustrine shale and claystone and sandstone interbeds. The Eocene Green River and Miocene Browns Park Formations were mapped east of the Deserado coal area by Hail (1974) and Hail and Barnum (1993). Quaternary deposits consisting of alluvium, colluvium, and terrace gravels are also present throughout the coal field.

The Deserado coal area includes the coal marker sands, rocks of main coal zone, upper coal unit of the coal unit and the upper unit of the Mesaverde Group; the main body and lower member of the Wasatch Formation, and Quaternary deposits. The northern, southern, and western boundaries of the Deserado coal area were drawn on the top of the coal marker sands. The eastern boundary was drawn the base of the Tertiary rocks and the southeastern boundary was drawn at the contact between the Cretaceous rocks and the Quaternary deposits.

Structure

The Lower White River coal field lies on the northern margin of the Piceance Basin south of the Dinosaur National Monument (fig. 1). The Deserado coal area lies on the northeast flank of the Rangely Anticline (fig. 2). The axis of the Red Wash Syncline passes through the northern part of the coal area (fig. 2). A structure map drawn on the top of the coal marker sands (fig. 6) was constructed using drill hole geophysical logs (Garrigues, 1976) and outcrop data from 7.5 minute quadrangle geologic maps (Barnum and Garrigues, 1980; Garrigues and Barnum, 1980). The coal-bearing units in the study are the coal area, north of the axis of the Red Wash Syncline, the rock units dip more steeply to the south. No significant faulting is known to occur in the study area.

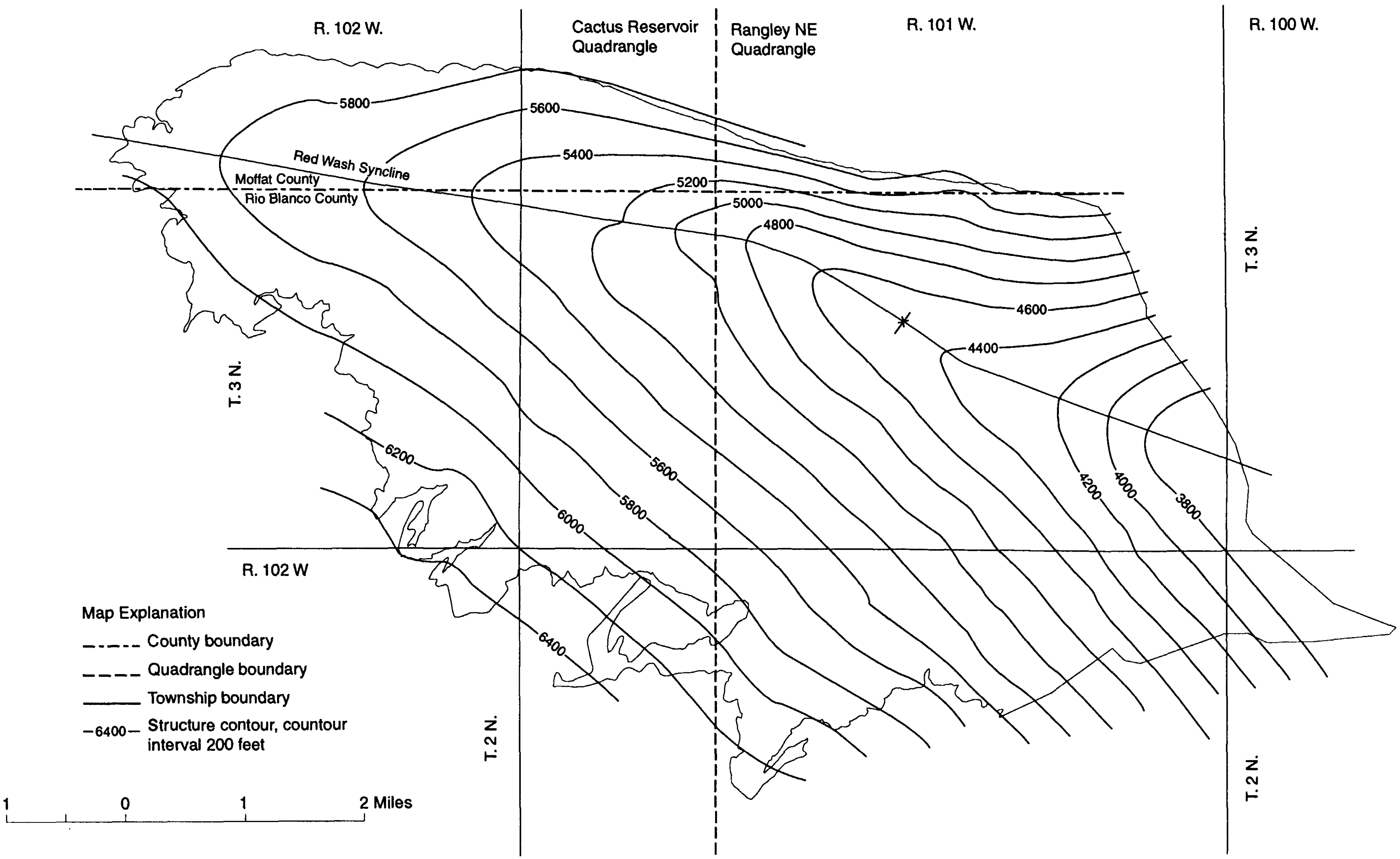

Figure 6. Structure contour map drawn on the top of the coal marker sands, coal unit Upper Cretaceous Mesaverde Group, Deserado coal area, Lower White River coal field, Colorado. Modified after Barnum and Garrigues (1980), Garrigues and Barnum (1980).

COAL GEOLOGY OF THE DESERADO COAL AREA

Stratigraphy

The coal unit (fig. 5) of the Mesaverde Group in the Lower White River coal field ranges in thickness from 300 (90 m) to 600 (180 m) feet and is divided into three subunits (Barnum and Garrigues, 1980 and Garrigues and Barnum, 1980). Within the Deserado coal area the coal unit averages about 490 feet (150 m) thick. The subunits are, in ascending order, the lower coal unit. the main coal zone, and upper coal unit.

The lower coal unit (fig. 5) averages about 150 feet (46 m) thick, but the complete unit is rarely penetrated in the drill holes studied. The lower coal unit is predominately a transitional unit between the lower unit of the Mesaverde Group (fig. 5) which is dominated by thick fluvial channel sandstone successions and the overlying main coal zone which was deposited in a coastal plain environment. The lower coal unit consists primarily of fine sediments (mudstones and shales) with interbedded sandstone deposited in a coastal plain environment. Thin lenticular coals occur throughout the lower coal unit and are more locally persistent near the top of the subunit.

The uppermost part of the lower coal unit is marked by an interval containing from 1 to 3 thin but persistent ledges of well-sorted, planar bedded sandstone which contain abundant carbonaceous fragments. Gale (1910) first mapped these persistent sandstones, which he called the "white rock", and stated that they marked the base of the mineable coals. These sandstone ledges were mapped as the "coal marker" sands (fig. 5) by Barnum and Garrigues (1980), and they can usually be identified on geophysical logs (figs. 8 and 9). The sands of the coal-marker are interpreted to represent deposition in a low-energy beach environment, probably a lagoonal beach behind an active barrier island system. The coal marker sands range in thickness from 0 to 35 feet (0-11 m).

The main coal zone (fig. 5) contains all of the thicker and economically important coal beds in the Deserado coal area. Data from the drill holes and geologic mapping indicate that the main coal zone averages about 160 feet (49 m) thick and is predominantly composed of mudstones, sandstones, and coals deposited in a coastal plain environment. The thicker and more persistent coal beds occur in the lower part of the zone. The coals present in the upper part of the zone tend to be thin and lenticular. The main coal zone appears to represent one period of nearshore deposition favorable to coal formation. The environment of deposition became progressively less favorable for coal formation as the shoreline retreated eastward.

The upper coal unit averages about 180 feet (55 m) thick in the study area drill holes, although the thickness varies considerably. This unit represents a transition from coastal to a fluvial environment of deposition similar to the lower coal unit. Coal is present throughout the upper coal unit, but the coals are generally thin and lenticular. One persistent coal bed which ranges up to 5 feet thick occurs near the top of the unit and may represent the landward vestige of a second period of nearshore coal deposition. If so, this part of the stratigraphic section could be expected to contain a second major coal zone a few miles east of the study area.

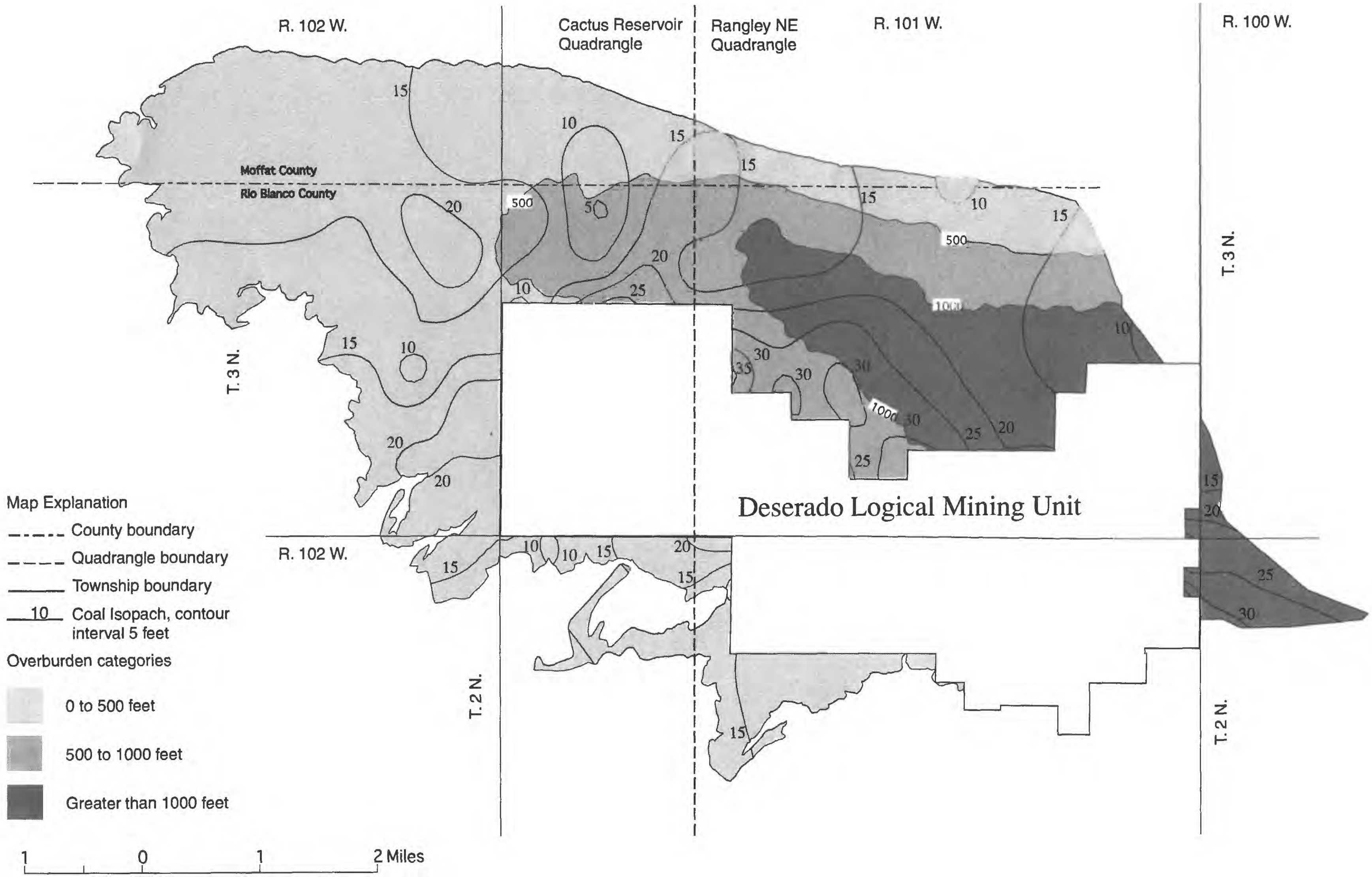

Figure 7. Map showing total net coal thickness and overburden thickness categories for the coal unit, Upper Cretaceous Mesaverde Group, Deserado coal area, Lower White River coal field, Colorado. Data not shown for Deserado Logical Mine Unit.

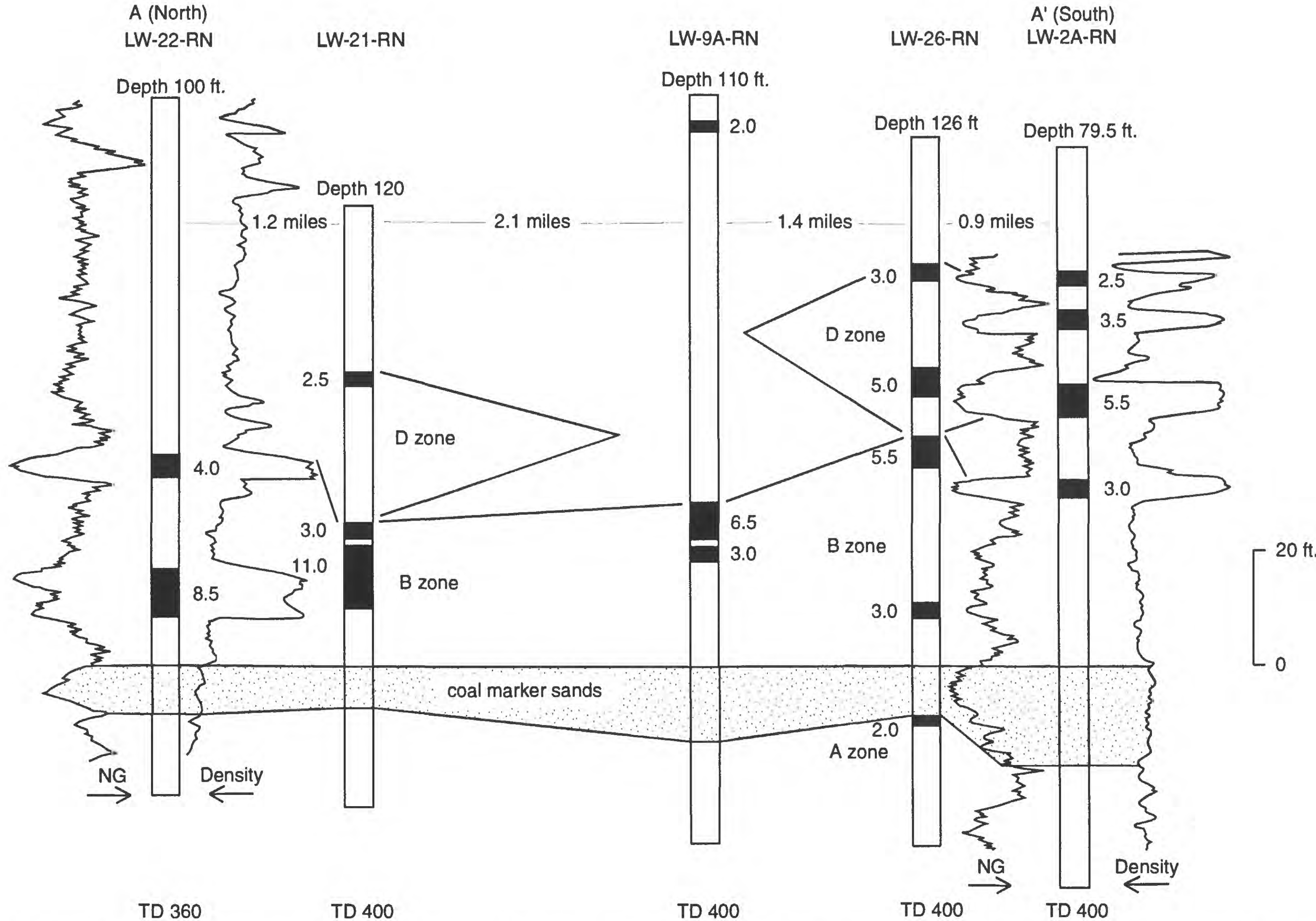

Figure 8. Cross section A-A' showing a portion of selected geophysical log traces (natural gamma and gamma-gamma density) and lithologic units of B and D coal zones and the coal marker sands for selected exploratory bore holes, Deserado coal area, Lower White River coal field, Colorado. Location of cross section shown in figure 3. Coal beds shown in black, coal marker sands stippled. Total depth (TD) shown at bottom of column, depth of upper limit of selection shown at top of the column. Thickness of coal beds shown in feet.

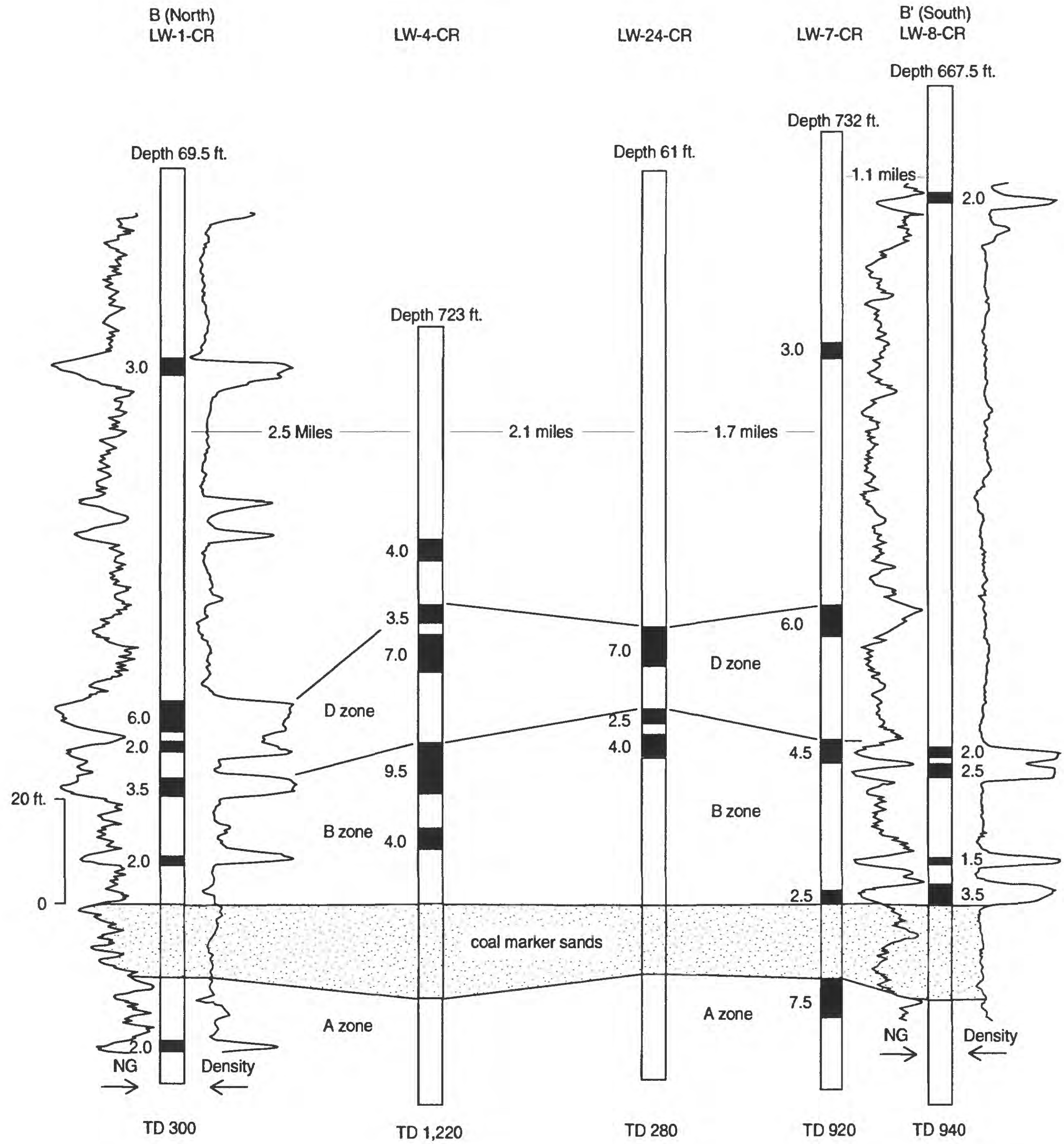

Figure 9. Cross section B-B' showing a portion of selected geophysical log traces (natural gamma and gamma-gamma density) and lithologic units of B and D coal zones and the coal marker sands for selected exploratory bore holes, Deserado coal area, Lower White River coal field, Colorado. Location of cross section shown in figure 3. Coal beds shown in black, coal marker sands stippled. Total depth (TD) shown at bottom of column, depth of upper limit of selection shown at top of the column. Thickness of coal beds shown in feet.

Coal distribution

In the Deserado coal area the coal unit of the Mesaverde Group has been subdivided into 9 coal zones eight of which are show in figure 5. Western Fuels, Inc. has named these coal zones A, lower B, upper B (C), D, E, F, G, H, and I in ascending order within the Deserado Mine area (B. E. Barnum, U. S. Bureau of Land Management, written commun., 1988). Coal zone A is below and coal zones lower B through I are above the coal marker sands. For this report lower B and upper B were combined as the B coal zone.

Although 9 coal zones have been recognized in the coal unit, most coal resources in the Deserado coal area are contained within two coal zones, the B and the D respectively. The B and D occur in the lower part of the main coal zone just above the coal marker sands (fig. 5). The B coal zone rests directly on the coal marker sands, contains one to three coal beds, and averages about 55 (17 m) feet thick. The top of the B coal zone contains a volcanic ash unit that could be traced throughout the study area and was used to correlate the major coal zones. The base of the D coal zone is approximately 55 feet (17 m) above the coal marker sands. The D zone contains up to 2 beds and averages about 30 feet thick.

The net coal thickness and overburden (fig. 10) and the coal thickness categories (fig. 12) maps of the B coal zone display a thinning of the total coal to the east and with a thickening to the west of the coal zone. The thickest net coal in the B zone is found in the center of the study area south of the axis of the Red Wash syncline and in the western part of the study area. The net coal thickness and overburden (fig. 11) and the net coal thickness categories (fig. 13) maps of the D coal zone display a thinning of the total coal to the north and a thickening to the east and west. The variability in coal zone thickness within the study area is due in part to the lenticularity and number of beds within each coal zone.

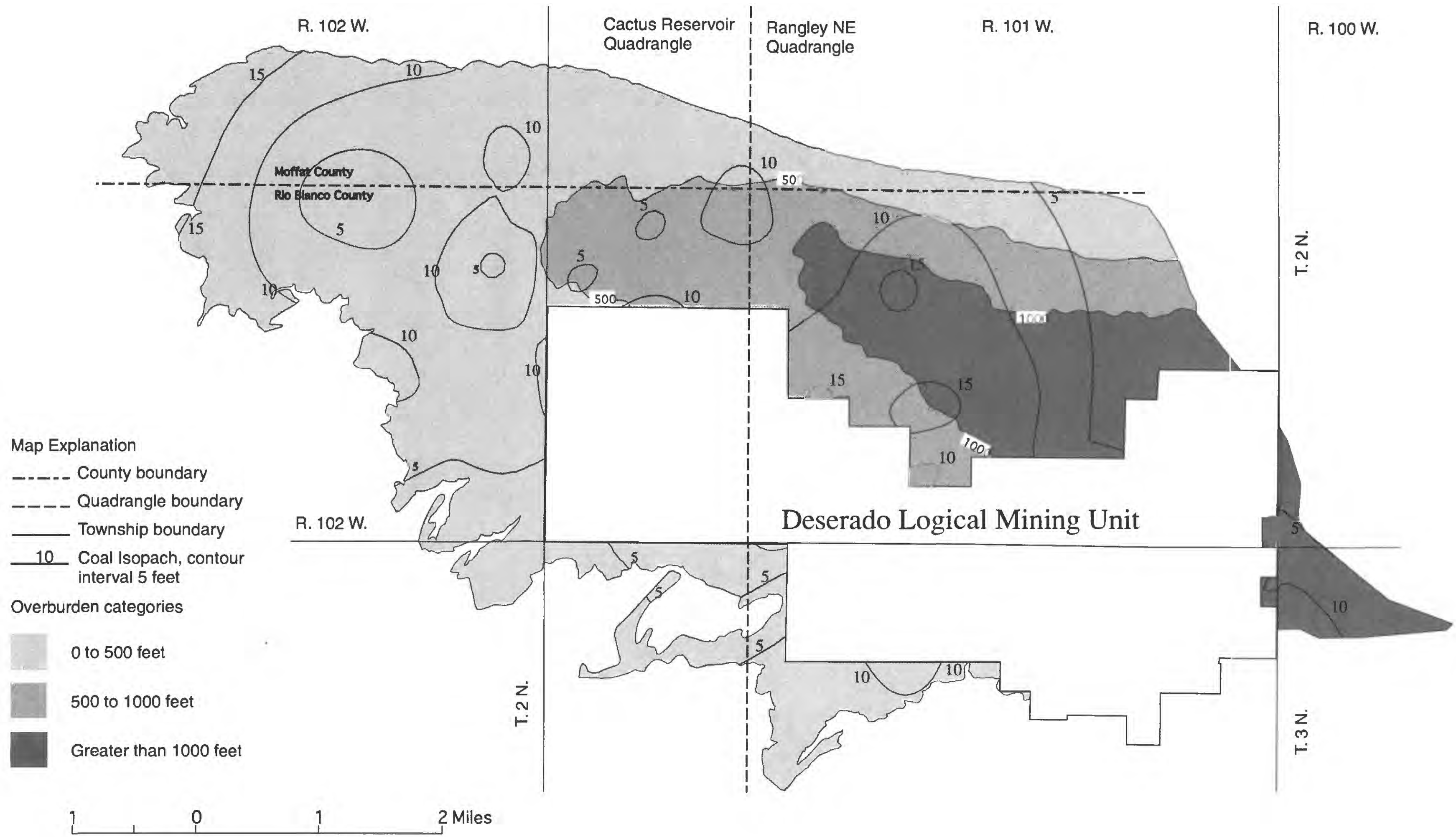

Figure 10. Map showing total net coal thickness and overburden thickness categories for the B coal zone, Upper Cretaceous Mesaverde Group, Deserado coal area, Lower White River coal field, Colorado. Data not shown for Deserado Logical Mining Unit.

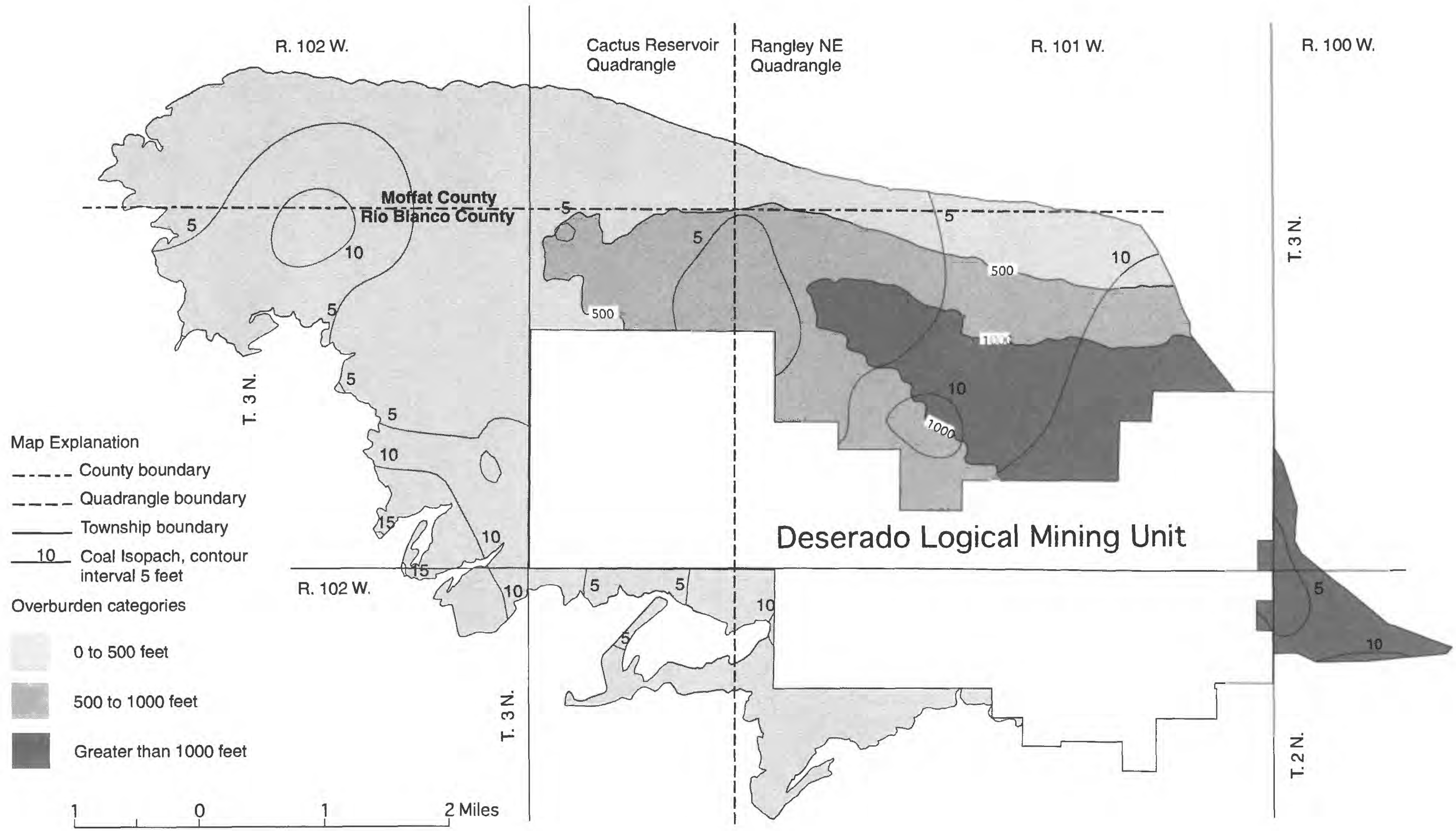

Figure 11. Map showing total net coal thickness and overburden thickness categories for the D coal zone, Upper Cretaceous Mesaverde Group, Deserado coal area, Lower White River coal field, Colorado. Data not shown for Deserado Logical Mining Unit.

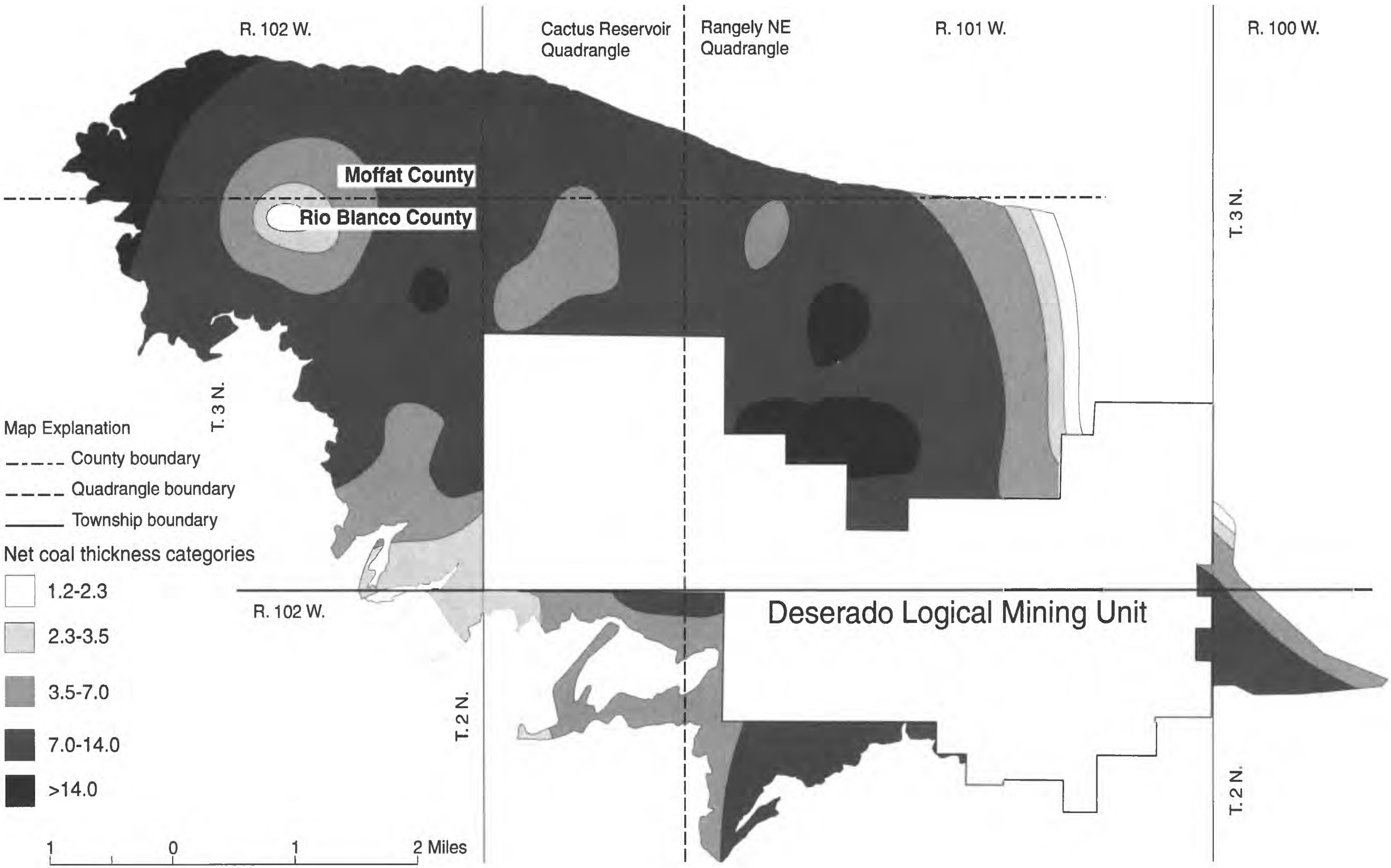

Figure 12. Map showing bituminous net coal thickness categories for the B coal zone, Deserado coal area, Upper Cretaceous Mesaverde Group, Lower White River coal field, Colorado. Thickness categories from Wood and other (1983). Data not shown for Deserado Logical Mining Unit.

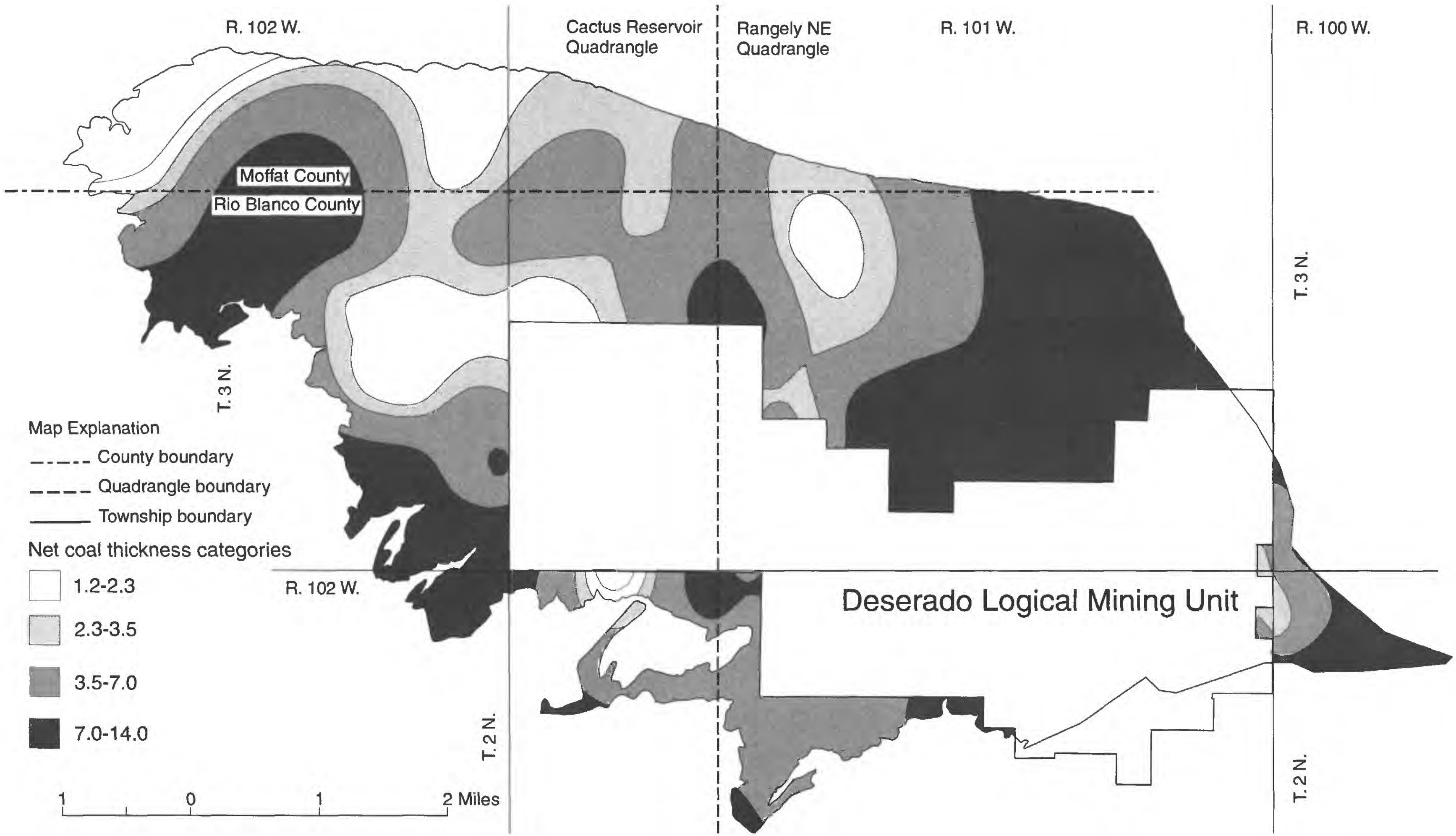

Figure 13. Map showing bituminous net coal thickness categories for the D coal zone, Deserado coal area, Upper Cretaceous Mesaverde Group, Lower White River coal field, Colorado. Thickness categories from Wood and other (1983). Data not shown for Deserado Logical Mining Unit.

Coal quality

Gale (1910) reported coal analysis data from the Rector Mine in the southeastern part of the Deserado coal area. The heat of combustion ranged from 11,080 to 11,490 Btu/lb, sulfur content from 0.4 to 0.46 percent, and an ash yield from 5.53 to 8.06 percent on an as-received basis. The apparent rank of the coal was determined to be high-volatile C bituminous. Hildebrand and Garrigues (1981) reported proximate and ultimate data on nine coal samples from the Lower White River coal field. The coal has a mean heat of combustion of 10,490 Btu/lb, moisture content of 10.4 percent, a sulfur content of 0.5 percent, and an ash yield of 13.0 percent on an as-received basis. The apparent rank for nine samples from the Lower White River coal field was determined to be high-volatile C bituminous and the calculated mean heat of combustion (moist, mineral-matter free basis) is 12,210 Btu/lb. The apparent rank was calculated using the Parr formula (American Society for Testing and Materials, 1997, D388).

In the present study, the 13 coal samples listed (Table 2) from the Deserado coal area of the Lower White River coal field were determined to be high-volatile C bituminous in apparent rank. Two samples were collected at outcrops and the rest were from

Table 2. Number of samples, range, arithmetic mean, and standard deviation of proximate and ultimate analyses, heat of combustion, forms of sulfur, and ash-fusion temperatures of coal from the Lower White coal field, Colorado (All values are in percent except Btu/lb and ash-fusion-temperatures, and are reported on the as-received basis).

	Number of samples	Range		Arithmetic mean	Standard deviation
		Minimum	Maximum		
Proximate and ultimate analyses					
Moisture	13	6.7	22.3	12.02	5.17
Volatile matter	13	29.6	36.8	33.39	2.2
Fixed carbon	13	35.6	51.13	42.95	5.69
Ash	13	4.08	23.9	11.64	5.31
Hydrogen	13	4.5	5.6	5.28	0.28
Carbon	13	44.8	66.9	58.22	7.39
Nitrogen	13	1	1.4	1.27	0.12
Oxygen	13	17.7	36.6	23.04	6.34
Sulfur	13	0.4	1.11	0.55	0.19
Heat of combustion, Btu/lb					
Btu/lb	13	7,240	11,720	10,090	1,490
Forms of sulfur					
Sulfate	12	0.01	0.05	0.02	0.01
Pyritic	13	0.01	0.43	0.18	0.13
Organic	13	0.11	0.63	0.34	0.15
Ash-fusion temperatures, °F					
Initial deformation	13	2,215	2,855	2,595	235
Softening temperature	13	2,305	2,910	2,660	200
Fluid temperature	13	2,415	2,910	2,710	170

Table 3. Number of samples, range, arithmetic mean, and standard deviation of ash and 39 elements in coal from the Lower White River coal field, Colorado. (All analyses are in percent or parts per million and are reported on a whole coal basis. L, less than value shown).

	Number of Samples	Range Minimum	Range Maximum	Arithmetic mean	Standard deviation
		Percent			
Ash	17	4.8	25	13	5.7
Si	17	0.19	7.1	3.3	1.9
Al	17	0.34	2.6	1.5	0.62
Ca	17	0.17	1.4	0.56	0.37
Mg	17	0.046	0.23	0.12	0.061
Na	17	0.077	0.17	0.12	0.023
K	17	0.005	0.21	0.069	0.065
Fe	17	0.094	1.9	0.38	0.42
Ti	17	0.006	0.13	0.079	0.03
		Parts per million			
As	16	0.25	0.93	0.47	0.22
B	17	30	84	53	14
Ba	17	110	680	360	170
Be	17	0.26L	1.2	0.66	0.32
Co	17	0.58	4.9	1.6	1
Cr	14	1.4	21	7.5	5.4
Cu	17	2	16	7.2	3.3
F	17	50	210	110	42
Ga	17	0.72	7.7	3.7	1.8
Hg	17	0.01	0.1	0.038	0.026
La	16	6.8L	17	9	3.9
Li	17	1.7	26	11	5.7
Mn	17	2.2	540	40	130
Mo	14	0.48	2.3	1.1	0.6
Nb	17	0.72	13	5	2.7
Ni	17	1.3	11	4.2	2.9
Pb	17	1.4	41	7.5	9.1
Sb	16	0.043	0.63	0.32	0.19
Sc	17	0.58	3.8	2	0.87
Se	17	0.35	2.3	1.1	0.44
Sr	17	30	270	170	67
Th	17	0.24	7.7	3.3	2.2
U	17	0.26L	3.4	1.6	0.99
V	17	2.1	34	15	8
Y	17	4.3	18	8.6	3.8
Yb	17	0.21	1.8	0.78	0.43
Zn	17	2.9	30	13	8.5

drill cores within the Lower White River coal field and the B and D zones in the Deserado coal area. The coal has a mean heat of combustion of 10,090 Btu/lb, a sulfur content of 0.55 percent, and an ash yield of 11.6 percent on an as-received basis. Ranges in values for proximate and ultimate analyses are given in Table 2. Means and ranges of selected trace-element data for 17 coal samples from the Lower White River coal field and the B and D zones of the Deserado coal area are given in Table 3 on a whole coal basis (R.H. Affolter, U. S. Geological Survey, written commun., 1998). The methods for sampling and inorganic analysis of coal used to determine the elements listed are discussed in Golightly and Simon (1989).

METHODOLOGY USED

The coal benches and parting thicknesses are determined from geophysical logs using the natural gamma and density traces. Coal bed thickness is calculated using the methodology of Wood and others (1983). After the bed thickness is determined, coals less than 1.2 feet thick are subtracted before the net coal thickness is calculated because bituminous coal beds less than 1.2 feet thick are not considered as resource (Wood and others, 1983). The thickest coal is located near the center of the study area, south of the axis of the Red Wash syncline (figs. 6 and 7). The coal thins to the east and west along the axis of the syncline. This variability in total coal thickness is due to the lenticularity of the coals and the number of coal beds in the main coal zone and upper coal unit.

Coal resources in the Deserado coal area are reported in the identified resource category (Wood and others, 1979). Identified resources are located within a 3-mile radius of a data point and include the reliability categories measured, indicated, and inferred. Measured resource category has the highest-degree of geologic assurance and is located within a 0.25 mile radius of a data point. Indicated resource cat-

Table 4. Identified total coal resources in millions of short tons, for the coal unit of the Upper Cretaceous Mesaverde Group, Deserado coal area, Lower White River coal field. Resources are shown by overburden, county, township, quadrangle, and Federal and nonfederal (State and private) ownership categories. Resources do not include area inside Logical Mining Unit boundaries. Coal resources rounded to 2 significant figures.

Geographic Category	Overburden categories in feet			Total
County	0—500	500—1000	>1000	
Moffat	93	1.8	0	95
Rio Blanco	160	89	95	340
Total	250	91	95	440
Township				
T2NR100W	0	0	19	19
T2NR101W	33	0	1.1	34
T2NR102W	5.6	0	0	5.6
T3NR100W	0	0	3.2	3.2
T3NR101W	46	91	72	210
T3NR102W	170	.41	0	170
Total	250	91	95	440
7.5' Quadrangle				
Cactus Reservoir	49	64	95	210
Rangely NE	200	27	0	230
Total	250	91	95	440
Coal ownership				
Federal	240	91	95	430
Nonfederal	8.1	.28	0	8.4
Total	250	91	95	440

egory has a moderate-degree of geologic assurance and is located within an area bounded by a 0.25 to 0.75 mile radius from a data point. Inferred resource category has a low-degree of geologic assurance and is located with an area bounded by a 0.75 to 3 mile radius from a data point. The coal resources estimated for this study do not include the area inside the Deserado Logical Mining Unit. Estimated coal tonnages are calculated using the methodology of Wood and others (1983) and are determined by multiplying the calculated volume of coal by its mean density. The volume of coal in the Deserado coal area is the product of its net thickness times its areal extent shown in figure 7. The apparent rank of the coal in the Deserado coal area is bituminous, so an average density of 1.32 g/cm^3 or 1800 short tons per acre foot was assumed (Wood and others, 1983, p. 22). Coal-bed thickness was measured to the nearest tenth of a foot. Reported coal resource tonnages were rounded to 2 significant figures. Totals may not equal the sum of individual categories because of independent rounding.

In order to better quantify the coal resource found in the B and D coal zones, various aspects of coal distribution were analyzed, including overburden and coal bed thickness. The maximum overburden for the B and D coal zones was determined by utilizing structure contours drawn on the top of the coal marker sands and the surface elevations imported from 1:24,000 Digital Elevation Model for the Cactus Reservoir and Rangely NE quadrangles. Estimated coal resources are calculated in overburden categories of 0-500, 500-1000, and greater than 1000 feet by integrating the overburden map with the net coal isopach maps. To quantify the distribution of bituminous coal thickness categories (Wood and others, 1983) of the B and D coal zones, series of isopach maps were developed that show net coal in thickness categories of 1.2-2.3, 2.3-3.5, 3.5-7.0, 7.0-14.0, and greater than 14.0 feet. Coal resources are reported by thickness category, coal ownership, county, and quadrangle.

Table 5. Identified coal resource in millions of short tons for the B coal zone of the Upper Cretaceous Mesaverde Group, Deserado coal area, Lower White River assessment area by county, coal ownership, and overburden categories. Resources do not include area inside the Logical Mining Unit boundaries. Coal resources rounded to 2 significant figures.

Geographical category	Overburden categories in feet			Total
County	0—500	500—1000	>1000	
Moffat	58	1.1	0	59
Rio Blanco	72	44	42	160
Total	130	45	42	220
Coal Ownership				
Federal	120	45	42	210
Nonfederal	5.9	.15	0	6.1
Total	130	45	42	220

COAL RESOURCES

The total net-coal thickness map (fig. 7) and cross sections (figs. 8 and 9) demonstrate the variability in the coal accumulation within the coal unit of the Mesaverde Group in the Deserado coal area. The total net-coal ranges from less than 5 feet to more than 35 feet thick and the number of coal beds varies from 1 to 10. The coal unit of the Mesaverde Group in the Deserado coal area, Lower White River coal field, contains an estimated original coal resource of about 440 million short tons (Table 4) in the identified resource reliability category (Wood and others, 1983). The coal resource includes all coal beds greater than 1.2 feet thick to a depth of more than 1500 feet in the eastern part of the study area along the axis of the Red Wash syncline. The coal resources estimated for this study do not include the area inside the Deserado Logical Mining Unit. Coal resources were calculated for county, township, quadrangle, and Federal and nonfederal (State and private) ownership categories (Table 4). More than 97 percent of the coal in the coal unit in the Deserado coal area is Federally owned, with more than 90 percent administrated by the Bureau of Land Management. Over 77 percent of the total coal is found within the 1000 foot overburden category with over 57 percent within the 500 foot overburden category.

Over 84 percent of the total coal resource is contained in the B and D coal zones in the main coal zone, 220 and 150 million short tons respectively; resources were not calculated for the area within the Logical Mining Unit. In order to better quantify the coal resource found in the B and D zones, various aspects of coal distribution were analyzed, including overburden and coal bed thickness. Maximum overburden for the B and D zones was delineated and displayed at 500, 1000, and greater than 1000 foot intervals (figs. 10 and 11). Only within the extreme eastern portion of the study area is the maximum overburden greater than 1500 feet. Estimated coal resources were calculated in overburden categories (Tables 5 and 8) by integrating the overburden maps with the net coal isopach maps (figs. 10 and 11). An apparent rank of high-volatile C bituminous was calculated for the coal in the Deserado coal area and is based on analyses from core and mine samples summarized in Table 2. Isopach maps were generated that show net-coal thickness categories (1.2-2.3, 2.3-3.5, 3.5-7.0, 7.0-14.0, and greater than 14.0 feet, Wood and others, 1983) for bituminous coal in the B and D zones (figs. 12 and 13). Coal resources were estimated for each of these thickness categories by township and are listed in Tables 6 and 9. Coal resources were also reported by Federal and nonfederal (State and private) ownership and county in Tables 5 and 8 and by quadrangle in Tables 7 and 10. More than 97 percent of the coal in the B and D zones is Federally owned, with more than 90 percent administrated by the Bureau of Land Management. About 59 percent of the coal in the B zone and about 57 percent of the coal in the D zone is within the 500 foot overburden category.

Although the Deserado coal area contains estimated original resources of 440 million short tons of coal, this resource figure does not reflect economic, land-use, environmental, technological, and geologic constraints that may affect its availability and recoverability (T. J. Rohrbacher, U. S. Geological Survey, written communication, 1998). Some of the economic constraints are costs to build or move infrastructures such as railroads, highways, and primary electrical transmission lines. Environmental restrictions include river valleys, towns and communities, wildlife habitat, and air quality issues. Geologic constraints include faulting, coal bed thickness, and the dip of the strata. Any combination of these constraints and/or restrictions can reduce the amount of coal that is available and recoverable to 10 to 20 percent of the original resource (Rohrbacher and others, 1994).

Within the Deserado coal area the recoverable coal will be restricted because the two assessed coal zones (B and D) currently being mined are too close together and do contain partings and splits that restrict mining. Currently the Deserado Mine is producing coal by long wall methods from both B and D within the mine property at different times. Once the coal is produced from either the B or D zone, the other zone is removed from the resource base because of the current mining process. The mining procedure also reduces the original resource because the long wall mining equipment was engineered for a limited range of coal-bed thickness, less than 14 feet. The thickness of the partings and splits can also limit the thickness of the coal bed being mined.

Table 6. Identified coal resources in millions of short tons for the B coal zone of the Upper Cretaceous Mesaverde Group, Deserado coal area, Lower White River assessment area by township, overburden, and net-coal thickness categories. Resources do not include area inside the Logical Mining Unit boundaries. Resources rounded to 2 significant figures.

Township	0—500 feet overburden net coal thickness categories					0-500 Total	500—1000 feet overburden net coal thickness categories					500-1000 Total	>1000 feet overburden net coal thickness categories					>1000 Total	Grand Total
	1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0	>14.0		1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0	>14.0		1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0	>14.0		
T2N R100W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.4	4.9	0	6.3	6.3
T2N R101W	0	.38	6.1	8.2	0	15	0	0	0	0	0	0	0	0	0	.41	0	.41	15
T2N R102W	.46	.34	0	0	0	.80	0	0	0	0	0	0	0	0	0	0	0	0	.80
T3N R100W	0	0	0	0	0	0	0	0	0	0	0	0	.042	.077	.51	.12	0	.75	.75
T3N R101W	.18	.35	2.8	20	0	23	.12	.23	6.0	31	7.6	45	.18	.39	3.3	23	7.6	35	103
T3N R102W	.17	1.9	10.4	62	16	91	0	0	0	.20	0	.20	0	0	0	0	0	0	91
Grand Total	.81	3.0	19	91	16	130	.12	.23	6.0	31	7.6	45	.22	.47	5.2	28	7.6	42	220

Table 7. Identified coal resources in millions of short tons for the B coal zone of the Upper Cretaceous Mesaverde Group, Deserado coal area, Lower White River assessment area by overburden, net-coal thickness, and quadrangle categories. Resources do not include area inside the Logical Mining Unit boundaries. Coal resources rounded to 2 significant figures.

Quadrangle	0—500 feet overburden net coal thickness categories					0-500 Total	500—1000 feet overburden net coal thickness categories					500-1000 Total	>1000 feet overburden net coal thickness categories					>100 0 Total	Grand Total
	1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0	>14.0		1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0	>14.0		1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0	>14.0		
Cactus Reservoir	.18	.35	4.9	15	0	20	.12	.23	2.2	21	7.6	31	.22	.47	5.2	28	7.6	42	94
Rangely NE	.63	2.6	14	76	16	110	0	0	3.8	10	0	14	0	0	0	0	0	0	124
Grand Total	.80	3.0	19	91	16	130	.12	.23	6	31	7.6	45	.22	.47	5.2	28	7.6	42	220

Table 8. Identified coal resources in millions of short tons for D coal zone of the Upper Cretaceous Mesaverde Group, Deserado coal area, Lower White River assessment area by county, Federal nonfederal (State and private) ownership, and overburden categories. Resources do not include area inside the Logical Mining Unit boundaries. Coal resources rounded to 2 significant figures.

Geographical categories	Overburden categories in feet			Total
County	0—500	500—1000	>1000	
Moffat	21	.09	0	21
Rio Blanco	64	31	33	130
Total	85	31	33	150
Coal ownership				
Federal	84	31	33	150
Nonfederal	1	.02	0	1
Total	85	31	33	150

Table 9. Identified coal resources in millions of short tons for the D coal zone of the Upper Cretaceous Mesaverde Group, Deserado coal area, Lower White River assessment area by overburden, net-coal thickness, and township categories. Resources do not include area inside the Logical Mining Unit boundaries. Coal resources rounded to 2 significant figures.

Township	0—500 feet overburden net coal thickness categories				0-500 total	500—1000 feet overburden net coal thickness categories				500-1000 total	>1000 feet overburden net coal thickness categories				>1000 total	Grand total
	1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0		1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0		1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0		
T2N R100W	0	0	0	0	0	0	0	0	0	0	0	.21	1.3	4	5.4	5.4
T2N R101W	.10	.23	9.6	3.2	13	0	0	0	0	0	0	.04	.11	.03	.17	13
T2N R102W	0	0	0	4.1	4.1	0	0	0	0	0	0	0	0	0	0	4.1
T3N R100W	0	0	0	0	0	0	0	0	0	0	0	.01	.93	.2	1.1	1.1
T3N R101W	.58	3.7	6.5	8.2	19	.63	2.2	11	17	31	.15	.98	2	23	26	77
T3N R102W	3.5	4.7	13.7	27	49	0	0	0	0	0	0	0	0	0	0	49
Grand total	4.2	8.6	30	42	85	.63	2.2	11	17	31	.15	1.2	4.3	27	33	150

Table 10. Identified coal resources in millions of short tons for the D coal zone Upper Cretaceous Mesaverde Group, Deserado coal area, Lower White River assessment area by overburden, net-coal thickness, and quadrangle categories. Resources do not include area inside the Logical Mining Unit boundaries. Coal resources rounded to 2 significant figures.

Quadrangle	0—500 feet overburden net coal thickness categories				0-500 total	500—1000 feet overburden net coal thickness categories				500-1000 total	>1000 feet overburden net coal thickness categories				>1000 total	Grand total
	1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0		1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0		1.2-2.3	2.3-3.5	3.5-7.0	7.0-14.0		
Cactus Reservoir	.089	.97	9.6	10	21	.55	1.2	7	16	25	.15	1.2	4.3	28	33	79
Rangely NE	4.1	7.7	20	32	64	0.077	1	4.4	.81	6.3	0	0	0	0	0	70
Grand total	4.2	8.7	30	42	85	.63	2.2	11	17	31	.15	1.2	4.3	28	33	150

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