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GEOLOGIC OVERVIEW, COAL DEPOSITS, AND POTENTIAL FOR METHANE RECOVERY FROM COALBEDS PICEANCE BASIN, COLORADO

BY

RAOUL CHOATE, DAVID J URICH,

AND

GEORGE J. SAULNIER, JR.

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Methane Recovery from Coalbeds Project
Morgantown, West Virginia 26505

by

TRW, Inc.
Energy Engineering Division
McLean, Virginia 22102

and

Denver Field Office
Lakewood, Colorado 80228

FOREWORD

The report was prepared by TRW for the Department of Energy (DOE) under DOE Contract No. De-AC21-78MC08089. This contract is administered by the Morgantown Energy Technology Center (METC) under the direction of the DOE Methane Recovery from Coalbeds Project Manager, John Duda, and Dr. Harold Shoemaker, the Technical Project Officer in Morgantown, West Virginia.

This report, compiled from on-site investigations, publications, open-file reports, and personal communications with persons familiar with the area, is intended to be an up-to-date, comprehensive handbook of the geology, coal, and coalbed methane resources of the area. The maps, figures, tables, and format of this document provide the reader with a tool for office use or to be taken along as a part of the field investigation. As with any document, information gathered from subsequent investigations may alter the facts, ideas, and conclusions reached in this report. It is the intent of DOE/METC that this document be updated as appropriate.

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1. SUMMARY

Piceance Basin in northwestern Colorado has one of the greatest potentials for near-term production of coalbed methane of any basin in the western United States. Coalbeds of the Late Cretaceous Mesaverde Group underlie 6,570 square miles of the total basin area of 6,680 square miles. Preliminary estimates based on interpretation of geophysical logs of oil and gas wells indicate that the average value for total coal thickness throughout the basin is approximately 50 feet and that the total coal resource to depths exceeding 10,000 feet, is 380 billion tons. Methane contained within the coalbeds comprising this resource is estimated to average 60 trillion cubic feet (tfc). Lower and upper limits for coalbed methane content in the basin are estimated at 30 and 110 tcf, respectively. The area with the highest potential for coalbed methane production is found in the southeastern Piceance Basin (Figure 1-1).

The Piceance Basin is a north-northwest trending asymmetrical basin in the northeast part of the Colorado Plateau Physiographic Province. The basin's topographic expression is diverse and includes many high mesas and mountainous areas caused by differential erosion and resistant caprocks. Climate grades from semiarid to mountain highland depending on elevetion, which ranges from 4,500 to 12,000 feet above sea level. The basin is topographically outlined by the contact of the Late Cretaceous Mesaverde Group with its resistant sandstone ridges, and the older, easily erodible, valley-forming Mancos Shale.

Vegetation within the basin varies from sage and shrub to Douglas fir and pine forest. The area is not heavily populated; principal industries are ranching, resource recovery, and tourism.

In the past, geologic mapping within the basin has been conducted in piecemeal fashion, and stratigraphic studies were most common. Interest in the oil shale resources of northern Piceance Basin has led to a more intense effort in that area, and a greater body of literature is now available for the northern part of Piceance Basin. Many of the coal sequences are in steeply dipping beds not amenable to strip mining, and local underground mines are common. The largest strip mine is the Colowyo mine, north of Meeker in the Danforth Hills field, which produces coal from the

Williams Fork Formation. The largest underground mine is the Somerset, which produces one million tons of coal annually. The presence of large quantities of coking coals in the southeastern Piceance Basin has made the area one of considerable historic mining activity.

The Piceance Basin was the site of depositional activity through the Paleozoic and the Mesozoic except for a brief period of Triassic-Jurassic uplift. The Paleozoic Eagle Basin was a stable shelf area until the Carboniferous, when large sequences of shales, sandstones, and evaporites accumulated in response to uplift of the ancestral Rocky Mountains. Following a period of erosion, nearshore and transitional deposits of the Morrison and Dakota Formations preceded development of the Rocky Mountain Seaway. A thick sequence of marine shales was then deposited including the thick deposits of the Mancos Shale. Middle Cretaceous orogenic activity to the west of the seaway began the gradual filling and deltaic sedimentation sequence which included a southeastward shoreline transgression. This Late Cretaceous transgressive sequence involved long-term maintenance of marsh and deltaic environments. The result was the series of thick lake sequences of the Mesaverde Group which have been lithified to the current coalbeds of interest.

Laramide orogenic activity began at the end of the Cretaceous. Block-faulted uplifts of the Rocky Mountains formed today's basins and mountain ranges. Erosion of the newly formed ranges resulted in the thick Eocene Wasatch Formation.

Mountain building forces set igneous activity into motion which continued into the Pliocene. Two probable batholiths existed to the east and south of Piceance Basin, and expressions of these large magma chambers resulted in intrusive and extrusive activity. Epizonal laccoliths and sills folded and arched strata, and locally metamorphosed sediments and coals. Dikes, flows, and volcanic peaks in the West Elk Mountains are further evidence of the large heat flows which have existed in the southeastern Piceance Basin since the Laramide began.

Coals of the Mesaverde Group outcrop around the periphery of the basin, and eight coal fields have been established in these units. Clockwise from the northwest part of the basin, the fields are the Lower White River, Danforth Hills, Grand Hogback, Carbondale, Crested Butte,

Somerset, Grand Mesa, and Book Cliffs. Coal resources within the basin were estimated to be 380 billion short tons. Coking coals are abundant in the Grand Hogback, Carbondale, Crested Butte, and Somerset coal fields where 0.45 billion short tons have been estimated to be present at depths less than 1,000 feet. Total cumulative production in the basin by 1978 was over 87 million tons, and projected 1980 production has been estimated at 6.75 million short tons, more than double the 1978 figure.

Ranks of Piceance Basin coals range mainly from high-volatile C to medium-volatile bituminous. In the southeastern basin, the high heat associated with Tertiary igneous activity has resulted in coals being metamorphosed to semi-anthracite and anthracite rank. Individual coalbeds vary widely in thickness and stratigraphic position and coalbed names generally are not carried throughout the basin. Coal thicknesses decrease to the west and northwestern parts of the basin.

The Lower White River coal field includes the western Piceance Creek Basin, the northern Douglas Creek area, and the area around the Rangely Dome. Coals occur in the Iles and Williams Fork Formations and have been mined in the Rangely area. High-volatile coal occurs in 8- to 12-foot beds and may amount to over 11 billion tons up to depths of 6,000 feet. No mines are currently active.

The Danforth Hills field extends from Meeker to Axial and is separated from the Green River coal region by the Axial Basin. The Iles and Williams Fork Formations contain mainly good-quality, high-volatile C bituminous coals in numerous beds up to and exceeding 20 feet thick. More than 10 billion tons of coal are estimated to depths of 6,000 feet. Both underground and open-pit mines are currently operating.

The Grand Hogback field extends from Meeker to Glenwood Springs along the eastern rim of Piceance Basin. These steeply dipping coalbeds grade from high-volatile C in the north to high-volatile B bituminous to the east. Numerous coalbeds are present in five coal groups with beds from 3 to 18 feet thick. More than three billion tons are estimated to depths of 6,000 feet. Present mining activity is minimal.

The Carbondale field extends from Glenwood Springs to Redstone and yields high quality coking coal from the Mesaverde Group. Coal rank ranges from high-volatile A bituminous to anthracite in metamorphosed areas. The Coal Basin area is considered to be the gassiest of coal areas in the western United States. Over five billion tons are estimated up to depths of 6,000 feet.

The Crested Butte field occupies the southeastern tip of the Piceance Basin and coalbeds are found at elevations exceeding 10,000 feet. Igneous activity has folded and faulted the strata in the Mesaverde Group, and coal rank ranges from high-volatile C bituminous to anthracite. Some good coking coal is present. Between one and two billion tons are estimated up to depths of 6,000 feet.

The Somerset field contains thick coal sequences in the Williams Fork Formation in beds up to 30 feet thick. Coal rank is from high-volatile C to high-volatile B bituminous, and good-quality coking coal is produced at several mines. Over eight billion tons of coal are estimated up to depths of 6,000 feet. The Book Cliffs field contains high-quality coal in the Mount Garfield Formation. Coal rank is mainly high-volatile C bituminous with some high-volatile B also present. Several underground mines are currently operating, and over seven billion tons are estimated to depths of 6,000 feet.

Historical data of mining accidents in the southeast Piceance Basin indicate that at least 176 persons have been killed in gas-related accidents since the 1880s. Methane emission data from underground mines are abundant. Longwall operations at the Mid-Continent Coal Company mines use ventilation systems to reduce the high methane content in the mines. An extensive drainage system has been installed, and part of the methane obtained in this way is used in the coal-fired dryers.

Methane desorption data have been gathered from surface wells on projects other than DOE's Methane Recovery from Coalbeds Project (MRCP). Data from several of these sites were used to construct an east-west cross section which provides insight into the nature of methane generation. From west to east, a U.S. Geological Survey (USGS) well, two Coors wells, one Teton Energy well, two Exxon Energy wells, a Union Oil well, and four U.S. Steel exploration wells were used.

The Exxon Vega 2 well is currently in production with over 400 Mcfd being produced, and with an estimated methane resource of 35.9 billion cubic feet of gas per square mile. The Exxon Vega 3 well is estimated at over 45 billion cubic feet of gas per square mile. The U.S. Steel wells also are very gassy with gas contents that range from 107 to 1,041 cu ft/ton of coal. The property has an estimated resource of over 24 billion cubic feet of gas per square mile. Union Oil's Overland No. 1 well is significant because, at a depth of 6,700 feet in the central portion of the basin, a coalbed was encountered which had been intruded and baked by a silicic sill. Data along the cross-section indicate that methane content increases with increasing aggregate coal thickness, increasing overburden thickness, and proximity to igneous intrusions. Data collected in northern Piceance Basin by the Geological Survey and the DOE/TRW/MRCP indicate that these lower rank coals are not very gassy.

The MRCP data collection program has further amplified information obtained from private sources. Desorption analysis of the Teton Energy well--Walck 23-2--samples yielded up to 300 cu ft/ton. One Coors well was hydro-fractured to stimulate the production of coalbed methane.

The weight of accumulated data for Piceance Basin supports the theory that increased overburden thickness and geothermal heat flow resulted in higher coal rank and greater amounts of coalbed methane. Based on the authors' analyses, the following conditions would be indicative of target areas:

- Areas where overburden thickness is greater than 2,000 feet
- Areas of thick coal, particularly near the basin center
- Areas of higher heat flow, especially greater than 1.5 to 2 heat flow units
- Areas where epizonal intrusive igneous activity has caused folding and arching of coal-bearing strata, regardless of depth
- Axes of major synclines and anticlines
- Areas where igneous activity has faulted and fractured coal-bearing sequences
- Areas downdip from gassy mines in the direction of higher heat flow values

- Coincidence of any two of the above criteria would constitute a "prime" target area.

Figure 1-1 shows the author's estimate of the principal target area in southeastern Piceance Basin. Parts a, b, c, and d of Figure 1-1 illustrate how coal thickness, depth of overburden, coal rank, and coalbed methane content were used to arrive at the target area shown in Part e.

To aid in further delineation of additional target areas the following program is recommended:

- Review of all recent state and federal mine inspection reports for figures on methane ventilation from mines and any mine explosions or accidents caused by gas accumulation.

- Review of older literature for references to gassy mines or mine accidents in old abandoned mines, particularly in the eastern Grand Hogback field and the Carbondale field.

- Review of the lithologic and geophysical well log file available for the basin for:

  - Occurrence and thickness of coals at all depths throughout the basin

  - Evidence of gas shows and drill stem tests in coal-bearing intervals.

- Review of all water data of the State Water Resources Department and the USGS for reports of high gas content, including methane, ammonia, nitrogen, carbon dioxide, and hydrogen sulfide.

- Contact companies with deep drilling permits, in southeastern Piceance in particular, and in other parts of the basin, to request mutual exploration participation to investigate coal zones above the primary pay zones of interest.

- Perform detailed logging, sampling, desorption, and testing, including fracing if possible, of coalbeds.

- Encourage commercial ventures in the southeastern Piceance Basin to provide:

  - A more thorough examination of coal zones and their methane content

  - A chance for government agencies and private corporations to share expertise and data, thus stimulating production and further understanding of processes of coalbed methane occurrence.

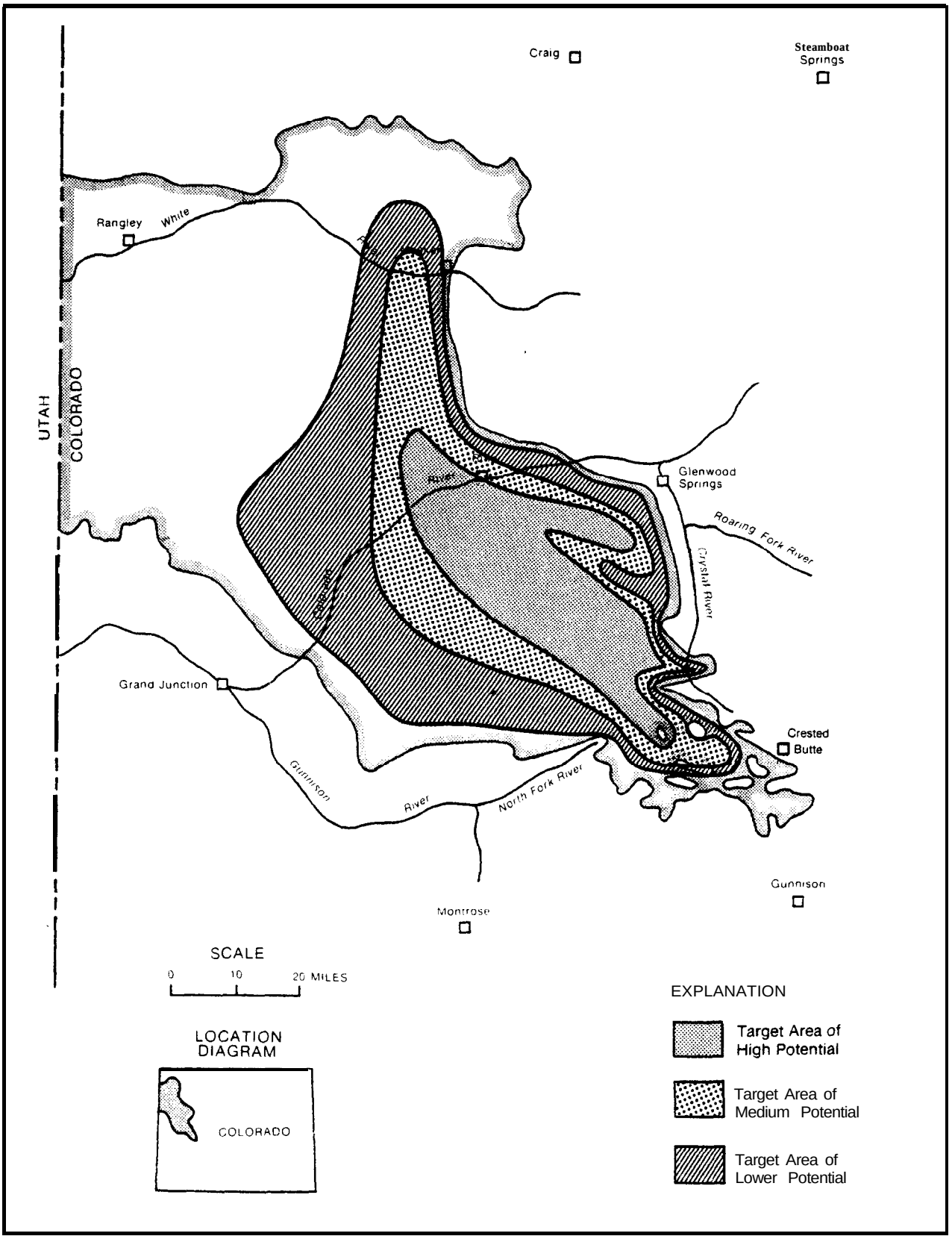


Figure I-I. Piceance Basin Coalbed Methane Target Areas

2. INTRODUCTION

The objective of this report is to assess the magnitude of the coalbed methane resource in the Piceance Basin of northwestern Colorado. To achieve this, the report will:

- Summarize the general geology and occurrence of coal in the basin
- Compile all existing and available data on the occurrence and production of methane associated with coalbeds in the basin, with the aim of identifying large amounts of methane associated with coalbeds
- Relate the occurrence of coalbed methane to depth of burial, igneous activity, and measured heat flow.

After reviewing these three areas, the report will define target areas which may have the greatest methane recovery potential. This report is part of the Department of Energy's (DOE) MRCP. The MRCP consists of a planned sequence of resource characterization, research and development, and technology tests, designed to evaluate and test the technical and economical extraction and utilization of gas associated with coalbeds.

The report is organized into four main parts. Following the Summary and this Introduction, Section 3 deals with the general physiography and geology of Piceance Basin, emphasizing coal-bearing formations of the Late Cretaceous Mesaverde Group and Tertiary intrusive and extrusive rocks. Brief discussions of oil shale, uranium, and conventional oil and gas resources also are included. Section 4 contains a general discussion of coal resources; their rank, distribution, and production in Piceance Basin; and a description of each of the basin's eight coal fields. Section 5 presents a compilation of known methane occurrences, detailed well production figures, and desorption data and quantitative methane evaluation of wells and individual coalbeds in particular sections of the basin. Section 6 gives certain conclusions relating the occurrence of coalbed methane to heat flow and depth of burial. These correlations will be used to recommend target areas for more intensive exploration. Sections 7 and 8 list cited and additional references, respectively. Four appendices contain topographic maps of the basin, geologic index maps and map references, and maps and cross sections compiled from available data for this report.

3. BASIN SETTING

3.1 GEOGRAPHIC SETTING

3.1.1 Geography

Piceance Basin is located in northwestern Colorado in the extreme northeast corner of the Colorado Plateau physiographic province (Figure 3-1). The basin is bounded by the Axial Basin Uplift and Uinta Mountains to the north; Grand Hogback, White River Uplift, and Sawatch Range to the east; Gunnison Uplift to the south; and Douglas Creek Arch and Uncompahgre Uplift to the west (Figure 3-2).

The surface landforms in Piceance Basin are diverse. Grand and Battlement Mesas are topographic highs protected from rapid erosion by caprocks of resistant basalt flows. The deep canyons of the Colorado and Gunnison Rivers were superposed on the basin during a period of Plio-Pleistocene uplift. Volcanic peaks of the West Elk Mountains dominate the southeastern Piceance Basin landscape. The smaller Piceance Creek Basin is an elevated topographic basin protected from erosion by upturned ridges of erosion-resistant kerogenaceous marlstones of the Green River Formation (oil-shale).

Piceance Basin includes parts of Moffat, Rio Blanco, Garfield, Mesa, Delta, Pitkin, and Gunnison Counties and has an areal extent of roughly 7,225 square miles (Collins, 1976) (Figure 3-3). Grand Junction, the region's largest city and center of commerce, lies on the southwest border of the basin at the confluence of the Colorado and Gunnison Rivers. Large towns in and around the basin include Meeker, Rangely, Rifle, Glenwood Springs, Carbondale, Gunnison, Paonia, Delta, and Montrose. While the region is not heavily populated, there are several small mining and resort communities, especially in mountainous areas. Paved and improved roads provide access to much of the basin. Direct north-south travel is difficult because of the high, unpopulated mesas and deep east-west canyons. Major rail routes run through the basin center (along the Colorado River) and on its western border (Figure 3-3). Oil and gas pipelines connect to major regional lines, providing a ready outlet for locally produced petrochemicals.

Principal industries in Piceance Basin are oil and gas production, metal mining, coal mining, agriculture, and tourism. Energy development, especially in coal and oil shale, is currently undergoing rapid growth, especially in the area north of the Colorado River. Tight gas sands are being explored in the western Piceance Creek Basin/Douglas Creek Arch area and gas exploration activity is presently very active. A small vanadium mill is operating at Rifle and a large molybdenum prospect awaits development near Crested Butte. Coalbeds are being mined for coking coals in the southeastern basin and for coal-fired power plants in the northern basin. Prototype oil shale projects are currently operating in Piceance Creek Basin, where interest in the sodium minerals nahcolite, dawsonite, and halite is also strong. Cattle and sheep ranching operations are found throughout the basin and fruit growing is a large industry along the lower Colorado River valley from Grand Valley to Fruita. Outdoor recreation, including skiing, hunting, and fishing, supplements local industries in Piceance Basin.

3.1.2 Physiography

Piceance Basin is an elongated northwest-trending basin strongly asymmetrical to the northeast (Figure 3-4) with a well-defined structure in the subsurface, as seen on a Precambrian structural map (Figure 3-5). However, on the surface, the basin form is not as evident. The rising of the White River uplift at the opening of Cenozoic time may have been partly responsible for the basinal asymmetry and the sinuous shape of the basin's axis (Figure 3-5). The Douglas Creek arch separates Piceance Basin from the larger Uinta Basin of Utah (Murray and Haun, 1974). Igneous intrusive and extrusive activity in the Somerset-Crested Butte area has modified the structure and surface expression of the southeastern part of the basin.

The surface expression of the basin area is outlined by the upturned resistant sandstones of the Mesaverde Group which form a distinctive topographic break with the underlying, easily erodible Mancos Shale. The basin measures approximately 150 miles along its axis. Its width diminishes northwest to southeast, from 90 miles to about 47 miles wide from Grand Junction to the Grand Hogback, to less than 20 miles wide at the southeast part. The total topographic relief in the basin is about 7,500

feet, from less than 4,500 feet along the Colorado River to just under 12,000 feet in the West Elk Mountains. The majority of the landscape lies between 5,000 are 8,000 feet above sea level.

3.1.3 Climate

The climate prevailing within Piceance Basin varies over short distances because of differences in elevation, topography, and aspect. However, because Piceance Basin lies to the west of major mountain systems, the climate within an individual valley, mesa, or range in the basin may be reasonably consistent. The climate varies from semiarid in the lowlands and mesas in the western and northwestern areas, to mountain-highland climate at higher elevations in the southeastern part of the basin.

Elevation is the primary climatic control in the Piceance Basin. Lower portions of the basin have a lower mean annual rainfall, higher seasonal mean temperatures, and large diurnal temperature variations. With increasing elevation, rainfall increases and temperature decreases. Most precipitation falls at the higher elevations and the winter snowpack is the major water reservoir sustaining stream flow throughout the year. Vegetation types also vary with precipitation, elevation, and temperature ranges. Sagebrush and shrubs are common in the lowlands, with forested areas established in succession with altitude, from pinyon-juniper through Douglas fir and pine forests. Northern and eastern slopes retain snow the longest and are the most densely forested. The more moderate climates of the valleys of the Colorado, Gunnison, White, and Roaring Fork Rivers are the setting for most of the agricultural activity in the basin.

For the Piceance Basin as a whole, the following temperature ranges are published by the U.S. Department of Commerce (Berry, 1968): January maximum 28° to 36°F; January minimum -10° to +8°F; July maximum 68° to 92°F; and July minimum 40° to 56°F. The extreme low temperatures occur in the mountainous areas and the extreme highs in the lowlands. Mean annual precipitation (Figure 3-6) ranges from 8 inches in the northwest Piceance Basin to over 40 inches in the mountainous areas (U.S. Weather Bureau, 1967). Precipitation is distributed evenly throughout the year with much of the precipitation occurring as snow. Summer precipitation consists mainly of low-duration, high-intensity storms. Prevailing winds are

generally from the south and southwest, although individual localities may experience valley breezes oriented along major rivers for much of the year (Berry, 1968).

3.2 GEOLOGY

3.2.1 Stratigraphy

The coal-bearing formations of Piceance Basin are primarily continental and mixed continental-marine sediments of Cretaceous age. These beds, and those from the Cambrian through the Jurassic, were deposited in environments controlled by the presence of seaways along the western margin of North America. These seaways represented various manifestations of epicontinental seas which spread over the continent in varying configurations, creating shelf environments in the early Paleozoic and eugeosynclinal and transitional environments from Pennsylvanian through Jurassic. Water depths were variable, and Paleozoic facies of differing thicknesses and lithologies are recognized. Periodic minor uplifts and periods of erosion have resulted in thin or missing sections in the Silurian and Devonian section (Murray and Haun, 1974). These variable conditions, coupled with the depth and regional position of the Piceance Basin, have led to equivalent formation terminologies across the basin. The following section briefly describes the pre-Cretaceous stratigraphic section (see Figure 3-7).

3.2.1.1 Pre-Cretaceous Rocks

The oldest rocks exposed in Piceance Basin are Precambrian crystalline rocks found in the cores of uplifts and the bottom of deep canyons. The lithologies represented are granites, granodiorites, quartz monzonites, and a variety of metavolcanics and metasediments, gneisses, and granitic gneisses.

Approximately 1,500 feet of pre-Mississippian sedimentary rocks are found in Piceance Basin. During these time periods, stable shelf environments prevailed and a series of dolomites, limestones, sandy dolomites, sandstones, and quartzites were deposited with some cyclothems indicated. Formation names include the Sawatch Quartzite and the Dotsero, Manitou, Parting, and Dyer Formations.

The Mississippian represents the last widespread marine environment with up to 300 feet of Leadville Limestone (a Madison equivalent) found in the basin. This massive, cream gray, buff, and brown, finely to coarsely crystalline limestone is well-displayed around the White River Uplift. Some cherty zones are present, and secondary solutioning and cave development can be seen near Glenwood Springs.

Pennsylvanian time saw the emergence of the ancestral Rocky Mountains and creation of the Eagle Basin, part of which is non-Piceance Basin. Continental and marine sediments interfingered in the basin until a massive series of Permo-Pennsylvanian arkoses, shales, siltstones, and sandstones--the richly colored Maroon Formation (which includes the thin eastern feather edge of the Weber Sandstone)--filled in Eagle Basin. For a time, a closed basin existed which produced the Eagle Valley evaporites, mainly gypsum with some halite, and the Paradox Formation which also contains evaporite facies. The Beldon Formation (lower Pennsylvanian) and the Minturn Foundation (middle Pennsylvanian) are shale sequences including some organic and coaly shales. Up to 6,000 feet of Permo-Pennsylvanian beds are present.

The Permian-Triassic boundary is difficult to establish because these continental sedimentary rocks are not rich in fossils. The State Bridge and Moenkopi Formations and the Shinarump Conglomerate contain up to 1,000 feet of shaly siltstones and crossbedded sandstones. These formations are distinctively red in color. The remainder of the Triassic and Early Jurassic units are a series of shales, siltstones, limestone pebble conglomerates, and massive crossbedded sandstones. These sediments may have infilled large interior basins and many are highly colored (the orange Chinle Formation and the lavender Kayenta Formation). Arid to semiarid climates probably prevailed as indicated by the eolian festoon crossbedded Wingate and Entrada (Navajo equivalent) Sandstones. These sandstones sometimes form impressive cliffs. The thin Curtis and Summerville Formations cap up to 2,800 feet of sedimentary rocks representing the Late Permian through Middle Jurassic time periods.

The end of Jurassic time saw emergence of highlands to the west of Piceance Basin and the beginning of low-lying marshy environments which became highly developed in the Cretaceous. The Morrison Formation, a

highly fossiliferous varicolored shale, mudstone, and sandstone sequence, was deposited at the close of Jurassic time. The Morrison became subject to Early to Middle Cretaceous erosion when the developing Rocky Mountain geosyncline signalled a major change in depositional environments (Figure 3-8).

3.2.1.2 Cretaceous Rocks

The environment of deposition in Piceance Basin changed markedly at the end of Jurassic time as a period of regional uplift ensued. Exposed Jurassic rocks were eroded and this surface became the site of sandstone and conglomerate deposition. Throughout Early Cretaceous time a continental environment prevailed. Shales, sandstones, and some thin coals (Dakota Formation) were deposited. Deposition of reworked older sediments and organic material continued until the mid-Cretaceous when a seaway representing the Rocky Mountain Geosyncline advanced through the Piceance Basin area from the north (Figure 3-8). Thousands of feet of marine and some non-marine sediments accumulated in Middle and Late Cretaceous time. The total sequence of all Cretaceous formations adds up to the thickest time period sequence in northwest Colorado (Murray and Haun, 1974).

The Wasatch uplift caused the shoreline to regress southeastward in the Late Cretaceous. With the retreat of the sea, a vast tidal and lowland marsh environment was maintained as several thousand feet of clastic and organic sediment were deposited. Coals, sandstones, and some shales of both marine and non-marine origin testify to the fluctuating nature of the environment as the sea level transgressed and regressed in response to changing conditions. Toward the end of Cretaceous time, continental conditions were dominant in Piceance Basin. The sulfur content of the coals is used to aid in the marine versus non-marine determination, with high sulfur values associated with salt marsh and brackish tidal marsh deposits. The majority of coals in the Mesaverde Group (those above the Rollins Sandstone) are considered to be fresh water in origin (Collins, 1976).

The two most plausible explanations for the sandstone/coal/shale associations represented by the Mesaverde Group are the deltaic complex argument (Collins, 1976), and the barrier beach-coastal plain argument (Young, 1966). Collins(1976) presents strong evidence to support the idea

that the Mesaverde coals were deposited in a widespread prograding deltaic complex at the western edge of the epicontinental sea in the Rocky Mountain Geosyncline. Sea level changes are proposed to occur in response to variations in sedimentation rates, compaction, and deltaic growth faulting. Cyclic sedimentation is presumed to result from changes in sea level, changes in the delta distributary system, and the development of barrier beaches.

The formation terminology of the Mesaverde Group is quite complicated and the principal stratigraphic units possess different names depending on their geographic location (Figure 3-9). The term Mesaverde Group is the most widely accepted term which includes all the major coal-bearing units of Late Cretaceous age. Many formation usages are coal field-specific, and no unified description of the entire basin exists (Figure 3-10).

> East of the Colorado-Utah boundary (sic) five units are recognized termed (sic) the Mount Garfield and Hunter Canyon Formations, Sego Sandstone, Buck Tongue of Mancos Shale and Castlegate Sandstone.... East of Palisade, Colorado the comparable interval is referred to as the Mesaverde Formation.... In the northern Piceance Basin and along the Grand Hogback south to the Colorado River, The Mesaverde Group is subdivided into two units, termed the Williams Fork and Iles Formations.... (Anderson, 1980, p. 18).

Figure 3-10 summarizes some of the terminology used over the basin. The following section summarizes the lithologies of the Cretaceous formations.

Early Cretaceous

Cedar Mountain Formation (Burro Mountain Formation) (0 to 125 feet) These equivalent units consist of white, gray to buff, fine- to coarsely-crystalline sandstone interbedded with green to purplish siltstones, shales, and calcareous mudstones. A basal conglomerate is locally present.

Late Cretaceous

Dakota Sandstone (100 to 200 feet) The Dakota Sandstone contains yellowish brown and gray, well-sorted, quartzitic, and conglomeratic sandstones with interbedded carbonaceous shales. Lenses of thin coal may be present locally in the upper unit. The sandstones weather rust brown and form ridges.

Mancos Shale (4,000 to 6,000 feet) The Mancos is a medium-to-dark gray to black, fossiliferous marine shale with local interbeds of siltstone, sandstone, and limestone. The shales may also be calcareous. The upper Mancos interfingers with overlying Mesaverde Group.

Mesaverde Group (2,300 to 6,500 feet) The Mesaverde Group includes the Blackhawk, Prince River, Hunter Canyon, Mount Garfield, Williams Fork, and Iles Formations. The central portion of the group contains the major coalbeds of northwestern Colorado. The sequence contains continental and marine rocks consisting of siltstones, sandstones, shales, and coalbeds. Many thick sandstone members are ridge formers including the Castlegate, Cozette, Fox Canyon, Meeker, Morapos, Sego, Tow Creek, Trout Creek-Rollins, and Twenty Mile Sandstones (Figure 3-11). The upper unit is shaly and capped by sandstones and the Ohio Creek Conglomerate (Johnson and May, 1978). Major coalbeds are discontinuous and have not been correlated basin-wide, although named coal zones (see Section 4) are referred to in the literature (Erdmann, 1934; Goolsby et al., 1979). Plate 2 identifies coal "groups" recognized in the Danforth Hills, Grand Hogback, and Carbondale coal fields (Collins, 1976).

3.2.1.3 Post Cretaceous Rocks

The end of Cretaceous time brought the Laramide orogeny and a disruption of the depositional conditions which produced the Mesaverde coals. The shoreline regressed to the southeast, mountain-building forces disrupted the Colorado Plateau breaking up the epicontinental sea into a series of small basins, and continental depositional conditions were established (Wasatch and Fort Union Formations). While deep basins developed in the central Rockies in Early Cenozoic time, some coal- producing environments persisted during Wasatch deposition as evidenced by thin coals encountered in deep drill holes in Piceance Creek Basin (Murray, 1974).

A large lake, Lake Uintah, existed in the northern portion of Piceance Basin during Eocene time. This lake was biologically highly productive and became the depositional site for as much as 2,000 feet of argillaceous marlstone with a high kerogen content (oil shale). The lake's salinity varied from fresh to brine, depending on the Eocene climate. During stagnant high evaporation conditions, minerals such as nahcolite and halite

were deposited in the lake muds and directly from saturated brines (Bradley, 1964). As the lake basin gradually filled, the marlstones became more clastic and less organic. The Green River Formation then gives way to the deltaic and fluvio-lacustrine siltstones of the Uinta Formation (Cashion and Donnell, 1974).

3.2.1.4 Igneous Rocks

Miocene through Pliocene time in the Piceance Basin is represented by extrusive and intrusive igneous rocks. Some of the extrusive sequences also contain sands, gravels, and water-laid tuffs associated with volcanic activity. Because igneous activity is believed by the authors to have had a strong influence on the gas content of Piceance Basin coals, a more detailed account of igneous activity will now be presented. This material, unless otherwise noted, originates from Collins (1976).

A large number of laccoliths occur in the southeast portion of Piceance Basin. These intrusives cut and alter coal-bearing rocks. The laccoliths, when exposed at the surface, range in composition from granodiorite to quartz monzonite. The exact ages of the laccoliths are not known although they are observed to cut rocks of Eocene age. This series of intrusives caused local metamorphism of sedimentary rocks to hornfels and marble. These intrusive bodies are now seen in conspicuous topographic features like Mt. Sopris, Chair Mountain, Snowmass Peak, Capital Peak, and Haystack Mountain (Kent and Arndt, 1980b). Sills of similar composition occur in the Coal Basin and Marble areas.

Basaltic to dacitic vertical dikes from 1 to 50 feet thick, striking from east-west to N30°W, are found in the Coal Basin area. Radial dikes occur around West Elk Mountain and the Purple Mountain area (Figure 3-12). The dikes locally affect the strata they intrude and are affected by them as well. In the Coal Basin area, the dikes are aphanitic below the Rollins Sandstone and porphyritic above it. Coal seams also have been altered by the dikes.

Extrusive basalt flows and some volcanic tuffs and volcano-sedimentary rocks also occur in the basin. The flows are olivene basalts which cap Grand and Battlement Mesas, and are found on Sunlight Peak and the West Elk

Mountains. These flows are Miocene-Pliocene in age (Murray and Haun, 1974) and do not appear to have affected the rocks or coals in the area.

3.2.2 Structural Geology

3.2.2.1 General Basin Structure

Piceance Basin has a relatively simple structure best illustrated by contours showing the top of the Precambrian basement (Figure 3-5). The basin is a northwest-southeast-trending feature, asymmetric to the northeast with slightly sinuous axis. The lowest point in the basin is over 13,000 feet deep in the Piceance Creek Basin. The White River Uplift, which causes the S-shape of the basin axis, exposes Precambrian rocks at over 10,000 feet and the Uncompahgre Uplift contains Precambrian rocks at over 8,000 feet, making the structural relief between 26,000 and 28,000 feet. The basin is separated from the structurally similar Uinta Basin of Utah by the broad Douglas Creek Arch.

The Piceance Basin area was a broad platform through the early Paleozoic until the ancestral Eagle Basin was formed during the Pennsylvanian (Quigley, 1965). The rapid growth of the Uncompahgre Uplift and the Ancestral Front Range created a deep basin receiving a complex series of deltaic, fan, and evaporite deposits through Jurassic time. The basin was reactivated during the Late Cretaceous, as isopachs and cross sections of these rocks show (Figures 3-13 and 3-14). The basin was altered by the rising of the White River Uplift, and remnants of the Eagle Basin are found in a few small basins and the larger Piceance Basin. The Piceance Basin was an intermontane basin receiving a large quantity of continental and lacustrine sediment. During early Pliocene time, basalt flows covered what may have been a broad alluvial plain (Murray and Haun, 1974). This period of activity was followed by regional uplift which continues today and has caused over 5,000 feet of downcutting since the Pliocene (Murray and Haun, 1974). Tertiary sediments are now being exhumed, but the process is a slow one, because of the resistant beds of the Green River Formation and the basalt caps on the high mesas.

3.2.2.2 Folds and Faults

Piceance Basin is not highly deformed, and faulting and folding occur mainly in the southeast portions near intrusive activity along bends in the

trend of the Grand Hogback (Plate 1), and the Piceance Creek Basin-Sulfur Creek area. High angle normal faulting and shallow anticlines and synclines are the major expressions of deformation.

The major fold structure in the Piceance Basin is the Grand Hogback monocline which runs along the eastern boundary of the basin. The flexure is probably the result of the formation of the White River Uplift. Dips along the monocline are variable, but generally between 30 and 70 degrees, with a few instances of vertical to overturned bedding. The Grand Hogback forms a prominant topographic feature--the result of the differential resistance to erosion of the sandstones of the Mesaverde Group.

Shallow minor folds occur mainly in the northern and southern parts of the basin. In Piceance Creek Basin, folds trend generally northwest and dips are shallow except for the Red Wash syncline and the Sulfur Creek syncline north of Meeker where some beds are steeply dipping on the north flanks of these structures. The folds in the southern part of the Piceance Basin are mainly a result of laccolith and stock intrusion. The Coal Basin anticline and the Divide Creek anticline are examples of this style of folding (Figure 3-15).

The Rangely and Horse Draw anticlines are associated with the Douglas Creek Arch and lie just to the west of the basin as structurally defined. These domal folds form major oil and gas traps (Figure 3-15).

Faulting in Piceance Basin consists primarily of high-angle normal faults with displacements of tens to hundreds of feet. Most faulting is tensional, with fault planes oriented mainly northwest-southeast. A few small grabens are noted in the Green River Formation in Piceance Creek Basin (Dyni, 1969), and a set of northeast-trending normal faults is mapped along the Douglas Creek Arch (Cashion, 1973). Minor faulting is found along bends in the trend of Grand Hogback (Plate 1) and associated with the igneous intrusions of the southeastern Piceance Basin. In a few instances, high-angle reverse faults and thrust faults are present. Collins (1976) points out that severely sheared coal is present in many deformed areas and that the coalbeds may have served as slippage surfaces during periods of folding. These bedding plane faults are difficult to detect and displacements cannot usually be measured. Tweto (1977) believes that the

strong northwest trend in the area reflects reactivation of Precambrian structural weaknesses by forces present in Laramide and post-Laramide time. The Elk Mountain thrust fault (Figures 3-11 and 3-16) predates the laccolithic activity and dike swarms and may have resulted from earlier igneous activity (Godwin and Gaskill, 1964).

3.2.2.3 Volcanic Features

Gaskill et al. (1973) identify a volcanic center north of Gunnison in the West Elk Mountains. A map of the area by Godwin and Gaskill (1964) (Figure 3-12) shows a complex series of dikes, sills, and laccoliths which cause arching of horizontal strata (Figure 3-16). Additional thicknesses of volcanics are believed responsible for the Elk Mountain thrust fault. The Treasure Mountain Dome, which probably represents more recent plutonic activity (12.5 million years), further disturbed sedimentary strata in the area, especially around Marble. The more silicic composition of this intrusion indicates possible explosive venting may have taken place in this area (Lipman et al., 1969). Upper Cretaceous rocks intruded by the epizonal intrusives of the West Elk Volcanic center are folded and faulted as a result of this igneous activity.

Gravity measurements indicate that large-scale batholiths lie to the north and south of the West Elk Mountains and are responsible for the more silicic extrusives in the San Juan Mountains and the stocks to the northeast of the Elk Mountains (see discussion and illustrations in Section 5.3). The shallow, more mafic intrusives of the West Elk Mountains probably represent a deeper, less differentiated source, although probably related to the large-scale magma zone responsible for most of the early to middle tertiary volcanism of central Colorado (Steven, 1975).

The latest period of volcanic activity is represented by alkali basalt flows along the Roaring Fork River, and Battlement and Grand Mesas (Figure 3-16). These Pliocene alkali basalts covered low-relief terrain before the regional uplift which resulted in the deep canyons now evident on major streams (Larson et al., 1975).

3.3 BASIN HYDROLOGY

3.3.1 Surface Water

3.3.1.1 Major Streams and Watersheds

The major streams flowing through or heading in the Piceance Basin are the Colorado River, the White River, and the North Fork of the Gunnison River. A small portion of the Danforth Hills area drains north to the Williams Fork of the Yampa River, and parts of the southern portion of the basin drain directly to the Gunnison River. Major tributary streams are the Crystal River, the Roaring Fork River, and Plateau Creek, which flow to the Colorado River; Piceance and Yellow Creeks, which flow to the White River; and Muddy and Anthracite Creeks, which flow to the North Fork of the Gunnison. Figure 3-17 shows the drainage network.

The Colorado River has its head east of the Piceance Basin in Rocky Mountain National Park. At Glenwood Springs its average annual discharge is 2,705 cubic feet per second (cfs) and after crossing Piceance Basin, the discharge above Grand Junction is 5,360 cfs (USGS, 1964). Thus the river almost doubles its discharge after passing through the Piceance Basin. The majority of this increase in flow is derived from the Roaring Fork River at Glenwood Springs and from Plateau Creek near Palisade.

The White River flows across the northern part of the Piceance Basin but receives little discharge in that reach. However, the water that it does receive is of poorer quality than upstream sources. The North Fork of the Gunnison originates in the Piceance Basin and derives most of its approximately 500 cfs of discharge from the basin before it joins the main stem of the Gunnison River.

The contributary areas to stream discharge in Piceance Basin range from low-lying semiarid areas which yield little runoff to steep mountainous terrain from which the majority of stream flow is derived. The mountains are the source areas of most perennial streams in the basin. Peak discharge occurs during snow melt runoff periods from April to July, with later peaks derived from the highest elevation watersheds. During low flow periods, stream flow is sustained by ground water discharge at a reasonably uniform rate. Isolated discharge peaks may occur during low flow time due to storm runoff.

3.3.1.2 Surface Water Quality

The quality of surface water in Piceance Basin varies considerably. Water in the high, mountainous areas is of excellent quality. Water leaving the basin is considerably poorer in quality due to saline ground water discharge, irrigation return flow, industrial and urban discharges, and dissolution of natural minerals from bedrock formations. Because the concentration of dissolved solids is inversely proportional to discharge, water quality in the major rivers is markedly improved during periods of snowmelt runoff. The average salt load leaving Piceance Basin is approximately six to seven times that entering the basin while the discharge increases by four to 50 times (Warner and Heimes, 1979).

The headwaters of most streams originating within Piceance Basin have dissolved solids concentrations less than 200 milligrams per liter (mg/L), and calcium and bicarbonate are the dominant ions. Major streams pick up sodium, sulfate, and chloride salts to increase their dissolved solids concentration to between 500 and 1,000 mg/L. The principal sources of ionic species are the saline minerals from Pennsylvanian marine and evaporate rocks; saline mineral springs such as those at Glenwood Springs and along the Uncompahgre River; and irrigation return flow from agricultural fields on the Mancos Shale such as found in Grand Valley and the area around Grand Junction. Figure 3-18 illustrates the increase in salt load from a runoff event involving soils developed on the Mancos Shale (Bentley et al., 1978).

Runoff from coal mines can contribute significantly to surface water deterioration. In Colorado, coal mine drainage presents much less of a problem than in eastern coal fields. Wentz (1974) found that the low sulfur content of Colorado coals was a major influence on the low occurrence of acid mine drainage. Within the Piceance Basin, surface water is more likely to be adversely affected by metal mine drainage than coal mine drainage. Metalliferous deposits occur in association with igneous deposits along the Colorado Mineral Belt. Drainage from old mine areas, such as found in the Crested Butte area, can contribute locally significant quantities of dissolved metallic ions to surface water streams (Wentz, 1974).

3.3.2 Ground Water

3.3.2.1 Major Hydrostratigraphic Units

Ground water availability varies widely over the basin and excellent high-yielding aquifers generally are not present. Differences in lithology, fracturing, and availability of recharge all affect the quantity of ground water and configuration of local hydrostratigraphic units. Water-bearing properties of coal formations affect the ability of these units to retain and yield methane. Hydrologic characteristics must be understood to assess their dewatering and hydrofracturing capability.

Giles (1980) and Brogden and Giles (1976) assessed the water-yielding properties of formations in the southern Piceance Basin (Figures 3-19 and 3-20). The most productive units are the alluvial deposits along major streams, such as the North Fork of the Gunnison River and the main stem of the Gunnison. Yields in excess of 100 gallons per minute (gpm) are reported in the thickest alluvial deposits, but the heterogeneous nature of the deposits makes yields highly variable. The average production from these units is 20 gpm.

Alluvial deposits along the Colorado River can be expected to have higher yields, especially downstream of New Castle. Yields of up to 1,000 gpm have been reported (Boettcher, 1972), but such wells are rare. Because the extent of the alluvial aquifer is limited, this high production rate could not be maintained. The valley of the White River can be quite productive, and the town of Meeker obtains its primary water supply from an alluvial well field. Piceance Creek alluvial wells also have short-term yields greater than 1,000 gpm (Coffin et al., 1968).

Bedrock units are not significant sources of water in the Piceance Basin except where local fracture and solution enhancement of permeability occurs. Certain fractured basalts and other volcanic deposits yield up to 20 gpm but these units may also act as confining layers (Giles, 1980). The Dakota Formation yields up to 60 gpm in the Gunnison area and flowing wells from this formation are common. Other sandstone and limestone units may have hydrologic potential but they have not been investigated adequately to predict their potential. Well fields in the Entrada and Wingate Sandstones and in sandstones of the Morrison Formation have been developed near Grand

Junction. Originally artesian, the low permeability of the formations has caused large declines and reduced well yields over time (McGuinness, 1963). Welder (written communication, 1978) believes the Leadville Limestone may store significant quantities of water in the northern Piceance Basin and northwestern Colorado, but its potential has not been evaluated. The Green River Formation is a generally poor aquifer but high-yielding wells have been drilled in fractured and solutioned areas (Dale and Weeks, 1978).

The water-bearing characteristics of the Mesaverde Group have not been fully assessed. Because of the lithologic variation in the group, hydrologic characteristics vary widely. Where exposed, the sandstones act as recharge to the formations and the shale beds act as confining layers putting the sandstones under artesian conditions in the center of the basin. Because the sandstones are poorly sorted, and calcium carbonate cement is present, permeabilities and yields in the Mesaverde Group are correspondingly low. Giles and Brogden (1978) report hydraulic conductivities for the Williams Fork and Iles Formations which average 0.5 ft/day. Giles (1980) reports Mesaverde well yields in the southeastern Piceance Basin are less than 10 gpm.

3.3.2.2 Ground Water Quality

A broad characterization of ground water quality in Piceance Basin is not possible due to wide lithologic variations and the great flowpath lengths present. Deep structural basins generally display large concentration gradients from fresher water along the margins to brackish and saline water in the basin centers. In Piceance Basin this pattern is modified by the presence both of evaporite rocks in Pennsylvanian and Eocene strata and of coal and metalliferous deposits. The range in dissolved solids concentration is from less than 200 mg/L to greater than 50,000 mg/L.

Ground water in high mountainous parts of the basin, where igneous and metamorphic rocks are found, yields calcium bicarbonate water of good quality. Water discharging from thermal springs and springs in the Eagle Valley evaporite has high concentrations of sodium chloride and sodium and calcium sulfate, respectively. Marine shales such as the Mancos have poor water quality away from recharge areas and contain concentrations of sodium and chloride or sulfate in the thousands-of-mg/L range. Ground water in the Maroon Formation and Weber Sandstone varies from calcium to sodium

bicarbonate water with a dissolved solids range from 200 to 1,200 mg/L (Brogden and Giles, 1976). Sands in the Wasatch Formation produce good water locally, but regionally the formation's water is generally poor in quality, probably caused by a long formation residence time. Sodium chloride waters with tens of thousands of mg/L dissolved solids are reported from the Piceance gas dome (Saulnier, 1978).

The Green River Formation has a wide range in water quality but almost always a sodium bicarbonate water is found (Robson and Saulnier, 1980). Water in recharge areas has less than 500 mg/L dissolved solids and ground water which encounters the evaporate minerals nahcolite and halite may have greater than 50,000 mg/L dissolved solids.

Better quality water is found in some of the confined, well-sorted sandstones such as the Entrada and the Wingate, and in sandstones of the Morrison Formation. These waters are generally sodium bicarbonate waters with dissolved solids concentrations of less than 1,000 mg/L (Alley et al., 1978a). The Dakota Sandstone and the Leadville Limestone have fresher water near recharge areas, but spring discharge may originate in deeper formations and from thermal sources and migrate along fractures to spring orifices in other formations. Highly saline water occurs in thermal springs near Dotsero and at Glenwood Springs (Alley et al., 1978a).

Alluvial water quality is generally good but may be locally affected by ground water discharge (Alley et al., 1978a and b). Dissolved solids concentrations are generally less than 1,000 mg/L, but alluvium which has been derived from marine formations and receives saline spring discharge can contain significantly lower water quality (Brogden and Giles, 1976).

The Mesaverde Group ground water is generally of good quality but may contain objectionable quantities of sulfate. In many cases the water is hard. The higher sulfate concentrations are a result of the oxidation of reduced sulfur species contained in coal deposits. High iron and manganese values are also reported for similar reasons (Giles and Brogden, 1978). Soft potable water occasionally may be present in sandstones of the Mesaverde Group, such as near the Wilson Creek oil field (Saulnier, written communication, 1978). Surface disposal of ground water associated with coals of the Mesaverde Group may present quality problems. Acid mine drainage problems have been reported at Oak Creek northwest of Piceance

Basin (Wentz, 1974), and in eastern Piceance Basin (Alley et al., 1978b). This problem, although local, will have to be assessed in any dewatering schemes involving these formations.

3.4 ENERGY RESOURCES OTHER THAN COAL

3.4.1 Oil Shale

Vast reserves of oil shale are present in the Green River Formation of the northern Piceance Basin. The estimates of total petroleum reserves are up to 1.3×10^{12} barrels of recoverable shale oil with 300 to 600×10^{6} barrels in thick rich beds (Biesecker et al., 1978). Present efforts to recover this resource are primarily at government prototype lease tracts and a number of private lease areas in Piceance Creek Basin. Future trends indicate increasing emphasis on the resource and testing of various efforts at recovering and retorting the kerogen-containing marlstone.

Oil shale development is a process which will require large amounts of water for materials handling, spent shale disposal, and expected population increases. Environmental concerns have raised many questions concerning development, and spent shale disposal is expected to have deleterious effects on local water systems (Robson and Saulnier, 1980). Continued demand for fossil energy sources probably will lead to pilot-scale development projects in the near future. Most intense efforts are concentrated on developing the Mahogany Zone, a kerogen-rich bed which averages about 30 gallons of oil per ton of rock.

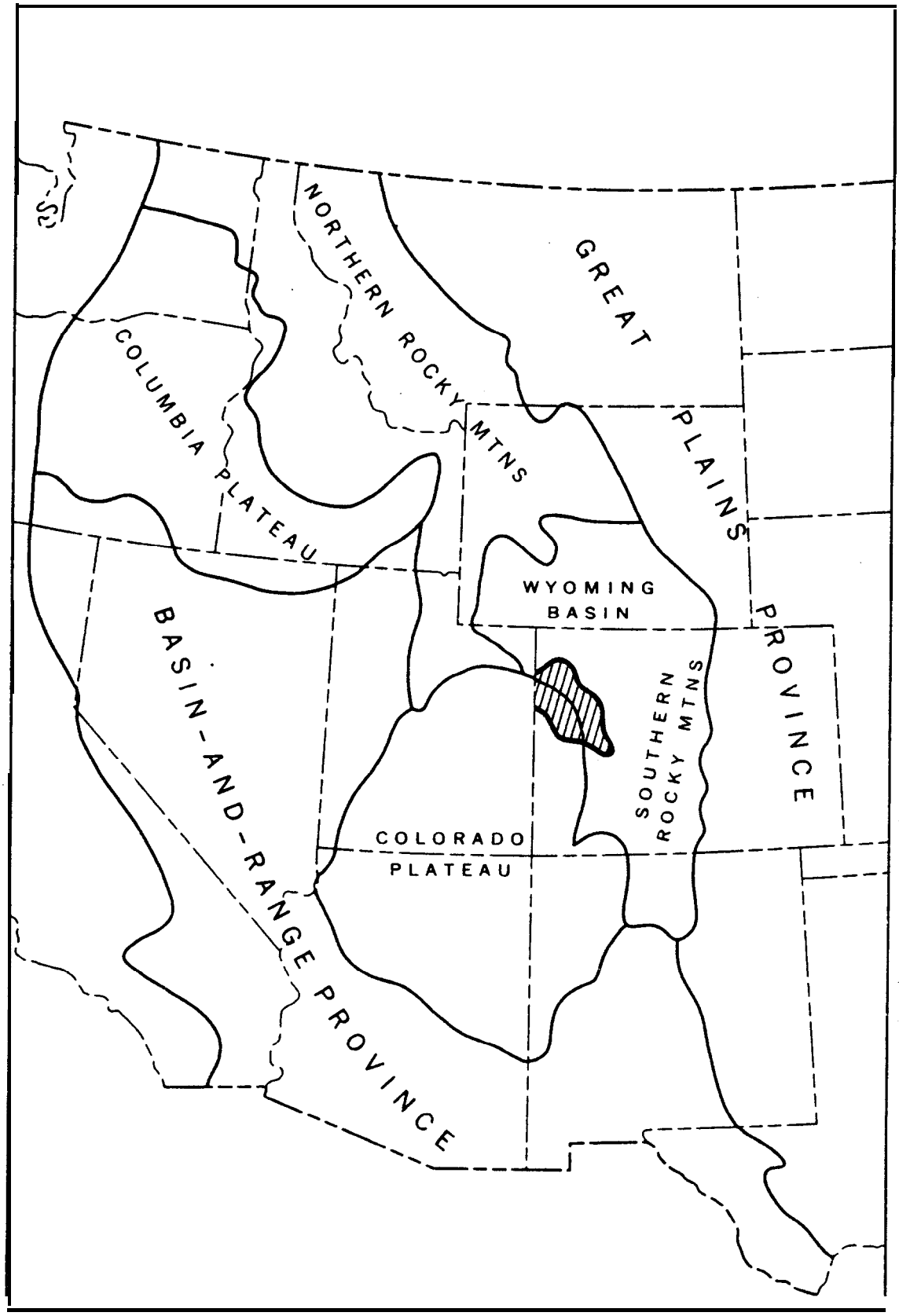
3.4.2 Uranium

Uranium resources in Piceance Basin are not extensive. A uranium-vanadium prospect has been mined at Rifle, Colorado, although only vanadium has been produced since 1972. The deposits are in sandstones of the Morrison Formation and similar to the Colorado Plateau-type, roll front deposits on the Uncompahgre monocline southwest of Piceance Basin. Small uranium prospects are also found east of Meeker at Uranium Peak and north of Piceance Basin in the Lay-Maybell area.

3.4.3 Oil and Gas

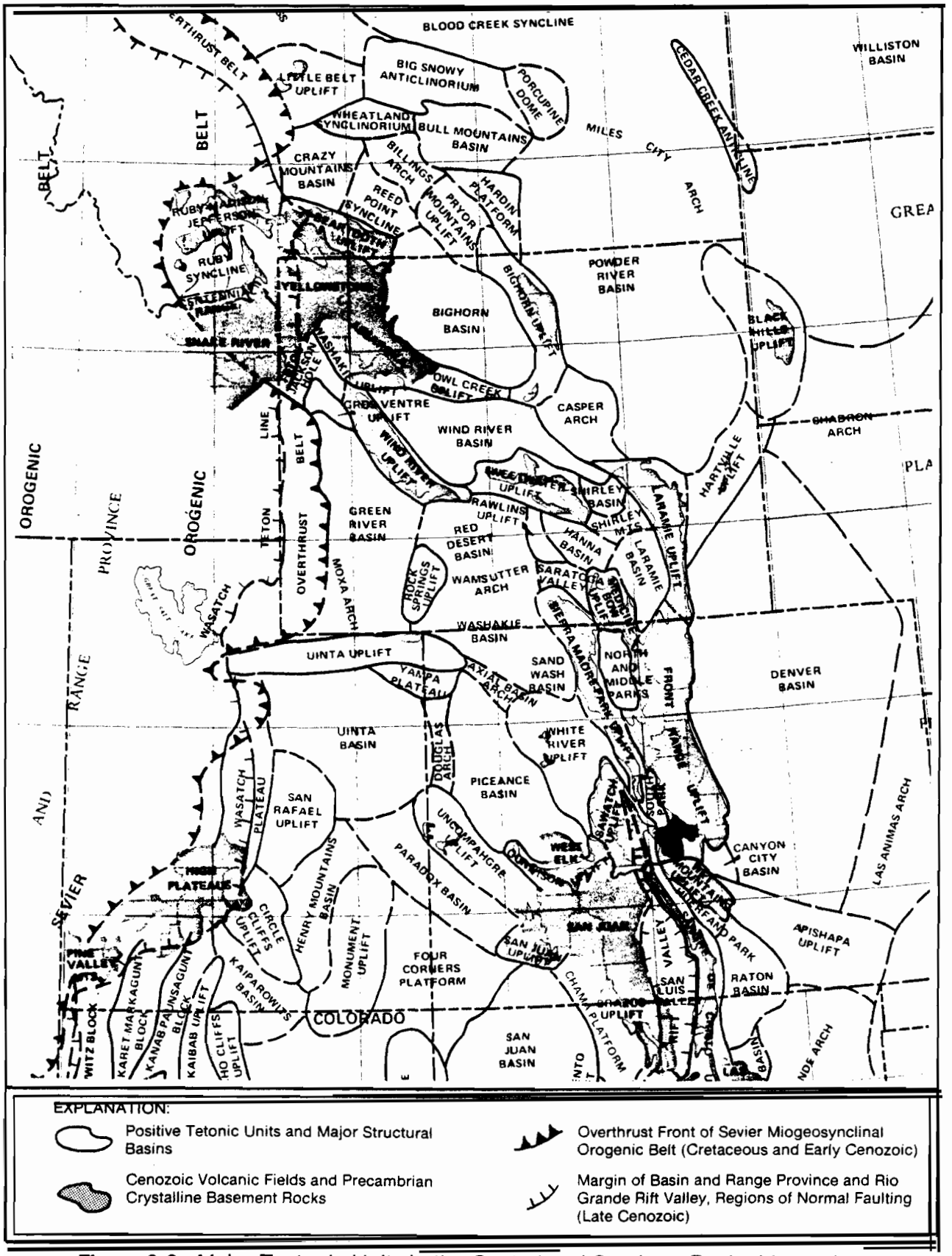
Oil and gas reservoirs in Piceance Basin occur in rocks from Pennsylvanian through Eocene age (Figure 3-11). Gas is the principal hydrocarbon produced in the basin and most occurs in stratigraphic traps (Dunn, 1974). Oil has been produced for many years from the Rangely field from the Mancos Shale. The Weber Formation, Entrada Sandstone, Dakota Sandstone, Morrison Formation, and Wasatch Formation are also known to produce oil from various fields (Wilson Creek, Danforth Hills, and Iles Fields in the Axial Basin).

Gas is produced from many of the sandstone units within the Piceance Basin. The Piceance field produces from the Eocene Wasatch Formation and the Douglas Creek Member of the Green River Formation. Gas is found in most sandstones in the Mesaverde Group (Dunn, 1974). Most of this gas is developed in the non-marine portions of the group. Much of the gas-bearing sequence of the Mesaverde Group has low permeability, and stimulation techniques will be, and are being, used to increase production, particularly in the Douglas Creek Arch-Piceance Creek Basin area (Alcock et al., 1974).



Piceance Basin

Figure 3-1. Major Physiographic Provinces in Western United States (Modified from Howard and Williams, 1972)



EXPLANATION:

- Positive Tetonic Units and Major Structural Basins
- Cenozoic Volcanic Fields and Precambrian Crystalline Basement Rocks
- Overthrust Front of Sevier Miogeosynclinal Orogenic Belt (Cretaceous and Early Cenozoic)
- Margin of Basin and Range Province and Rio Grande Rift Valley, Regions of Normal Faulting (Late Cenozoic)

Figure 3-2. Major Tectonic Units in the Central and Southern Rocky Mountains (Modified from Grose, 1972)

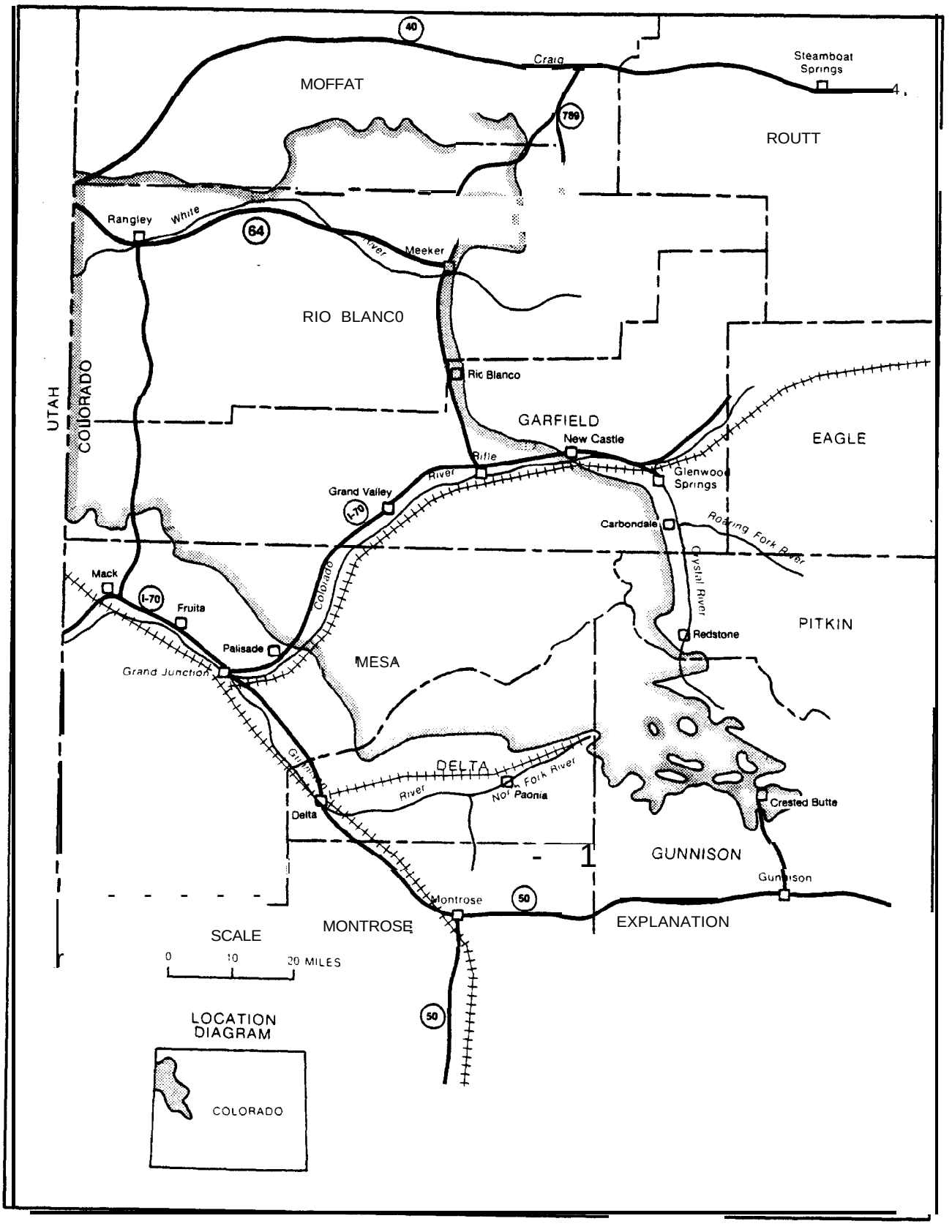


Figure 3-3. Map of the Piceance Basin Showing Counties, Major Roads, and Railroads

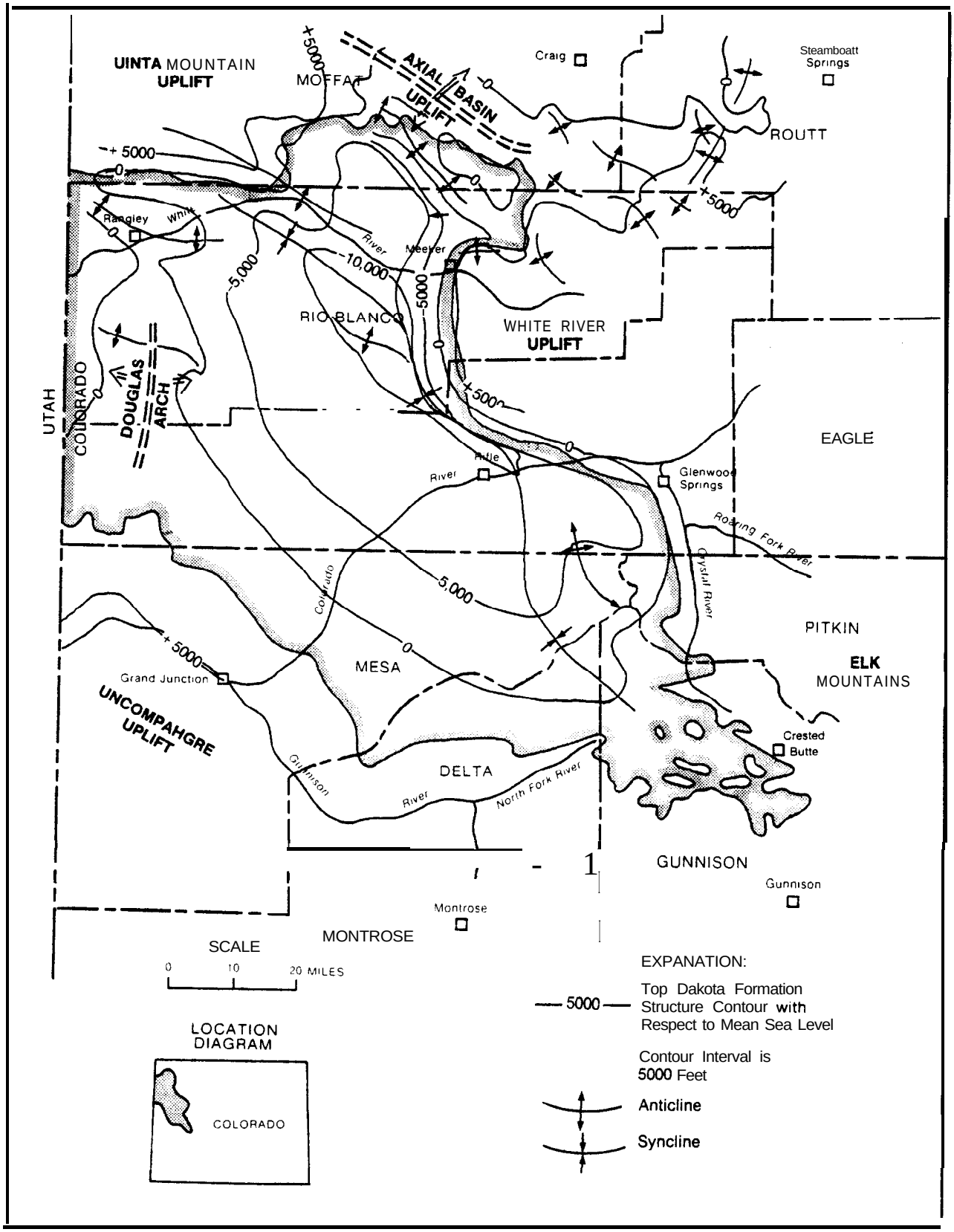


Figure 3-4. Major Structural Elements, Piceance Basin and Contiguous Areas, Northwest Colorado (Structural Data from Dunn, 1974)

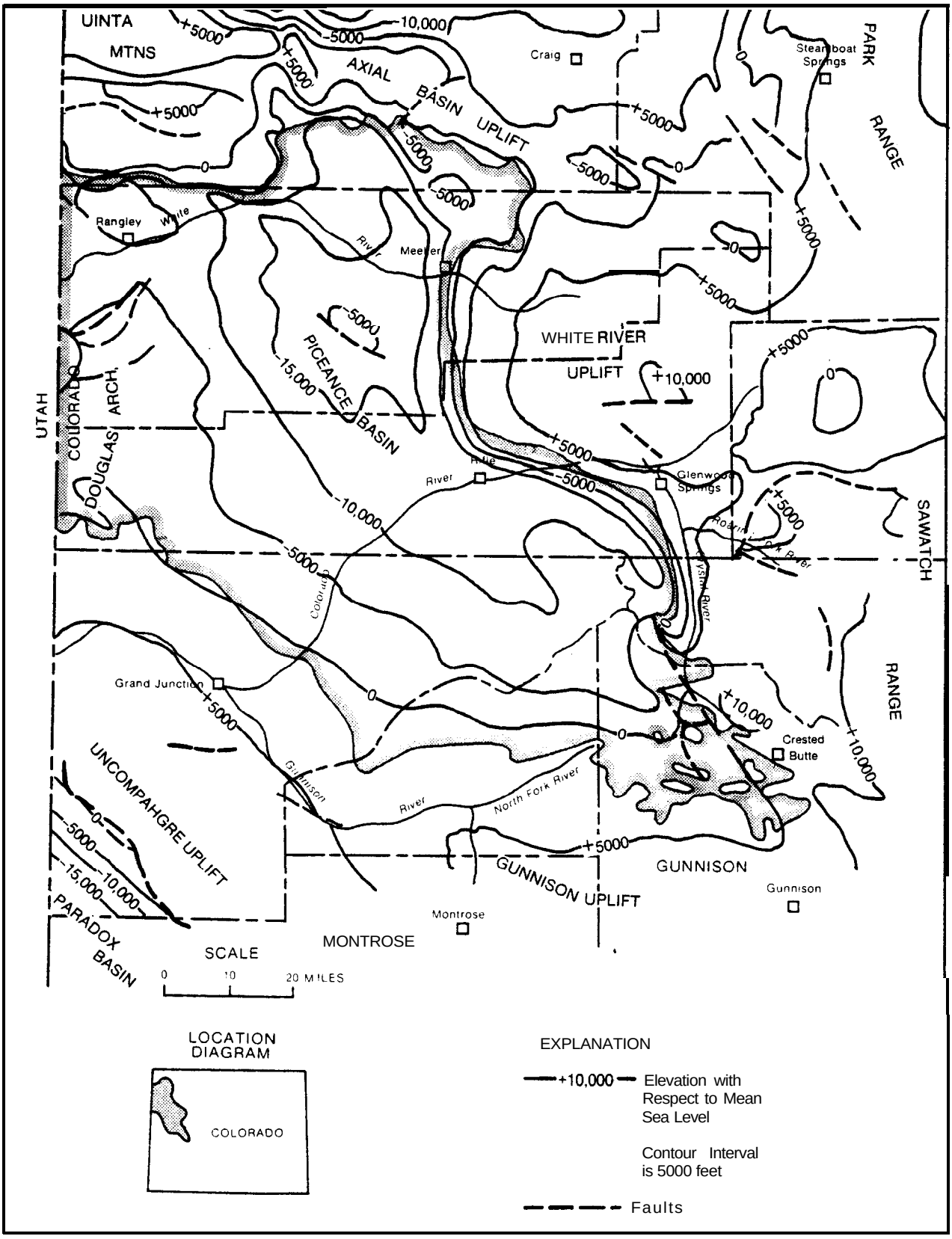


Figure 3-5. Configuration of the Crystalline Basement Rocks of Northwest Colorado, Showing Major Structural Elements (Murray and Haun, 1974)

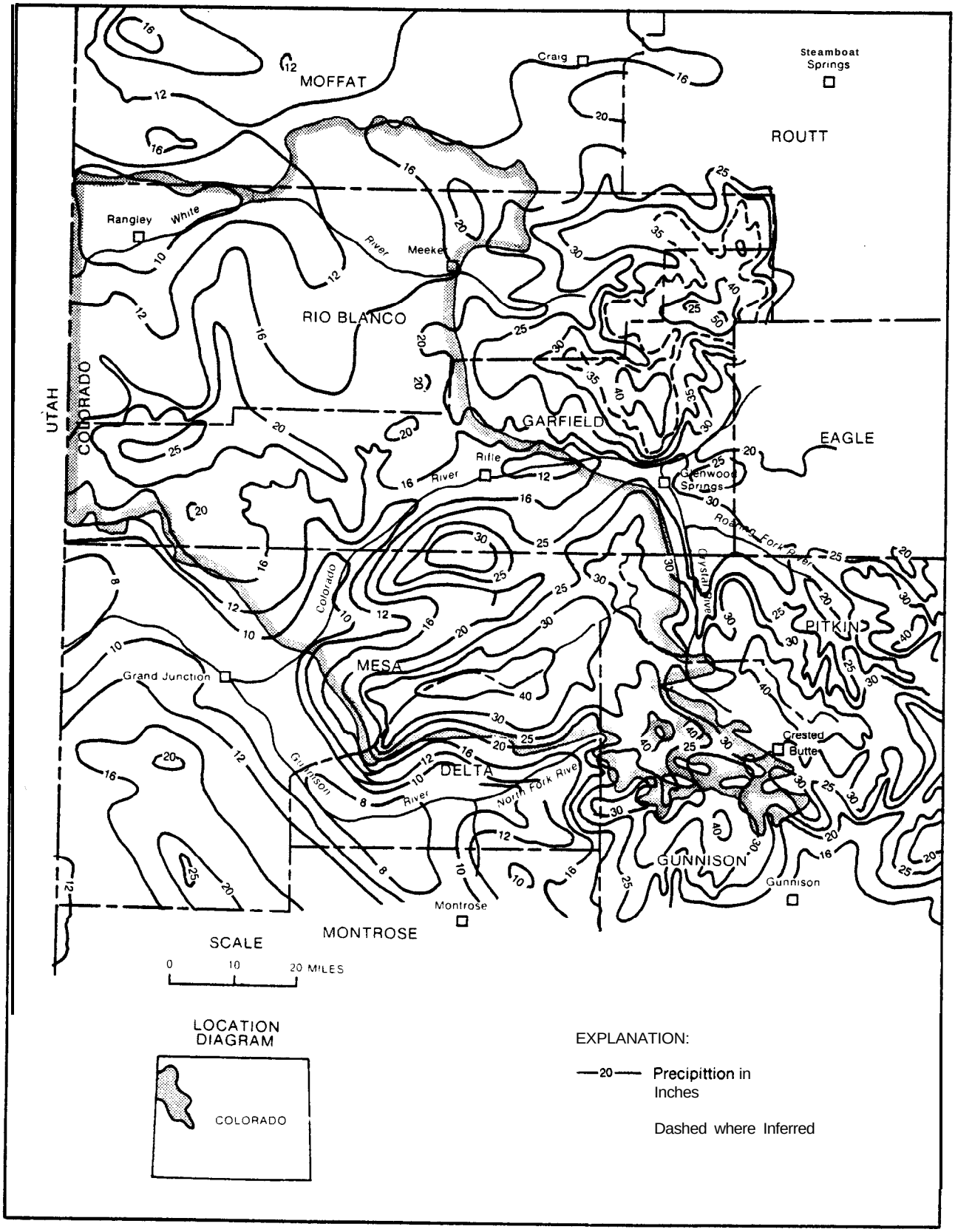


Figure 3-6. Mean Annual Precipitation (in inches) Piceance Basin Based on Period 1931-55 (U.S. Weather Bureau, 1967)

System	Series	Stratigraphic Unit		Related Units
Tertiary	Eocene	Uinta Formation		
		Green River Formation	Parachute Creek Member	Anvil Points Member
			Garden Gulch Member	
			Douglas Creek Member	
		Wasatch Formation		
	Paleocene	Fort Union Formation		
Cretaceous	Upper Cretaceous	Mesaverde Group	Ohio Creek Conglomerate	
			Lance Formation	
			Fox Hills Sandstone	
			Lewis Shale	
			Lion Canyon Sandstone	
			Williams Fork Formation	Hunter Canyon Formatio
			Iles Formation	Mount Garfield Formatio
			Sego Sandstone	
			Castlegate Sandstone	
		Mancos Shale	"Main Body" of Mancos Shale	
			Niobrara Equivalent	
			Frontier Member	
			Mowry Shale Member	
	Lower Cretaceous	Dakota Sandstone		
		Cedar Mountain Formation		Burro Canyon Formatior
Jurassic	Upper Jurassic	Morrison Formation		
		Curtis Formation		Summerville Formation
		Entrada Sandstone		
		Carmel Formation		
	Middle Jurassic			
	Lower Jurassic	Navajo Sandstone		Nugget Sandstone Glen Canyon Sandstone
Triassic	Late Triassic	Chinle Formation		
	Early Triassic	Shinarump Conglomerate		
		Moenkopi Formation		
Permian	Leonardian and Guadelapean	Park City, Phosphoria, Woodside Formations		
	Wolfcampian	Weber Sandstone		
Carboniferous	Pennsylvanian	Missourian and Virgillian	Maroon Formation	
		Des Moinesian	Paradox Formation	Minturn Formation
		Morrowan and Atokan	Belden Formation	
			Molas Formation	
	Mississippian	Osagean	Leadville Limestone	Madison and Deseret Limestones
			Unconformity	
Devonian	Upper Devonian	Chaffee Group	Dyer Formation	
			Parting Formation	
Ordovician	Canadian Series	Manitou Formation	Tie Gulch Dolomite Member	
			Dead Horse Conglomerate Member	
Cambrian	Upper Cambrian	Dotsero Formation	Clinetop Algal Member	
			Glenwood Canyon Member	Lodore Formation
		Sawatch Quartzite		
Precambrian		Uinta Mountain Group		
		Older Precambrian flocks		

Figure 3-7. Generalized Stratigraphic Section of the Piceance Basin, Northwest Colorado (Anderson, 1980)

Late in the
EARLY CRETACEOUS EPOCH

A Composite for
LATE CRETACEOUS TIME
Showing the Maximum Submergence

Figure 3-8. Cretaceous Paleogeography of North America (Dunbar, 1964)

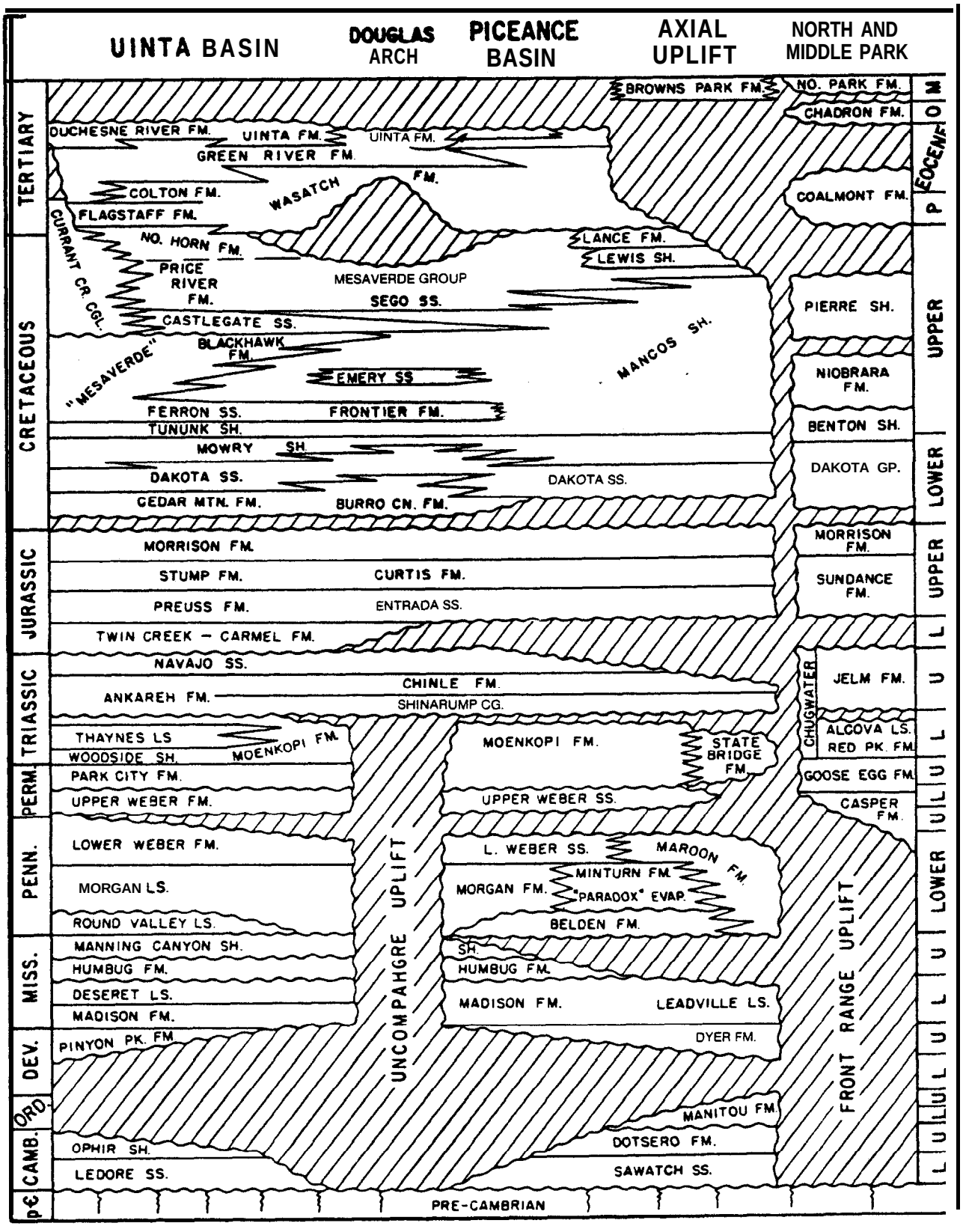


Figure 3-9. Generalized Stratigraphic Correlation Diagram, Northeast Utah and Northwest Colorado (Modified from Sanborn, 1977)

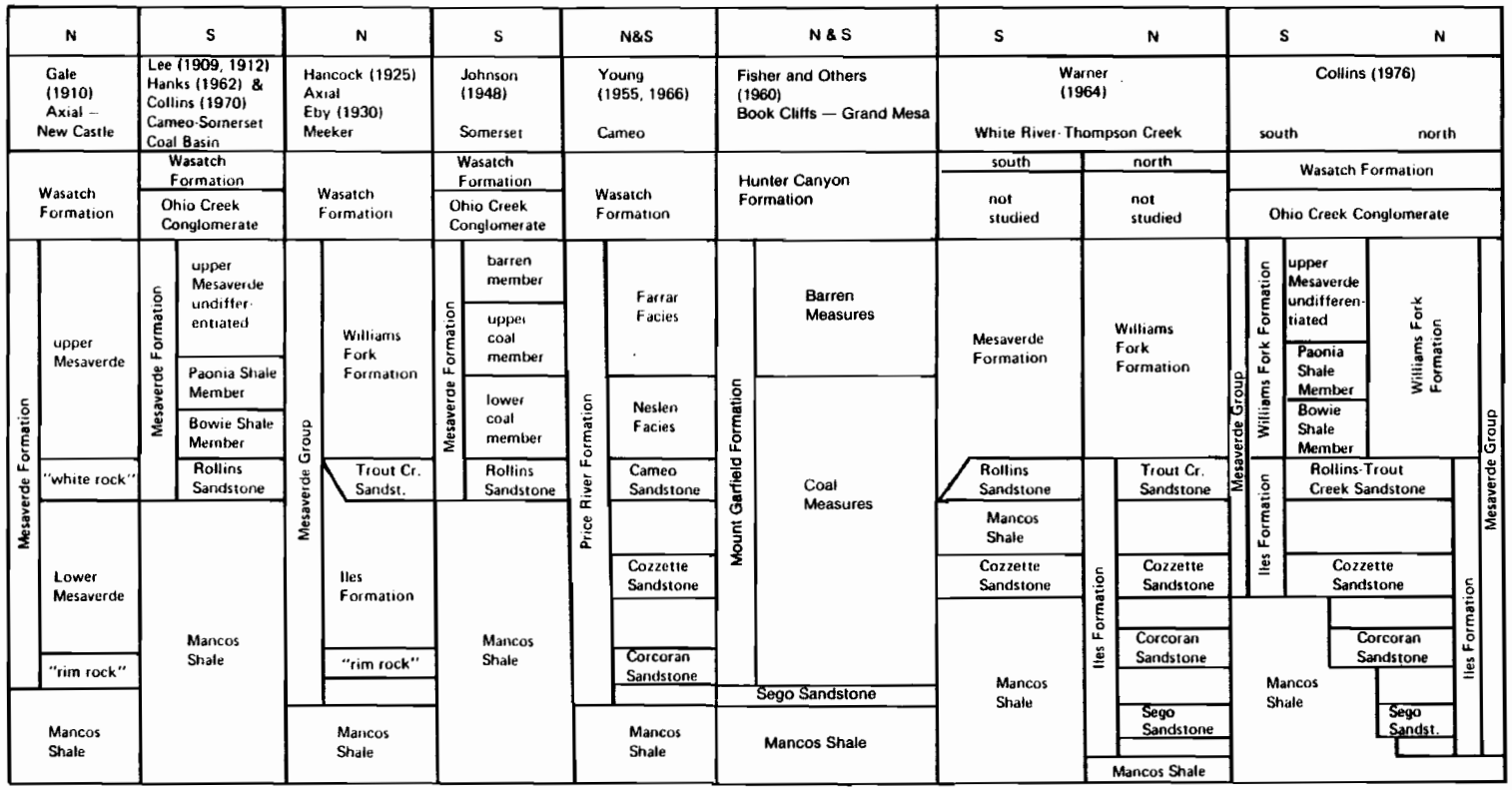
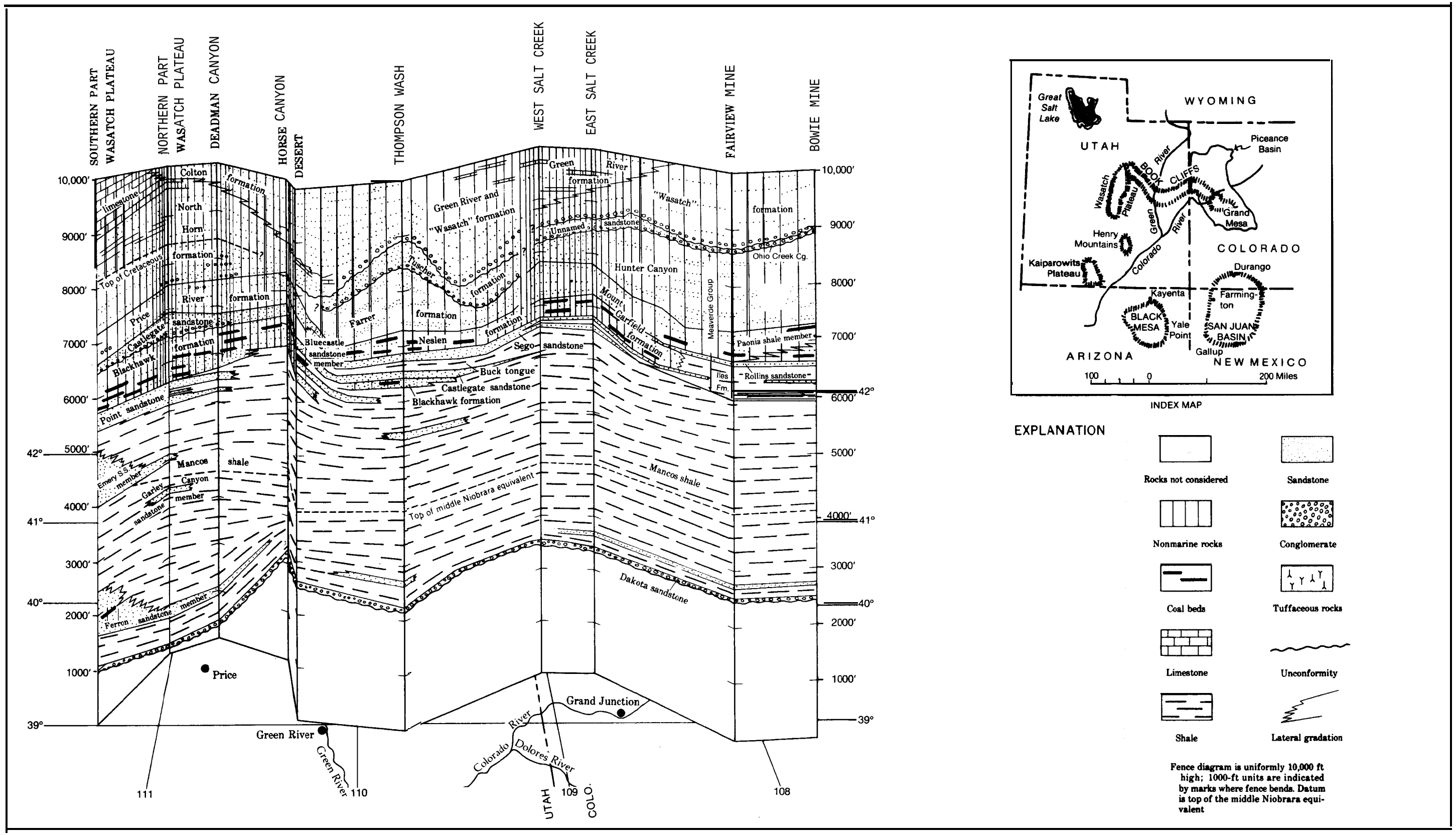


Figure 3-10. Nomenclature Used by Various Authors for Upper Cretaceous and Early Tertiary Rocks in the Piceance Basin (Collins, 1976 and Schwochow, 1978)



INDEX MAP

EXPLANATION

Rocks not considered
Sandstone
Nonmarine rocks
Conglomerate
Coal beds
Tuffaceous rocks
Limestone
Unconformity
Shale
Lateral gradation

Fence diagram is uniformly 10,000 ft high; 1000-ft units are indicated by marks where fence bends. Datum is top of the middle Niobrara equivalent

Figure 3-11. Perspective Diagram of Correlations of Cretaceous and Tertiary Formations from East Central Utah to West Central Colorado (Modified from Fisher, Erdmann and Reeside, 1960)

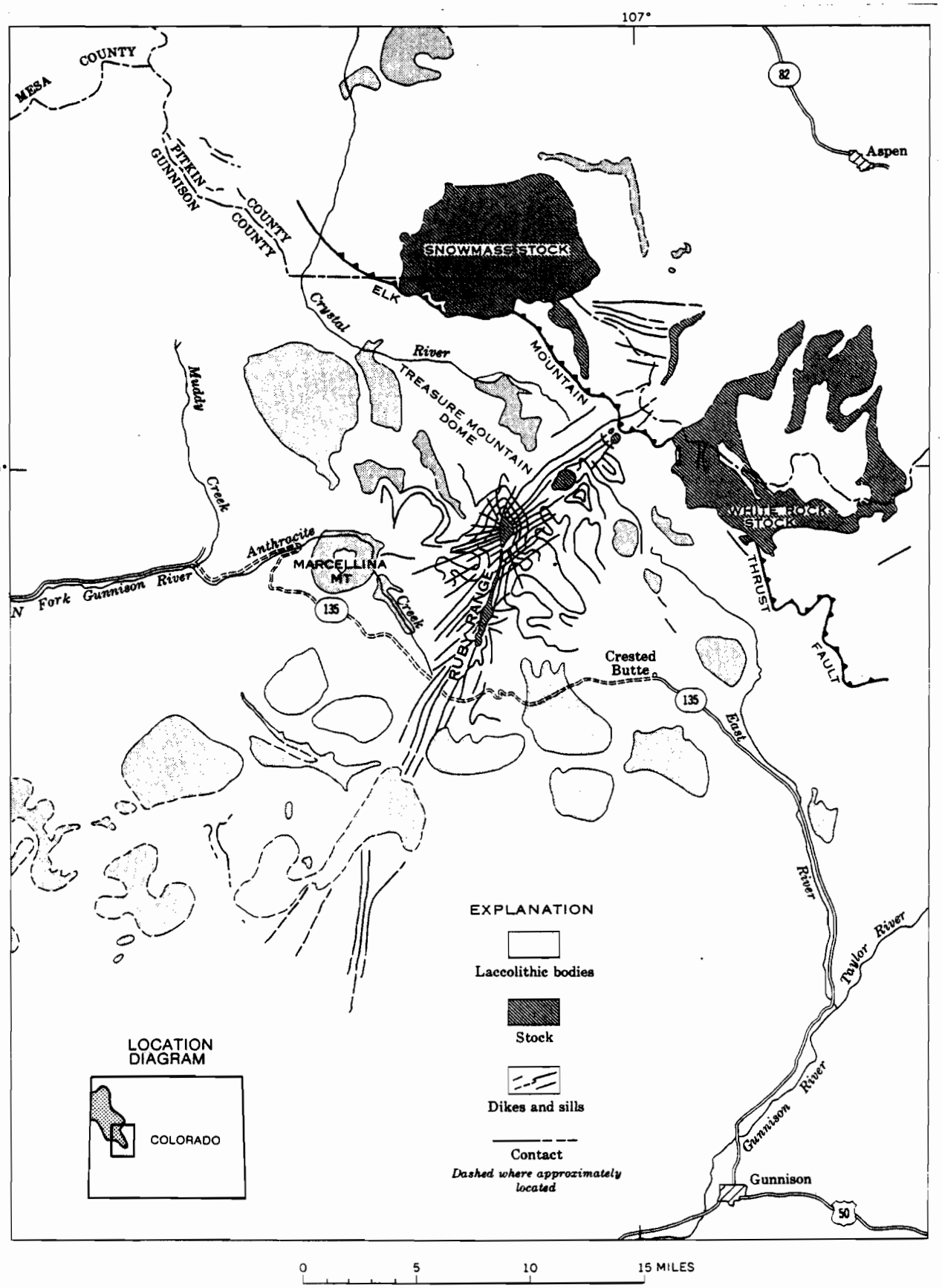


Figure 3-12. Index Map of the West Elk Laccolithic Cluster (Godwin and Gaskill, 1964)

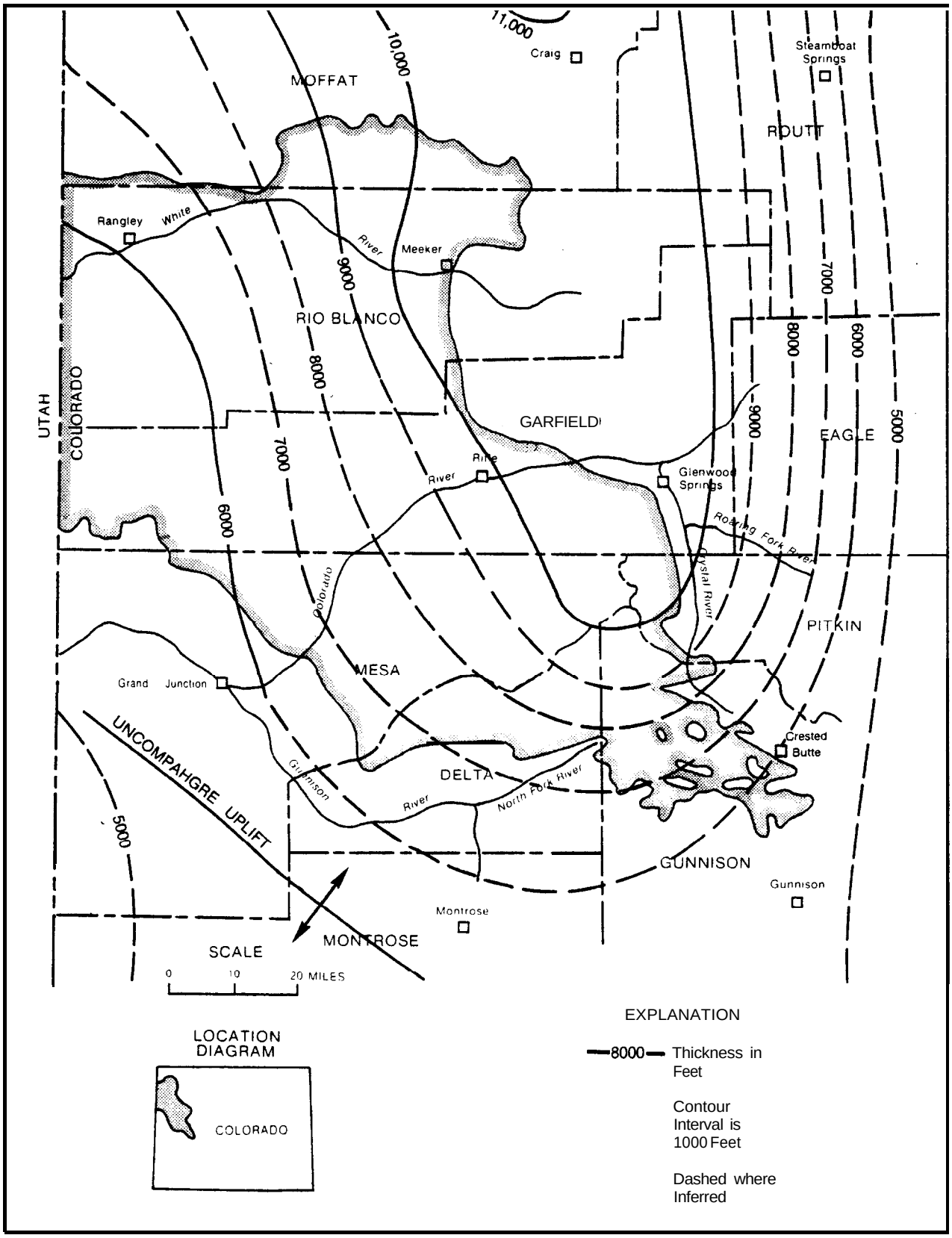


Figure 3-13. Isopachous Map of the Upper Cretaceous, Piceance Basin (After Quigley, 1965)

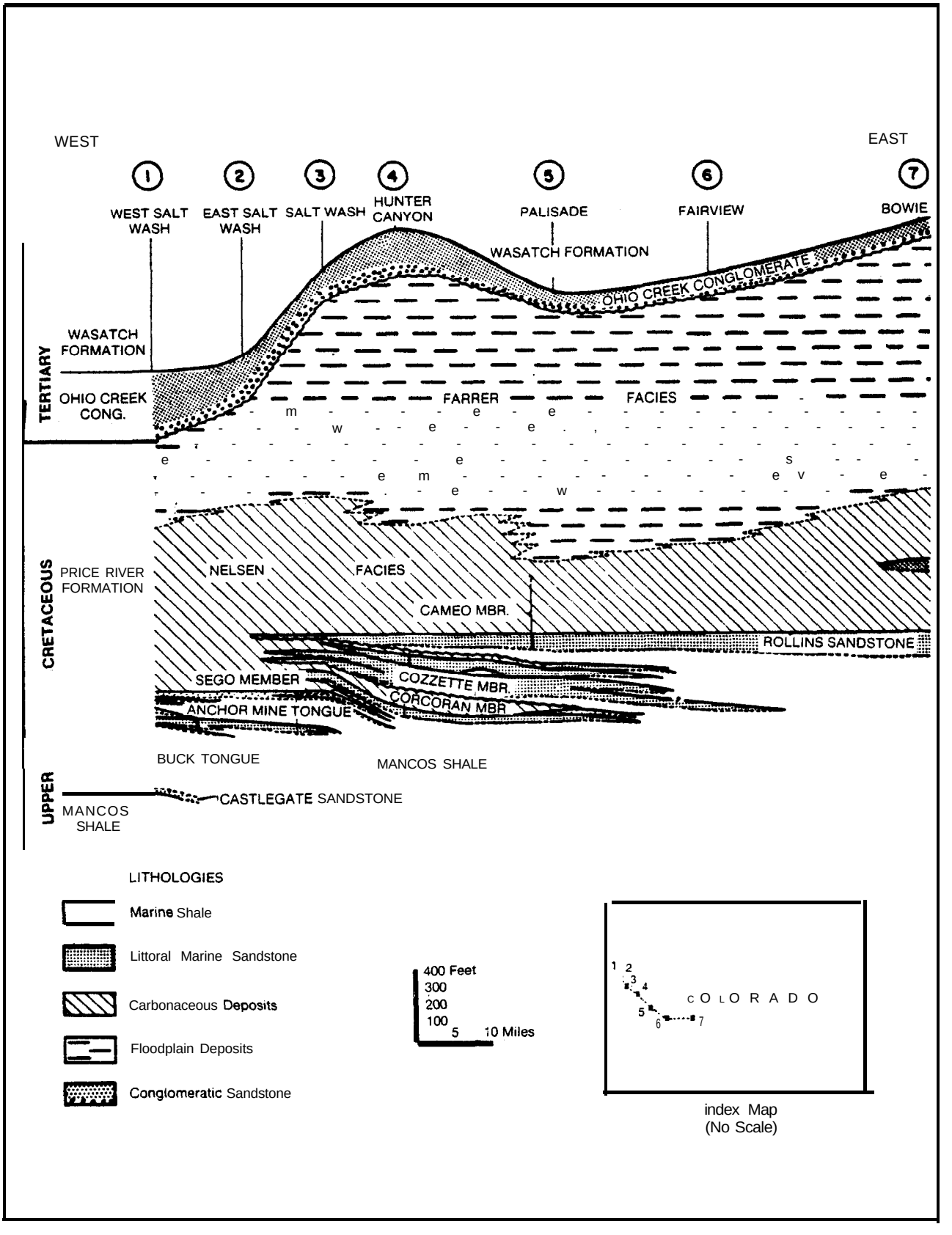
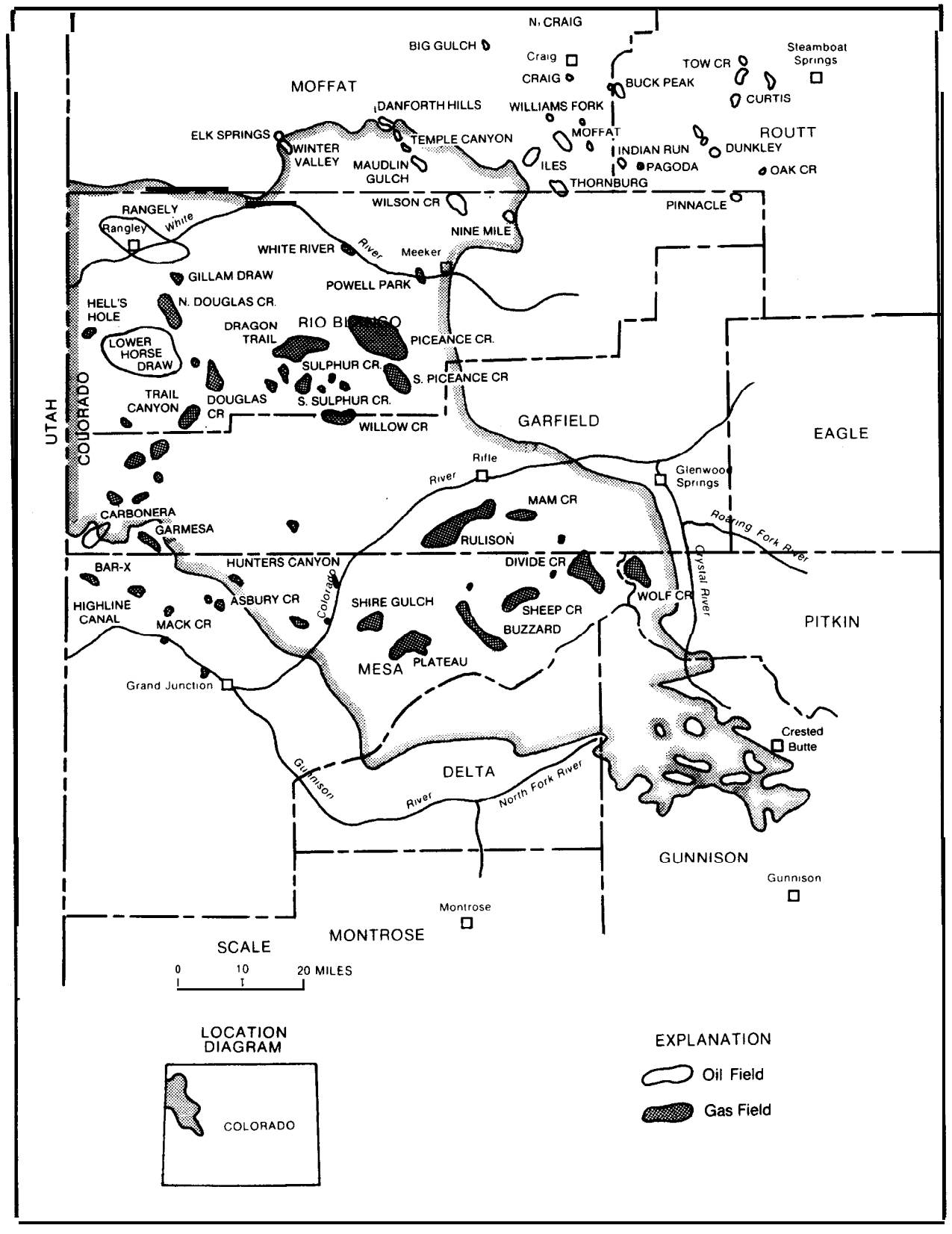


Figure 3-14. Upper Cretaceous and Lower Tertiary Deposits of Book Cliffs and Grand Mesa (Quigley, 1965)



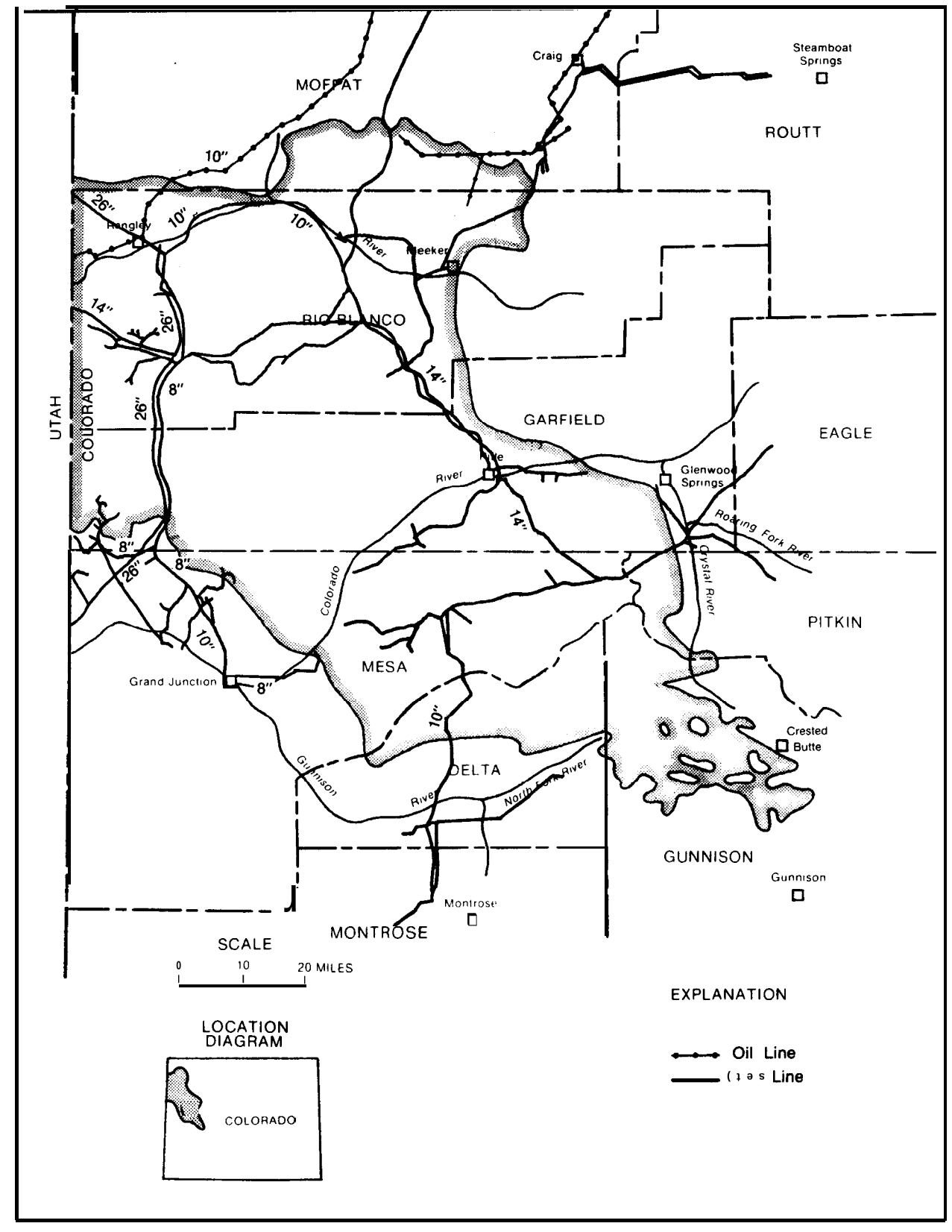


Figure 3-15. Oil and Gas Fields and Pipelines, Piceance Basin and Contiguous Areas (After Dunn, 1974 and after U.S.G.S. 1977)

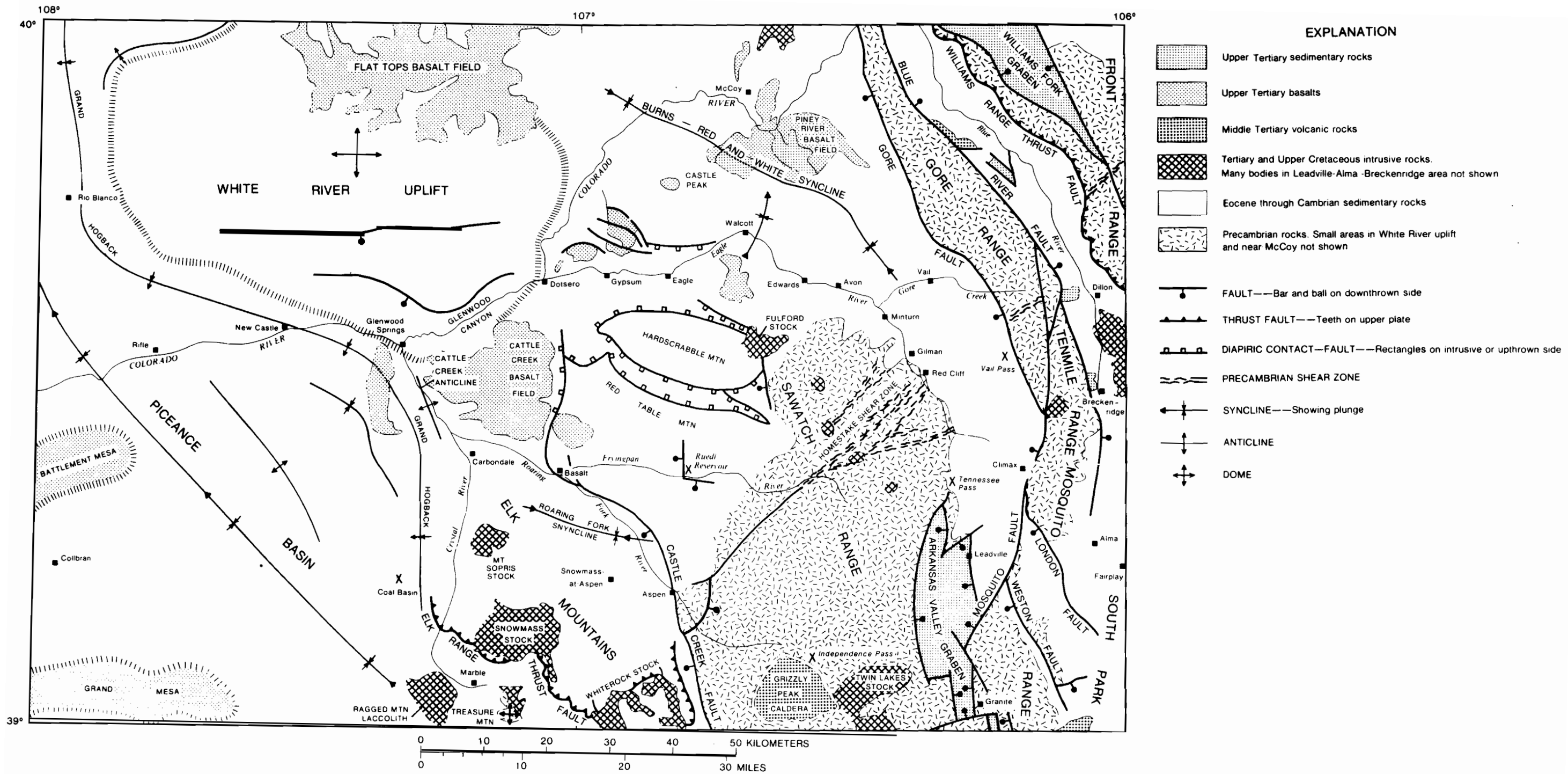


Figure 3-16. Principal Geographic and Tectonic Features in West Central Colorado (Tweto, 1977)

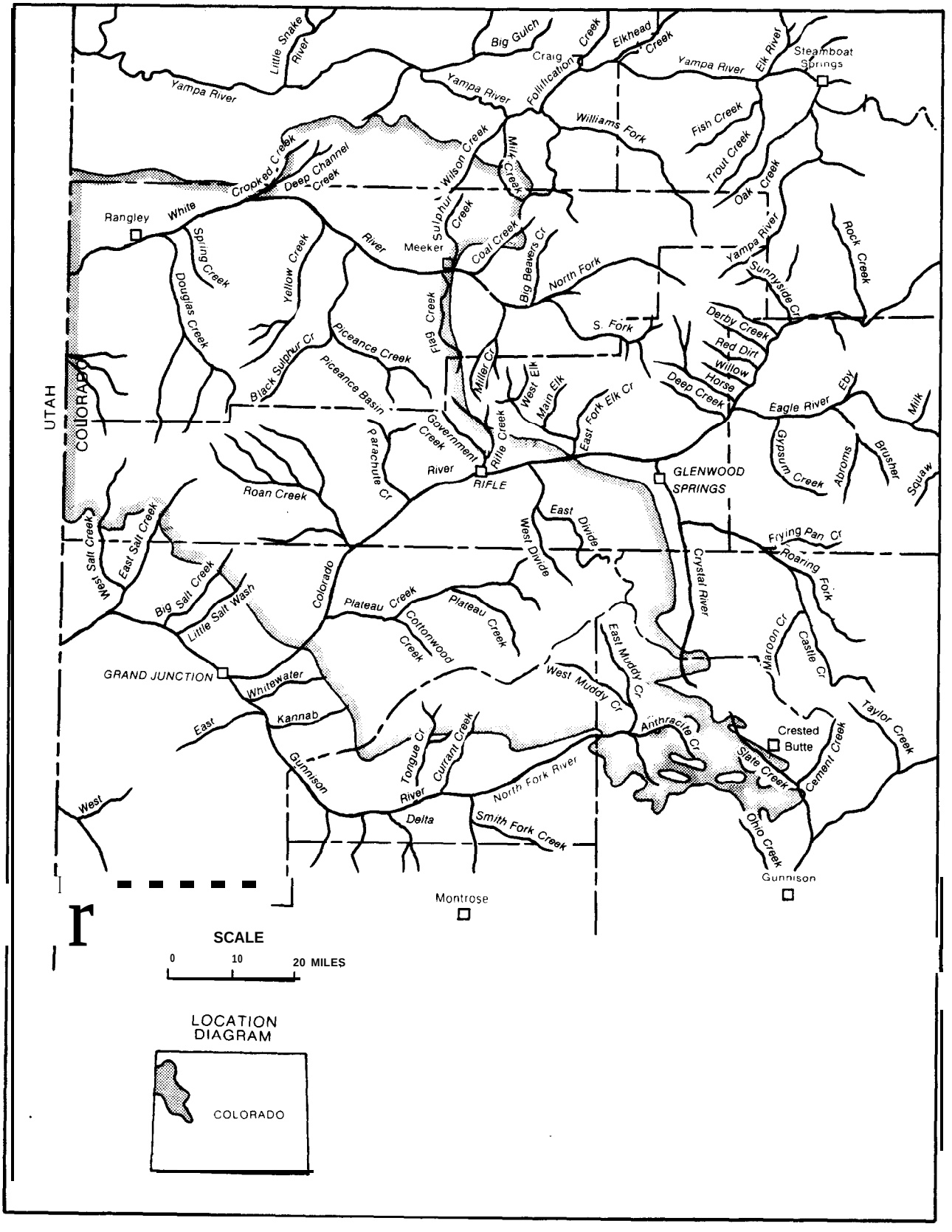


Figure 3-17. Major Streams and Tributaries in the Piceance Basin (Modified from Bentley, et al., 1978)

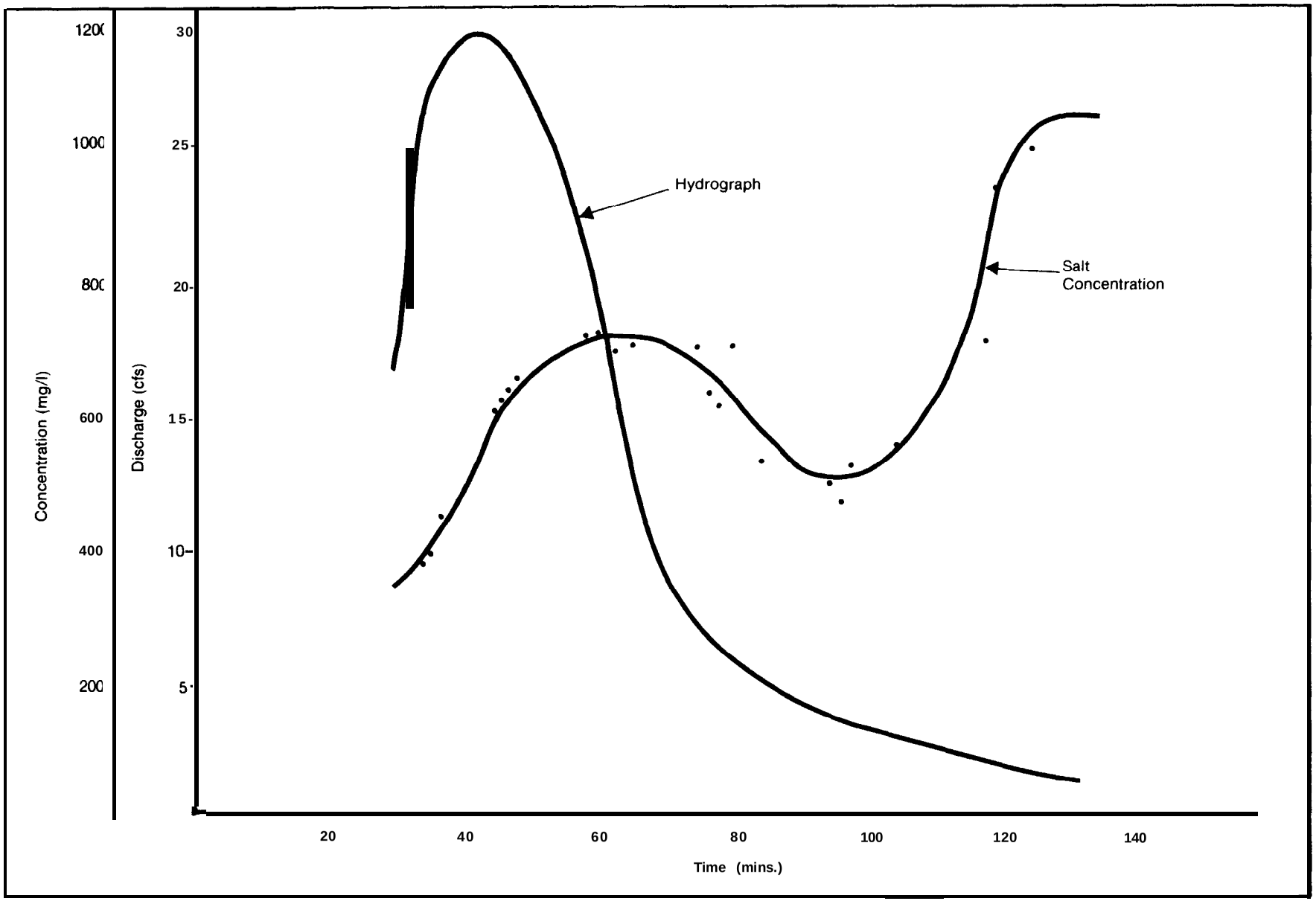


Figure 3-18. Runoff Hydrograph and Associated Salt Concentrations from a Runoff Event from Mancos Shale-derived Soils, 5/26/77 (Bentley, et al., 1978)

GEOLOGIC AGE		GEOLOGIC UNITS	MAXIMUM THICKNESS (feet)	HYDROLOGIC CHARACTERISTICS
QUATERNARY	Holocene	Unconsolidated alluvium, glacial drift, landslide deposits, and talus deposits	140 (Estimated)	Reported well yields range from 2 to 100 gal/min, but average 20 gal/min. Important source of water in the Gunnison and Crested Butte areas. The abundant colluvial material in Taylor Park is a source of water for several springs. See table of selected well data and aquifer characteristics for additional information.
	Pleistocene			
TERTIARY	Miocene and Oligocene	Miocene basalts, Oligocene ashflow tuffs, Oligocene sedimentary rocks, and middle Tertiary intrusive rocks	Unknown	Water quantity is variable, depending on underlying bedrock and the extent of the fractured volcanic material. Reported well yields locally are greater than 20 gal/min from the basalts and tuffs. Not considered an important source of water. In the southern part of the area, the lava flows act as confining layers to mesozoic sandstones.
	Eocene and Paleocene	Wasatch and Ohio Creek Formations	2,200	
CRETACEOUS	Late Cretaceous	Mesaverde Group	2,300	Data for only one well obtained; yield is 9.3 gal/min. See table of selected well data and aquifer characteristics for additional information.
		Mancos Shale	5,000	Reported well yields are as much as 15 gal/min; Yields of 1 to 5 gal/min are more common. Largest well yields are developed in landslides and slump blocks developed on the shale.
		Dakota Sandstone	200	Reported well yields range from 5 to 60 gal/min. Primary source of water in the Gunnison area. Flowing wells (2 to 40 gal/min) can be found in the Ohio Creek and Gunnison River valleys and in areas where the Dakota and Entrada Sandstones are overlain by impervious shales of the Mancos Shale and Morrison Formation. See table of selected well data and aquifer characteristics for additional information.
	Early Cretaceous	Burro Canyon Formation	100	
JURASSIC	Late Jurassic	Morrison Formation	400	
		Junction Creek Sandstone	180	
		Entrada Sandstone	85	
PERMIAN		Maroon Formation	3,500	May be aquifers near outcrop areas. Reported well yields are less than 15 gal/min. Leadville Limestone may have potential for larger veilds.
PENNSYLVANIAN		Gothic (of local usage) or Minturn Formation	1,750	
		Belden Formation	650	
MISSISSIPPIAN		Leadville Limestone	300	
CAMBRIAN		Peerless Formation Sawatch Quartzite	300	
PRECAMBRIAN		Granitic rocks and interlayered felsic and hornblendic gneisses	.....	Reported well yields range from 1 to 3 gal/min where rocks are fractured.

Figure 3-19. Hydrologic Characteristics of Geologic Units in the Gunnison-Crested Butte Area, Colorado (Modified from Giles, 1980)

SYSTEM	SERIES	GEOLOGIC UNIT	MAXIMUM THICKNESS (feet)	HYDROLOGIC CHARACTERISTICS
JURASSIC	Upper Jurassic	Morrison Formation	325	No information available. May be an aquifer in outcrop area.
		Entrada Sandstone	150	No information available. May be an aquifer in outcrop area.
TRIASSIC	Upper Triassic	Chinle Formation	1,000	No information availalble. May be an aquifer in outcrop area
	Lower Triassic and Upper Permian	State Bridge Formation	2.700	Data for only one well obtained; water is a calcium bicarbonate type. Dissolved-solids concentration is 489 mg/l.
PERMIAN	Upper Permian	Weber Sandstone	100	No information available. May be an aquifer in outcrop area.
	Lower Permian and Upper Pennsyl-vanian	Maroon Formation	5,000	Reported well yields range from 5 to 25 gal/min. Where fractured extensively, may yield greater quantitites of water to wells. Important source of water in Carbondale area and Crystal River drain-age basin. Water is a calcium bicarbonate type in the Cattle Creek and Carbondale areas and a sodium bicarbonate type in the Crystal River drainage basin. Dissolved-solids concentration ranges from 194 to 1,160 mg/l.
PENNSYLVANIAN	Middle Pennsyl-Vanian	Eagle Valley Evaporite	3,000	Reported well yields range from 5 to 25 gal/min. Usec as a source of water in the Carbondale and Cattls Creek areas. Water is a calcium sulfate type. Dissolved, solids concentration ranges from 247 to 2,630 mg/l. The occurrence of selenium is localized: concen-trations in excess of U.S. Public Health Service (1962) drinking-water standards occur in the Cattle Creek anc Carbondale areas.
	Lower Pennsyl-vanian and older	Minturn Formation Gothic Formation of Langenheim (1952) Belden Formation Leadville Limestone Chaffee Formation Manitou Dolomite Peerless Formation Sawatch Quartzite	4,650	No information available.

Figure 3-20. Hydrologic Characteristics of Geologic Units in the Crystal River and Cattle Creek Drainage Basins, near Glenwood Springs, Colorado (Modified from Brogden and Giles, 1976)

SYSTEM	SERIES	GEOLOGIC UNIT	MAXIMUM THICKNESS (feet)	HYDROLOGIC CHARACTERISTICS
QUATERNARY	Holocene	Colluvium	50	Reported well yields are as much as 25 gal/min. Source of water for many springs. Water quality dependent on composition of parent material.
		Alluvium	200	Reported well yields are as much as 85 gal/min. Important source of water in Carbondale area. Water quality variable and dependent on underlying bedrock and source of alluvial material. Water is a calcium sulfate type or a calcium bicarbonate type. Dissolved-solids concentration ranges from 245 to 1,460 mg/l. Selenium occurs in excess of U.S. Public Health Service (1962) drinking-water standards where alluvium is in contact with the Eagle Valley Evaporite. Hydraulic conductivity values range from 1.0 ft/d in the Cattle Creek valley to 100 ft/d in the Roaring Fork River valley.
	Pleistocene	Basalt	1,000	Reported well yields generally range from 25 to 50 gal/min; yields of 100 gal/min are not uncommon in collapsed areas. Basalt is primary source of water in Cattle Creek drainage basin: no information available for basalt in western part of Crystal River drainage basin. Water is a calcium bicarbonate type. Disdolved-solids concentration ranges from 111 to 475 mg/l. Hydraulic conductivity values range from 1.0 to 40 ft/d.
TERTIARY	Pliocene Miocene Oligocene	Igneous rocks	Indeterminate	No information available. Not an aquifer in study area.
	Eocene	Wasatch Formation	6,000	No information available. Not an aquifer in study area.
8 ETACEOUS	Upper Cretaceous	Mesaverde Formation	2,700	Data for only one well obtained; water is a calcium biocarbonate type. Dissolved-solids concentration is 181 mg/l.
		Mancos Shale	4.000	Data for only one well obtained; water is a calcium bicarbonate type. Dissolved solids concentration is 237 mg/l.
	Lower Cretaceous	Dakota Sandstone and Burro Canyon Formation	300	No information available. May be an aquifer in outcrop area.

Figure 3-20. Hydrologic Characteristics of Geologic Units in the Crystal River and Cattle Creek Drainage Basins, near Glenwood Springs, Colorado (Modified from Brogden and Giles, 1976) (Continued)

4. COAL RESOURCES

4.1 REGIONAL SETTING

The depositional environment in the Piceance Basin in Late Cretaceous was primarily an open seaway with a delta-deltaic plain complex prograding to the southeast. The constantly shifting strandline resulted in a complex series of interfingering marine and non-marine sediments. This sequence of events results in the long-term maintenance of swamps in which coal-forming material accumulated.

The major coalbeds were deposited behind the beach sands as the Cretaceous sea retreated. Several other less significant and highly erratic coalbeds were deposited ahead of the beach's beds when occasional fluctuations in the sea level caused the shoreline to temporarily move up slope. In some areas, acid leached from the coal has bleached the sandstone white. These resistant white sandstone beds stand out as prominent caprocks and benches and indicate the presence of coalbeds. The thickest coalbeds in the basin are located above the Rollins-Trout Creek or its equivalent sandstone which marks the top of the Iles Formation of the Mesaverde Group (Figure 3-10). Coals that have a similar occurrence are found above the Cozzette, Corcoran, and Sego sandstones.

The Iles and Williams Fork Formations, which comprise the Mesaverde Group in the northern and eastern portions of the basin, are the principal coal-bearing formations in the Piceance Basin. In the southwest part of the basin, the coal-bearing Mount Garrison Formation is considered the lithologic equivalent of the coal-bearing parts of the Mesaverde Group. The periphery of the basin, defined by the continuous outcrop of the coal-bearing rocks, has been divided into eight coal fields. Clockwise from the northwest corner of the basin near Rangely, these fields are: the Lower White River; Danforth Hills; Grand Hogback; 'Carbondale; Crested Butte; Somerset; Grand Mesa; and. Book Cliffs (Figure 4-1).

Coals range in rank from high-volatile C to medium-volatile bituminous over most of the basin. The rank generally increases from north to south (Table 4-l and Plate 6). In the southeastern portion of the basin, abnormally high heat flow, resulting from Tertiary igneous intrusives and

related movement, has metamorphosed the coal to semi-anthracite and anthracite. In some locations, the coal has been metamorphosed to graphite.

Hornbaker et al. (1976) estimated the coal resource for the basin to a depth of 6,000 feet to be approximately 55 billion tons (Table 4-Z). Within this resource, significant coking coal reserves totaling 0.45 billion tons have been identified at depths less than 1,000 feet in southeastern Piceance Basin in the Grand Hogback, Carbondale, Crested Butte, and Somerset Fields by Goolsby et al. (1979) (Tables 4-3 and 4-4). Collins (1977) estimated the coal resource for the entire basin, for beds over 42 inches thick, to be approximately 123.8 billion tons. In this report (Section 5.4), the authors, using geophysical logs and in some cases logs covering only a portion of the entire coal section, estimated the coal resource of the basin to be 382 billion tons. Over 75 percent of the coal-bearing rocks lie at depths greater than 3,000 feet in the interior of the basin (Figure 4-2 and Plate 5). Coal mining has concentrated on the basin periphery where the coalbeds outcrop and are readily accessible (Figure 4-3, Table 4-3, and Plate 3). As of January 1, 1978, the Piceance Basin had produced 87.3 million tons of coal--14 percent of the Colorado state total of 607.7 million tons (Dawson and Murray, 1978).

4.2 COAL FIELDS

4.2.1 Lower White River Coal Field

The Lower White River coal field is situated along the White River in Moffat and Rio Blanco Counties (Figure 4-l). The field includes the part of the continuous outcrop of the Mesaverde rocks that extends from the Danforth Hills coal field south and west along the White River to the Utah state line. The northeastern tip of the coal field is characterized by strata that dip from 40 to 70 degrees to the south. South of this area the coals strike north-south and dip from 11 to 16 degrees to the east. The coal-bearing rocks form a narrow hogback on the northern side of the White River in the central portion of the field. Here the beds have an average dip of 45 degrees to the south. The western portion of the field is a broad shallow anticline where the coal-bearing rocks have been eroded from the center to expose the Mancos Shale.

Original in-place coal resources for the 930 square mile area to a depth of 6,000 feet have been estimated to be 11.76 billion short tons (Hornbaker et al., 1976). Coals in this field average high-volatile C bituminous in rank and vary in thickness from 8 to 12 feet. Most of the mining has taken place in the Rangely area on the flanks of the anticline. Coal mining has not occurred in the Lower White River coal field for several years.

Although the coals in this field probably are very similar in occurrence to those in the Danforth Hills coal field, no attempt has been made to correlate coals of the two fields. The following is a description taken from Gale (1910) of the coal resources by township units beginning at the northeastern part and proceeding west and south and ending in the vicinity of Rangely. The Douglas Creek district is the southern extension of the Lower White River field. It will be discussed briefly following descriptions of the Lower White River field coalbeds.

Several coalbeds are evident in the northeastern tip of the coal field where the strata abruptly change from a strike of N45°W to N45°E and dip from 45 to 70 degrees to the southeast. Only one coalbed was mined, where six to eight feet of coal were exposed, dipping 71 degrees. The coal-bearing strata then change to a north-south strike with dips varying from 10 to 60 degrees--generally in a southeasterly direction. Several prospects have opened coals 8 or more feet thick, dipping from 15 to 20 degrees. In T4N, R98W the coal-bearing rocks strike north-south and have very uniform dips of 5 to 6 degrees to the east. Coals appear to be concentrated in three groups. The lower group consists of a few relatively unimportant beds. The middle group occurs just above the "white rock" (Trout Creek Sandstone) noted in the Danforth Hills coal field. One coalbed, 5 to 6 feet thick from the middle group, has been opened. The upper coal group has at least five beds that range in thickness from 2 to 6 feet. Other beds probably are obscured by terrace gravels, slides, and debris.

At the south end of Pinyon Ridge the coal-bearing strata outcrop swings to an east-west strike, forming a narrow belt that extends for 15 miles to the eastern flank of the breached Rangely anticline. The rocks of this narrow outcrop form a hogback in which the strata dip from 25 to 45

degrees to the south. Coal is exposed in several outcrops and has been mined at several entries. The coals generally are confined to a single zone in which the beds vary from slightly more than 2 to 8 feet in thickness. The beds tend to be of good quality, clear, hard, and bright with a few partings of bony or woody coal. At the western end of the hogback several thick coalbeds are exposed. The base of the coal group lies immediately above a massive, white sandstone thought to be the Trout Creek Sandstone.

Outcrops of the coal-bearing strata swing south again in T3N, R101W, describing the eastern flank of the breached Rangely anticline. The coals have burned in this area. Beds occur in the upper walls of the canyons and on the highest ridges. One bed, 4 feet thick, was mined on the north bank of the White River in Sec. 11, T3N, R101W. The coalbed contains several irregular layers of bone. Several other entries were abandoned because the coal was either too thin or bony. Several coalbeds were encountered in four DOE/TRW well tests drilled in conjunction with Western Fuels Association on the eastern flank of the Rangely anticline. Up to six coalbeds, ranging in thickness from 1 to 8.5 feet, were encountered in a 60-foot interval. The coals occur at depths that range from 750 to 1,200 feet.

Gaskill and Horn (1961) investigated the coal resources of the northeast flank of the Rangely anticline in T2N, R101 and 102W, and T3N, R101 and 102W, an area of 73 square miles. They identified 28 coalbeds that range in thickness from 0.1 to 9.5 feet and have an aggregate thickness of 45 feet. The coal is high-volatile C bituminous in rank, well-exposed, and often burned. The principal coal zone in this area varies from 60 to 100 feet thick and occurs as a series of interfingering, lenticular, and generally thin beds.

At the southern end of the field the base of minable coals is commonly marked by a sandstone assumed to be the "white rock." Above this horizon burned shales and ashes identify the position of coals that probably are of workable thickness beyond the burned zone. Where burning has not occurred, several beds--one up to 8 feet thick--have been prospected. Several coals, 6 to 10 inches thick, occurring in the lower part of the Mesaverde Formation, are exposed in the black shales along Douglas Creek.

The western flank of the Rangely anticline contains several coalbeds that dip from 9 to 30 degrees, generally to the southeast. Several coals are present close to the Utah state line in the northern part of the coal field. One bed, 8 feet thick, was mined in this area. Other beds are exposed above and below this bed but have not been prospected. Following the western flank of the anticline south, several thick coals up to 12 feet thick have been identified.

In T1N, R102W, some thick coals have been opened and mined. The following measurements were made at the J. W. Rector Mine (Sec. 14, T1N, R102W):

Coal	1 ft
Shale	5 ft
Coal (A)	4 plus ft
Shale	15 ft
Coal (B)	5 to 12 ft
Sandstone and Shale	17 plus ft
Coal (C)	5 plus ft

Coal-bearing rocks in the White River field are continuous south of Raven Park and cover an area of several hundred square miles. Known as the Douglas Creek district, this area is arbitrarily separated by the 40°00' line of latitude. Except for thin, irregular coals of the lower coal group, the only coals of this district occur in the middle coal group. Those from the middle zone are commonly burned. Where the coal is not burned, it appears to be bituminous in rank.

4.2.2 Danforth Hills Coal Field

The Danforth Hills coal field extends southward from the town of Axial to Meeker and is congruent with the mountainous area of the same name (Figure 4-l). The Danforth Hills coal field lies in Rio Blanco and Moffat Counties and is bounded by Cretaceous coal-bearing rocks that outcrop north of the White River, south of the Axial basin, west of the White River Plateau, and east of Strawberry Creek and Citadel Plateau.

Original in-place coal resources, to a depth of 6,000 feet in the approximately 400 square miles of the coal field, total more than 10.5 billion short tons (Hornbaker et al., 1976). Most of the coal in the field is generally high-volatile C bituninous in rank.

All minable coalbeds are found in the Iles and William Fork Formations of the Mesaverde Group (Figures 4-4 and 4-5). Coalbeds in the Grand Hogback monocline near Meeker and along the western margin, in the hogback-related Strawberry Creek Valley, dip from 20 to 60 degrees to the west. The beds in the interior of the field are relatively flat-lying to gently uplifted, and have dips ranging from 3 to 12 degrees. Coalbeds that occur along the northern and eastern margins dip steeply, from 20 to 80 degrees, towards the interior of the coal field.

The lower part of the Iles Formation contains coalbeds that are thin, discontinuous, and generally regarded as unminable. However, significant coals occur near the top of the Iles Formation, below the Trout Creek Sandstone, and within the Black Diamond coal group (Hancock, 1925). Four to six coalbeds varying from slightly less than 2 to 14 feet thick include, from bottom to top: the Meeker bed, 4 to 7 feet thick; the Sulphur Creek bed, 2 to 4 feet thick; the Wilson bed, 8 to 13 feet thick; and the Pollard bed, 3 to 13 feet thick. These beds are difficult to correlate outside of the Meeker area. Black Diamond coals are exposed along the eastern and northern margins of the coal field and in the canyons of the Coal Butte area (T3N, R94W) north of Meeker. In the Coal Butte area, two beds of poor quality were exposed. These beds, 14 and 15 inches thick separated by 8 feet of shale, occur about 150 feet below the Trout Creek Sandstone. The Black Diamond group coals appear to thin to the north. Near the town of Axial an exposed coalbed, approximately 2 feet thick, is described by Gale (1910) as occurring in the stratigraphic interval below the "white rock" (possibly the Trout Creek Sandstone) and near the base of the Mesaverde Formation. Black Diamond coals of minable thickness are poorly exposed west of Axial. On the western margin of the coal field the coalbeds have been burned and have not been correlated. The stratigraphic section below the "white rock" is not exposed in the northwest corner of the coal field. Coals from this group average high-volatile C bituminous in rank.

Coalbeds that crop out north of the Meeker area have been divided only by the Iles-Williams Fork Formations' contact, and in many areas this correlation is tentative. Several problems are encountered in the northern portion of the Danforth Hills coal field when attempting to correlate

coalbeds. Several significant coalbeds have burned and are thought to be present but cannot be measured or sampled for analysis. Important coal zones are commonly obscured by rock debris and soils. Faulting and slumping also make coalbed correlation difficult in many areas. In addition to these problems, the coalbeds split, coalesce, and pinch out within the coal zones so that identification of individual beds is further complicated.

Hancock and Eby (1930) divided the Williams Fork Formation into three coal groups. These, from bottom to top, are: the Fairfield, comprised of 1,300 feet of coal-bearing rocks above the Trout Creek Sandstone; the Goff, comprised of 700 feet of coal-bearing rocks underlying the Lion Canyon Sandstone that occurs approximately 3,000 feet above the Trout Creek Sandstone; and the Lion Canyon group consisting of 1,000 feet of the Williams Fork Formation that crops out immediately above the Lion Canyon Sandstone (Figure 4-5). Collins (1976) divided the Fairfield group of Hancock and Eby (1930) into the following three groups: the Fairfield, consisting of the lowermost coals of Hancock and Eby's Fairfield group; the South Canyon, consisting of the interval from 160 to 750 feet above the Trout Creek Sandstone; and the Coal Ridge group, consisting of the upper 400 feet of the old Fairfield group. Very little work has been done using Collins nomenclature. This report uses the original coal groups in discussing the occurrence of Williams Fork coals in the Danforth Hills coal field.

The Fairfield coal group contains six correlated coal zones, including the Major, Bloomfield, Fairfield, Fairfield No. 2, Wesson, and Agency. These zones have been identified primarily in the Meeker area where up to 14 beds have been correlated. The beds range from less than 1 to 30 feet in thickness, In Sec. 28 and 29, T1N, R94W, where the White River cuts through the hogback, the Major bed is about 13 feet thick; the Fairfield bed contains 20 feet of coal in two benches; the Fairfield No. 2 is 10 feet thick; and the Agency is 5 feet thick (Hancock and Eby, 1930). Just north of the White River exposure, several of the Fairfield group coals have burned; however, beds measured here contained at least 50 feet of coal (Hancock and Eby, 1930).

Coals from the Goff and Lion Canyon groups present in the Meeker area are exposed primarily along the hogback and the Strawberry Creek escarpment. Hancock and Eby (1930) recorded 16 coals in the Goff group and 30 in the Lion Canyon group that vary in thickness from less than 1 to 18 feet. Coals from these groups commonly contain numerous partings of impure coal. The coals are poorly exposed north of Meeker because of extensive burning. Northeast of Meeker the Lion Creek Sandstone is difficult to map, and it is not possible to separate coals of the Goff and Lion Canyon groups. The coals northwest of Meeker vary from 1 to 7 feet in thickness.

4.2.3 Grand Hogback Coal Field

The Grand Hogback coal field is located along the eastern margin of the Piceance Basin in Garfield and Rio Blanco Counties. The field is defined by that portion of the Grand Hogback that lies between the White River and Glenwood Springs (Figure 4-l). Coal-bearing strata that outcrop in the Grand Hogback coal field generally are continuous with the Danforth Hills coal field to the north and the Carbondale coal field to the south. Original in-place coal resources in the Grand Hogback coal field have been estimated at more than 3.1 billion short tons (Hornbaker et al., 1976). Coal rank ranges from high-volatile C to high-volatile A bituminous.

All the coals occur in the Iles and the overlying Williams Fork Formations (Figure 4-6). The Iles Formation generally is barren of coal except in the upper 200 to 300 feet. The Black Diamond coal zone at the top of the Iles Formation north of the coal field, near the town of Meeker, contains coals of minable thicknesses. Black Diamond coals pinch out to the south, with no coal from this group occurring south of the town of New Castle (Collins, 1976).

The important coals of the Grand Hogback field are found in three principal zones in the Williams Fork Formation known as the Fairfield, South Canyon, and Coal Ridge coal groups. The principal coal-bearing interval thickens from 630 feet in the Carbondale field to the south to 920 feet at White River to the north--due primarily to pinching out of marine shale tongues.

The lowermost coal zone, the Fairfield, is the most persistent, easily correlated, and economically important zone in this group. The Fairfield group progressively thickens to the north, reaching a maximum interval thickness at Rifle Gap, where nine coalbeds occur throughout the 470-foot interval between the Trout Creek (Rollins) Sandstone and the first major sandstone unit in the Williams Fork (Collins, 1976).

The South Canyon coal group consists of one or two major beds, the Allen, and the overlying Anderson. These coals average high-volatile C bituminous in rank.

The Coal Ridge group coals appear to be the most erratic of the three major groups, and do not outcrop at some of the exposed sections. The Upper Williams Fork Formation contains several lenticular and usually thin coalbeds. These coals, known as the Keystone group, occur in minable thicknesses in the northern and southern parts of the field.

The coalbeds of the Grand Hogback field are poorly exposed on the flanks of the hogback and most mining has been concentrated in areas where streams have cut through that structure. These cuts, or gaps, include from north to south: Piceance Gap (Sec. 35, T3S, R94W); Rifle Gap (Sec. 7 and 8, T5S, R92W); Harvey Gap (Sec. 24, T5S, R92W); the Colorado River cut at New Castle (Sec. 31, T5S, R90W); and the South Canyon Cut (Sec. 14, T6S, R90W).

Coals at Piceance Gap generally are less than 3 feet thick or contain thick bony, brown, or woody coal partings. Strata in this area dip from 38 to 45 degrees to the west (Figure 4-7). Several exposures of burned coal-beds, reddened rock, and some slag indicate the presence of several thick coalbeds. Keystone group coals have been developed, but the workings are now abandoned. Three beds range in thickness from 6 to 9.5 feet and occur within an interval of from 50 to 75 feet.

Coalbeds at Rifle Gap dip from 70 to 84 degrees to the southwest (Figure 4-8) and have been burned, as is evident by the abundance of baked

rocks, slag, and clinker. A typical stratigraphic coal section of the Rifle Gap area would contain the following beds:

Fairfield	Coal, Wheeler	30 ft
	Interburden	110 ft
Black Diamond	Coal	16 ft
	Interburden	130 ft
	Coal	5 ft
	Interburden	110 ft
	Coal	4 ft
	Interburden	355 ft
	Coal	7 ft

Coalbeds at Harvey Gap also have been burned or are mostly covered. At least one coalbed of the Fairfield group, about 12 feet thick, is exposed at this location. Old reports refer to a 40-foot bed that correlates with the Wheeler coalbed. Although uncovered in past developments, it is now obscured. All beds in this area are steeply dipping to the southwest.

To the west, near the town of New Castle, the Fairfield group is represented by four coalbeds (Figure 4-9). The following list of coals was presented in a published report by a chief engineer of the Colorado Fuel and Iron Company (Hosea, 1897). The measurements were made while the coals were being developed and represent the most complete record available (Gale, 1910).

"D" bed	5 ft
Wheeler	45-48 ft
"E" bed	18 ft
"F" bed	4 ft

These coals dip from 45 to 50 degrees to the southwest.

At the Coryell mine (Section 3, T6S, R91W) at least one bed of the South Canyon group and three beds of the Coal Ridge group are present. The Allen bed of the South Canyon group is 14 feet thick and dips 50 degrees to the south (Gale, 1910). At this mine the Allen is principally high-volatile A bituminous in rank. Gale (1910) quotes a description given by Hosea(1897) of coalbeds in the New Castle area, which Gale states "are

evidently more complete than the measurements of stratigraphic sections made during the present survey." Hosea describes the Allen bed as 20 feet thick and the Anderson as 8 feet thick. The Coal Ridge group coals at the Coryell mine are named, from bottom to top: the "C" bed--6 feet thick; the "B" bed--5.5 feet thick; and the "A" bed--5.5 feet thick. These beds all occur within an 80-foot interval. Coalbeds of the Keystone group occur in minable thickness 680 feet stratigraphically above the Coal Ridge group in the New Castle area. Here the Keystone contains four coalbeds in a 320-foot interval. The beds are, from bottom to top: 3.5; 3.5; 3; and 3 feet thick. The Keystone group coals have a less severe dip 25 to 27 degrees to the southwest--than the underlying coals of the Coal Ridge, South Canyon, and Fairfield coal groups.

In the southern part of the field, at South Canyon, four coalbeds of the Fairfield group occur within a 300-foot interval (Figure 4-10). The Wheeler bed, supposedly correlatable with the "C" or Wheeler bed in the Carbondale field, is about 18 feet thick with a parting 4.5 to 5 feet from the roof. A second bed, correlated with the "D" in the Carbondale field, is about five feet thick. Gale (1910) reported that both coals were gassy. Both beds have burned in the South Canyon area. The beds at this location have a dip of up to 50 degrees to the southwest.

At the South Canyon mine (Sec. 13, 14, T6S, R90W) the South Canyon coal group coals, the Allen and the Anderson, occur 290 feet stratigraphically above the Fairfield coal group. Here the Allen is 14 feet thick and separated from the overlying 4.5-foot Anderson by 40 feet of interbedding. These coalbeds average high-volatile C bituminous in rank. Two beds of the Coal Ridge group are present in South Canyon. Here the Coal Ridge group occurs approximately 320 feet stratigraphically above the South Canyon group. The Coal Ridge coals, the "B" and "C" beds, are 4 and 5 feet thick, respectively. The "B" bed occurs approximately 180 feet above the "C" bed.

4.2.4 Carbondale Coal Field

The Carbondale coal field is located along the eastern margin of the Piceance Basin in Garfield and Pitkin Counties (Figure 4-l). The field extends from the Glenwood Springs area where it merges with the Grand

Hogback coal field, to the Coal Basin area north of Chair Mountain where the West Elk Mountains separate it from the Somerset and Crested Butte coal fields.

Original in-place coal reserves to a depth of 6,000 feet in the 165 square-mile field have been estimated at more than 5.21 billion short tons. Coals of the Carbondale field increase in rank from high-volatile C bituminous in the northern part to medium-volatile bituminous in the southern part. Heat from Tertiary intrusive igneous rocks of the Elk and West Elk Mountains is the major cause of the anomalously high rank of coal in the southern part of the coal field. In some areas portions of coalbeds have been metamorphosed to anthracite and low- to medium-grade graphite. Coked coal zones are found on either side of dikes approximately half the thickness of the dike, with a low-volatile zone of approximately the same thickness separating the coke from the unaltered coal.

All minable coal is found in the Upper Cretaceous Williams Fork Formation of the Mesaverde Group (Figure 4-6). The Williams Fork Formation consists of three members, which from oldest to youngest are: the Bowie Shale Member; the Paonia Shale Member; and an undifferentiated member. Three coal groups occur in the Bowie Shale and Paonia Shale Members. The undifferentiated member is essentially barren.

The most important coal group, the Fairfield, occurs directly on the Rollins Sandstone of the underlying Iles Formation. Other coal groups of more local importance occur immediately above two similar sandstones. Correlating individual coalbeds has not been successful in the Carbondale coal field. Faulting, sedimentary variations, and differing nomenclature make accurate correlation on a bed basis difficult.

In the southern part of the coal field, the Fairfield group coals consist of the Coal Basin "A" and "B" beds and up to two thin rider beds. These coalbeds have a cumulative thickness ranging from 17 to 35 feet. In the Bear Creek area (Sec. 21, T10S, R89W) the four Coal Basin coalbeds have thicknesses of, from bottom to top: 2; 3; 2; and 10 feet. These coalbeds are separated by partings of 5 feet, 1 foot, and 1 foot, respectively. Coals of these groups in this area vary from less than 1 to 18 feet in thickness. In the 4th North entry of the L.S. Wood mine (SW1/4, Sec. 8,

T10S, R89W) one bed approximately 35 feet thick is present. Less than one-half mile north, along the South Fork of Coal Creek, three beds--3, 6, and 8 to 10 feet thick--are present. These beds are separated by partings of 3 to 4, and 4 to 6 feet, respectively. West of the old Coal Basin townsite, a single coalbed, Coal Basin "A", is approximately 35 feet thick. Fairfield group coals in the southern part of the coal field average medium-volatile bituminous in rank. Coals in the Coal Basin mine dip from 12 to 16 degrees to the west. Gale (1907) reported that coals in this mine are cut by several normal faults and contain many rolls. He also reported that the coal was very gassy.

In the central part of the coal field, the Fairfield group coalbeds consist of two to four beds, from bottom to top: the "A"; "B"; "C"; and "D". At Thompson Creek No. 1 mine (Sec. 34 and 35, T8S, R89W) the "A" and "B" beds, both averaging 6 feet in thickness, are separated by a 38-foot parting. These beds are high-volatile A bituminous in rank.

In the northern portion of the Carbondale coal field, four Coal Basin beds are present. These beds, from bottom to top, are: the "A" or Black Diamond; the "B"; the "C" or Wheeler; and the "D" or Pocahontas. At the Sunlight mine (Sec. 33 and 34, T7S, R89W) the following section is typical:

Coal ("D" bed)	9 ft
Shale	25 ft
Coal ("C" bed)	3 ft
Shale and Sandstone	16 ft
Coal ("A" bed)	10 ft

The "A" and "D" coalbeds were reported by Gale (1907) to be very gassy. They dip from 42 to 44 degrees to the west in this area.

Three miles to the north, in the Black Diamond mine (Section 8, T7S, R89W), there are seven workable coalbeds. The lowermost of these is the Black Diamond bed correlatable with the "A" coalbed of the Fairfield group. The Black Diamond bed averages 5 feet thick; other coalbeds range from 2 to 5 feet in thickness. Coalbeds in this area dip 52 degrees to the southwest.

The South Canyon coal group (Collins, 1976) occurs directly above the first persistent sandstone in the Bowie Shale Member. Coalbeds in the South Canyon group are less persistent than those in the Fairfield group.

In the Coal Basin area of the Carbondale coal field only one bed--the Dutch Creek--is of minable thickness. It consists of 3 to 20 feet of medium-volatile bituminous coal usually containing a bony band 10 to 18 inches thick, 2 to 4 feet from the bottom of the coalbed. A rider bed, where present, ranges in thickness from a few inches to 4 feet and is separated from the main bed by 0 to 8 feet of massive sandy siltstone and 2 to 18 inches of bony coal. The coalbed reaches its maximum thickness where the parting is absent.

Minable coalbeds of the South Canyon group appear to be absent at North Thompson Creek (Donnell, 1962). Correlation of the South Canyon group in the northern part of the field is difficult because the coalbeds have been extensively burned or are not exposed. Two major coalbeds occur in the basal 100 feet of the group in this area. In the Gulch mine (Secs. 22 and 27, T8S, R89W) the Sunshine coalbed of the South Canyon group lies 800 feet stratigraphically above the Fairfield coal group. The Sunshine bed is 9 to 14 feet thick, averaging 12 feet. The Anderson bed occurs 50 feet stratigraphically above the Sunshine bed and ranges from 4.5 to 6 feet in thickness. At the Sunlight mine (Secs. 33 and 34, T7S, R89W) the Sunshine bed occurs 800 feet above the Fairfield group and is 16 feet thick.

The third and uppermost of the coal groups, the Coal Ridge, occurs in the basal 400 feet of the Paonia Shale Member of the Williams Fork Formation. Coals of this group have not been extensively investigated except in the fields south of Coal Basin, and have been mined only at North Thompson Creek and Spring Gulch (Collins, 1976). Coal Ridge group coals appear to be the most erratic of the three groups. In the Coal Basin-Chain Mountain-Marble area, the group consists of up to nine coalbeds varying from a few inches to 7 feet in thickness. The thickest coalbed occurs directly above the upper sandstone. Coalbeds mined in this area include the Placita and Sunshine, and have an average rank of high-volatile A bituminous.

In the North Thompson Creek area there are up to 10 coalbeds in the Coal Ridge group. The thickest of these is 9 feet and occurs 65 feet above the upper sandstone. The Sunshine is the only named coalbed in this area.

Coal Ridge coals in the northern part of the Carbondale field area have been burned. At least one mine, however, has been opened in this area. The Sunshine (now Sunlight) is approximately 7 feet thick here. The undifferentiated Mesaverde Formation, also known as the Upper Williams Fork Formation, contains only thin and unminable coalbeds.

Coal mining in the Carbondale coal field is hindered by the dip of up to 15" of the coal-bearing strata. Special equipment and mining techniques are being used to recover the coal.

4.2.5 Crested Butte Coal Field

The Crested Butte coal field lies southeast of the Somerset field and south of the Carbondale field in Gunnison County (Figure 4-1). The coal-bearing Mesaverde rocks of this part of the Piceance Basin have been extensively affected by the intrusive West Elk Mountain complex. As in the eastern part of the Somerset field, the coals have been folded, faulted, and intruded. The Crested Butte coal field is very mountainous with much of the field lying at elevations above 10,000 feet.

Original in-place coal resources to a depth of 6,000 feet, in the 240-square-mile area of the Crested Butte field are estimated to be more than 1.56 billion short tons (Hornbaker et al., 1976). Coal quality in this field ranges from high-volatile C bituminous in the northern and western parts to semianthracite to anthracite in the southeastern part of the field. The field contains important resources of premium-grade high-volatile A and B bituninous coking coal.

The Crested Butte field is divided into three districts; the Floresta; Mount Carbon; and Crested Butte.

The Crested Butte district lies in the Slate River valley where coalbeds outcrop near the level of the valley floor, but more commonly outcrop high in the Canyon Walls to altitudes of more than 11,500 feet. The coalbeds have a generally southerly dip primarily due to the Treasure Mountain uplift. South of the town of Crested Butte the general inclination of the coal-bearing rocks has been reversed by intrusion of the laccolithic mass of Mount Wheatstone. The Crested Butte mine (Section 3, T14S, R86W) is the point at which the character of the coal changes from

bituminous to the southeast to anthracite in the northwest. Lee (1912) quotes Hills (1893) as stating that "the mine workings are confined to a zone of coking coal less than 1 mile wide, which graduates into semicoking coal on one side and into anthracite on the other."

Several coalbeds have been identified in the Crested Butte district varying in number from six in the southern end to a single bed pinching out in the northern end of the district. Major coals are numbered beginning with lowermost coal that occurs immediately above the Rollins Sandstone. The No. 1 coal attains a maximum thickness of 6.7 feet in the southeastern part of the field. It is not present in all parts of the district, and thins to the northwest, eventually pinching out to be replaced by a shale containing thin beds of coal. The locations both of several measured sections from this district and of other sections are shown on Figure 4-11. The measured sections from the Crested Butte district are presented in Figure 4-12.

Coal No. 2 is persistent throughout the field.' The No. 2 ranges in thickness from 5 to 6.7 feet, increasing in thickness to the northwest. Coal No. 3 is also found everywhere in the field and is the most important bed of the Crested Butte district. The No. 3 bed varies in thickness, the result of the intrusive rocks and associated faulting and folding (Lee, 1912). In several areas the coal has been crushed, and in the Crested Butte mine the No. 3 coal varies from a few inches to 22 feet thick. A fourth coalbed, the No. 4 coal, occurs irregularly throughout the district. At the Crested Butte mine it appears as 3.5 feet of coal 190 feet above the No. 1 coal. It apparently thins to the west and at the Anthracite mine (Section 17, T13S, R86W) it is approximately 2 feet thick. It too has been altered by the igneous intrusions. At the Crested Butte mine it is bituminous and at the Anthracite mine it is anthracite.

The Floresta district lies approximately 7 miles east of the Coal Creek district on the northern flank of the Anthracite Range. The Anthracite Range is a igneous intrusive that was thrust up through the coal-bearing rocks displacing all the coalbeds. All the coal occurs in the Paonia Shale Member which dips from 18 to 24 degrees to the north. Only one coal of minable thickness has been identified in this field. Other small beds 2 to 6 inches thick occur above the main coalbed (Figure 4-13).

The Ruby-Anthracite mine (Sec. 16, T14S, R88W) produced from the main bed which averaged 4 feet thick in the mine (Lee, 1912). The bed thins to 1 foot to the west, and thickens to 5 feet to the east. The coal is anthracite, with vitreous luster, conchoidal fracture, and a banded texture. Several small faults and slips were encountered in the mine, and several dikes of igneous rocks cut the coal. Very little methane was reported in the mine (Lee, 1912).

The Mount Carbon district lies south of the Crested Butte district separated from it by Mount Carbon, Mount Axtell, and Mount Wheatstone. The coals orobably are not present in commercial quantities under the Mount Carbon laccolith. Coalbeds are known to exist under the Mount Wheatstone laccolith and probably underlie the Mount Axtell laccolith. The intrusives, besides displacing and destroying the coalbeds, also threw the coals and associated rocks into undulations producing many small faults (Lee, 1912).

Two coalbeds of significance occur in the Paonia Shale Member of the Williams Fork Formation, in the Mount Carbon district. The lowermost, or Coal No. 1, occurs just above a massive sandstone bed. The No. 1 bed attains a maximum thickness of 11 feet in the southernmost part of the district and thins to 7.5 inches in the northeast. In the northeast part of the district the No. 2 bed occurs 85 feet above the basal sandstone. The No. 2 coal is persistent throughout the field and, where prospected, was found to be relatively uniform in character (Lee, 1912). Fossils found in this bed correlate with the No. 8 coal in the Coal Creek district to the west. The Coal No. 3 is not thought to be of great economic importance in the Mount Carbon district. It is represented by a series of lenticular coalbeds that occur at about the same horizon throughout the district. Coal from this district is generally high-volatile C bituminous in rank. In sane areas heat from the igneous intrusives has metamorphosed the coal from bituminous to anthracite. At the Robinson mine (Sec. 36, T14S, R86W) located on the flank of Mount Wheatstone, four feet of coal have been metamorphosed to anthracite by the heat of the Mount Wheatstone laccolith.

4.2.6 Somerset Coal Field

The Somerset coal field is located along the southeastern edge of the Piceance Basin in Delta and Gunnison Counties (Figure 4-1). It is part of a continuous outcrop of Mesaverde coal-bearing strata that stretches more than 100 miles from the Book Cliffs field to the northwest to the Crested Butte field to the southeast. The Somerset field contains coalbeds that outcrop along the north fork of the Gunnison River, along Minnesota Creek east of Paonia, and along Coal Creek east of Mount Gunnison.

The coals occur in the Bowie and Paonia Shale Members and are more numerous and better exposed than in the Grand Mesa coal field to the west (Figure 4-14). Almost all mining and most of the prospecting in this field has been done in the Bowie Shale Member in which there are at least seven thick coalbeds having an aggregate thickness of 38 to 43 feet (Lee, 1912). As in the other coal fields, the coals vary greatly in thickness within short distances, and commonly split into as many as six benches or coalesce into a single bed 42 feet thick. In many places the coals are not well exposed or are burned. Even at the best exposed section of the coal-bearing rocks, ash and clinker at several horizons indicate that not all of the coalbeds are exposed (Lee, 1912) (Figure 4-15).

Original in-place coal resources for beds less than 6,000 feet deep in the 320-square-mile Somerset field are estimated to be more than 8.04 billion short tons (Hornbaker et al., 1976). Coals range in rank from high-volatile C to high-volatile B bituminous, with coal in the eastern part of the field generally of coking quality. Coal-bearing strata in the eastern part of the Somerset field are intruded by plutons of the Oligocene West Elk Mountains complex (Murray et al., 1977).

Near the town of Paonia, several opennings have been made into coals of the Bowie Shale Member. The coal-bearing sections contains up to five coalbeds within an interval of 75 feet. The lowermost coal occurs immediately above a massive 75-foot-thick sandstone.

The lowermost coal varies from 11 to 14 feet thick and at the Conine mine (Sec. 24, T13S, R92W) contains a 2-foot shale parting 6 feet from the bottom of the bed (Lee, 1912). In the Paonia Coal Company mine (Sec. 17,

T13S, R91W), the coalbed consists of 8.7 feet of good coal overlain by 2 feet of bony coal. Other coals in this zone vary from 1 to 3 feet in thickness.

To the east, near the town of Bowie, the coal-bearing section lying imnediately above the massive sandstone changes somewhat in character. At the New King mine (Sec. 15, T13S, R91W) the thickest coalbed, known as the Juanita, lies about 50 feet above the base of the coal-bearing rocks and is the fourth bed above the sandstone (Lee, 1912). The bed contains 11.5 feet of good coal and 0.6 foot of shale and dirty coal. One-half mile to the west, at the Old King mine (Section 15, T13S, R91W), the lowermost coal occurring imnediately above the sandstone is 5.5 feet thick. Coal at the New King mine was described by Lee (1912) as black bituminous having a conchoidal fracture, vertically jointed, and not gassy. At other openings around the Bowie area the Juanita bed is reported to be up to 16 feet thick. Further upstream, near the town of Somerset, the Juanita is reported to be 22 feet thick and of coking quality. In this area the Juanita is overlain by a second coalbed that averages 7 feet thick. Other mines in the area have opened several coalbeds that vary in thickness from 5.5 to 10 feet and have not been correlated. Some coals have burned in this area.

Several prospects have been made along Minnesota Creek south of Somerset. On the western flank of Mount Gunnison, a composite section was made using several of the prospects in Section 6, T14S, R90W is given below:

		Thickness in Feet
Paonia Shale	Sandstone	
	Coal	12.2
	Shale and Sandstone	57
	Coal	3.8
	Sandstone and Shale	40
	Coal	1
	Sandstone and Shale	40
	Coal	10

		Thickness in Feet
Bowie Shale	Sandstone	85
	Coal	8
	Sandstone	50
	Ash and Clinker	20
	Coal, metamorphosed	2
	Shale and Sandstone	48
	Coal, metamorphosed	2
	Shale and sandstone	40
	Coal	5.6
	Shale	25
	Coal	6
	Limestone, Shelly	3
	Shale	15
	Coal	5.4
	Shale	14
	Coal	6
	Shale, sandy	21
	Coal	4.5
	Shale, sandy	16
	Coal	3
	TOTAL	543.5

The U.S. Bureau of Mines conducted a coal reserve investigation east of Paonia in Sections 31, 32, and 33 T13S, R90W, and Sections 4, 5, 6, 8, 9, and 10, T14S, R90W. This investigation included drilling, coring, and field mapping. Results indicated a total of 781 million tons of measured, indicated, and inferred high-volatile bituminous coal reserves in the area of investigation. The coals vary from 0.3 to 16.8 feet in thickness. Coalbeds greater than 4 feet thick were identified by letters, and the lowest bed was assigned the letter "A". The "E" bed, known locally as the No. 10 coal, was thickest and ranged from 14.1 to 16.3 feet. Results from the coring operations are summarized.

Drillhole	Number of Beds	Number of beds greater than 4 feet thick	Total thickness of beds greater than 4 feet thick (ft)
1-33	21	6	53.3
2-33	21	5	58.0
3-33	14	5	37.2
4-33	15	4	26.0
5-33	16	6	54.0

In 1976, Colorado Westmoreland Incorporated (CWI) opened a new underground coal mine in the Somerset field near Paonia. CWI's Orchard Valley mine (Section 24, T13S, R92W) is mining the highest major coalbed in the Bowie Shale Member. The coalbeds are identified as letters of the alphabet, the lowest bed referred to as the "B" bed. The Orchard Valley mine is producing from the "D" bed which averages 26 feet thick. Based on CWI's drilling data, the following coal section is considered typical in the vicinity of the new mining activity (Murray et al., 1977):

		Thickness (ft)
Paonia Shale Member	"D" bed	26
	Interbedding	80-100
Bowie Shale Member	"C" bed	13
	"C" Interbedding	75-80
	"B" bed, 2 splits	6.2 upper 4.5 lower
	Rollins Sandstone	

Coal occurs in the south slope of Mount Gunnison as crushed, faulted, and deformed blocks included within the igneous rocks that constitute the majority of the mountain. The coals are poorly exposed and most coal measurements were made at prospect openings. Coalbeds in this area are irregular in character and vary greatly in thickness due to crushing caused by rock movement. Coal varies from 12 feet to a few inches thick, often pinching out entirely. Heat from the igneous intrusions has locally increased the rank of the coal from bituminous to anthracite. In some areas the coal appears to have been partially melted under pressure (Lee, 1912).

Coalbeds of the Somerset district disappear toward the east under younger rocks and outcrop again in Coal Creek Canyon. The coal-bearing rocks have been disturbed by the intrusion of the igneous Mount Gunnison and the Cliff and by the associated tectonic activity. The coals outcrop at altitudes of up to 10,300 feet and dip to the north, passing beneath the bottom of Coal Creek Canyon at an elevation of about 7,000 feet. Although the coalbeds that occur in the Coal Creek Canyon generally are continuous with those in the Somerset district to the west, the nomenclature of the

beds differs. Coalbeds in the Coal Creek district are numbered beginning with the lowermost coalbed that occurs imnediately above the Rollins Sandstone. Eight beds have been identified and correlated in the Coal Creek district (Figure 4-16). Usually only three or four of the coalbeds are exposed at any one location.

The lowest or Coal No. 1 is very lenticular and in some areas is represented only by carbonaceous shale (Lee, 1912). Coal No. 2 usually is found 60 feet above the base of the Rollins Sandstone and ranges from 1 to 13.5 feet in thickness. Coal No. 3 occurs a few feet above Coal No. 2 and ranges in thickness from 1.5 to 7.5 feet. Coal No. 4 usually is closely associated with Coals No. 2 and 3, it varies in thickness from 1.5 to 3.5 feet.

Coal No. 5 appears to be very regular in thickness and is one of the most important coalbeds in the Coal Creek district. It averages 5 feet thick and at one location contains a l-foot parting of bony coal. Coal No. 6 is persistent throughout the district, maintaining a uniform thickness of approximately 8 feet, but locally varying from 4 to 10 feet in thickness. The No. 7 coal occurs 4 to 15 feet above the No. 6 coal and averages only 2 feet thick. Coal No. 8 occurs immediately above a thick sandstone bed and averages 12 feet thick.

Toenges et al. (1952) investigated the coal deposits of the Coal Creek district. Their investigation included the drilling and coring of 16 exploration holes, all located in T13S, R89W. Up to 12, but more commonly six, coalbeds were encountered in a 30- to 60-foot coal zone. Coals in this zone vary from 0.2 to 14.8 feet in thickness. Three beds, all greater than 3.5 feet thick, were identified as the Upper, Middle, and Lower. The Lower bed typically occurs directly above the Rollins Sandstone; the Middle bed occurs from 6 to 51 feet above the Lower; and the Upper is found from 2 to 34 feet above the Middle bed. These three beds contain reserves of 108.5 million tons of metallurgical grade and 12.5 million tons of non-coking coal in the area of investigation.

4.2.7 Grand Mesa Coal Field

The Grand Mesa coal field stretches for approximately 50 miles along the southern and southwestern border of the Piceance Basin (Figure 4-l). The field is part of the continuous outcrop of the coal-bearing Mesaverde Formation. It is separated from the Book Cliffs field to the north by the Colorado River and bounded on the south by the Somerset field. The Grand Mesa Field is situated on the south flank of the Grand Mesa, primarily in Delta County, with the northwest portion of the field in Mesa County.

Coals in the Grand Mesa field range from high-volatile C bituminous to subbituminous A in rank. Original in-place resources, to a depth of 6,000 feet in the 530-square-mile area of the field, exceed 8.6 billion short tons (Hornbaker et al., 1976).

The northern part of the field south of the Colorado River is characterized by gently dipping, cliff-forming sandstones eroded into ridges and points with up to 2,500 feet of relief. The remainder of the field is composed of steep slopes, on which outcrops are commonly obscured by colluvium. The Mesaverde coals in the Grand Mesa field occur above the Rollins Sandstones in the Bowie and Paonia Shale Members of the Williams Fork Formation (Murray et al., 1977) (Figure 4-17).

The present-day Grand Mesa field is divided into two districts: the Palisades, which includes the west slope of Grand Mesa between the Colorado River and the southwestern point of the mesa; and the Rollins district, which extends from the southwestern point of the Grand Mesa eastward to Paonia.

Lee (1912) mapped the Rollins Sandstone as the base of the Mesaverde in the Grand Mesa coal field. Later geologic studies showed Lee's Rollins to be the second or third massive sandstone above the base of the Mesaverde. Schwochow (1978) states, "... although the Rollins is not the base of the Mesaverde, it marks the base of the coal-bearing portion."

The coal-bearing sequence above the Rollins was divided by Lee into the Bowie and the Paonia Shale Members. The underlying Bowie contains only one significant coalbed in the Palisades district. The Bowie occurs as a 3.3-foot bed in the Stokes Mine (Sec. 2, T11S, R98W) and thins to 1 foot toward the south. Lee (1912) correlated the Bowie coal with the

Palisades coal that occurs north of the Colorado River where it is 3.3 feet thick at the Palisades Mine.

Lee identified several coalbeds in the Paonia Shale Member--only one of which has been developed. It occurs at the base of the Paonia and ranges from 4 to 7 feet in thickness (Figure 4-18). Lee correlated this bed with the Cameo north of the Colorado River. Several other coalbeds are found at higher horizons in the Paonia; the thickest one measured contains 3 feet of coal. At the Patterson Mine (Sec. 17, T12S, R97W), the Cameo and two other overlying beds were measured as follows:

Coal	2 ft
Sandstone	22 ft
Coal	3 ft
Shale	16 ft
Coal (Cameo)	5 ft
Shale	6 ft
Rollins Sandstone	75 ft

Several coals of the Cameo zone were encountered in a TRW well test performed in conjunction with the Energy Division, Adolph Coors Company. The well is located east of the Palisade district near the town of Mesa. Coal-bearing strata in this well dip from 1 to 3 degrees to the east. Two beds, 10 and 12 feet thick, were encountered in a 60-foot interval. The aggregate thickness of the two Cameo coals and seven minor beds in the 100-foot Cameo zone is 39 feet.

All coals in the Rollins district occur in the Paonia Shale Member. A thick coal usually occurs near the base of the member, and other coals occur in the higher horizons and are more numerous than those in the Palisades district (Figure 4-19). The basal coalbed is difficult to trace, often splitting and coalescing. The higher coals increase in number and thickness to the east. The basal coal varies from 7 to 16 feet in thickness, and at the Kuhnley mine (Sec. 34, T13S, R96W) grades from nearly pure coal through bony coal to carbonaceous shale (Lee, 1912). Approximately one mile northeast, at the Rollins mine (Sec. 35, T13S, R96W), the basal coal is 14 feet thick and of much better quality. At this location, as at many in the district, the upper coals have burned. East of the Rollins mine the upper coals vary in number from one to three, and in thickness from 1.5 to 14 feet. Where exposed, the upper coals average 10 feet in aggregate thickness, but can be as great as 26 feet.

4.2.8 Book Cliffs Coal Field

The Book Cliffs coal field stretches for approximately 50 miles between the Colorado River and the Utah state line on the southern rim of the Piceance Basin (Figure 4-l). Named for the conspicuous Book Cliffs escarpment lying on the north side of the Grand Valley, this coal field occupies approximately 800 square miles in Garfield and Mesa Counties. Coals occur in the Upper Cretaceous Mount Garfield Formation and the Mancos Shale Member of the Mesaverde Group. The coalbeds are mostly flat-lying but in places are tilted and faulted.

Original in-place coal resources (to a depth of 6,000 feet) estimated for the coal field total more that 7.2 billion short tons (Hornbaker et al., 1976). Most coals in the field are high-volatile C bituminous in rank, with some high-volatile B.

Erdmann (1934) published the first complete description of coal resources for the Book Cliffs coal field. Earlier works by Richardson (1907) gave a preliminary description of coals but did not correlate the coal into zones. Much of the stratigraphic correlation work done by Erdmann has been restructured by Young (1955). Young's work does not affect Erdmann's coal descriptions, but redefines stratigraphic units in which the coals occur.

Erdmann divided the coals into four zones. The lowest, the Anchor, occurs in the Anchor Mine tongue of the Mancos Shale which splits the Sego Sandstone into an upper and lower bench. The second coal zone, the Palisade, occurs above the upper bench. of the Sego Sandstone approximately 50 feet above the Anchor coal zone. Cameo occurs immediately above the Rollins Sandstone, 200 to 450 feet above the Palisade zone. The fourth, the Carbonera, occurs 60 feet above the Cameo zone.

Young described the Anchor coal zone as occurring above the upper Sego Sandstone bench. The Palisade zone, according to Young, occurs immediately above the Corcoran Sandstone approximately 160 feet stratigraphically above Erdmann's Palisade coal zone. Young's Cameo coal zone consists of 250 feet of coal-bearing strata lying imnediately above the Rollins Sandstone approximately 250 feet above his Palisade coal zone. This report uses

Erdmann's coal sections and correlation charts in describing coal resources of the Book Cliffs coal field (Figure 4-20).

The lowest of the coal zones, the Anchor, occurs at the top of the Anchor Mine tongue which splits the Sego Sandstone into upper and lower benches. The westward-projecting Anchor coal first appears in the central part of the field and is very irregular in quality and thickness. The coal thickens to the west, with a minable bed appearing near the Anchor No. 1 mine in Sec. 27, T8S,R101W. Near the Anchor No. 1 mine, the coal is up to 6.5 feet thick and has an average thickness of 5 feet. From this location the bed is traceable to the west for approximately nine miles to the vicinity of Sec. 10, T8S, R102W where it disappears (Erdmann, 1934). Several thin local lenses appear at the Anchor zone horizon in the western part of the coal field. The Anchor coal zone has a maximum thickness of 9 feet but is commonly much thinner and contains a high percentage of bony material. The coal has an average rank of high-volatile C bituminous.

The Palisade coal zone occurs immediately above the upper bench of the Sego Sandstone. Coalbeds of the Palisade zone are the most persistent in the Book Cliffs coal field and can be traced from the eastern extent of the field into Utah. The coal zone varies from 30 to 60 feet in thickness and contains at least seven coalbeds. Only three of these beds are represented at any location (Erdmann, 1934). There are several thin, lenticular coals that are not of minable thickness. Most of the major beds are difficult to mine because of local irregularities in thickness due to nondeposition, partings, and rolls in the bed floor. Beds in the western part of the field generally are considered useless became of difficult access and burned zones (Schwochow, 1978).

Palisade coals do not outcrop along the Colorado River on the eastern margin of the coal field because the beds dip below the river level. Just west of the river the coal zone consists of four major beds that have an aggregate thickness of 7 feet. These four beds are traceable along the face of the cliffs to the central part of the field near the Hidden Treasure mine (Sec. 5, T9S, R100W). West of the Hidden Treasure mine the Palisade zone commonly consists of three beds, each 2 or more feet thick, that thin slightly to the west where the aggregate thickness averages approximately 3 feet. In the westernmost part of the coal field the

Palisade coal becomes very thin and outcrops in very inaccessible areas, so that it is of little or no commercial importance. Palisade coal averages high-volatile C bituminous in rank.

The interval between the bases of the Palisade and the Cameo coal zones ranges in thickness from 200 feet in the western part of the field to 450 feet in the eastern part. The Cameo zone can be traced throughout the entire field. It occurs directly above the Rollins Sandstone in the eastern part of the field. West of the Book Cliffs mine (Section 8, T10S, R99W) the Rollins Sandstone is replaced by several thin sandstone beds separated from the base of the Cameo coal by carbonaceous shale and mudstone (Erdmann, 1934).

The Cameo coal tends to be bony and in some locations bony coal dominates the coalbed. The lower beds of the zone are the dirtiest. Cameo coals are also characterized by sandstone "dikes." Heat and pressure generated by the implacement of the sandstone dikes caused local increases in the coal rank. The coal has burned in some areas, as evidened by clinker, ash, and slag.

Along the Colorado River in the eastern portion of the field the Cameo zone consists of a single bed containing up to 11.3 feet of coal, and one or more partings containing from 0.7 to 2.8 feet of bony coal and shale. In the Book Cliffs mine the Cameo coalbed consists of two benches that have a total coal thickness of 7.5 feet. The benches are separated by about 1 foot of bony coal. The Book Cliffs mine caught fire in 1923 and was finally abandoned in 1924.

The Cameo coals are thickest in the central portion of the field, often characterized by two beds separated by a thick sandstone unit. The beds have an aggregate thickness of from 8 to 23 feet. The coal is burned along much of the outcrops which occur high on the cliffs and is partially covered by talus. The beds thin to the west, and in the vicinity of the Utah state line vary from 1 to 3.5 feet thick (Figure 4-21).

Youngest of the coal zones, the Carbonera occurs approximately 60 feet stratigraphically above the base of the Cameo coal zone. The zone is characterized by two and sometimes three coalbeds. The coals have been heavily

develooed in the western portion of the field. As with the Cameo coals, the Carbonera coals have been burned and are difficult to trace in some parts of the field. The Carbonera zone consists of a series of detached coalbeds that have been correlated based principally on the character and stratigraphic position of the coals. The Carbonera coals diminish in number and thickness from west to east, and pinch out entirely before the Colorado River on the eastern margin of the field.

Near the Book Cliffs mine a zone of carbonaceous shale occurs about 80 feet above the top of the Cameo zone. Erdmann (1934) states that there may be from two to four thin coals that probably are equivalent to the Carbonera coal zone. Near the central part of the field, at the Buniger mine (Sec. 1, T8S, R102W), the Carbonera coal zone consists of three beds 2, 3, and 7 feet thick that occur 65 feet above the Cameo coal zone. The coals are not traceable very far in any direction.

In the western part of the field the Carbonera coalbeds thicken dramatically in T7S, R102W and thin again to the west. In T7S, R102W the Carbonera coal zone consists of two or three lenticular and overlapping coalbeds that occur from 40 to 110 feet above the Cameo coal zone. The coals vary in thickness from 1 to 5 feet and have an average aggregate thickness of 7 feet. North of the abandoned town of Carbonera, two coals from this zone outcrop, 13 and 7 feet thick, separated by 30 feet of carbonaceous shale. The coals have burned north of Carbonera.

Gualtieri (1979) describes the occurrence of coal in a USGS exploration drillhole located in the westernmost part of the Book Cliffs field. The drillhole, USGSCBBC1, is situated in an unmapped portion of the field in T7S, R104W. A total of 26 coalbeds having an aggregate thickness of 34 feet were logged at this location. Only one bed greater than 5 feet thick was identified in this drillhole.

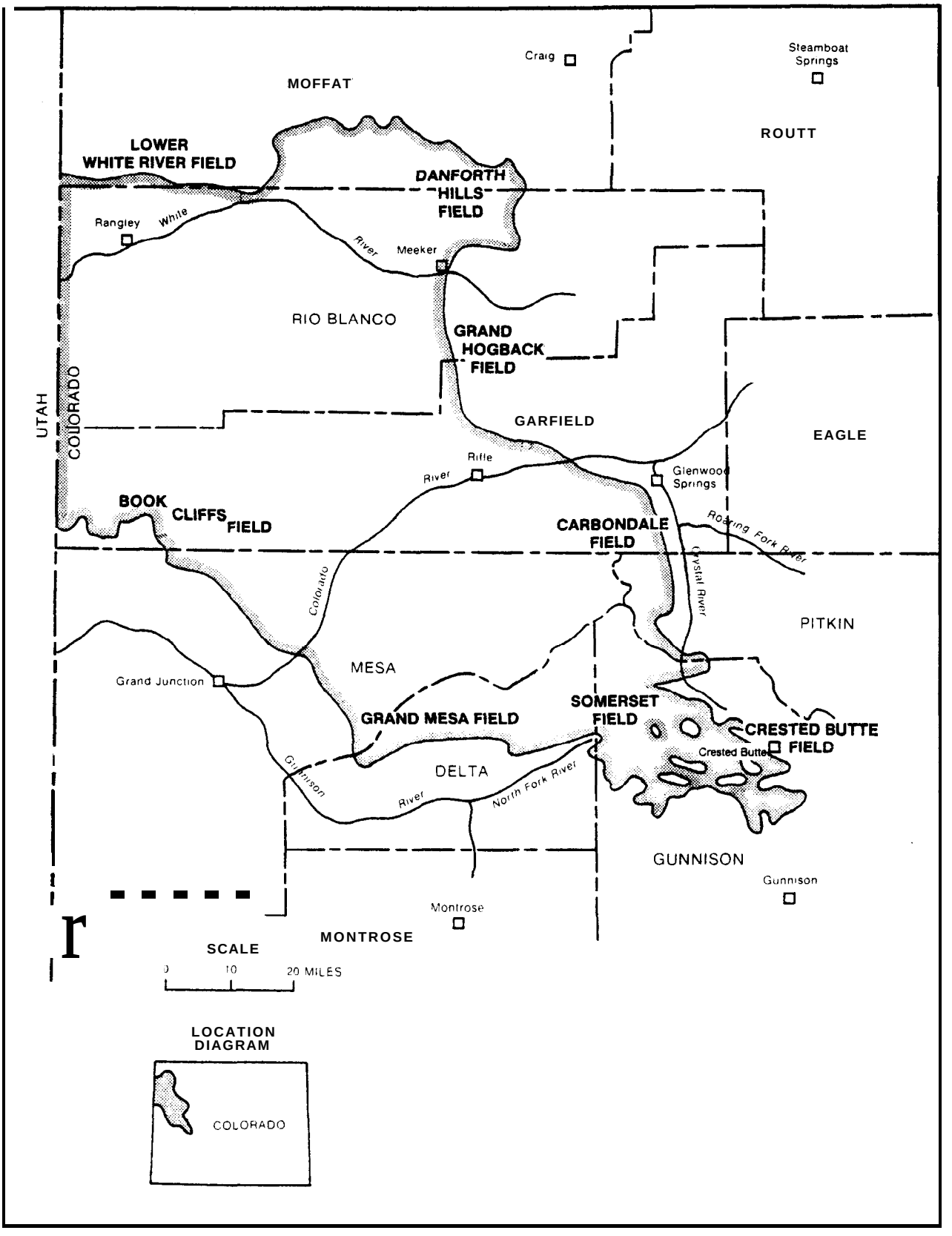


Figure 4-1. Coal Fields of the Piceance Basin

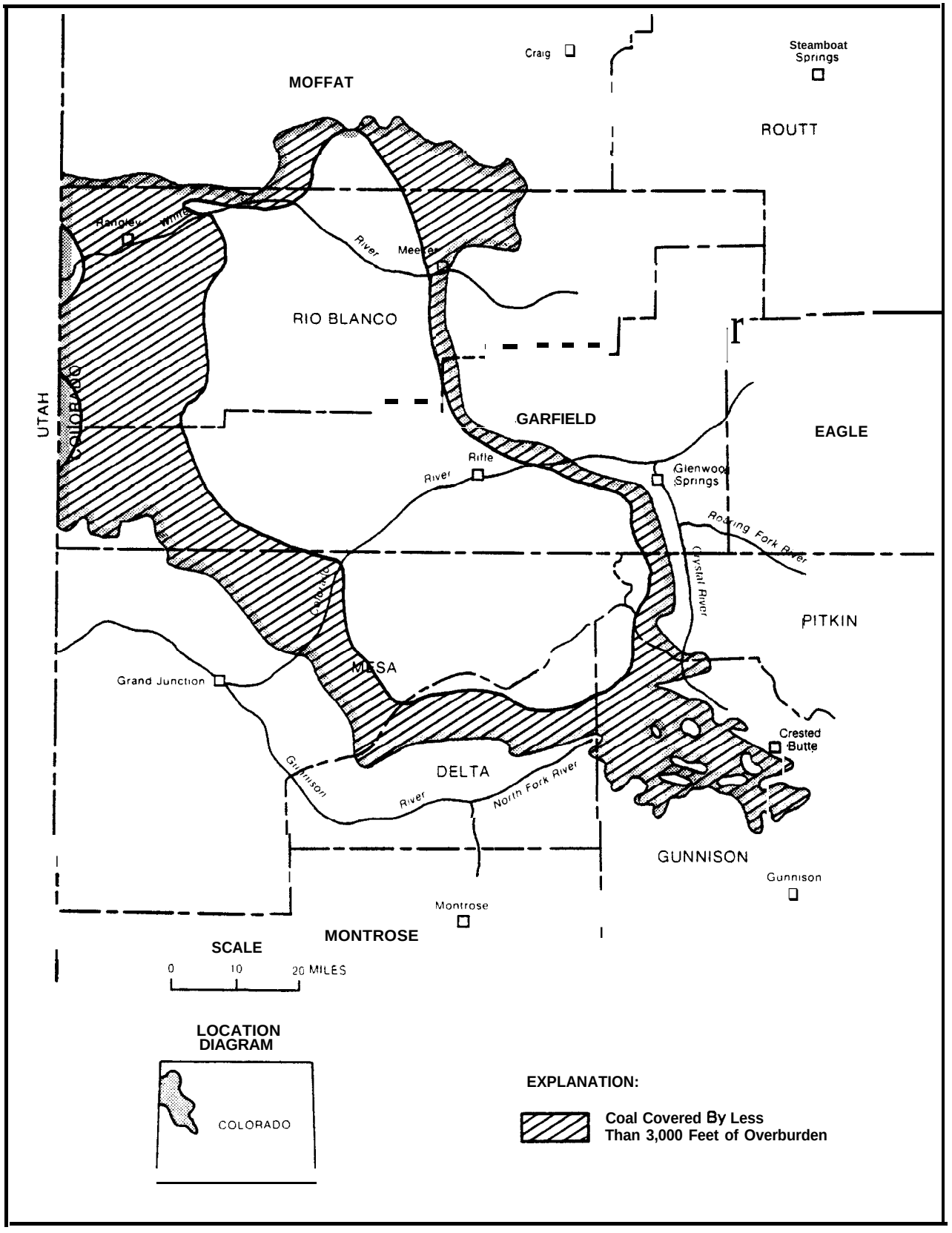
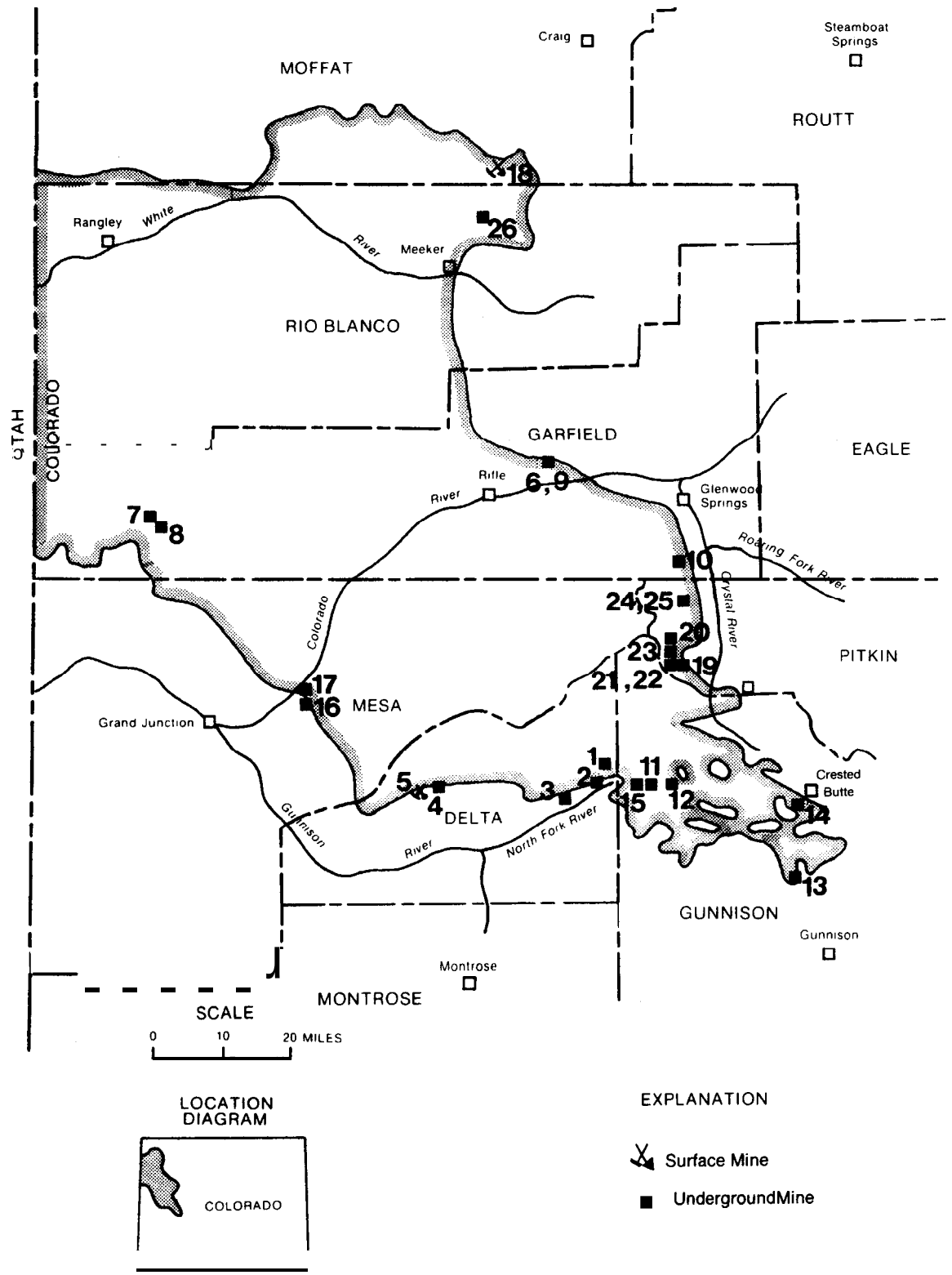


Figure 4-2. Map of the Piceance Basin Showing Areas where Coal Is Covered by Less than 3,000 Feet of Overburden



COAL MINE INFORMATION

MINE NAME (Section, Township, Range)
Coal-bearing bed, formation/ thickness (ft)/ rank* (use)**
No. employees (May '78)/ 1977 avg. daily prod. (S.T.)/ 1977 prod (S.T.)/ cum. prod. (S.T.) to 6/1/78

*rank: SB = Subbituminous; B = Bituminous; A = Anthracite
**use: C = coking; D = domestic; S = steam

DELTA COUNTY

1. Blue Ribbon (Sec 2,T13S,R91W)
"E", Mesaverde/6'/B (S)
8/ 260/ 16,640/ 52,445

2. King (Sec 15,T13S,R91W)
Uncorrelated, Mesaverde/16'/B (S)
0/ 0/ 0/ 2,996,239

3. Orchard Valley (Sec 24,T13S,R92W)
"B", Mesaverde/17.3'/B (S)
150/ 1,100/ 286,129/ 421,300

4. Red Canon No. 1 (Sec 12,13,T13S,R95W)
Unknown ("E" or Rollins), Mesaverde/4'/B (S)
0/ 2/ 412/ 233,852

5. Tomahawk Strip (Sec 9,15,16,T13S,R95W)
"A","B","C","D","E""F", Mesaverde/11.5'/B (S)
7/ 125/ 24,174/ 144,048

GARFIELD COUNTY

6. Eastside (Sec 24,T5S,R92W)
"E", Williams Fork/12.5'-16'/B (S)
1/ 2/ 257/ 378

7. McClane Canyon (Sec 21,T7S,R102W)
-,- / - / -
4/ 405/ 47,816/ 47,816

8. Munger Canyon (Sec 27,T7S,R102W)
-,- ' - ' - (S)
43/ 419/ 20,531/ 93,230

9. Nu-Gap No. 3 (Sec24,T5S,R92W)
Sunnyridge,Williams Fork/6.5'/B (S)
1/ 2/ 397/ 6,316

10. Sunlight (Sec 34,T7S,R89W)
"D","A","C", Mesaverde/D,A=9';C=7.5'/B (S)
0-3/ 7/ 1,792/ 176,053

GUNNISON COUNTY

11. Bear (Sec 9,16,T13S,R90W)
"Juanita C",lower.Mesaverde/7'-12'/B (ε)
58/ 992/ 226,221/ 3,776,279

12. Hawks Nest East (Sec 11,T13S,R90W)
"B", Mesaverde/9'/B(ε)
143/9 0 6 T190,350/1,227,319

13. O. C. Mine No. 2 (Sec 16,T15S,R86W)
"C" Kubler, Mesaverde/5.5'-6.0'/B(8)
S 118/3,696/6 S.S O T

14. Peanut (Sec 28,T13S,R86W)
- , -/"thin"/A (-)
0/ 0/ 0/ 0

15. Somerset (Sec 8,T13S,R90,91 W)
"B" Bear Seam, Mesaverde/12' mined/B (C)
298/ 3,644/ 914,552/ 18,965,202

MESA COUNTY

16. Cameo (Sec 27,28,33,34,T10S,T98W)
Cameo "B", Mesaverde/6'-9.5'/B (S)
0/ 0/ 0/ 4,216,274

17. Roadside (CMC mine)(Sec 34,T10S,R98W)
Cameo "B", Mesaverde/6.7'-7'/B (S)
149/ 1,215/ 300,199/ 936,499

MOFFAT COUNTY

18. Colowyo Strip(Red Wing mine)(Sec 2,3,4,9,T3N,R93W)
"X","Y","A"-"F",Williams Fork/10 beds 59.4'/B,SB (S)
275/ 891/ 290,531/ 4,652,112

PITKIN COUNTY

19. Bear Creek (Sec 21,T10S,R89W)
Coal Basin "B", Mesaverde/7'/B (C)
51/ 229/ 58,352/ 742,422

20. Coal Basin (Sec 5,T10S,R89W)
Coal Basin "B"&"C", Mesaverde/7'/B (C)
86/ 483/ 123,182/ 1,517,829

21. Dutch Creek No. 1 (Sec 17,T10S,R89W)
Coal Basin "B" or Dutch Creek,Mesaverde/7'/B (C)
114/ 884/ 232,481/ 6,064,721

22. Dutch Creek No. 2 (Sec 17,T10S,R89W)
Dutch Creek, Mesaverde/7'/B (C)
86/ 816/ 208,142/ 1,309,477

23. L. S. Wood (Sec 8,T10S,R89W)
Coal Basin "B", Mesaverde/7'/B (C)
109/ 1,170/ 298,405/ 1,067,076

24. Thompson Creek No. 1 (Sec 34,T8S,R89W)
"A" and "B", Mesaverde/8'/B (C)
81/ 30/ 7,455/ 1,094,620

25 Thompson Creek No. 3 (Sec 34,T8S,R89W)
Sunshine, Mesaverde/9',1'-7',3'-5.5'/B (C)
94/ 33/ 8,413/ 685,370

RIO BLANCO COUNTY

26. Rienau No. 2 (Sec 29,T2N,R93W)
Rienau, Mesaverde/20'-24'/B (S)
0/ 36/ 8,836/ 10,542

Figure 4-3. Licensed Coal Mines in Piceance Basin as of June 1, 1978 (Modified from Goolsby and Reade, 1978)

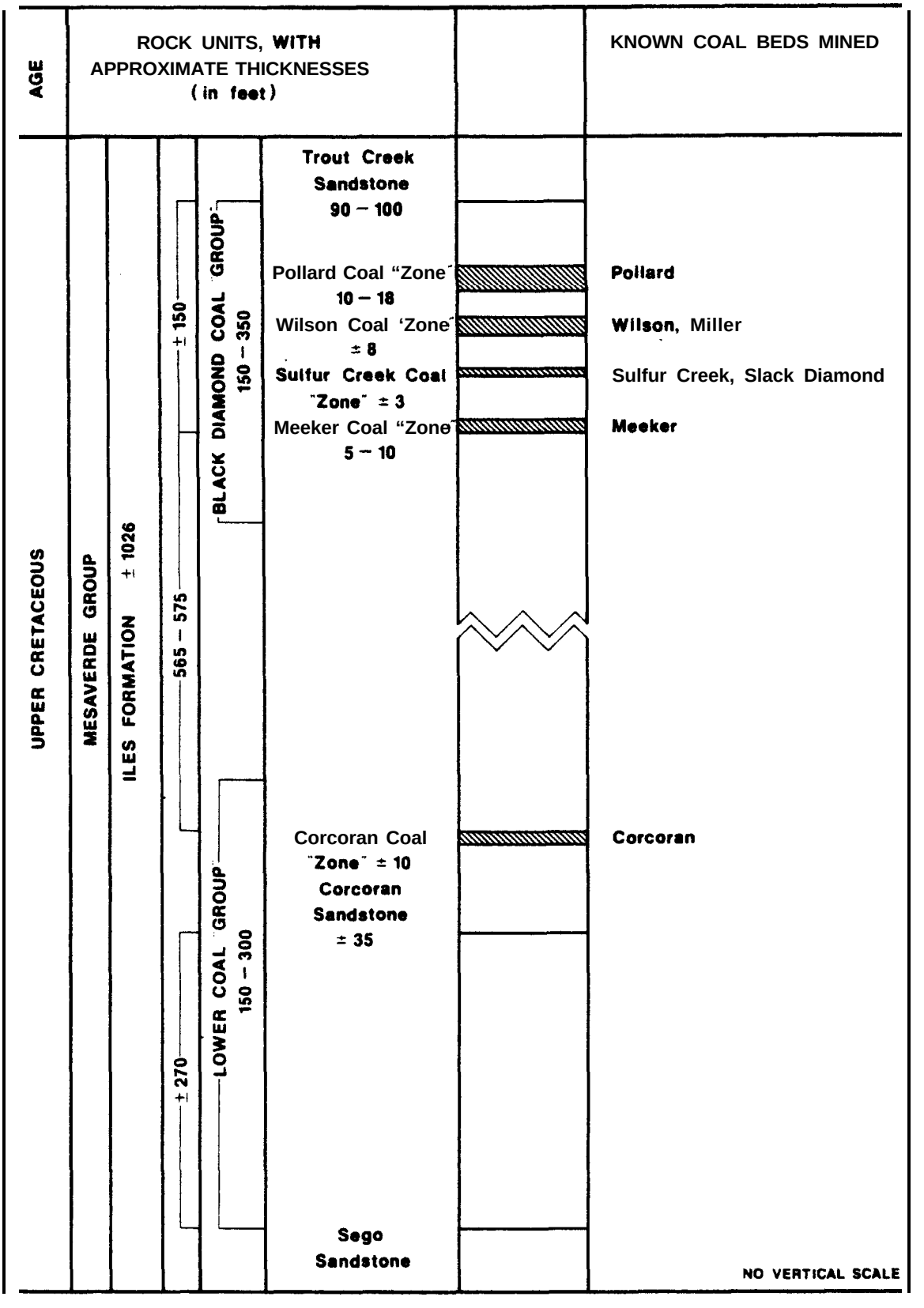


Figure 4-4. Coal Zone and Coalbed Stratigraphy of the lies Formation, Danforth Hills Field, Colorado (Boreck and Murray, 1979)

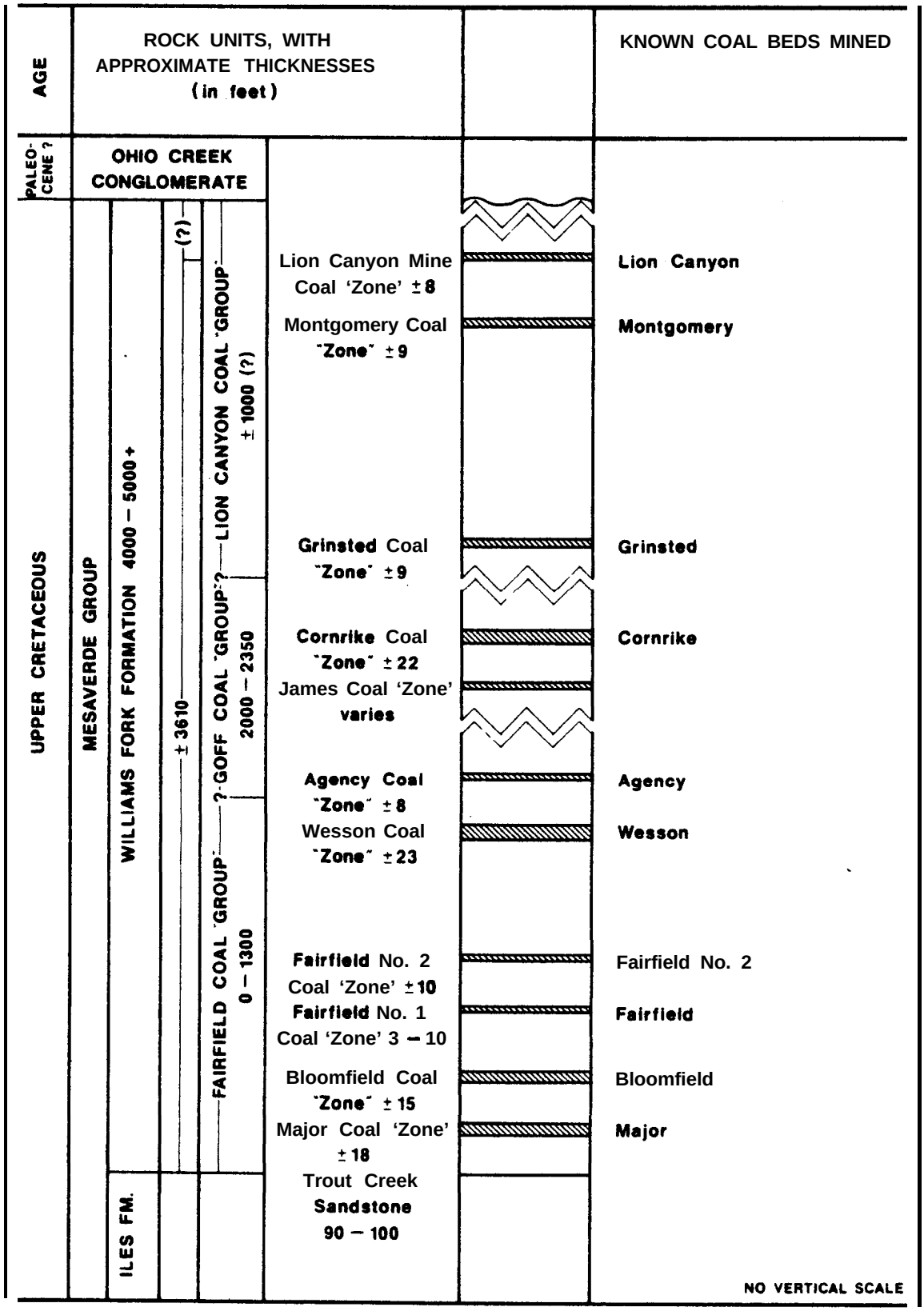


Figure 4-5. Coal Zone and **Coalbed** Stratigraphy of the Williams Fork Formation, **Danforth** Hills Field, Colorado (Boreck and Murray, 1979)

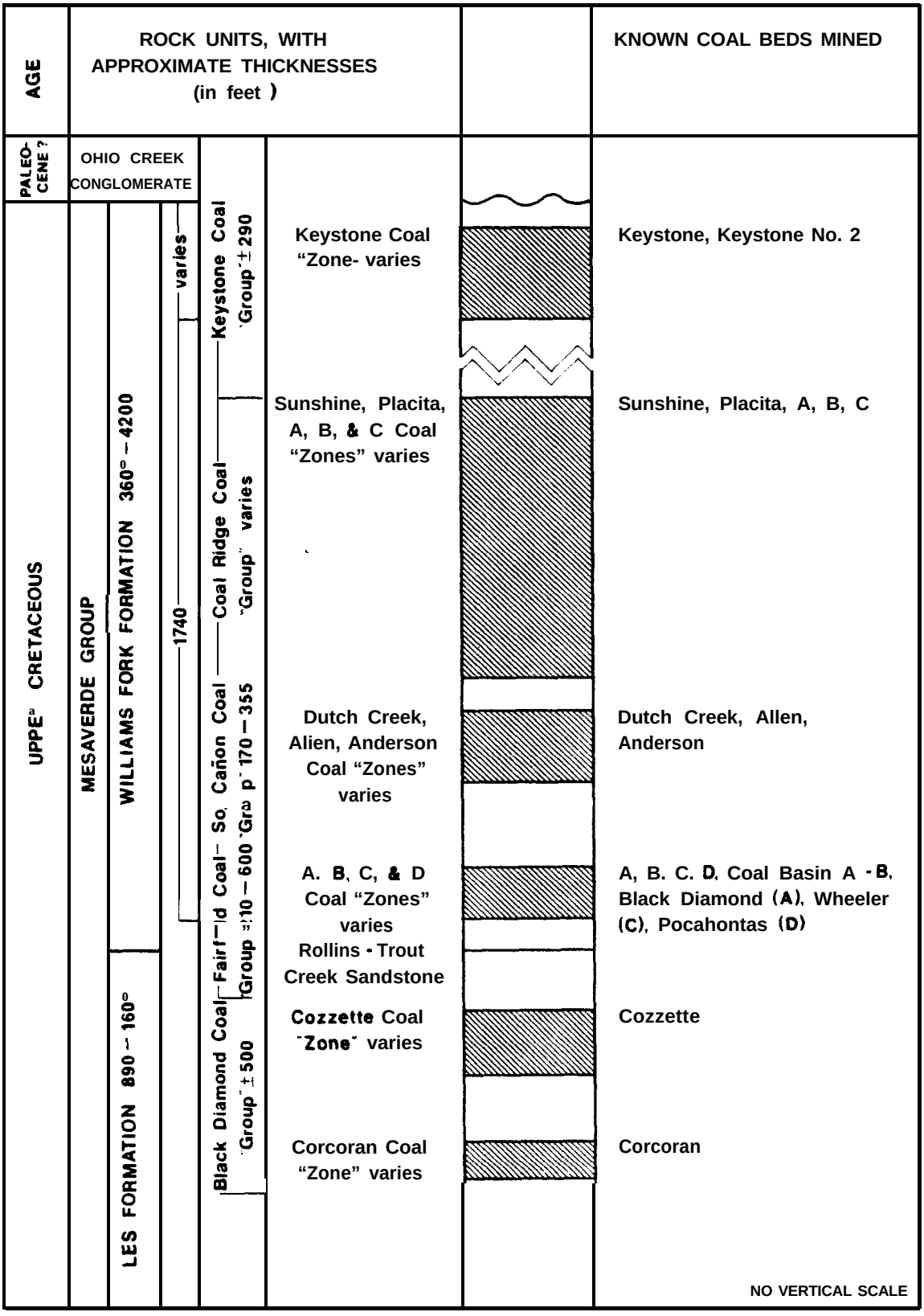


Figure 4-6. Coal-Bearing Formations, Coal Zone, and Coalbed Stratigraphy of the Grand Hogback and Carbondale Fields, Colorado (Boreck and Murray, 1979)

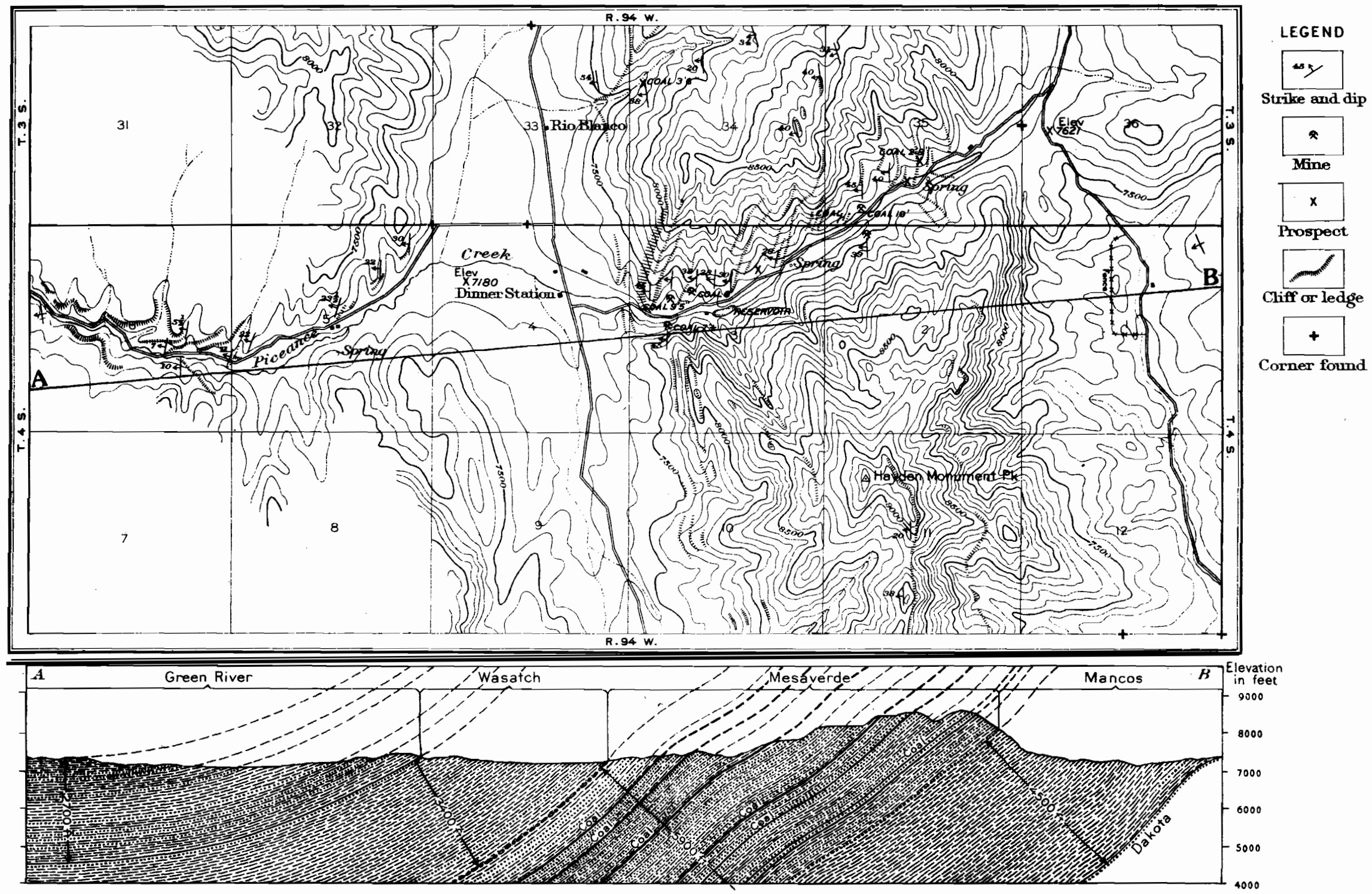


Figure 4-7. Topographic Map and Structure Section of Piceance Gap Locality, Colorado (Gale, 1910)

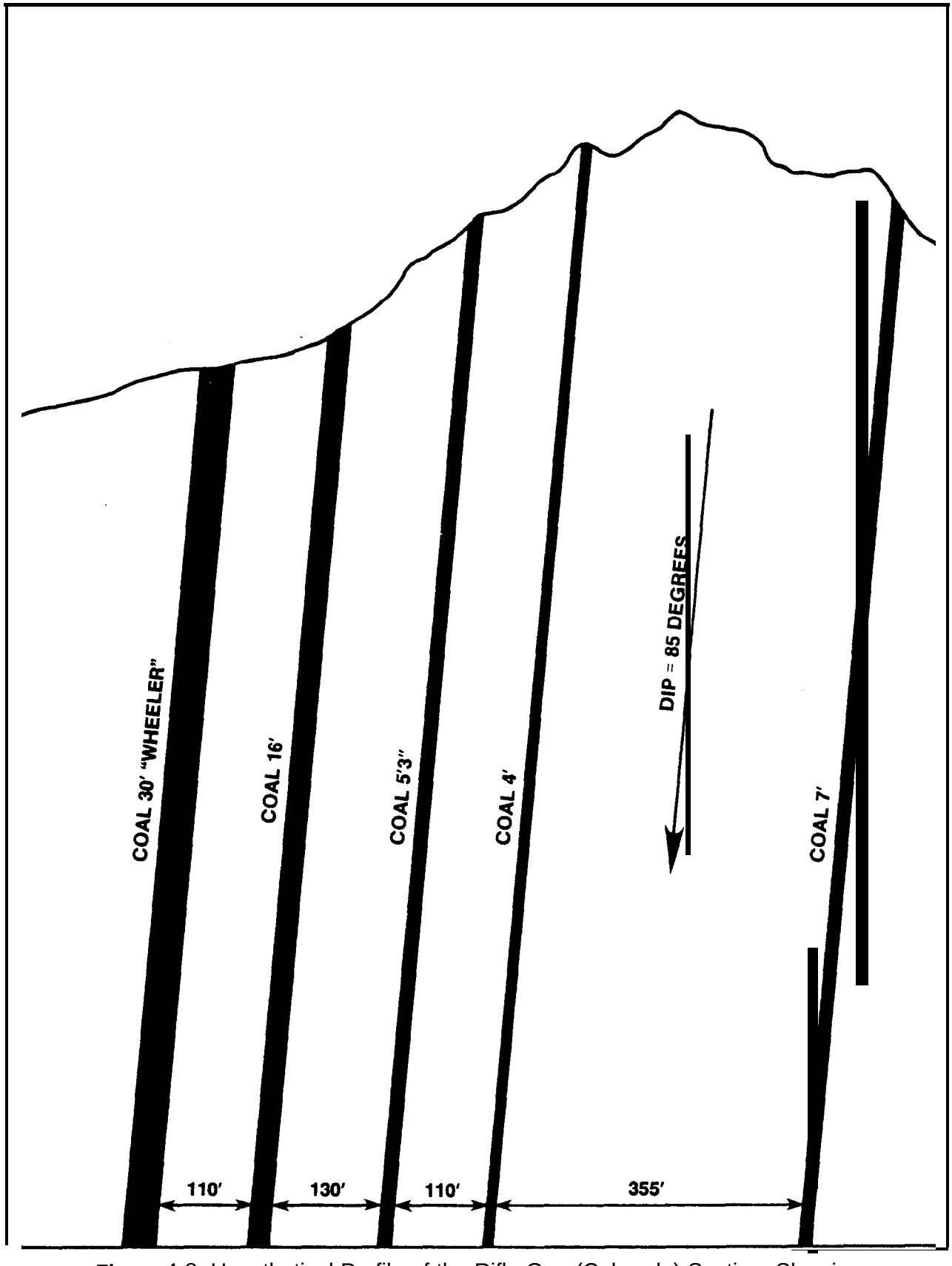
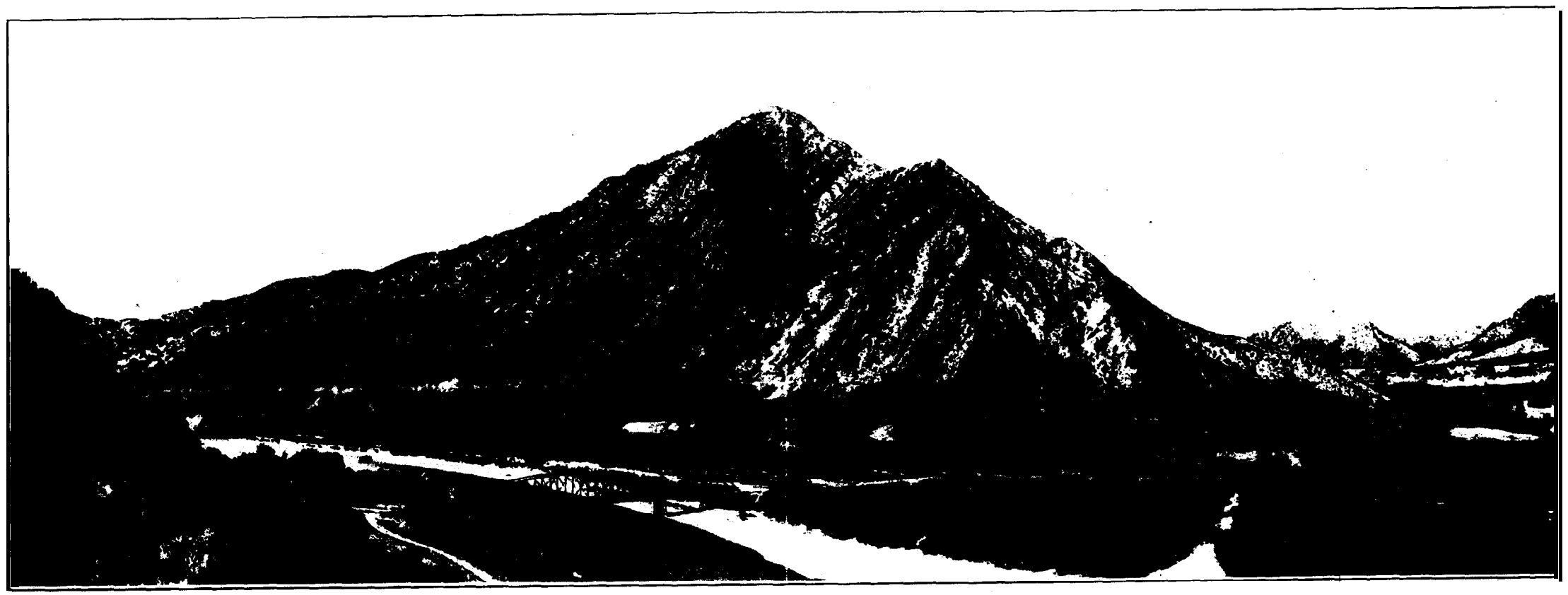


Figure 4-8. Hypothetical Profile of the Rifle Gap (Colorado) Section, Showing Measured Intervals Between the Various Coalbeds (Gale, 1910)



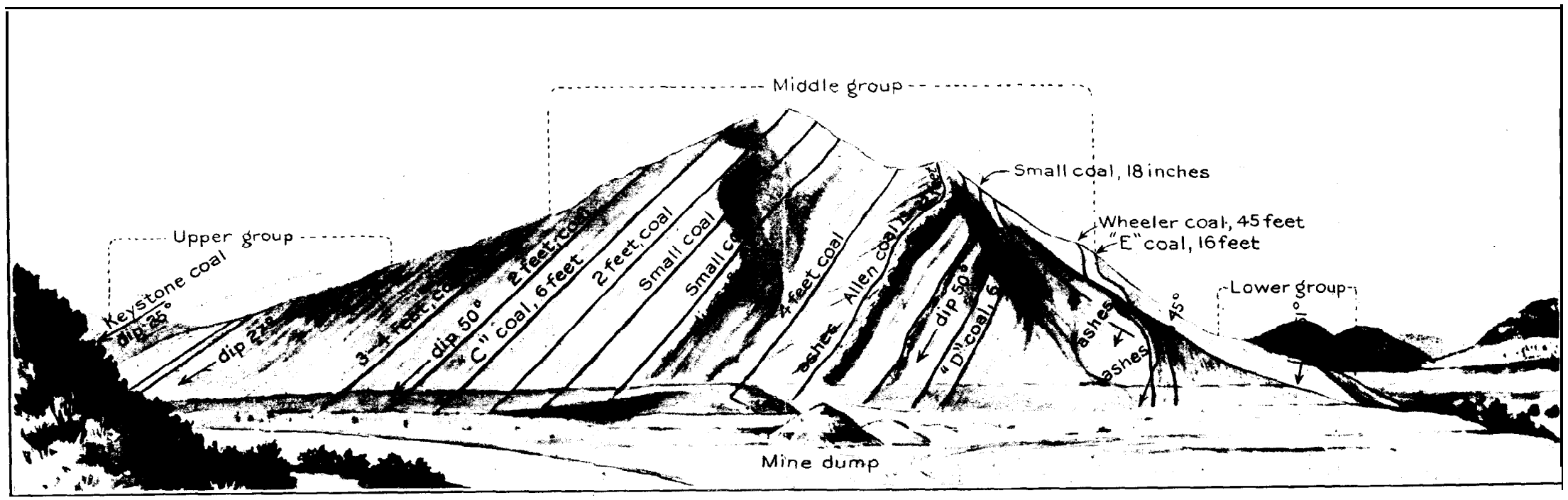


Figure 4-9. Mesaverde Group Stratigraphic Section at Newcastle, Colorado, Showing Position of Coalbeds (Gale, 1910)

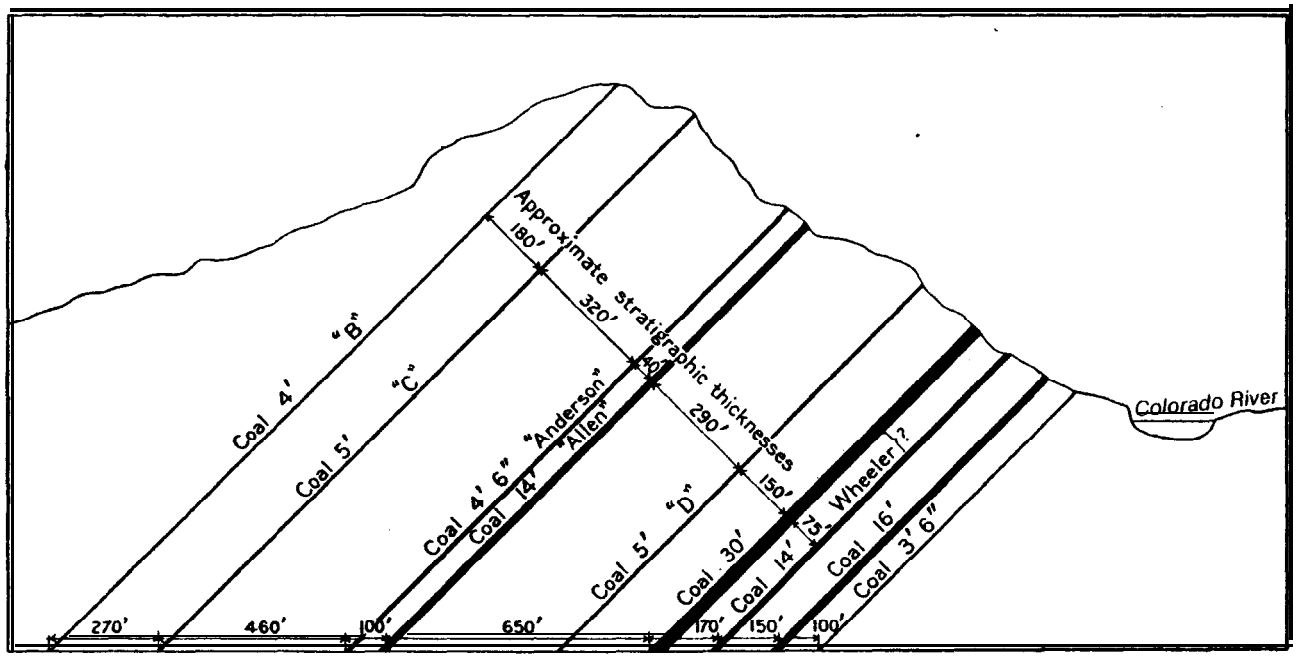


Figure 4-10. Hypothetical Profile of Section of South Canyon, Colorado, Showing the Measured Intervals Between the Various **Coalbeds** (Gale, 1910)

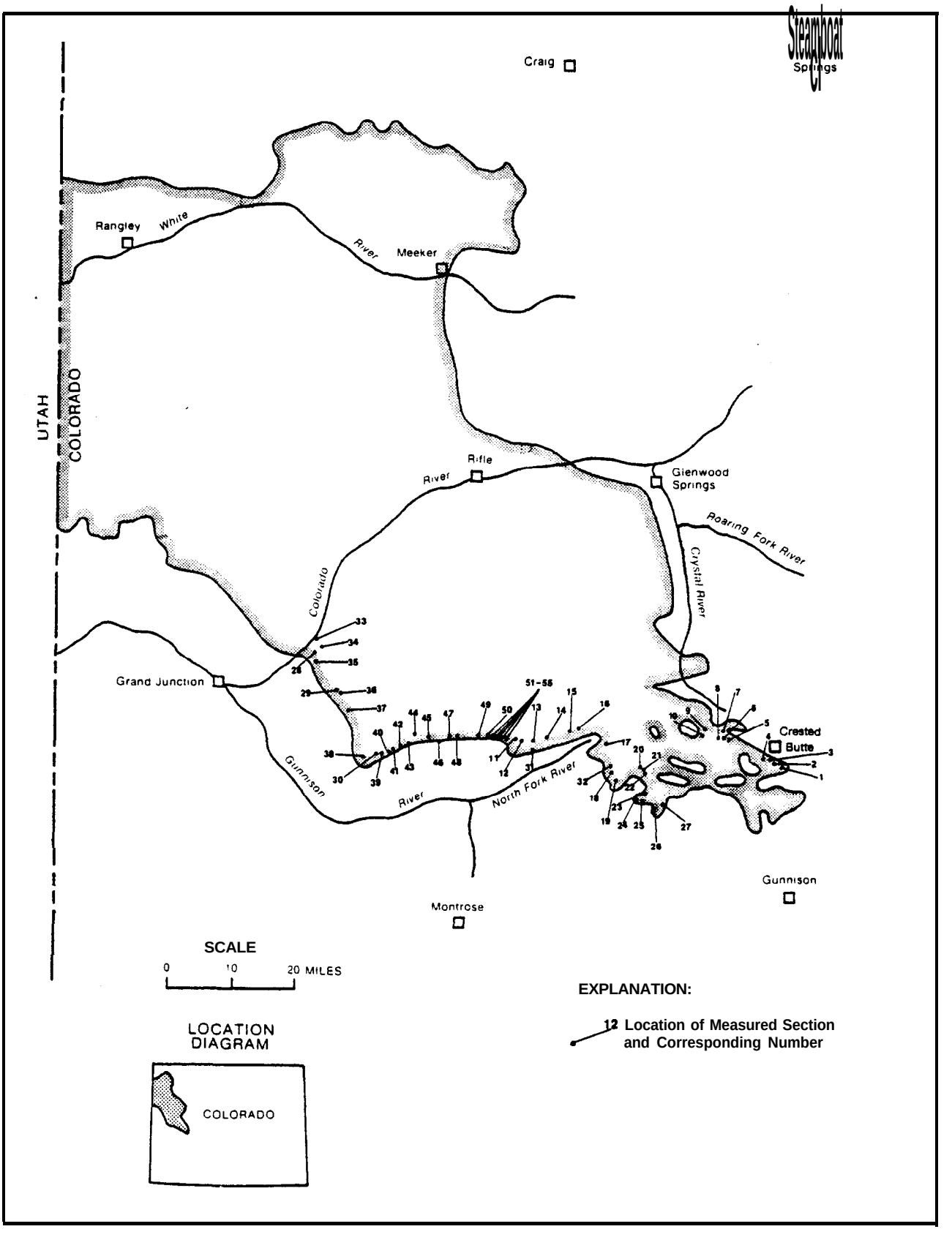


Figure 4-11. Map of the Piceance Basin Showing the Location of Measured Sections Depicted in Figures 4-12 and 4-15 through 4-19

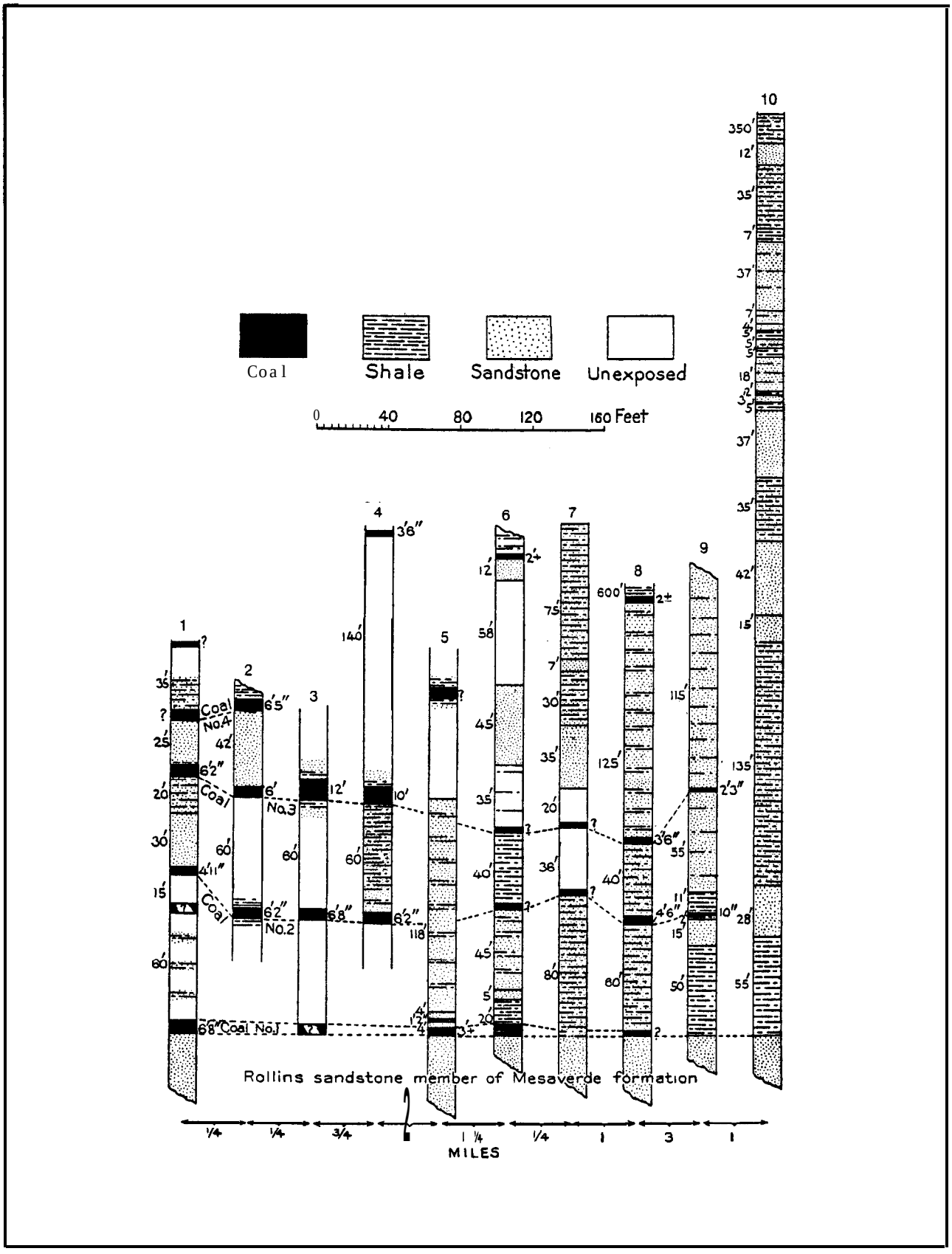


Figure 4-12. Columnar Sections of Coal-Bearing Rocks Measured in the Crested Butte Coal Field (Lee, 1912). Reference Figure 4-11

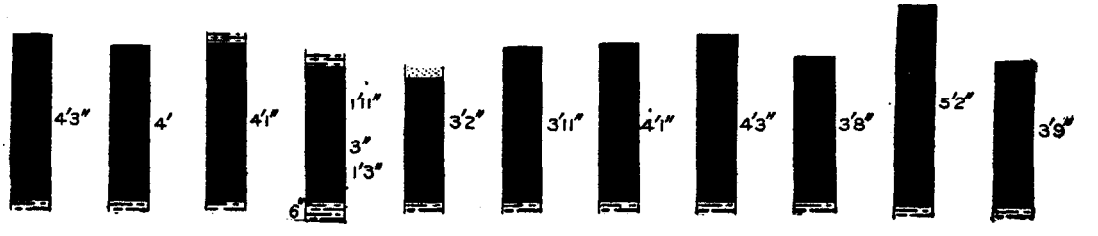


Figure 4-13. Sections of Coal Measured at the Outcrop in the Floresta District of the Crested Butte Field in Order from West to East (Lee, 1912)

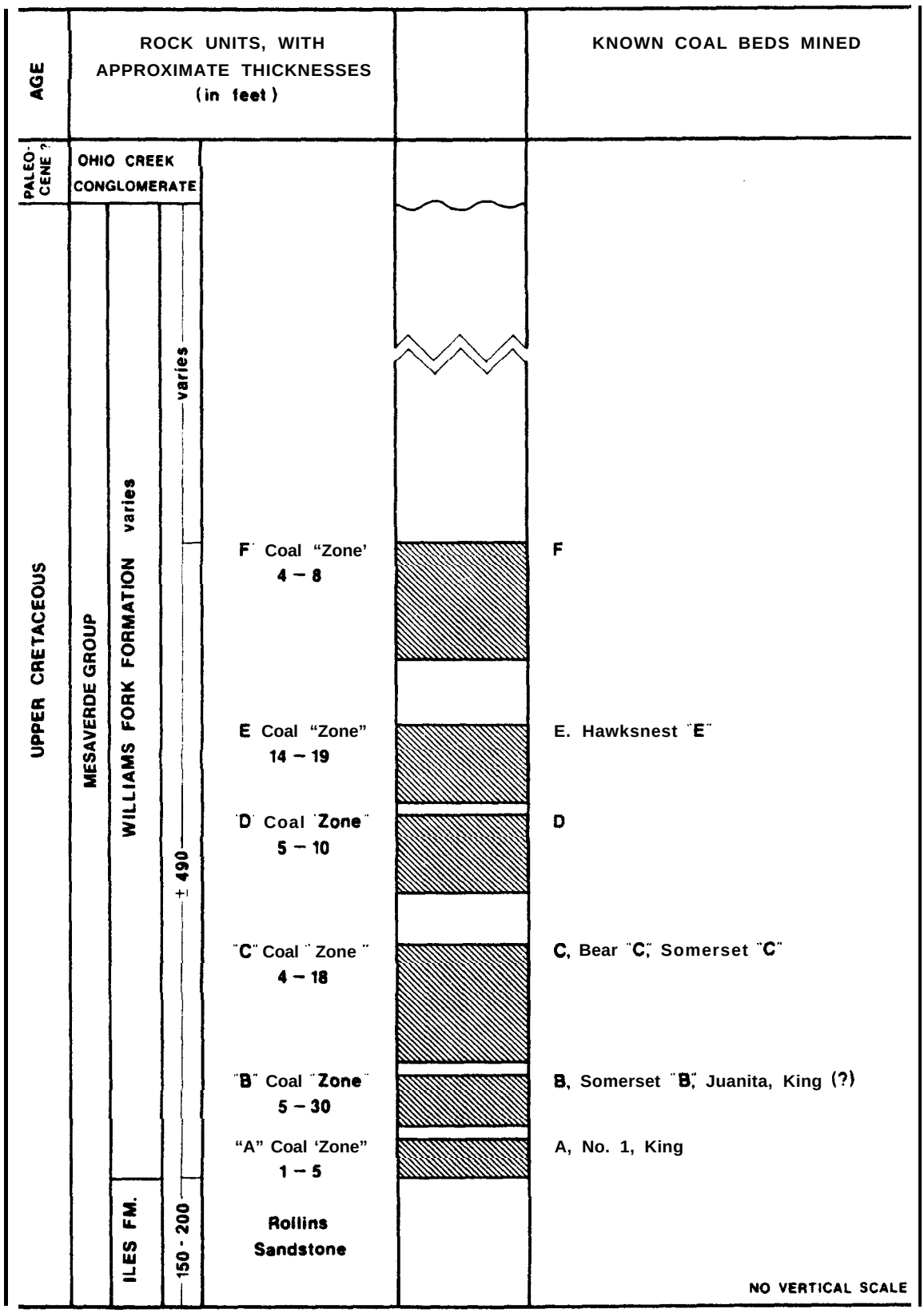


Figure 4-14. Coal-Bearing Formations, Coal Zone, and Coalbed Stratigraphy of the Somerset Field, Colorado (Boreck and Murray, 1979)

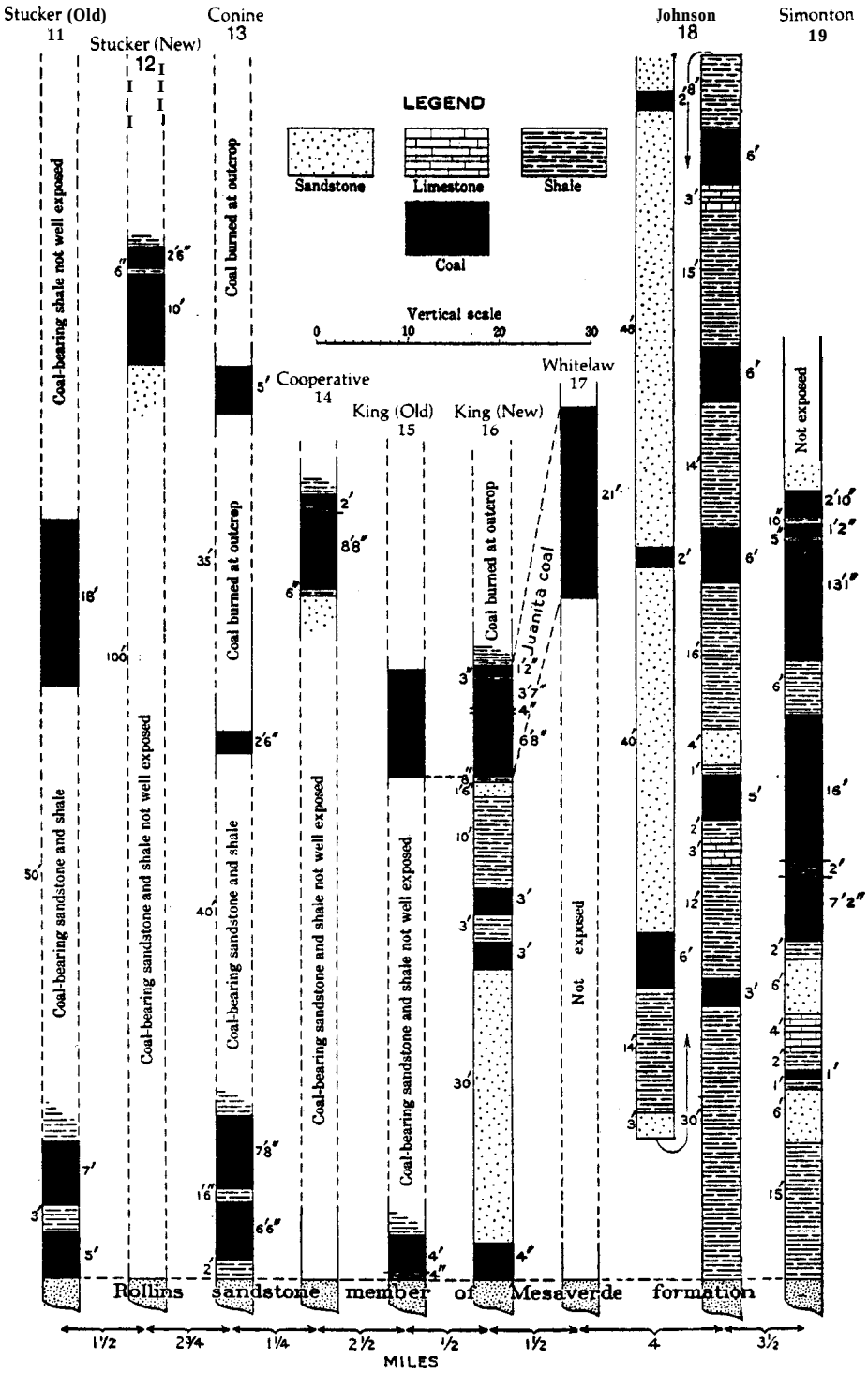


Figure 4-15. Columnar Sections of the Coal-Bearing Rocks in the Somerset District Colorado (Lee, 1912). Reference Figure 4-l 1

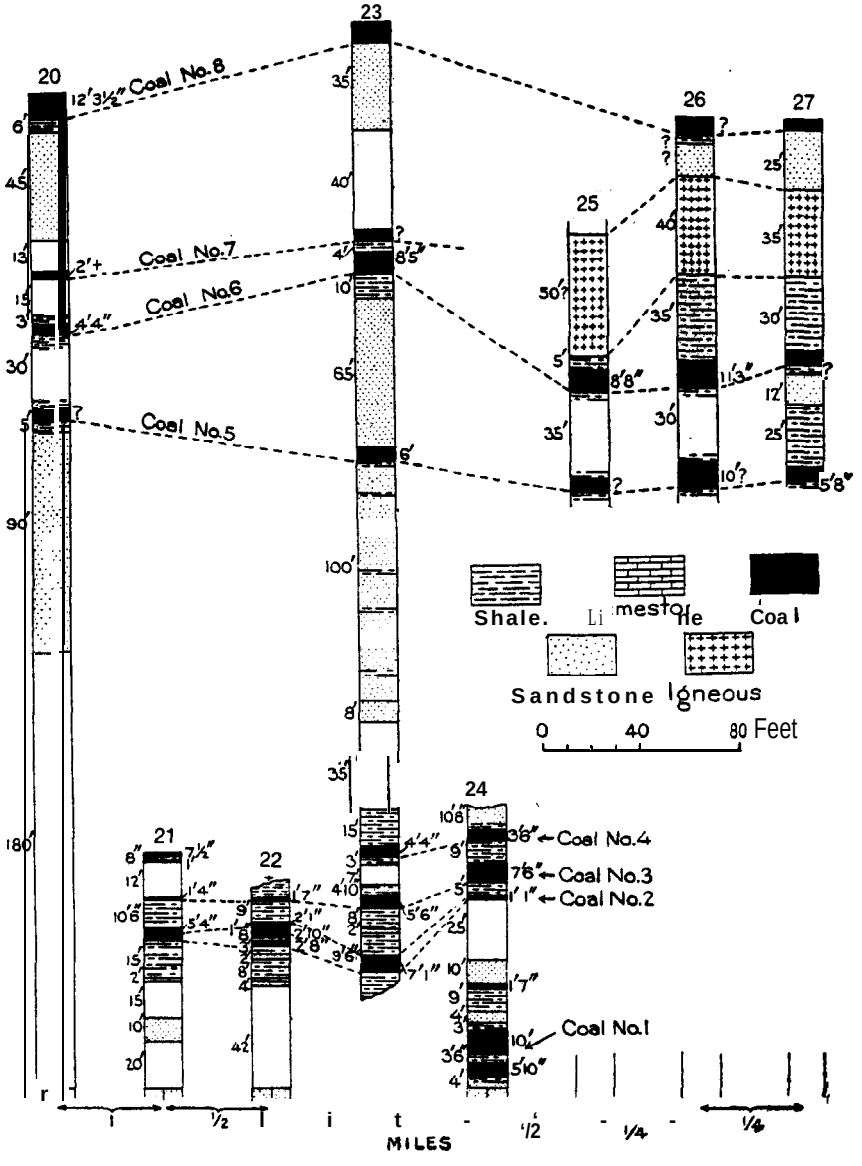


Figure 4-16. Columnar Sections Measured in the Coal Creek District of the Somerset Field Showing The Occurrence and Correlation of the **Coalbeds** (Lee, 1912). Reference Figure 4-l 1

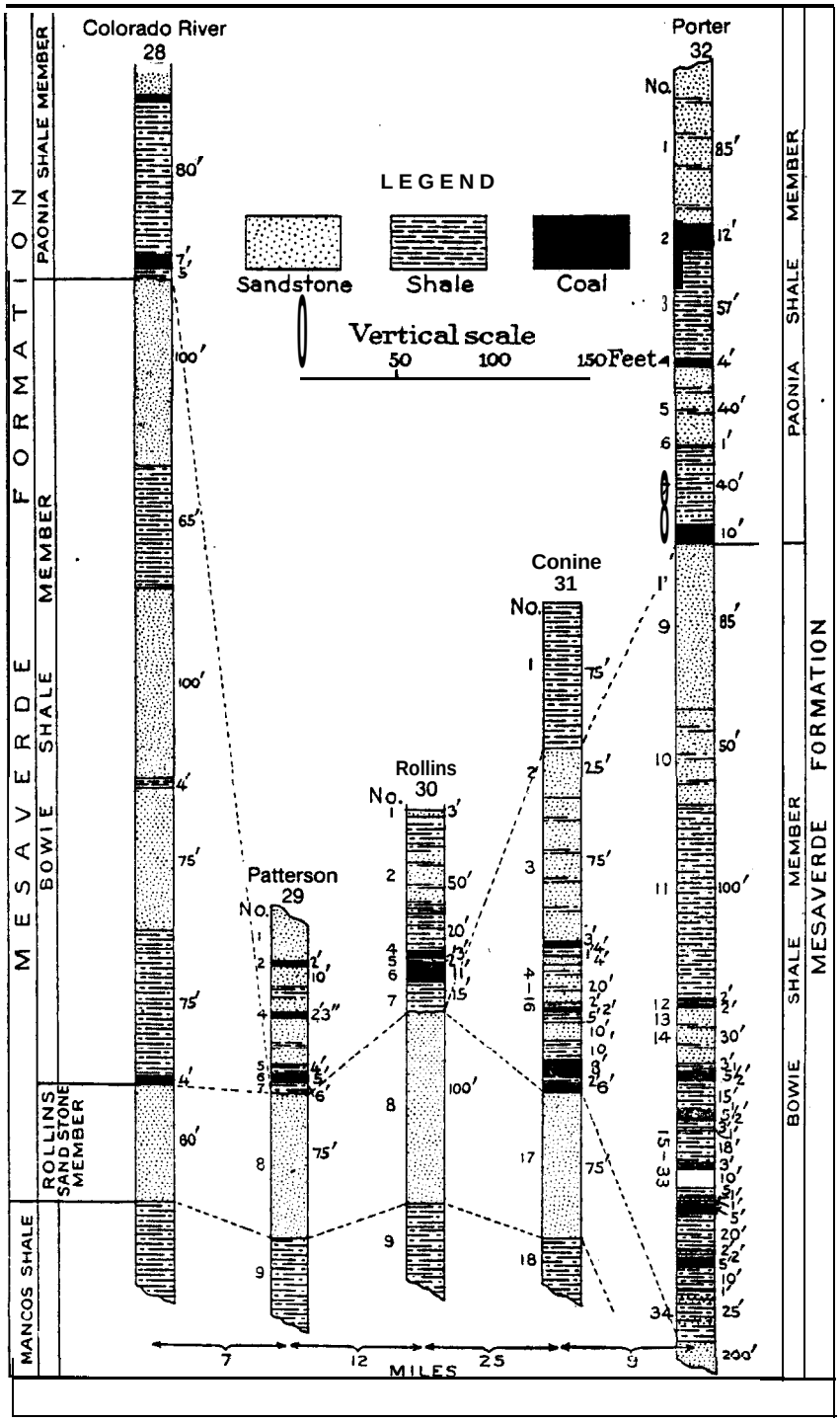


Figure 4-17. Detailed Columnar Sections of the Coal-Bearing Part of the Mesaverde Formation in the Grand Mesa and Somerset Fields as identified by Lee (1912). Reference 4-l 1

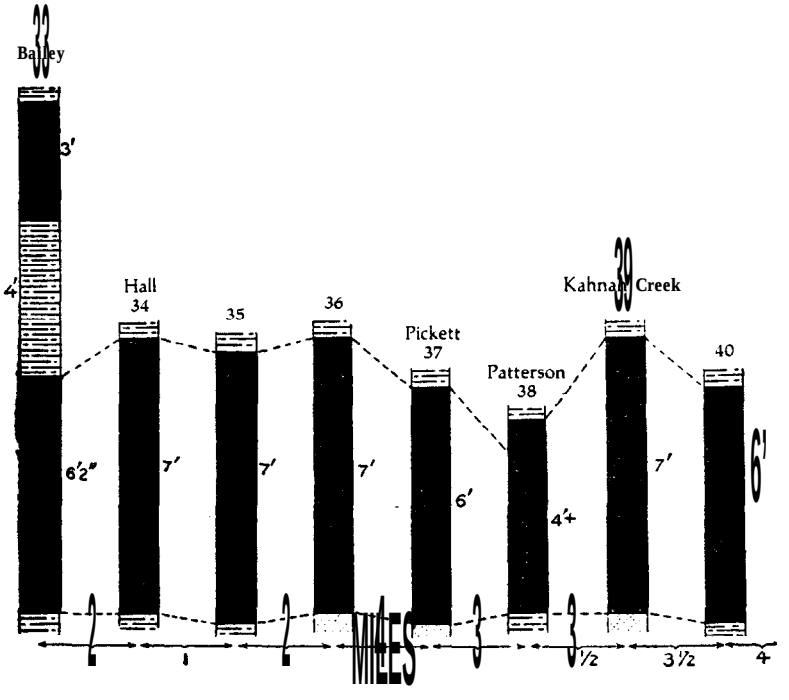


Figure 4-18. Sections of Coal Measured by Lee (1912) in the Palisades District of the Grand Mesa Field. Reference Figure 4-11

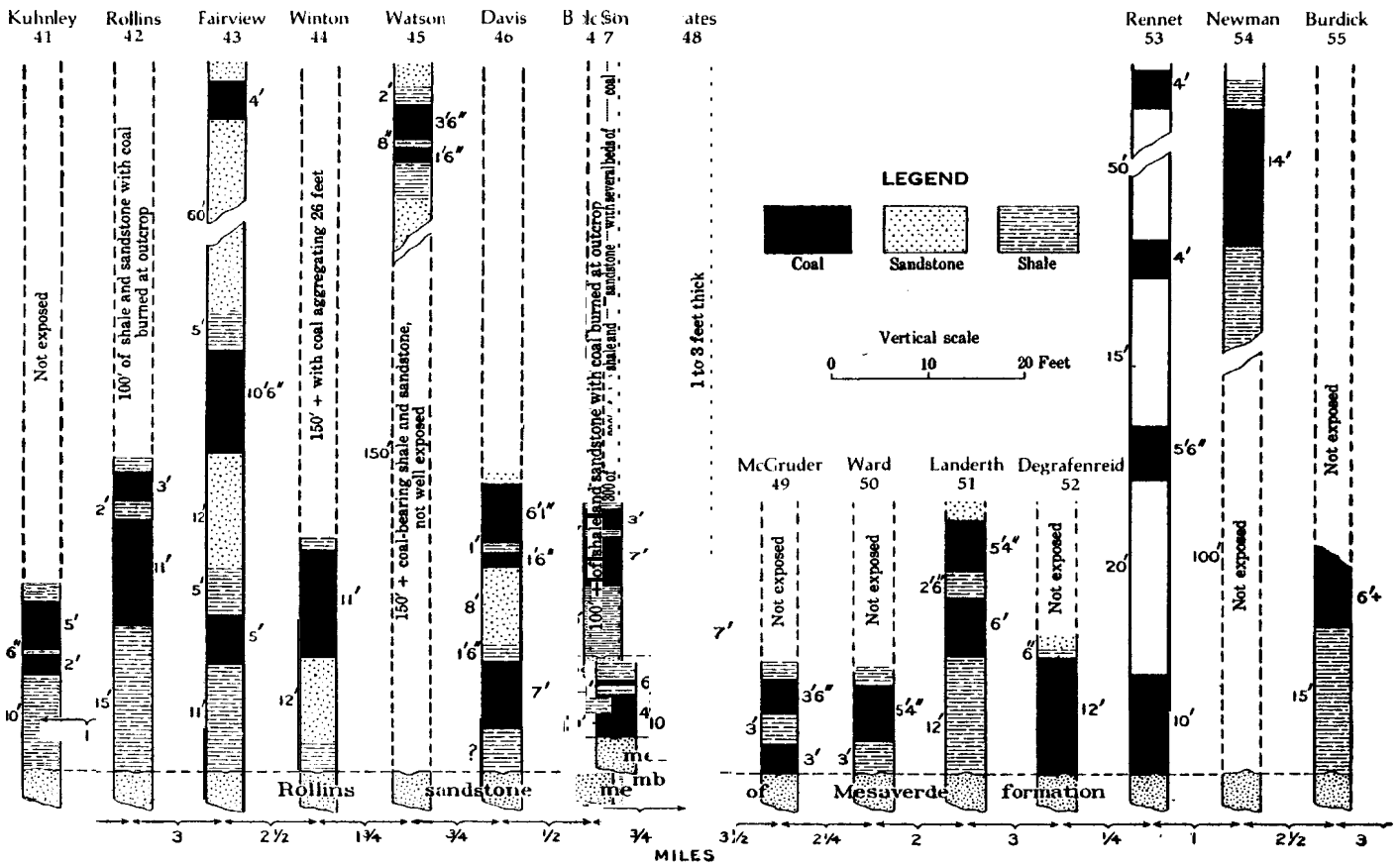


Figure 4-19. Sections of Coal-Bearing Rocks in the Rollins District of the Grand Mesa Coal Field (Lee, 1912). Reference Figure 4-11

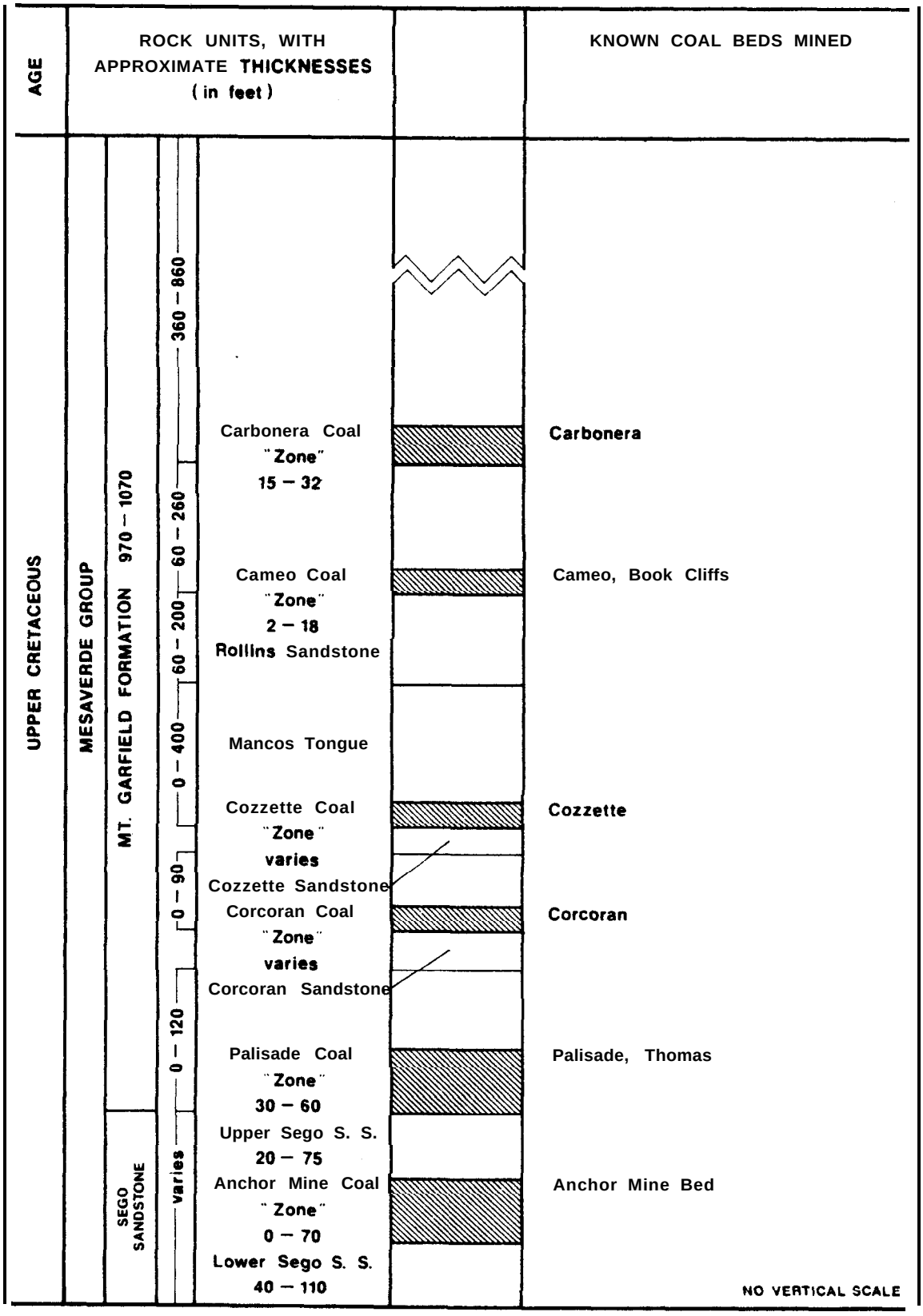


Figure 4-20. Coal-Bearing Formations, Coal Zone, and Coalbed Stratigraphy of the Book Cliffs Field, Colorado (Boreck and Murray, 1979)

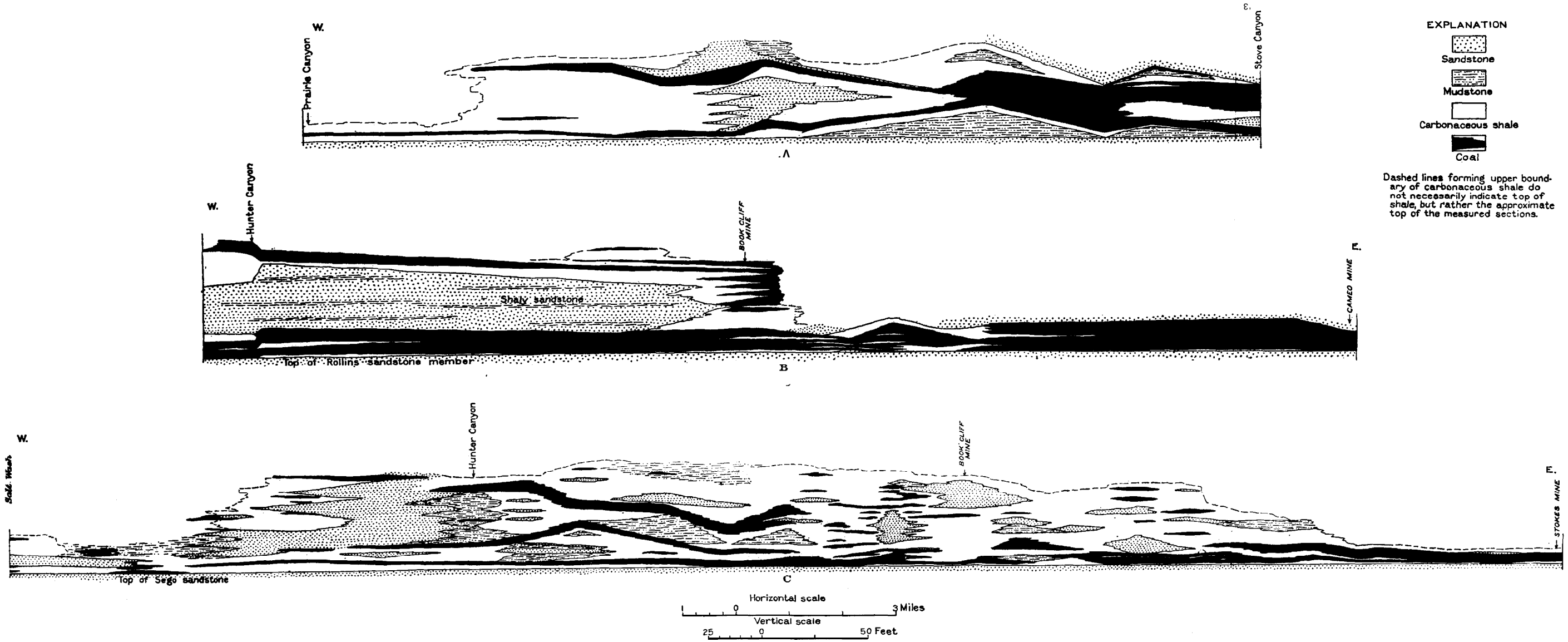


Figure 4-21. Diagrammatic Sections of Coal Zones in Book Cliffs Field (Erdmann, 1934)

Table 4-1. Original Coal Resources of the Piceance Basin (Hornbaker, et al., 1976)

COAL FIELD	ORIGINAL COAL RESOURCES UNDER LESS THAN 6,000 FEET OF OVERBURDEN (MILLIONS TONS)	ORIGINAL COAL RESERVES UNDER LESS THAN 3,000 FEET OF OVERBURDEN (MILLIONS TONS)		
		Anthracite	Bituminous	Subbituminous
Book Cliffs	7,200	—	2,294	—
Grand Mesa	8,800	—	139	1,430
Somerset	8,000	—	3,348	—
Crested Butte	1,580	37	207	—
Carbondale	5,200	53	745	—
Grand Hogback	3,000	—	885	—
Danforth Hills	10,500	—	7,854	—
Lower White River	11.780	—	7,013	—
TOTAL	55,820	90	41,893	1,430

Table 4-2. identified Original In-Place Coking-Coal Reserves in the Grand Hogback, Carbondale, Crested Butte, and Somerset Coal Fields, in the Piceance Basin, Colorado (Goolsby, et al., 1979)

Coking-Coal Classification	Short Tons x 10^6	% of Total
Premium grade high-volatile A to medium-volatile bituminous	21.23	4.75
Premium grade high-volatile A bituminous	128.05	28.66
Premium grade high-volatile B bituminous	78.86	17.65
Premium grade high-volatile A to B bituminous	129.37	28.96
Premium to marginal grade high-volatile B bituminous	54.04	12.10
Marginal grade high-volatile B bituminous	35.17	7.87
Total	446.72	99.99*

*Note: Total does not equal 100% due to independent rounding

Table 4-3. Licensed Coal Mines, Coking-Coal Characteristics, and 1977 and 1978 Coal Production Values in the Piceance Basin, Colorado (Goolsby, et al., 1979)

Mine	County	Production (in short tons)[1] 1977	1978	Coking-Coal[2] Classification
Eastside	Garfield	257	253	PhvBb
Nu-Gap No. 3	Garfield	397	281	?
Sunlight	Garfield	1,792	487	MhvBb
Bear Creek	Pitkin	58,352	44,171	Pmvb
Coal Basin	Pitkin	123,182	132,396	Mmvb
Dutch Creek No. 1	Pitkin	232,481	161,208	Mmvb
Dutch Creek No. 2	Pitkin	208,142	225,464	Pmvb
L. S. Wood	Pitkin	298,405	318.212	Pmvb
Thompson Creek No. 1	Pitkin	7,455	15,733	MhvAb
Thompson Creek No. 3	Pitkin	8,413	-	PhvAb
Blue Ribbon	Delta	16,640	15,294	PhvBb
King	Delta	2,996		PhvAb
Bear	Gunnison	226,221	226,705	PhvBb
Hawk's Nest East	Gunnison	190,350	330,997	PhvBb
Hawk's Nest West	Gunnison	12,362	-	PhvBb
Somerset	Gunnison	914,552	650,210	PhvAb
Total		2,301,997	2,094,618	

1) 1977 production data from Colorado Division of Mines, 1978b; 1978 production data are preliminary (Colorado Division of Mines, 1978a).

2) Pmvb = Premium grade medium-volatile bituminous
Mmvb = Marginal grade medium-volatile bituminous
PhvAb = Premium grade high-volatile A bituminous
MhvAb = Marginal grade high-volatile A bituminous
PhvBb = Premium grade high-volatile B bituminous
MhvBb = Marginal grade high-volatile B bituminous

Table 4-4. Range of Analyses of Piceance Basin, Colorado Coals on an As-Received Basis (Murray, 1980)

COAL FIELD, FORMATION, (Coalbed)	MOISTURE (%)	VOLATILE MATTER (%)	ASH (%)	SULFUR (%)	HEATING VALUE (Btu/lb)	ASH FUSION TEMPERATURE (°F)	FSI
Book Cliffs							
Mt. Garfield Fm. (Mesaverde Group)							
(Carbonera, Cameo, Palisade, Thomas, Anchor Mine)	3.3-14.0	29.8-35.4	4.9-23.3	0.4-I .7	9,833-13,560	2,130-2,960	O-I.0
Carbondale							
Williams Fork Fm. ("South Canyon Group", Dutch Creek, Allen, Anderson)	0.8-3.4	22.0-28.1	3.4-10.0	0.3-1.3	12,470-15,190	2,140-2,505	8.5-9.0
("Fairfield Group" or A,B,C,D, Coal Basin A-B)	0.8-4.0	21.8-39.3	3.4-6.7	0.4-I .5	12,609-15,088	2,180-2,455	I-9
Crested Butte							
Williams Fork Fm.. Paonia Mbr. (6 beds)	2.5-13.3	—	3.2-9.1	0.4-I .9	11,400-14,170	2,130-2,480	0
Danforth Hills							
Williams Fork Fm. (Lion Cyn., Goff, Fairfield Groups)	8.4155	—	2.2-9.6	0.3-1.4	10,140-11,790	2,210-2,910	—
Iles Fm. ("Black Diamond Group")	9.2-13.4	—	3.7-10.0	0.4-0.6	11,200-I 1,970	2,210-2,990	—
Grand Hogback							
Williams Fork Fm. (E, Sunnyridge)	4.0-4.8	37.2-39.8	6.1-10.4	0.6-0.7	12,060-12,581	2,230-2,910	1.0-1.5
Grand Mesa							
Mt. Garfield Fm. (Mesaverde Group) (68 beds)	3.1-19.5	30.4-35.0	2.1-17.9	0.5-2.2	8,298-13,489	2,060-2,970	—
Lower White River							
Williams Fork Fm.	11.2-14.1	—	4.4-8.5	0.4-0.5	10,800-11,230	2,060-2,910	O-I.5
Somerset							
Williams Fork Fm. (F,E,D,C,B,A, beds)	3.2-13.6	35.3-37.7	3.2-11.4	0.5-0.8	10,040-13,453	2,1452.810	O-3.0

5. POTENTIAL METHANE RESOURCE

5.1 METHANE DATA IN THE LITERATURE AND IN GOVERNMENT AND COMPANY FILES

All data used in the following descriptions were acquired from public files, released reports, or non-confidential personal communications.

5.1.1 Data on Gassy Underground Mines

Data compiled by the U.S. Bureau of Mines clearly indicate that Piceance Basin, particularly the area southeast of a line connecting Rio Blanco and Mack, is the gassiest coal region in the western United States (Murray et al., 1977). Figure 5-l shows graphically the data of Table 5-I and illustrates the area's historical record of mine explosions and fires from accumulations of methane gas, and gas and dust. The mine emission data on Table 5-l further indicate that, according to Mine Safety and Health Administration (MSHA) (formerly the Mine Enforcement and Safety Administration), 18,000 to 2.235 million cubic feet per day of methane are released from active coal mines in the southern Piceance Basin. The Coal Basin area mines emit the most gas, with four mines averaging over one million cubic feet per day and high percentages of gas per ton of coal.

The gassy nature of the Piceance Basin coals has led to numerous safety and regulatory problems. Since the late 19th century the area around Newcastle (Grand Hogback field) has been the site of many mine fires and explosions. On December 16, 1913, a gas explosion killed 37 miners at the Vulcan Mine. Further south at Sopris, Colorado, 17 miners died in an explosion on March 24, 1922. From 1883 to 1932 in Pitkin, Gunnison, and Garfield Counties, 21 gas fires or explosion accidents resulted in 176 deaths (Humphrey, 1960; Kintz and Denny, 1933).

Reviewing the percent volatile matter figures of Table 5-l (Murray et al., 1977), there appears to be a correlation between high methane content and the percent volatile matter. The very low percentage of volatile matter in anthracite coals corresponds to low gas content, with both caused by the intense heat and pressure required to metamorphose the coal to anthracite. Medium-volatile coals, such as those in the Coal Basin area, are quite gassy. High-volatile C bituminous coals such as those in the

northern Piceance Basin have a lower methane content. In addition, the Free Swelling Index (FSI) also appears to correlate directly with methane content as shown in Kent and Arndt (1980a, p. 32). Detailed statistical correlation of these data has not been performed but as the data base grows, such analysis is suggested.

5.1.2 Methane Emission Data from Underground Mine Measurements

Mid-Continent Mines, Carbondale Field

The Mid-Continent Coal and Coke Company operates five underground coal mines in the Coal Basin district of the Carbondale field. In the Bear Creek, Coal Basin, and Dutch Creek #2 mines, coal is cut by continuous miners while the L.S. Wood and the Dutch Creek #1 mines utilize longwall mining systems. Total production for the five mines is about 1 million tons. All the coal is either marginal- or premium-grade medium-volatile bituminous. Slightly more than half the coal is shipped to U.S. Steel's Geneva Plant near Provo, Utah, and the balance is shipped to Kaiser Steel, Fontana, California (Dawson and Murray, 1978). The average methane emission for the five mines in 1977 (first quarter, 1977; MESA) totaled 8,226,000 cubic feet per day.

In the two longwall operations, the beds dip approximately 13 degrees into the basin away from the outcrop. The coalbeds are mined along strike for approximately 3,600 feet. Methane drainage holes are drilled into the roof as mining advances (i.e., after the coal is mined) (Figure 5-2). The drainage holes are drilled up into the micro-fracture system of the caving roof at an angle of approximately 60 degrees to the horizontal. Drilled on 75-foot centers for the total advancement, the holes are cased and cemented with 60 feet of 2-inch metal pipe and connected to a 4-inch collection pipe. The collection system is entirely closed to the atmosphere and the internal pressure is held at approximately 6 inches of mercury vacuum. The holes have a total length of 160 feet; the last 100 feet are 1-7/8 inches in diameter and are not cased; i.e., are open holes.

The two drainage systems produce approximately 3.02 million cubic feet per day from a total of about 110 holes. In the L.S. Wood mine, 30 holes have been drilled but only 15 are producing gas at any one time. Of the 80

holes drilled in the Dutch Creek #1 mine, only about one-third are in operation and flowing gas at any one time. Individual holes are shut-off when atmospheric air begins leaking into the closed system, and start producing less than 30 percent methane; however, some of the holes produce 100 percent methane. The mine operators try to maintain an average of 70 percent methane by opening and closing the various drainage holes.

Air temperature within the mine is very low due to the elevation of the mines (10,000 feet at mine portals) and the large volumes of required ventilation. The gas is water-saturated and eliminating water from the system is a problem. The water cornnonly freezes, shutting down the ventilation system. Mid-Continent is exploring the possibility of using the methane to heat the air ventilated through the mine.

The gas injected into the coal-fired dryers cuts coal consumption by approximately two-thirds. The savings are twofold: reduction in coal consumption; and when burning metallurgical grade coal, the furnaces are coated with coke that must be cleaned out every two weeks. Thus, by burning gas, savings in both downtime and manpower are realized.

Electricity represents the only commercial power supply in the Coal Basin area. An electric bill for mining operations can exceed $100,000 per month. A large portion of this charge is attributable to the ventilation fans, heating water for over 300 showers per day, heating of the change areas, and the coal preparation equipment. Utilization of produced methane could substantially reduce energy costs for mining operations.

5.1.3 Surface Drill Hole Data from Other Projects

U.S. Geological Survey

USGS drill hole No. CA-77-2, (Sec 13, T10S, R98W) is on Plateau Creek at an elevation of 4,830 feet just upstream from where it flows into the Colorado River. It lies in the Palisade District of the Grand Mesa coal field approximately 4.6 miles upstream from the Cameo Mine. This hole marks the western extent of the cross section for the southeastern Piceance Basin (Plate 4).

The Colorado Geological Survey collected coal core samples for desorption analysis from the Cameo zone just above the Rollins Sandstone and from the Palisade zone immediately above the Cozzette Sandstone

(Figures 5-3 and 5-4). The Cameo zone occurs at an interval from 800 to 875 feet deep and contains five coalbeds that have a cumulative thickness of 17 feet. One sample taken from the highest coal of this zone had a gas content of 80 cubic feet per ton (cu ft/ton). The Palisade zone contains two beds--l.0 and 3.5 feet thick--in a 20-foot interval. A second sample taken from the thicker coalbed for desorption analysis had a gas content of 223 cu ft/ton (Figure 5-5).

Exxon Vega No. 2

In the authors' opinion, the Vega No. 2 well (Sec 34, T9S, R93W, Mesa County) is by far the most important well in understanding the coalbed methane regime within Piceance Basin. With an 8,000-foot depth to the Rollins Sandstone, the well is near the synclinal axis of the basin, and has been completed in the Cameo coal zone, immediately above the Rollins. It is the only Piceance Basin well known to the authors in which commercial completion has been strictly restricted to individual coalbeds. More important, this well has been connected to a pipeline and has just commenced production. In fact, production began during the final days of preparing this report. A careful evaluation of all completion and stimulation techniques employed in this well, along with daily production records involving both gas and water flow, should provide valuable information on how to proceed in production of Piceance Basin coalbed methane. Following is a detailed development history of this well compiled from sources that include Exxon geologists and engineers, official state agency files, log service companies, and others.

Vega No. 2 well, near the center of the east-west cross section of Plate 4, is about 12 miles east of the Teton Energy well, Walck 23-2, one of the major wells for which coal core desorption tests have been performed in the MRCP. Kelly bushing elevation for Vega No. 2 is 8,154 feet (8,140 feet ground level). The hole bottomed at 8,888 feet in the Corcoran Sandstone. Planned potential gas targets were the Corcoran and the overlying Cozzette and Rollins Sandstones. The hole was spudded on April 29, 1978, with a mud log and drill-chip lithologic log being run concurrently with drilling, starting at hole depth of 1,520 and continuing to total depth (TD). Figure 5-6 shows the critical section of this log involving the coalbed completion zone.

On completion of drilling, geophysical logs were run by Schlumberger and included caliper, spontaneous potential (SP), resistivity (dual-induction), gamma ray, and formation density. After evaluation of the mud and geophysical logs, Exxon attempted to complete in the Cozzette, with perforations between 8,615 and 8,620 feet (9 shots at 1 shot/l-l/2 foot) and 8,634 to 8,647 feet (10 shots at 1 shot/1-1/2 foot spacing). Chemical treatment comprised acidization using 250 gallons of gel acid. After negative results in the Cozzette, it was decided to attempt completion in the Cameo coalbeds above the Rollins Sandstone. A cement plug was placed between 8,140 and 8,600 feet and the casing was perforated in the following zones:

7,847-7,851	1 Shot/l-l/2 feet	3 Shots
7,863-7,879	1 Shot/l-l/Z feet	9 Shots
7,985-8,007	1 Shot/2 feet	12 Shots
8,046-8,062	1 Shot/2 feet	4 Shots

Engineers and geologists who worked on this well state that the completion was designed specifically for, and tailored to, individual coal-beds within the Cameo coal zone. This can be demonstrated by comparing the perforated intervals with the geophysical logs in Figure 5-6. The perforated zones are plotted on the geophysical logs and all perforations occur within the boundaries of the four major coalbeds. These boundaries are very clearly indicated on the gamma ray, density, and dual-induction logs. There is no possibility of misinterpreting these beds as coalbeds because of the existence of the mud log, where major coalbeds are indicated by the original drill-cutting lithologic log. The lithologic portion of the mud log shows the approximate location of each coalbed. This suite of mud and geophysical logs is extremely important because it shows that completion is strictly limited to the individual coalbeds, and does not include any adjacent sandstones.

The authors' interpretation of the records indicates that the next step performed by Exxon was to break down the formation with 9,200 gallons of 2-percent potassium chloride (KCl) water over the four zones of perforation. Next, a massive frac, whose design comprised 143,200 gallons of Versa gel 2500, with initial proppant consisting of 50,000 pounds of 100-mesh sand, to be followed with 222,400 pounds of 20-40 mesh sand, was begun.

All of the lo-mesh sand was pumped into the frac system using 61,760 gallons of Versa gel. However, after pumping in 120,960 pounds of 20-40 mesh sand with 30,240 gallons of Versa gel, the frac system sanded up and further pumping of the remaining Versa gel and sand of the original design ceased.

Evaluation of the Vega No. 2 well from this point on is important, providing information on the intricate relationship of coalbed methane gas production to water present in a coalbed. Even the limited data available to date on U.S. coalbed methane indicate that it is generally necessary to keep formation water content at very low levels if coalbed methane is to desorb and flow. In Vega No. 2, during a 30-day cleanup period, the rate of water production steadily decreased. During the last 6 days of this 30-day period, water production was, consecutively, 75, 48, 36, 36, 29, and 12 barrels per day. Nine days later the well was flowed for a 24-hour test. Test fluid produced included 109 barrels of water. It is interesting to note that if one takes the 12 barrels produced on the last day of the 30-day period, and multiplies this value by the 9-day shut-in interval, the amount is 108 barrels of water, almost exactly the 109 barrels actually produced. This may indicate that 12 barrels per day may approach steady-state water inflow into the fracture system. Gas produced during the 24-hour flow test was 440 thousand cubic feet (Mcf) and was analyzed at 1,072 British thermal units (Btu) per cubic foot.

After the above test; the well was closed in, to await connection to a regional pipeline. After connection to the Rocky Mountain Natural Gas Co. pipeline, production was initiated on February 4, 1981. The well is flowing naturally against pipeline pressure of 550 pounds per square inch (psi). The first day's production exceeded 1 million cubic feet, and included a small amount of water. On the second day, flow rate dropped to as low as 180 Mcf per day and then recovered to produce a total of 520 Mcf for the 24-hour period, along with 60 to 100 barrels of water. The following three-day gas production was 444, 432, and 432 Mcf. Water production for each of these days was 175 barrels. The foregoing data indicate the fracture zone had loaded up with water during its long shut-in and is retarding gas flow; however, data on water produced during the final stages

of cleanup indicate that after a relatively short period of production the water now accumulated in the fracture system should be disposed of. Because of the tight nature and low permeability of Mesaverde strata, the steady-state future flow of water into the system should be quite low. At that point, gas production from the well should recover to over 1 MMcfd.

Coalbeds at Vega No. 2 comprise two coal zones as shown on the geophysical logs of Figure 5-6--a lower zone that correlates with the Cameo coal zone and an upper zone that correlates with the Carbonera coal zone of the Book Cliff field. A single coalbed above the Carbonera zone, in other Plateau Creek area wells, is not present in Vega No. 2 (Plate 4). Coalbed sequence at Vega No. 2 is:

1. The upper Carbonera coal zone, at a depth interval of 7,648 to 7,750 feet, consisting of 5 coalbeds ranging in thickness from 1 to 4 feet and totaling 14 feet of coal in a 102-foot section.

2. The lower Cameo coal zone, at a depth interval of 7,836 to 8,052 feet, consisting of 5 coalbeds ranging in thickness from 4 to 25 feet and totaling 62 feet of coal in a 216-foot section.

Coal and coalbed methane resources calculated for the Vega No. 2 area, per one-square-mile section of land, using a total coal thickness of 76 feet, a tonnage factor of 1.152 million tons per foot of coal per square mile of land, and the average core sample methane desorption value of 410 cu ft/ton as determined for Vega No. 3*, are:

Coal resource
(76 x 1.152**) = 87.6 million tons/square mile

Methane resource
(410 x 87.6) = 35.9 billion cubic feet of gas (cfg)/square mile

Exxon Well Veaa No. 3

Vega No. 3 well (Sec 10, T10S, R93W, Mesa County), 1.9 miles southeast of Vega No. 2, is one of the wells included in the east-west cross section

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* Gas desorption values from Vega No. 3 were used in these calculations because no desorption data exist from Vega No. 2.

**Millions of tons of bituminous coal in a l-foot bed per square mile.

of Plate 4 and shown on the structural contour map of Plate 3. This well is important because coring was performed in the Cameo coal zone above the Rollins Sandstone and methane desorption measurements were made on the coal core samples. Desorption data from Vega No. 3, in conjunction with the detailed well history and coalbed methane production records available on Vega No. 2, provide the most complete composite picture for coalbed methane potential of any known area in the western United States.

Coalbeds in Vega No. 3 well, above the Rollins Sandstone, comprise the following sequence (Figure 5-7):

1. An upper coalbed, 3 feet thick, at a depth of 7,128 feet.

2. A middle coal zone, at a depth interval of 7,131 to 7,260 feet, consisting of 4 coalbeds ranging in thickness from 1 to 6 feet and totaling 14 feet of coal in a 108-foot section.

3. A lower coal zone, at a depth interval of 7,460 to 7,652 feet, consisting of 7 coalbeds ranging in thickness from 2 to 27 feet, and totaling 75 feet of coal in a 192-foot section.

Within the Cameo and Carbonera coal zones at Vega No. 3, 11 coalbeds ranging in thickness from 1 to 27 feet and totaling 89 feet of coal were encountered within a stratigraphic distance of 392 feet.

Coal bed sequence and spacing in Vega No. 3 well, as measured on geophysical logs in Figure 5-7, correlate closely with Vega No. 2 and with coal zone lithologies to the west--in the Teton Energy well Walck 23-2, south of Colbran; the Adolph Coors wells Nichols l-24 and 1-23 CM, west of Mesa; and the USGS well CA-77-2, near the Cameo Mine on the Colorado River (Plate 4). In all of these wells, coalbeds occur principally in two coal zones that extend uninterrupted from the Colorado River at Cameo, eastward to the Piceance Basin synclinal axis near the Vega wells. The lower of these two coal zones is almost certainly the Cameo coal zone of the Book Cliffs and Grand Mesa coal fields; the upper, the Carbonera coal zone. The relative coalbed stratigraphic relationships and coal thicknesses in these wells are sumnarized in Figure 5-3. Also indicated on this illustration is the thickening of the coal zones toward the basin center, along with the barren zones between the coal zones. Thickness of individual coalbeds and total coal thickness also increase toward the basin axis.

An isolated coalbed ranging in thickness from 2 to 4 feet commonly occurs from 70 to 130 feet above the top of Carbonera coal zone. This bed has been extremely useful as a guide in picking core points during MRCP drilling operations. During drilling, penetration of this bed can be seen on the geolograph log and confirmed by drill cuttings. During drilling, careful correlation of the geolograph and geophysical logs of adjacent wells in the Plateau Creek area has permitted picking core points with accuracies of 1 to 3 feet during MRCP operations.

Methane desorption values for two coal-core samples from Vega No. 3 have been reported by the Colorado Geological Survey (1980). Both core samples came from the same bed with a recorded depth of 7,598 feet. This depth correlates with the 13.5-foot-thick bed shown on Figure 5-7, which is just above the 27-foot-thick basal bed of the Cameo zone. Total gas reported for the two samples is 381 and 438 cu ft/ton, with an average for the two samples of 410 cu ft/ton.

Coal and coalbed methane resources calculated for the Vega No. 3 area, per one-square-mile section of land, using a total coal thickness of 92 feet, are:

Coal Resource:
(92 x 1.152*) = 106.0 million tons/square mile

Methane Resource:
(410 cf ton x 106 million tons) = 43.5 billion cfg/square mile

U.S. Steel Exploration *Core* Holes

U.S. Steel holds the lease on approximately 10 square miles of federal land in T10S, R89 and 90W in the Coal Basin area of the Carbondale field (Figure 5-8). To retain the lease it must develop the coal in the 1980s. For the purpose of determining ventilation requirements for an underground mine design, U.S. Steel drilled four exploration holes and cored and sampled four coalbeds for desorption analysis. These samples from the Placita "V", "B", and "A" beds were found to have gas contents that range from 107

*Millions of tons bituminous coal in a l-foot bed per square mile.

to 1,041 cu ft/ton. It should be noted that the U.S. Steel gas measurement procedure varies somewhat from that used by TRW. The coal sample is broken to one-inch pieces before being sealed in the desorption canister.

U.S. Steel personnel consider that the amount of gas desorbed in this way most closely approximates what would be produced from the coal during mining (U.S. Steel personnel, personal communication 1980). In addition, the samples were not crushed to release the residual gas. Instead, a USBM curve was used to estimate this component of the total gas. The USBM has determined that the curve does not consistently predict residual gas content and its use has been discontinued (P. Diamond, 1981, personal communication). The total gas content values reported by U.S. Steel are therefore considered approximate.

The locations of the drillholes (Numbers 16, 17, 18, and 19) as shown on the map (Figure 5-8) are approximate. Given the general location by section, township, range, the trend and elevation of the holes, a best-fit location was approximated. A summary of the samples taken at each of the holes, the desorption results, and a methane resource estimate for the test area is presented in Table 5-2.

The weighted average gas content for all of the samples was calculated to be 569 cu ft/ton. Using bed thicknesses measured in the core holes and a tonnage multiplier (1,800 tons per acre-foot of bituminous coal or 1.152 million tons per section-foot) shows the coal resource to be 43.1 million tons per section of land. Using the calculated coal resource and average gas content of the coal on a by-bed basis, the total methane resource in the four sampled coalbeds is estimated to be 24.5 billion cubic feet per section of land.

Union Oil Well Overland No. 1

Overland No. 1 well (Sec 13, T11S, R92W, Delta County), shown on the east-west cross section of Plate 4, is approximately half-way between the Exxon Vega wells, in the center of the basin to the west, and the U.S. Steel exploration holes at Coal Basin. The hole, spudded September 7, 1957, and completed October 10, 1957, was drilled to 7,600 feet TD from a surface elevation of 9,421 feet. Depth to the Rollins Sandstone is 6,757

feet. A total of 37 cores were taken at various points through the interval 4,318 to 7,384 feet and 14 drill-stem tests were performed within the interval 4,387 to 7,477 feet.

Of specific interest in this well is the fact that core samples were recovered from a thick coalbed, just above the Rollins Sandstone that had been intruded by a sill of acidic igneous rock. In the core-log description, coal is reported occurring in cores No. 29 and 30 at a depth interval between 6,724 and 6,741 feet. However, no documentation was made in the written report of the occurrence of the intruded igneous sill. Suspicions were evidently aroused, however, and the events reported to the USGS. Averitt (USGS Coal Branch office in Denver) gives a brief description of this rare core sample as follows (Averitt, 1975, p. 74):

> . ..in a well drilled in Sec. 13, T. 11 S., R. 92 W., in which the coal is 6,723 feet below the surface.....the drill penetrated 14 feet of natural coke, underlain by an estimated 12-14 feet of quartz latite, which is under-lain by 12 feet of coal.

This intrusion of a coalbed by acidic igneous magma is comparable to similar occurrences in the highly gassy coalbeds directly to the east in Coal Basin, and to the southeast in the Crested Butte Field. In these two areas, the intruding dikes and sills are commonly in close proximity to larger igneous bodies--stocks and plutons--of comparable acidic compositions. The sill that cuts the coalbed in Overland No. 1 well probably formed from a feeder dike originating from an igneous pluton at somewhat greater depth, as indicated in the cross section of Plate 4. The complex of stocks and plutons at Coal Basin, Crested Butte, and probably below the Overland No. 1 well, may likely represent cupolas and roof pendents of a much larger, deeper, igneous body, of batholithic proportions. If so, the potential for regional coalbed methane production caused by heat released during cooling of magmatic bodies lying below the basin's coalbeds, is extremely high in the entire southeastern portion of Piceance Basin.

The only testing performed at Overland No. 1 were the Drill Stem Tests (DST) mentioned above, none of which were in the coal-bearing beds just above the Rollins Sandstone. No gas production is listed for the well.

Hawk's Nest Mine

The Hawk's Nest Mine property is located in Sections 1, 2, 3, 10, 11, and 12, T13S, R90W in the Somerset field. The two operating mines, Hawk's Nest East (No. 2) and Hawk's Nest West (No. 3), both produce from the "E" coalbed. This bed averages 9.0 feet thick and dips from 2 to 3 degrees to the northwest. The coal is premium-grade high-volatile B bituminous and is shipped to U.S. Steel in Provo, Utah, at a cost of $20 per ton.

Colorado Geological Survey personnel were permitted to collect coal samples for desorption analysis from four exploration drill holes on the Hawk's Nest property (Figure 5-9). Geophysical logs, coalbed thicknesses, and gas desorption results are shown on Figure 5-10. Desorption results and methane resource estimates are presented in Table 5-3. A total of 25 samples were collected from the "A" to "D" and Wild coalbeds. Gas contents ranged from 80 to 245 cu ft./ton. One anomalously low sample (a factor of 10 lower than the lowest of the other 24 samples (Table 5-4)) was not included in the calculations because it was not considered by the authors to be representative of the bed. The weighted average gas content of beds "A" through Wild was used to estimate the methane resource of the "E" and higher coalbeds. Three gas samples from the "B" and "C" beds were analyzed for Btu content and hydrocarbon composition (Table 5-5).

The coal resource of all beds encountered in the four drill holes was calculated to determine the amount of coalbed methane contained in the study area. This resource, approximately 85.8 million tons per section of land, contains 13.5 billion cubic feet of methane. The weighted average gas content of the coalbeds is 157 cu ft/ton.

Colorado Geological Survey

Methane desorption test results from core samples taken in the Danforth Hills, Grand Mesa, and Somerset coal fields are taken from a report presented by the Colorado Geological Survey at the Department of Energy review on "Coal Methane Resource for Western Basins" at the Morgantown Energy Technology Center, Morgantown, West Virginia, October 30, 1980. Data in that report are limited to desorption results, with locations of test sites identified on a small-scale map. Detailed locations

and drill hole surface elevations are not given. The approximate locations of the drill holes are presented in Figure 5-11, and the desorption results are summarized in Table 5-6. Along with those from TRW well tests (Section 5.2.2), these results indicate low gas contents in coalbeds of the northern coal fields and in coals covered by less than 1,000 feet of overburden.

Rio Colorado Well No. 1 Cactus Valley 23-6-9

No. 1 Cactus Valley (NW 1/4, NW 1/4, Sec 23, T6S, R90W, Garfield County) was spudded about October 20, 1979 by Rio Colorado Oil and Gas Company to explore the coalbed methane potential of the thick sequence of coalbeds in South Canyon, south of the Colorado River and about 5 miles west of Glenwood Springs in Garfield County. As indicated in Figure 5-12, No. 1 Cactus Valley is 0.8 mile south of the South Canyon mine. The cross sectional sketch at South Canyon from Gale (1910), shows at least nine coalbeds ranging in thickness from 4 to 30 feet, and a total of 96 feet of coal in a 640-foot stratigraphic section. The South Canyon coalbeds are in the Bowie Shale Member, at the base of the Williams Fork Formation of the Mesaverde Group (Collins, 1976). The coalbeds crop out on the northeast slope of Coal Ridge, which forms part of the Grand Hogback. According to Gale (1910), the bed mined at the South Canyon mine was the Wheeler. The attitude of this coalbed is N60W, dipping 52 SW. Ground elevation at the South Canyon mine adit is about 6,400 feet. Ground elevation at the No. 1 Cactus Valley well is 6,681 feet. Horizontal distance between the well and the mine adit as projected in the downdip direction is approximately 2,700 feet (see Figure 5-12). The drilling permit application (Colorado Oil and Gas Commission files) shows that the planned TD for No. 1 Cactus Valley was 4,000 feet, with coring intervals of 3,250 to 3,450 feet and 3,700 to 4,000 feet.

As shown in the cross sectional sketch of Figure 5-12, the projection of the thicker coalbeds from the surface, in the downdip direction, intercepts the planned coring intervals. The drilling permit indicates that the hole prognosis was to set 150 feet of 9-5/8-inch surface casing, drill an 8-3/4-inch hole to TD, and then run 5-1/2-inch casing to TD and cement. After completion, published reports indicated Rio Colorado planned to conduct production testing for gas in the most promising coalbeds identified during drilling, coring, and logging.

During coring, coal core samples were collected and placed into desorption canisters at the site by USBM personnel. Release of the desorption test results by the USBM has not yet been approved by Rio Colorado. Also, details of DSTs, perforations, fracing, or flow tests have not yet been released by Rio Colorado. A recent scout report by Petroleum Information Service received at the time of publication of this report provides some additional data: that 8-5/8-inch surface casing was set to a depth of I67 feet; 5-1/2-inch casing was then set and cemented to a TD of 4,393 feet; casing was perforated in the intervals of 2,440 to 2,550, 2,740 to 3,320, and 3,868 to 4,130 feet; a foamfrac was performed; and the well was undergoing pressure tesing.

The heating values of four as-received coal samples from surface and mine outcrops collected at South Canyon (Collins, 1976) range from 11,643 to 13,127 Btu. These values indicate coal rank ranging from high-volatile C to high-volatile A bituminous. However, directly downdip from No. 1 Cactus Valley along the Grand Hogback Monocline, about 5 miles to the southwest, these coalbeds reach a depth of over 9,000 feet. Here, Freeman (1979) has measured vitrinite reflectance values of 2.1 from drilling samples, and has mapped the coal as semianthracite in rank (see discussion and figures in Section 5.3). Gale (1910, p. 131) notes that in the underground workings at South Canyon, "There is a large volume of gas in the coal, and Wolf safety lamps are used." No. 1 Cactus Valley, located only 11 miles north of the extremely gassy Coal Basin'mines, should be favorable for coalbed methane production. However, because of the steep dip of the coalbeds on the Grand Hogback monocline, methane may have had an unusually favorable path for updip migration and loss to the atmosphere could occur. If coalbed methane production proves unfavorable at No. 1 Cactus Valley, an attempt should be made at the center of the narrow syncline, five miles to the southwest (Plate 3).

Chevron Well Skonberg No. 1

Skonberg No. 1 (Sec. 9, T7S, R93W, Garfield County) is of interest because the bottom 1,850 feet of the well were completed open-hole in coal-rich strata of the Williams Fork Formation above the Rollins Sandstone. In Figure 5-13, a lithologic log of the open-hole section of the well is shown

along with a 300-foot interval of the compensated density log. This interval was chosen to amplify the section where coalbeds are thickest. Table 5-7 summarizes the coalbed occurrences in the open-hole section of the well. In the 1,584-foot interval from 754 to 8,614 feet, six coal zones occur which contain 39 coalbeds varying in thickness from 1 to 14 feet with an aggregate thickness of 156 feet of coal. This amounts to coal strata covering 10 percent of the open-hole.

The Skonberg No. 1 well is on the northwestern nose of the Divide Creek Anticline (see structural contour map, Plate 3), about half the distance between Rifle and the Garfield-Mesa County line. This location places the coal sequence in this hole in the low-volatile bituminous range, according to Freeman's map of coal rank based on drill cuttings and vitrinite reflectance measurements (Freeman, 1979). To date, only limited data are available on this well. Johnson et al. (1979b) present a cross section indicating this is a producing gas well. Geophysical logging performed on March 1 and March 15, 1966, indicated Skonberg No. 1 was the discovery well for the Mam Creek gas field.

The log run on March 1st shows that the fluid in the hole was fresh gel and diesel oil. Two weeks later on March 15, however, the fluid in the hole was recorded as dry gas. The 1979 Colorado Oil and Gas Statistics (Colorado Oil and Gas Conservation Comnission, 1979) show there were only two wells with 1979 records of production in the Mam Creek field--Arco-Exxon well No. 1-36 (Sec. 36, T6S, R93W) and California well Schaffer No. 1 (Sec. 7, T7S, R93W). Recent POMCO (1980) maps of oil and gas well locations show only three wells in the Mam Creek Field as being producers--the two wells mentioned above and the Chevron Skonberg No. 1. Total field production (all from the Mesaverde Formation) to January 1, 1980 is 740 MMcf. Of the total production, 564 MMcf are allocated to the Schaffer No. 1 well and 94 MMcf to the Arco-Exxon No. l-36 well. This leaves the remaining field production of 91 MMcf attributable to the Skonberg No. 1 well. The 91 MMcf produced from Skonberg No. 1 must be distributed among both the coalbeds and the interbedded sandstones. There is no way to break down this production but it is thought that whatever the producing zone, all the gas probably was derived from the coalbeds.

Amoco Production Company

Amoco Production Company has submitted applications to drill three wells and have requested a permit to degasify the coalbeds above the Rollins Sandstone. The Green Mountain Unit No. 1 (Sec. 20, T12S, R92W) has a projected TD of 3,000 feet. Copies of the applications for the other wells, the Bowie Unit No. 1 (SW 1/4, NE 1/4, Sec 15, T12S, R91W) and the Somerset Unit No. 1 (SE 1/4, NW 1/4, Sec 9, T12S, R90W), were not available for inspection at the office of the Colorado State Oil and Gas Commission.

All three of the wells are located on U.S. government land on which Amoco holds the oil and gas leases, but not the coal rights. Since the target coals are less than 3,000 feet deep (potentially minable in the future), a legal decision was sought from the solicitor's office at the Department of the Interior as to ownership of the coalbed methane. As of January, 1981, the opinion had not yet been forwarded to the USGS Conservation Division, which issues the drilling permits.

The planned Amoco wells lie in a highly favorable location within the southeastern Piceance Basin, southeast of the Exxon Vega properties, southwest of the U.S. Steel Coal Basin exploration area with its very high coalbed methane indications, and north of the gassy Somerset coal field. As shown on the depth of overburden map Plate 5, depth to the Rollins Sandstone and the base of the coalbeds at the Amoco sites ranges from approximately 3,300 to 4,100 feet.

Aries Resources Wells Leon Lake Nos. 1 and 2

Aries Resources, Inc. plans on drilling Leon Lake No. 1 (NW 1/4, Sec. 12, T12S, R94W) and No. 2 (NE 1/4, Sec. 14, T12S, R94W) in northern Delta County, just west of the Amoco wells described above. The two Leon Lake wells are planned for early spring, 1981, just as soon as weather and ground conditions permit access. These wells are planned as explorations for coalbed methane in the coal zone imnediately above the Rollins Sandstone.

5.2 METHANE RECOVERY FROM COALBEDS PROJECT DATA

5.2.1 Piceance Basin Studies

TRW and DOE have cooperated with oil and gas companies at drilling sites in three areas of Piceance Basin--the Rangely area and the Douglas Creek area of Rio Blanco County in northwestern Piceance Basin; and the Plateau Creek area of Mesa County in southeastern Piceance Basin.

During the early stages of the MRCP, the program was essentially unknown to the oil and gas industry and it was difficult to finalize testing programs with potential cooperators. Some of the earliest cooperators in the program were Western Fuels, Fuelco, and Twin Arrow Drilling--all had their operations in the northwestern portion of the basin. As the MRCP progressed, and knowledge of the program's objectives became better known, more companies became interested in potentially cooperating at drilling sites not only in other portions of Piceance Basin, but throughout the other major basins of the Rocky Mountain Region. Because of this expanded interest by oil and gas companies, it became possible during the 1980 field season to initiate cooperative drilling agreements in southeastern Piceance Basin, which, from the beginning of the program, had been a major coalbed methane target. Thus it was that two coal characterization (coring, sample desorption, and DST) and one production (perforating, fracing, and flow testing) well tests were performed in the Plateau Creek area of Mesa County with Adolph Coors and Teton Energy Companies.

5.2.2 Summary of Piceance Basin Test Sites

5.2.2.1 Plateau Creek Area

Teton Energy Well Walck 23-2 (FAI)

Teton Energy well Walck 23-2 (NW 1/4, NW 1/4, Sec 23, T10S, R95W) was spudded March 10, 1980 at a ground elevation of 7,017 feet in the Wasatch Formation and bottomed at the base of the Mesaverde Group. The gas targets of Teton Energy were, from the top down, the Rollins, Cozzette, and Corcoran Sandstones. The MRCP objective was to sample the coalbeds immediately above the Rollins Sandstone.

Coalbeds encountered in lower Mesaverde strata in the Walck 23-2 well comprised the following zones, as measured from the geophysical logs (these measurements are 6.5 feet deeper than on-site measurements):

1. An upper coalbed, 4 feet thick, at a depth of 4,483 feet

2. A middle coal zone, at a depth interval of 4,557 to 4,613 feet, consisting of five coalbeds ranging in thickness from 1 to 4 feet, and totaling 17 feet of coal in a 56-foot section

3. A lower coal zone, at a depth interval of 4,667 to 4,814 feet, consisting of eight coalbeds ranging in thickness from 1 to 14 feet, and totaling 59 feet of coal in a 147-foot section.

A stratigraphic section showing the above relationships is given in Figure 5-14. As summarized in this column, within a stratigraphic distance of 311 feet, 14 coalbeds were encountered, ranging in thickness from 1 to 14 feet, and totaling 80 feet of coal.

Because the Walck 23-2 well is in the interior of Piceance Basin, several miles from any of the coal fields that ring the basin's margin, coalbed correlations are not known. Tentatively, the lower coal zone in the well is correlated with the Cameo coal zone, and the middle coal zone with the Carbonera coal zone of the Book Cliffs and Grand Mesa coal fields.

Coring and sampling were restricted to the lower coal zone. Three intervals were cored: 4,682 to 4,696; 4,726 to 4,759; and 4,798 to 4,819 (these footage values are as measured on-site, and are 6.5 feet shallower than on the geophysical logs). Within the cored intervals, the strata consisted of 41.5 feet of coal, 5.0 feet of carbonaceous shale, and 21.5 feet of sandstone. The Rollins Sandstone is the 11 feet of sandstone immediately underlying the basal coalbed. This section was deliberately cored in order to obtain data on the Rollins Sandstone. A 3.5-inch diameter core was recovered using a 60-foot core barrel. Core recovery in the shale and sandstone was essentially 100 percent; recovery in coal was approximately 25 percent.

A total of 16 methane desorption samples were collected--13 from cores and 3 from drill cuttings. Desorption measurements, excluding residual gas, over periods up to 236 days have provided gas content values for the three drill-cutting samples of 134, 155, and 165 cu ft/ton. The average

for the three samples is 151 cu ft/ton. Values for eight core samples representing relatively pure coal are 113, 186, 189, 191, 273, 274, 289, and 290 cu ft/ton. The average of these samples is 226 cu ft/ton. Desorption data collected to date are summarized in Table 5-8. A curve, representative of a typical sample and depicting the relatively rapid initial desorption and the slower, but continuous, gas desorption for longer periods, is shown in Figure 5-15.

Samples considered most representative of methane content for individual coalbeds were three collected from the basal 14-foot-thick bed with an average gas content of 284 cu ft/ton, and three samples collected from the next higher, thick bed (12 feet thick) with an average gas content of 216 cu ft/ton.

Coal and methane resources per section of land for the area adjacent to the Walck 23-2 well are summarized in Table 5-9. These estimates are based on the coalbed thicknesses as given in Figure 5-14 and the gas desorption results for eight core samples that represent pure coal from within three coalbeds (Figure 5-14). The total coal resource is 92 million tons per square mile of area and the total methane resource is 19 billion cubic feet per square mile of area. Gas concentration based on a weighted average is 210 cu ft/ton and an arithmetic average is 207 cu ft./ton.

Compositions of gas samples collected during desorption from seven of the samples are given in Table 5-10. These analyses indicate that the average composition of the seven samples is 77 percent methane, 11 percent ethane, 2 percent propane, and less than 0.3 percent total of all other hydrocarbons. Non-hydrocarbons average 8 percent carbon dioxide and 2 percent nitrogen.

Three samples, labelled R-l, R-2, and R-3, of roof and floor rock were taken for physical property analysis. Sample R-l was taken 2 feet below the 8.0-foot coalbed in core No. 2. The floor rock of this coalbed is 4.5 feet thick and is a dark gray, massive, non-fissile, carbonaceous shale. Sample R-2 was collected 1.1 feet above the 12.2-foot coalbed in core No. 2. The roof rock of this bed is a light gray, medium-grained sandstone that contains carbonaceous laminae that are very dense immediately above the coalbed for 1.1 feet and less dense above this zone. Sample R-3 was

taken from the Rollins Sandstone 3.5 feet below the 13.5-foot coalbed of core No. 3. The floor rock is a light gray, fine-grained, subrounded, carbonaceous quartz sandstone that is composed of 60 percent quartz, 30 percent carbonaceous material, and 10 percent silica cement.

A uniaxial compressive strength determination was made for the floor rock sample R-l. Roof rock sample R-2 was tested for triaxial compressive strength, and floor rock sample R-3 was not tested for strength. All three samples were tested for permeability and bulk density. Test results are summarized below.

Sample Number	Triaxial Comp. Strength (psi)	Uniaxial Comp. Strength (psi)	Permeability (millidarcies)	Bulk Density (gm/cc)
R-l		9,170	0.12	2.30
R-2	20,400		0.03	2.50
R-3			0.44	2.52

Adolph Coors Well, Nichols l-24 (FAJ)

The Adolph Coors Nichols l-24 (NW 1/4, NW 1/4, Sec 23, T10S, R97W) was initially drilled in 1978 to a depth of 3,600 feet. During the months of April, May, and June, 1980, the well was plugged back to 2,720 feet and the casing perforated over an 8-foot interval (2,625 to 2,633 ft) in the Cameo coal zone and the well tested for coalbed methane production (Figure 5-16). No attempt was made to stimulate the coalbeds imnediately above the Rollins Sandstone because of potential water inflow. In this well 11 coalbeds having an aggregate thickness of 75 feet occur within a 360-foot interval. The coalbeds range in thickness from 2 to 13 feet. Geophysical logs run on this hole include compensated density, neutron, induction electric, gamma ray, and SP. The compensated density log over part of this interval of interest is shown in Figure 5-16.

The well was stimulated using 52,500 gallons of 75-percent quality nitrogen foam and 49,000 pounds of sand proppant. Production testing, after post-frac well cleanup and swabbing over a 15-day interval following the treatment, resulted in no sustained methane production. A conventional step-rate injectivity test was performed to evaluate the stimulation treatment. The injection test results show that a previously fractured

formation accepted the injected fluid. The results of this testing are presented in detail in a MRCP well test report on the subject well (TRW, 1981).

When the production testing provd unsuccessful, desorption samples were collected from the nearby Adolph Coors Nichols l-23 CM well to confirm that the stimulated coalbed in the Nichols l-24 well contained producible quantities of gas.

Adolph Coors Well, Nichols l-23 CM (FAK)

The Adolph Coors Nichols l-23 CM (Sec. 23, T10S, R97W) was spudded September 30, 1980 at a surface elevation of 5,966 feet. The target depths of this well were 7,700 and 8,000 feet in the Dakota Sandstone and the Jurassic Salt Wash Sandstone Member of the Morrison Formation, respectively. The objective of the MRCP test was the coalbeds immediately above the Rollins Sandstone. This test site was selected by TRW for desorption sampling and drill stem testing in hopes of determining the reason for the negligible methane production at the Adolph Coors Nichols l-24 well test site approximately one-half mile to the east.

The coalbeds occur in two zones:

1. Upper zone (Carbonera coals) 54 feet thick containing four beds, from top to bottom, 3.8, 1.2, 2.0, and 6.0 feet thick, a total of 13 feet of coal.

2. Lower zone (Cameo coals) 149 feet thick, separated from the upper zone by 46 feet of barren rock. This zone contains nine coalbeds that range from 0.8 to 11.4 feet thick with a cumulative thickness of 44 feet. The lowest coalbed occurs directly on top of the Rollins Sandstone.

A stratigraphic description of the above coal zones is given in Figure 5-17. A total of 57 feet of coal in 13 beds was encountered in a 249-foot interval occurring immediately above the Rollins Sandstone.

The Cameo coal zone was cored and sampled for desorption. Sample depths ranged from 2,631 to 2,770 feet. A substantial portion of the coal was pulverized during coring so that the depths measured from the cores are approximately 3 feet short compared to those measured on the geophysical logs. A total of 11 methane desorption samples were collected--nine from

coalbeds and two from roof rock. Desorption measurements, excluding lost and residual gas, over a period of 69 days provided gas content values that range from 88 to 199 cu ft/ton for the coal samples, and 2 and 18 cu ft/ton for the two roof rock samples. Gas samples will be analyzed for chemical composition. A summary of the methane desorption results to date is given in Table 5-11.

Coal and methane resources per section of land for the area adjacent to the Nichols l-23 CM well are summarized in Table 5-12. These estimates are based on the coalbed thicknesses given in Figure 5-17 and the gas desorption results for eight core samples that represent pure coal from within three coalbeds (Figure 5-17). The total coal resource is 28 million tons per square mile of area and the total methane resource is 4.2 billion cubic feet per square mile of area. Desorbed gas concentration (exclusive of lost and residual gas) based on a weighted average is 153 cu ft/ton and an arithmetic average is 141 cu ft/ton.

Two drill stem tests were conducted on the lowermost coals immediately above the Rollins Sandstone. The first test was performed on the lower of the two beds. A very small blow of gas and 40 feet of borehole fluid were recovered. During the second test, on the higher coalbed, 2 feet of borehole fluid were recovered and no blow of gas was recorded. A summary of the formation pressures in pounds per square inch gauge (psig) is as follows:

	DST No. 1 (2,754.0' to 2,769.5')		DST No. 2 (2,708' to 2,723')	
	Inside	Outside	Inside	Outside
Initial Flow psig	13.5	26.6	8.1	13.3
Initial Shut-In psig	120.7	132.7	13.5	26.6
Final Flow psig	26.9	26.6	8.1	13.3
Final Shut-In psig	93.9	106.2	13.5	26.6
Initial Hyd. psig	1,240.1	1,265.8	1,187.1	1,239.5
Final Hyd. psig	1,226.8	1,239.5	1,173.8	1,160.6

Samples of the shale roof rock were analyzed for permeability and compressive strength. The tests indicate low permeability, from less than 0.01 to 0.07 millidarcy, and an average compressive strength of 17,500 psi.

Dual induction, compensated neutron, formation density, gamma, and SP logs were run after reaching TD. Copies of the logs for the coal zones are presented in Figure 5-17.

5.2.2.2 Douglas Creek Area

TRW cooperated on four exploration wells in the Douglas Creek area--two with Fuelco, and two with Twin Arrow Drilling Company. All four wells spudded in the upper part of the Mesaverde Group. Their locations are shown on Figure 5-18, and geophysical logs showing coalbeds and cored intervals are shown on Figure 5-19. Results of desorption tests for samples from these wells are listed in Table 5-13. The following is a brief summary of each well.

Fuelco Well, Cathedral 0-28-3-101-S (FAA)

The Cathedral 0-28-3-101-S well (Sec. 28, T3S, R101W) penetrated five coalbeds that ranged from 4 to 12 feet thick. These coalbeds occurred within a 220-foot interval from 1,380 to 1,600 feet deep. Geophysical logs for this hole include the compensated neutron-formation density and the dual induction-laterolog. Two coal samples were taken from the two deepest coalbeds for desorption analysis. Results indicate gas contents of 18 and 81 cu ft/ton.

Twin Arrow Well, C&K #1-13 (FAB)

The C&K well No. 1-13 (SW 1/4, NW 1/4, Sec. 13, T3S, R101W) was in the process of being abandoned by Twin Arrow when TRW isolated and performed flow testing on the coalbeds. If flow was observed, production testing was contemplated. Geophysical logs available for this hole include induction-electric log, compensated density log and a cement bond log. The coalbeds identified using the compensated density log, correlate very well with those identified at site FAC, but the calibration of the scale is incorrect. The coals on the Welex log at site FAB indicate a specific gravity of I.9 grams per cubic centimeter (gm/cc) whereas the log at site FAC indicates a specific gravity of 1.4 gm/cc for the coals. The latter figure is consistent with other analyses of coals in this part of the Piceance Basin. Five zones were tested: 573 to 581, 627 to 633, 661 to 665, 726 to 736, and 801 to 810 feet. A bridge plug was set at 1,050 feet and the hole

was pressure- and flow-tested. Pressure and flow were negligible. Casing was cemented from 1,050 to 320 feet and then perforated in the test zones using a one-shot-per-foot spacing. The coal zones were then treated with 500 gallons of 7.5-percent HF. The hole was swabbed dry and pressure-tested. The shut-in pressure was zero and no flow was observed.

Several other coalbeds were not tested at site FAB, due to hole conditions. These beds were identifed at the following footage intervals on the Welex density log:

1,278 - 1,282 ft
1,494 - 1,496 ft
1,864 - 1,870 ft
2,116 - 2,119 ft
2,148 - 2,154 ft

Twin Arrow Well, C&K #4-14 (FAC)

The C&K well No. 4-14 (Sec. 14, T3S, R101W) was spudded on November 25, 1978 and drilled to a depth of 925 feet before it was abandoned. TRW collected 150 feet of core from 636 to 828 feet and recovered 78 percent of the section. After cementing the abandoned hole, the rig was moved approximately 30 feet and a twin hole was drilled and logged. The well location given above is taken from logs of the twin hole. Ten coalbeds occurring within a 520-foot interval were identified on the density log. Nine samples, from 685 to 986 feet, were taken for desorption analysis. The samples had gas contents that ranged from 86 to 243 cu ft/ton for the coal, and from 24 to 214 cu ft/ton for the carbonaceous shale and coal samples. All of the coal sampled for desorption was high-volatile B bituminous.

Fuelco Well, D-26-3-101-S (FAH)

TRW collected 96 feet of core at well D-26-3-101-S (Sec. 26, T3S, R101W). Six coalbeds were recovered from the coring operations, two of which were sampled for desorption analysis. Three samples, two from an 8.7-foot bed at a depth of 1,209 to 1,218 feet, and one from a 2.0-foot bed at a depth of 1,223 to 1,225 feet, had gas contents that ranged from 16 to 26 cu ft/ton. Borehole geophysical logs run include a dual induction-laterolog, compensated formation density-compensated neutron, gamma-ray, and caliper.

5.2.2.3 Rangely Area

TRW participated with Western Fuels on four wells located on the northeast flank of the Rangely anticline in the Lower White River coal field (Figure 5-20). All of the wells were spudded in the Mesaverde Group and drilled to the Rollins Sandstone at depths ranging from 800 to 1,400 feet. A graphic depiction of coalbeds encountered in the four wells is presented in Figure 5-21. Desorption sampling results are presented in Table 5-14. A brief summary of each well is given below. Borehole geophysical logs run in these wells include electric, gamma-ray, gamma-gamma, and caliper.

No. 310136-2 (FAD)

Well No. 310136-2 (SW 1/4, SW 1/4, Sec. 36, T3N, R103W) was a twin-hole operation with coring conducted in the second hole. Eleven coalbeds, all greater than 2 feet thick, were penetrated in this well. Three beds, the "E", "D", and "C", encountered at depths of 1,351, 1,330, and 1,325 feet, respectively, were sampled for desorption analysis. These samples had gas contents that ranged from 48 to 61 cu ft/ton.

No. 21011-5 (FAE)

Well No. 21011-5 (NE 1/4, SW 1/4, Sec. 1, T2N, R101W) encountered 15 coalbeds greater than 2 feet thick in an interval of 270 feet. Eight coal samples were taken for desorption from the six lowest coalbeds from 740 to 810 feet. The samples had gas contents that ranged from 16 to 90 cu ft/ton.

No. 310129-4 (FAF)

Well No. 310129-4 (NW 1/4, NW 1/4, Sec 29, T3N, R101W) drilled or cored through eight coalbeds greater than 2 feet thick within a 290-foot interval. One siltstone roof rock and two coal samples were taken for desorption analysis from the two deepest coalbeds cored at depths of 880 and 905 feet. All the samples had gas contents of less than 10 cu ft/ton.

No. 310135-4 (FAG)

Well No. 310135-4 (SW 1/4, SW 1/4, Sec 35, T3N, R101W) penetrated 10 coalbeds occurring in an interval 350 feet thick. One coal sample and one shale floor rock sample were taken for desorption analysis. The coal

sample had a gas content of 32 cu ft/ton and the floor rock sample had a gas content of 1 cu ft/ton.

5.3 DISCUSSION OF METHANE RESOURCES

A unique set of circumstances places the Piceance Basin in the position of a testing ground for ideas concerning the origin and occurrence of coalbed methane. The combination of aggregate coal thickness, variable depth of overburden, and local and regional igneous activity gives the Piceance Basin a broad range in coalbed methane reserves. Variability in gas content per unit volume of coal and detailed stratigraphic data make cross sections and area1 plots particularly useful in identifying target areas (Figure 5-3 and Plates 3, 4, and 5).

Early work on the vertical variability of coal rank by Erdmann (1934) shows how coal rank increases with depth in the coal section in the Book Cliffs coal field. He points out that, with increased depth, the heating value of the coals and the degree of carbonization increase with depth while the percentage of volatile matter decreases. These trends are indicative of the potential for increase in methane content. In addition, the coal zones and aggregate coal thickness increase markedly from west to east as shown on Figure 5-3 and Plate 4. This trend also correlates with an increase in methane production.

Reviewing cross sections, the well histories presented earlier, and maps showing gas content of coals and gassy mines, shows that gas content of coalbeds increases with proximity to the area of igneous intrusive activity. The map of regional heat flow in Colorado (in heat flow units) strongly supports this correlation (Figure 5-22). Kent and Arndt (1980a, p. 43) point out that ". . ..local advances in rank of coal in the Thompson Creek mining area and to the south resulted from accelerated thermal metamorphism caused by very steep geothermal gradients during and following localized emplacements of magma masses in Oligocene time." From data assembled for this report it appears that such regional thermal metamorphism was partly responsible for creating the observed large reserves of methane. Steven (1975) (Figure 5-23) shows two postulated Laramide Tertiary batholiths to the east and south of the basin. These batholiths could have been the source of magna for the laccoliths, sills, and silicic

volcanics observed in the region. The batholiths also would cause the observed elevated heat flow values, providing additional support for the concept of regional thermal metamorphism. As the regional metamorphism is accentuated by local metamorphism due to epizonal intrusive activity, coal rank increases still more--as does gas content. When anthracite and meta-anthracite rank is reached, as in local baked zones of sills and dikes, volatile matter and gas content may drop off. At present, the medium- to low-volatile bituminous ranks appear to be the most gassy in southeastern Piceance Basin. Figure 5-24 from Freeman (1979) shows this relation quite clearly, especially for the Coal Basin-Thompson Creek areas. Also evident in this illustration is the correspondence of the semi-anthracite range and the thickest sections on the depth of overburden map, Plate 5.

Dolly and Meissner (1977) discuss the high gas content of mines in the Raton Basin. Their review of coal rank, gas content, and occurrence of igneous rocks reveals associations similar to those found in Piceance Basin. On page 262, they note:

> In addition to the "average" coal ranks reported in the various mining areas of the basin and those predicted regionally at depth, significant volumes of coal have been locally metamorphosed to considerably higher rank in "natural coke" zones associated with widespread igneous dike and sill intrusion prevalent in all parts of the basin.

In the Raton Basin, Dolly and Meissner (1977) found that coal mines in higher rank coals were very gassy, and believed this provided evidence of an association of high methane gas content and levels of organic metamorphism. Figure 5-25 illustrates their view of the relationship between organic metamorphism, coal rank, percent volatile matter, and methane gas content.

The depth of overburden-depth of burial concept is hard to quantify because the total thickness of Eocene deposits is unknown. However, because the age of uplift is considered to be in the Pliocene (Larsen et al., 1975), the coalbeds probably were at great depth during most of the Tertiary. Coalification and rank increase due to depth of burial are highly probable, especially in light of the previously mentioned data collected by Erdmann (1934).

Whether methane production is high in any prospect areas depends on several factors other than coal rank. If an area is heavily fractured and the coals are deep, production could be high as in Coal Basin and Thompson Creek. Shallower, fractured coals are less likely to be gassy, because the gas may have escaped--particularly if the coals lie above the water table. Data collected for this report indicate that productive depths for coalbed methane in the southeastern part of the basin begin at depths greater than 2,000 feet except where adjacent to igneous intrusions.

Sandstone beds, often associated with the coals, may act as reservoirs for methane leakage. Many of the productive sands, such as at the Divide Creek gas field, may be producing coalbed methane (Murray et al., 1977). Coals that are naturally or artifically fractured may reverse the process and produce gas and water until a dewatered system would yield only gas. Of course, if the sandstones were highly permeable, they would be the most appropriate target.

The above analysis has led to the following proposed guidelines for future targeting in the Piceance Basin: The southeastern Piceance Basin has high methane content where a) overburden thickness is greater than 2,000 feet; b) areas where the heat flow is greater than 1.5 to 2 heat flow units; c) areas close to epizonal igneous intrusives; d) areas of faulting; e) areas of high aggregate coal thickness; and f) along field axes, both synclinal and anticlinal. Prime target areas are those where two or more of these guidelines apply.

5.4 ESTIMATED RESOURCE VOLUME

Coal resources of the Piceance Basin were estimated on a field-by-field basis by Hornbaker et al. (1976) to a depth of 6,000 feet, as summarized in the columns below.

	Size of Area Considered* (square miles)	Coal Resources* (billions of tons)	Total Thickness of Coal Represented** (feet)
Lower White River	930	11.8	11.0
Danforth Hills	400	10.5	22.8
Grand Hogback	160	3.0	16.3
Carbondale	165	5.2	27.4
Crested Butte	240	1.6	5.8
Somerset	320	8.0	21.7
Grand Mesa	160	8.6	16.3
Book Cliffs	800	7.2	7.8
	3,545	55.9 Total	13.7 Average

* Data from Hornbaker et al. (1976)

**Total thickness determined by using a tonnage factor of 1.152 million tons of bituminous coal per square mile of area per foot of coal.

Total area of the Piceance Basin underlain by Mesaverde coalbeds as measured by planimeter is 6,570 square miles. The area of the basin used by Hornbaker et al., above, where they considered the coals to be less than 6,000 feet deep, was 3,545 square miles, more than half the basin's area. Total coal resource for depths less than 6,000 feet for this area, calculated by them, was 55.9 billion tons. In the final column at the right above, the total coal thickness for each field resulting from Hornbaker et al.'s values ranges from 5.8 to 27.4 feet, and averages 13.7 feet of coal for the entire 3,545 square mile area they considered.

It is the authors' opinion that the above average value of 13.7 feet for total thickness of coal underlying over half the area of Piceance Basin substantially understates the amount of coal actually present. In a preliminary attempt to arrive at a better evaluation, an incomplete map of total coal thickness in Piceance Basin was constructed, based principally on drill-hole geophysical logs. This map incorporates data accumulated during this study from Fender and Murray (1978), recent USGS drilling programs, and some selected data from underground mine measurements reported principally in early 1900 USGS Bulletins. Data points accumulated to date are principally concentrated south of the Colorado River. Here, data was sufficient to construct a preliminary isopach map of total thickness of

Mesaverde coals to a 20-foot contour interval (Figure 5-26). North of the Colorado River, data points are insufficient to contour; however, enough points are present to sketch an approximate location for the 40-foot contour line.

In attempting to estimate the coalbed methane resource for Piceance Basin, a range of values was selected, having as end points the lower and upper reasonable limits for the average value for total thickness of coal in the basin. For the basin south of the Colorado River, the 40-foot thickness contour seems to be a conservative lower limit, as it encompasses about 65 percent of the area. The 80-foot contour interval is a reasonable upper limit as it encompasses about 20 percent of the area. Thus, for the approximately 2,430 square miles south of the Colorado River underlain by coal, 60 feet will be used as an average thickness of total coal, and for the lower and upper limits, 40 and 80 feet. These values provide a quick approximate estimate for Mesaverde coal resource present south of the Colorado River:

2,430 square miles x 60 feet x 1.152 x 10^6 tons = 168 billion tons.

In an attempt to be more exact in estimating coalbed thickness distribution for the area south of the Colorado River, the areas between each 20-foot contour line were planimetered with results shown below:

Contour Interval (feet)	Area[1] (square miles)	Total Coal[2] (millions tons)
0-20	536	6.2
20-40	300	10.4
40-60	608	35.1
60-80	521	42.0
80-100	413	42.8
100-120	35	4.5
120-140	14	2.0
140-160	5	0.8
Totals	2,432	144

[1] Values include separate calculations for average thickness of coal for high and low points on the coal isopach map.

[2] Tonnage factor is 1.152 million tons of coal per foot of coal per one square mile of area.

As shown above, the basin underlain by Mesaverde coals south of the Colorado River is 2,430 square miles, total coal resource present is 144 billion tons, and the average thickness is 51 feet.

For the approximately 4,140 square-mile area north of the Colorado River underlain by Mesaverde coal, values of 40 feet for the lower limit, 60 feet for the upper limit, and 50 feet for the average value will be used. Thus, for the area north of the Colorado River, Mesaverde coal present is estimated at:

4,140 square miles x 50 feet x 1.152 x 10^6 tons = 238 billion tons.

The methane gas resource for the area south of the Colorado River will have the following values: 150 cu ft/ton as a lower limit; 450 cu ft/ton as an upper limit; and 250 cu ft/ton as an average value. For the area north of the Colorado River, with its demonstrated lower methane concentrations, 25 cu ft/ton as a lower limit, 200 cu ft/ton as an upper limit, and 100 cu ft/ton as a possible average will be used.

Using the values derived above, the estimated methane resource for Piceance Basin areas south and north of the Colorado River, separately, are shown in Table 5-15. The estimated coalbed methane resource in the Piceance Basin, south of the Colorado River, is 36 trillion cubic feet, and north of the river, 24 trillion cubic feet. For the entire basin, the methane resource is estimated at 60 trillion cubic feet, with an estimated lower limit of 28 and an upper limit of 112 trillion cubic feet. These values are rounded to 60, 30, and 110 trillion cubic feet, respectively.

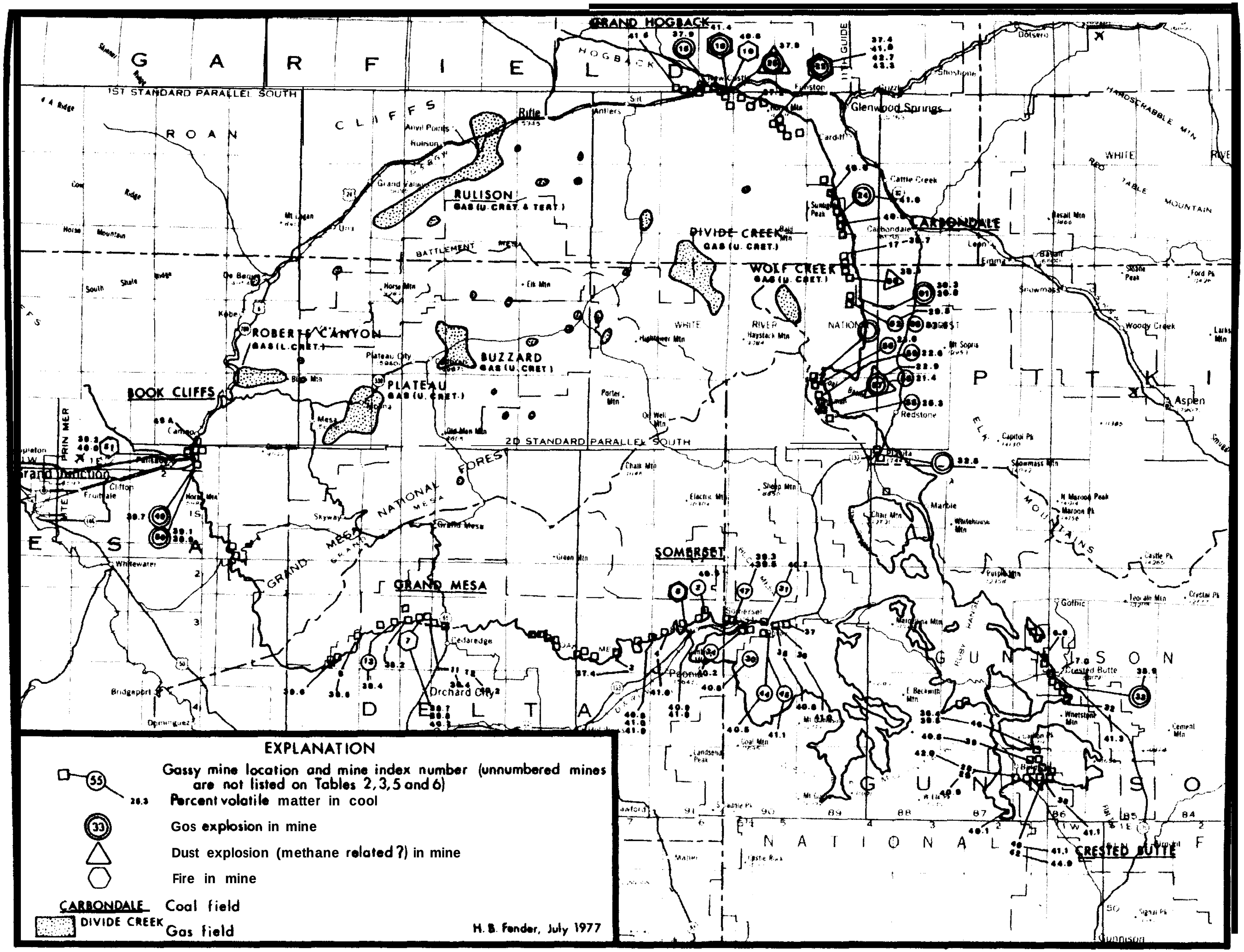


Figure 5-1. Gassy Coal Mines and Percent Volatile Matter in Coal, Southeastern Piceance Basin (Murray, et al., 1977)

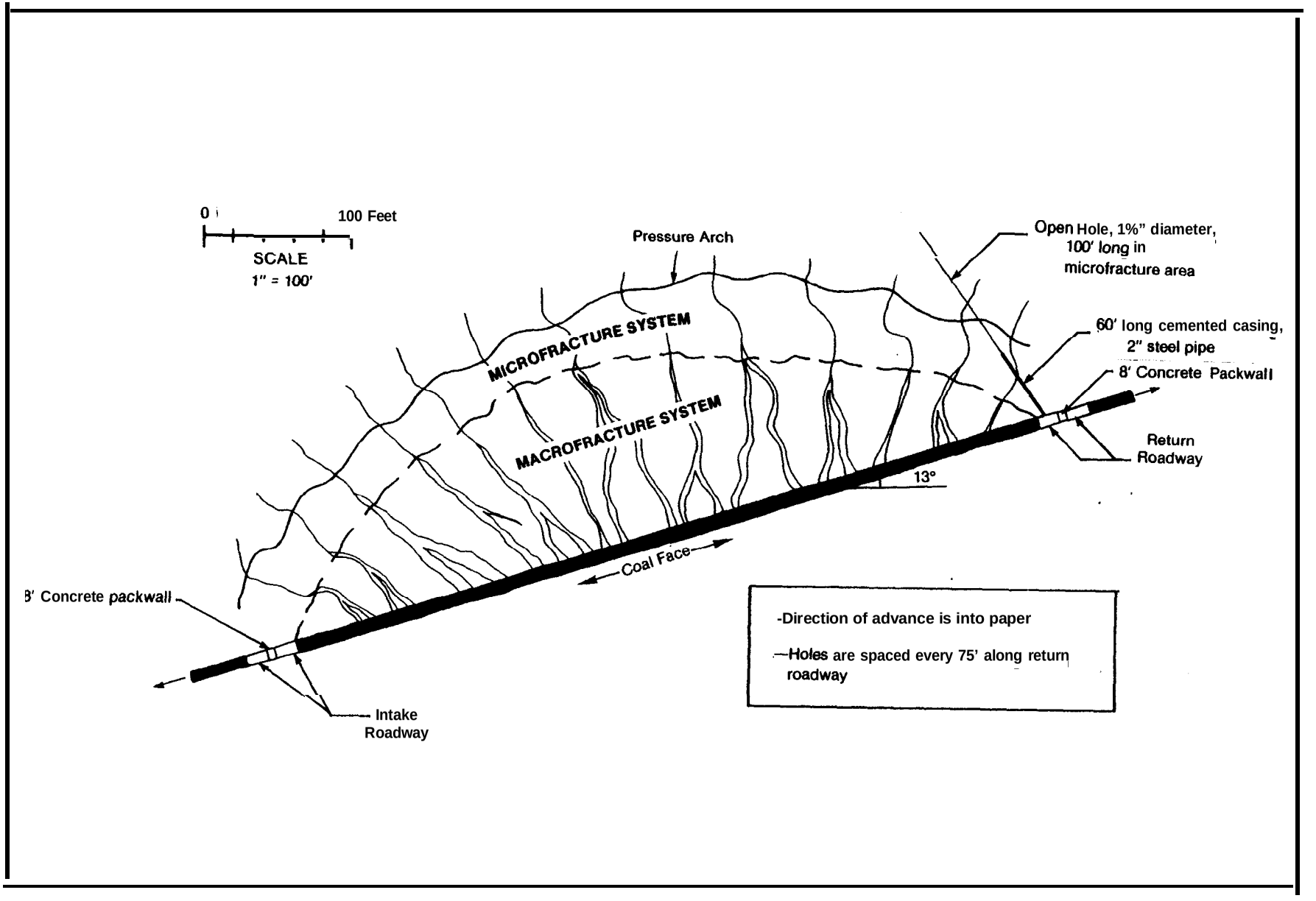


Figure 5-2. Cross Section of Mid-Continent Longwall Mining Operations Showing Methane Drainage System (Personal Communication, Turnipseed, 1980)

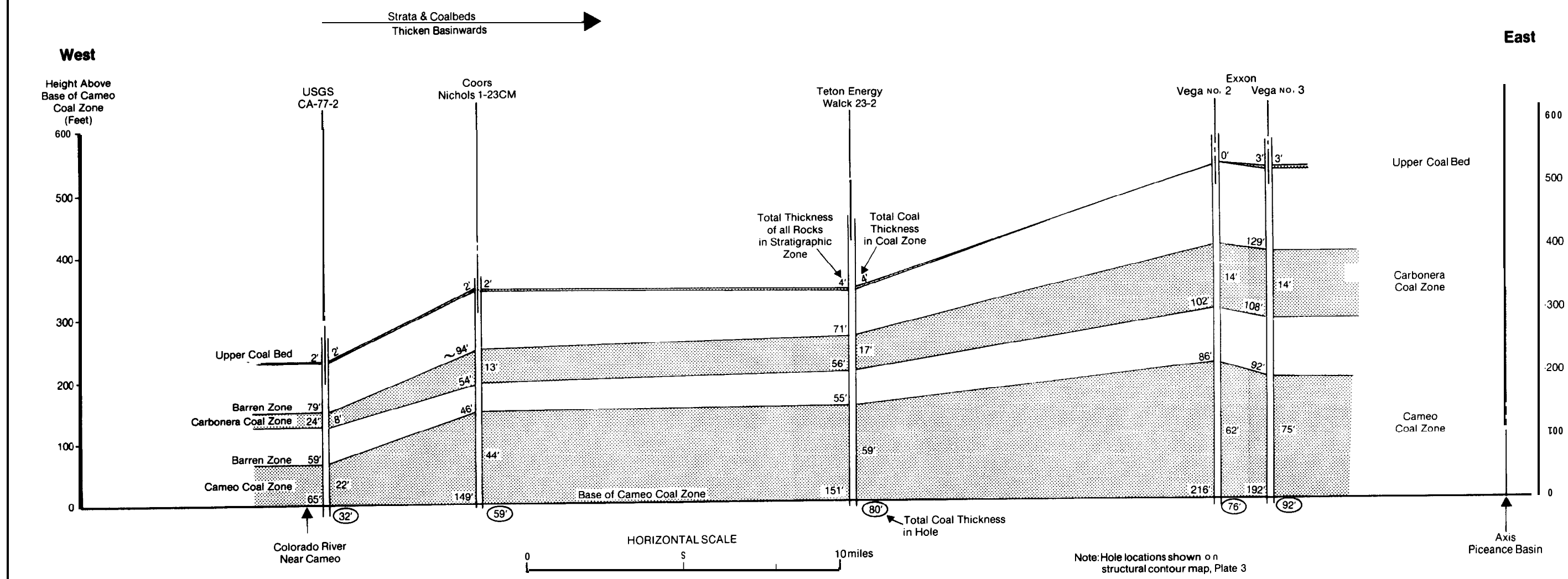


Figure 5-3. East-West Section from the Colorado River to Piceance Basin Synclinal Axis Showing Correlation of Coal Zones in Five Wells, with the Cameo and Carbonera Coal Zones of the Book Cliffs Coal Field

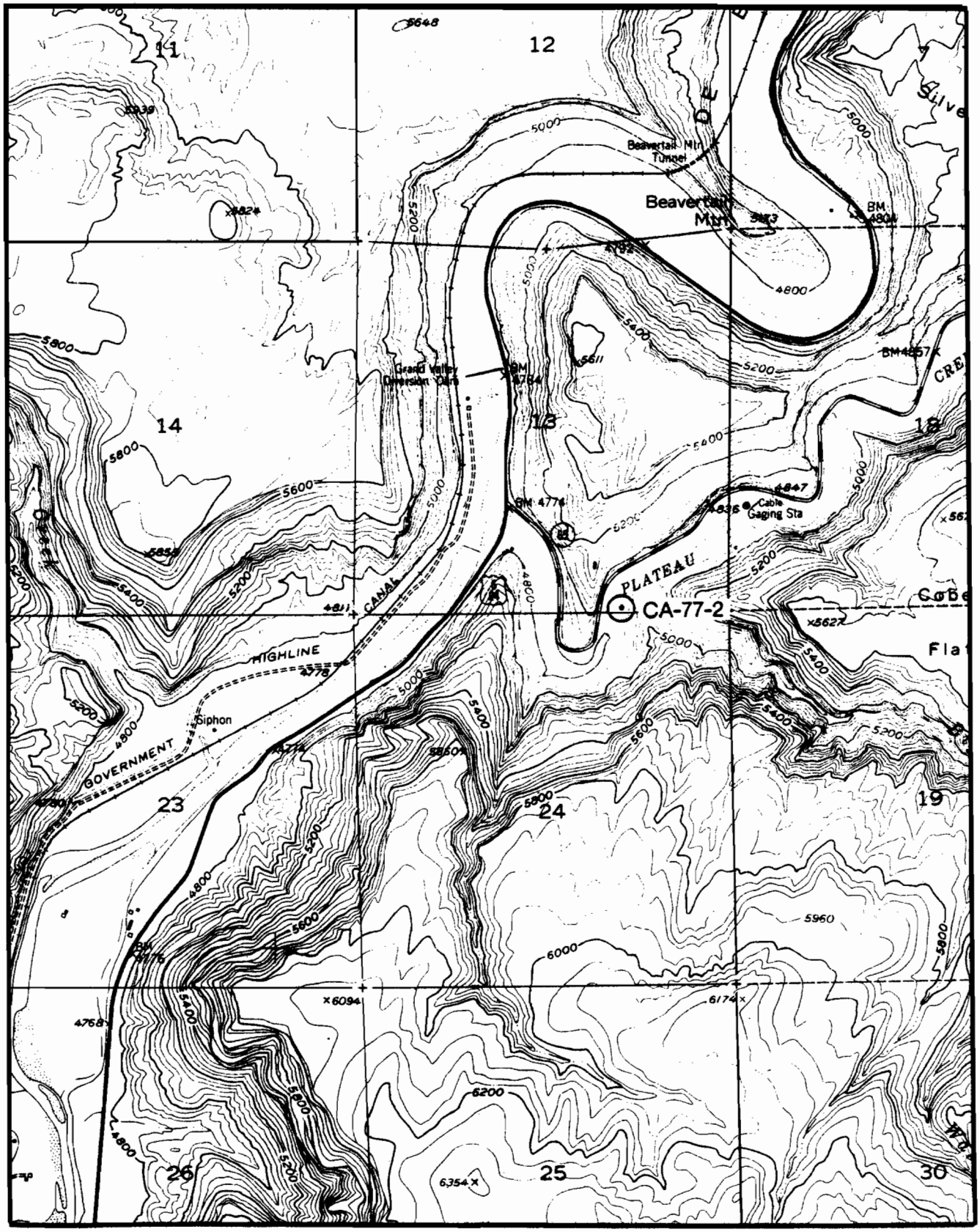


Figure 5-4. Map Showing Location of USGS Drill-Hole CA 77-2 Near the Juncture of Plateau Creek and Colorado River

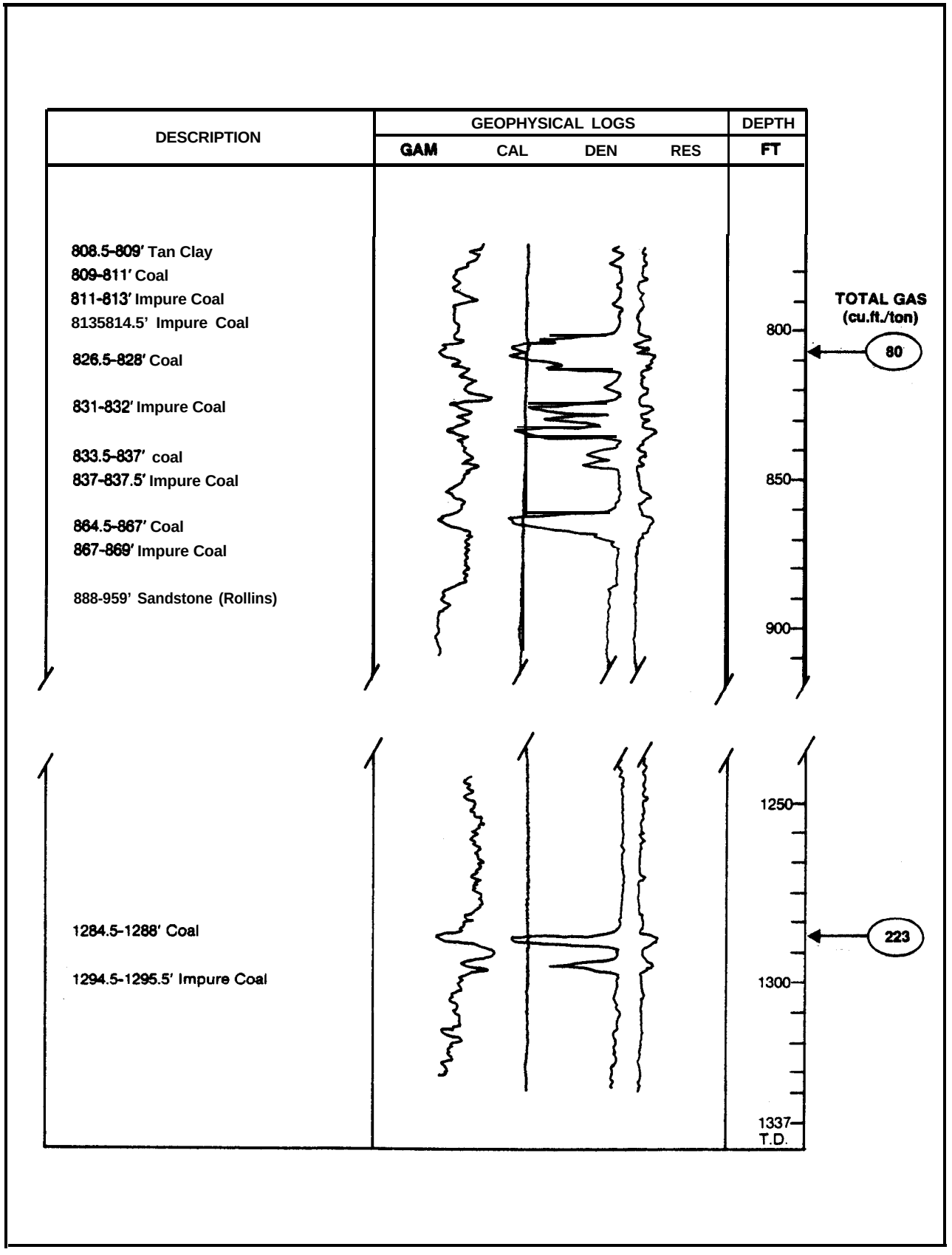


Figure 5-5. Coal Desorption Data With Correlation of Core Descriptions and Geophysical Logs of USGS Drill Hole No. CA 77-2 (Eager 1979; Colorado Geological Survey, 1980)

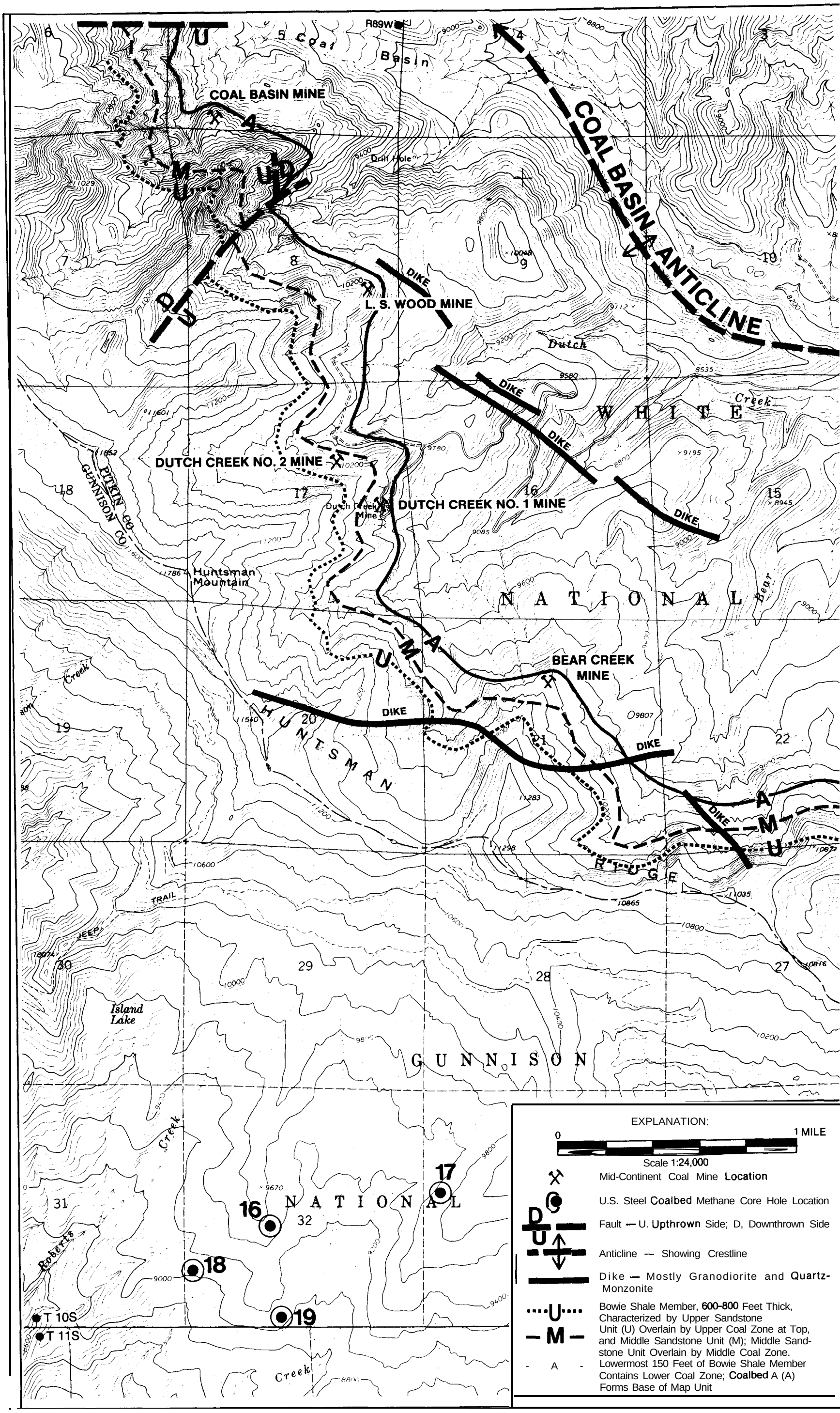


Figure 5-8. Geologic and Topographic Map of the Coal Basin Area Showing Locations of the Mid-Continent Mines and the U.S. Steel Coalbed Methane Drilling Sites (Modified from Kent and Arndt, 1980b)

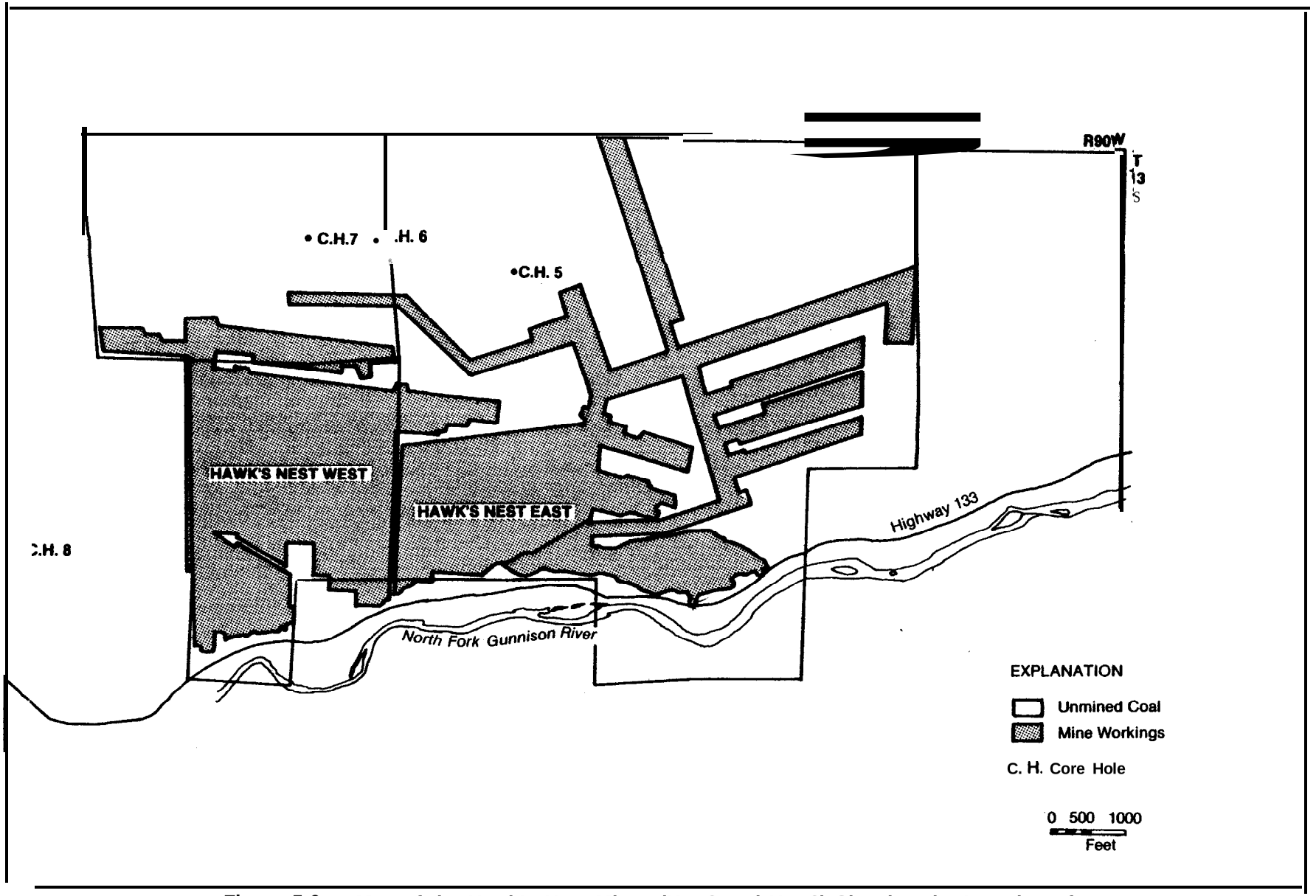
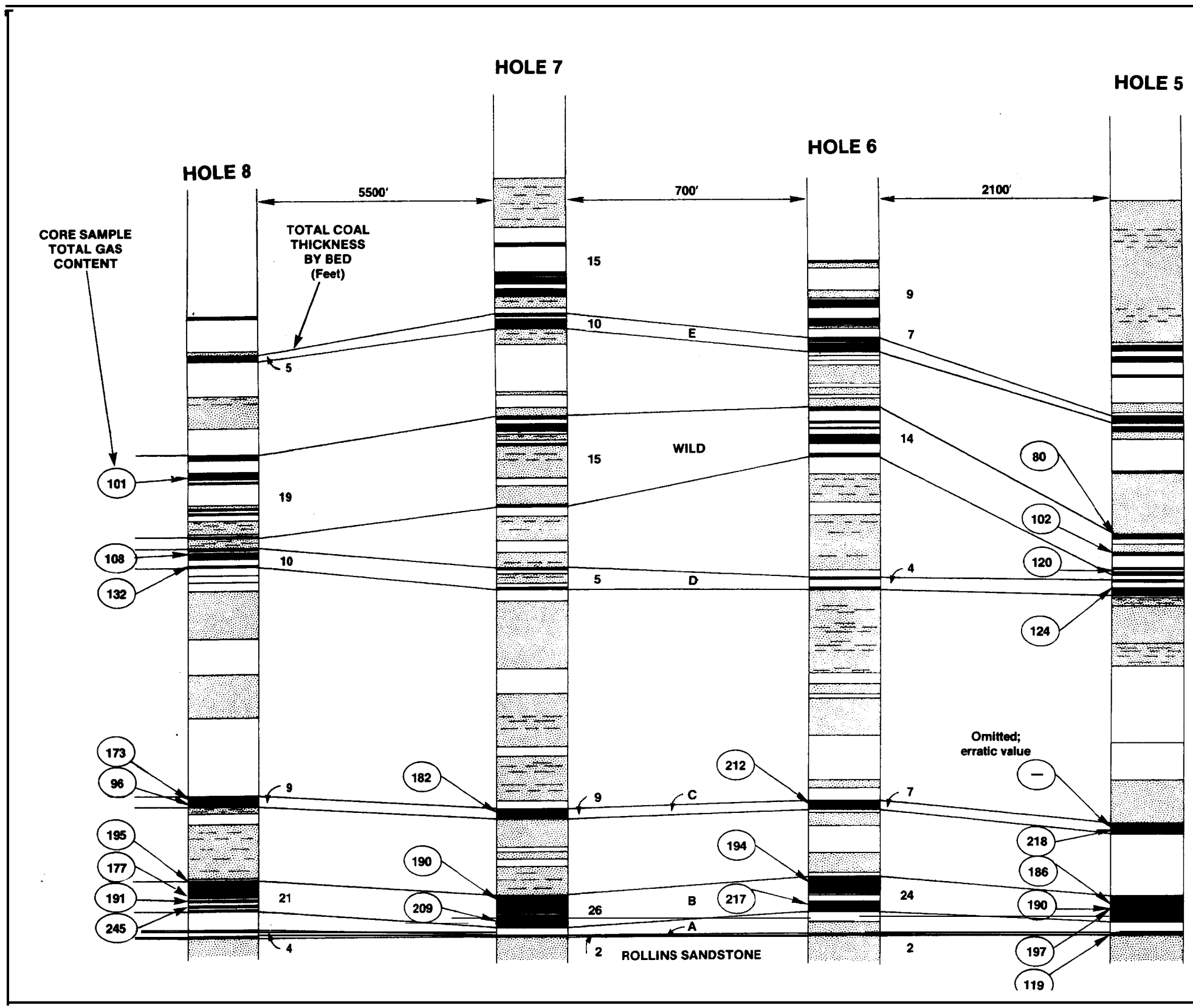


Figure 5-9. Map of the Hawk's Nest Mines (No. 2 and No. 3) Showing the Location of the Exploration Drill Holes Sampled for Desorption Analysis. Reference Plate 3 (After Boreck and Strever, 1980)



AVERAGED VALUES BY COAL ZONE		
COAL ZONE OR COALBED	TOTAL GAS (cu. ft./ton)	TOTAL COAL THICKNESS (Feet)
		11 (beds above E; from 3 holes)
m		7
Wild	101 (4 Samples)	14.75
o	121 (3 Samples)	6.75
	133 (5 Samples)	8.5
B	199 (11 Samples)	23.75
A	119 (1 Sample)	2.75
	TOTAL COAL	74.5

Figure 5-10. Sections of Core Holes at Hawk's Nest Mine (Modified Boreck and Strever, 1980)

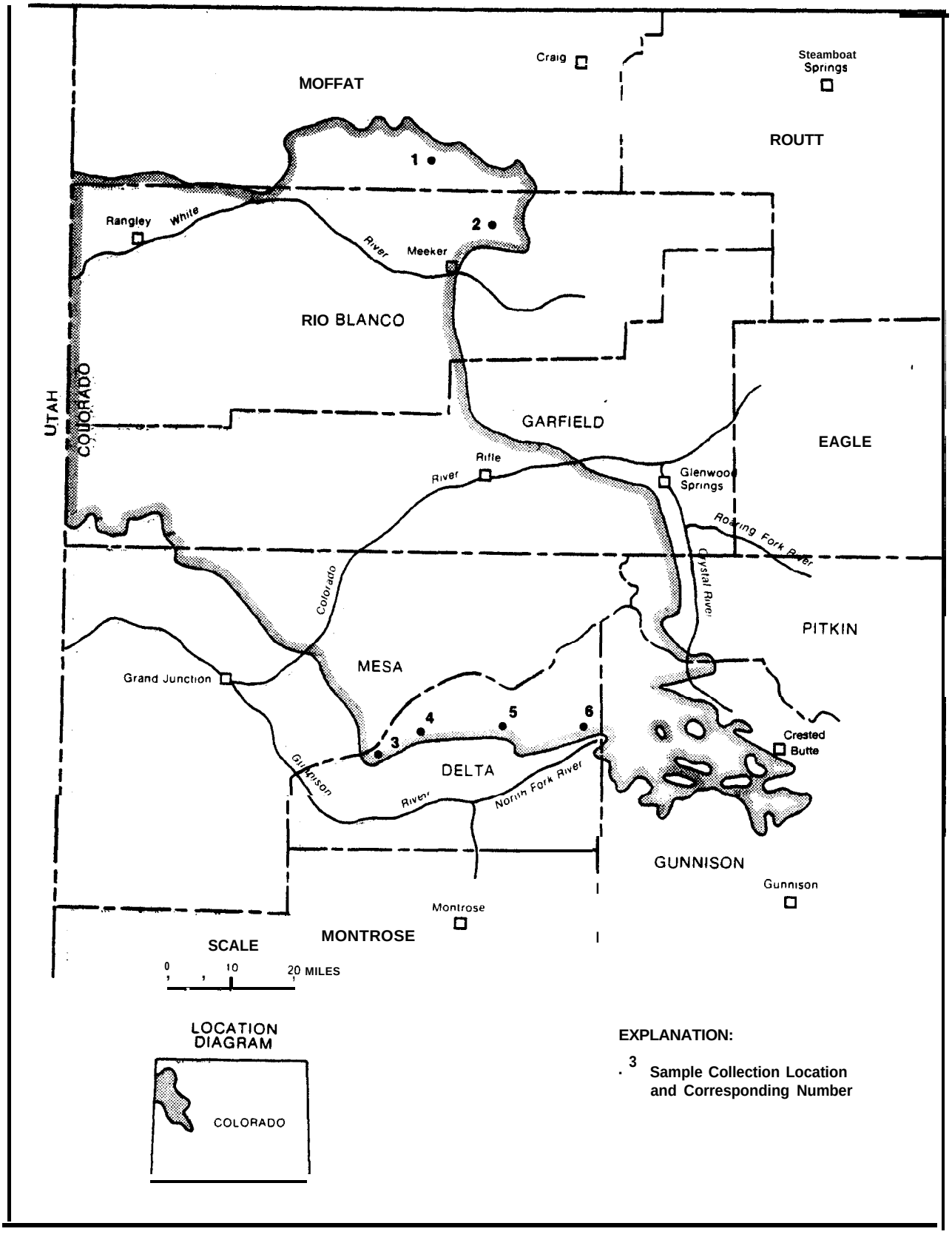
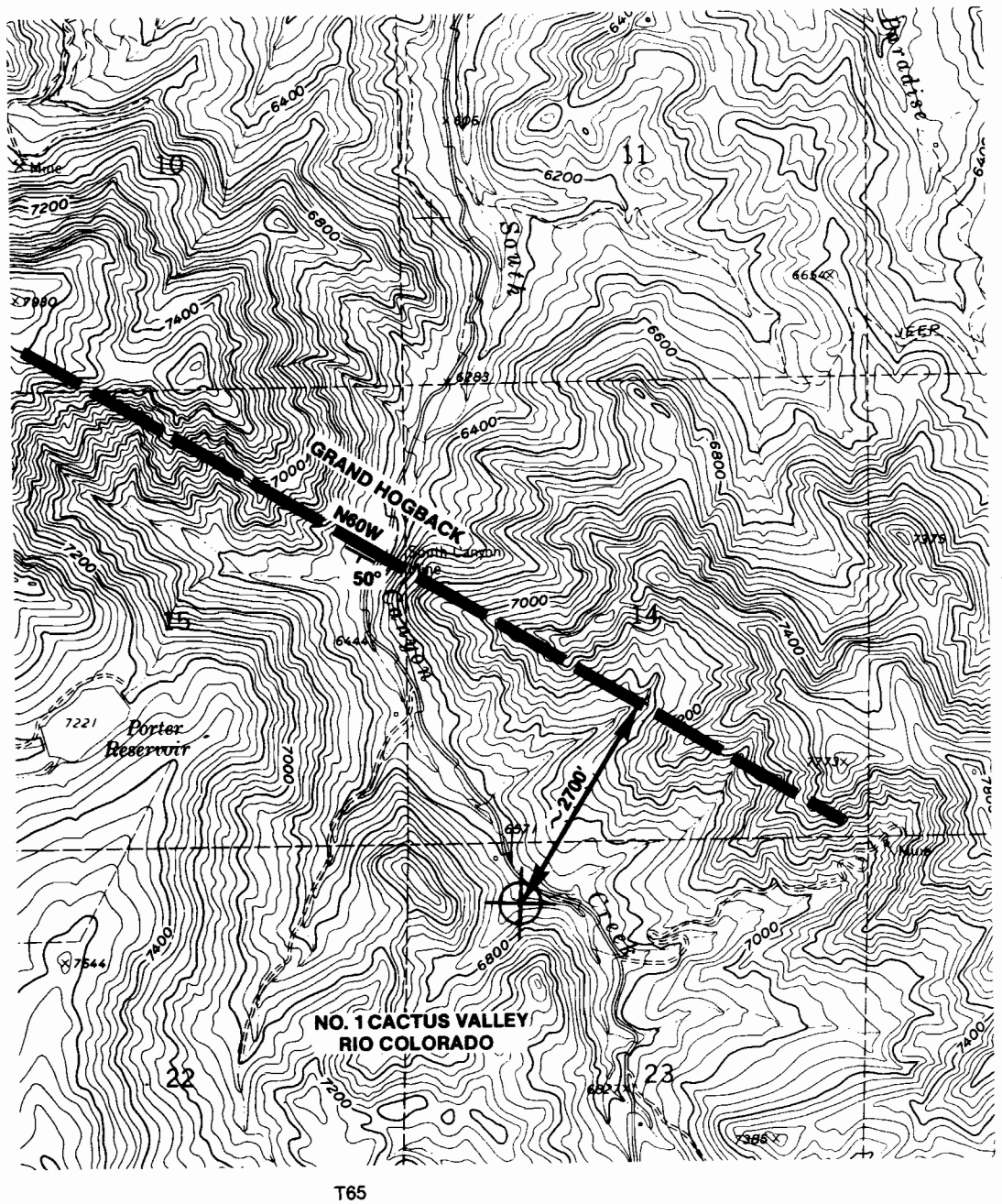


Figure 5-11. Locations of Six Areas where Coaibed Core Samples Were Collected by the Colorado Geological Survey for Methane Desorption Measurements (Modified from Colorado Geological Survey, 1980)



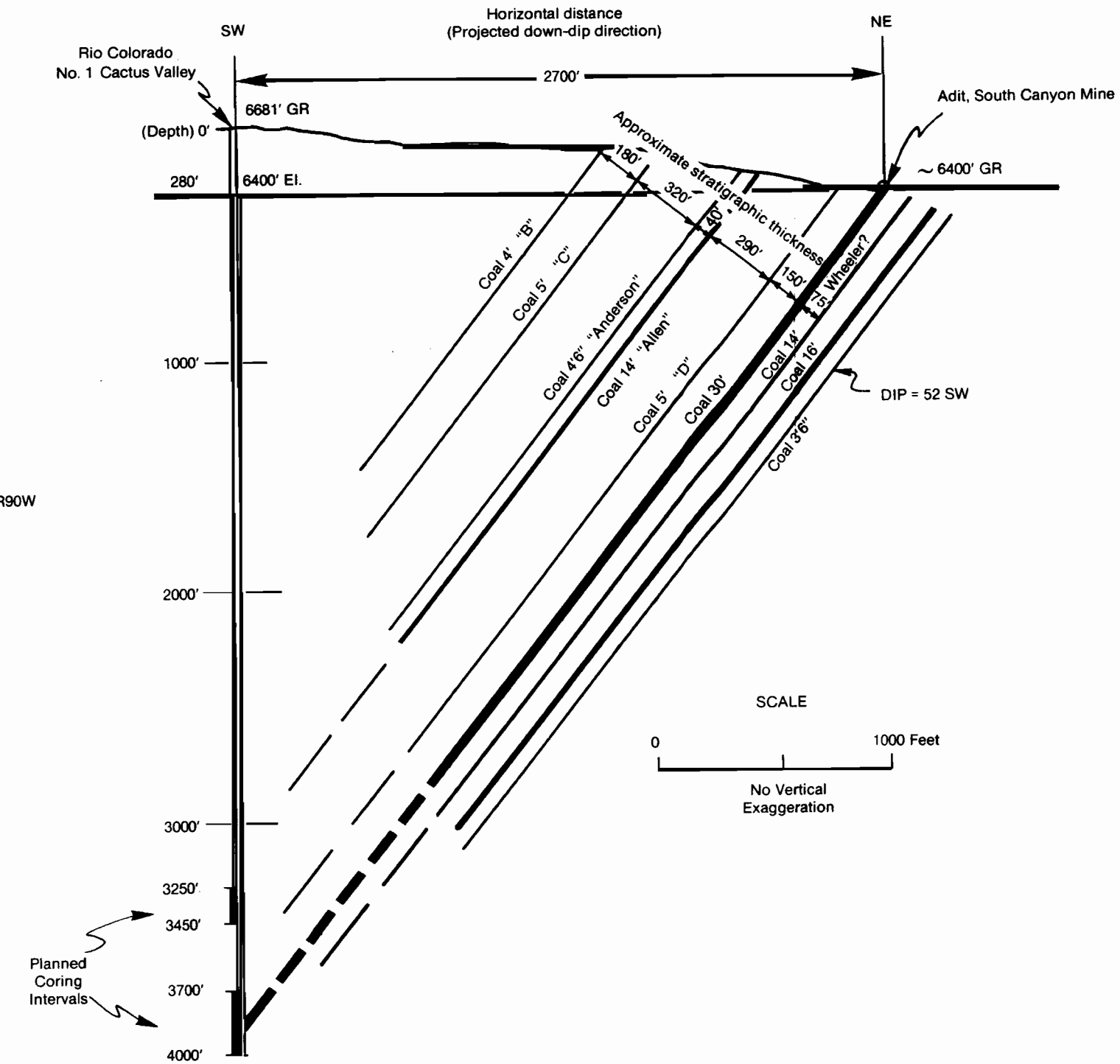


Figure 5-12. Map Showing Location of Rio Colorado Well No. 1 Cactus Valley in Garfield County, and a Cross Section Showing the Coalbed Targets of the Well (After Gale, 1910)

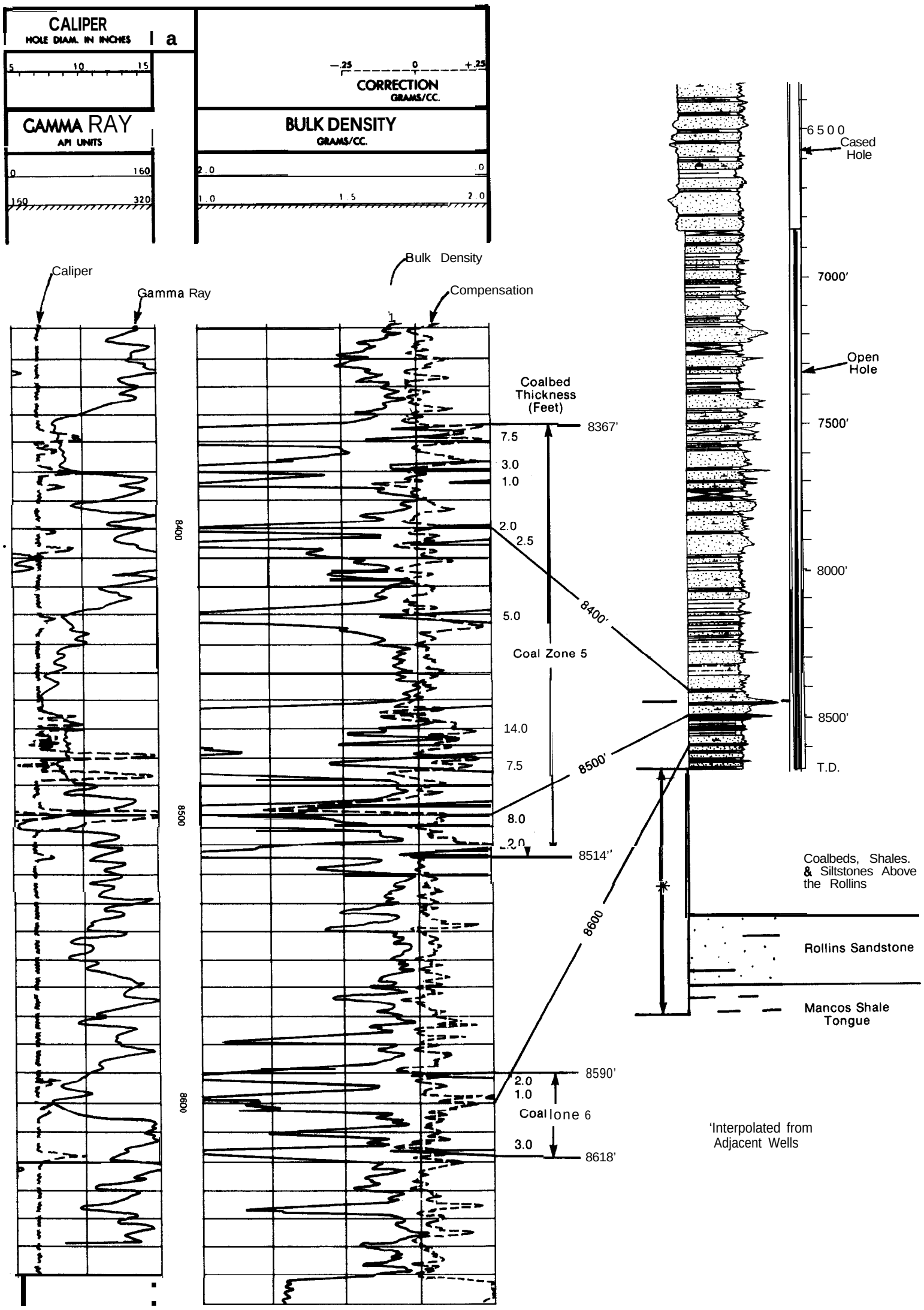


Figure 5-13. Compensated Formation Density and Lithologic Logs Showing Extent of Coalbeds in the Open-Hole Completion Zone of Chevron Well Skonberg No. 1 on the Axis of Divide Creek Anticline, Garfield County (Lithologic Log Modified from Johnson, et al., 1979b)

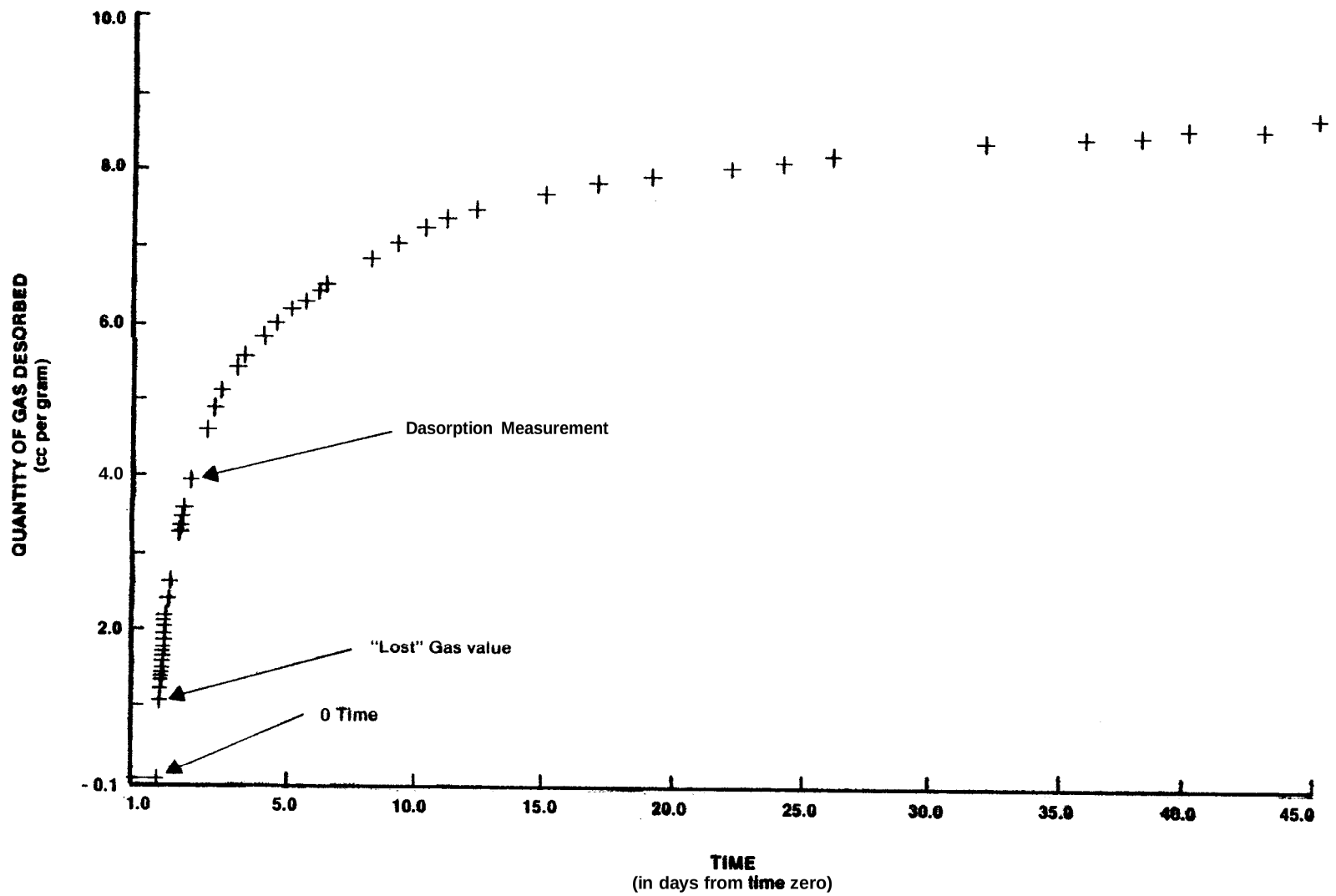


Figure 5-15. Cumulative Curve of Gas Desorbed for First 45 Days, Sample No. 12 Cored from the 14-Foot-Thick Coalbed just above the Rollins Sandstone, Depth 4,800 feet, Teton Energy Well, Walck 23-2, Piceance Basin, Colorado

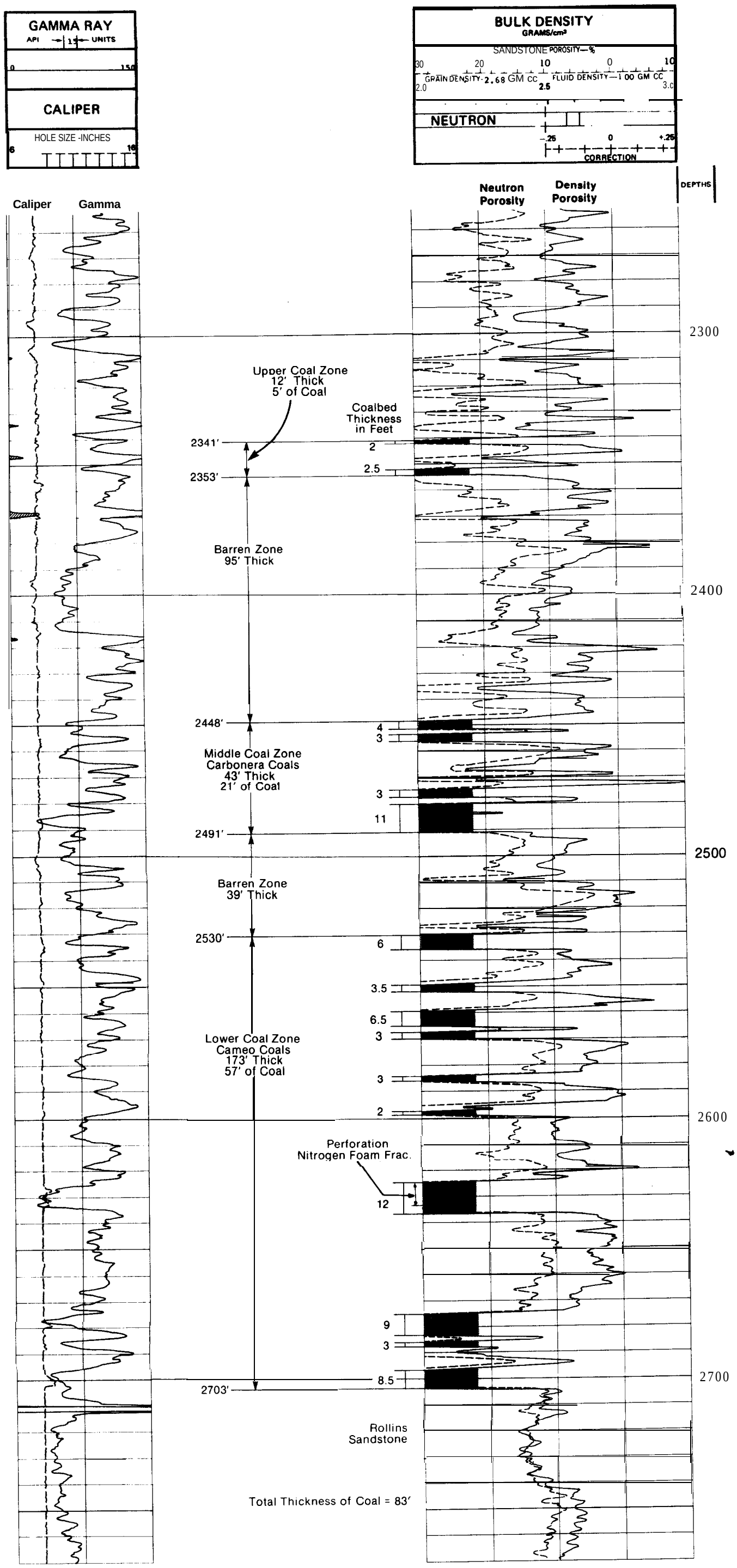


Figure 5-16. Density Log Showing Coalbed Locations and Thicknesses Along With Locations of Perforation and Nitrogen Foam-Frac for Adolph Coors Well, Nichols 1-24. Shaded Portions on Density Log Indicate Individual Coalbeds

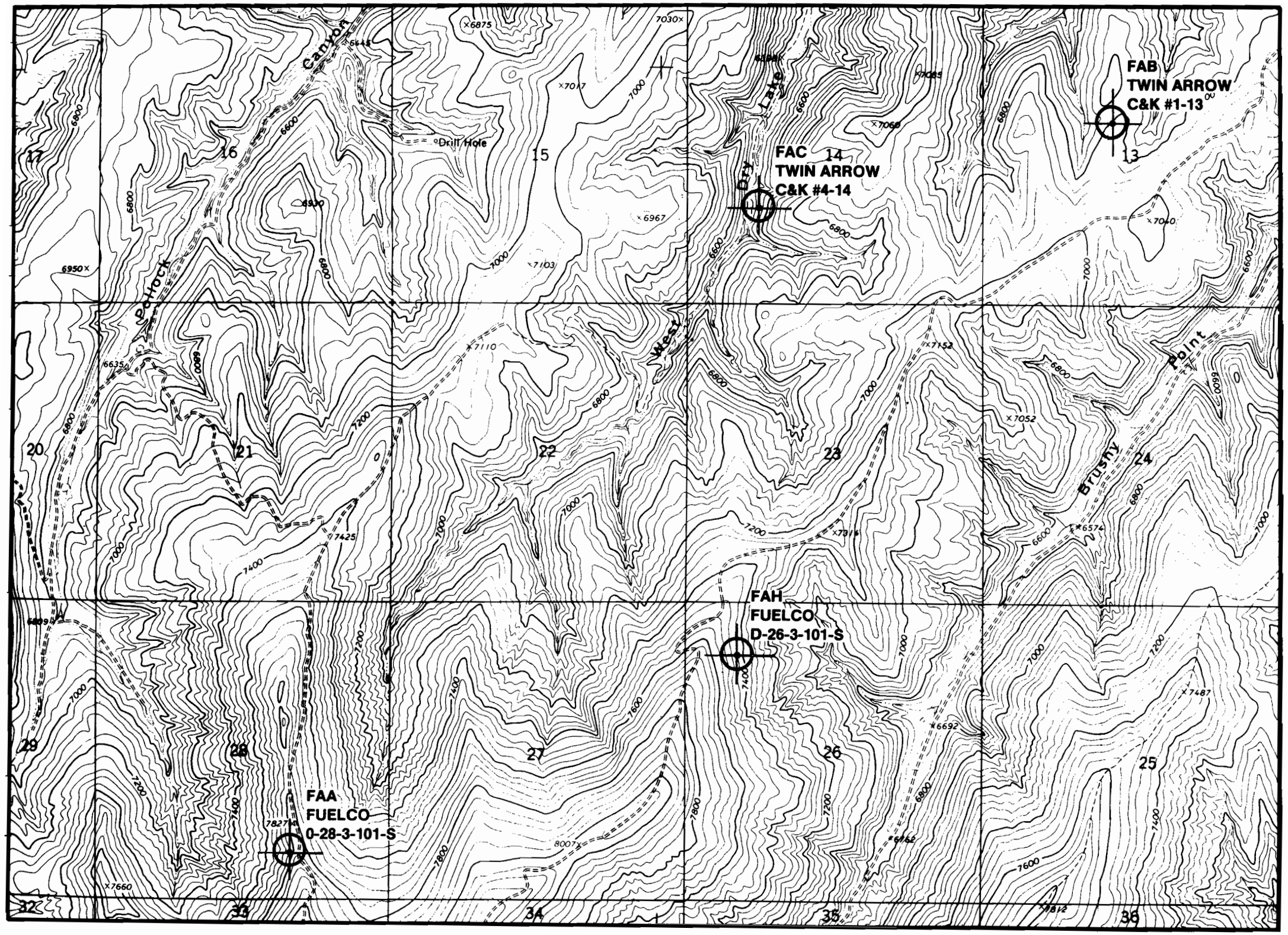


Figure 5-18. Topographic Map Showing Locations of Douglas Creek Area MRCP Drill Sites in T3S, R101S, Rio Blanco County, Colorado

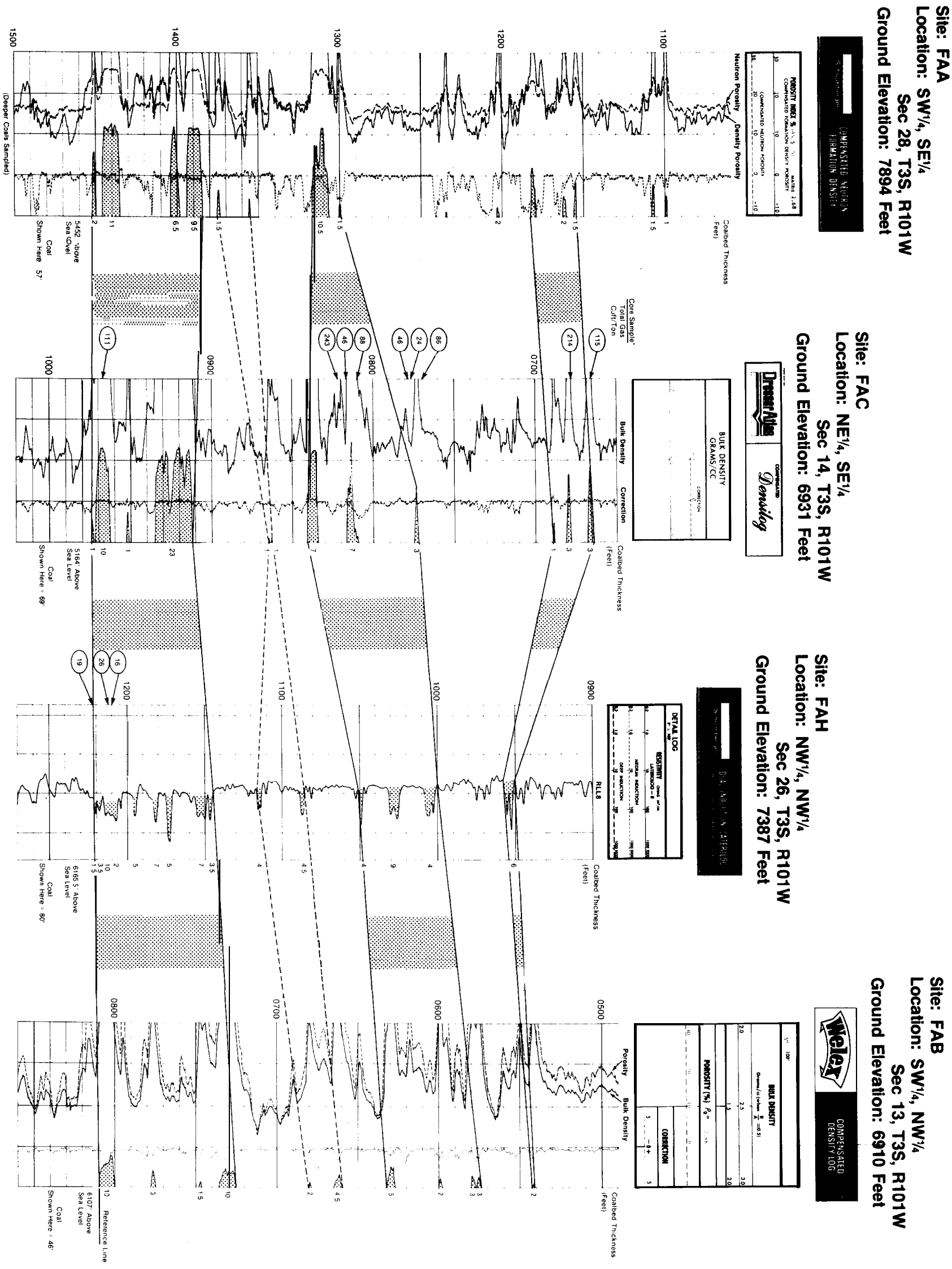


Figure 5-19. Geophysical Logs Showing Coalbeds and Methane Desorption Results for Douglas Creek Area MRCP Drill Sites in T3S, R101 W, Rio Blanco County, Colorado. (All Ground Elevations are Relative to Mean Sea Level)
Shaded Areas Indicate Coal Zones; Dashed Lines Show Tentative Correlations; Shaded Portions of Density Log Indicate Individual Coalbeds.

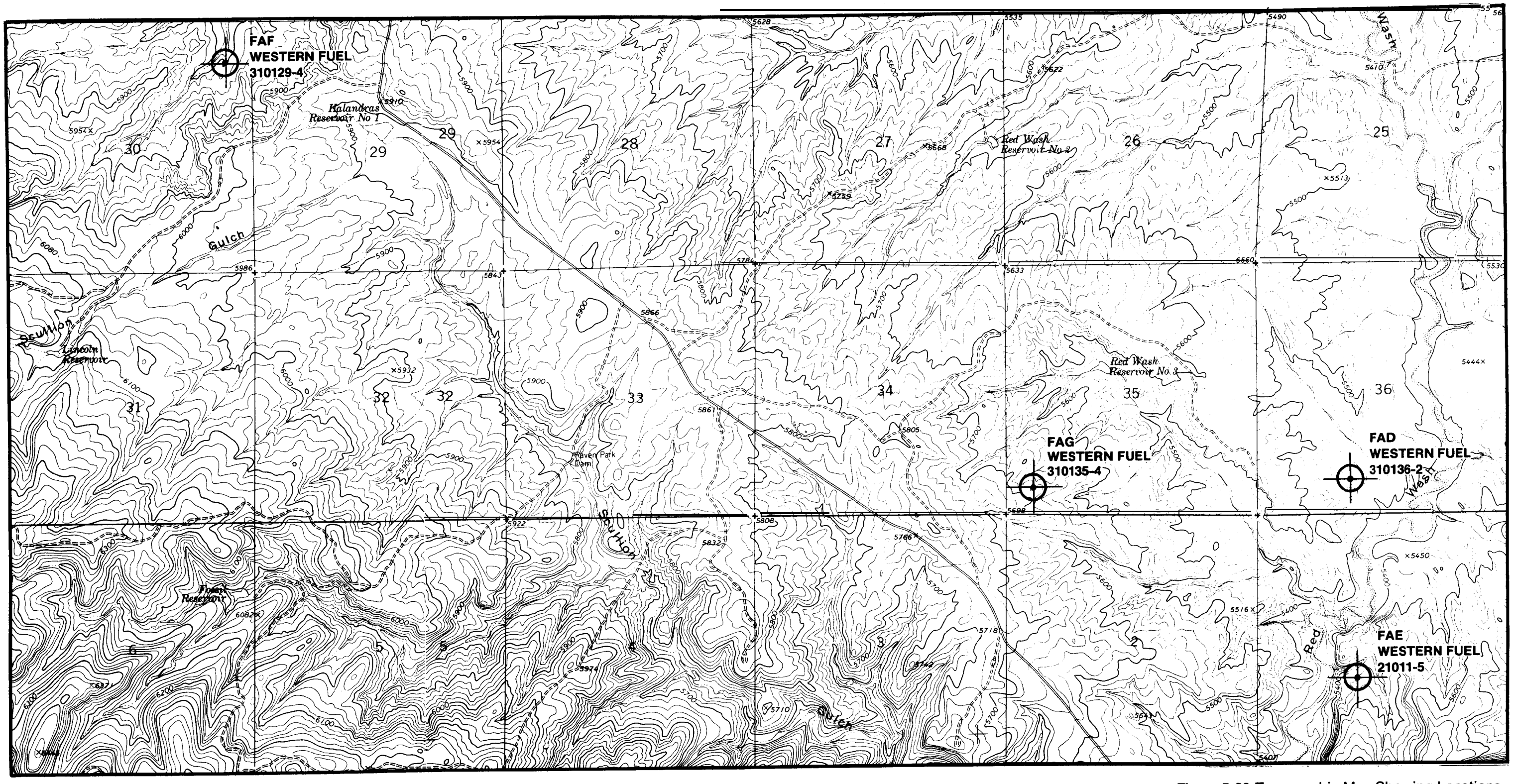


Figure 5-20. Topographic Map Showing Locations of Rangely Area MRCP Drill Sites in T2-3N, R101W, Rio Blanco County, Colorado

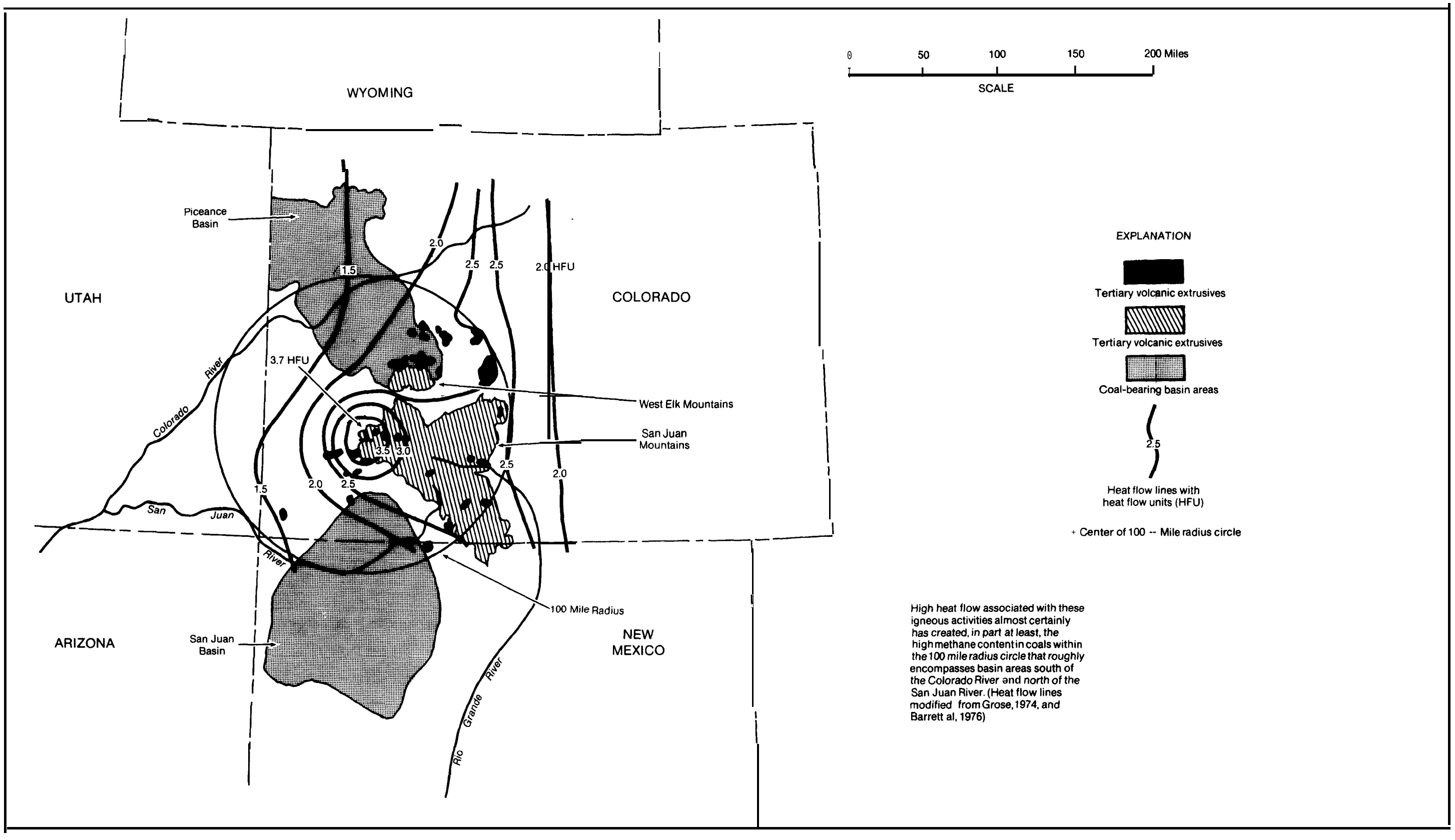


Figure 5-22. Map Showing Physical Relationship of Southeastern Piceance Basin and Northern San Juan Basin to Tertiary Volcanics, Heat Flow, and Igneous Intrusives (Modified from Grose, 1974 and Barrett, et al., 1976)

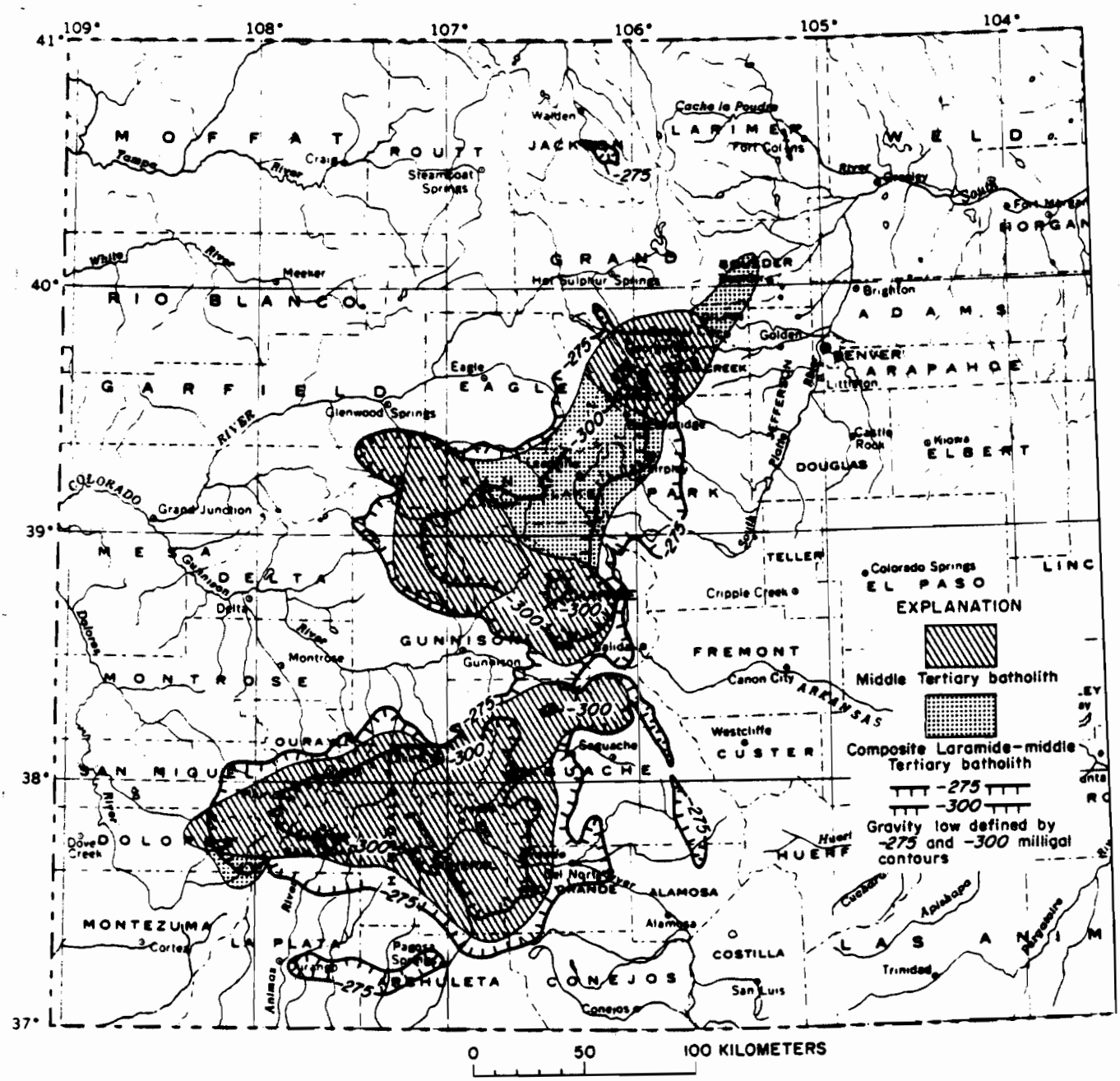
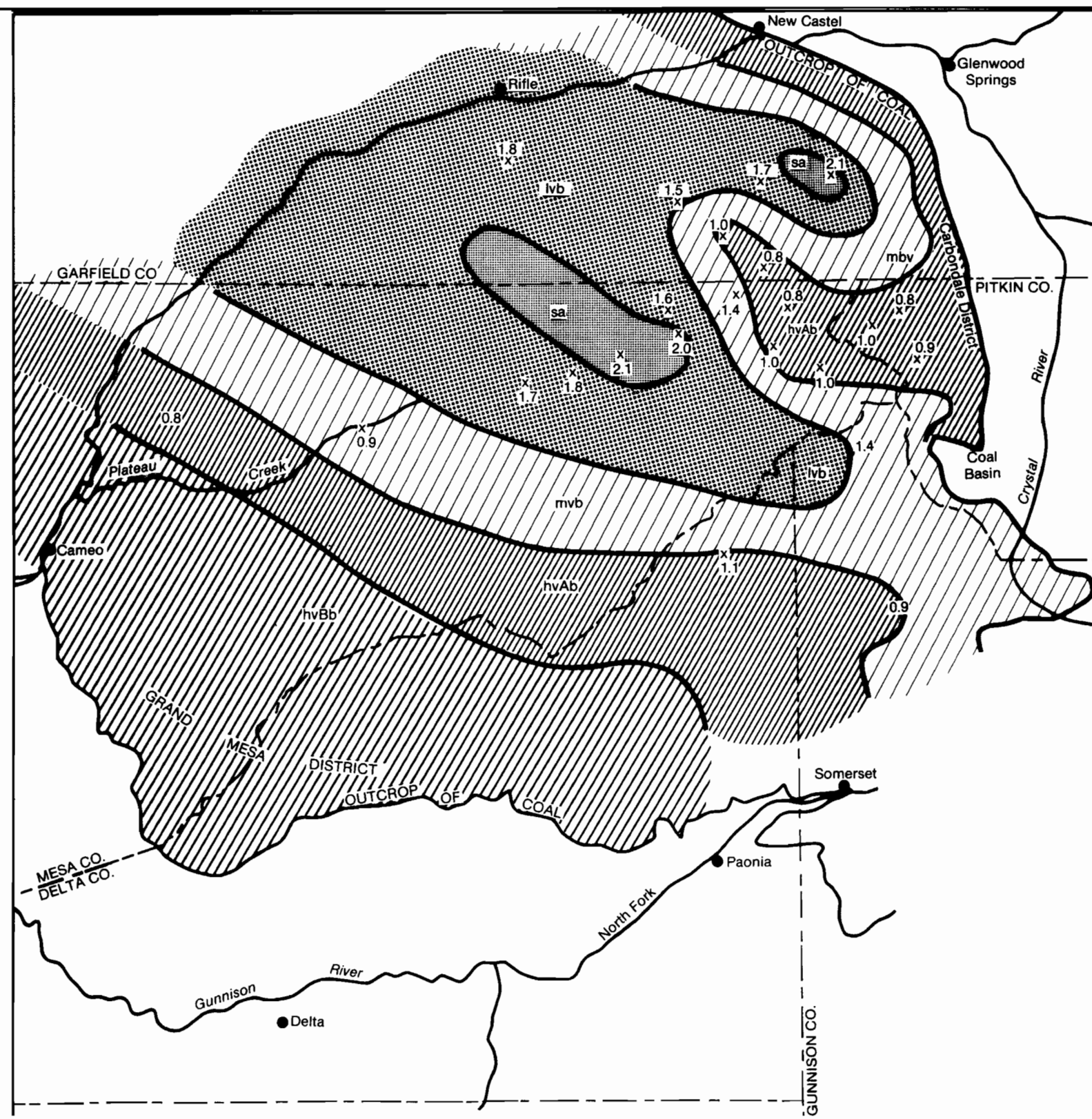


Figure 5-23. Map Showing Relation of Postulated Batholiths to Gravity Lows, West-Central Colorado (Steven, 1975)



EXPLANATION

sa — Semi-Anthracite

lvb — low volatile bituminous

mbv — Medium volatile bituminous

hv A b — high volatile A bituminous

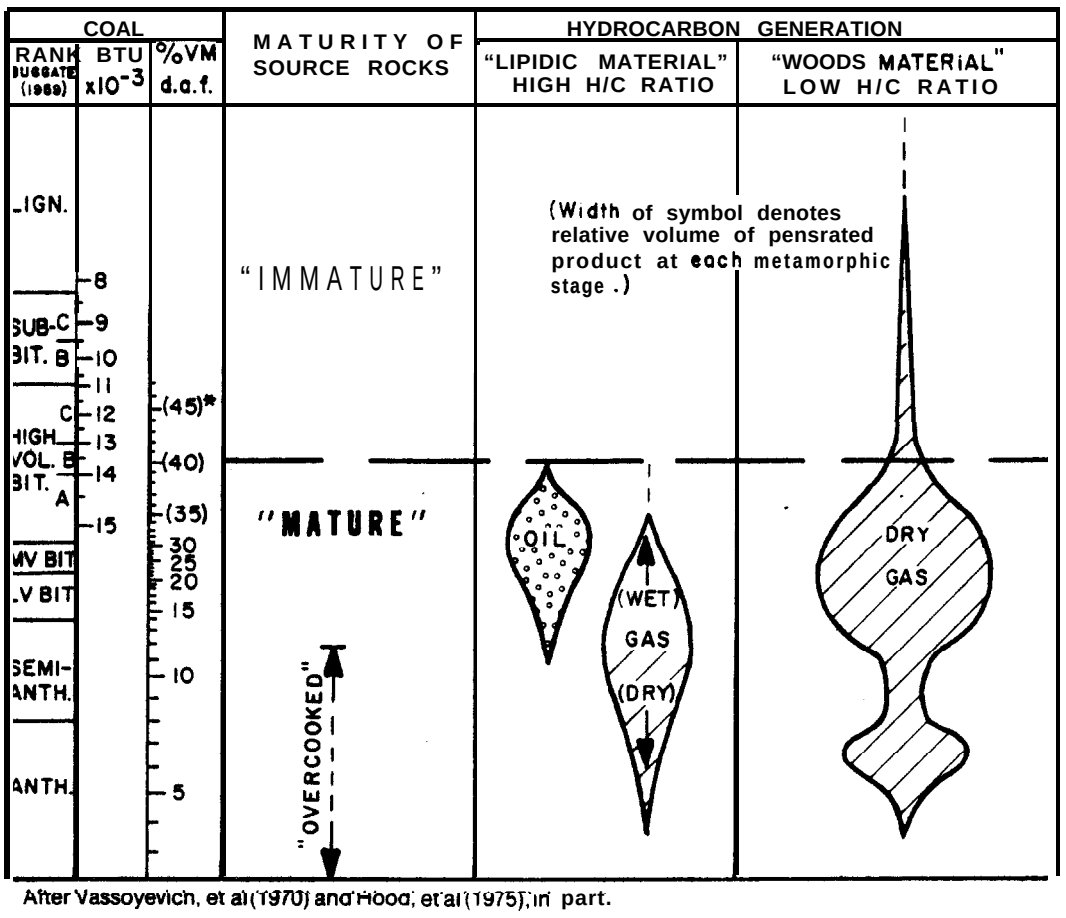
hv B b — high volatile B bituminous

X 1.8 — location and vitrinite reflectance value for drill-hole coal chip or core samples

0 — 10 Miles
SCALE

Note that coal rank increases with depth, having highest rank in two synclinal troughs at depths approximately greater than 8,000 feet. Also, rank is high along the southeastern border of the basin where coals have been affected by igneous intrusions.

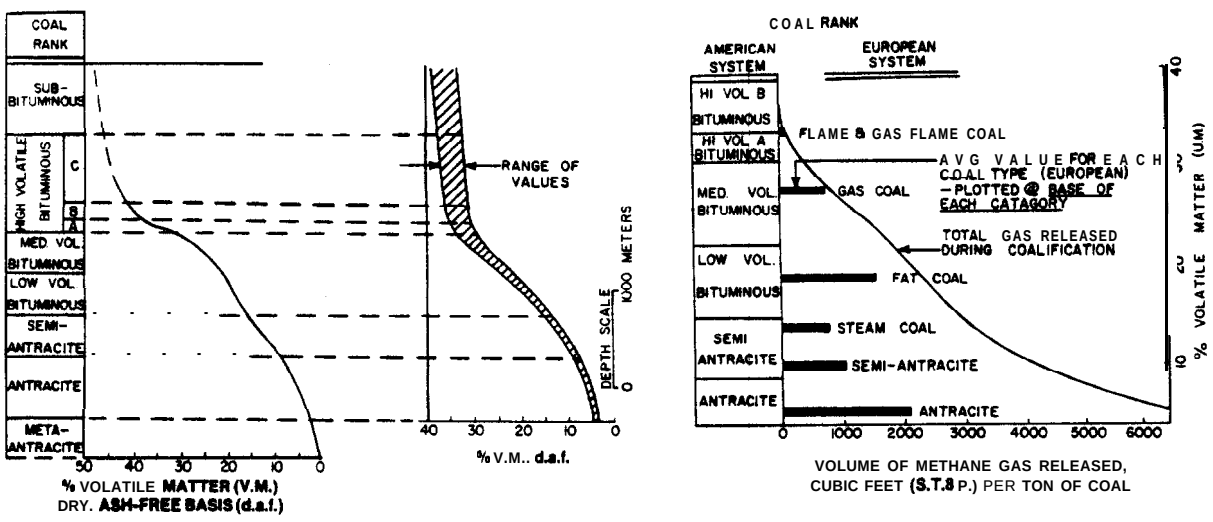
Figure 5-24. Map of Coal Rank Boundaries in Southeastern Piceance Basin as Determined from Vitrinite Reflectance Measurements from Drill Hole Chips and Core Samples (After Freeman, 1979)



After Vassoyevich, et al (1970) and Hood, et al (1975), in part.

*% Volatile matter in parenthesis is suitable only for Humic, Vitrinitic Coals.

Organic metamorphism in coals and its relation to hydrocarbon generation In the two **main** types of **organic material deposited** in **sediments.**



A) Coal vs. Volatile Matter Content, ASTM STD (1954), Extended to Ranks Lower Than Hi-Vol-C Bituminous by Hood et al.. (1975) for Humic Coals.

B) Coal Rank and Depth vs. Volatile Matter in Coals from the Fluhr District, Germany (After Pattiesky & Teichmuller, 1960; Teichmuller. 1966)

C) Generation of Methane Gas During the Organic Metamorphism of Different Ranks of Bituminous & Antracite Coals (Based on Juntgen & Karweil, 1966)

Organic **metamorphism** of coals and **its** relation to **devolatilization** and methane **generation.**

Figure 5-25. Relationship of Organic Metamorphism in Coals, Coal Rank, Coal Devolatilization, and Methane Generation (Dolly and Meissner, 1977)

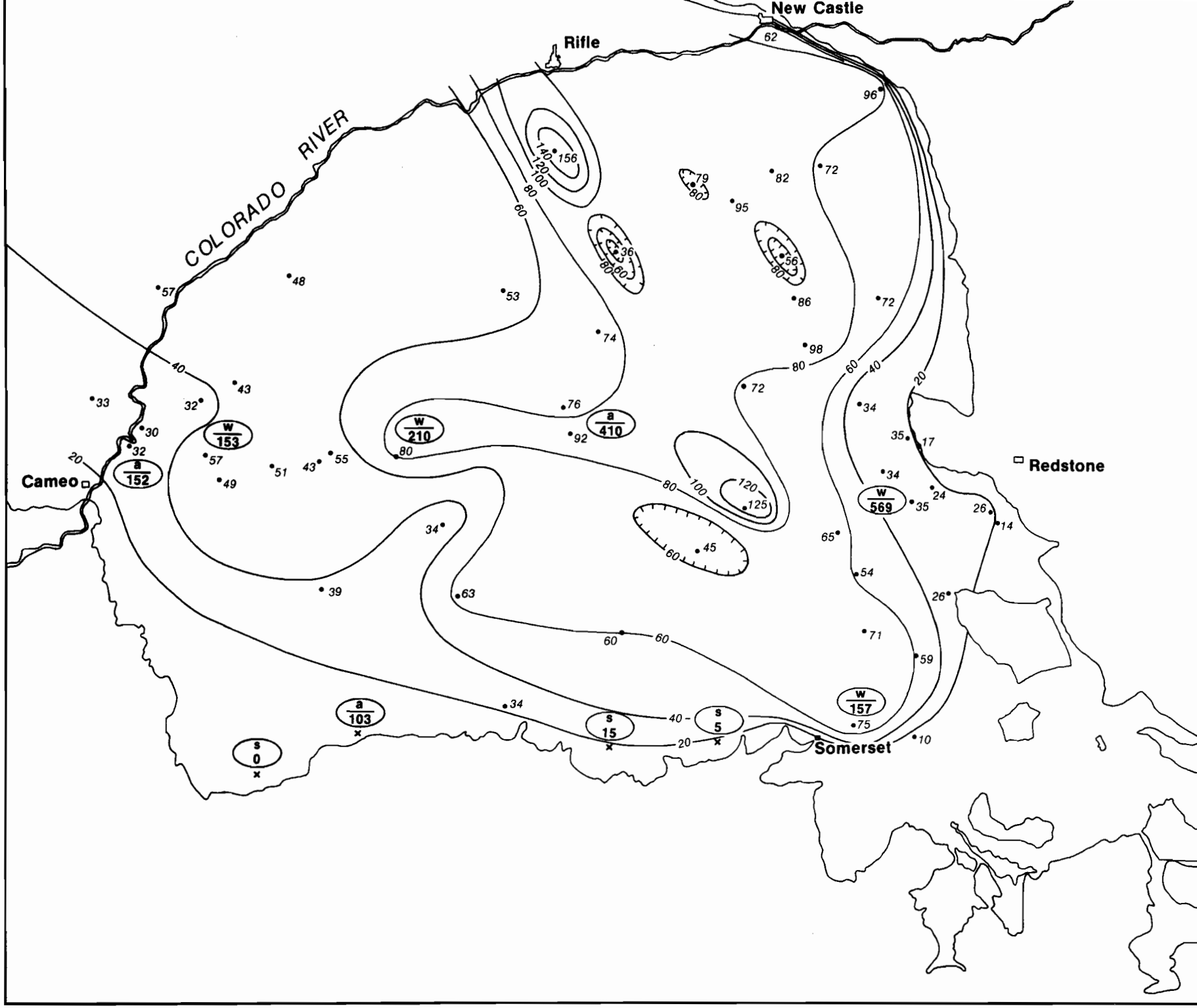

New Castle
Rifle
COLORADO RIVER
Cameo
Redstone
Somerset
W 153
W 210
a 410
a 152
W 569
W 157
a 103
s 0
s 15
s 5

Table 5-1. Summary of Known Conditions or Events Indicating Anomalously High Methane Gas in Underground Mines in the Piceance Basin, Colorado (After Boreck and Strever, 1980)

MAP INDEX NUMBER	COUNTY COAL REGION (FIELD) MINE NAME	COAL BED THICKNESS (Ft)	OVERBURDEN THICKNESS (Ft)	COAL RANK[2]	AVERAGE DAILY PRODUCTION (Tons)	AVERAGE METHANE EMISSION (Cu. Ft./Day) (Data from Y.E.S.A. District 9[3])	CU. FT. GAS PER TON OF COAL MINED	OCCURRENCE OF GAS IN MINES
	Delta (Somerset)							
2	Blue Ribbon (Grand Mesa)	6	U[1]	hvBb	Closed			"Gassy"
7	Independent XI	6.2	100	hvCb	Closed			Mine Fire 1930
7	Independent #2 (Somerset)	10	100	hvCb	Closed			
8	King	16	2.100	hvAb	Closed			"Gassy" Mine Fire 1911
	(Grand Mesa)							
13	Tomahawk Garfield (Grand Hogback)	11	U	hvCb	Closed			"Gassy"
15	Coryell (Carbondale)	14.5	O-125	hvAb	Closed			Gas Explosion 1901
24	Sunlight (Grand Hogback)	9.5	0-1,000	hvBb	40	None	None	Gas Explosion 1897
16	Newcastle	6-42	U	hbBb	Closed			Gas Explosion 1901 Dust Explosion 1888 Mine Fire 1954
19	Newcastle-Vulcan Vulcan a3	a14	350-400	hvBb	Closed			Mine Fire 1962 Gas Explosion 1956
22	South Canon #1	18	506550	hvBb	Closed			Gas Explosion 1912 Mine Fire 1951
25	Vulcan	14-47	350-400	hvAb	Closed			Gas Explosion 1896 Gas Explosion 1916 Dust Explosion 1913
	Gunnison (Somerset)							
30	Bear	a	290-1,440	hvBb	600	259,000	432	"Gassy"
31	Black Beauty (Crested Butte)	10	697	hvBb	Closed			"Gassy"
33	crested Butte	5-25	3 w - m	hvAb	Closed			Gas or Dust Explosior 1663. Gas Explosion 1884
	(Somerset)							
34	Edwards	6	511-634	hvBb	Closed			"Gassy"
36	Hawk's Nest East (#	7-9	U	hvBb	150	29,000	193	New Mine
37	Hawk's Nest West (#	e-9	U	hvBb	600	425,000	531	New Mine
44	Oliver #2	7	U	hvBb	Closed			"Gassy"
45	Oliver #3	7	174-500	hvBb	Closed			"Gassy"
47	Somerset	7 & 25	1,000-1.500	hvBb	4.500	1,692,000	376	"Gassy"
	Mesa (Grand Mesa)							
49	Grand View	4-5	U	sub A (?)	Closed			Gas Explosion 1908
49	C.M.C.	7	U	hvBb (?)	300	24.000	80	No Data
50	Midwest Red Arrow (Book Cliffs)	4.6	100	hbBb	Closed			Gas Explosion 1923
51	Palisade	3-4	U	hvBb	Closed			Mine Fire 1900
	Pitkin (Carbondale)							
55	Bear Creek	7	200-1,500	mvb	480	885,000	1.644	"Gassy"
56	Coal Basin	6.Q-6	150-600	mbv	431	1,750.000	4.060	"Gassy"
57	Dutch Creek #1	7	c-2.250	mvb	642	2,235,000	3.461	Dust Explosion 1957 Gas Explosion 1965
56	Dutch Creek #2	7	1,370-1,800	mvb	1.006	1,489,000	1,477	"Gassy"
59	L. s. wood	7	0-1,650	mvb	1,800	1,867,000	1,037	"Gassy"
60	Spring Gulch	45-11.5	o-I ,000	hvAb	Closed			oust Explosion 1901
61	Thompson Creak #1	8	300±	hvAb	113	18.000	159	Gas Explosion 1956
62	Thompson Creek X2	7	80-100	hvAb	Closed			"Gassy"
63	Thompson Creek #3	9	U	hvAb	54	Tested none		"Gassy"

(1) U = Unknown
(2) B-HV = Bituminous - High Volatile
B-MV = Bituminous
(3) As of first quarter 1977

Table 5-2. Core Sample Gas Desorption Results, Coal Resource, and Methane Resource for U.S. Steel's Property, Coal Basin, **Carbondale** Coal Field, Gunnison and **Pitkin** Counties, Colorado

COAL BED	SAMPLE PARAMETERS	HOLE NUMBER AND **DESORPTION** RESULTS				**AVERAGE** BED THICKNESS AND GAS CONTENT	COAL RESOURCE PER SECTION OF LAND (Million Tons)	METHANE RESOURCE PER SECTION OF LAND (Billions Cu. Ft.)
		SUMMER 1979		SUMMER 1960				
		No. 16	No. 17	No. 16	No. 19			
Placita	Coring Interval (Ft)	1570.2-I 675.7	1219.7-1226.4					
	Coalbed Thickness (Ft)	5.5	6.7	Data Not Available	Data Not Available	6.1'		
	Number of Samples	4	3			(7 samples)	7.027	4.39
	Gas Content (cu. ft./ton) Range	720.3-812.0	107.4-620.8					
	Gas Content (cu. ft./ton) Average	765.3	435.9			624 cf t		
V	Coring Interval (Ft)	1847.5-1859.6	1506.9-I 518.5	2018.5-2032.6	2093.6-2107.1			
	Coalbed Thickness (Ft)	12.1	12.0	14.1	14.6	13.2'		
	Number of Samples	8	4	4	5	(21 samples)	17.518	11.09
	Gas Content (cu. ft./ton) Range	641.4-760.2	409.7-708.8	642-851	41 I-1041			
	Gas Content (cu. ft./ton) Average	716.4	630.4	759	527	633 cft		
B	Coring Interval (Ft)	2251.4-2260.0	1964.9-1971.9	2467.2-2475.1	2530.1-2539.7			
	Coalbed Thickness (Ft)	8.6	7.0	7.9	9.6	8.3'		
	Number of Samples	2	1	3	3	(9 samples)	9.562	5.00
	Gas Content (cu. ft./ton) Range	475.0 & 485.9	249.5	395740	537-658			
	Gas Content (cu. ft./ton) Average	480.5	249.5	537	628	623 cf t		
A	Coring Interval (Ft)	2269.6-2277.7		2480.9-2488.2	2546.6-2554.3			
	Coalbed Thickness (Ft)	8.1	No	7.5	7.7	7.8		
	Number of Samples	2	Samples	2	3	(7 samples)	8.986	4.03
	Gas Content (cu. ft./ton) Range	190.9 & 676.3		520-568	285486			
	Gas Content (cu. ft./ton) Average	520.9	Collected	553	329	448 cf t		
					Totals	35.4 ft. of coal	43.1	24.5

Note: Tonnage calculations assume 1800 tons per acre-foot for bituminous coal; ie, 1.152 million tons per acre-foot per 640-acre, section of land. Tonnages are probably higher than calculated because coal rank is medium-volatile B bituminous.

Weighted Average Gas Content for All Four Beds = 569 cu. ft./ton

Table 5-3. Coal Sample Gas Desorption Results, Coal Resource, and Methane Resource for Hawk's Nest Mine Property, Somerset Field, Mesa County, Colorado

COALBED	AVERAGED VALUES BY COAL ZONE		Total Coal Thickness By Coal Zone (feet)	BEDS A-WILD		BEDS E AND ABOVE	
	Number of Samples	Total Ga (cu. ft./ ton)		Coal Resource per Section of Land (Millions of Tons)	Methane Resource par Section of land (Billions of cu. ft.)	Coal Resource per Section of Land (Millions of Tons)	Methane Resource Per Section of Land (Bil. of Cu. ft.
Beds Above E			11.00			12.672	1.99 (157x12.6721
E			7.00			8.064	1.27 (157x8.064)
Wild	4	101 (80-120)	14.75	16.992	1.72		
D	3	121 (108-132)	6.75	7.776	0.94		
C	5	176 (96-218)	8.50	9.792	1.72		
a	11	199 177-245) (	23.75	27.360	5.44		
A	1	119	2.75	3.168	0.38		
			Sub Totals	65.066	10.2	20.736	3.26

Note: Tonnage calculations assume 1800 tons per acre-foot for bituminous coal, i.e., 1 .152 million tons per acre-foot per 640-acre section of land. Tonnages are probably higher than calculated because coal rank is medium-volatile B bituminous.

Weighted Average Gas Content in Beds A-Wild = 157 cf/ton

Total Coal Resource, all beds = 85624,000 tons/section of land

Total Gas Resource, all beds = 13.46 Bcf per section of land

Weighted Average Gas Content, all beds = 157 cu. ft./ton

Table 5-4. Sample Data and Desorption Results for 25 Core Samples from the Hawk's Nest Property (After Boreck and Strever, 1980)

HELL NO.	TEST NO.	SAMPLE NUMBER	COAL BED NAME	DATE SAMPLED	BED THICKNESS (ft.)	TEST PERIOD (days)	GAS DESORBED (CC)	LOST GAS (CC)	RESIDUAL GAS (cc/gm)	TOTAL GAS (cc/g)	TOTAL GAS (cf/t)
5	96	WSC #5 1-A	Wild Seam	1 I-27-78	4.8	30	458	15	1.8	2.49	80.
	97	WSC #5 1-B	Wild Seam	1 I-29-78	6.1		2220	45	0.4	3.2	102.
	98	w s c #5 1-c	Wild Seam	11-29-78	1.6	217	1800	35	0.9	3.74	120.
	99	WSC #5 1-D	D Seam	1 I-29-78	2.9	238	2261	140	0.8	3.88	124.
	100	WSC #5 1-E	C Seam	12-04-78	6.7	23	159	10	1.4	.28	9.
	101	WSC #5 1-F	C Seam	12-04-78	6.7	261	3775	25	0.8	6.81	217.9
	102	WSC #5 1-G	Upper B Seam	12-06-78	14.0	259	5955	150	1.5	5.82	186.2
	103	w s c #5 1-H	Upper B Seam	12-06-78	14.0	233	5147	190	1.5	5.94	190.0
	104	w s c #5 I	Lower B Seam	12-06-78	6.8	259	3345	35	2.0	6.15	197.
	105	WSC #5 J	A Seam	12-07-78	1.2		1256	75	.97cc/g	3.72	119.
6	106	WSC #6 B1	Upper B Seam	1-12-79	13.0		2581	110	2.2	6.06	194.
	107	WSC #6 B11	Upper B Seam	1-12-79	13.0	194	4250	300	1.9	6.77	217.
	108	WSC #6 C	C Seam	I-Io-79	6.0	175	4495	7	1.2	6.62	212.
	109	w s c #7 c	C Seam	2-07-79	6.9	196	5510	120	1.3	5.70	182.4
7	110	WSC #7 UB	Upper B Seam	2-I 2-79	12.7	191	5701	75	1.8	5.93	198.7
	111	SWC #7 LB	Lower B Seam	2-I 2-79	5.3	191	4131	40	2.1	6.53	208.9
	112	WSC #8 Wild	Wild Seam	2-21-79	12.0	133	1390	Not Calc.*	1.1	3.16	101.
	113	WSC #8 DU	D Seam	2-21-79	8.0	154	2510	35	1.0	3.36	108.
8	114	WSC #8 DL	D Seam	2-21-79	8.0	154	2364	Not Calc.*	1.5	4.12	132.
	115	WSC #8 CU	C Seam	2-23-79	12.0	180	3936	55	1.2	5.42	173.4
	116	WSC #8 CL	C Seam	2-23-79	12.0	100	480	70	2.3cc/g	2.99	98.
	117	WSC #8 UBU	Upper B Seam	2-23-79	14.6	180	3973	80	1.8	6.10	195.2
	118	WSC #8 UBL	Upper B Seam	2-23-79	14.6	152	3274	50	2.1	5.53	177.
	119	WSC #8 LBU	Lower B Seam	2-23-79	6.75	308	4840	90	1.4	5.98	191.3
	120	WSC #8 LBL	Lower B Seam	2-23-79	6.75	280	2237	Not Calc.*	2.2	7.66	245.

Table 5-5. Gas Compositions of Three Samples Collected from the B and C Coal Seams, Hawk's Nest Mine, Somerset Coal Field, Mesa County, Colorado (Boreck and Strever, 1980)

GAS COMPONENT	SAMPLE NUMBER		
	1	2	3
Oxygen	—	—	—
Hydrogen Sulfide	—	—	—
Carbon Dioxide	16.15	11.62	2.37
Nitrogen	18.83	31.50	—
Methane	60.34	56.57	96.9
Ethane	.98	.31	.64
Propane	—	—	.06
iso-Butane	—	—	.04 all rem gases
n - Butane	—	—	—
is0 - Pentane	—	—	—
n - Pentane	—	—	—
Hexanes - plus	3.69	—	—
Btu/cubic ft	799	575	998

'Western Slope Carbon analysis.

Table **5-6.** Methane Desorption Results of Samples from the Six Colorado Geological Survey Drill Sites Shown on Figure 5-11

SITE NUMBER	SAMPLE NUMBER	DEPTH TO COAL BED (ft)	BED THICKNESS (ft)	TOTAL GAS		APPARENT RANK OF COAL
				(cc/g)	(cf/t)	
MOFFAT COUNTY						
1	61	144	13	0.36	12	subA-hvCb
	62	144	13	0.39	13	subA-hvCb
	63	163.5	19.5	0.24	8	subA-hvCb
	64	287.5	4.3	0.15	5	subA-hvCb
	65	294.8	20.7	0.118	4	subA-hvCb
RIO BLANC0 COUNTY						
2	11	2218	15	.50	16	—
	12	2243	4	1.31	42	—
	13	2122	12	.98	31	—
	14	2106	8	.10	3	—
	15	48.7	10.8	0	0	hvCb
	16	502.6	12	0	0	hvCb
DELTA COUNTY						
3	24	579	4.5	0	0	hvCb
4	18	706.7	7.6	5.62	179	hvCb
	19	708.7	7.6	.82	26	hvCb
5	23	992.5	14.5	.46	15	hvCb
6	17	504	5.8	.19	6	hvCb

Tab& 5-7, Summary of Coalbed Occurrences in Open-Hole Section of Chevron Well Skonberg No. 1, Mam Creek Area, Garfield County

ZONE	DEPTH INTERVAL (FEET)	ZONE THICKNESS (FEET)	NO. OF COALBEDS	RANGE OF COALBED THICKNESSES (FEET)	TOTAL THICKNESS OF COA (FEET)
1	7054-7242	188	11	I-11	57
2	7738-7794	56	5	I-3	8
3	787C 7922	47	6	I-5	21
4	8024-8147	123	4	2-5	11
5	8367-8514	147	10	1-14	53
6	8590-8618	28	3	I-3	6
Total Open-Hole Section	7054-8618	1564	39	1-14	156

SAMPLE NUMBER	CORE NUMBER	CANISTER NUMBER	CORING INTERVAL	COALBED OR ROCK UNIT NAME	SAMPLE LITHOLOGY	SAMPLE WEIGHT (gm)	GAS CONTENT										GAS COMPOSITION SAMPLE
							Lost Gas		Altitude Change[2]		Desorbed Gas			Residual Gas	Total Gas		
							cc	cc/gm	cc	cc/gm	Days	cc	cc/gm	cc/gm	cc/gm	cu ft/ton	
Z	1	14	< 6680	Mesaverde Gr.	Noncarb. Shale	1,046			0	0	109	123	0.118	–	0.12	4(F)[4]	
1	1	1	4682-4696	"Cameo Zone"	Coal & Shale	2,255	284	0.126	47	.021	236	2772	1.229	3	1.38	44	X
8	Z	79	4726.0-4726.8	"Cameo Coals"	Coal, dull	3,804	329	0.086	33	.008	235	4139	1.088	3	1.18	38	
6	Z	60	4730.5-4731.3	"Cameo Coals"	Coal	3,003	731	0.244	103	.034	235	9783	3.258	3	3.54	113	X
7	Z	87	4734.9-4735.7	"Cameo Zone"	Carb. Shale	3,864	49	0.013	16	.004	235	1000	0.259	3	0.27	9	
3	2[1]	53	4752-4753	"Cameo Coals"	Coal,cuttings	486	79	0.163	68	.140	108	1893	3.895	0.794	4.99	160(F)	
10	Z	84	4753.0-4753.8	"Cameo Coals"	Coal	2,313	1,310	0.566	103	.045	235	12267	5.304	3	5.92	189	
4	2[1]	54	4755-4757	"Cameo Coals"	Coal, cuttings	2,278	853	0.374	103	.045	235	10812	4.746	3	5.17	165	X
9	Z	81	4755.1-4755.7 and 4756.5-4756.7	"Cameo Coals"	Coal	1,186	1,072	0.721	103	.069	235	11563	7.781	3	8.57	274	
5	Z	69	4755.7-4756.5	"Cameo Coals"	Coal	1,009	954	0.475	103	.051	235	10627	5.290	3	6.81	186	X
14	3	88	4798.3-4799.1	"Cameo Coals"	Coal	1,621	2,475	1.527	103	.064	234	12063	7.442	3	9.00	289	
13	3	86	4801.0-4801.8	"Cameo Coals"	Coal	1,733	1,820	1.060	103	.069	234	12839	7.409	3	8.52	273	
12	3	86	4804.0-4804.8	"Cameo Coals"	Coal	1,829	1,934	1,057	103	.056	234	14561	7.961	3	9.08	290	X
11	3[1]	80	4807-4808	"Cameo Coals"	Coal, cuttings	397	129	0.325	63	.159	107	1732	4.363	1.040	6.89	188(F)	X
16	3	89	4808.0-4808.3	"Cameo Coals"	Coal	631	783	1.241	84	.133	107	2888	4.577	0.324	6.28	201(F)	
16	3	90	4816.0-4816.8	Rollins[5]	Sandstone	2,805	1,986	0.708	56	.020	107	4970	1.772		2.50	80(F)	X

1. Drill cuttings collected off the shale shaker while coring.
2. Altitude correction made for moving samples from test site to laboratory.
3. Sample still under desorption.
4. F=Final value for total gas.
5. Sample depths given above are as measured on site at the time of coring. Top of the Rollins Sandstone, used as a marker horizion, is 6.5 feet deeper on the geophysical logs.

Table 5-8. Summary of coalbed Methane Sampling Results to date for Teton Energy Well, Walck 23-2, Southeastern Piceance Basin, Colorado

Table 5-9. Coal and Methane Resource per Section of Land at Teton Energy Well Walck 23-2

BED THICKNESS (feet)	SAMPLE DESPORTION VALUE		COAL RESOURCE' PER SECTION OF LAND (millions of tons)	METHANE RESOURCE PER SECTION OF LAND (billions of cu. ft.)	COAL RESOURCE PER SECTION OF LAND (millions of tons)	METHANE RESOURCE PER SECTION OF LAND (billions of cu. ft.)
	INDIVIDUAL SAMPLE VALUE (cu ft/ton)	AVERAGE (cu ft/ton)				
(beds not sampled) 46					52.99	11.13 (210 x 52.99)
8.0	38,133	76	9.22	0.70		
12.2	189,274,186	216	14.05	3.03		
13.5	289,273,290	284	15.55	4.42		
	207 (average)	Totals	38.8	8.15	53.0	11.13

'Tonnage factor of 1.152 million tons of bituminous coal per foot of coal per square mile of area.

Arithmetic average = 207 cu ft/ton
Weighted average = 210 cu ft/ton

Total coal resource, all beds = 92 million tons per section of land.
Total methane resource, all beds = 19 billion cu ft gas per section of land.

Table S-10. Summary of Gas Compositions for Teton Energy Well. Walck 23-2, Southeastern Piceance Basin, Colorado. Data Recalculated on an Air-free Basis and Normalized to 100 Percent

COMPONENT	SYMBOL	SAMPLE NUMBER & PERCENT							
		1	4	5	6	11	12	15	AVERAGE
Methane	C_1	66.94	73.84	80.18	80.18	78.28	85.10	73.23	76.82
Ethane	C_2	7.73	14.64	7.86	7.99	15.06	8.04	16.59	11.13
Propane	C_3	2.12	4.77	0.76	0.74	0.88	0.74	1.61	1.66
I-Butane	C_4	0.18	0.39	0.13	0.15	—	0.10	0.16	0.16
N-Butane		0.12	0.32	0.10	0.11	—	0.09	0.24	0.14
Higher Hydrocarbons	C_{5+}	—	0.06	—	—	—	—	—	0.01
Nitrogen	N_2	13.77	0.34	0.10	0.12	0	0.10	2.49	2.42
Carbon Dioxide	CO_2	9.14	5.64	10.87	10.71	5.78	5.83	5.68	7.66
Totals		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Analyses performed by Spectron Labs, Denver, Colorado.

Table 5-11. Summary of Coalbed Methane Sampling Results to date for Adolph Coors Well, Nichols I-23 CM, Mesa County, Southeastern Piceance Basin, Colorado

SAMPLE NUMBER	CORE NUMBER	CANISTER NUMBER	CORING INTERVAL	COALBED OR ROCK UNIT NAME	SAMPLE LITHOLOGY	SAMPLE WEIGHT (gm)	Desorbed Gas		
							cc	cc/gm	cu ft/ton
1	_	57	2631.0-2633.0	"Cameo Coals"	Coal, chips	1191	4216	3.64	113
2	1	16	2670.7-2671.4	Mesaverde Gr.	Sandstone	5022	356	0.07	2
3	1	15	2672.5-2673.3	"Cameo Coals"	Coal	2632	17201	2.74	88
4	2	152	2714.0-2714.9	"Cameo Coals"	Coal	2110	10419	4.94	158
5	2	146	2721.0-2721.7	"Cameo Coals"	Coal	1494	7734	5.18	166
6	2	38	2729.2-2729.7	"Cameo Coals"	Coal	2063	5777	2.80	90
7	2	158	2730.0-2730.8	"Cameo Coals"	Coal	1161	5275	4.54	145
8	3	102	2750.9-2751.9	"Cameo Coals"	Coal	1342	8275	6.17	197
9	3	5	2765.4-2766.0	Mesaverde Gr.	Sandstone	3611	2028	0.56	18
10	3	151	2766.4-2767.1	"Cameo Coals"	Coal	2501	15534	6.21	199
11	3	115	2768.2-2769.1	"Cameo Coals"	Coal	2152	12257	5.70	182

1. Samples still under desporption; values as of 1-16-1981.

2. Gas values do not include lost or residual gas.

3. Sample number 1 comprises chips collected off the shale shaker; all others are core samples.

4. Sample depths given above are as measured on site at the time of coring. Top of the Rollins Sandstone, used as a marker horizion, is 6.6 feet deeper on the geophysical logs. Coolbed tops range from 3.6 to 5.2 feet deeper on the geophysical logs.

Table 5-12. Coal and Methane Resource per Section of Land at Coors Well Nichols 1-23 CM

BED THICKNESS (feet)	SAMPLE GAS DESORPTION VALUE		COAL RESOURCE* PER SECTION OF LAND (millions of tons)	METHANE RESOURCE* PER SECTION OF LAND (millions of tons)	COAL RESOURCE' PER SECTION OF LAND (millions 01 tons)	METHANE RESOURCE PER SECTION OF LAND (billions cu ft)
	INDIVIDUAL SAMPLE VALUE (cu ft/ton)	AVERAGE (cu ft/ton)				
(beds not sampled) 24					27.65	4.23 (153 x 27.65)
3.8	88	88	4.38	0.39		
11.4	158,166	162	13.13	2.13		
9.0	SO.45	118	10.37	1.22		
3.6	197	197	4.15	0.82		
5.6	199,182	191	6.45	1.33		
	141 (average)	Totals	38.5	5.89	27.7	4.23

'Tonnage factor of 1.152 million tons of bituminous coal per foot of coal per square mile of area.

Arithmetic average = 141 cu ftfton
Weighted average = 153 cu ft/ton

Total coal resource, all beds = 66.2 millions of ton
Total methane resource, all beds = 10.1 billions of cu ft gas

Table 5-13. Desorption Data for Core Samples from the Four Douglas Creek Area Drill Sites, Rio Blanco County, Colorado

DRILL SITE	SAMPLE DEPTH (ft)	LITHOLOGY	SAMPLE WEIGHT (gm)	DESORBED GAS (cc/gm)	RESIDUAL GAS (cc/gm)	LOST GAS (cc/gm)	TOTAL GAS PER UNIT (cc/gm)	TOTAL GAS PER UNIT (cf/ton)
FAA	1585	Coal	1584	0.5	—	0.1	.6	18
	1603	Coal	144	1.5	—	1.0	2.5	81
FAB	No core samples were collected for desorption							
FAC	685	Coal	355	1.0	0.1	2.5	3.6	115
	698	Carb. Shale/Coal	353	0.7	0.8	5.2	6.7	214
	772	Carb. Siltstone	393	0.8	0.0	0.6	1.4	46
	771	Carb. Shale w/Coal	593	0.5	0.0	0.3	0.8	24
	759	Coal	397	0.9	0.8	1.0	2.7	86
	809	Coal	119	2.8	2.5	2.9	7.6	243
	802	Coal	306	0.8	0.6	1.3	2.7	88
	804	Carb. Shale	643	0.5	0.2	0.7	1.4	46
	986	Coal	653	0.9	1.2	1.4	3.5	111
FAH	1210	Coal	1498				0.5	16
	1211	Coal	1312				0.8	26
	1223	Coal	1249				0.6	19

Table 5-14. Desorption Data for Core Samples from the Rangely Area Drill Sites, Rio Blanco County, Colorado

DRILL SITE	SAMPLE DEPTH (ft)	LITHOLOGY	SAMPLE WEIGHT (gm)	DESORBED GAS (cc/gm)	RESIDUAL GAS (cc/gm)	LOST GAS (cc/gm)	TOTAL GAS PER UNIT (cc/gm)	TOTAL GAS PER UNIT (cf/ton)
FAD	1325	Coal	1558	1.9	—	0.0	1.9	61
	1331	Coal	1599	1.9	—	0.0	1.9	61
	1333	Coal	1614	1.7	—	0.0	1.7	54
	1336	Coal	1651	1.5	—	0.0	1.5	48
	1351	Coal	1453	1.5	—	0.0	1.5	48
FAE	741	Coal	1703	0.2	0.1	0.2	0.5	16*
	744	Coal	1820	1.9	—	0.2	2.1	69
	759	Coal	1596	1.6	—	0.1	1.7	54
	765	Coal	1731	2.1	—	0.1	2.2	70
	772	Coal	1622	2.3	—	0.5	2.8	90
	795	Coal	1646	1.8	—	0.1	1.9	64
	797	Coal	1620	1.8	—	0.1	1.9	61
	809	Coal	1665	1.1	—	0.0	1.1	35
	*Possible canister leak							
FAF	880	Coal	1512	0.1	0.0	0.1	0.2	6
	905	Interburden Siltstone	1785	0.1	0.0	?	0.1	3
	911	Coal	1527	0.01	0.0	?	0.01	0.3*
	*Does not include lost gas							
FAG	1191	Sl Floor Rock	2783	0.04	—	0.0	0.04	1.0*
	1206	Coal	2018	0.9	—	0.1	1.0	32
	*Does not include lost gas							

Table 5-15. Methane Resource Estimates for Piceance Basin Areas South and North of the Colorado River

AREA	COAL RESOURCE (billions tons)	METHANE CONCENTRATION (cu ft per ton)			METHANE RESOURCES (trillions of cu ft)		
		LOWER LIMIT	UPPER LIMIT	ESTIMATED AVERAGE	LOWER LIMIT	UPPER LIMIT	ESTIMATED AVERAGE
South of Colorado River	144	150	450	250	21.6	64.6	36.0
North of Colorado River	236	25	200	100	5.9	47.6	23.6
Totals	362				26	112	60
Rounded Values	360				30	110	60

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Piceance Basin, one of the largest coal basins in Colorado with an estimated 380 billion tons of coal in place, also contains some of the gassiest mines in the western United States. Active mines in the basin emit as much as 2.2 million cubic feet of methane per day. The gassiest coals occur in the southeast portion of the basin at depths exceeding 2,000 feet. Limited drilling exploration in the basin to date has encountered coalbeds where the gas concentrations exceed 750 cu ft./ton. A well completed near the basin center had an initial production exceeding 1 million cubic feet of gas in a 24-hour period. The potential depths from which gas may be economically recovered may exceed 10,000 feet.

The high gas content of the southeastern Piceance Basin coals probably is caused by combination of the large overburden thickness, which may exceed 10,000 feet, and the high heat flows present in that part of the basin. Examination of heat flow maps indicates the highest heat flow values are coincident with some of the gassiest mines. Coal rank also increases with geothermal heating, and high-quality coking coal mines are gassy. A cross section constructed from available data shows that methane content of coalbeds increases with depth and approach to Tertiary intrusives.

Gas contents of beds in the northern basin do not appear to be high but the deepest coalbeds lie at depths of 10,000 feet and have not been explored for their methane content. Many sandstone gas fields occur in the Piceance Basin and a large percentage of these are in the coal-bearing Mesaverde Group. The fields are both structural and stratigraphic traps. It is probable that some fields derive their gas from coalbeds, although that has not as yet been proven.

Productive gas-bearing coal sequences may produce water along with the gas. The Mesaverde Group is not known to be a highly productive aquifer. The producing zones are probably under both gas and artesian pressure. With continued production, water yields will probably be reduced significantly. This reduction could yield to more cost-effective wells and better

production from the coalbeds as they are dewatered. Since deep groundwater in Piceance Basin is sometimes of poor quality, production of water-bearing gassy zones may lead to waste water disposal problems.

The following criteria are suggested for delineating target areas for future exploratory drilling in southeastern Piceance Basin.

- Areas where overburden thickness is greater than 2,000 ft
- Areas of thick coals, particularly near the basin center
- Areas of higher heat flow especially greater than 1.5 to 2 heat flow units
- Areas where epizonal intrusive igneous activity has caused folding and arching of coal-bearing strata, regardless of depth
- Areas of major synclines and anticlines
- Areas where igneous activity has faulted and fractured coal-bearing sequences
- Areas downdip from gassy mines in the direction of higher heat flow values
- Coincidence of any two of the above criteria would constitute a "prime" target area.

Figure 6-l shows the authors' estimate of the principal target area in southeastern Piceance Basin. Parts a, b, c, and d of Figure 6-l illustrate how coal thickness, depth of overburden, coal rank, and coalbed methane content were used to arrive at the target area shown in part e.

6.2 RECOMMENDATIONS

To aid in further delineation of additional target areas the following program is recommended:

- A review of all recent state and federal mine inspection reports for figures on methane ventilation from mines and any mine explosions or accidents caused by gas accumulation
- A review of older literature for references to gassy mines or mine accidents in old abandoned mines, particularly in the eastern Grand Hogback field and the Carbondale field

- A review of the lithologic and geophysical well log file available for the basin for:

  - occurrence and thickness of coals at all depths throughout the basin

  - evidence of gas shows and drill stem tests in coal-bearing intervals.

- Review of all water data of the State Water Resources Department and the USGS for reports of high gas content, including methane, ammonia, nitrogen, carbon dioxide, and hydrogen sulfide.

- Contacting companies with deep-drilling permits, in southeastern Piceance in particular, and in other parts of the basin, to request mutual exploration participation to investigate coal zones above the primary pay zones of interest.

- Detailed logging, sampling, desorption, and testing, including fracing, if possible, of coalbeds

- Encouragement of commercial ventures in the southeastern Piceance Basin to provide:

  - A more thorough examination of coal zones and their methane content

  - A chance for government agencies and private corporations to share expertise and data, thus stimulating production and further understanding of processes of coalbed methane occurrence.

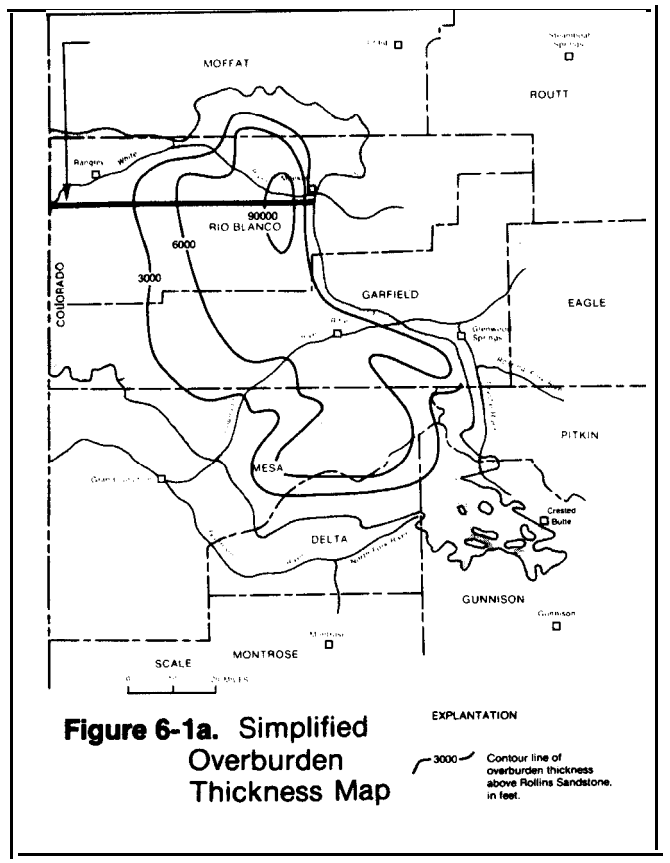


Figure 6-1a. Simplified Overburden Thickness Map

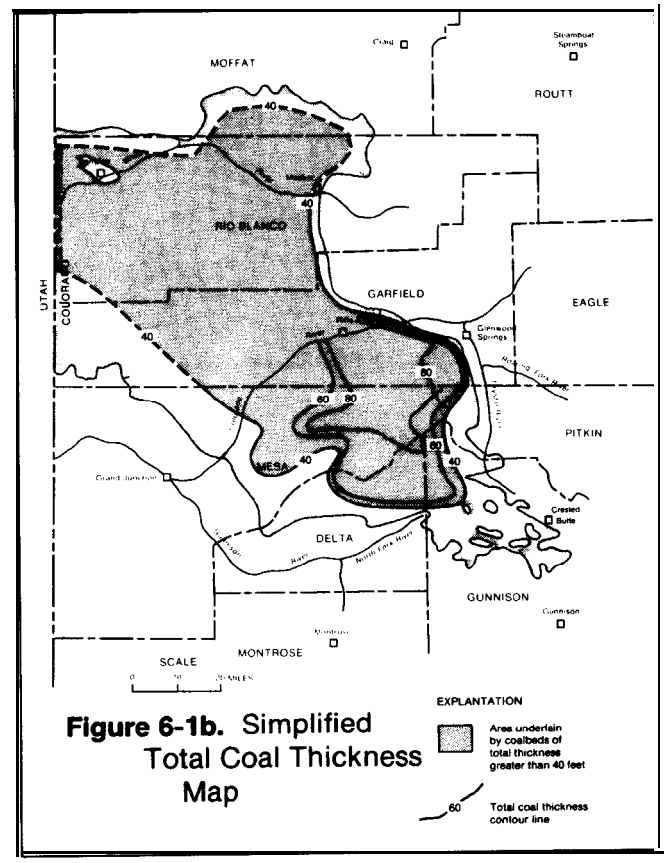


Figure 6-1b. Simplified Total Coal Thickness Map

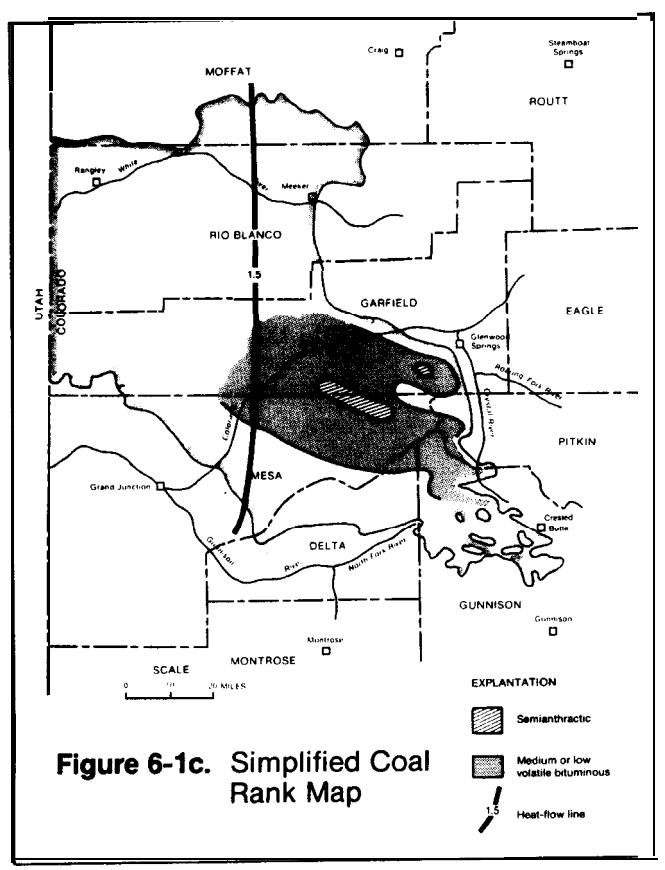


Figure 6-1c. Simplified Coal Rank Map

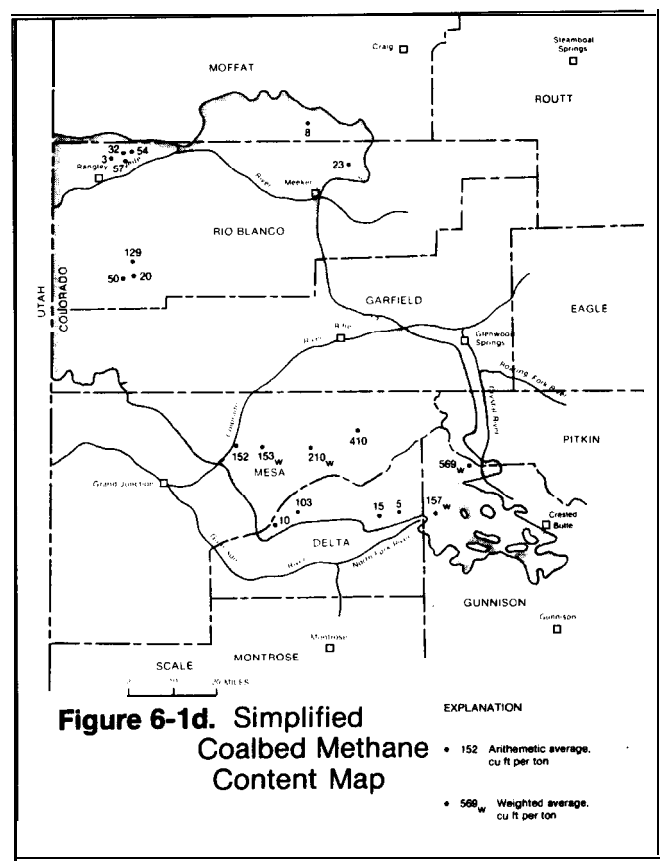


Figure 6-1d. Simplified Coalbed Methane Content Map

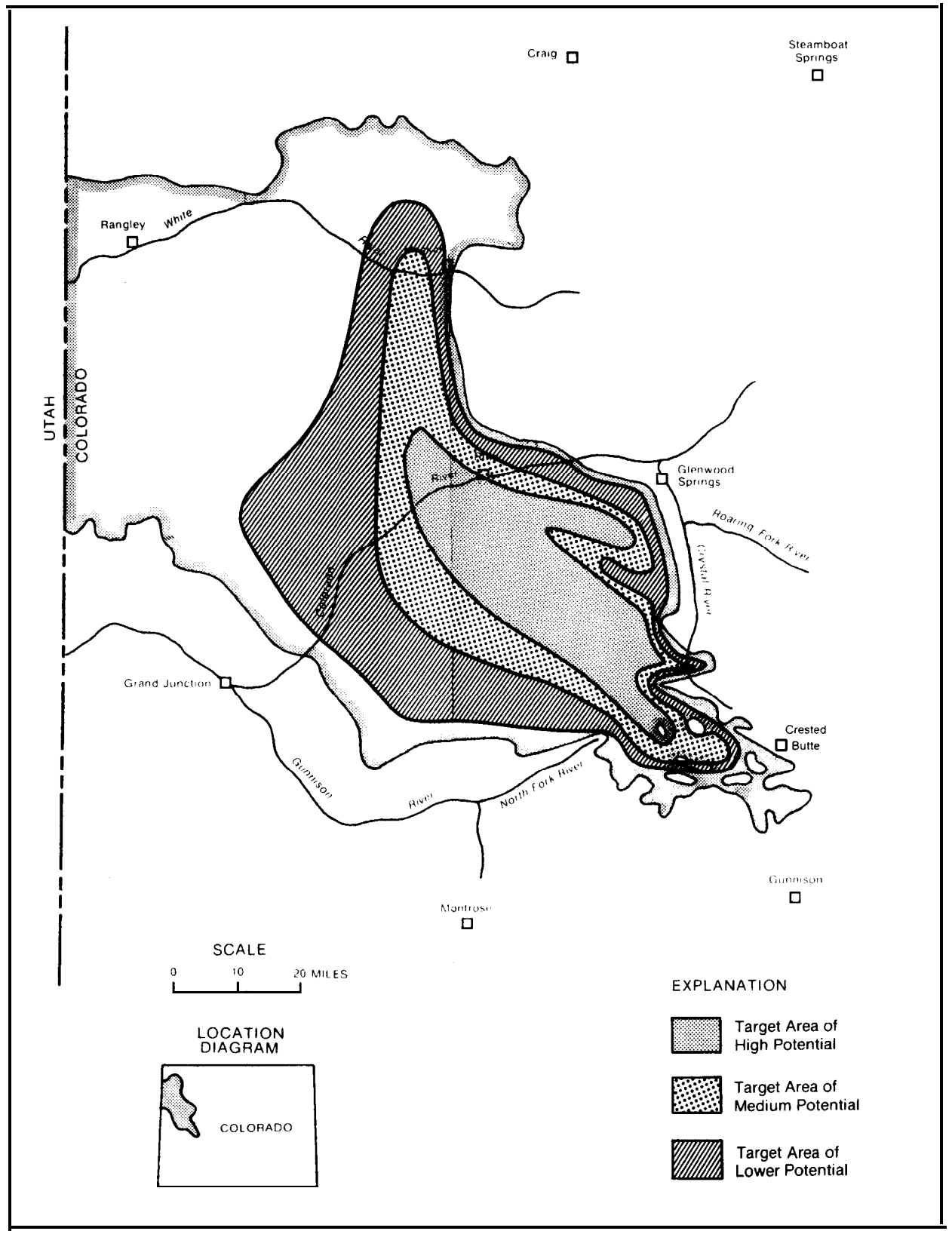


Figure 6-1. Piceance Basin Coalbed Methane Target Areas

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APPENDIX A

TOPOGRAPHIC MAPS COVERING THE PICEANCE BASIN

Enclosures:

A-1	USGS Topographic Map Index - Scale 1:250,000
A-2	USGS Topographic Map Index to Colorado (7 1/2")
A-3	Index to Topographic Maps of the United States At a Scale of 1:1,000,000
A-4	Cheyenne, United States - Scale: 1:1,000,000
A-5	Grand Canyon, United States - Scale: 1:1,000,000
A-6	Great Salt Lake, United States - Scale: 1:1,000,000
A-7	Pikes Peak, United States - Scale: 1:1,000,000
Plate 1	
Plate 2	
Plate 3	
Plate 4	
Plate 5	
Plate 6	

CHEYENNE, U.S. 1:1,000,000

TOPOGRAPHIC MAP

CURRENTLY OUT OF PRINT

WILL BE INCLUDED IN UPDATE

APPENDIX B

GEOLOGIC MAPS COVERING THE PICEANCE BASIN

Enclosure:

B-l Geologic Map Index of Colorado, 1977

APPENDIX C

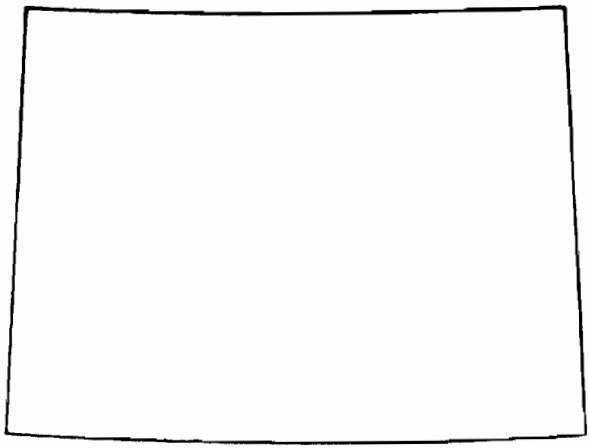
WATER-RESOURCES INVESTIGATIONS IN THE PICEANCE BASIN

Enclosure:

C-l Water-Resources Investigations in Colorado, 1977

List of Geological Survey
Geologic and Water-Supply Reports and Maps for

COLORADO



December 1977

U.S. DEPARTMENT OF THE INTERIOR

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GEOLOGIC AND WATER-SUPPLY REPORTS AND MAPS

COLORADO

December 1977

This list contains reports and maps published by the Geological Survey relating to the geology and mineral and water resources of Colorado. A separate list of bibliographies and publications of general interest is available on request, as are a general catalog of Geological Survey publications (not including topographic maps), and State indexes to topographic mapping.

Bulletins, professional papers, water-supply papers, and other book reports for which a price is stated, including some that have gone out of print at the Government Printing Office, as indicated by an asterisk (*), are for sale by the BRANCH OF DISTRIBUTION, U.S. GEOLOGICAL SURVEY, 1200 SOUTH EADS STREET, ARLINGTON, VA 22202, and from the U.S. Geological Survey, Public Inquiries Offices: Federal Building, Room 1012, 1961 Stout Street, Denver, CO 80294; and Federal Building, Room 8102, 125 South State Street, Salt Lake City, UT 84138 (authorized agents of Superintendent of Documents). Prepayment is required and should be made by check or money order payable to the U.S. Geological Survey. Numerous libraries and educational institutions throughout the country are depositories for this material and a list of Colorado depositories is included.

Maps, folios, hydrologic atlases, and charts are sold by the Geological Survey. They may be purchased over the counter or ordered from the BRANCH OF DISTRIBUTION, U.S. GEOLOGICAL SURVEY, BLDG. 41, FEDERAL CENTER, DENVER, CO 80225. Remittances should be made by check or money order payable to U.S. Geological Survey. A discount of 30 percent is allowed on an order of $300 or more, based on the retail price. No other discount is applicable. Maps may also be purchased *over the counter* at the U.S. Geological Survey offices where books are sold, and at the Survey's Public Inquiries Offices: Geological Survey, National Center, Room 1C402, 12201 Sunrise Valley Drive, Reston, Va.; and General Services Building, Room 1028, 19th and F Streets, NW., Washington, D.C.

References to geologic information on Colorado may be obtained from the following Geological Survey publications: Geologic Map Index of Colorado, described herein, and from Bibliographies of North American Geology - Bulletins *746 (1785-1918), *747 (1785-1918), *823 (1919-28), *937 (1929-39), *985 (1950), *1025 (1951), *1035 (1952-53), *1049 (1940-49), *1054 (1954), *1065 (1955), *1075 (1956), *1095 (1957), *1115 (1958), *1145 (1959), *1195 (1950-59) set of 4 volumes, *1196 (1960), *1197 (1961), *1232 (1962), *1233 (1963), *1234 (1964), *1235 (1965), 1266 (1966), $8.25, *1267 (1967), *1268 (1968), 1269 (1969) $11.35, and 1370 (1970) $8.70. Bibliographies and indexes of publications relating to ground water are Water-Supply Papers *992 (1879-1945), *1492 (1946-55), *1863 (1963), and *1864 (1964). A water resources investigations folder, available free upon request to the Geological Survey, 420 National Center, 12201 Sunrise Valley Drive, Reston, VA 22092, shows the location of stream-gaging stations, observation wells, quality-of-water sample collection sites, areal hydrologic studies, average annual runoff, average discharge of principal streams, and availability of ground water. A brief text lists the hydrologic network, the areal and Statewide projects, and selected references. Additional information is obtainable from Assistant Director, Central Region, U.S. Geological Survey, Denver Federal Center, Denver, CO 80225, and Director and State Geologist, Colorado Geological Survey, 254 Columbine Bldg., Denver, CO 80203.

Information on altitudes in the United States is contained in Bulletins *5, *76, *160, *274, *689, *817, and *1212; information on boundaries and areas of the United States, with historical outlines of boundary changes, is contained in Bulletins *13, *171, *226, *302, *689, *817, *1212, and Professional Paper 909; information on results of primary triangulation and primary traverse from 1894 to 1918 is contained in Bulletins *122, *181, *201, *216, *245, *276, *310, *440, *496, *551, *644, *709, and Parts 1 of the *18th, *19th, *20th, and *21st Annual Reports. Further information on more recent triangulation, transit traverse, and spirit leveling in Colorado is obtainable upon specific request.

Current Publications are announced by means of monthly notices, "New Publications of the Geological Survey." Free on application to the Geological Survey, 329 National Center, 12201 Sunrise Valley Drive, Reston, VA 22092.

ANNUAL REPORTS

*Second, 1880-80. 1882. Contains: Abstract of report on geology and mining industry of Leadville, Lake County, Colo., by S. F. Emmons. p. 201-290.

*Sixth, 1884-84. 1885. Contains: Mount Taylor and the Zuni Plateau, by C. E. Dutton. p. 105-198.

*Eighth, 1886-87. 1889. Part 1 contains: The fossil butterflies of Florissant, Colo., by S. H. Scudder. p. 433-474.

*Ninth, 1887-88. 1889. Contains: On the geology and physiography of a portion of northwestern Colorado and adjacent parts of Utah and Wyoming, by C. A. White. p. 667-712.

*Thirteenth, 1891-92. 1892. Part 3 (1893) contains: Report upon the construction of topographic maps and the selection and survey of reservoir sites in the hydrographic basin of Arkansas River, Colo., by A. H. Thompson. p. 429-444.

*Fourteenth, 1892-93. 1893. Part 2 (1894) contains: The laccolithic mountain groups of Colorado, Utah, and Arizona, by Whitman Cross. p. 157-241.

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*Seventeenth, 1895-96. 1896. Part 2 contains: Geology of Silver Cliff and the Rosita Hills, Colo., by Whitman Cross. p. 263-403; The mines of Custer County, Colo., by S. F. Emmons. p. 405-472; The underground water of the Arkansas Valley in eastern Colorado, by G. K. Gilbert. p. 551-601.

*Eighteenth, 1896-97. 1897. Part 3 (1898) contains: Preliminary report on the mining industries of the Telluride quadrangle, Colorado, by C. W. Purington. p. 745-850.

*Twentieth, 1898-99. 1899. Part 2 (1900) contains: Devonian fossils from southwestern Colorado: The fauna of the Ouray limestone, by G. H. Girty. p. 25-81. Part 5 (1900) contains: The forests of the United States, by Henry Gannett. p. 1-37; Pikes Peak, Plum Creek, and South Platte reserves, by J. G. Jack. p. 39-115; White River Plateau Timber Land Reserve, by G. B. Sudworth. p. 117-179; and Battlement Mesa Forest Reserve, by G. B. Sudworth. p. 181-243.

*Twenty-first, 1899-1900. 1900. Part 2 contains: Geology of the Rico Mountains, Colo., by Whitman Cross and A. C. Spencer. p. 7-165. Part 4 (1901) contains: The High Plains and their utilization, by W. D. Johnson. p. 601-741. (See Twenty-second Annual Report.)

*Twenty-second, 1900-1901. 1901. Part 1 contains: The asphalt and bituminous rock deposits of the United States, by G. H. Eldridge. p. 209-452. Part 2 contains: The ore deposits of the Rico Mountains, Colo., by F. L. Ransome. p. 229-398. Part 3 (1902) contains: The Rocky Mountain coal fields, by L. S. Storrs. p. 415-471. Part 4 (1902) contains: The High Plains and their utilization (conclusion), by W. D. Johnson. p. 631-669.

(Beginning with the twenty-third (1901-2), the annual reports of the Geological Survey contain no technical papers but were published separately until 1933. Since 1933 a condensed form has been included in the annual report of the Secretary of the Interior. For the fiscal years 1936 to 1963, a limited number of copies of the report as it appeared in the annual report of the Secretary were reprinted separately for official use; copies of these may be had free by persons directly interested, insofar as they are in stock.)

MINERAL RESOURCES OF THE UNITED STATES

The annual volumes of Mineral Resources of the United States contain statistics of production by calendar years and matters relating to technology and resources. Some of the chapters deal with a particular mineral or group of minerals, but much of the information is statistical. These volumes are not listed. The volumes of Mineral Resources were issued by the Geological Survey for the years 1882 to 1923. Reports for 1924 and subsequent years are published by the Bureau of Mines, Washington, DC 20244, as Minerals Yearbooks.

MONOGRAPHS

*10. Dinocerata—A monograph of an extinct order of gigantic mammals, by O. C. Marsh. 1866. 243 p.
*12. Geology and mining industry of Leadville, Colo., with atlas, by S. F. Emmons. 1886. 770 p. and atlas of 35 sheets folio.
*21. Tertiary rhynchophorous Coleoptera of the United States, by S. H. Scudder. 1893. 206 p.
*27. Geology of the Denver Basin in Colorado, by S. F. Emmons, Whitman Cross, and G. E. Eldridge. 1896.
*31. Geology of the Aspen mining district, Colorado, with atlas, by J. E. Spurr. 1898. 260 p., and atlas of 30 sheets folio.
*35. The later extinct floras of North America, by J. S. Newberry. 1898. 295 p.
*40. Adephagous and clavicorn Coleoptera from the Tertiary deposits at Florissant, Colo., by S. H. Studder. 1900. 148 p.
*44. Pseudoceratites of the Cretaceous, by Alpheus Hyatt. 1903. 351 p.
*49. The Ceratopsia, by J. B. Hatcher. 1907. 300 p.
*51. Cambrian Brachiopoda, by C. D. Walcott. 1912. In two parts. Part 1, 872 p.; part 2, 363 p.
*54. The Mesozoic and Cenozoic Echinodermata of the United States, by W. B. Clark and M. W. Twitchell. 1915. 341 p.

GEOLOGIC FOLIOS

*7. Pikes Peak, Colo., by Whitman Cross. 1894. 8 p., 5 maps.
*9. Anthracite-Crested Butte, Colo., by S. F. Emmons, Whitman Cross, and G. H. Eldridge. 1894. 11 p., 8 maps.
*36. Pueblo, Colo., by G. K. Gilbert. 1897. 9 p., 5 maps.
*48. Tenmile district special, Colorado, by S. F. Emmons. 1898. 6 p., 4 maps.
*57. Telluride, Colo., by Whitman Cross and C. W. Purington. 1899. 19 p., 4 maps.
*58. Elmoro, Colo., by R. C. Hills. 1899. 6 p., 5 maps.
*60. La Plata, Colo., by Whitman Cross, A. C. Spencer, and C. W. Purington. 1899 (1901). 14 p., 4 maps.
*68. Walsenburg, Colo., by R. C. Hills. 1900. 6 p., 6 maps.
*71. Spanish Peaks, Colo., by R. C. Hills. 1901. 7 p., 6 maps.
*120. Silverton, Colo., by Whitman Cross, Ernest Howe, and F. L. Ransome. 1905. 34 p., 4 maps.
*131. Needle Mountains, Colo., by Whitman Cross, Ernest Howe, J. D. Irving, and W. H. Emmons. 1905. 14 p., 4 maps.
*135. Nepesta, Colo., by C. A. Fisher. 1906. 6 p., 3 maps.
*153. Ouray, Colo., by Whitman Cross, Ernest Howe, and J. D. Irving. 1907. 20 p., 3 maps.
*171. Engineer Mountain, Colo., by Whitman Cross, and A. D. Hole. 1910. 14 p., 3 maps.
*186. Apishapa, Colo., by G. W. Stose. 1912. 12 p., 3 maps.
*198. Castle Rock, Colo., by G. B. Richardson. 1915. 14 p., 3 maps.
*203. Colorado Springs, Colo., by G. I. Finlay. 1916. 16 p., 5 maps.
*214. Raton-Brilliant-Koehler, N. Mex.-Colo., by W. T. Lee. 1922. 17 p., 10 maps.

PROFESSIONAL PAPERS

*16. The Carboniferous formations and faunas of Colorado, by G. H. Girty. 1903. 546 p.
*32. Preliminary report on the geology and underground water resources of the central Great Plains, by N. H. Darton. 1905. 433 p.

PROFESSIONAL PAPERS—Continued

*52. Geology and underground waters of the Arkansas Valley in eastern Colorado, by N. H. Darton. 1906. 90 p.

*54. Geology and gold deposits of the Cripple Creek district, Colorado, by Waldeman Lindgren and F. L. Ransome. 1906. 516 p.

*63. Economic geology of the Georgetown quadrangle (together with the Empire district), Colorado, by J. E. Spurr and G. H. Garrey, with general geology, by S. H. Ball. 1908. 422 p.

*67. Landslides in the San Juan Mountains, Colo., including a consideration of their causes and their classification, by Ernest Howe. 1909. 58 p.

*75. Geology and ore deposits of the Breckenridge district, Colorado, by F. L. Ransome. 1911. 187 p.

*90. Shorter contributions to general geology, 1914. 1915. Contains: Geology of the pitchblende ores of Colorado, by E. S. Bastin. p. 1-5; Dike rocks of the Apishapa quadrangle, Colorado, by Whitman Cross. p. 17-31; Contributions to the stratigraphy of southwestern Colorado, by Whitman Cross and E. S. Larsen. p. 39-50; The history of a portion of Yampa River, Colo., and its possible bearing on that of Green River, by E. T. Hancock. p. 183-189.

*94. Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colo., by E. S. Bastin and J. M. Hill. 1917. 379 p.

*95. Shorter contributions to general geology, 1915. 1916. Contains: Eocene glacial deposits in southwestern Colorado, by W. W. Atwood. p. 13-26; Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico, by W. T. Lee. p. 27-58.

*98. Shorter contributions to general geology. 1916. 1917. Contains: The flora of the Fox Hills sandstone, by F. H. Knowlton. p. 85-93.

*100. The coal fields of the United States. 1929. Contains: General introduction, by M. R. Campbell. p. 1-33. (Published in June 1917.)

*101. Geology and paleontology of the Raton Mesa and other regions in Colorado and New Mexico, by W. T. Lee and F. H. Knowlton. 1917 (1918). 450 p.

*120. Shorter contributions to general geology, 1918. 1919. Contains: Some American Cretaceous fish scales, with notes on the classification and distribution of Cretaceous fishes, by T. D. A. Cockerell. p. 165-206.

*130. The Laramie flora of the Denver Basin, with a review of the Laramie problem, by F. H. Knowlton. 1922. 175 p.

*131. Shorter contributions to general geology, 1922. 1923. Contains: Revision of the flora of the Green River formation, with descriptions of new species, by F. H. Knowlton. p. 133-182; Fossil plants from the Tertiary lake beds of south-central Colorado, by F. H. Knowlton. p. 183-197; The fauna of the so-called Dakota Formation of northern central Colorado and its equivalent in southeastern Wyoming, by J. B. Reeside, Jr. p. 199-212.

*132. Shorter contributions to general geology. 1923-24. 1925. Contains: Relations of the Wasatch and Green River Formations in northwestern Colorado and southern Wyoming, with notes on oil shale in the Green River Formation, by J. D. Sears and W. H. Bradley. p. 93-107.

*134. Upper Cretaceous and Tertiary formations of the western part of San Juan Basin, Colo., and N. Mex., by J. B. Reeside, Jr., and Flora of the Animas Formations, by F. H. Knowlton. 1924. 117 p.

*135. The composition of the river and lake waters of the United States, by F. W. Clarke. 1924. 199 p.

*138. Mining in Colorado—A history of discovery, development, and production, by C. W. Henderson. 1926. 263 p.

*148. Geology and ore deposits of the Leadville mining district, Colorado, by F. S. Emmons, J. D. Irving, and G. F. Loughlin. 1927. 368 p.

*149. Correlation of geologic formations between east-central Colorado, central Wyoming, and southern Montana, by W. T. Lee. 1927. 80 p.

*151. The cephalopods of the Eagle sandstone and related formations in the Western Interior of the United States, by J. B. Reeside, Jr. 1927. 87 p.

*154. Shorter contributions to general geology, 1928. 1929. Contains: Algae reefs and oolites of the Green River Formation, by W. H. Bradley. p. 203-223; Additions to the flora of the Green River Formation, by R. W. Brown. p. 279-299.

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*155. The flora of the Denver and associated Formations of Colorado, by F. H. Knowlton. 1930. 142 p.

*158. Shorter contributions to general geology, 1929. 1930. Contains: The occurrence and origin of analcite and meerschaum beds in the Green River Formation of Utah, Colorado, and Wyoming, by W. H. Bradley. p. 1-7; The contact of the Fox Hills and Lance Formations, by C. E. Dobbin and J. B. Reeside, Jr. p. 9-25; The varves and climate of the Green River epoch, by W. H. Bradley. p. 87-110.

*166. Physiography and Quaternary geology of the San Juan Mountains, Colo., by W. W. Atwood and K. F. Mather. 1932. 176 p.

*168. Origin and microfossils of the oil shale of the Green River Formation of Colorado and Utah, by W. H. Bradley. 1931. 58 p.

*169. Geology and ore deposits of the Bonanza mining district, Colorado, by W. S. Burbank, with a section on history and production, by C. W. Henderson. 1932. 166 p.

*176. Geology and ore deposits of the Breckenridge mining district, Colorado, by T. S. Lovering. 1934. 64 p.

*178. Geology and ore deposits of the Montezuma quadrangle, Colorado, by T. S. Lovering. 1935. 119 p.

*183. Correlation of the Jurassic formation of parts of Utah, Arizona, New Mexico, and Colorado, by A. A. Baker, C. H. Dane, and J. B. Reeside, Jr. 1936. 66 p.

*185-B. Paleozoic formations of the Mosquito Range, Colo., by J. H. Johnson. 1934 (1935). p. 15-34.

*185-C. The recognizable species of the Green River flora, by R. W. Brown. 1934 (1935). p. 45-77.

*185-D. A flora of Pottsville age from the Mosquito Range, Colo., by C. B. Read. 1934. p. 79-96.

*185-I. Geomorphology of the north flank of the Uinta Mountains, by W. H. Bradley. 1936. p. 136-204.

*186-J. Additions to some fossil floras of the Western United States, by R. W. Brown. 1937. p. 163-206.

*186-K. The stratigraphy of the Upper Cretaceous rocks north of the Arkansas River in eastern Colorado, by C. H. Dane, W. G. Pierce, and J. B. Reeside, Jr. 1937. p. 207-232.

*189-I. Fossil plants from the Colgate member of the Fox Hills sandstone and adjacent strata, by R. W. Brown. 1939. p. 239-275.

*197-A. Alkalic rocks of Iron Hill, Gunnison County, Colo., by E. S. Larsen. 1942. p. A1-A64.

*219. Geology and ore deposits of the La Plata district, Colorado, by E. B. Eckel, with sections by J. S. Williams, F. W. Galbraith, and others. 1949 (1950). 179 p.

*221-D. Cretaceous plants from southwestern Colorado, by R. W. Brown. 1950. p. 45-66.

*221-G. Pre-Wisconsin soil in the Rocky Mountain region—A progress report, by C. B. Hunt and V. P. Sokoloff. 1950. p. 109-123.

223. Geology and ore deposits of the Front Range, Colo., by T. S. Lovering and E. N. Goddard. 1950 (1951). 319 p. $9.50. (Reprint.)

*227. Pegmatite investigations in Colorado, Wyoming, and Utah, 1942-44, by J. B. Hanley, E. W. Heinrich, and L. R. Page. 1950. 125 p.

*233-B. Molluscan fauna of the Morrison Formation, by Teng-Chien Yen, with a summary of the stratigraphy, by J. B. Reeside, Jr. 1952. p. 21-51.

*235. Geology and ore deposits of the west slope of the Mosquito Range, Colo., by C. H. Behre, Jr. 1953. 176 p.

*239. Scaphitoid cephalopods of the Colorado group, by W. A. Cobban. 1951 (1952). 42 p.

*245. Geology and ore deposits of the Boulder County tungsten district, Colorado, by T. S. Lovering and Ogden Tweto. 1953 (1954). 199 p.

*254-A. American Upper Cretaceous Echinoidea, by C. W. Cooke. 1953. p. A1-A44.

*254-B. Nonmarine mollusks of Late Cretaceous age from Wyoming, Utah, and Colorado, by Teng-Chien Yen. 1954. p. 45-66.

*258. Geology and petrology of the San Juan region, southwestern Colorado, by E. S. Larsen, Jr., and Whitman Cross. 1956. 303 p.

*265. Geology of the Quartz Creek pegmatite district, Gunnison County, Colo., by M. H. Staatz and A. F. Trites, Jr. 1955. 111 p.

PROFESSIONAL PAPERS—Continued

*272-D. Evaporation from the 17 Western States, by J. S. Meyers, with a section on Evaporation rates, by T. J. Nordenson, U.S. Weather Bureau. 1962. p. 71-100.

*272-F. Methods to compute long-wave radiation from the atmosphere and reflected solar radiation from a water surface, by G. E. Koberg. 1964. p. 107-136.

*274-B. Dakota group in northern Front Range foothills, Colorado, by K. M. Waagé. 1955. p. 15-51.

*274-H. Palmlike plants from the Dolores Formation (Triassic), southwestern Colorado, by R. W. Brown. 1956. p. 205-209.

*274-M. Metamorphism and the origin of granitic rocks, Northgate district, Colorado, by T. A. Steven. 1957. p. 335-375.

*279. Cenozoic geology of the Colorado Plateau, by C. B. Hunt. 1956. 99 p.

*289. Geology and ore deposits of the Garfield quadrangle, Colorado, by M. G. Dings and C. S. Robinson. 1957. 110 p.

*291. Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo Country, by J. W. Harshbarger, C. A. Repenning, and J. H. Irwin. 1957. 74 p.

*294-A. North American Mesozoic Charophyta, by R. E. Peck. 1957. p. A1-A44.

*313-A. The Phosphoria, Park City, and Shedhorn Formations in the western phosphate field, by V. E. McKelvey and others. 1959. p. A1-A47.

*316-A. Regional geophysical investigations of the Uravan area, Colorado, by H. R. Joesting and P. E. Byerly. 1958 (1959). p. A1-A17.

*316-C. Regional geophysical investigations of the Lisbon Valley area, Utah and Colorado, by P. E. Byerly and H. R. Joesting. 1959. p. 39-50.

*316-F. Regional geophysical investigations in the La Sal Mountains area, Utah and Colorado, by J. E. Case, H. R. Joesting, and P. E. Byerly. 1963. p. 91-116.

*318. Occurrence of nonpegmatite beryllium in the United States, by L. A. Warner, W. T. Holser, V. R. Wilmarth, and E. N. Cameron. 1959. 198 p.

*319. Geology and ore deposits of the Chicago Creek area, Clear Creek County, Colo., by J. E. Harrison and J. D. Wells. 1959. 92 p.

*320. Geochemistry and mineralogy of the Colorado plateau uranium ores, compiled by R. M. Garrels and E. S. Larsen 3d. 1959. 236 p.

*332. Cretaceous and Tertiary formations of the Book Cliffs, Carbon, Emery, and Grand Counties, Utah, and Garfield and Mesa Counties, Colo., by D. J. Fisher, C. E. Erdmann, and J. B. Reeside, Jr. 1960. 80 p.

*343. Geology and ore deposits of the Summitville district, San Juan Mountains, Colo., by T. A. Steven and J. C. Ratté. 1960. 70 p.

*352-B. The shape of alluvial channels in relation to sediment type, by S. A. Schumm. 1960. p. 17-30.

*352-C. Effect of sediment characteristics on erosion and deposition in ephemeral-stream channels, by S. A. Schumm. 1961. p. 31-70.

*354-G. Deposition of uranium in salt-pan basins, by K. G. Bell. 1960. p. 161-169.

*355. Studies of the Mowry shale (Cretaceous) and contemporary formations in the United States and Canada, by J. B. Reeside, Jr., and W. A. Cobban. 1960. 126 p.

*356-A. Oil yield and uranium content of black shales, by V. E. Swanson. 1960. p. A1-A44.

*356-B. Uranium and other trace elements in petroleums and rock asphalts, by K. G. Bell. 1960 (1961). p. B1-B65.

*356-D. Geology of uranium in coaly carbonaceous rocks, by J. D. Vine. 1962. p. 113-170.

*359. Economic geology of the Central City district, Gilpin County, Colo., by P. K. Sims, A. A. Drake, Jr., and E. W. Tooker. 1963. 231 p.

*366. Ash-flow tuffs: Their origin, geologic relations, and identification, by C. S. Ross and R. L. Smith. 1961. 81 p.

*371. Geology of uranium and associated ore deposits, central part of the Front Range mineral belt, Colorado, by P. K. Sims and others. 1963. 119 p.

*372-A. The meteorologic phenomenon of drought in the Southwest, by H. E. Thomas. 1962. p. A1-A43.

*372-B. General effects of drought on water resources of the Southwest, by J. S. Gatewood, Alfonso Wilson, H. E. Thomas, and L. R. Kister. 1964. p. B1-B55.

*372-D. Effects of drought in the Rio Grande basin, by H. E. Thomas and others. 1963. p. D1-D59.

*372-F. Effects of drought in the Colorado River basin, by H. E. Thomas and others. 1963. p. F1-F51.

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373. Aerial photographs in geologic interpretation and mapping, by R. G. Ray. 1960. 230 p. $5.25. (Reprint.)

*374-B. Joints in Precambrian rocks, Central City-Idaho Springs area, Colorado, by J. E. Harrison and R. H. Moench. 1961. p. B1-B14.

*374-I. Yampa Canyon in the Uinta Mountains, Colo., by J. D. Sears. 1962. p. I1-I33.

*375. Paleocene flora of the Rocky Mountains and Great Plains, by R. W. Brown. 1962. 119 p.

*378-A. Geology and ore deposits of the South Silverton mining area, San Juan County, Colo., by D. J. Varnes. 1963. p. A1-A56.

*378-B. Analysis of plastic deformation according to Von Mises' theory, with application to the South Silverton area, San Juan County, Colo., by D. J. Varnes. 1962. p. B1-B49.

Title page and contents for volume available free on application to the Geological Survey.

*400-A. Geological Survey Research 1960, Synopsis of geologic results. 1960. p. A1-A136.

*400-B. Short papers in the geological sciences, Articles 1-232. 1960. p. B1-B515. Contains the following articles, which are not available separately.

2. Varieties of superbene zinc deposits in the United States, by A. V. Heyl, Jr., and C. N. Bozion. p. B2.
4. Relation of the Colorado mineral belt to Precambrian structure, by Ogden Tweto and P. K. Sims. p. B8.
5. Pre-ore age of faults at Leadville, Colo., by Ogden Tweto. p. B10.
6. Pre-ore propylitization, Silverton caldera, Colorado, by W. S. Burbank. p. B12.
7. Ring-fractured bodies in the Silvarton caldera, Colorado, by R. G. Luedke and W. S. Burbank. p. B13.
8. Relation of mineralization to caldera subsidence in the Creede district, San Juan Mountains, Colo., by T. A. Steven and J. C. Ratté. p. B14.
22. Distribution and lithologic characteristics of sandstone beds that contain deposits of copper, vanadium, and uranium, by R. P. Fischer and J. H. Stewart. p. B42.
34. Pre-mineralization faulting in the Lake George area, Park County, Colo., by C. C. Hawley, W. N. Sharp, and W. R. Griffitts. p. B71.
35. Bertrandite-bearing griesen—A new beryllium ore, in the Lake George district, Colorado, by W. N. Sharp and C. C. Hawley. p. B73.
44. Geochemical prospecting for beryllium, by W. R. Griffitts and Uteana Oda. p. B90.
45. Variations in base-metal contents of monzonitic intrusives, by W. R. Griffitts and H. M. Nakagawa. p. B93.
50. Thermoluminescence and porosity of host rocks at the Eagle mine, Gilman, Colo., by C. H. Roach. p. B107.
111. Pliocene sediments near Salida, Chaffee County, Colo., by R. E. Van Alstine, and G. E. Lewis. p. B245.
112. Some Late Cretaceous strand lines in northwestern Colorado and northeastern Utah, by A. D. Zapp and W. A. Cobban. p. B246.
113. Stratigraphy and structure of the Precambrian metamorphic rocks in the Tenmile Range, Colo., by A. H. Koschmann and M. H. Bergendahl. p. B249.
114. Salt anticlines and deep-seated structures in the Paradox basin, Colorado and Utah, by H. R. Joesting and J. E. Case. p. B252.
115. Distribution and physiographic significance of the Browns Park Formation, Flaming Gorge and Red Canyon areas, Utah-Colorado, by W. R. Hansen, D. M. Kinney, and J. M. Good. p. B257.
116. Probable late Miocene age of the North Park Formation in the North Park area, Colorado, by W. J. Hail, Jr., and G. E. Lewis. p. B259.
117. Paleocene and Eocene age of the Coalmont Formation, North Park, Colo., by W. J. Hail, Jr., and E. B. Leopold. p. B260.
118. Pre-Cutler unconformities and early growth of the Paradox Valley and Gypsum Valley salt anticlines, Colorado, by D. P. Elston and E. R. Landis. p. B261.

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*405. Saline minerals of the Green River Formation, by J. J. Fahey, with a section on X-ray powder data for saline minerals of the Green River Formation, by M. E. Mrose. 1962. 50 p.

*421-A. Quaternary geology and geomorphic history of the Kassler quadrangle, Colorado, by G. R. Scott. 1963. p. A1-A70.

*421-B. Bedrock geology of the Kassler quadrangle, Colorado, by G. R. Scott. 1963. p. 71-125. (Includes title page and contents for volume.)

*424-A. Geological Survey Research 1961, Synopsis of geological and hydrologic results. 1961. p. A1-A194.

*424-B. Short papers in the geologic and hydrologic sciences, Articles 1-146. 1961. p. B1-B344. Contains the following articles, which are not available separately.

1. Temperature of formation of a Precambrian massive sulfide deposit, Copper King mine, Front Range, Colo., by P. K. Sims and Priestley Toulmin 3d. p. B1.
2. Coffinite in uranium vein deposits of the Front Range, Colo., by P. K. Sims, E. J. Young, and W. N. Sharp. p. B3.
54. Origin of cross-strata in fluvial sandstone layers in the Chinle Formation (Upper Triassic) on the Colorado Plateau, by J. H. Stewart. p. B127.
55. Fossil woods associated with uranium on the Colorado Plateau, by R. A. Scott. p. B130.
56. Late Cenozoic events of the Leadville district and upper Arkansas Valley, Colo. by Ogden Tweto. p. B133.
57. Movement of the Slumgullion earthflow near Lake City, Colo., by D. R. Crandell and D. J. Varnes. p. B136.
58. Relations of metals in lithosols to alteration and shearing at Red Mountain, Clear Creek County, Colo., by P. K. Theobald, Jr., and C. E. Thompson. p. B139.
59. Hydrology of small grazed and ungrazed drainage basins, Badger Wash area, western Colorado, by G. C. Lusby. p. B141.
60. Abandonment of Unaweep Canyon, Mesa County, Colo., by capture of the Colorado and Gunnison Rivers, by S. W. Lohman. p. B144.
61. Tripartition of the Wasatch Formation near De Beque in northwestern Colorado, by J. R. Donnell. p. B147.
80. Stratigraphy of desert varnish, by C. B. Hunt. p. B194.
96. Age of the Ohio Creek conglomerate, Gunnison County, Colo., by D. L. Gaskill. p. B230.
99. Corals from Permian rocks of the northern Rocky Mountain region, by Helen Duncan. p. B235.
121. Four environments of thorium-, niobium-, and rare-earth-bearing minerals in the Powderhorn district of southwestern Colorado, by D. C. Hedlund and J. C. Olson. p. B283.
122. Rhenium in plant samples from the Colorado Plateau, by A. T. Myers and J. C. Hamilton. p. B286.
123. Classification of elements in Colorado Plateau uranium deposits and multiple stages of mineralization, by A. T. Miesch. p. B289.
125. Grantsite—A new hydrated sodium calcium vanadyl vandate from New Mexico and Colorado—A preliminary description, by A. D. Weeks, M. L. Lindberg, and Robert Meyrowitz. p. B293.
131. Relation of supports to geology in the Harold D. Roberts Tunnel, Colo., by E. E. Wahlstrom, L. A. Warner, and C. S. Robinson. p. B303.

*424-C. Short papers in the geologic and hydrologic sciences, Articles 147-292. 1961. p. C1-C398. Contains the following articles, which are not available separately.

149. Origin and evolution of ore and gangue-forming solutions, Silverton caldera, San Juan Mountains, Colo., by W. S. Burbank and R. G. Luedke. p. C7.
153. Spheroidal coal in the Trinidad coal field, south-central Colorado, by R. B. Johnson. p. C20.
154. Potential oil-shale reserves of the Green River Formation in the southeastern Uinta Basin, Utah and Colorado, by W. B. Cashion. p. C22.

PROFESSIONAL PAPERS—Continued

195. Proposed classification of ground-water provinces, hydrologic units, and chemical types of ground water in the Upper Colorado River Basin, by D. A. Phoenix. p. C125.
196. Metamorphism and structural history of the Coal Creek area, Front Range, Colo., by J. D. Wells, D. M. Sheridan, and A. L. Albee. p. C127.
197. Early and late growth of the Gypsum Valley salt anticline, San Miguel County, Colo., by E. R. Landis, E. M. Landis, E. M. Shoemaker, and D. P. Elston. p. C131.
198. Emplacement of the Wilson Peak stock and associated intrusive rocks, San Miguel Mountains, Colo., by C. S. Bromfield. p. C137.
199. Stream directions in Triassic rocks of the Colorado Plateau, by F. G. Poole. p. C139.
209. Middle and upper Tertiary rocks of southeastern Wyoming and adjoining areas, by N. M. Denson and M. H. Bergendahl. p. C168.
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271. Two occurrences of thorium-bearing minerals with rhabdophane-like structure, by J. R. Dooley, Jr., and J. C. Hathaway. p. C339.
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326. Central vent ash-flow eruption, western San Juan Mountains, Colo., by R. G. Luedke and W. S. Burbank. p. D94.
337. Potash-bearing evaporite cycles in the salt anticlines of the Paradox basin, Colorado, and Utah, by R. J. Hite. p. D135.
352. Stratigraphy of lower and middle parts of the Pierre shale, northern Great Plains, by J. R. Gill and W. A. Cobban. p. D185.
382. Stratigraphic significance of the Cretaceous fern *Tempskya* in the western conterminous United States, by C. B. Read and S. R. Ash. p. D250.
406. Geographic distribution of major constituents in stream waters of the western conterminous United States, by C. E. Robinson. p. D334.
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17. Lower Pleistocene Prairie Divide Till, Larimer County, Colo., by D. V. Harris and R. K. Fahnestock. p. B45.
22. Recent discoveries of the Cretaceous ammonite *Haresiceras* and their stratigraphic significance, by W. A. Cobban. p. B58.

44. Use of inflatable packers in multiple-zone testing of water wells, by F. C. Koopman, J. H. Irwin, and E. D. Jenkins. p. B108.

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61. A rare sodium niobate mineral from Colorado, by R. L. Parker, J. W. Adams, and F. A. Hildebrand. p. C4.
62. Localization of the Uravan mineral belt by sedimentation, by D. R. Shawe. p. C6.
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87. Age of Larimide porphyries near Leadville, Colo., by R. C. Pearson, Ogden Tweto, T. W. Stern, and H. H. Thomas. p. C78.
90. *Clioscaphites saxitonianus* (McLearn)—A discrete ammonite zone in the Niobrara Formation at Pueblo, Colo., by G. R. Scott and W. A. Cobban. p. C85.

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129. Age of the Leadville Limestone in the Glenwood Canyon, western Colorado, by W. E. Hallgarth and B. A. L. Skipp. p. D37.
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154. Precambrian gabbro in the central Front Range, Colo., by R. B. Taylor and P. K. Sims. p. D118.
161. Late Cretaceous *Desmoscaphites* Range Zone in the western interior region, by W. A. Cobban. p. D140.
163. Wind directions in late Paleozoic to middle Mesozoic time on the Colorado Plateau, by F. G. Poole. p. D147.

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B. Age of uranium-bearing veins in the conterminous United States, by G. W. Walker. p. 29-35.
C. Host rocks and their alterations as related to uranium-bearing veins in the conterminous United States, by G. W. Walker. p. 37-53.
D. Mineralogy, internal structural and textural characteristics, and paragenesis of uranium-bearing veins in the conterminous United States, by G. W. Walker and J. W. Adams. p. 55-90.
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128. Reinterpretation of the late growth of the Gypsum Valley salt anticline, San Miguel County, Colo., by F. W. Cater. p. D33.
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Similarity of Cenozoic igneous activity in the San Juan and Elk Mountains, Colo., and its regional significance, by P. W. Lipman, F. R. Mutschler, Bruce Bryant, and T. A. Steven. p. D33.

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1936	* 817		1947	*1100		1953	*1269				
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("a" indicates data on quality of water for irrigation)

Year	WSP	Price
1941	*942	
1942	*950	
1943	*970	
1944	*1022	
1945	*1030	
1946	*1050	
1947	*1102	
1948	*1133	
1949	*1163	
1950	*1189	
1951	*1200	
(a)	*1264	
1952	*1251	
	*1252	
	*1253	
	*1362	
1953	*1291	
	*1292	
(a)	*1293	
	*1380	
1954	*1351	
	*1352	
	*1353	
(a)	*1430	
1955	*1401	
	*1402	
	*1403	
(a)	*1465	
1956	*1451	
	*1452	
	*1453	
(a)	*1485	
1957	*1521	
	*1522	
	*1523	
(a)	*1524	
1958	*1572	
	*1573	
	*1574	
(a)	*1575	
1959	*1643	
	*1644	
1959	*1645	
(a)	*1699	
1960	*1743	
	*1744	
	*1745	
(a)	*1746	
1961	*1883	
	*1884	
	*1885	
(a)	*1886	
1962	*1943	
	*1944	
	*1945	
	*1946	
1963	*1949	
	*1950	
	*1951	
(a)	*1952	
1964	*1956	
	*1957	
	*1958	
1964(a)	*1960	
1965	*1963	
	*1964	
	*1965	
(a)	*1967	
1966	*1993	
	*1994	
	*1995	
1967	*2013	
	2014	
	*2015	
1968	*2095	
	*2096	
	2097	$3.45
	*2098	
1969	2145	3.25
	2146	3.85
	2147	4.00
	*2148	
1970	2150	3.50
	*2155	
	2157	4.50
	2158	3.40

Stream measurements in the years mentioned

Year	WSP	Price
1897	*15	
	*16	
1898	*28	
1899	*37	
	*38	
1900	*49	
	*50	
1901	*66	
	*75	
1902	*84	
	*85	
1903	*99	
	*100	
1904	*131	
	*133	
1905	*172	
	*173	
	*174	
	*175	
1906	*208	
	*209	
	*210	
	*211	
1907-8	*246	
	*247	
	*248	
	*249	
1909	*266	
	*267	
	*268	
	*269	
1910	*286	
	*287	
	*288	
	*289	
1911	*306	
	*307	
	*308	
	*309	
1912	*326	
	*327	
	*328	
	*329	
1913	*356	
	*357	
	*358	
	*359	
1914	*386	
	*387	
	*389	
1915	*406	
	*407	
	*408	
1916	*436	
	*437	
	*439	
1917	*456	
	*457	
	*459	
1918	*476	
	*477	
	*479	
1919-20	*506	
	*507	
	*509	
1921	*526	
	*527	
	*529	
1922	*546	
	*547	
	*549	
1923	*566	
	*567	
	*569	
1924	*586	
	*587	
	*589	
1925	*606	
	*607	
	*608	
	*609	
1926	*626	
	*627	
	*628	
	*629	
1927	*646	
	*647	
	*649	
1928	*666	
	*667	
	*669	
1929	*686	
	*689	
1930	*701	
	*702	
	*704	
1931	*716	
	*719	
1932	*731	
	*733	
	*734	
1933	*746	
	*749	
1934	*761	
	*762	
	*763	
	*764	
1935	*786	
	*787	
	*788	
	*789	
1936	*806	
	*807	
	*808	
	*809	
1937	*826	
	*827	
	*828	
	*829	
1938	*856	
	*857	
	*858	
	*859	
1939	*876	
	*877	
	*878	
	*879	
1940	*896	
	*897	
	*898	
	*899	
1941	*926	
	*927	
	*928	
	*929	
1942	*956	
	*957	
	*958	
	*959	
1943	*976	
	*977	
	*978	
	*979	
1944	*1006	
	*1007	
	*1008	
	*1009	
1945	*1036	
	*1037	
	*1038	
	*1039	
1946	*1056	
	*1057	
	*1058	
	*1059	
1947	*1086	
	*1087	
	*1088	
	*1089	
1948	*1116	
	*1117	
	*1118	
	*1119	
1949	*1146	
	*1147	
	*1148	
	*1149	
1950	*1176	
	*1177	
	*1178	
	*1179	
1951	*1210	
	*1211	
	*1212	
	*1213	
1952	*1240	

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Annual reports of the Geological Survey containing data of the water resources of the United States—Continued

Year	WSP	Price	Year	WSP	Price	Year	WSP	Price	Year	WSP	Price
				Stream measurements in the years mentioned—Continued							
	*1241		1955	*1391			*1561			*1919	
	*1242			*1392			*1562			*1921	
	*1243			*1393			*1563			*1923	
1953	*1280		1956	*1440		1959	*1630		1961-65	*1924	
	*1281			*1441			*1631			*1925	
	*1282			*1442			*1632		1966-70	2118	$5.65
	*1283			*1443		1959	*1633			*2119	
1954	*1340		1957	*1510		1960	*1710			*2121	6.15
	*1341			*1511			*1711			*2123	5.70
	*1342		1957	*1512			*1712			*2124	
	*1343			*1513			*1713			2125	4.40
1955	*1390		1958	*1560		1961-65	*1918				

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GQ-69. Hamm Canyon, Colo. Geology, by F. W. Cater, Jr. 1955. Lat 38° to 38° 07′30″, long 108° 45′ to 108° 52′30″. (See Map MF-21.)

GQ-71. Davis Mesa, Colo. Geology, by F. W. Cater, Jr. 1955. Lat 38° 15′ to 38° 22′30″, long 108° 45′ to 108° 52′30″. (See Map MF-31.)

GQ-72. Paradox, Colo. Geology, by C. F. Withington. 1955. Lat 38° 15′ to 38° 22′30″, long 108° 52′30″ to 109°. (See Map MF-22.)

GQ-77. Anderson Mesa, Colo. Geology, by F. W. Cater, Jr. 1955. (1956). Lat 38° 07′30″ to 38° 15′, long 108° 52′30″ to 109°. (See Map MF-25.)

GQ-78. Uravan, Colo. Geology, by F. W. Cater, Jr., A. P. Butler, Jr., and E. J. McKay. 1955. Lat 38° 15′ to 38° 22′30″, long 108° 37′30″ to 108° 45′, (See Map MF-24.)

GQ-81. Juanita Arch, Colo. Geology, by E. M. Shoemaker. 1955. Lat 38° 30′ to 38° 37′30″, long 108° 52′30″ to 109°. (See Map MF-28.)

GQ-83. Rock Creek, Colo. Geology, by E. M. Shoemaker. 1956. Lat 38° 22′30″ to 38° 30′, long 108° 52′30″ to 109° (See Map MF-23.)

GQ-103. Golden, Colo. Bedrock geology, by Richard Van Horn. 1957. Lat 39° 45′ to 39° 52′30″, long 105° 07′30″ to 105° 15′.

GQ-151. Louisville, Colo. Bedrock geology, by F. D. Spencer. 1961. Lat 39° 52′30″ to 40°, long 105° 07′30″ to 105° 15′.

GQ-152. Ouray, Colo. Geology, by R. G. Luedke and W. S. Burbank. 1962. Lat 38° to 38° 07′30″, long 107° 37′30″ to 107° 45′.

GQ-267. Geology of the Central City quadrangle, Colorado, by P. K. Sims. 1964. Lat 39° 45′ to 39° 52′30″, long 105° 30′ to 105° 37′30″.

GQ-291. Geology of the Ironton quadrangle, Colorado, by W. S. Burbank and R. G. Luedke. 1964. Lat 37° 52′30″ to 38°, long 107° 37′30″ to 107° 45′.

GQ-397. Geologic map of the Fort Lupton quadrangle, Weld and Adams Counties, Colo., by P. E. Soister. 1952. Lat 40° to 40° 07′30″, long 104° 45′ to 104° 52′30″.

GQ-398. Geologic map of the Hudson quadrangle, Weld and Adams Counties, Colo., by P. E. Soister. 1965. Lat 40° to 40° 07′30″, long 104° 37′30″ to 104° 45′.

GQ-399. Geologic map of the Platteville quadrangle, Weld County, Colo., by P. E. Soister. 1965. Lat 40° 07′30″ to 40° 15′, long 104° 45′ to 104° 52′30″.

GQ-486. Geologic map of the Cerro Summit quadrangle, Montrose County, Colo., by R. G. Dickinson. 1965 (1966). Lat 38° 22′30″ to 38° 30′, long 107° 37′30″ to 107° 45′.

GQ-504. Geologic map of the Telluride quadrangle, southwestern Colorado, by W. S. Burbank and R. G. Luedke. 1966. Lat 37° 52′30″ to 38°, long 107° 45′ to 107° 52′30″.

GQ-511. Geologic map of the Marcellina Mountain quadrangle, Gunnison County, Colo., by D. L. Gaskill and L. H. Godwin. 1966. Lat 38° 52′30″ to 39°, long 107° 07′30″ to 107° 15′.

GQ-512. Geologic map of the Marble quadrangle, Gunnison and Pitkin Counties, Colo., by D. L. Gaskill and L. H. Godwin. 1966. Lat 39° to 39° 07′30″, long 107° 07′30″ to 107° 15′.

GQ-536. Geologic map of the Dolores Peak quadrangle, Dolores and San Miguel Counties, Colo., by A. L. Bush and C. S. Bromfield. 1966. Lat 37° 45′ to 37° 52′30″, long 108° to 108° 07′30″.

GQ-578. Geologic map of the Oh-be-joyful quadrangle, Gunnison County, Colo., by D. L. Gaskill, L. H. Godwin, and F. E. Mutschler. 1967. Lat 38° 52′30″ to 39°, long 107° to 107° 07′30″.

GQ-596. Geologic map of the Mount Tyndall quadrangle, Custer County, Colo., by M. R. Brock and Q. D. Singewald. 1968. Lat 38° 07′30″ to 38° 15′, long 105° 15′ to 105° 22′30″. 2 sheets. Accompanied by 5-page text.

GQ-631. Geologic map of the Bristol Head quadrangle, Mineral and Hinsdale Counties, Colo., by T. A. Steven. 1967. Lat 37° 45′ to 38°, long 107° to 107° 15′. Scale 1:62,500.

GQ-702. Geologic map of the Elk Springs quadrangle, Moffat County, Colo., by J. R. Dyni. 1968. Lat 40° 15′ to 40° 30′, long 108° 15′ to 108° 30′. Scale 1:62,500.

GEOLOGIC QUADRANGLE MAPS—Continued

GQ-703. Geologic map of the Banty Point quadrangle, Rio Blanco County, Colo., by H. L. Cullins. 1968. Lat 40° to 40° 07′30″, long 108° 52′30″ to 109°.

GQ-704. Geologic map of the Chair Mountain quadrangle, Gunnison and Pitkin Counties, Colo., by L. H. Godwin. 1968. Lat 39° to 39° 07′30″, long 107° 15′ to 107° 22′30″.

GQ-725. Geologic map of the Hanover NW quadrangle, El Paso County, Colo., by P. E. Soister. 1968. Lat 38° 37′30″ to 38° 45′, long 104° 22′30″ to 104° 30′.

GQ-747. Geologic map of the Black Ridge quadrangle, Delta and Montrose Counties, Colo., by W. R. Hansen. 1968. Lat 38° 37′30″ to 38° 45′, long 107° 45′ to 107° 52′30″.

GQ-783. Geologic map of the Corral Bluffs quadrangle, El Paso County, Colo., by P. E. Soister. 1968. Lat 38° 45′ to 38° 52′30″, long 104° 30′ to 104° 37′30″.

GQ-788. Geologic map of the Maroon Bells quadrangle, Pitkin and Gunnison Counties, Colo., by Bruce Bryant. 1969. Lat 39° to 39° 07′30″, long 106° 52′30″ to 107°.

GQ-797. Geologic map of the Rico quadrangle, Dolores and Montezuma Counties, Colo., by W. P. Pratt, E. T. McKnight, and R. A. DeHon. 1969. Lat 37° 37′30″ to 37° 45′, long 108° to 108° 07′30″.

GQ-812. Geologic map of the Black Cabin Gulch quadrangle, Rio Blanco County, Colo., by W. B. Cashion. 1969. Lat 39° 45′ to 39° 52′30″, long 108° 30′ to 108° 37′30″.

GQ-823. Geologic map of the Casa Grande quadrangle, Colfax County, N. Mex., and Las Animas County, Colo., by C. L. Pillmore. 1969 (1970). Lat 36° 45′ to 37°, long 104° 45′ to 105°. Scale 1:62,500.

GQ-829. Geologic map of the Drake quadrangle, Larimer County, Colo., by W. A. Braddock, Prinya Nutalaya, S. J. Gawarecki, and G. C. Curtin. 1970. Lat 40° 22′30″ to 40° 30′, long 105° 15′ to 105° 22′30″.

GQ-832. Geologic map of the Masonville quadrangle, Larimer County, Colo., by W. A. Braddock, R. H. Calvert, S. J. Gawarecki, and Prinya Nutalaya. 1970. Lat 40° 22′30″ to 40° 30′, long 105° 07′30″ to 105° 15′.

GQ-833. Geologic map of the Nederland quadrangle, Boulder and Gilpin Counties, Colo., by D. J. Gable. 1969 (1970). Lat 39° 52′30″ to 40°, long 105° 30′ to 105° 37′30″.

GQ-835. Geologic map of the Mellen Hill quadrangle, Rio Blanco and Moffat Counties, Colo., by H. L. Cullins. 1969 (1970). Lat 40° 07′30″ to 49° 15′, long 108° 52′30″ to 109°.

GQ-853. Geologic map of the Snowmass Mountain quadrangle, Pitkin and Gunnison Counties, Colo., by F. E. Mutschler. 1970. Lat 39° to 39° 07′30″, long 107° to 107° 07′30″.

GQ-863. Geologic map of the Hayden Peak quadrangle, Pitkin and Gunnison Counties, Colo., by Bruce Bryant. 1970. Lat 39° to 39° 07′30″, long 106° 45′ to 106° 52′30″.

GQ-875. Geologic map of the Peoria quadrangle, Arapahoe and Adams Counties, Colo., by P. E. Soister. 1972. Lat 39° 37′30″ to 39° 45′, long 104° to 104° 07′30″.

GQ-903. Geologic map of the Rangely quadrangle, Rio Blanco County, Colo., by H. L. Cullins. 1971. Lat 40° to 40° 07′30″, long 108° 45′ to 108° 52′30″.

GQ-932. Geologic map of the Highland Peak quadrangle, Pitkin County, Colo., by Bruce Bryant. 1972. Lat 39° 07′30″ to 39° 15′, long 106° 52′30″ to 107°.

GQ-933. Geologic map of the Aspen quadrangle, Pitkin County, Colo., by Bruce Bryant. 1971. Lat 39° 07′30″ to 39° 15′, long 106° 45′ to 106° 52′30″.

GQ-952. Geologic map of the Mount Harvard quadrangle, Chaffee and Gunnison Counties, Colo., by M. R. Brock and Fred Barker. 1972. Lat 38° 45′ to 39°, long 106° 15′ to 106° 30′. Scale 1:62,500.

GQ-967. Geologic map of the Woody Creek quadrangle, Pitkin and Eagle Counties, Colo., by V. L. Freeman. 1972. Lat 39° 15′ to 39° 22′30″, long 106° 52′50″ to 107°.

GQ-978. Geologic map of the Tungsten quadrangle, Boulder, Gilpin, and Jefferson Counties, Colo., by D. J. Gable. 1972. Lat 39° 52′30″ to 40°, long 105° 22′30″ to 105° 30′.

GQ-1001. Geologic map of the Red Creek Ranch quadrangle, Wyoming, Utah, and Colorado, by H. W. Roehler. 1972. Lat 41° to 41° 07′30″, long 109° to 109° 07′30″.

GQ-1002. Geologic map of the Four J Rim quadrangle, Sweetwater County, Wyo., and Moffat County, Colo., by H. W. Roehler. 1972. Lat 41° to 41° 07′30″, long 108° 52′30″ to 109°.

GQ-1004. Geologic map of the Ruedi quadrangle, Pitkin and Eagle Counties, Colo., by V. L. Freeman. 1972. Lat 39° 15′ to 39° 22′30″, long 106° 45′ to 106° 52′30″.

GQ-1011. Geologic map of the Wetterhorn Peak quadrangle, Colorado, by R. G. Luedke. 1972. Lat 38° to 38° 07′30″, long 107° 30′ to 107° 37′30″.

GEOLOGIC QUADRANGLE MAPS—Continued

GQ-1018. Geologic map of the Brushy Point quadrangle, Rio Blanco and Garfield Counties, Colo., by H. W. Roehler. 1972. Lat 39° 37′30″ to 39° 45′, long 108° 37′30″ to 108° 45′.

GQ-1019. Geologic map of the Razorback Ridge quadrangle, Rio Blanco and Garfield Counties, Colo., by H. W. Roehler. 1972. Lat 39° 37′30″ to 39° 45′, long 108° 30′ to 108° 37′30″.

GQ-1052. Geologic map of the Spar City quadrangle, Mineral County, Colo., by T. A. Steven and P. W. Lipman. 1973. Lat 37° 30′ to 37° 45′, long 106° 45′ to 107°. Scale 1:62,500.

GQ-1053. Geologic map of the Creede quadrangle, Mineral and Saguache Counties, Colo., by T. A. Steven and J. C. Ratte. 1973. Lat 37° 45′ to 38°, long 106° 45′ to 107°. Scale 1:62,500.

GQ-1070. Geologic map of the Carpenter Ridge quadrangle, Gunnison County, Colo., by D. C. Hedlund and J. C. Olson. 1973 (1974). Lat 38° 22′30″ to 38° 30′, long 107° 07′30″ to 107° 15′.

GQ-1071. Geologic map of the Gateview quadrangle, Gunnison County, Colo., by J. C. Olson and D. C. Hedlund. 1973 (1974). Lat 38° 15′ to 38° 22′30″, long 107° 07′30″ to 107° 15′.

GQ-1073. Geologic map of the Indian Hills quadrangle, Jefferson County, Colo., by Bruce Bryant, R. D. Miller, and G. R. Scott. 1973 (1974). Lat 39° 30′ to 39° 37′30″, long 105° 07′30″ to 105° 15′.

GQ-1086. Geologic map of the Calf Canyon quadrangle, Garfield County, Colo., by H. W. Roehler. 1973 (1974). Lat 39° 30′ to 39° 37′30″, long 108° 37′30″ to 108° 45′.

GQ-1113. Geologic map of the Henderson Ridge quadrangle, Garfield County, Colo., by H. W. Roehler. 1973 (1974). Lat 39° 30′ to 39° 37′30″, long 108° 30′ to 108° 37′30″.

GQ-1115. Geologic map of the Kremmling quadrangle, Grand County, Colo., by G. A. Izett and C. S. V. Barclay. 1973 (1975). Lat 40° to 40° 15′, long 106° 15′ to 106° 30′. Scale 1:62,500.

GQ-1131. Geologic map of the Smizer Gulch quadrangle, Rio Blanco and Moffat Counties, Colo., by W. J. Hail, Jr. 1973 (1974). Lat 40° 07′30″ to 40° 15′, long 108° 15′ to 108° 22′30″.

GQ-1134. Geologic map of the Iris NW quadrangle, Gunnison and Saguache Counties, Colo., by D. C. Hedlund and J. C. Olson. 1974. Lat 38° 22′30″ to 38° 30′, long 106° 52′30″ to 107°.

GQ-1144. Geologic map of the Lone Mountain quadrangle, Moffat County, Colo., by E. J. McKay. 1974. Lat 40° 30′ to 40° 45′, long 108° 15′ to 108° 30′. Scale 1:62,500.

GQ-1145. Geologic map of the Maybell quadrangle, Moffat County, Colo., by E. J. McKay and M. J. Bergin. 1974. Lat 40° 30′ to 40° 45′, long 108° to 108° 15′. Scale 1:62,500.

GQ-1153. Geologic map of the Big Mesa quadrangle, Gunnison County, Colo., by D. C. Hedlund. 1974 (1975). Lat 38° 22′30″ to 38° 30′, long 107° to 107° 07′30″.

GQ-1156. Geologic map of the Trail Mountain quadrangle, Grand County, Colo., by G. A. Izett. 1974. Lat 40° 07′30″ to 40° 15′, long 105° 52′30″ to 106°.

GQ-1166. Geologic map of the Scrivner Butte quadrangle, Sweetwater County, Wyo., and Moffat County, Colo., by H. W. Roehler. 1974. Lat 41° to 41° 07′30″, long 108° 45′ to 108° 52′30″.

GQ-1177. Geologic map of the Rudolph Hill quadrangle, Gunnison, Hinsdale, and Saguache Counties, Colo., by J. C. Olson. 1974. (1975). Lat 38° 07′30″ to 38° 15′, long 107° to 107° 07′30″. Scale 1:24,000. Paleotopographic-contour interval 100 feet.

GQ-1178. Geologic map of the Powderhorn quadrangle, Gunnison and Saguache Counties, Colo., by D. C. Hedlund and J. C. Olson. 1975. Lat 38° 15′ to 38° 22′30″, long 107° to 107° 07′30″. Scale 1:24,000. Paleotopographic-contour interval 100 feet.

GQ-1195. Geologic map of the Rough Gulch quadrangle, Rio Blanco and Moffat Counties, Colo., by W. J. Hail, Jr. 1974 (1975). Lat 40° 07′30″ to 40° 15′, long 108° 22′30″ to 108° 30′. Scale 1:24,000. Structure-contour intervals 100 and 500 feet.

GQ-1224. Geologic map of the Bottle Pass quadrangle, Grand County, Colo., by R. B. Taylor. 1975. Lat 39° 52′30″ to 40°, long 105° 52′30″ to 106°. Scale 1:24,000.

GQ-1229. Geologic map of the Niwot quadrangle, Boulder County, Colo., by D. E. Trimble. 1975. Lat 40° to 40° 07′30″, long 105° 07′30″ to 105° 15′. Scale 1:24,000. (Supersedes OF 74-10).

GEOLOGIC QUADRANGLE MAPS—Continued

GQ-1248. Geologic map of the Black Hawk quadrangle, Gilpin, Jefferson, and Clear Creek Counties, Colorado, by R. B. Taylor. 1976. Lat 39° 45′ to 39° 52′30″, long 105° 22′30″ to 105° 30′. Scale 1:24,000 (1 inch = 2,000 feet) Sheet 32 by 40 inches.

GQ-1277. Geologic map of the Ward quadrangle, Boulder County, Colo., by D. J. Gable and R. F. Madole. 1976. Lat 40° to 40° 07′30″, long 105° 30′ to 105° 37′30″. Scale 1:24,000.

GQ-1286. Geologic map of the Iris quadrangle, Gunnison and Saguache Counties, Colo., by J. C. Olson. 1976. Lat 38° 22′30″ to 38° 30′, long 106° 45′ to 106° 52′ 30″. Scale 1:24,000. (Supersedes Open-File 75-63.)

GQ-1287. Geologic map of the Houston Gulch quadrangle, Gunnison and Saguache Counties, Colorado, by J. C. Olson. 1976, Lat 38° 22′30″ to 38° 30′, long 106° 37′30″ to 106° 45′. Scale 1:24,000. (Supersedes Open-file 75-62.)

GQ-1323. Geologic map of the Big Narrows quadrangle, Larimer County, Colorado, by J. T. Abbott. 1976. Lat 40° 37′30″ to 40° 45′, long 105° 22′30″ to 105° 30′. Scale 1:24,000 (1 inch = 2,000 feet) Sheet 3[illegible] by 34 inches.

GQ-1337. Geologic map of the Sq[illegible]w Pass quadrangle, Clear Creek, Jefferson, and Gilpin Counties, Colorado, by D. [illegible] Sheridan and S. P. Marsh. 1976 (1977). Lat 39° 37′30″ to 39° 45′, long 105° 22′30″ to 105° 30′. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 29 by 42 inches.

GQ-1343. Geologic map of the Milligan Lakes quadrangle, Park County, Colorado, by D. G. Wyant and Fred Barker. 1976 (1977). Lat 39° 15′ to 39° 22′30″, long 105° 45′ to 105° 52′30″. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 31 by 33 inches.

GQ-1345. Geologic map of the Jefferson quadrangle, Park and Summit Counties, Colorado, by Fred Barker and D. G. Wyant. 1976. (1977). Lat 39° 22′30″ to 39° 30′, long 105° 45′ to 105° 52′30″. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 30 by 31 inches.

GQ-1403. Geologic map of the Canyon of Lodore south quadrangle, Moffat County, Colorado, by W. R. Hansen. 1977. Lat 40° 30′ to 40° 37′30″, long 108° 52′30″ to 109°. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 29 by 42 inches.

GEOPHYSICAL INVESTIGATIONS MAPS

GP-125. Airborne radioactivity survey of part of Moffat County, Colo., north of 40° 45′, by R. W. Johnson. 1955. Scale 1:62,500. $1.25.

GP-126. Airborne radioactivity survey of part of Moffat County, Colo., south of 40° 45′, by R. W. Johnson. 1955. Scale 1:62,500. $1.25.

GP-505. Natural gamma aeroradioactivity map of the Denver area, Colorado, by Peter Popenoe. 1965. Lat 39° 07′30″ to 40° 35′, long 104° to about 105° 15′. Scale 1:250,000. $1.25.

GP-557. Aeromagnetic map of the Denver area, Colorado, by A. J. Petty, J. L. Vargo, and F. C. Smith. 1966. Vicinity of lat 40°, long 104° 30′. Scale 1:250,000. $1.25.

GP-597. Aeromagnetic and gravity profiles of the United States along the 37th parallel—A contribution to the upper mantle project, by Isidore Zietz and J. R. Kirby. 1967. Lat 35° to 39°, long 70° to 125°. Scale 1:2,500,000. $1.25.

GP-638. Gravity map of the Trinidad quadrangle, Colo., by D. L. Peterson, Peter Popenoe, J. R. Gaca, and D. E. Karig. 1968. Lat 37° to 38°, long 104° to 106°. Scale 1:250,000. $1.25.

GP-836. Aeromagnetic map of Colorado, by Isidore Zietz and J. R. Kirby, Jr. 1972. Lat 37° to 41°, long 102° to 109°. Scale 1:500,000. $1.25.

GP-840. Aeromagnetic map of the Ridgway—Pagosa Springs area, southwestern Colorado. 1972 (1973). Lat 37° 15″ to 38° 15″, long 106°30′ to 108°15′. Scale. 1:500,000. $1.25.

GP-880. Aeromagnetic map of Colorado, by Isidore Zietz and J. R. Kirby, Jr. 1972. Lat 37° to 41°, long 102° to 109°. Scale 1:000,000. $1.50.

GP-895. Bouguer gravity map of Colorado, compiled by J. C. Behrendt and L. Y. Bajwa. 1974. Lat 37° to 41°, long 102° to 109°. Scale 1:500,000. $1.25.

GP-896. Bouguer gravity and generalized elevated maps of Colorado, by J. C. Behrendt and L. Y. Bajwa. 1974 (1975). Lat 37° to 41°, long 102° to 109°. Scale 1:1,000,000. 2 sheets. $2.75.

HYDROLOGIC INVESTIGATIONS ATLASES

HA-2. Areas of principal ground-water investigations in the Arkansas, White, and Red River basins, by S. W. Lohman and V. M. Burtis. 1953 (1954). Lat 31° to 39°, long 91° to 106°. Scale 1:2,300,000. $1.

HYDROLOGIC INVESTIGATIONS ATLASES—Continued

HA-3. General availability of ground water and depth to water level in the Arkansas, White and Red River basins, by S. W. Lohman, V. M. Burtis, and others. 1953 (1954). Lat 31° to 39°, long 91° to 106°. Scale 1:2,500,000. (1975) $1.

HA-9. Ground-water resources of parts of Weld, Logan, and Morgan Counties, Colo., by L. J. Bjorklund, with a section on The Chemical quality of the ground water, by F. H. Rainwater. 1957 (1958). $1.50.

HA-41. Floods at Boulder, Colo. 1961 (1962). Scale 1:6,000. $1.75.

HA-61. Stream composition of the conterminous United States, by E. H. Rainwater. 1962. 3 sheets. $6 per set.

HA-189. Calcium, sodium, sulfate, and chloride in stream water of the western conterminous United States to 1957, by J. H. Feth. 1965. 4 sheets. Scale 1:2,500,000. $5 per set.

HA-194. Generalized map showing annual runoff and productive aquifers in the conterminous United States, by C. L. McGuinness. 1964. Scale 1:5,000,000. $2.

HA-199. Preliminary map of the conterminous United States showing depth to and quality of shallowest ground water containing more than 1,000 parts per million dissolved solids, by J. H. Feth and others. 1965. Scale 1:3,168,000. 2 sheets. Accompanied by 31-page text. $1.75 per set.

HA-200. Chemical quality of public water supplies of the United States and Puerto Rico, 1962, shown as Statewide averages, mainly in graphic and tabular form, by C. N. Durfor and Edith Becker. 1964. $1.25.

HA-212. Annual runoff in the conterminous United States, by M. W. Bushby. 1966. Scale 1:7,500,000. $1.25.

HA-217. General availability of ground water and depth to water level in the Missouri River basin, by G. A. La Rocque, Jr. 1966. Lat 36° to 49°, long 90° to 114°. Scale 1:2,500,000. $1.75.

HA-235. Temperature of surface waters in the conterminous United States, by J. F. Blakey. 1966. Scale 1:5,000,000. 3 sheets. Accompanied by 8-page text. $1.75 per set.

HA-236. Ground water in Black Squirrel Creek valley, El Paso County, Colo., by H. E. McGovern and E. D. Jenkins. 1966. Vicinity of lat 38° 50′, long 104° 25′. $1.25.

HA-370. Geohydrology of the Piceance Creek structural basin between the White and Colorado Rivers, northwestern Colorado, by D. L. Coffin, F. A. Welder, and R. K. Glanzman. 1971. Lat about 39° 15′ to 40° 15′, long about 108° to 108° 45′. 2 sheets. $2.50 per set.

HA-381. Hydrology of the San Luis Valley, south-central, Colorado, by P. A. Emery, A. J. Boettcher, R. J. Snipes, and H. J. McIntyre, Jr. 1971. Lat 37° to 38° 15′, long 105° 30′ to 106° 30′. 2 sheets. $2.50 per set.

HA-461. Hydrogeologic characteristics of the valley-fill aquifer in the Arkansas River valley, Bent County, Colo., by R. T. Hurr and J. E. Moore. 1972 (1973). Lat 38° to 38° 10′, long 102° 45′ to 103° 22′30″. Scale 1:62,500. 2 sheets. $2.50 per set.

HA-477. Selected hydrologic data in the upper Colorado River basin, by Don Price and K. M. Waddell. 1973 (1974). Lat 36° to 43°, long 106° to 112°. Scale 1:2,500,000. 2 sheets. $3 per set.

HA-510. Reconnaissance investigation of ground water in the Rio Grande drainage basin—with special emphasis on saline ground-water resources, by T. E. Kelly. 1974. Lat 26° to 38° , long 98° to 108°. Scale 1:2,500,000. 4 sheets. $5.50 per set.

STATE HYDROLOGIC MAP

COLORADO. 1974. An overprint of the 1:500,000-scale State base map. Shows counties, location and names of all cities and towns and most of the smaller settlements, railroads, and township and range lines in black; water features in blue; hydrologic boundaries and codes in red; county codes in green. No contours. Sheet 41 by 58 inches. $1.25.

***INTERPRETING GEOLOGIC MAPS FOR ENGINEERING PURPOSES.** 1953 (1954). Six maps of the Hollidaysburg, Pa. quadrangle. Scale 1:62,500.

***LAND CLASSIFICATION MAPS OF THE CENTRAL GREAT PLAINS:**

*Sheet 4, Northeastern Colorado, by Depue Falck, E. R. Greenslet, and R. E. Morgan.

*Sheet 5, Southeastern Colorado, by Depue Falck, E. R. Greenslet, and R. E. Morgan.

*Western Colorado, by L. R. Brooks, J. F. Deeds, Depue Falck, E. R. Greenslet, G. M. Kerr, and J. Q. Peterson. 2 sheets.

MISCELLANEOUS FIELD STUDIES MAPS

MF-12. Geologic map of the Pando area, Eagle and Summit Counties, Colo., by Ogden Tweto. 1953 (1954). Lat 39° 25′ to 39° 30′, long 106° 12′30″ to 106° 22′30″. Scale 1:14,400. $1.75.

*MF-13. Geology of the Northgate fluorspar district, Colorado, by T. A. Steven. 1954. Scale 1:24,000. 2 sheets. (See Bulletin 1082-F and Professional Paper 274-M.)

MF-16. Preliminary geologic map showing the distribution of uranium deposits and principal ore-bearing formations of the Colorado Plateau region, compiled by W. I. Finch. 1955. Scale 1:500,000. $1.25.

*MF-17. Preliminary geologic map of the Red Canyon quadrangle, Colorado, by D. J. McKay. 1954. Lat 38° 22′30″. to 38° 30′, long 108° 45′ to 108° 52′30″. Scale 1:24,000. (See Map GQ-58.)

*MF-18. Preliminary geologic map of the Atkinson Creek quadrangle, Colorado, by E. J. McKay and D. A. Jobin. 1954. Lat 38° 22′30″ to 38° 30′, long 108° 37′30″ to 108° 45′. Scale 1:24,000. (See Map GQ-57.)

*MF-19. Preliminary geologic map of the Gypsum Gap quadrangle, Colorado, by F. W. Cater, Jr. 1954 (1955). Lat 38° to 38° 07′30″, long 108° 37′30″ to 108° 45′. Scale 1:24,000. (See Map GQ-59.)

*MF-20. Preliminary geologic map of the Pine Mountain quadrangle, Colorado, by F. W. Cater, Jr. 1954. Lat 38° 37′30″ to 38° 45′, long 108° 45′ to 108° 52′30″. Scale 1:24,000. (See Map GQ-60.)

*MF-21. Preliminary geologic map of the Hamm Canyon quadrangle, Colorado, by F. W. Cater, Jr. 1955. Lat 38° to 38° 07′30″, long 108° 52′30″. Scale 1:24,000. (See Map GQ-69.)

*MF-22. Preliminary geologic map of the Paradox quadrangle, Colorado, by C. F. Withington. 1955. Lat 38° 15′ to 38° 22′30″, long 108° 52′30″ to 109°. Scale 1:24,000. (See Map GQ-72.)

*MF-23. Preliminary geologic map of the Roc Creek quadrangle, Colorado, by E. M. Shoemaker. 1955. Lat 38° 22′30″ to 38° 30′, long 108° 52′30″ to 109°. Scale 1:24,000. (See Map GQ-83.)

*MF-24. Preliminary geologic map of the Uravan quadrangle, Colorado, by F. W. Cater, Jr., and E. J. McKay. 1955. Lat 38° 15′ to 38° 22′30″, long 108° 37′30″ to 108° 45′. Scale 1:24,000. (See Map GQ-78.)

*MF-25. Preliminary geologic map of the Anderson Mesa quadrangle, Colorado, by F. W. Cater, Jr. 1955. Lat 38° 07′30″ to 38° 15′, long 108° 52′30″ to 109°. Scale 1:24,000. (See Map GQ-77.)

*MF-26. Preliminary geologic map of the Egnar quadrangle, Colorado, by F. W. Cater, Jr. 1955. Lat 37° 52′30″ to 38°, long 108° 52′30″ to 109°. Scale 1:24,000. (See Map GQ-68.)

*MF-27. Preliminary geologic map of the Joe Davis Hill quadrangle, Colorado, by F. W. Cater, Jr. 1955. Lat 37° 52′30″ to 38°, long 108° 45′ to 108° 52′30″. Scale 1:24,000. (See Map GQ-66.)

*MF-28. Preliminary geologic map of the Juanita Arch quadrangle, Colorado, by E. M. Shoemaker. 1955. Lat 38° 30′ to 38° 37′30″, long 108° 52′30″ to 109°. Scale 1:24,000. (See Map GQ-81.)

*MF-29. Preliminary geologic map of the Horse Range Mesa quadrangle, Colorado, by F. W. Cater, Jr. 1954 (1955). Lat 38° to 38° 07′30″, long 108° 52′30″ to 109°. Scale 1:24,000. (See Map GQ-64.)

*MF-30. Preliminary geologic map of the Naturita NW quadrangle, Colorado, by F. W. Cater, Jr. 1955. Lat 38° 07′30″ to 38° 15′, long 108° 37′30″ to 108° 45′. Scale 1:24,000. (See Map GQ-65.)

*MF-31. Preliminary geologic map of the Davis Mesa quadrangle, Colorado, by F. W. Cater, Jr., and E. J. McKay, 1955. Lat 38° 15′ to 38° 22′30″, long 108° 45′ to 108° 52′30″. Scale 1:24,000. (See Map GQ-71.)

*MF-32. Preliminary geologic map of the Calamity Mesa quadrangle, Colorado, by F. W. Cater, Jr. 1955. Lat 38° 30′ to 38° 37′30″, long 108° 45′ to 108° 52′ 30″. Scale 1:24,000. (See Map GQ-61.)

MF-34. Geologic map of the Tennessee Pass area, Eagle and Lake Counties, Colo., by Ogden Tweto. 1956. Scale 1:14,400. 75¢.

*MF-37. Geologic and radiometric maps of the McKinley Mountain area, Wet Mountains, Colo., by Q. D. Singewald and others. 1955. Scale 1:7,200. 4 sheets. (See Bulletin 1072-H and Map GQ-596.)

MF-54. Uranium and vanadium deposits of the Colorado Plateau that produced more than 1,000 tons of ore through June 30, 1955, by R. T. Chew 3d. 1956. Scale 1:750,000. 75¢.

*MF-96. Preliminary geologic map of Placerville quadrangle, Colorado, by A. L. Bush, C. S. Bromfield, and C. T. Pierson. 1956. Lat 38° to 38° 07′30″, long 108° to 108° 07′30″. Scale 1:24,000. (See Bulletin 1072-E.)

MF-120. Uranium deposits and principal ore-bearing formations of the central Cordilleran foreland region, by T. L. Finnell and I. S. Parrish. 1958. Scale 1:750,000. 2 sheets. $1.50 per set. (See Bulletin 1087-I.)

MF-122. Preliminary geologic map of sections of the western part of the Gateway district, Mesa County, Colo., and Grand County, Utah, by L. J. Eicher, D. C. Hedlund, and G. A. Miller. 1957. Lat 38° 36′15″ to 38° 45′, long 109° to 109° 10′. Scale 1:24,000. 75¢.

*MF-123. Preliminary geologic map of the Mount Peale 1 SE quadrangle, Montrose County, Colo., and San Juan County, Utah, by W. D. Carter and J. L. Gualtieri. 1957. Lat 38° 15′ to 38° 22′30″, long 109° to 109° 07′30″. Scale 1:24,000. (See Professional Paper 508.)

*MF-130. Preliminary tectonic map of northern Colorado and northeastern Utah, showing the distribution of uranium deposits, compiled by F. W. Osterwald and B. G. Dean. 1958. Scale 1:500,000. 2 sheets. (See Bulletin 1087-I.)

*MF-132. Preliminary geologic map of the Sentinel Peak NW quadrangle, Montezuma County, Colo., by E. B. Ekren and F. N. Houser. 1957. Lat 37° 07′30″ to 37° 15′, long 108° 52′30″ to 109°. Scale 1:24,000. (See Professional Paper 481.)

*MF-139. Preliminary geologic map of the Mount Peale 1 NE quadrangle, San Juan County, Utah, and Montrose County, Colo., by W. D. Carter, J. L. Gualtieri, and E. M. Shoemaker. 1958. Lat 38° 22′30″ to 38° 30′, long 109° to 109° 07′30″. Scale 1:24,000. (See Professional Paper 508.)

MF-149. Preliminary geologic map of the Mount Peale 4 SE quadrangle, San Juan County, Utah, and San Miguel County, Colo., by G. W. Weir and W. P. Puffett. 1960 (1961). Lat 38° to 38° 07′30″, long 109° to 109° 07′30″. Scale 1:24,000. 75¢.

MF-150. Preliminary geologic map and section of the Mount Peale 4 NE quadrangle, San Juan County, Utah, and Montrose and San Miguel Counties, Colo., by G. W. Weir, W. D. Carter, W. P. Puffett, and J. O. Gualtieri. 1960. (1961). Lat 38° 07′30″ to 38° 15′, long 109° to 109° 07′30″. Scale 1:24,000. 75¢.

MF-169. Exploration for uranium-vanadium deposits by the U.S. Geological Survey in the Club Mesa area, Uravan district, Montrose County, Colo., by R. L. Boardman, L. R. Litsey, and H. E. Bowers. 1958. Scale 1:7,200. $1.50.

MF-176. Preliminary geologic map of the Gray Head quadrangle, San Miguel County, Colo., by A. L. Bush, C. S. Bromfield, O. T. Marsh, and R. B. Taylor. 1961. Lat 37° 52′30″ to 38°, long 107° 52′30″ to 108°. Scale 1:24,000. $1.50.

*MF-179. Preliminary map of bedrock geology of the Ralston Buttes quadrangle, Jefferson County, Colo., by D. M. Sheridan, C. H. Maxwell, A. L. Albee, and Richard Van Horn. 1958. Lat 39° 45′ to 39° 52′30″, long 105° 15′ to 105° 22′30″. Scale 1:24,000. (See Professional Paper 520.)

*MF-203. Preliminary geologic map of the Slick Rock district, San Miguel and Dolores Counties, Colo., by D. R. Shawe, G. C. Simmons, and W. B. Rogers. 1961. Lat 37° 45′ to 38°, long 108° 37′30″ to 109°. Scale 1:48,000. (See Bulletin 1107-B and Professional Paper 576-A.)

*MF-216. Preliminary geologic map of the Moqui SW quadrangle, Montezuma County, Colo., by F. N. Houser and E. B. Ekren. 1959. Lat 37° 15′ to 37° 22′30″, long 108° 52′30″ to 109°. Scale 1:24,000. (See Professional Paper 481.)

*MF-217. Preliminary geologic map of the Cortez SW quadrangle, Montezuma County, Colo., by E. B. Ekren and F. N. Houser. 1959. Lat 37° 15′ to 37° 22′30″, long 108° 37′30″ to 108° 45′. Scale 1:24,000. (See Professional Paper 481.)

MISCELLANEOUS FIELD STUDIES MAPS—Continued

*MF-221. Preliminary geologic map of the Moqui SE quadrangle, Montezuma County, Colo., by E. B. Ekren and F. N. Houser. 1959. Lat 37° 15′ to 37° 22′30″, long 108° 45′ to 108° 52′30″. Scale 1:24,000. (See Professional Paper 481.)

*MF-223. Preliminary geologic map of the Little Cone quadrangle, San Miguel County, Colo., by A. L. Bush, O. T. Marsh, and R. B. Taylor. 1959. Lat 37° 52′30″ to 38°, long 108° to 108° 07′30″. Scale 1:24,000. (See Bulletin 1082-G.)

*MF-224. Preliminary geologic map of the Sentinel Peak NE quadrangle, Montezuma County, Colo., by E. B. Ekren and F. N. Houser. 1959. Lat 37° 07′30″ to 37° 15′, long 108° 45′ to 108° 52′30″. Scale 1:24,000. (See Professional Paper 481.)

*MF-241. Exploration for uranium-vanadium deposits by U.S. Geological Survey 1948-56 in western Disappointment Valley area, Slick Rock district, San Miguel County, Colo. (West half) (East half), by W. B. Rogers and D. R. Shaw. 2 Scale 1:12,000. 3 sheets. (See Professional Paper 576-A.)

MF-271. Preliminary geologic map of the Hot Sulphur Springs SE quadrangle, Grand County, Colo., by G. A. Izett and D. L. Hoover. 1963. Lat 40° to 40° 07′30″, long 106° to 106° 07′30″. Scale 1:24,000. 75¢.

*MF-273. Preliminary geologic map of the Mount Wilson quadrangle, San Miguel and Dolores Counties, Colo., by C. S. Bromfield and A. R. Conroy. 1963 (1964). Lat 37° 45′ to 37° 52′30″, long 107° 52′30″ to 108°. Scale 1:24,000. (See Bulletin 1227.)

MF-291. Preliminary geologic map of the Hot Sulphur Springs SW quadrangle, Grand County, Colo., by G. A. Izett and C. S. V. Barclay. 1964. Lat 40° to 40° 07′30″, long 106° 07′30″ to 106° 15′. Scale 1:24,000. 75¢.

MF-308. Preliminary engineering geologic map of the Golden quadrangle, Jefferson County, Colo., by M. E. Gardner and S. S. Hart. 1971 (1972.) Lat 39° 45′ to 39° 52′30″, long 105° 07′30″ to 105° 15′. 6 sheets. Scale 1:24,000. Accompanied by 21-page text. $4.50 per set.

MF-309. Structure contours and overburden on the top of the Mahogany zone, Green River Formation, in the northern part of the Piceance Creek basin, Rio Blanco County, Colo., by A. C. Austin. 1971 (1972). Lat 39° 45′ to about 40° 10′, long 108° to about 108° 35′. Scale 1:62,500. 75¢.

MF-346. Historic trail map of the La Junta 2° quadrangle, Colorado, compiled by G. R. Scott. 1972. Lat 37° to 38°, long 102° to 104°. Scale 1:250,000. 75¢.

MF-347. Preliminary geologic map of the Barcus Creek SE quadrangle, Rio Blanco County, Colo., by R. J. Hail, Jr. 1972. Lat 40° to 40° 07′30″, long 108° 15′ to 108° 22′30″. Scale 1:24,000. 2 sheets. $1.50 per set.

MF-348. Geologic map of the Arvada quadrangle, Adams, Denver, and Jefferson Counties, Colo., by R. M. Lindvall. 1972. Lat 39° 45′ to 39° 52′30″, long 105° to 105° 07′30″. Scale 1:24,000. 2 sheets. $1.50 per set.

MF-352. Reconnaissance geologic map of the Beulah NE quadrangle, Pueblo County, Colo., by G. R. Scott. 1972. Lat 38° 07′30″ to 38° 15′, long 104° 45′ to 104° 52′30″. Scale 1:24,000. 75¢.

MF-353. Reconnaissance geologic map of the Hobson quadrangle, Pueblo and Fremont Counties, Colo., by G. R. Scott. 1972. Lat 38° 15′ to 38° 22′30″, long 104° 52′30″ to 105°. Scale 1:24,000. 75¢.

MF-354. Reconnaissance geologic map of the Swallows quadrangle, Pueblo County, Colo., by G. R. Scott. 1972. Lat 38° 15′ to 38° 22′30″, long 104° 45′ to 104° 52′30″. Scale 1:24,000. 75¢.

MF-482. Reconnaissance geologic map of Colorado Springs and vicinity, Colorado, by G. R. Scott and R. A. Wobus. 1973. Lat 38° 37′30″ to 39°, long 104° 37′30″ to 105°. Scale 1:62,500. 2 sheets. $1.50 per set.

MF-513. Map showing mined areas of the Boulder-Weld coal field, Colorado, by R. B. Colton and R. L. Lowrie. 1973. Lat 39° 55′ to 40° 07′30″, long 104° 52′30″ to 105° 15′. Scale 1:24,000. 75¢.

MF-547. Reconnaissance geologic map of the Owl Canyon quadrangle, Pueblo County, Colo., by G. R. Scott. 1973 (1974). Lat 38° 07′30″ to 38° 15′, long 104° 52′30″ to 105°. Scale 1:24,000. 75¢.

MF-548. Reconnaissance geologic map of the Wetmore quadrangle, Custer and Pueblo Counties, Colo., by R. B. Taylor and G. R. Scott. 1973 (1974). Lat 38° 07′30″ to 38° 15′, long 105° to 105° 07′30″. Scale 1:24,000. 75¢.

MISCELLANEOUS FIELD STUDIES MAPS—Continued

MF-551. Reconnaissance geologic map of the Beulah quadrangle, Pueblo County, Colo., by G. R. Scott and R. B. Taylor. 1973 (1974). Lat 38° to 38° 07′30″, long 104° 52′30″ to 105°. Scale 1:24,000. 75¢.

MF-555. Reconnaissance geologic map of the Fairplay West, Mount Sherman, South Peak, and Jones Hill 7½-minute quadrangles, Park, Lake, and Chaffee Counties, Colo., by Ogden Tweto. 1974. Lat 39° to 39° 15′, long 106° to 106° 15′. Scale 1:62,500. 75¢.

MF-556. Geologic map of the Mount Lincoln 15-minute quadrangle, Eagle, Lake, Park, and Summit Counties, Colo., by Ogden Tweto. 1974. Lat 39° 15′ to 39° 30′, long 106° to 106° 15′. Scale 1:62,500. 75¢.

MF-562. Reconnaissance geologic map of the Rockvale quadrangle, Custer and Fremont Counties, Colo., by G. R. Scott and R. B. Taylor. 1974. Lat 38° 15′ to 38° 22′30″, long 105° 07′30″ to 105° 15′. Scale 1:24,000. 75¢.

MF-570. Preliminary geologic map of the Segar Mountain quadrangle, Rio Blanco County, Colo., by R. B. O'Sullivan. 1974. Lat 39° 52′30″ to 40°, long 108° to 108° 07′30″. Scale 1:24,000. 75¢.

MF-597. Reconnaissance geologic map of the Conifer quadrangle, Jefferson County, Colo., by Bruce Bryant. 1974. Lat 39° 30′ to 39° 37′30″, long 105° 15′ to 105° 22′30″. Scale 1:24,000. 75¢.

MF-598. Reconnaissance geologic map of the Pine quadrangle, Jefferson County, Colo., by Bruce Bryant. 1974. Lat 39° 22′30″ to 39° 30′, long 105° 15′ to 105° 22′30″. Scale 1:24,000. 75¢.

MF-619. Preliminary geologic map and section of the Barcus Creek quadrangle, Rio Blanco County, Colo., by W. J. Hall, Jr. 1974. Lat 40° to 40° 07′30″, long 108° 22′30″ to 108° 30′. Scale 1:24,000. 75¢.

MF-628. Reconnaissance geologic map of the Electric Peak quadrangle, Custer and Saguache Counties, Colo., by G. R. Scott and R. B. Taylor. 1974. Lat 38° to 38° 15′, long 105° 30′ to 105° 45′. Scale 1:62,500. 75¢. (Reprinted 1977.)

MF-631. Geologic map and engineering data for the Highlands Ranch quadrangle, Arapahoe and Douglas Counties, Colo., by J. O. Maberry and R. M. Lindvall. 1974 (1975). Lat 39° 30′ to 39° 37′30″, long 104° 52′30″ to 105°. Scale 1:24,000. 3 sheets. $2.25 per set.

MF-651. Preliminary geologic map of the Buckskin Point quadrangle, Rio Blanco County, Colo., by G. N. Pipiringos and R. C. Johnson. 1975. Lat 40° to 40° 07′30″, long 108° to 108° 07′30″. Scale 1:24,000. Structure-contour interval 100 feet. 75¢.

MF-656. Geologic map of the Lafayette quadrangle, Adams, Boulder, and Jefferson Counties, Colo., by M. N. Machette. 1975. Lat 39° 52′30″ to 40°, long 105° to 105° 07′30″. Scale 1:24,000. 75¢.

MF-657. Reconnaissance geologic map of the Buena Vista quadrangle, Chaffee and Park Counties, Colo., by G. R. Scott. 1975. Lat 38° 45′ to 39°, long 106° to 106° 15′. Scale 1:62,500. 75¢.

MF-658. Geologic map of the Poncha Springs quadrangle, Chaffee County, Colo., by G. R. Scott, R. E. Van Alstine, and W. N. Sharp. 1975. Lat 38° 30′ to 38° 45′, long 106° to 106° 15′. Scale 1:62,500. 75¢.

MF-666. Preliminary geologic map of the Craig 1° by 2° quadrangle, northwestern Colorado, compiled by Ogden Tweto. 1975. Lat 40° to 41°, long 106° to 108°. Scale 1:250,000. 75¢.

MF-682. Reconnaissance geologic map of the Chama Peak quadrangle, Conejos and Archuleta Counties, Colo., by P. W. Lipman and W. J. Hail, Jr. 1975. Lat 37° to 37° 15′, long 106° 45′. Scale 1:48,000. 75¢.

MF-688. Preliminary geologic map, oil shale yield histograms and stratigraphic sections, Long Point quadrangle, Garfield County, Colo., by R. C. Johnson. 1975. Lat 39° 22′30″ to 39° 30″, long 108° 15′ to 108° 22′30″. Scale 1:24,000. 2 sheets. $1.50.

MF-689. Reconnaissance map showing relative amounts of soil and bedrock in the mountainous part of the Ralston Buttes quadrangle and adjoining areas to the east and west in Jefferson County, Colo., by K. L. Pierce and P. W. Schmidt. 1975. Lat 39° 45′ to 39° 52′30″, long about 105° 14′ to 105° 24′. Scale 1:24,000. 75¢.

MF-691. Preliminary geologic map of the Cutoff Gulch quadrangle, Rio Blanco and Garfield Counties, Colo., by W. J. Hail, Jr. 1975. Lat 39° 37′30″ to 39° 45′, long 108° 07′30″ to 108° 15′. Scale 1:24,000. 2 sheets. $1.50.

MISCELLANEOUS FIELD STUDIES MAPS—Continued

MF-695. Reconnaissance map showing relative amounts of soil and bedrock in the mountainous part of the Eldorado Springs quadrangle, Boulder and Jefferson Counties, Colo., by K. L. Pierce and P. W. Schmidt. 1975. Lat 39° 52′30″ to 40°, long 105° 15′ to about 105° 22′30″. Scale 1:24,000. 75¢.

MF-696. Preliminary map of landslide deposits, Vernal 1° by 2° quadrangle, Colorado and Utah, by P. E. Carrara, R. B. Colton, J. A. Holligan, and L. W. Anderson. 1975. Lat 40° to 41°, long 108° to 110°. Scale 1:250,000. 75¢.

MF-697. Preliminary map of landslide deposits, Grand Junction 1° by 2° quadrangle, Colorado and Utah, by R. B. Colton, J. A. Holligan, L. W. Anderson, and K. C. Shaver. 1975. Lat 37° to 38°, long 108° to 110°. Scale 1:250,000. 75¢.

MF-698. Preliminary map of landslide deposits, Moab 1° by 2° quadrangle, Colorado and Utah, by R. B. Colton, J. A. Holligan, L. W. Anderson, and K. C. Shaver. 1975. Lat 38° to 39°, long 108° to 110°. Scale 1:250,000. 75¢.

MF-699. Preliminary map of landslide deposits, Cortez 1° by 2° quadrangle, Colorado and Utah, by R. B. Colton L. W. Anderson, J. A. Holligan, P. E. Patterson, and K. C. Shaver. 1975. Lat 37° to 38°, long 108° to 110°. Scale 1:250,000. 75¢.

MF-700. Preliminary map of landslide deposits, Craig 1° by 2° quadrangle, Colorado, by R. B. Colton, J. A. Holligan, P. E. Patterson, and L. W. Anderson. 1975. Lat 40° to 41°. long 106° to 108°. Scale 1:250,000. 75¢.

MF-701. Preliminary map of landslide deposits, Leadville 1° by 2° quadrangle, Colorado, by R. B. Colton, J. A. Holligan, L. W. Anderson, and P. E. Patterson. 1975. Lat 39° to 40°, long 106° to 108°. Scale 1:250,000. 75¢.

MF-702. Preliminary map of landslide deposits, Montrose 1° by 2° quadrangle, Colorado, by R. B. Colton, P. E. Patterson, J. A. Holligan, and L. W. Anderson. 1975. Lat 38° to 39°, long 106° to 108°. Scale 1:250,000. 75¢.

MF-703. Preliminary map of landslide deposits, Durango 1° by 2° quadrangle, Colorado, by R. B. Colton, J. A. Holligan, and L. W. Anderson. 1975. Lat 37° to 38°, long 106° to 108°. Scale 1:250,000. 75¢.

MF-704. Preliminary map of landslide deposits, Greeley 1° by 2° quadrangle, Colorado, by R. B. Colton, J. A. Holligan, and L. W. Anderson. 1975. Lat 40° to 41°, long 104° to 106°. Scale 1:250,000. 75¢.

MF-705. Preliminary map of the landslide deposits, Denver 1° by 2° quadrangle, Colorado, by R. B. Colton, J. A. Holligan, and L. W. Anderson. 1975. Lat 39° to 40° long 104° to 106°. Scale 1:250,000. 75¢.

MF-706. Preliminary map of landslide deposits, Pueblo 1° by 2° quadrangle, Colorado, by R. B. Colton, G. R. Scott, J. A. Holligan, and L. W. Anderson. 1975. Lat 38° to 39°, long 104° to 106°. Scale 1:250,000. 75¢.

MF-707. Preliminary map of landslide deposits, Trinidad 1° by 2° quadrangle, Colorado, by R. B. Colton, J. A. Holligan, and L. W. Anderson. 1975. Lat 37° to 38°, long 104° to 106°. Scale 1:250,000. 75¢.

MF-708. Preliminary map of landslide deposits, La Junta 1° by 2° quadrangle, Colorado and Kansas, by R. B. Colton, L. W. Anderson, and J. A. Holligan. 1975. Lat 37° to 38°, long 102° to 104°. Scale 1:250,000. 75¢.

MF-713. Geologic map of the Spring Hill Creek quadrangle, Saguache County, Colo., by J. C. Olson, T. A. Steven, and D. C. Hedlund. 1975. Lat 38° 15′ to 38° 22′30″, long 106° 52′30″ to 107°. Scale 1:24,000. 75¢.

MF-733. Geologic map of the Sawtooth Mountain quadrangle, Saguache County, Colo., by J. C. Olson and T. A. Steven. 1976. Lat 38° 15′ to 38° 22′30″, long 106° 45′ to 106° 52′30″. Scale 1:24,000. 75¢.

MF-736. Preliminary geologic map and correlation diagram of the White River City quadrangle, Rio Blanco County, Colo., by G. N. Pipiringos and R. C. Johnson. 1976. Lat 40° to 40° 07′30″, long 108° 07′30″ to 108° 15′. Scale 1:24,000. $1.25.

MF-740. Reconnissance map showing relative amounts of soil and bedrock in the mountainous part of the Morrison-Evergreen quadrangles and adjoining areas to the west in Jefferson County, Colorado, by P. W. Schmidt. 1976. Lat 39° 37′30″ to 39° 45′, long 105° 10′ to about 105° 22′30″. 75¢.

MF-741. Reconnaissance map showing relative amounts of soil and bedrock in the mountainous part of the Indian Hills quadrangle, in Jefferson County, Colorado, by P. W. Schmidt. 1976. Lat 39° 30′ to 39° 37′30″, long 105° 07′30″ to 105° 15′. Scale 1:24,000. $1.25.

MF-746. Structure contours and overburden on the top of the Mahogany zone, Green River Formation, in the southern part of Piceance Creek basin, Rio Blanco and Garfield Counties, Colo., by M. C. Mullens. 1976. Lat about 39° 20′ to 39° 45′, long about 108° to about 108° 40′. Scale 1:63,360. 75¢.

MF-748. Geologic map of the Razor Creek Dome quadrangle, Saguache County, Colo., by J. C. Olson and T. A. Steven. 1976. Lat 38° 15′ to 38° 22′30″, long 106° 37′30″ to 106° 45′. Scale 1:24,000. 75¢.

MF-753. Preliminary geologic map of Wolf Ridge quadrangle, Rio Blanco County, Colo., by D. C. Duncan. 1976. Lat 39° 52′30″ to 40°, long 108° 22′30″ to 108° 30′. Scale 1:24,000. 75¢.

MF-754. Preliminary geologic map of Square S Ranch quadrangle, Rio Blanco County, Colo., by D. C. Duncan. 1976. Lat 39° 52′30″ to 40°, long 108° 15′ to 108° 22′30″. Scale 1:24,000. 75¢.

MF-755. Preliminary geologic map of Greasewood Gulch quadrangle, Rio Blanco County, Colo., by D. C. Duncan. 1976. Lat 39° 52′30″ to 40°, long 108° 07′30″ to 108° 15′. Scale 1:24,000. 75¢.

MF-756. Preliminary geologic map of Jessup Gulch quadrangle, Rio Blanco County, Colo., by D. C. Duncan. 1976. Lat 39° 45′ to 39° 52′30″, long 108° 07′30″ to 108° 15′. Scale 1:24,000. 75¢.

MF-757. Preliminary geologic map of Rock School quadrangle, Rio Blanco County, Colo., by D. C. Duncan. Lat 39° 45′ to 39° 52′30″, long 108° 15′ to 108° 22′30″. Scale 1:24,000. 75¢.

MF-758. Preliminary geologic map of Yankee Gulch quadrangle, Rio Blanco County, Colo., by D. C. Duncan. 1976. Lat 39° 45′ to 39° 52′30″, long 108° 22′30″ to 108° 30′. Scale 1:24,000. 75¢.

MF-759. Reconnaissance geologic map of the Glentivar quadrangle, Park County, Colo., by R. A. Wobus. 1976. Lat 39° to 39° 07′30″, long 105° 30′ to 105° 37′30″. Scale 1:24,000. 75¢.

MF-760. Preliminary geologic map of the Leadville 1° × 2° quadrangle, northwestern Colorado, by Ogden Tweto, R. H. Moench, and J. C. Reed, Jr. 1976. Lat 39° to 40°, long 106° to 108°. Scale 1:250,000. 75¢.

MF-761. Preliminary geologic map of the Montrose 1° × 20° quadrangle, southwestern Colorado, by Ogden Tweto, T. A. Steven, W. J. Hail, Jr., and R. H. Moench. 1976. Lat 38° to 39°, long 106° to 108°. Scale 1:250,000. 75¢. (Reprinted 1977.)

MF-770. Reconnaissance map showing relative amounts of soil and bedrock in the Conifer quadrangle and adjoining areas to the west in Jefferson County, Colorado, by P. W. Schmidt. 1976. Lat 39° 30′ to 39° 37′30″, long 105° 15′ to 105° 22′30″. Scale 1:24,000. 75¢.

MF-771. Preliminary landslide overview map of the conterminous United States, by D. H. Radbruch-Hall, R. B. Colton, W. E. Davis, B. A. Skipp, Ivo Lucchitta, and D. J. Varners. 1976. Lat 25° to 50°, long 65° to 125° Scale 1:7,500,000. 75¢.

MF-775. Geologic map of the Pueblo 1° by 2° quadrangle, south-central Colorado, by G. R. Scott, R. B. Taylor, R. C. Epis, and R. A. Wobus. 1976. Two sheets. Lat 38° to 39°, long 104° to 106°. Scale 1:187,500 (1 inch = about 2.9 miles). Sheet 1, 30 by 40 inches; sheet 2, 30 by 36 inches. $1.50. (Reprinted 1977.)

MF-778. Reconnaissance geologic map of the Picacho Mountains, Arizona, by Warren Yeend. 1976. Lat about 32° 40′ to 33°, long 111° 15′ to 11° 30′. Scale 1:62,500 (1 inch = about 1 mile). Sheet 25 by 31 inches. 75¢.

MF-786. Preliminary overview map of volcanic hazards in the 48 conterminous United States, by D. R. Mullineaux. 1976 (1977). Lat about 25° to about 50°, long about 65° to about 125°. Scale 1:7,500,000 (1 inch = about 118 miles). Sheet 29 by 36 inches. 75¢. (Reprinted 1977.)

MF-788. Preliminary geologic map of Colorado, compiled by Ogden Tweto. 1976 (1977). Two sheets. Lat 37° to 41°, long 102° to 109°. Scale 1:500,000 (1 inch = about 8 miles). Sheet 1, 42 by 52 inches; sheet 2, 42 by 34 inches. $1.50 per set.

MISCELLANEOUS FIELD STUDIES MAPS—Continued

MF-797. Isopach map and cross section of the Mahogany zone of the Green River Formation derived principally from geophysical well logs, eastern Uinta Basin, Utah and Colorado, by W. B. Cashion and G. H. Dixon. 1976. Lat about 39° 52′ 30″ to about 40° 30′, long 108° to 110°. Scale 1:250,000 (1 inch = 4 miles). Sheet 26½ by 31 inches. 75¢.

MF-803. Reconnaissance map showing relative amounts of soil and bedrock in the Platte Canyon quadrangle, Jefferson County, Colorado, by P. W. Schmidt. 1976 (1977). Lat 39° 22′30″ to 39° 30′, long 105° 07′30″ to 105° 15′. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 32 by 40 inches. 75¢.

MF-804. Reconnaissance map showing relative amounts of soil and bedrock in the Pine quadrangle and adjoining areas to the west in Jefferson County, COLORADO, by P. W. Schmidt. 1976 (1977). Lat 39° 22′30″. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 29 by inches. 75¢.

MF-805. Reconnaissance geologic map of the Cripple Creek-Pikes Peak area, Teller, Fremont, and El Paso Counties, Colorado, by R. A. Wobus, R. C. Epis, and G. R. Scott. 1976. Lat 38° 37′30″ to 38° 52′30″, long 105° to 105° 15′. Scale 1:48,000 (1 inch = 4,000 feet). Sheet 27 by 40 inches. 75¢. (Reprinted 1977.)

MF-810. Geologic map and details of the beryllium and molybdenum occurrences, Mount Antero, Chaffee County, Colorado, by W. N. Sharp. 1976 (1977). Lat about 38° 35′ to 42° 30′, long about 106° 10′ to 106° 17′30″. Scale 1:24,000 (1 inch = 2,000 feet). Two sheets: sheet 1, 32 by 42 inches; sheet 2, 24 by 44 inches. $1.50 per set.

MF-812. Seismicity map of the conterminous United States and adjacent areas, 1965-1974, by C. W. Stover. 1977. Lat about 25° to about 50°, long about 65° to about 125°. Scale 1:5,000,000 (1 inch = about 80 miles). Sheet 30 by 46 inches. 75¢.

MF-816. Reconnaissance geologic map of the Bailey quadrangle, Jefferson and Park Counties, Colorado, by Bruce Bryant. 1976 (1977). Lat 39° 22′30″ to 39° 30′, long 105° 22′30″ to 105° 30′. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 29 by 36 inches. 75¢.

MF-819. Map showing potential snow avalanche areas in the Telluride quadrangle, San Miguel, Ouray, and San Juan Counties, Colorado, by R. G. Luedke. 1976. Lat 37° 52′30″ to 38°, long 107° 45′ to 107° 52′30″. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 29 by 30 inches. 75¢.

MF-824. Geologic map of the Weaver Ridge quadrangle, Uintah County, UTAH, and Rio Blanco County, COLORADO, by W. B. Cashion. 1977. Lat 39° 52′30″ to 40°, long 109° to 109° 07′30″. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 26 by 33 inches. 75¢.

MF-829. Preliminary geologic map and cross section of the Saddle quadrangle, Garfield County, COLORADO, by R. C. Johnson. 1977. Lat 39° 22′ 30″ to 39° 30′, long 108° 22′30″ to 108° 30′. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 42 by 46 inches. 75¢.

MF-830. Preliminary geologic map of the Bull Fork quadrangle, Garfield and Rio Blanco Counties, COLORADO, by W. J. Hail, Jr. 1977. Lat 39° 37′30″ to 39° 45′, long 108° 15′ to 108° 22′30″. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 30 by 44 inches. 75¢.

MF-831. Preliminary geologic map of the Fort Logan quadrangle, Jefferson, Denver, and Arapahoe Counties, COLORADO, by R. M. Lindvall. 1976 (1977). Lat 39° 37′30″ to 39° 45′, long 105° to 105° 07′30″. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 31 by 44 inches. 75¢.

MF-836. Preliminary geologic map of the Indian Valley quadrangle, Rio Blanco and Moffat Counties, COLORADO, by G. N. Pipiringos and G. C. Rosenlund. 1977. Lat 40° 07′30″ to 40° 15′, long 108° 07′30″ to 108° 15′. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 29 by 36 inches. 75¢.

MF-837. Preliminary geologic map of the White Rock quadrangle, Rio Blanco and Moffat Counties, Colorado, by G. N. Pipiringos and G. C. Rosenlund. 1977. Lat 40° 07′30″ to 40° 15′, long 108° to 108° 07′30″. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 34 by 42 inches. 75¢.

MF-842. Reconnaissance geologic map of the Woodland Park quadrangle, Teller County, Colorado, by R. A. Wobus and G. R. Scott. 1977. Lat 38° 52′ 30″ to 39°, long 105° to 105° 07′30″. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 29 by 31 inches. 75¢.

MF-861. Map and list of reported occurrences of platinum-group metals in the conterminous United States, by W. N. Blair, N. J Page and M. G. Johnson. 1977. 2 sheets. Scale 1:5,000,000 (1 inch = about 80 miles). Sheet 1, 35 by 41 inches; sheet 2, 29½ by 31 inches. $1.50 per set.

MISCELLANEOUS FIELD STUDIES MAPS—Continued

MF-871. Photo interpretive map showing areas underlain by landslide deposits and areas susceptible to landsliding in the Louisville quadrangle, Boulder and Jefferson Counties, Colorado, by R. B. Colton and J. A. Holligan. 1977. Lat 39° 52′30″ to 40°, long 105° 07′30″ to 105° 15′. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 29 by 30 inches. 75¢.

MF-882. Preliminary geologic map of the Erie quadrangle, Boulder, Weld, and Adams Counties, Colorado, by R. B. Colton and L. W. Anderson. 1977. Lat 40° to 40° 07′30″, long 105° to 105° 07′30″. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 28 by 35 inches. 75¢.

MF-892. Reconnaissance geologic map of the Canon City quadrangle, Fremont County, Colorado, by G. R. Scott. 1977. Lat 38° 22′30″ to 38° long 105° 07′30″ to 105° 15′. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 30 by 37 inches. 75¢.

MINERAL INVESTIGATIONS RESOURCE MAPS

The following maps cover the resources indicated for the United States exclusive of Alaska and Hawaii. All are printed at a scale of 1:3,168,000 and are sold at $1.25 each, unless otherwise indicated.

MR-2. Uranium deposits, compiled by R. W. Schnable. 1955. Scale 1:5,000,000. $1.75.

MR-3. Potash occurrences, by M. F. Byrd. 1955. Scale 1:5,000,000. $1.75.

MR-13. Copper, by A. R. Kinkle, Jr., and N. P. Peterson. 1962.

MR-14. Borates, by W. C. Smith. 1962.

MR-15. Lead, by E. T. McKnight, W. L. Newman, and A. V. Heyl, Jr. 1962.

MR-16. Vanadium, by R. P. Fischer. 1962.

MR-17. Asbestos, by A. H. Chidester and A. F. Shride. 1962.

MR-18. Pyrophyllite, and kyanite and related minerals, by G. H. Espenshade. 1962.

MR-19. Zinc, by E. T. McKnight, W. L. Newman, and A. V. Heyl, Jr. 1962.

MR-20. Antimony, by D. E. White. 1962.

MR-21. Epigenetic uranium deposits, by A. P. Butler, Jr., W. I. Finch, and W. S. Twenhofel. 1962.

MR-22. Bismuth, by J. R. Cooper. 1962.

MR-23. Manganese, by M. D. Crittenden and Louis Pavlides. 1962.

*MR-24. Gold, by A. H. Koschmann and M. H. Bergendahl. 1962.

MR-25. Tungsten, by D. M. Lemmon and O. L. Tweto. 1962.

MR-26. Chromite, by T. P. Thayer and M. H. Miller. 1962.

MR-27. Magnesite and brusite, by Benjamin Gildersleeve. 1962.

MR-28. Thorium and rare earths, by J. C. Olson and J. W. Adams. 1962.

MR-29. Titanium, by C. L. Rogers and M. C. Jaster. 1962.

MR-30. Mercury, by E. H. Bailey. 1962.

MR-31. Talc and soapstone, by A. H. Chidester and H. W. Worthington. 1962.

MR-33. Gypsum and anhydrite, by C. F. Withington. 1962.

*MR-34. Silver, by E. T. McKnight, W. L. Newman, Harry Klemic, and A. V. Heyl, Jr. 1962.

MR-35. Beryllium, by W. R. Griffitts, D. M. Larrabee, and J. J. Norton. 1962.

MR-36. Niobium and tantalum, by R. L. Parker, 1963.

MR-37. High-alumina kaolinitic clay, by Helen Mark. 1963.

MR-43. Barite, by D. A. Brobst. 1965.

MR-44. Tin, by P. L. Killeen and W. L. Newman. 1965.

MR-51. Iron, by M. S. Carr, P. W. Guild, and W. B. Wright. 1967. Accompanied by 20-page text.

MR-55. Molybdenum, by R. U. King. 1970. Accompanied by 21-page text.

MR-57. Reported occurrences of selected minerals in Colorado. 1971. Scale 1:500,000.

MR-58. Map showing localities and amounts of metallic mineral production in Colorado, by W. R. Marsh and R. W. Queen. 1974. Lat 37° to 41°, long 102° to 109°. Scale 1:500,000.

MR-60. Fluorite, compiled by R. G. Worl, R. E. Van Alstine, and A. V. Heyl, 1974. Accompanied by 13-page text.

MR-70. Map showing fluorspar deposits in Colorado, compiled by B. T. Brady. 1975 (1976). Lat 37° to 41°, long 102° to 109°. Scale 1:500,000. Accompanied by 20-page text.

MINERAL INVESTIGATIONS (STRATEGIC) MAPS

*3-173. Geologic map of the Gateway area, Mesa County, Colo., and adjoining part of Grand County, Utah, by W. L. Stokes, R. T. Russell, R. P. Fischer, and A. P. Butler, Jr. 1945. Scale 1:63,360.

*3-212. Iron-ore deposits of the Western United States, by C. E. Dutton and M. S. Carr 1947 . Scale 1:5,000,000. (See Bulletin 1082-C and Map MR-51.)

*3-226. Vanadium region of southwestern Colorado and southeastern Utah, by R. P. Fischer. 1947. Scale 1:187,500. (See Bulletin 936-P.)

MISCELLANEOUS INVESTIGATIONS SERIES

I-90. Photogeologic map of the Aneth-1 quadrangle, San Juan County, Utah, and Montezuma County, Colo., by R. J. Hackman. 1965. Lat 37° 22′30″ to 37° 30′, long 109° to 109° 07′30″. Scale 1:24,000. $1.25.

I-97. Photogeologic map of the Aneth-8 quadrangle, San Juan County, Utah, and Montezuma County, Colo., by R. J. Hackman. 1955. Lat 37° 15′ to 37° 22′30″, long 109° to 109° 07′30″. Scale 1:24,000. $1.25.

I-157. Photogeologic map of the Mount Peale-9 quadrangle, San Juan County, Utah, and Montrose and San Miguel Counties, Colo., by R. J. Hackman. 1956. Lat 38° 07′30″ to 38° 15′, long 109° to 109° 07′30″. Scale 1:24,000. $1.25.

I-165. Photogeologic map of the Mount Peale-1 quadrangle, San Juan County, Utah, and Montrose County, Colo., by R. J. Hackman. 1956. Lat 38° 22′30″ to 38° 30′, long 109° to 109° 07′30″. Scale 1:24,000. $1.25.

I-174. Photogeologic map of the Mount Peale-8 quadrangle, San Juan County, Utah, and Montrose County, Colo., by R. J. Hackman. 1956. Lat 38° 15′ to 38° 22′30″, long 109° to 109° 07′30″. Scale 1:24,000. $1.25.

I-175. Paleotectonic maps of the Jurassic System, by E. D. McKee, S. S. Oriel, V. E. Swanson, J. E. MacLachlan, J. C. MacLachlan, K. B. Ketner, J. W. Goldsmith, R. Y. Bell, and D. J. Jameson, with a separate section on Paleogeography, by R. W. Imlay. 1956. Scales 1:2,500,000 and 1:5,000,000. $15.

I-176. Photogeologic map of the Mount Peale-16 quadrangle, San Juan County, Utah, and San Miguel County, Colo., by R. J. Hackman. 1956. Lat 38° to 38° 07′30″, long 109° to 109° 07′30″. Scale 1:24,000. $1.25.

I-274. Photogeologic map of the Escalante Forks quadrangle, Mesa, Montrose, and Delta Counties, Colo., by R. J. Hackman. 1958. Lat 38° 30′ to 38° 45′, long 108° 15′ to 108° 30′. Scale 1:62,500. $1.25.

I-277. Photogeologic map of the Iris SE and Doyleville SW quadrangles, Saguache County, Colo., by Kathleen McQueen. 1958. Lat 38° 15′ to 38° 22′30″, long 106° 37′30″ to 106° 52′30″. Scale 1:31,680. $1.25.

I-278. Photogeologic map of the Coach Creek SE quadrangle, Grand County, Utah, and Mesa County, Colo., by R. J. Hackman. 1959. Lat 38° 45′ to 38° 52′30″, long 109° to 109° 07′30″. Scale 1:24,000. $1.25.

I-279. Photogeologic map of the Coach Creek NE quadrangle, Grand County, Utah, and Mesa County, Colo., by R. J. Hackman. 1959. Lat 38° 52′30″ to 39°, long 109° to 109° 07′30″. Scale 1:24,000. $1.25.

I-281. Photogeologic map of the Yellow Jacket quadrangle, Montezuma and Dolores Counties, Colo., by R. J. Hackman. 1959. Lat 37° 30′ to 37° 45′, long 108° 30′ to 108° 45′. Scale 1:62,500. $1.25.

I-282. Photogeologic map of the Delta quadrangle, Montrose and Delta Counties, Colo., by C. H. Marshall. 1959. Lat 38° 30′ to 38° 45′, long 108° to 108° 15′. Scale 1:62,500. $1.25.

I-283. Photogeologic map of the Norwood-1 quadrangle, Montrose and Ouray Counties, Colo., by C. H. Marshall. 1959. Lat 38° 15′ to 38° 30′, long 108° to 108° 15′. Scale 1:62,500. $1.25.

I-299. Epigenetic uranium deposits in the United States, by W. I. Finch, I. S. Parrish, and G. W. Walker. 1959. Scale 1:5,000,000. 3 sheets. $4.25 per set.

I-300. Paleotectonic maps of the Triassic System, by E. D. McKee, S. S. Oriel, K. B. Ketner, M. E. MacLachlan, J. W. Goldsmith, J. C. MacLachlan, and M. R. Mudge. 1959. Scale 1:5,000,000. $15.

I-309. Geologic map of the igneous and metamorphic rocks of Colorado showing location of uranium deposits, compiled by E. A. Merewether. 1960. Lat 37° to 41°, long 102° to 109°. Scale 1:500,000. $1.50.

I-322. Geologic map of the Willow Creek Butte quadrangle, Utah—Colorado, by W. R. Hansen. 1961. Lat 40° 52′30″ to 41°, long 109° to 109° 07′30″. Scale 1:24,000. $1.50.

I-332. Geologic map of a part of southwestern Wyoming and adjacent States, by W. H. Bradley, 1961. Scale 1:250,000. $1.25.

I-333. Preliminary geologic map of the Indian Hills quadrangle, Jefferson County, Colo., by G. R. Scott. 1961. Lat 39° 30′ to 39° 37′30″, long 105° 07′30″ to 105° 15′. Scale 1:24,000. $1.25.

I-360. Geology, structure, and uranium deposits of the Moab quadrangle, Colorado and Utah, compiled by P. L. Williams. 1964. Lat 38° to 39°, long 108° to 110°. Scale 1:250,000. 2 sheets. $3.25 per set. (Reprinted 1977.)

I-383. Preliminary geologic map of the Eldorado Springs quadrangle, Boulder and Jefferson Counties, Colo., by J. D. Wells. 1963. Lat 39° 52′30″ to 40°, long 105° 15′ to 105° 22′30″. Scale 1:24,000. $1.25.

I-387. Fluoride content of ground water in the conterminous United States, by Michael Fleischer. 1962. Scale 1:5,000,000. $1.25.

I-404. Geologic map of the Grand Junction area, Colorado, by S. W. Lohman. 1975, Lat about 38° 48′ to about 39° 12′, long 108° 25′ to 108° 47′. Scale 1:31,680. $1.75.

I-408. Geology of the Northwest and Northeast Pueblo quadrangles, Colorado, by G. R. Scott. 1964. Lat 38° 15′ to 38° 22′30″, long 104° 30′ to 104° 45′. Scale 1:24,000. $1.25.

I-428. Geology of the sedimentary rocks of the Morrison quadrangle, Colorado, by J. H. Smith. 1964. Lat 39° 37′30″ to 39° 45′, long 105° 07′30″ to 105° 15′. Scale 1:24,000. Accompanied by 3-page text. $1.25.

I-439. Geologic and biostratigraphic map of the Pierre Shale between Jarre Creek and Loveland, Colo., by G. R. Scott and W. A. Cobban. 1965. Lat 39° 52′30″ to 40° 22′30″, long 104° 50′ to 105° 17′30″. Scale 1:48,000. Accompanied by 4-page text. $1.75.

I-443. Preliminary geologic map of the Berthoud Pass quadrangle, Clear Creek and Grand Counties, Colo., by P. K. Theobald. 1965. Lat 30° 45′ to 39° 52′30″, long 105° 45′ to 105° 52′30″. Scale 1:24,000. $1.25.

I-448. Geologic and crustal cross section of the United States along the 37th parallel—A contribution to the upper mantle project, by Warren Hamilton and L. C. Pakiser. 1965. Scale 1:2,500,000. $1.50.

I-450. Paleotectonic maps of the Permian System, by E. D. McKee, S. S. Oriel, and others. 1967. $38.

I-496. Distribution of selected accessory minerals in the Caribou stock, Boulder County, Colo., by G. J. Neuerburg. 1967. Vicinity of lat 40°, long 105° 35′. Scale 1:12,000. $1.25.

I-558. Geologic map of the Trinidad quadrangle, south-central Colorado, by R. B. Johnson. 1969. Lat 37° to 38°, long 104° to 106°. Scale 1:250,000. $1.50.

I-560. Geologic and structure contour map of the La Junta quadrangle, Colorado and Kansas, by G. R. Scott. 1968 (1969) Lat 37° to 38°, long 102° to 104°. Scale 1:250,000. $1.75.

I-563. Geologic map and sections of the southwest quarter of the Dillon quadrangle, Eagle and Summit Counties, Colo., by M. H. Bergendahl. 1969. Lat 39° 30′ to 39° 37′30″, long 106° 07′30″ to 106° 15′. Scale 1:24,000. $1.50.

I-584. Geologic Map of the Black Canyon of the Gunnison River and vicinity, western Colorado, by W. R. Hansen. 1971. Sheet 1, lat 38° 30′ to 38° 37′30″, long 107° 30′ to 107° 52′30″; sheet 2, lat 38° 22′30″ to 38° 30′, long 107° 15′ to 107° 37′30″. Scale 1:31,680. 2 sheets. $3.50 per set.

I-597. Geologic map of the Southwest and Southeast Pueblo quadrangles, Colorado, by G. R. Scott. 1969 (1970). Lat 38° 07′30″ to 38° 15′, long 104° 30′ to 104° 45′. Scale 1:24,000. $1.75.

I-608. Maps showing distribution of selected accessory minerals in the Montezuma stock, Summit County, Colo., by G. J. Neuerburg. 1971. Lat about 39° 35′ to 39° 37′30″, long about 105° 50′ to 105° 55′. Scale 1:31,680. $1.25.

I-629. Geology, structure, and uranium deposits of the Cortez quadrangle, Colorado and Utah, compiled by D. D. Haynes, J. D. Vogel, and D. G. Wyant. 1972. Lat 37° to 38°, long 108° to 110°. Scale 1:250,000. 2 sheets. $3.25 per set. (Reprinted 1977.)

I-634. Maps showing soil analyses of interest for prospecting the Montezuma stock, Summit County, Colo., by G. J. Neuerburg. 1971. Lat about 39° 35′ to 39° 37′30″, long about 105° 50′ to 105° 55′. Scale 1:31,680. $1.25.

I-687. Geologic map of the lower Cache La Poudre River basin, north-central Colorado, by L. A. Hershey and P. A. Schneider, Jr. 1972. Lat 40° 25′ to 40° 50′, long 104° 30′ to 105° 10′. Scale 1:62,500. $1.50.

I-688. Generalized Tectonic map of North America, by P. B. King and G. J. Edmonston. 1972. Scale 1:15,000,000. $1.75.

I-697. Reconnaissance geologic map of the Cedaredge area, Delta County, Colo., by W. J. Hail, Jr. 1972. Lat 38° 45′ to 39°, long 107° 45′ to 108°. Scale 1:48,000. $1.75.

I-698. Reconnaissance geologic map of the Hotchkiss area, Delta and Montrose Counties, Colo., by W. J. Hail, Jr. 1972. Lat 38° 37′30″ to 39°, long 107° 30′ to 107° 45′. Scale 1:48,000. $1.75.

I-731. Generalized surficial geologic map of the Denver area, Colorado, by G. H. Chase and J. A. McConaghy. 1972 (1973). Lat 39° 22′30″ to 40°, long 104° 37′30″ to 105° 20′. Scale 1:62,500. $1.50.

I-736. Geologic and structure map of the Grand Junction quadrangle, Colorado and Utah, compiled by W. B. Cashion. 1973. Lat 39° to 40°, long 108° to 110°. Scale 1:250,000. $1.75.

I-750. Map showing geologic and structural control of ore deposits, Montezuma district, central Colorado, by G. J. Neuerburg and Theodore Botinelly. 1972 (1973). Lat 39° 30′ to 39° 37′30″, long 105° 47′30″ to 105° 55′. Scale 1:31,680. $1.25.

I-761-A. Surficial and bedrock geologic map of the Golden quadrangle, Jefferson County, Colo., by Richard Van Horn. 1972. Lat 39° 45′ to 39° 52′30″, long 105° 07′30″ to 105° 15′. Scale 1:24,000. $1.75. (Reprinted 1977.)

I-761-B. Map showing landslides in the Golden quadrangle, Jefferson County, Colo., by H. E. Simpson. 1973. Lat 39° 45′ to 39° 52′30″, long 105° 07′30″ to 105° 15′. Scale 1:24,000. $1.50.

I-761-C. Map showing areas of potential rockfalls in the Golden quadrangle, Jefferson County, Colo., by H. E. Simpson. 1973. Lat 39° 45′ to 39° 52′30″, long 105° 07′30″ to 105° 15′. Scale 1:24,000. $1.50.

I-761-D. Map showing earth materials that may compact and cause settlement in the Golden quadrangle, Jefferson County, Colo., by H. E. Simpson. 1973 (1974). Lat 39° 45′ to 39° 45′ to 39° 52′30″, long 105° 07′30″ to 105° 15′. Scale 1:24,000. $1.50.

I-761-E. Map showing man-modified land and man-made deposits in the Golden quadrangle, Jefferson County, Colo., by H. E. Simpson. 1973. Lat 39° 45′ to 39° 52′30″, long 105° 07′30″ to 105° 15′. Scale 1:24,000. $1.25.

I-764. Geologic map of the Durango quadrangle, southwestern Colorado, compiled by T. A. Steven, P. W. Lipman, W. J. Hail, Jr., Fred Barker, and R. G. Luedke. 1974. Lat 37° to 38°, long 106° to 108°. Scale 1:250,000. $1.75.

I-770-A. Geologic map of the Parker quadrangle, Arapahoe and Douglas Counties, Colo., by J. O. Maberry and R. M. Lindvall. 1972. Lat 39° 30′ to 39° 37′30″, long 104° 45′ to 104° 52′30″. Scale 1:24,000. $1.75.

I-770-B. Map showing areas of past flooding in the Parker quadrangle, Arapahoe and Douglas Counties, Colo., by J. O. Maberry. 1972. Lat 39° 30′ to 39° 37′30″, long 104° 45′ to 104°52′30″. Scale 1:24,000. $1.25.

I-770-C. Map showing transportation routes in the Parker quadrangle, Arapahoe and Douglas Counties, Colo., by J. O. Maberry. 1972. Lat 39° 30′ to 39° 37′30″, long 104° 45′ to 104° 52′30″. Scale 1:24,000. $1.50.

I-770-D. Map showing relative swelling-pressure potential of geologic materials in the Parker quadrangle, Arapahoe and Douglas Counties, Colo., by J. O. Maberry. 1972. Lat 39° 30′ to 39° 37′30″, long 104° 45′ to 104° 52′30″. Scale 1:24,000. $1.50.

I-770-E. Map showing landslide deposits and areas of potential landsliding in the Parker quadrangle, Arapahoe and Douglas Counties, Colo., by J. O. Maberry. 1972. Lat 39° 30′ to 39° 37′30″, long 104° 45′ to 104° 52′30″. Scale 1:24,000. $1.50.

I-770-F. Slope map of the Parker quadrangle, Arapahoe and Douglas Counties, Colo., by J. O. Maberry. 1972. Lat 39° 30′ to 39° 37′30″, long 104° 45′ to 104° 52′30″. Scale 1:24,000. $1.50.

I-770-G. Map showing relative erodibility of geologic materials in the Parker quadrangle, Arapahoe and Douglas Counties, Colo., by J. O. Maberry. 1972. Lat 39° 30′ to 39° 37′30″, long 104° 45′ to 104° 52′30″. Scale 1:24,000. $1.50.

I-770-H. Map showing relative excavatability of geologic materials in the Parker quadrangle, Arapahoe and Douglas Counties, Colo., by J. O. Maberry. 1972. Lat 39° 30′ to 39° 37′30″, long 104° 45′ to 104° 52′30″. Scale 1:24,000. $1.50.

I-770-I. Map showing inferred relative permeability of geologic materials in the Parker quadrangle, Arapahoe and Douglas Counties, Colo., by J. O. Maberry. 1972. Lat 39° 30′ to 39° 37′30″, long 104° 45′ to 104° 52′30″, Scale 1:24,000. $1.50.

I-770-J. Map of deposits especially susceptible to compaction or subsidence, Parker quadrangle, Arapahoe and Douglas Counties, Colo., by J. O. Maberry. 1972. Lat 39° 30′ to 39° 37′30″, long 104° 45′ to 104° 52′30″. Scale 1:24,000. $1.50.

I-770-K. Map showing approximate ground-water conditions in the Parker quadrangle, Arapahoe and Douglas Counties, Colo., by J. O. Maberry and E. R. Hampton. 1972. Lat 39° 30′ to 39° 37′30″, long 104° 45′ to 104° 52′30″. Scale 1:24,000. $1.50.

I-770-L. Map showing construction materials resources in the Parker quadrangle, Arapahoe and Douglas Counties, Colo., by J. O. Maberry. 1973. Lat 39° 30′ to 39° 37′30″, long 104° 45′ to 104° 52′30″. Scale 1:24,000. $1.50.

I-770-M. Map of pioneer trails, stage stops, and areas with a view in the Parker quadrangle, Arapahoe and Douglas Counties, Colo., by J. O. Maberry. 1973. Lat 39° 30′ to 39° 37′30″, long 104° 45′ to 104° 52′30″. Scale 1:24,000. $1.50.

I-770-N. Vegetation map of the Parker quadrangle, Arapahoe and Douglas Counties, Colo., by J. R. Keith and J. O. Maberry. 1973. Lat 39° 30′ to 39° 37′30″, long 104° 45′ to 104° 52′30″. Scale 1:24,000. $1.50.

I-785-A. Map showing areas of selected potential geologic hazards in the Aspen quadrangle, Pitkin County, Colo., by Bruce Bryant. 1972. Lat 39° 07′30″ to 39° 15′, long 106° 45′ to 106° 52′30″. Scale 1:24,000. $1.50.

I-785-B. Map showing ground-water potential in the Aspen quadrangle, Pitkin County, Colo., by Bruce Bryant. 1972. Lat 39° 07′30″ to 39° 15′, long 106° 45′ to 106° 52′30″. Scale 1:24,000. $1.50.

I-785-C. Map showing relative ease of excavation in the Aspen quadrangle, Pitkin County, Colo., by Bruce Bryant. 1972. Lat 39° 07′30″ to 39° 15′, long 106° 45′ to 106° 52′30″. Scale 1:24,000. $1.50.

I-785-D. Map showing mines, prospects, and areas of significant silver, lead, and zinc production in the Aspen quadrangle, Pitkin County, Colo., by Bruce Bryant. 1972. Lat 39° 07′30″ to 39° 15′, long 106° 45′ to 106° 52′30″. Scale 1:24,000. $1.25.

I-785-E. Slope map of the Aspen quadrangle, Pitkin County, Colo., by Bruce Bryant. 1972. Lat 39° 07′30″ to 39° 15′, long 106° 45′ to 106° 52′30″. Scale 1:24,000. $1.50.

I-785-F. Map showing relative permeability of rocks and surficial deposits of the Aspen quadrangle, Pitkin County, Colo., by Bruce Bryant. 1972. Lat 39° 07′ 30″ to 39° 15′, long 106° 45′ to 106° 52′30″. Scale 1:24,000. $1.25.

I-785-G. Map showing avalanche areas in the Aspen quadrangle, Pitkin County, Colo., by Bruce Bryant. 1972. Lat 39° 07′30″ to 39° 15′, long 106° 45′ to 106° 52′30″. Scale 1:24,000. $1.25.

I-785-H. Map showing types of bedrock and surficial deposits in the Aspen quadrangle, Pitkin County, Colo., by Bruce Bryant. 1972. Lat 39° 07′30″ to 39° 15′, long 106° 45′ to 106° 52′30″. Scale 1:24,000. $1.50.

I-786-A. Geologic map of the Evergreen quadrangle, Jefferson County, Colo., by D. M. Sheridan, J. C. Reed, Jr., and Bruce Bryant. 1972 (1973). Lat 39° 37′30″ to 39° 45′, long 105° 15′ to 105° 22′30″. Scale 1:24,000. $1.75.

I-786-B. Vegetation map of the Evergreen quadrangle, Jefferson County, Colo., by J. C. Reed, Jr., and J. R. Keith. 1972. Lat 39° 37′30″ to 39° 45′, long 105° 15′ to 105° 22′30″. Scale 1:24,000. $1.50.

I-786-C. Slope map of the Evergreen quadrangle, Jefferson County, Colo., by P. W. Schmidt. 1972. Lat 39° 37′30″ to 39° 45′, long 105° 15′ to 105° 22′30″. Scale 1:24,000. $1.50.

I-786-D. Map showing approximate density of houses in the Evergreen quadrangle, Jefferson County, Colo., by Bruce Bryant and J. C. Reed, Jr. 1972. Lat 39° 37′30″ to 39° 45′, long 105° 15′ to 105° 22′30″. Scale 1:24,000. $1.50.

I-786-E. Map showing approximate locations, depths, and estimated yields of water wells in the Evergreen quadrangle, Jefferson County, Colo., by P. W. Schmidt and J. C. Reed, Jr. 1972 (1973). Lat 39° 37′30″ to 39° 45′, long 105° 15′ to 105° 22′30″. Scale 1:24,000. $1.25.

I-786-F. Map showing faults, joints, foliation, and surficial deposits in the Evergreen quadrangle, Jefferson County, Colo., by J. C. Reed, Jr., D. M. Sheridan, and Bruce Bryant. 1973. Lat 39° 37′30″ to 39° 45′, long 105° 15′ to 105° 22′30″. Scale 1:24,000. $1.50.

I-786-G. Map showing thermal lineaments in the Evergreen quadrangle, Jefferson County, Colo., by T. W. Offield and H. A. Pohn. 1975. Lat 39° 37′30″ to 39° 45′, long 105° 15′ to 105° 22′30″. Scale 1:24,000. $1.25.

I-790-A. Geologic map of the Morrison quadrangle, Jefferson County, Colo., by G. R. Scott. 1972. Lat 39° 37′30″ to 39° 45′, long 105° 07′30″ to 105° 15′. Scale 1:24,000. $1.75.

I-790-B. Map showing landslides and areas susceptible to landsliding in the Morrison quadrangle, Jefferson County, Colo., by G. R. Scott. 1972. Lat 39° 37′30″ to 39° 45′, long 105° 07′30″ to 105° 15′. Scale 1:24,000. $1.25.

I-790-C. Map showing areas containing swelling clay in the Morrison quadrangle, Jefferson County, Colo., by G. R. Scott. 1972. Lat 39° 37′30″ to 39° 45′, long 105° 07′30″ to 105° 15′. Scale 1:24,000. $1.25.

I-790-D. Map showing potential source areas for non-metallic mineral resources. Morrison quadrangle, Jefferson County, Colo., by G. R. Scott. 1972. Lat 39° 37′30″ to 39° 45′, long 105° 07′30″ to 105° 15′. Scale 1:24,000. $1.50.

I-790-E. Map showing some points of geologic interest in the Morrison quadrangle, Jefferson County, Colo., by G. R. Scott. 1972. Lat 39° 37′30″ to 39° 45′, long 105° 07′30″ to 105° 15′. Scale 1:24,000. $1.50.

I-790-F. Map showing watercourses and areas inundated by historic floods in the Morrison quadrangle, Jefferson County, Colo., by G. R. Scott. 1972. Lat 39° 37′30″ to 39° 45′, long 105° 07′30″ to 105° 15′. Scale 1:24,000. $1.25.

I-790-G. Map showing inferred relative permeability of geologic materials in the Morrison quadrangle, Jefferson County, Colo., by G. R. Scott. 1972 (1973). Lat 39° 37′30″ to 39° 45′, long 105° 07′30″ to 105° 15′. Scale 1:24,000. $1.25.

I-791. Maps showing the approximate configuration and depth to the top of the Laramie-Fox Hills aquifer, Denver basin, Colorado, by J. C. Romero and E. R. Hampton. 1972. Lat about 38° 45′ to 40° 30′, long 104° to about 105°. Scale 1:500,000. $1.25.

I-792-A. Map showing rock fractures and veins in the Tungsten quadrangle, Boulder, Gilpin, and Jefferson Counties, Colo., by D. J. Gable. 1973. Lat 39° 52′30″ to 40°, long 105° 22′30″ to 105° 30′. Scale 1:24,000. $1.25.

I-792-B. Map showing density of dwelling units in the Tungsten quadrangle, Boulder, Gilpin, and Jefferson Counties, Colo., by H. R. Covington and D. J. Gable. 1973. Lat 39° . 52′30″ to 40°, long 105° 22′30″ to 105° 30′. Scale 1:24,000. $1.25.

I-792-C. Map showing water wells and springs in the Tungsten quadrangle, Boulder, Gilpin, and Jefferson Counties, Colo., by D. J. Gable. 1973. Lat 39° 52′30″ to 40°, long 105° 22′30″ to 105° 30′. Scale 1:24,000. $1.25.

I-828. Geologic map of the Platoro Caldera area, southeastern San Juan Mountains, southwestern Colorado, by P. W. Lipman. 1974 (1975). Lat 37° 15′ to 37° 30′, long 106° 15′ to 106° 45′. Scale 1:48,000. $1.75.

I-830. Geologic map and sections of the Holy Cross quadrangle, Eagle, Lake Pitkin, and Summit Counties, Colo., by Ogden Tweto. 1974. Lat 39° 15′ to 39° 30′, long 106° 15′ to 106° 30′. Scale 1:24,000. 2 sheets. $3.50 per set.

I-833. Geologic map and cross sections of the La Veta Pass, La Veta, and Ritter Arroyo quadrangles, Huerfano and Costilla Counties, Colo., by J. D. Vine. 1974. Lat 37° 30′ to 37° 37′30″, long 104° 52′30″ to 105° 15′. Scale 1:48,000. $1.50.

I-855-A. Lakes in the Boulder-Fort Collins-Greeley area, Front Range Urban Corridor, Colo., by J. F. Ficke and T. W. Danielson. 1973 (1974). Lat 40° to 40° 37′30″, long 104° 37′30″ to 105° 22′30″. Scale 1:100,000. $1.75.

I-855-B. Land-use classification map of the Boulder—Fort Collins—Greeley area, Front Range Urban Corridor, Colorado, by L. B. Driscoll. 1974. Lat 40° to 40° 37′30″, long 104° 37′30″ to 105° 22′30″. Scale 1:100,000. $1.75.

I-855-C. Map showing availability of hydrologic data, Boulder—Fort Collins—Greeley area, Front Range Urban Corridor, Colo., by E. R. Hampton G. A. Clark, and M. H. McNutt. 1974 (1975). Lat 40° to 40° 37′30″, long 104° 37′30″ to 105° 22′30″. Scale 1:100,000. $1.25.

I-855-D. Map showing potential sources of gravel and crushed-rock aggregate, in the Boulder—Fort Collins—Greeley area, Front Range Urban Corridor, Colo., by R. B. Colton and H. R. Fitch. 1974. Lat 40° to 40° 37′30″, long 104° 37′30″ to 105° 22′30″. Scale 1:100,000. $1.75.

I-855-E. Map showing flood-prone areas, Boulder—Fort Collins—Greeley area, Front Range Urban Corridor, Colo., by J. F. McCain and W. R. Hotchkiss. 1975. Scale 1:100,000. $1.25.

I-855-F. Map showing outstanding natural and historic landmarks in the Boulder—Fort Collins—Greeley area, Front Range Urban Corridor, Colorado, by B. N. Petrie. 1975. Lat 40° to 40° 37′30″, long 104° 37′30″ to 105° 22′30″. Scale 1:100,000. $1.25.

I-856-A. Map showing potential sources of gravel and crushed-rock aggregate in the greater Denver area, Front Range Urban Corridor, Colo., by D. E. Trimble and H. R. Fitch. 1974. Lat 39° 22′30″ to 40°, long 104° 37′30″ to 105° 22′30″. Scale 1:100,000. $1.75.

I-856-B. Lakes in the Greater Denver area, Front Range Urban Corridor, Colo., by T. W. Danielson. 1975. Lat 39° 22′30″ to 40°, long 104° 37′30″ to 105° 22′30″. Scale 1:100,000. $1.25.

I-856-C. Map showing availability of hydrologic data published by the U.S. Environmental Data Service, and by the U.S. Geological Survey and cooperating agencies, Greater Denver area, Front Range Urban Corridor, Colorado, by E. R. Hampton. 1975. Lat 39° 22′30″ to 40°, long 104° 37′30″ to 105° 22′30″. Scale 1:100,000. $1.25.

I-856-D. Map showing flood-prone areas, Greater Denver area, Front Range Urban Corridor, Colo., by J. F. McCain and W. R. Hotchkiss. 1975. Lat 39° 22′30″ to 40°, long 104° 37′30″ to 105° 22′30″. Scale 1:100,000. $1.25.

I-856-E. Land-use classification of the Greater Denver area, Front Range Urban Corridor, Colo., by L. B. Driscoll. 1975 (1976). Lat 39° 22′30″ to 40°, long 104° 37′30″ to 105° 22′30″. Scale 1:100,000. $1.75.

I-856-F. Map showing outstanding natural and historic landmarks in the greater Denver area, Front Range Urban Corridor, Colorado, by B. N. Petrie. 1976. Lat 39° 22′30″ to 40°, long 104° 37′30″ to 105° 22′30″. Scale 1:100,000. $1.25.

I-856-G. Historic trail map of the Greater Denver area, Colorado, by G. R. Scott. 1976. Lat 39° 22′30″ to 40°, long 104° 37′30″ to 105° 22′30″. Scale 1:100,000 (1 inch = about 1.6 miles). Sheet 30 by 37 inches. $1.25.

I-857-A. Map showing potential sources of gravel and crushed-rock aggregate in the Colorado Springs—Castle Rock area, Front Range Urban Corridor, Colo., by D. E. Trimble and H. R. Fitch. 1974. Lat 38° 37′30″ to 39° 22′30″, long 104° 37′30″ to 105°. Scale 1:100,000. $1.75.

I-857-B. Land-use classification map of the Colorado Springs—Castle Rock area, Front Range Urban Corridor, Colorado, by L. B. Driscoll. Lat 38° 37′30″ to 39° 22′30″, long 104° 37′30″ to 105° 07′30″. Scale 1:100,000. $1.75.

I-857-C. Map showing flood-prone areas, Colorado Springs—Castle Rock area, Front Range Urban Corridor, Colorado, by J. F. McCain and W. R. Hotchkiss. 1975. Lat 38° 37′30″ to 39° 22′30″, long 104° 37′30″ to about 105°. Scale 1:100,000. $1.25.

I-857-D. Map showing availability of hydrologic data published as of 1974 by the U.S. Environmental Data Service and by the U.S. Geological Survey and cooperating agencies, Colorado Springs—Castle Rock area, Front Range Urban Corridor, Colorado, by L. O. Anna. 1975. Lat 38° 37′30″ to 39° 22′30″, long 104° 37′30″ to about 105°. Scale 1:100,000. $1.25.

I-857-E. Lakes in the Colorado Springs—Castle Rock area, Front Range Urban Corridor, Colorado, by D. B. Adams. 1976. Lat 38° 37′30″ to 39° 22′30″, long 104° 37′30″ to 105° 07′30″. Scale 1:100,000. $1.50.

I-869. Reconnaissance geologic map of the Royal Gorge quadrangle, Fremont and Custer Counties, Colo., by R. B. Taylor, G. R. Scott, R. A. Wobus, and R. C. Epis. 1975. Lat 38° 15′ to 38° 30′, long 105° 15′ to 105° 30′. Scale 1:62,500. $1.50.

I-870. Reconnaissance geologic map of the Deer Peak quadrangle and southern part of the Hardscrabble Mountain quadrangle, Custer and Huerfano Counties, Colo., by R. B. Taylor. 1974 (1975). Lat 38° to about 38° 09′, long 105° 07′30″ to 105° 15′. Scale 1:24,000. $1.50.

I-892. Reconnaissance geologic map of the Howard quadrangle, central Colorado, by R. B. Taylor, G. R. Scott, and R. A. Wobus. 1975. Lat 38° 15′ to 38° 30′, long 105° 45′ to 106°. Scale 1:62,500. $1.50.

I-900. Reconnaissance geologic map of the Cotopaxi 15-minute quadrangle, Fremont and Custer Counties, Colo., by R. B. Taylor, G. R. Scott, R. A. Wobus, and R. C. Epis. 1975. Lat 38° 15′ to 38° 30′, long 105° 30′ to 105° 45′. Scale 1:62,500. $1.50.

I-901. Geologic map of the lower Conejos River Canyon area, southeastern San Juan Mountains, Colo., by P. W. Lipman. 1975. Lat 37° to 37° 15′, long 106° to 106° 30′. Scale 1:48,000. $1.50.

MISCELLANEOUS INVESTIGATIONS SERIES—Continued

I-912. Magnetic inclination in the United States—Epoch 1975.0, by N. W. Peddie, W. J. Jones, and E. B. Fabiano. 1976. 2 sheets. Scale 1:5,000,000. $3.

I-913. Magnetic horizontal intensity in the United States—Epoch 1975.0, by E. B. Fabiano and W. J. Jones. 1976. 2 sheets. Scale 1:5,000,000. $3.

I-914. Magnetic vertical intensity in the United States—Epoch 1975.0, by W. J. Jones and E. B. Fabiano. 1976 (1977). Two sheets. Scale 1:5,000,000 (1 inch = about 80 miles). Sheet 33 by 47 inches. $3.

I-915. Magnetic total intensity in the United States—Epoch 1975.0, by E. B. Fabiano, N. W. Peddie, and W. J. Jones. 1976. 2 sheets. Scale 1:5,000,000. $3.

I-930. Historic trail maps of the Pueblo 1° × 2° quadrangle, Colorado, by G. R. Scott. 1975 (1976). Lat 38° to 39°, long 104° to 106°. Scale 1:250,000. Accompanied by 9-page text. 2 sheets. $2.50 per set.

I-937. Geologic and biostratigraphic map of the Pierre Shale in the Canon City-Florence basin and the Twelvemile Park area, south-central Colorado, by G. R. Scott and W. A. Cobban. 1975 (1976). Lat 38° 12′30″ to 38° 30′, long 105° to 105° 15′. Scale 1:48,000. $1.25.

I-944. Geologic map of the Lamar quadrangle, COLORADO, and KANSAS, by J. A. Sharps. 1976. Lat 38° to 39°, long 102° to 104°. Scale 1:250,000 (1 inch = about 4 miles). Structure-contour interval 100 feet (30.5 m). Sheet 25½ by 40 inches. $1.50.

I-952. Geologic map of the Del Norte area, eastern San Juan Mountains, Colorado, by P. W. Lipman. 1976. Lat 37° 30′ to 37° 52′30″, long 106° 07′30″ to 106° 30′. Scale 1:48,000. $1.50.

I-962. Geologic map of the Lake City caldera area, western San Juan Mountains, southwestern Colorado, by P. W. Lipman. 1976 (1977). Lat 37° 45′ to 38° 07′30″, long 107° 15′ to 107° 37′30″. Scale 1:48,000 (1 inch = 4,000 feet). Sheet 39 by 58 inches. $1.50.

I-964. Preliminary map of landslide deposits in Colorado, by R. B. Colton, J. A. Holligan, L. W. Anderson, and P. E. Patterson. 1976. Lat 37° to 41°, long 102° to 109°. Scale 1:500,000 (1 inch = about 8 miles). Sheet 40 by 52 inches. $1.25.

I-965. Map showing nonmetallic mineral resources (except fuels) in bedrock, Front Range Urban Corridor, Colorado, by E. J. Crosby. 1976 (1977). Two sheets. Lat 38° 37′30″ to 40° 37′30″, long 104° 37′30″ to 105° 22′30″. Scale 1:100,000 (1 inch = about 1.6 miles). Sheet 1, 34 by 44 inches; sheet 2, 39 by 48 inches. $3 per set.

I-966. Geologic map of the South Fork area, eastern San Juan Mountains, southwestern Colorado, by P. W. Lipman and T. A. Steven. 1976. Lat 37° 30′ to 37° 45′, long 106° 30′ to 106° 45′. Scale 1:48,000 (1 inch = 4,000 feet). Sheet 28 by 30 inches. $1.50.

I-972. Geologic map of the Craig 1° by 2° quadrangle, northwestern Colorado, compiled by Ogden Tweto. 1976. Lat 40° to 41°, long 106° to 108°. Scale 1:250,000 (1 inch = about 4 miles). Sheet 29 by 41 inches. $1.50.

I-973-A. Map showing types of bedrock and surficial deposits in the Telluride quadrangle, San Miguel, Ouray, and San Juan Counties, Colorado, by R. G. Luedke and W. S. Burbank. 1976 (1977). Lat 37° 52′30″ to 38°, long 107° 45′ to 107° 52′30″. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 28 by 28 inches. $1.50.

I-973-B. Map showing potential geologic hazards in the Telluride quadrangle, San Miguel, Ouray, and San Juan Counties, Colorado, by R. G. Luedke and W. S. Burbank. 1977. Lat 37° 52′30″ to 38°, long 107° 45′ to 107° 52′30″. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 29 by 30 inches. $1.50.

I-980. Engineering geologic map of the Indian Hills quadrangle, Jefferson County, Colorado, by R. D. Miller and Bruce Bryant. 1976 (1977). Lat 39° 30′ to 39° 37′30″, long 105° 07′30″ to 105° 15′. Scale 1:24,000 (1 inch = 2,000 feet). Sheet 37 by 39 inches. $1.50.

I-1039. Energy resources map of Colorado, by U. S. Geological Survey and Colorado Geological Survey. 1977. Lat 37° to 41°, long 102° to 109°. Scale 1:500,000 (1 inch = about 8 miles). Sheet 42 by 59 inches. $1.75.

MISSOURI BASIN STUDIES

1. Mineral resources of the Missouri Valley region, compiled by D. H. Dow, D. M. Larrabee, and S. E. Glabaugh. 1945-46. These maps cover the entire basin. They show the sedimentary and igneous rocks of different ages. Structure-contour lines are also given. Part 1 shows the metallic mineral resources, part 2, the nonmetallic mineral resources, part 3, fuel resources, and part 4, construction materials. Scale 1:2,500,000.

MISSOURI BASIN STUDIES—Continued

*2. Preliminary map showing sand and gravel deposits of Colorado, compiled by Helen Varnes and D. M. Larrabee. 1946. Scale 1:500,000.

*8. Map showing mineral deposits of Colorado, compiled by R. P. Fischer, Wilbur Burbank, Helen Cannon, and others. 1946. Scale 1:1,000,000.

*10. Map showing construction materials and nonmetallic mineral resources of Colorado, compiled by D. M. Larrabee, S. E. Clabaugh, W. R. Griffitts, and others. 1947. Scale 1:500,000.

***MOSQUITO RANGE, COLO.** Preliminary geologic map of west slope of Mosquito Range near Leadville, Colo. Geology, by G. H. Behre, Jr., assisted by E. N. Goddard, and A. E. Sandburg. 1939. Scale 1:12,000.

OIL AND GAS INVESTIGATIONS CHARTS

*7. Correlation of basal Permian and older rocks in southwestern Colorado, northwestern New Mexico, northeastern Arizona, and southeastern Utah, by N. W. Bass. 1945.

16. Mesozoic and Paleozoic stratigraphy in northwestern Colorado and northeastern Utah, by C. R. Thomas, F. T. McCann, and N. D. Ramon. 1945. 2 sheets. $2.50 per set.

*39. Pre-Pennsylvanian rocks along the Front Range of Colorado, by J. C. Maher. 1950.

*OC-42. Subsurface geologic cross sections of Mesozoic rocks in northeastern Colorado, by R. W. Blair. 1951. 2 sheets.

OC-46. Correlation of Permian and Pennsylvanian rocks from western Kansas to the Front Range of Colorado, by J. C. Maher and J. B. Collins. 1952. 3 sheets. $3.75 per set.

OC-59. Stratigraphy of Paleozoic rocks in northwestern Colorado, by W. D. Hallgarth. 1959 (1960). $1.25.

OC-60. Stratigraphy of the Dakota group along the northern Front Range foothills, Colorado, by K. M. Waage. 1959. $1.25.

OC-63. Block diagram of the San Rafael Group and underlying strata in Utah and part of Colorado, by J. C. Wright and D. D. Dickey. 1963. $1.25.

OC-65. Chart showing correlation of selected key units in the organic-rich sequence of the Green River Formation, Piceance Creek basin, Colorado, and Uinta Basin, Utah, by W. B. Cashion and J. R. Donnell. 1972. $1.25.

OC-67. Chart showing correlation of selected restored stratigraphic diagram units of the Eocene Uinta and Green River Formations, east-central Piceance Creek basin, northwestern Colorado, by R. B. O'Sullivan. 1974. $1.25.

OC-68. Stratigraphic sections across Upper Cretaceous Mancos Shale—Mesaverde Group boundary, eastern Utah and western Colorado, by J. R. Gill and W. J. Hail, Jr. 1975. $1.25.

OC-69. Stratigraphic sections of some Triassic and Jurassic rocks from Douglas, Wyoming to Boulder, Colorado, by G. N. Pipiringos and R. B. O'Sullivan. 1976. $1.25.

OIL AND GAS INVESTIGATIONS MAPS

*7. Structure contour map of the exposed rocks in the Rangely anticline, Rio Blanco and Moffat Counties, Colo., by C. R. Thomas and others. 1944. Scale 1:31,680. (Superseded in part by Map 67.)

10. Map showing thickness and general character of the Cretaceous deposits in the western interior of the United States, by J. B. Reeside, Jr. 1944. Scale 1:13,939,200. $1.25.

32. Geology of the Washakie Basin, Sweetwater and Carbon Counties, Wyo., and Moffat County, Colo., by W. H. Bradley. 1945. Scale 1:190,080. $1.25.

*41. Structure contour maps of the Rangely anticline, Rio Blanco and Moffat Counties, Colo., by C. R. Thomas and others. 1945. Scale 1:31,680. (Superseded by Map 67.)

*67. Subsurface maps of the Rangely anticline, Rio Blanco County, Colo., by N. W. Bass. 1948. Scale 1:31,680.

*68. Structure contour map of the surface rocks of the Model anticline, Las Animas County, Colo., by N. W. Bass. 1947. Scale 1:42,240.

*73. Map of Colorado showing dry holes and oil and gas fields, by F. K. Demok, H. R. Castor, and N. W. Bass. 1947. Scale 1:500,000. (Superseded by Map OM-116.)

*81. Geology of the southern part of Archuleta County, Colo., by G. H. Wood, V. C. Kelley, and A. J. MacAlphin. 1948. Scale 1:63,360.

*93. Geology of the Egnar-Gypsum Valley area, San Miguel and Montrose Counties, Colo., by W. L. Stokes and D. A. Phoenix. 1948. Scale 1:48,000.

94. Geology of Naval Oil Shale Reserves 1 and 3, Garfield County, Colo., by D. C. Duncan and N. M. Denson. 1949. Scale 1:31,680. 2 sheets. $2.50 per set.

OIL AND GAS INVESTIGATIONS MAPS—Continued

*96. Stratigraphy and geologic structure in the Piedra River Canyon, Archuleta County, Colo., by C. B. Read, G. H. Wood, A. A. Wanek, and Pedro Verastegui Mackee. 1949. Scale 1:48,000.

*101. Pre-Pennsylvanian geology of southwestern Kansas, southeastern Colorado, and the Oklahoma Panhandle, by J. C. Maher and J. B. Collins. 1949. Scale 1:1,013,760. 4 sheets.

109. Geology and coal resources of the Durango area, La Plata and Montezuma Counties, Colo., by A. D. Zapp. 1949. Scale 1:31,680. 2 sheets. $2.50. per set.

*OM-114. Geology of DeBeque oil-shale area, Garfield and Mesa Counties, Colo., by F. R. Waldron, J. R. Donnell, and J. C. Wright. 1951. Scale 1:62,500. 2 sheets.

*OM-116. Map of Colorado showing test wells for oil and gas, pipelines, oil, and gas fields, and areas of pre-Cambrian rocks, compiled by F. W. Walker and N. W. Bass. 1951. Scale 1:500,000. 2 sheets.

OM-119. Geology and oil-shale resources of the eastern part of the Piceance Creek Basin, Rio Blanco and Garfield Counties, Colo., by D. C. Duncan and Carl Belser. 1950. Scale 1:96,000. $1.25.

OM-120. Geology of Dove Creek area, Dolores and Montezuma Counties, Colo., by E. A. Finley. 1951. Scale 1:48,000. $1.25.

*OM-134. Geology of the Cathedral Bluffs oil-shale area, Rio Blanco and Garfield Counties, Colo., by J. R. Donnell, W. B. Cashion, and J. H. Brown, Jr. 1953. Scale 1:62,500. (See Bulletin 1082-L.)

*OM-135. Permian and Pennsylvanian rocks of southeastern Colorado and adjacent areas, by J. C. Maher and J. B. Collins. 1953. Scale 1:1,143,180.

*OM-138. Geology of the Ignacio area, Ignacio and Pagosa Springs quadrangles, La Plata and Archuleta Counties, Colo., by Harley Barnes. 1953. Lat 37° 15′ to 37° 20′, long 107° 20′ to 107° 40′. Scale 1:63,360. 50¢.

*OM-146. Geology of the La Veta area, Huerfano County, by R. B. Johnson and J. G. Stephens. 1954. Lat 37° 30′30″ to 37° 45′, long 104° 55′ to 105° 07′30″. Scale 1:31,680.

OM-149. Geology and fuel resources of the Red Mesa area, La Plata and Montezuma Counties, Colo., by Harley Barnes, E. H. Baltz, Jr., and P. T. Hayes. 1954. Lat 37° to 37° 20′, long 107° 52′30″ to 108° 20′. Scale 1:62,500. $1.25.

*OM-152. Geologic map of the Mesa Verde area, Montezuma County, Colo., by A. A. Wanek. 1954. Lat 37° to 37° 20′, long 108° 20′ to 108° 45′. Scale 1:63,360. (See Bulletin 1072-M.)

OM-153. Geology of the Bonanza-Dragon oil-shale area, Uintah County, Utah, and Rio Blanco County, Colo., by W. B. Cashion and J. H. Brown, Jr. 1956. Scale 1:62,500. 2 sheets. $2.50 per set.

OM-161. Geologic map of the Walsenburg area, Huerfano County, Colo., by R. B. Johnson and J. G. Stephens. 1955. Scale 1:31,680. $1.25. (See Bulletin 1042-O.)

OM-174. Geology of the Trinidad-Aguilar area, Las Animas and Huerfano Counties, Colo., by R. L. Harbour and G. H. Dixon. 1956. Lat 37° 10′ to 37° 30′, long 104° 30′ to 104° 45′. Scale 1:31,680. $1.50. (See Bulletin 1072-G.)

OM-176. Preliminary structure contour map of the Colorado plains, by E. A. Finley, C. E. Dobbin, and E. E. Richardson. 1955 (1956). Lat 37° to 41°, long 102° to 105°. Scale 1:500,000. $1.25.

OM-183. Preliminary geologic map of the northern part of the Raton Mesa region and Huerfano Park in parts of Las Animas, Huerfano and Custer Counties, Colo., by R. B. Johnson, G. H. Wood, Jr., and R. L. Harbour. 1958. Lat 37° 30′ to 37° 52′30″, long 104° 37′30″ to 105° 22′30″. Scale 1:63,360. 2 sheets. $3 per set. (See Bulletin 1071-D.)

OM-184. Index map of central midcontinent region giving lines of sections that show detailed lithology of Paleozoic and Mesozoic rocks, by Jeannette Fox and M. G. Sheldon. 1957. Lat 33° to 46°, long 89° to 106°. Scale 1:2,500,000. $1.50.

OM-209. Preliminary structure contour map on top of salt in the Paradox member of the Hermosa Formation in the salt anticline region, Colorado and Utah, by D. P. Elston and E. M. Shoemaker. 1961. Lat 37° 45′ to 39°, long 108° to 110°. Scale 1:250,000. $1.25.

OM-216. Geologic map of the Thornburg oil and gas field and vicinity, Moffat and Rio Blanco Counties, Colo., by J. R. Dyni. 1966. Area lies in the vicinity of lat 40° 15′, long 107° 40′. Scale 1:24,000. Accompanied by 7-page text. $1.25.

***PALEOCENE DEPOSITS OF THE ROCKY MOUNTAINS AND PLAINS,** by R. W. Brown. 1949. Shows the areas of outcrop of the earliest Tertiary (Paleocene) rocks from Montana and North Dakota south to Arizona and New Mexico. The upper and lower boundaries of the Paleocene deposits and their areal relations with Cretaceous and younger Tertiary rocks are indicated. A brief discussion of Paleocene formations is printed on the same sheet. Scale 1:1,000,000. (See Professional Paper 375.)

PIKES PEAK AND VICINITY, COLORADO. 1948-56 (1957). Text on the reverse side of the map discusses the geologic story of Pikes Peak and the surrounding region, by A. H. Koschmann. Available in contour or shaded relief editions. $1 each.

MISCELLANEOUS REPORTS (free upon application to the Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202):

List 1. Press releases, preliminary maps, and preliminary reports released between Jan., 1, 1938, and Jan. 1, 1945.

List 2. Press releases, preliminary maps, and preliminary reports released between Jan. 1, 1945, and Jan. 1, 1946.

REFERENCE LIBRARIES

Many of the publications listed herein may be consulted in the following libraries in Colorado:

ALAMOSA:
- Adams State College.

BOULDER:
- University of Colorado.

COLORADO SPRINGS:
- Colorado College.

DENVER:
- Colorado Geological Survey.
- Colorado State.
- Colorado Water Conservation Board.
- Div. of Water Resources.
- Jefferson County Public.
- Public.
- Regis College.
- State Bureau of Mines.
- U.S. Geological Survey Offices-
  - Denver Federal Center and
  - Rm. 1012, Federal Bldg.
- University of Denver.

FORT COLLINS:
- Colorado State University.

GOLDEN:
- State School of Mines.

GRAND JUNCTION:
- Public.

GREELEY:
- University of Northern Colorado.

GUNNISON:
- Western State College.

PUEBLO:
- McClelland Public.
- Southern Colorado State College.

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APPENDIX D

This appendix presents the data base upon which the structure contour map on top of the Rollins Sandstone (Plate 3) and the isopach map of overburden thickness above the Rollins (Plate 5) were constructed. The top of the Rollins was selected as a reference plane because it is the base of the thickest and most persistent coal zone throughout the Piceance Basin, especially the southeastern Piceance, where coalbeds have the greatest methane concentrations. The data source was the scout cards compiled by Petroleum Information Company from the well completion reports on public file at the Colorado Oil and Gas Comnission. Formation tops reported on these cards generally are determined by the operator's geologist most familiar with the area being drilled. However, because of lack of agreement as to where formation contacts occur and the common lack of clear-cut log signatures, discrepancies in reported formation tops occur from well to well across the basin. Because of the scale of the maps and the 1,000-foot contours used, such discrepancies should cause only minor distortions to the overall structures represented.

In the following table, data are reported on 107 wells distributed across the basin, covering the townships south of the principal latitude (latitude line bisecting Rio Blanco County). Reported in the table, in sequence, are the following:

- Well number - As used on the structural contour and overburden maps
- Surface elevation - Kelly bushing (KB) or ground (GR) elevation above mean sea level
- Top of the Rollins Sandstone - Elevation in feet above mean sea level as determined from scout cards reported depth to Rollins <u>or</u> as interpolated or extrapolated from reported depths of other formation tops. North of the Colorado River, top of the Rollins equivalent was used.
- Top of the Cretaceous Mesaverde (Kmv)
- Top of the Cretaceous Mancos Shale (Km)

- **Tops** of other formations - **Tops** of other formations, whose depths tend to collaborate the depth selected for the Rollins or Rollins equivalent.

- Notes - Specific information used and depth interval selected from that formation top and the top of the Rollins or Rollins equivalent.

Table D-1. Piceance Basin Map Data Base

	Number/ Location	Elev.	Top of Rollins (or approx. equiv.)	Top K_{mv}	Top K_m	All Elevation Above Sea Level Others	Notes
1.	T1S R103W Sec 17	5584 KB	3400	5012	2840	Castlegate 2966, Buck Tongue 3194 Dakota-1480	t = K_{mv} - 1500 see 28 Note: Buck Tongue and Castlegate
2.	T1S R103W Sec 4	5950 KB	3300	4906		Castlegate 2850, Morapos 2655 Buck Tongue 3086, Dakota-1589	Same as 1.
3.	T1S R102W Sec 12	5700 KB	5100		3270	Morapos 4600, Rimrock 4958	t = Rimrock + 150
4.	T1S R97W Sec 7	6518 KB	-1800	518			t = K_{mv} - 2300 see 5, 7
5.	T1S R95W Sec 31	6650 GR	-3300			Wasatch 3402, Parachute Creek 6160 Mahogony 5638, Douglas Creek 3505 Garden Gulch 4690	t = Parachute - 9450 see 4, 7
6.	T1S R99W Sec 34	6640 KB	-750	1029		Wasatch 4931, Ft. Union 1667, Green River surf	t = K_{mv} - 1900
7.	T2S R96W Sec 18	7411 KB	-2850	-809		Wasatch 4849, Ft. Union 21, Parachute Creek 6541, Garden Gulch 4877 Douglas Creek 4877, Mahogony 6371 Ohio Creek -63	t = K_{mv} - 2100
8.	T2S R97W Sec 14	6920 KB	-2300		790	Garden Gulch 4926, Douglas Creek 4640	Same theory as 5
9.	T2S R98W Sec 23	6733 KB	-1600	393		Paragraph Creek 6279, Mahogony 5709	t = K_{mv} - 2000
10.	T2S R100W Sec 17	7146 GR	3975	surf	3264	Castlegate 3435, Anchor Tongue 3898 Sego 3826, Buck Tongue 3729	t = Sego + 150
11.	T2S R101W Sec 20	6200 KB	5900			Castlegate 5244, Anchor Tongue 5680 Sego 5546, Buck Tongue 5540	t = Sego + 150
12.	T2S R102W Sec 26	6503 KB	6400		5900	Mancos B 4538	t = K_m + 1800 (Assume Mancos to Mancos B 500)
13.	T2S R102W Sec 7	6171 GR	5450	surf	5121	Castlegate 4891, Rimrock 5237	t = Castlegate + 500
14.	T2S R103W Sec 2	6305	5150	surf	4485	Castlegate 4673	t = Castlegate + 500
15.	T2S R104W Sec 13	7229 GR	4700	5921	4477	Morapos 4163, Base Morapos 4124	t = Morapos + 850 see 28 Allow for thinning

Table D-1. Piceance Basin Map Data Base (Continued)

16.	T2S R103W Sec 7	7140 KB	5100	6450	3970	Castlegate 4230, Wasatch 6565 Buck Tongue 4430, Sego 4625	t = Sego + 500 see 33, 28
17.	T3S R103W Sec 25	6537 GR	5430	6200	5100	Wasatch surf	t = K_{mv} - 800
18.	T3S R102W Sec 16	7936 KB	5500	7376	5179	Dakota 1194	t = K_d + 4300 see 28 Allow for thinning
19.	T3S R102W Sec 7	7030 DF	5450	6630	4450	Morapos 4223, Fault 3110	t = K_d + 4300 see 28
20.	T3S R101W Sec 33	8223 GR	5900		5403	Morapos 5061, Dakota 1160	t = Morapos + 1200 see 28 Allow for thinning
21.	T3S R100W Sec 30	6415 KB	5900			Wasatch surf, Morapos 4655 Castlegate 4235, Dakota 385	Same as 20
22.	T3S R100W Sec 7	6207 KB	5450	surf	4797	Morapos 4264, Mancos B 3537	Same as 20
23.	T3S R99W Sec 28	8200 KB	2850	3855		Mahogany 7614	t = K_{mv} + 2000
24.	T3S R95W Sec 19	6750 KB	-2000			Douglas Creek 4215, Mahogany 6032	Same theory as 5
25.	T4S R93W Sec 31	6488 KB	-750		-2754	Iles -864, Corcoran - 1292, Ft. Union 5148, Ohio Creek 4576, Dakota -10622	t = Iles + 50 (Note: In many places Iles is very close to Rollins)
26.	T4S R98W Sec 15	7621 KB	600	2629			t = K_{mv} - 2000
27.	T4S R100W Sec 2	7522 KB	4550	5810	3082	Castlegate 3184, Wasatch 6772, Dakota -480	t = Castlegate + 1300
28.	T4S R101W Sec 25	7140 KB	5567	surf		Castlegate 4576, Sego 5107, Buck Tongue 4780, Morapos 4027, Dakota 413	Given
29.	T4S R102W Sec 26	7060 GR	5950			Sego 5639, Castlegate 5444, Mancos B 4234, Dakota 1180	t = Sego + 500
30.	T4S R103W Sec 28	6772 KB	4900	5902	4762	Basal Mesaverde 4794, Dakota 705	Inspection
31.	T5S R102W Sec 11	8817 KB	5800	7126	4633	Sego 5108, Castlegate 4799, Buck Tongue 5022, Mancos B 3792, Dakota 1185	t = Sego + 200
32.	T5S R101W Sec 19	8000	5300	6855	4287	Wasatch 7182, Dakota 80	t = Mancos + 1000 approximate ground elevation

Table D-1. Piceance Basin Map Data Base (Continued)

33.	T5S R98W Sec 13	7815 KB	500	2905		Cozzette 360, Castlegate -647, Wasatch 6019, Cameo coal 719	Given
34.	T6S R93W Sec 36	5864 KB	-1586	2204		Cozzette -2166, Corcoran -2474	Given
35.	T6S R100W Sec 7	6910 KB	4042	6255	4068	Cozzette 3988, Corcoran 3624, Sego 3500 Buck Tongue 3074, Castlegate 2916	Given
36.	T6S R101W Sec 2	7122 KB	4296	7055		Wasatch surf, Cameo 4462, Cozette 4290, Corcoran 4126, Dakota -589	Given
37.	T6S R102W Sec 14	6168 GR	5340				Given
38.	T6S R104W Sec 12	6431 GR	5400	surf	4794	Anchor Tongue 5321, Sego 5209, Buck Tongue 5123, Castlegate 4938, Dakota 1207	t = Sego + 200
39.	T7S R104W Sec 14	5524 KB	5075	5431	4994	Castlegate 4667, Dakota 960	t = Castlegate + 400
40.	T7S R101W Sec 16	6193 KB	4637	surf	3931	Cameo 4673, Cozette 4434, Corcoran 4208, Dakota -22	Given
41.	T7S R93W Sec 9	7156 KB	-850	1597		Wasatch 6972, Ohio Creek 2402	t = K_{mv} - 2450
42.	T7S R92W Sec 25	6362 DF	1650	5512		Cozzette 1167, Corcoran 957	t = Cozette + 600 see 35
43.	T7S R91W Sec 23	7137 KB	157			Corcoran -501	Given
44.	T7S R90W Sec 17	7965 KB	-1135	3007	-1379	Cozzette -1835, Corcoran -1973, Wasatch surf, Ohio Creek 3301, Cameo -905	Given
45.	T8S R90W Sec 26	9630 RB	5900			Cameo Coal 6054, Cozzette 5050 Corcoran 4802	t = Cameo - 50
46.	T8S R91W Sec 9	8955 RB	4495				Given
47	T8S R92W Sec 18	6945 DF	-1515	2545	-1755	Cozzette -2043, Wasatch surf, Ohio Creek 2645	Given
48.	T8S R94W Sec 25	8430 KB	-230	2728	-522	Cozzette -728, Corcoran -918	t = K_{mv} - 3900 see 47
49.	T8S R96W Sec 15	5731 GR	808		267	Cozette 533, Corcoran 391	Given
50.	T8S R97W Sec 12	5168 DF	950			Cameo Coal 1043, Iles 918, Cozette 616 Williams Fork 3408	t = Cameo - 100 see 52, 53, 54, 55 Note: Iles

Table D-1. Piceance Basin Map Data Base (Continued)

51.	T8S R97W Sec 25	5622 DF	1482		722	Cozette 1242, Corcoran 976, Dakota -3238	Given
52.	T8S R97W Sec 29	5238 KB	2218		1578	Cameo Coal 2508, Cozette 1998, Corcoran 1748	Given
53.	T8S R98W Sec 34	5347 KB	2967	5097	2397	Cameo 2997, Cozette 2697, Corcoran 2552, Dakota -1853	Given
54.	T8S 100W Sec 19	7207 GR	5209			Cameo 5239	Given
55.	T8S R100W Sec 29	6743 KB	5207			Cameo 5226	Given
56.	T8S R101W Sec 9	6650 KB	5450		5110	Cozzette 5238, Dakota 944	t = Cozette + 250 see 53
57.	T9S R100W Sec 28	5422 KB			surf	Dakota 2254	Eroded away
58.	T9S R99W Sec 35	6494 KB	4800		4294	Dakota 376	t = K_m + 500
59.	T9S R98W Sec 31	6679 KB	4700		3979	Cozette 4416, Corcoran 4236 Dakota 53	t = Cozette + 300 see 60, 61
60.	T9S R97W Sec 32	5648 KB	3602		3120	Cozette 3401, Corcoran 3196, Dakota -1066	Given
61.	T9S R96W Sec 31	5570 KB	2816	4878	2751	Cozette 2571, Corcoran 2398	Given
62.	T9S R95W Sec 13	6639 KB	619	3509		Lower Mesaverde 1874, Cozette 244, Corcoran 69, Wasatch surf, Ohio Creek 3549	Given
63.	T9S R95W Sec 29	6012 GR	1534	4116	1442	Cozette 1232, Corcoran 1054	Given
64.	T9S R95W Sec 36	6250 KB	1312	3912		Cameo 1720, Cozette 872	Given
65.	T9S R94W Sec 18	6631 KB	421	3386		Ohio Creek 3473, Lower Mesaverde 1671, Cozette 257, Corcoran 93	Given
66.	T9S R94W Sec 29	6562 KB	797	3565		Cameo 1322	Given
67.	T9S R94W Sec 20	6530 KB	695	3465	465	Ohio Creek 3515, Cameo 1100, Cozette 320, Corcoran 150	Given

Table D-1. Piceance Basin Map Data Base (Continued)

68.	T9S R93W Sec 12	7592 GR	517	3037		Ohio Creek 3147, Cozette -938, Corcoran -1154	Given
69.	T9S R93W Sec 20	7012 KB	-244		-1141	Cameo -205, Cozette -762, Corcoran -940	Given
70.	T9S R92W Sec 2	7727 DF	387	3432	-590	Cozette -283, Corcoran -481, Cameo Coal 485, Coal 697	Given
71.	T9S R90W Sec 15	9505 KB	5303		4785	Cozette 4172	Given
72.	T9S R90W Sec 4	9640 KB	5654		5233	Cozette 4658, Corcoran 4422	Given
73.	T10S R90W Sec 24	9048 KB	6668		6223	Cozette 6044, Corcoran 5803	Given
74.	T10S R93W Sec 9	8150 GR	550	3300	208	Cozette 60, Corcoran -140	t = Cozette + 500 see 75
75.	T10S R93W Sec 20	8777 KB	1227	3890	1042	Ohio Creek 3990, Cozette 694, Corcoran 549	Given
76.	T10S R93W Sec 29	9065 DF	1700		1465	Ohio Creek 5040, Corcoran 910	t = Corcoran + 800 see 75
77.	T10S R94W Sec 11	7601 KB	983	3854		Cameo 1439	Given
78.	T10S R94W Sec 24	8490 KB	1185	2520		Cameo 1490, Cozette 725, Corcoran 575, Ohio Creek 3040	Given
79.	T10S R95W Sec 3	6151 KB	1701			Cozette 1374, Corcoran 1199	Given
80.	T10S R95W Sec 15	6635 KB	2130		1990	Cameo 2408, Cozette 1833, Corcoran 1667, Dakota -2498	Given
81.	T10S R96W Sec 4	6170 KB	2366	4150	2260	Cozette 2086, Corcoran 1923	Given
82.	T10S R96W Sec 17	5480 KB	2780	4494	2676	Cozette 2506, Corcoran 2354	Given
83.	T10S R96W Sec 24	6326 KB	2536	4961	1896	Cozette 2256, Corcoran 2081	Given
84.	T10S R96W Sec 27	5985 KB	3047		815	Cozette 2733, Corcoran 2567	Given
85.	T10S R97W Sec 1	5830 KB	3080	5610	3025	Fault 2970, Cozette 2895, Corcoran 2717 Cameo 3130	Low confidence level

Table D-1. Piceance Basin Map Data Base (Continued)

86.	T10S R97W Sec 4	5688 KB	3483		2810	Cozette 3238, Corcoran 3038, Mancos Tongue 3338, Mancos Tongue 3126, Dakota -1132, Sego 2828	Given
87.	T10S R97W Sec 5	5754 KB	3609		2932	Cozette 3390, Corcoran 3172, Sego 2950, Dakota -950	Given
88.	T10S R98W Sec 6	6199 KB	4393		3755	Cozette 4214, Corcoran 3990, Dakota -364	Given
89.	T10S R100W Sec 8	4967 KB			surf	Dakota 2726	Above surface - eroded away
90.	T11S R97W Sec 26	10008 KB	5200	7413		Wasatch 8478, Ohio Creek 7508	t = K_{mv} - 2200 see 83
91.	T11S R95W Sec 13	9900 KB	3700	5570	3150	Ohio Creek 5758, Cozette 2970, Corcoran 2780	Low confidence level
92.	T11S R95W Sec 30	10191 KB	4200	6491	3551	Ohio Creek 6721, Base Mesa Verde 3931 Cozette 3801, Corcoran 3631	t = Base K_{mv} - 300
93.	T11S R94W Sec 4	9464 KB	2895	5164		Cameo 3254	Given
94.	T11S R94W Sec 21	10031 KB	3900	6199		Ohio Creek 6291	t = Ohio Creek + 2400 see 92
95.	T11S R92W Sec 13	9421 GR	2664		2527		Given
96.	T11S R91W Sec 6	8898 KB	2208	5258		Cozette 1538, Corcoran 1344	Given
97.	T11S R90W Sec 27	7549 KB	3830	6739	3638	Cozette 2999, Corcoran 2853	Given
98.	T11S, R90W Sec 9	7532 KB	3220	6360		Cameo 4165	Given
99.	T11S R90W Sec 7	8170 GR	2500			Cozette 1703, Corcoran 1590	t = Cozette + 800
100.	T12S R89W Sec 17	6764 DF	4204		4059		Given
101.	T12S R89W Sec 20	6538 GR	4008		3904		Given
102.	T12S R90W Sec 11	7041 KB	3900	surf	3771	Dakota -769	t = K_d + 4950
103.	T12S R92W Sec 8	9815 GR	4800		4615	Cozette 4288, Corcoran 4149	t = Cozette + 500

Table D-1. Piceance Basin Map Data Base (Continued)

104.	T12S R92W Sec 30	8908 GR	6200		6038		Low confidence level
105.	T12S R97W Sec 33	6705 KB	?		5965	Dakota 2909	Above ground - eroded away
106.	T13S R93W Sec 6	7562 KB	6400	7123	6257	Cozette 5852	$t = K_m + 250$
107.	T13S R89W Sec 8	7500	6750	surf	6550		$t = K_m + 200$ see 106 Approximate ground elevation