

Information Series 32

Coalbed Methane Development in Colorado, September 1990

By C. M. Tremain

(A Talk Presented at
the AAPG Section Meeting
in Denver, Colorado)

Colorado Geological Survey
Department of Natural Resources
Denver, Colorado/1990



COLORADO GEOLOGICAL SURVEY

COALBED METHANE PUBLICATIONS

MAP SERIES

- 19 The Coal Bed Methane Resources of Colorado

OPEN-FILE REPORTS

- 78-2 Data Accumulation on the Methane Potential of the Coal Beds of Colorado, Final Report
- 79-3 Content of Methane in Coal from Four Core Holes in the Raton and Vermejo Formations, Las Animas County, Colorado
- 80-2 Deep Coal Bed Methane Potential of the San Juan River Coal Region, Southwestern Colorado
- 80-4 The Coal Bed Methane Potential of the Raton Mesa Coal Region, Raton Basin, Colorado
- 80-5 Conservation of Methane from Colorado Mined/Minable Coal Beds—A Feasibility Study
- 80-7 Methane Drainage Plan Using Horizontal Holes at the Hawk's Nest East Mine, Paonia, Colorado
- 81-4 Coal Bed Methane Desorption Data
- 81-6 Coal Bed Methane Potential of the Sand Wash Basin, Green River Coal Region, Colorado
- 82-1 Coal Bed Methane Potential of the Piceance Basin, Colorado
- 82-4 Southern Ute/Department of Energy Coalbed Methane Test Wells
- 84-2 Colorado Desorption Samples—Descriptive Statistics and Gas Prediction Equations

Information Series 32

Coalbed Methane Development in Colorado, September 1990

**(A Talk Presented at the AAPG Section Meeting
in Denver, Colorado)**

By C. M. Tremain

**Colorado Geological Survey
Department of Natural Resources
Denver, Colorado/1990**

CONTENTS

Introduction	1
Raton Basin	7
San Juan Basin	14
Piceance Basin	22
Sand Wash Basin	27
Conclusions	31
References Cited	34

FIGURES

1.	Coal regions of Colorado	2
2.	U.S. Bureau of Mines methane desorption equipment	3
3.	Coalbed methane resources of the United States	3
4.	Coal depositional environments	4
5.	Cretaceous sea in North America	5
6.	Coal rank related to hydrocarbon generation	6
7.	The Raton Basin of Colorado and New Mexico	7
8.	Coal mines of the Raton Basin	8
9.	Gas occurrences in Raton Basin mines	9
10.	Columnar section, Vermejo Formation, Raton Basin	10
11.	Columnar section, Raton Formation, Raton Basin	11
12.	Vermejo Formation type log, Raton Basin	12
13.	Coalbed methane wells and desorption locations, Raton Basin	13
14.	Map of the San Juan Basin	15
15.	Coal mines in the San Juan River Coal Region	16
16.	Type log of coal-bearing formations in the San Juan Basin	17
17.	Fruitland Formation type log	18
18.	Major coal-occurrence trends in the Fruitland Formation	19
19.	Fruitland Formation coal rank map	20
20.	Coalbed methane wells and desorption locations, San Juan Basin	21
21.	Depth to base of coal, Cameo coal zone	23
22.	Type log showing Lower Mesaverde coals, southern Piceance Basin	24
23.	Mesaverde Formation coal rank map, Piceance Basin	25
24.	Coalbed methane wells and desorption locations, Piceance Basin	26
25.	Greater Green River Coal Region	28
26.	Sand Wash Basin coal bearing formations	28
27.	Type log of Mesaverde coals, Sand Wash Basin	29
28.	Type log of Fort Union coals, Sand Wash Basin	29
29.	Coalbed methane wells and desorption locations, Sand Wash Basin	30

TABLES

1. Coal bearing formations and depositional environments **31**
2. Coal thickness and rank **32**
3. Gas content and estimated resources **32**
4. Well tests and depths **33**
5. Colorado coalbed methane summary data **33**

ACKNOWLEDGMENTS

The author wishes to thank Samuel Friedman of the Oklahoma Geological Survey for his suggestion to publish this talk and John Rold of the Colorado Geological Survey for his encouragement and support. Production data came from the Colorado Oil and Gas

Conservation Commission and resource estimates and several illustrations from Colorado Geological Survey research and reports sponsored by the Gas Research Institute. Word processing was by Lucy Lopez and drafting, pasteup, and editing by Cheryl Brchan.

INTRODUCTION

As coal undergoes the coalification process from peat to anthracite, it emits methane, the principle component of natural gas. Much of this gas is lost to the atmosphere; some remains trapped in the coal. The trapped gas is both a coal mine explosion hazard and an unconventional natural gas resource.

Since 28 percent, or 26,000 square miles, of Colorado is underlain by coal (figure 1) and since the state has a history of gassy mines and coal gas shows in oil and gas wells, the U.S. Bureau of Mines funded a two-year grant (1975-1977) for the Colorado Geological Survey to study coalbed methane. This was followed by a series of U.S. Department of Energy grants from 1978 to 1984 and a Colorado Oil and Gas Commission grant (1980-1982).

Under these grants the Colorado Geological Survey and cooperating parties measured the gas content of over 200 coal core samples [by the U.S. Bureau of Mines whole core desorption method (figure 2)], mapped coal thicknesses, and compiled coal rank information in order to calculate the methane resources of the state. We calculated approximately 100 trillion standard cubic feet of coalbed methane in place in the Piceance and Sand Wash Basins and the Colorado portions of the San Juan and Raton Basins.

More recently, the Gas Research Institute estimates coalbed methane resources in

these four basins at: 18 trillion cubic feet for the Raton Basin (Colorado and New Mexico), 50 trillion cubic feet in the Fruitland Formation of the San Juan Basin, (Colorado and New Mexico), 84 trillion cubic feet in the Piceance Basin (Colorado), and 31 trillion cubic feet in the Greater Green River Region (Colorado and Wyoming) (figure 3). This is 183 trillion cubic feet of a total of 400 to 900 trillion cubic feet of coalbed methane resources estimated for the entire country [10 to 100 trillion cubic feet of these resources are potentially recoverable (Crouse, 1989)]. To further put this number into perspective, the 1989 U.S. proved gas reserves excluding Alaska are 167 trillion cubic feet (EIA, 1989).

In Colorado, gas is found in Cretaceous and Paleocene coals deposited in back barrier bar to fluvial environments (figure 4) that existed adjacent to the Cretaceous epeiric seaway (figure 5). Most of the gas occurs in high-volatile B to medium-volatile rank coals with the highest gas content in the higher rank coals (figure 6). Currently there are over 700 producing or shut-in coalbed methane wells in Colorado in four basins in the southeastern and western part of the state: the Raton, San Juan, Piceance, and Sand Wash. This report summarizes and compares the coalbed methane activity in each basin.

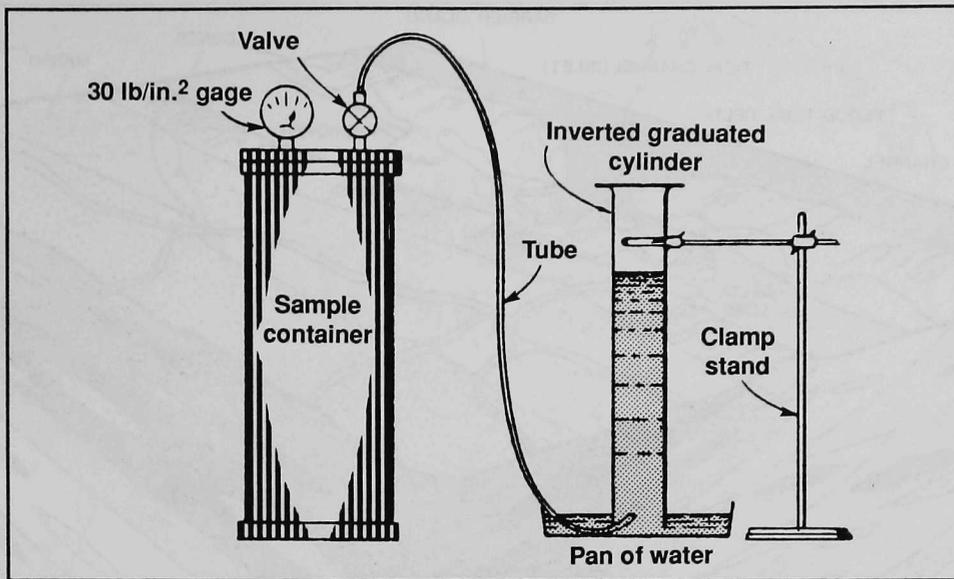


Figure 3. Methane desorption equipment used in U.S. Bureau of Mines desorption method (after McCulloch et al., 1975).

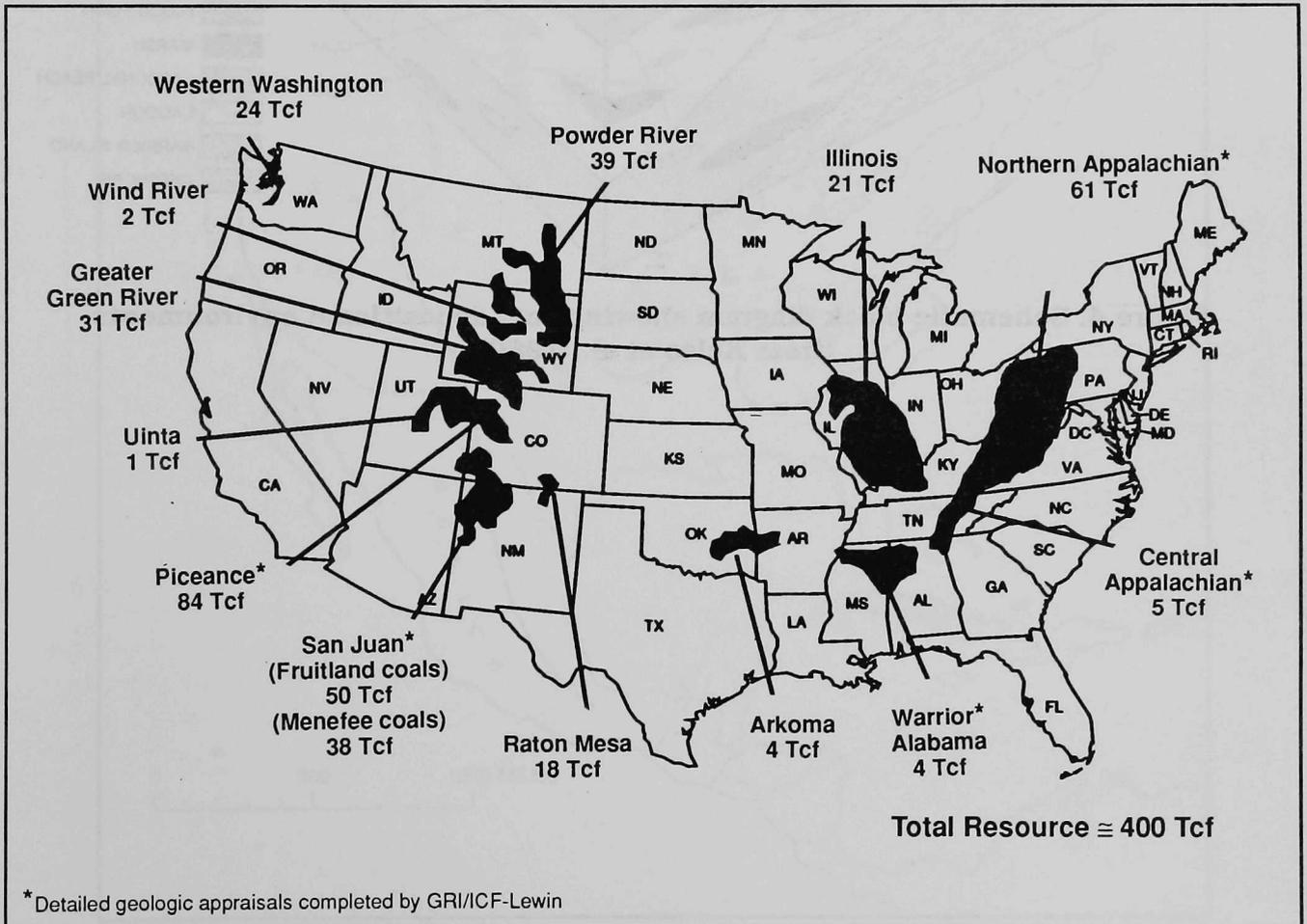


Figure 2. Coalbed methane resources of the United States (from G.R.I. 1989 Coalbed Methane Workshop).

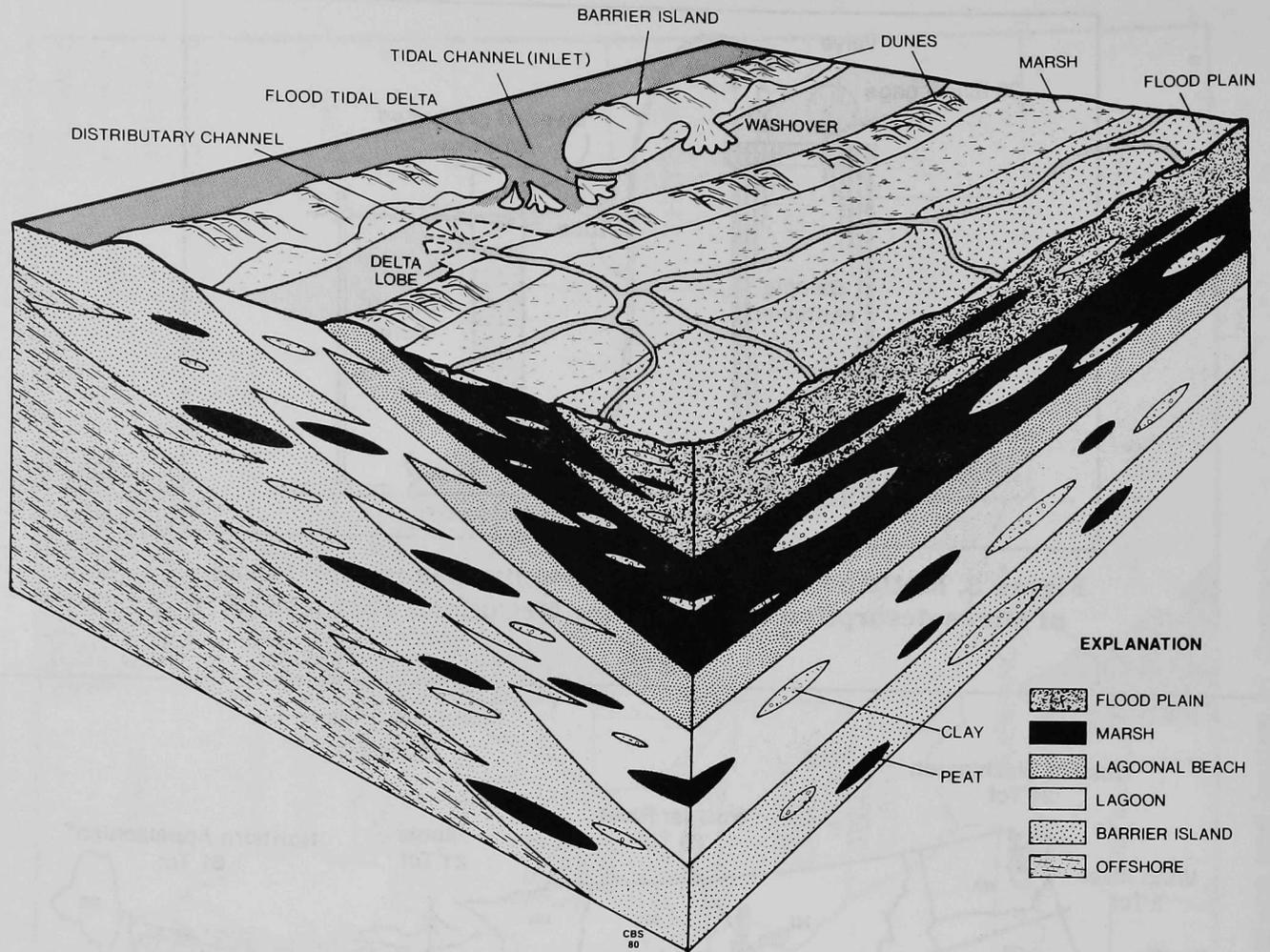


Figure 4. Schematic block diagram showing coal depositional environments (from Kelso et al., 1980).

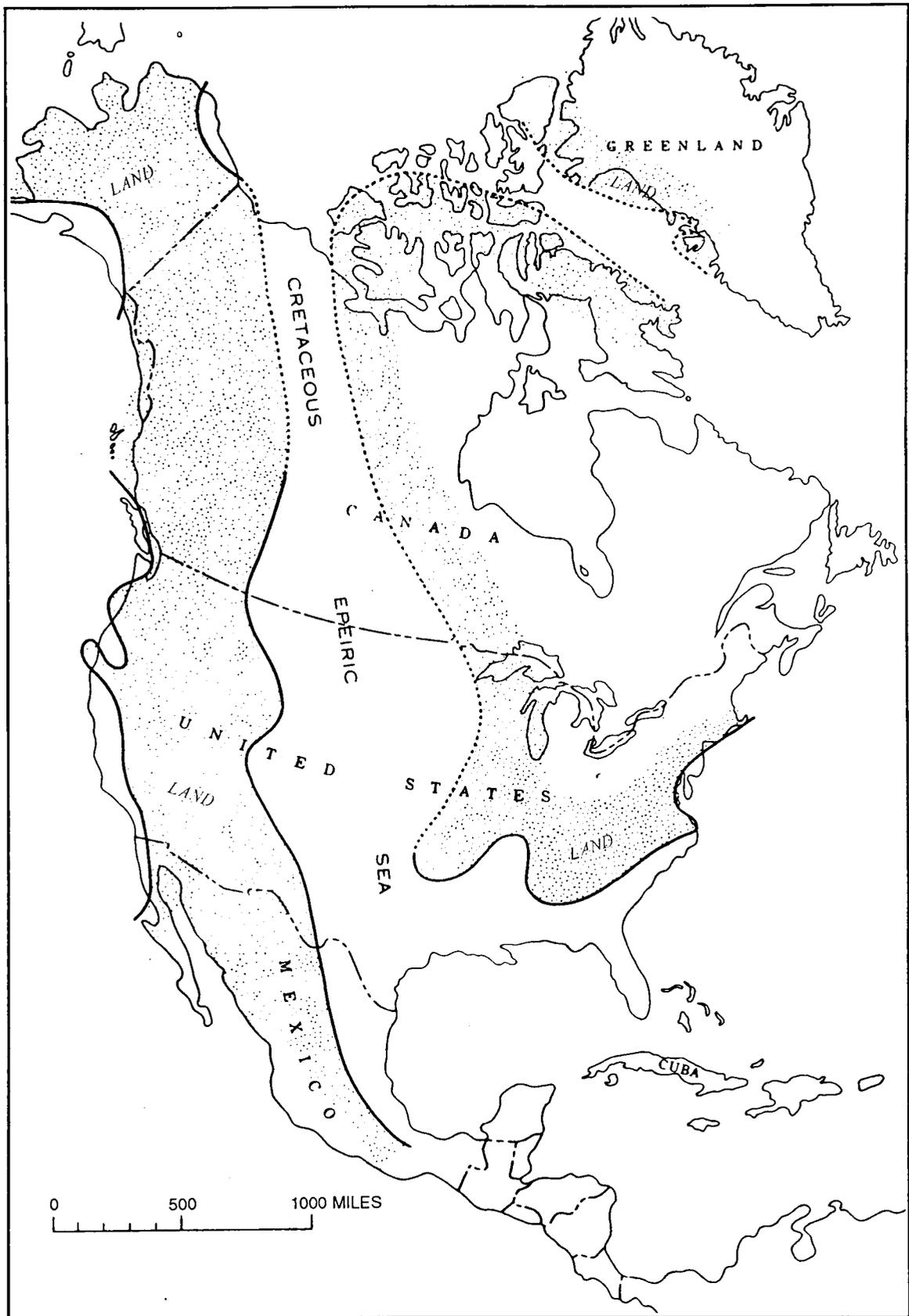
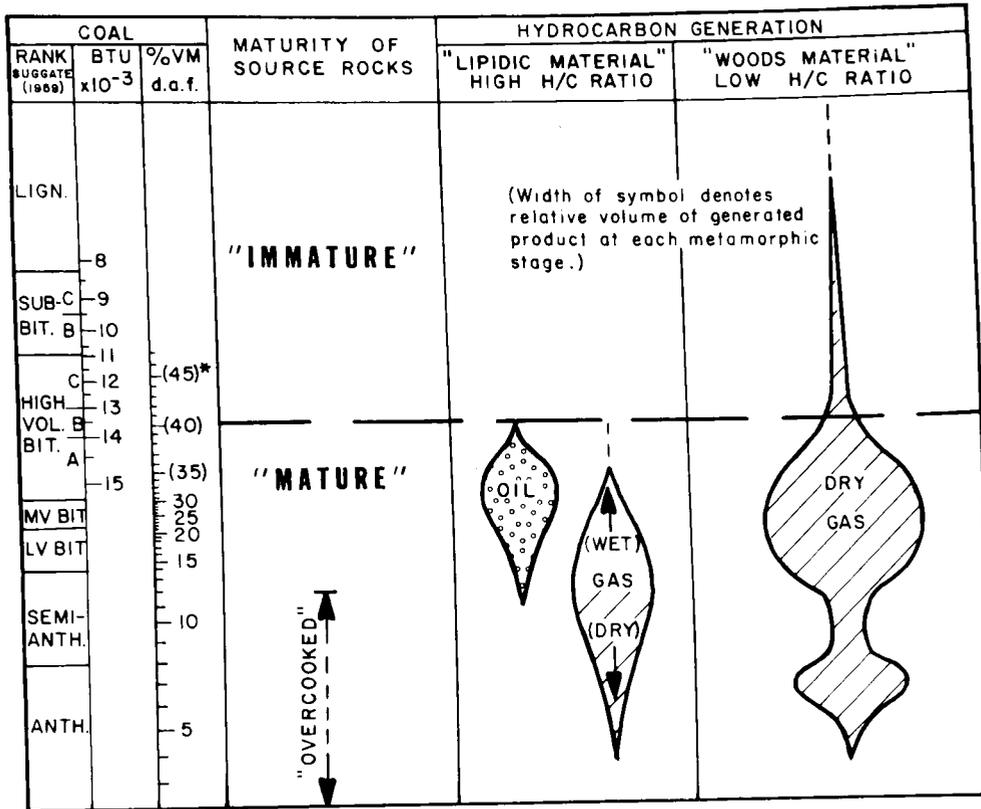


Figure 5. Location of the Cretaceous sea in North America (after Gill and Cobban, 1966).



*%Volatile matter in parenthesis is suitable only for humic, vitrinitic coals.

Figure 6. Coal rank related to hydrocarbon generation (from Dolly and Meissner, 1977).

RATON BASIN

The Raton Basin in the southeastern part of the state straddles the border between Colorado and New Mexico (figure 7). The basin is an asymmetrical syncline containing the 2200 square mile Raton Mesa Coal Region of Colorado and New Mexico. The Colorado portion of the region is approximately 1100 square miles. Coal has been mined in the Raton Coal Region since the 1870's (figure 8) and a number of mines have been gassy (figure 9).

Coal is found in the Cretaceous Vermejo (figure 10) and Cretaceous-Paleocene Raton (figure 11) Formations. The thickest coals are approximately 12 feet thick; frequently the coals are thinner as shown in the type log (figure 12). There are 17 published desorption data locations in the Colorado portion of the Raton Basin. The maximum gas content measured was 569 cubic feet of gas per ton (cf/t) of coal.

Currently there are 50 shut-in wells in the Colorado portion of the basin (figure 13). The average depth of the wells is 1200 to 2000 feet. The highest published initial production rate is from the State of Colorado AS No. 1 well (Sec. 36, T. 32 S., R. 67 W.); the October, 1989 "GRI Coalbed Methane Quarterly" reported an initial test of 239 thousand cubic feet of gas per day (MCFD) in that well. The wells in the Raton produce anywhere from zero to 1200 barrels of water a day (BWD).

There are 16 dry and abandoned wells in the Colorado part of the basin. Reasons for early dry holes include low gas content [i.e. CIG-CFI wells near Morley (Sec. 29,

T. 34 S., R. 63 W.)] or excessive water production [i.e. APGA City of Trinidad 1, 2, and 3 wells near the Purgatoire River west of Trinidad (Sec. 32, T. 33 S., R. 66 W.)]. Further development of the basin awaits the installation of additional pipeline capacity.

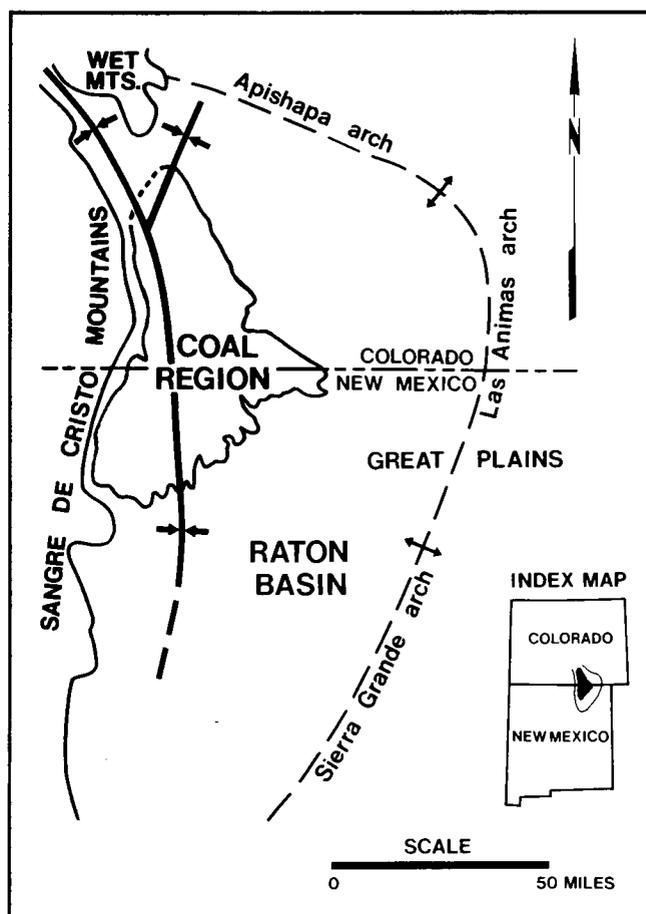


Figure 7. The Raton Basin of Colorado and New Mexico (after Johnson and Wood, 1956).

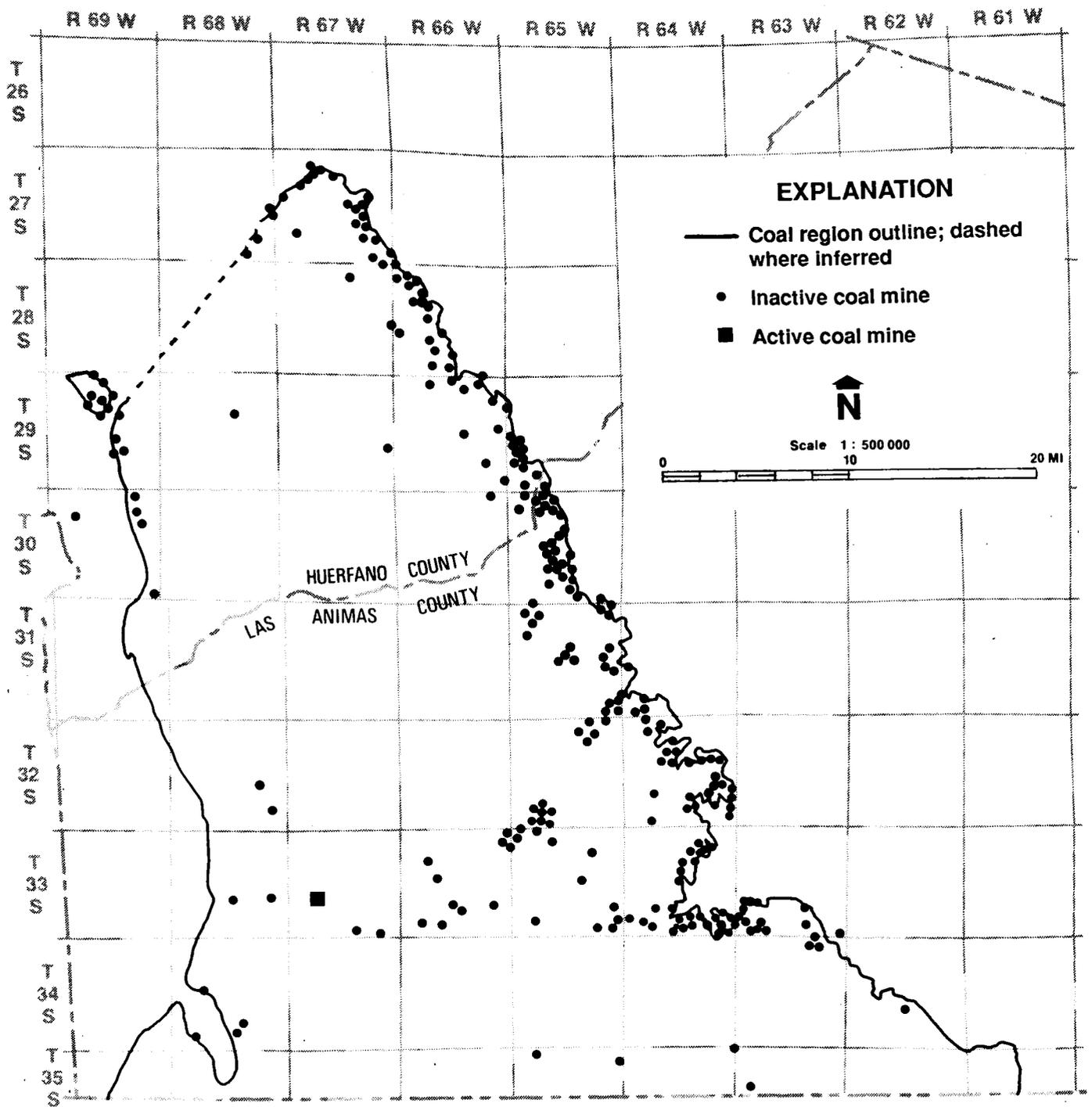


Figure 8. Coal mines of the Raton Basin, Colorado (after Tremain, 1980).

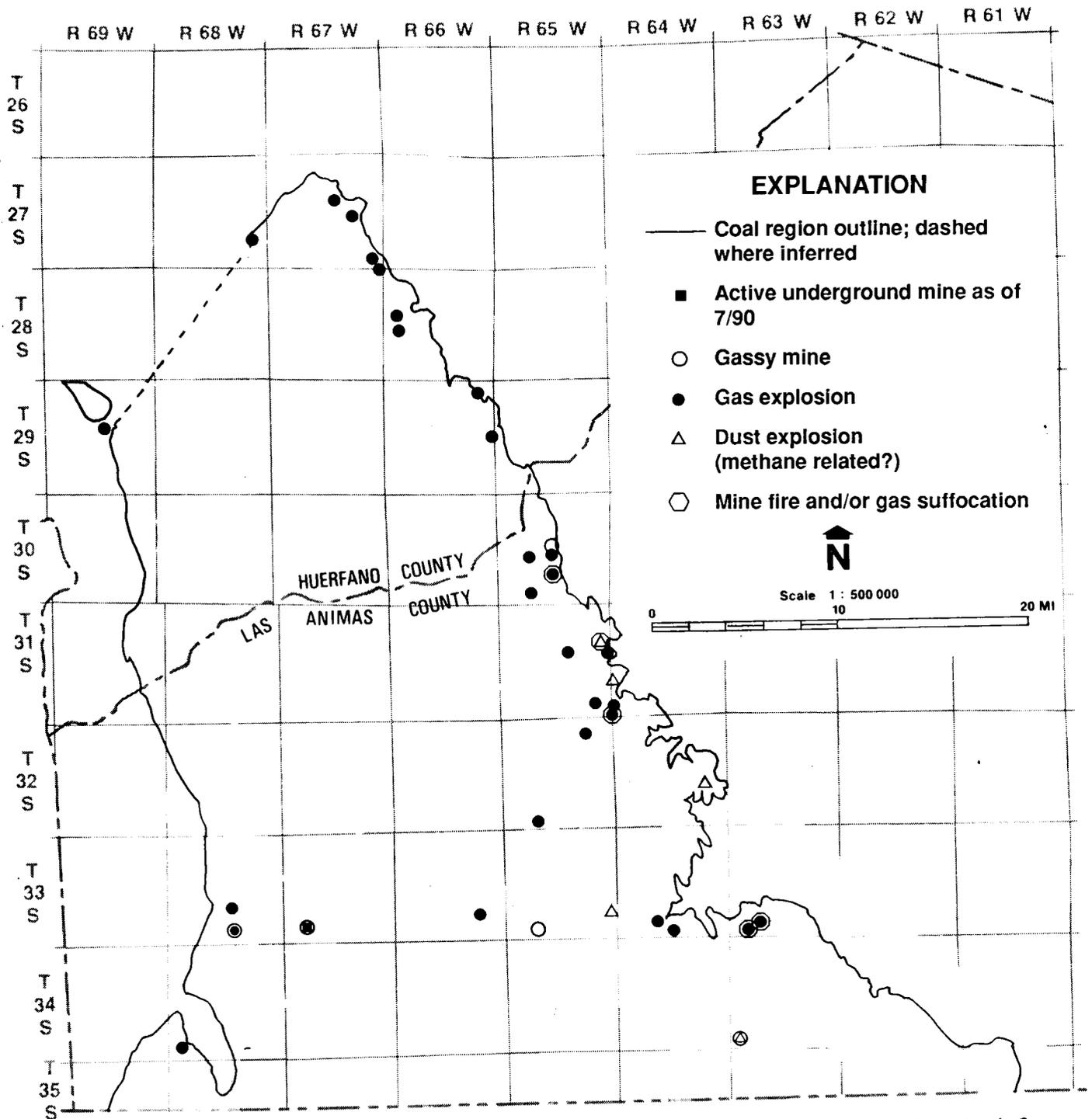


Figure 9. Coal mines with reported gas occurrences in the Raton Basin, Colorado (after Fender and Murray, 1979).

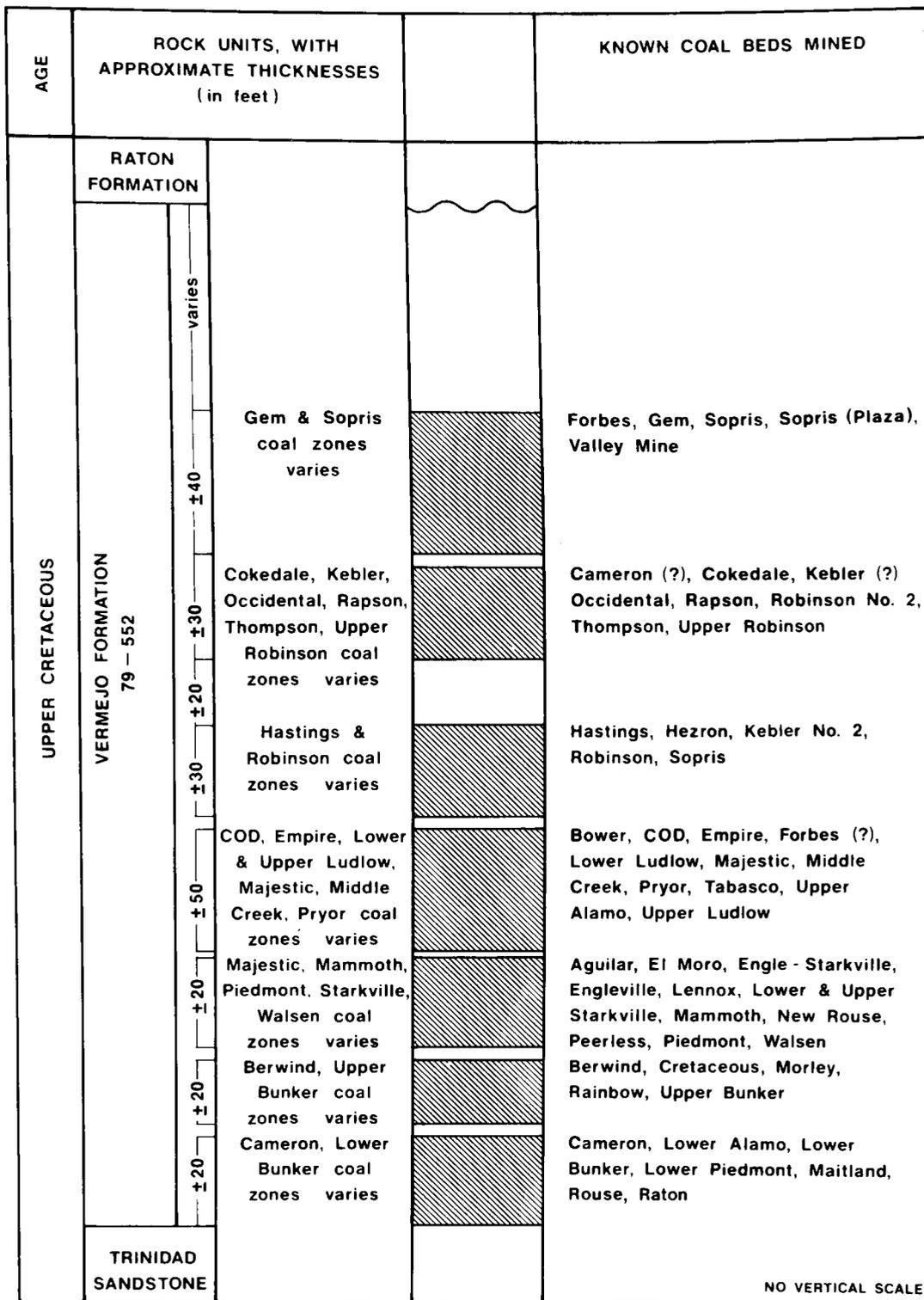


Figure 10. Generalized columnar section of the coal bearing rocks in the Vermejo Formation, Raton Basin, Colorado. Shaded areas are general locations of coal zones (from Boreck and Murray, 1979).

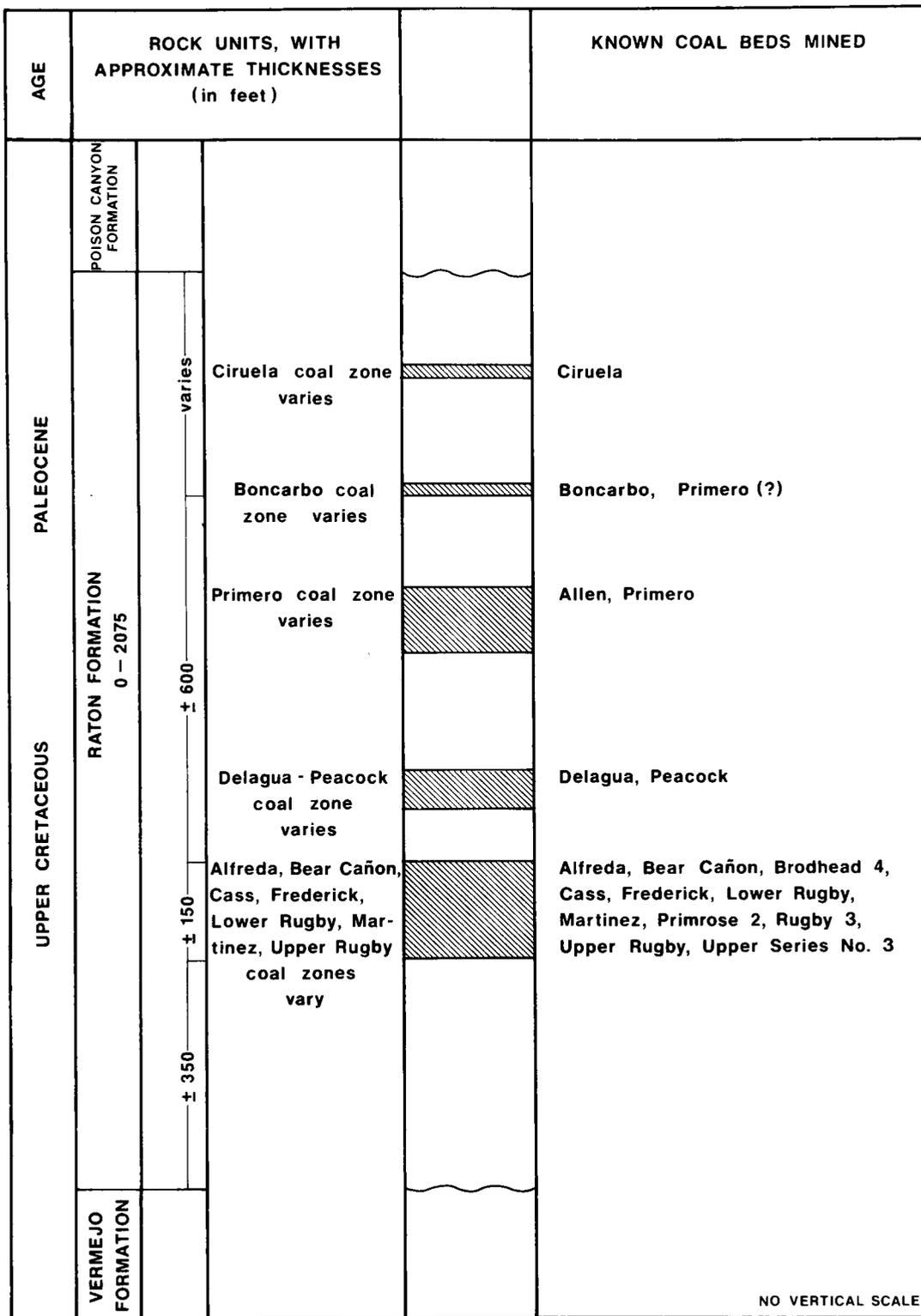
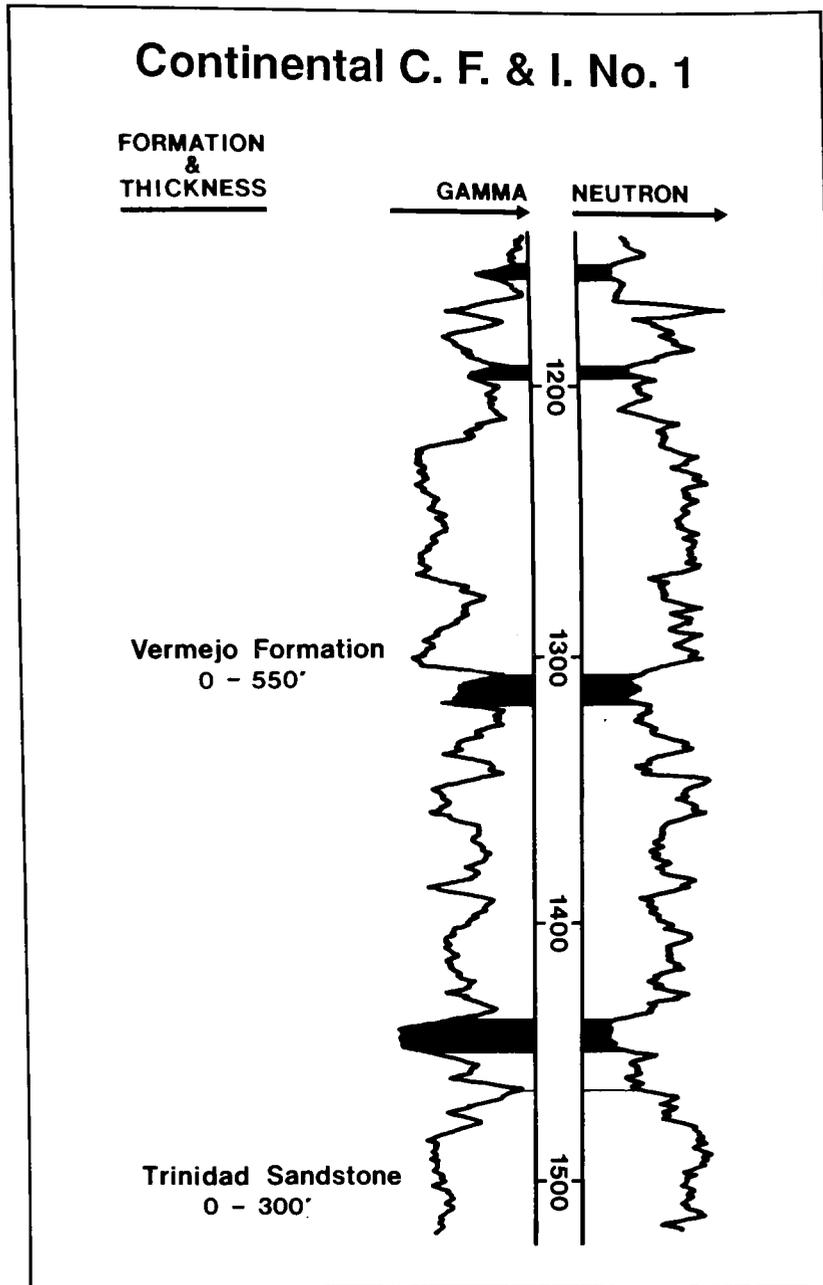


Figure 11. Generalized columnar section of the coal bearing rocks in the Raton Formation, Raton Basin, Colorado. Shaded areas are general locations of coal zones (from Boreck and Murray, 1979).



**Figure 12. Type log of the Vermejo Formation.
Coalbeds are in black (from Tremain, 1980).**

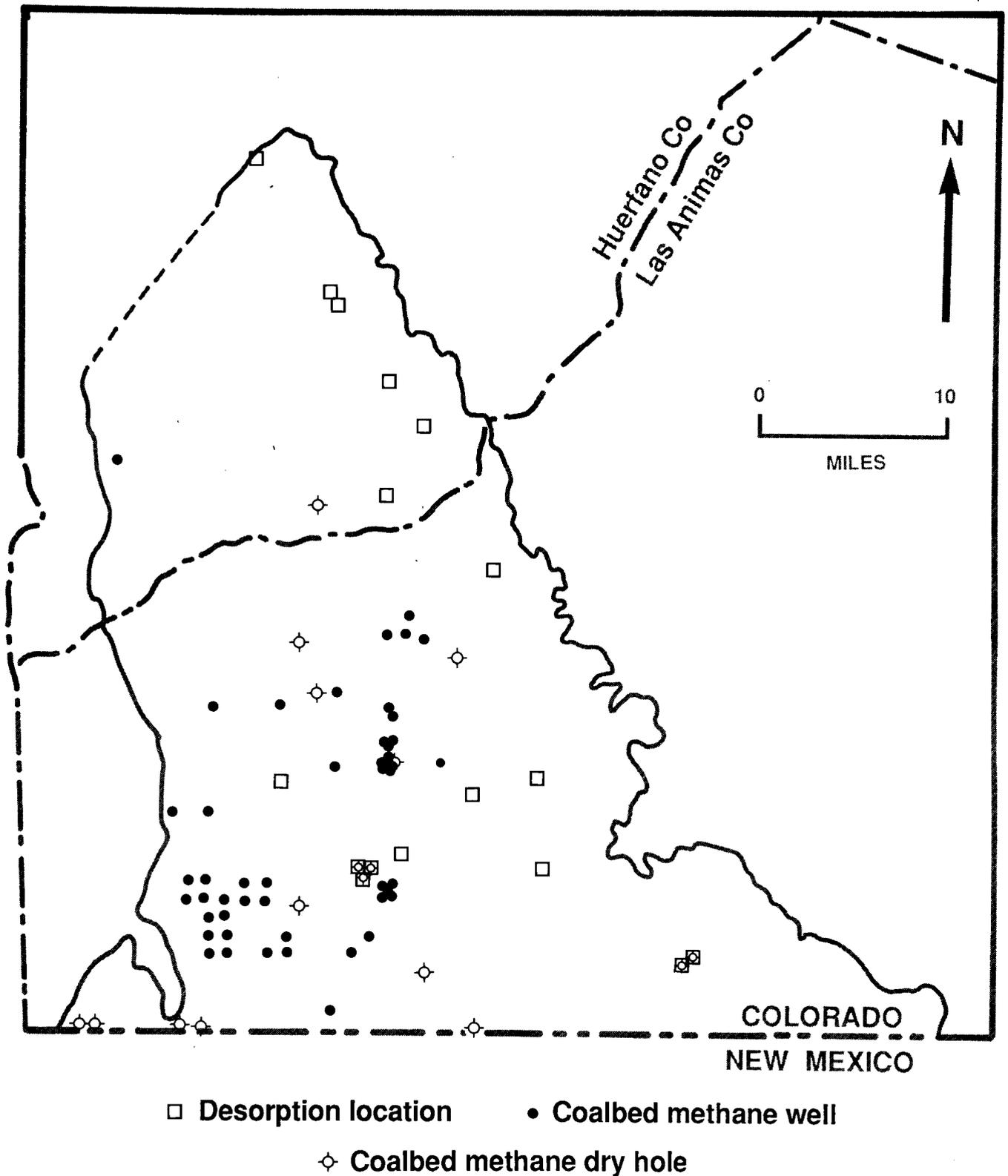


Figure 13. Coalbed methane wells and desorption locations in the Raton Basin.

SAN JUAN BASIN

The San Juan Basin of the San Juan River Coal Region in the southwestern corner of the State is the most active coalbed methane producing basin in Colorado. Like the Raton Basin, the San Juan is an asymmetrical syncline straddling the Colorado and New Mexico border. The basin contains roughly 6700 square miles within the Fruitland outcrop (figure 14). This is approximately three times the size of the Raton Mesa Coal Region.

The Colorado portion of the San Juan River Coal Region has been mined since the late 1800's (figure 15). Coal is found in the Cretaceous Dakota, Menefee, and Fruitland Formations (figure 16). The best developed coals are usually 20 to 40 feet thick (several times the thickest Raton Basin coals) and are found in the lower to middle Fruitland Formation (figure 17). The Fruitland coals trend northwesterly where they border ancient Pictured Cliffs strand lines and northeasterly where they border Fruitland sandstone

channels. The thickest coals trend northwesterly and occur in the northern part of the Basin (figure 18).

The gas contents of Fruitland coals at seven locations in or near Colorado reach a maximum of 479 to 609 cf/t. Maximum gas contents are found in the high-volatile A to low-volatile coal areas of the northern part of the basin (figure 19).

There are currently 550 producing and shut-in wells in Colorado in the Cretaceous Fruitland coals, mostly in La Plata County (figure 20). These wells produced nearly 12 billion cubic feet of coalbed methane in 1989. The average depths of the Colorado Fruitland coal wells are usually in the 2500 to 3000 foot range or approximately 1000 feet deeper than Raton Basin wells. Initial production rates range anywhere from 20 MCFD to 3.8 MMCFD and zero to 2145 BWD in Colorado. Some New Mexico wells have even higher gas production rates of over 10 MMCFD.

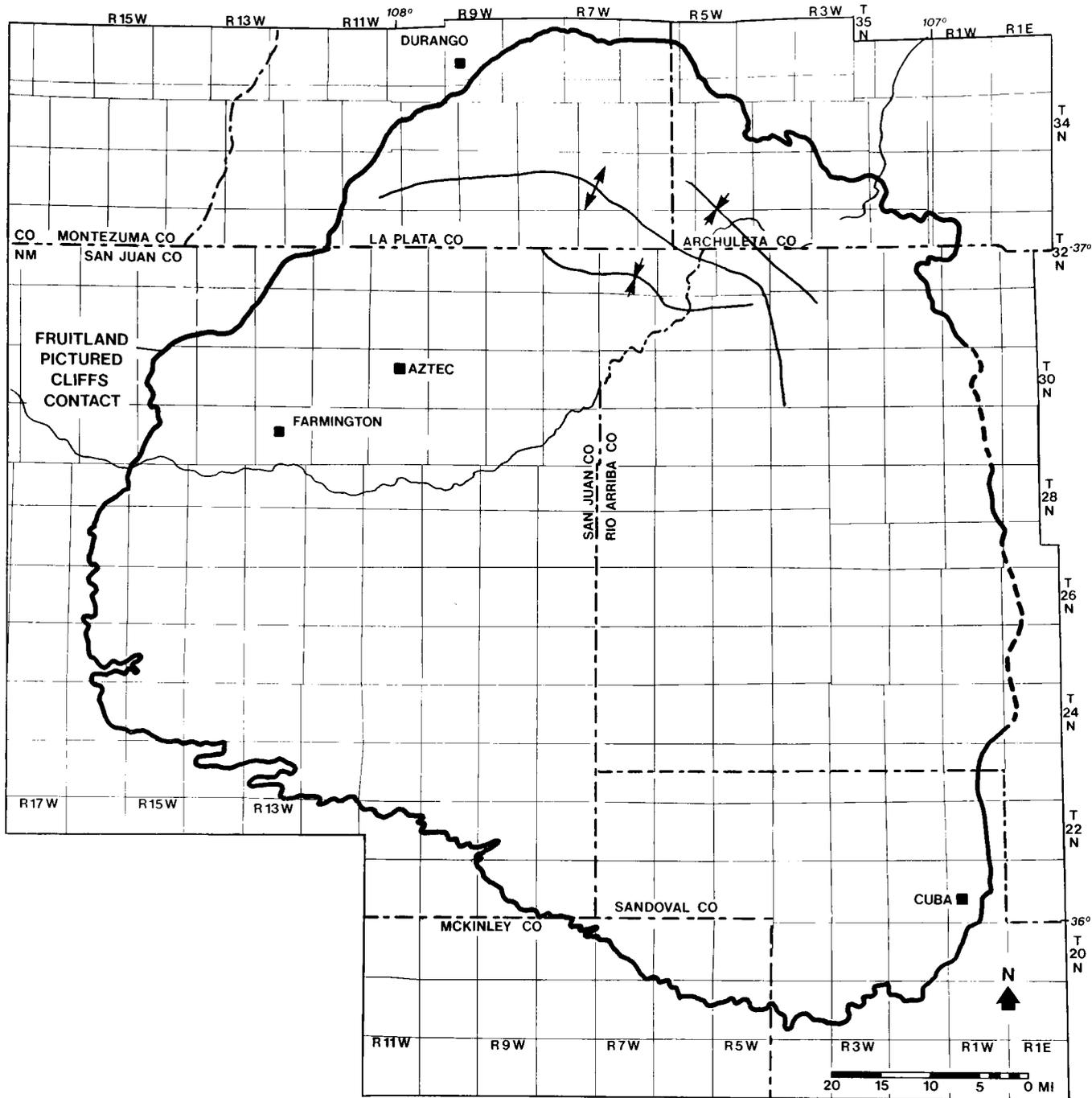


Figure 14. Map showing counties, major towns, anticlines, and synclines in the San Juan Basin (after Kelso et al., 1988).

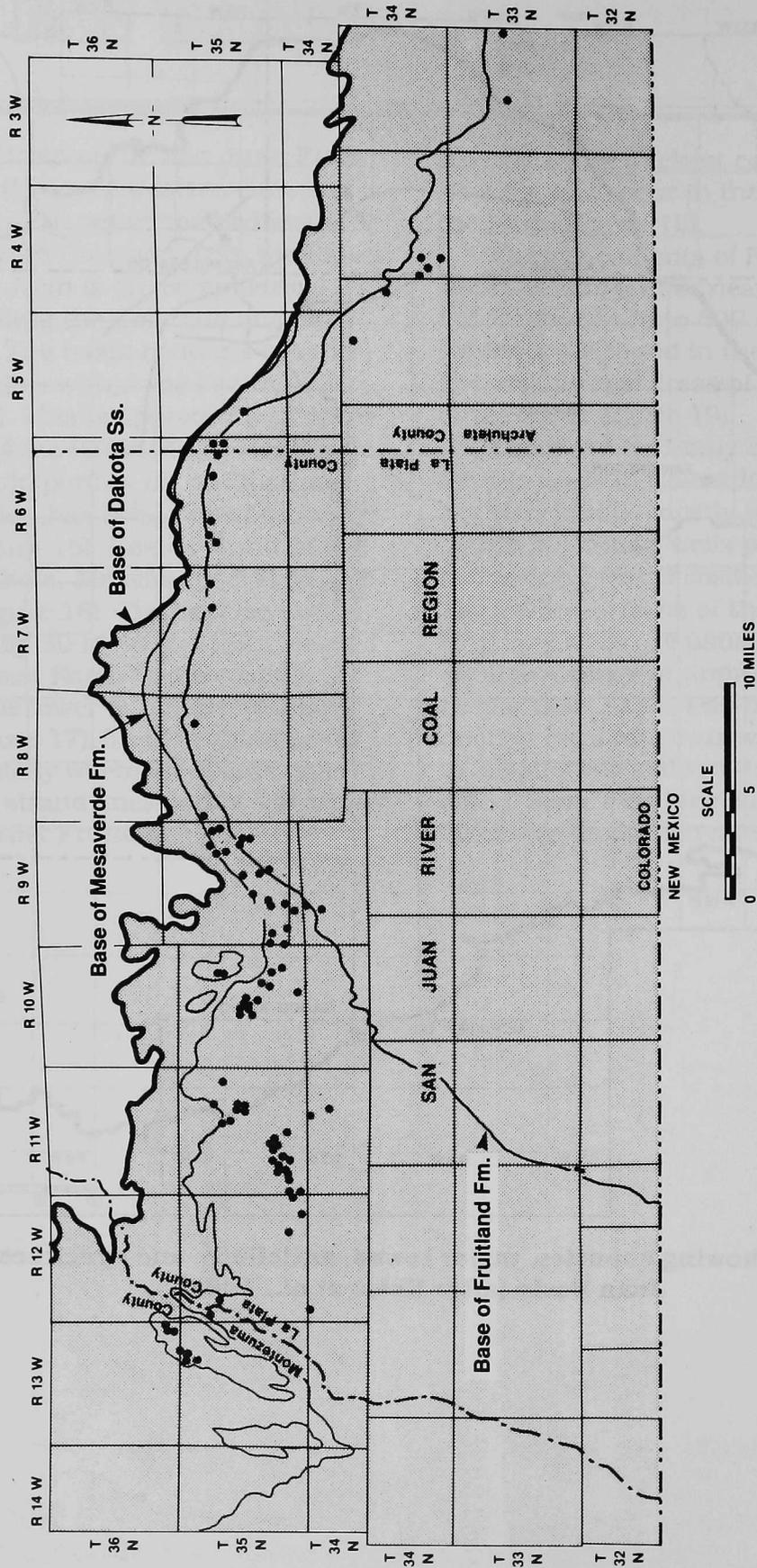


Figure 15. Active and historical coal mines in the San Juan River Coal Region, southwestern Colorado (from Kelso et al., 1980).

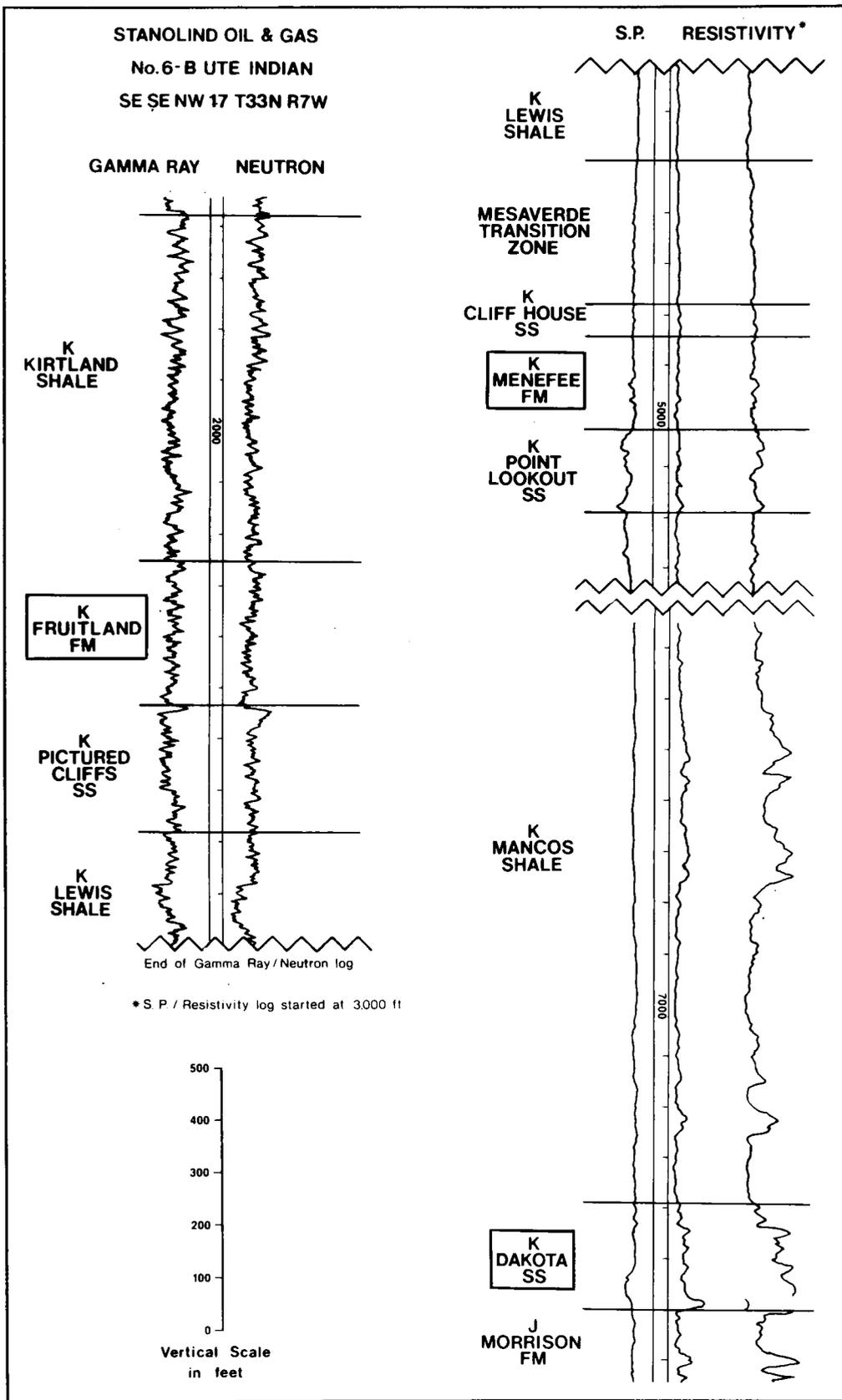


Figure 16. Type log of Cretaceous coal-bearing formations (Dakota, Menefee, and Fruitland) in the San Juan Basin (from Kelso et al., 1980).

Rincon Operating Co. Rea No. 1 SESE Sec. 32, T. 43 N., R. 8 W.

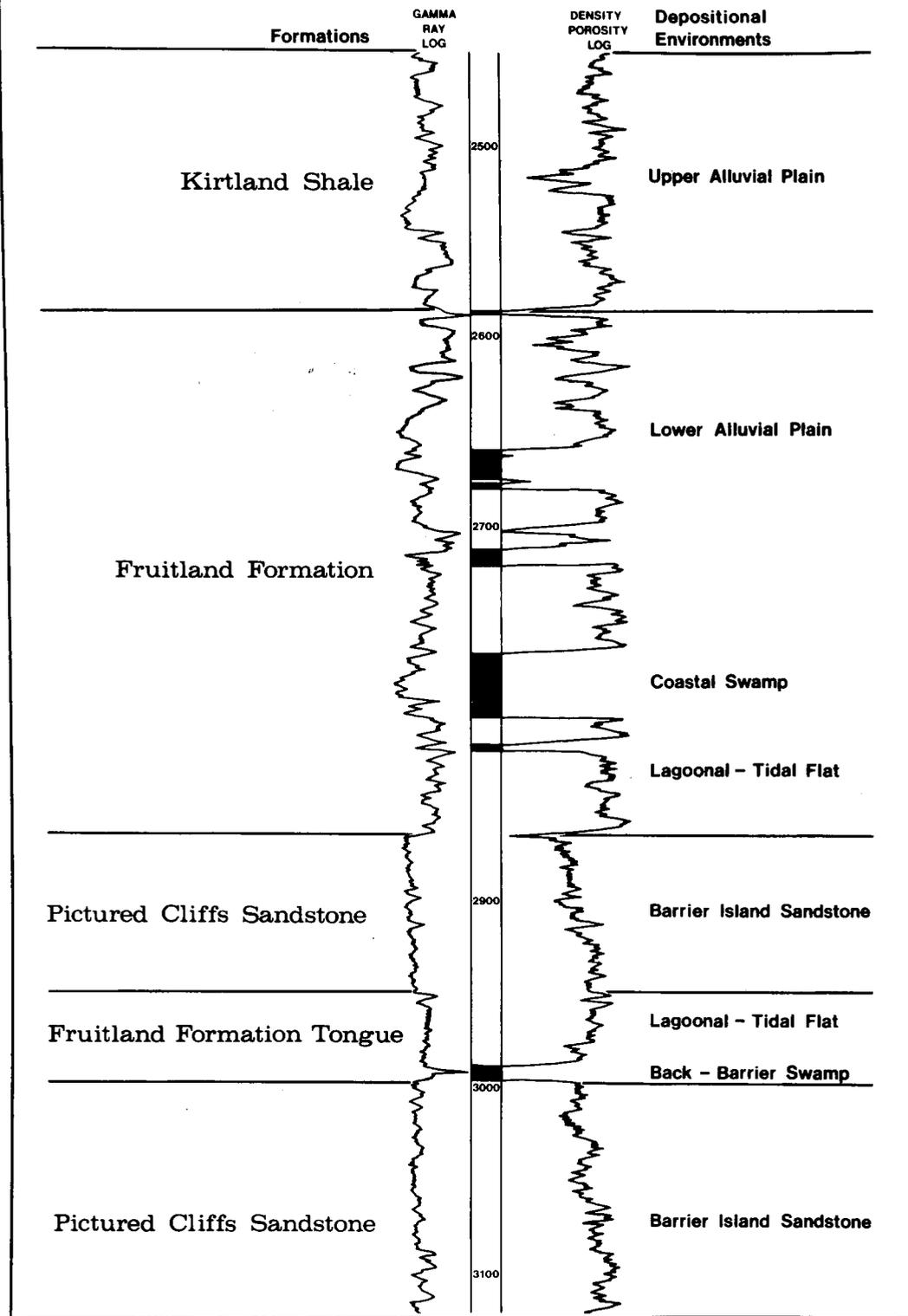


Figure 17. Type log of Upper Cretaceous Fruitland Formation. Coals are shown in black (from Kelso et al., 1980).

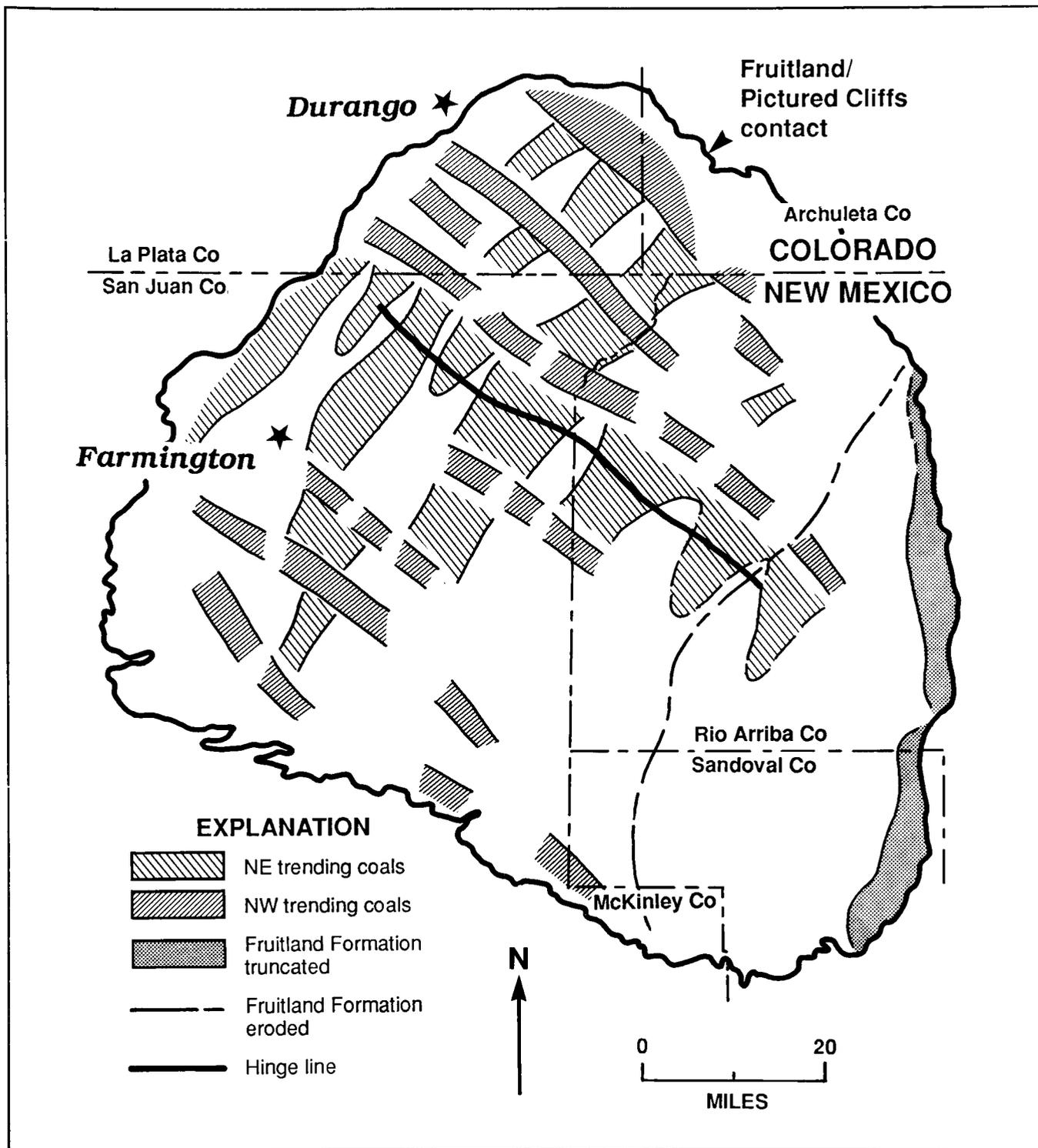


Figure 18. Major coal-occurrence trends in the Fruitland Formation. Thickest coal seams occur northeast of the structural hinge line and parallel northwest-trending upper Pictured Cliffs sandstone tongues (after Ayres and Ambrose, 1990).

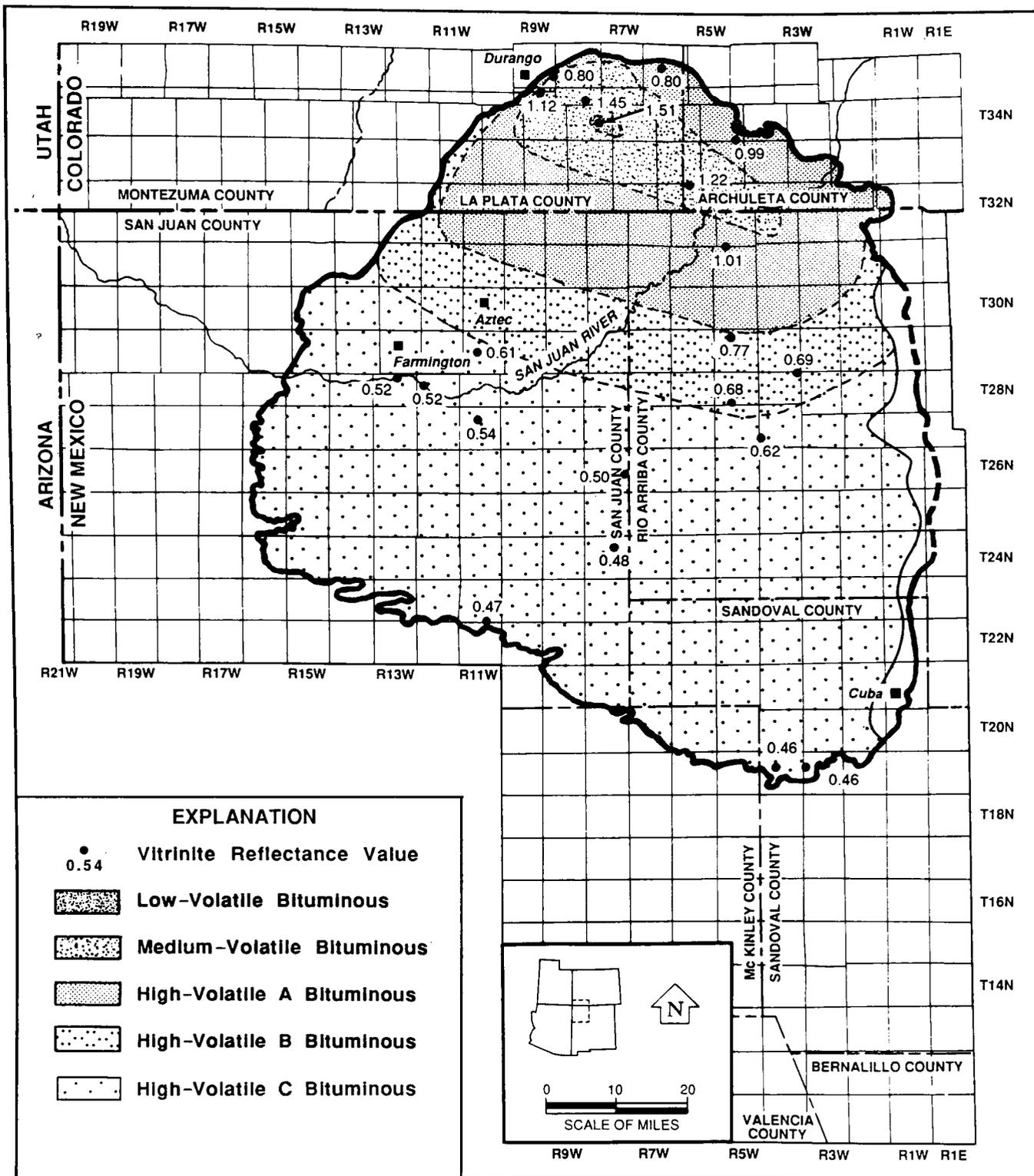


Figure 19. Coal rank map of Fruitland Formation coals (Kelso et al., 1988).

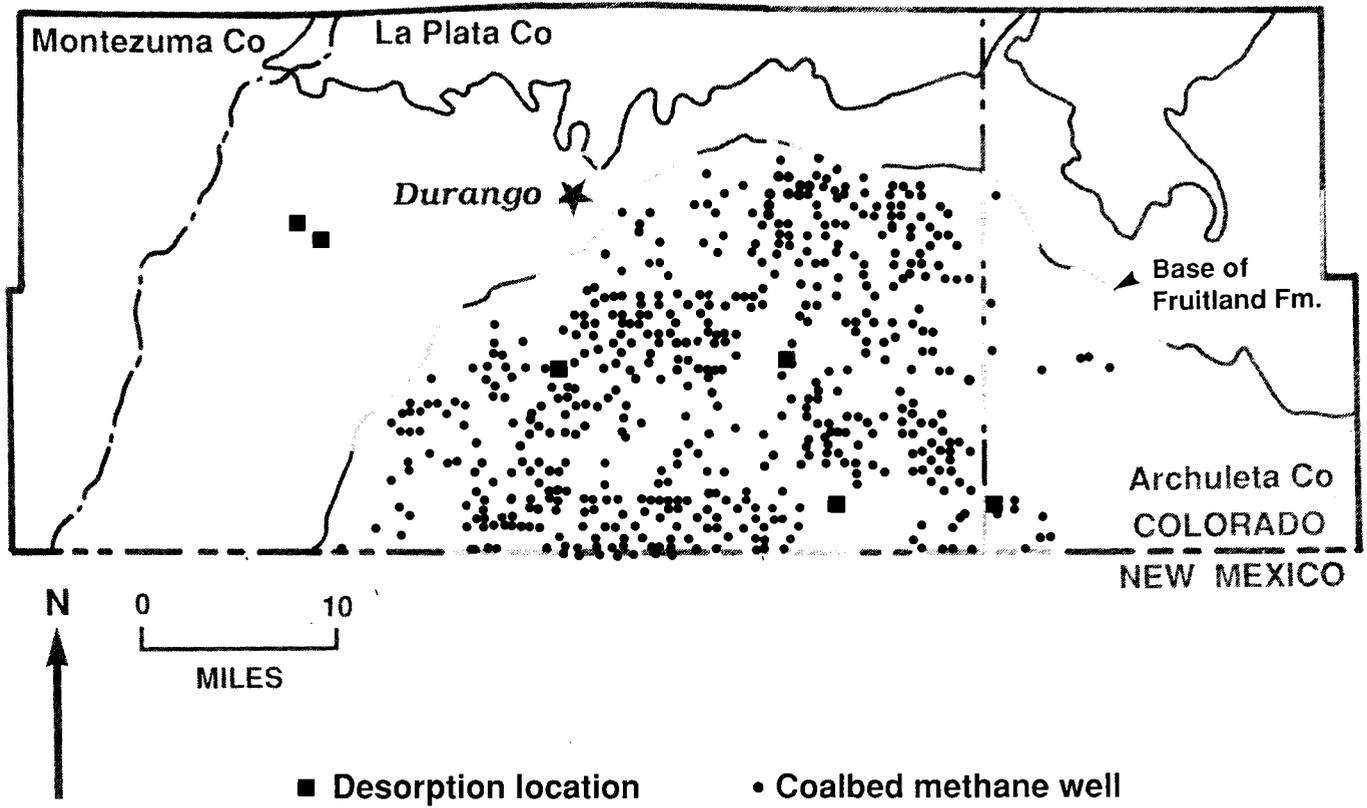


Figure 20. Coalbed methane wells and desorption locations in the Colorado portion of the San Juan Basin.

PICEANCE BASIN

Coal is found in the lower part of the Mesaverde Formation in the Piceance Basin of the northwest quarter of the State. Coals occur at depths of up to 10 thousand feet or more (figure 21). Total coal thicknesses of seams three feet thick or greater are up to 120 feet in the southern part of the basin and over 200 feet in the extreme northeastern part of the basin. Individual coal beds up to 50 feet thick occur near Rifle and Meeker. However, the thickest beds are usually in the 20-30 foot range, comparable to the thickest San Juan Basin coals (figure 22). The coals are also comparable in rank to Raton and San Juan coals ranking high-volatile C in the northeastern part of the basin to semi-anthracite in the southeast and interior (figure 23).

Gas contents from 31 locations in the basin reach maximums of 438 to 569 cf/t—

comparable to Raton and San Juan Basin maximums. There are 90 producing or shut-in wells in the coals of the Piceance Basin and 15 dry and abandoned holes (figure 24). The Piceance has the highest methane resource estimate of all U.S. basins at approximately 84 trillion cubic feet. Well depths in the Piceance range from 2000 to 8,900 feet and are the deepest of all four Colorado basins. Initial production rates in the coal seams range from 14 MCFD to 1.5 MMCFD with anywhere from zero to 2500 BWD. Wells dually completed in sandstones and coals of the lower Mesaverde have even higher production rates—up to 2.6 MMCFD. Coal producing environments of the Piceance exhibit all the range that is seen in the more heavily drilled San Juan including areas of under-pressure, low permeability, and excessive water production.

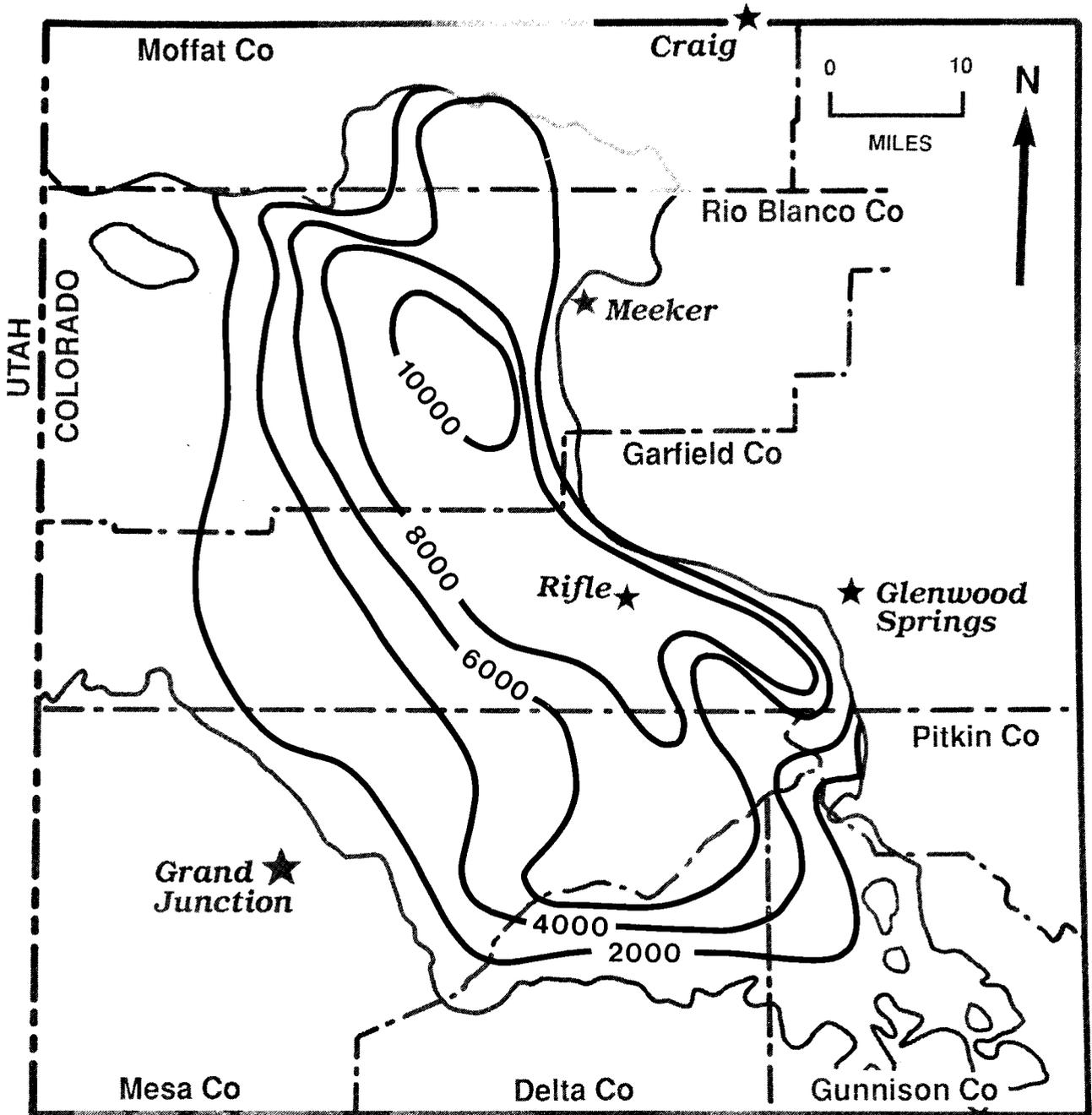


Figure 21. Generalized depth to base of coal (in feet) in the Cameo coal zone (after McFall, et al., 1986).

**Barrett Resources MV-10-23
Sec. 23, T. 6 S., R. 96 W.**

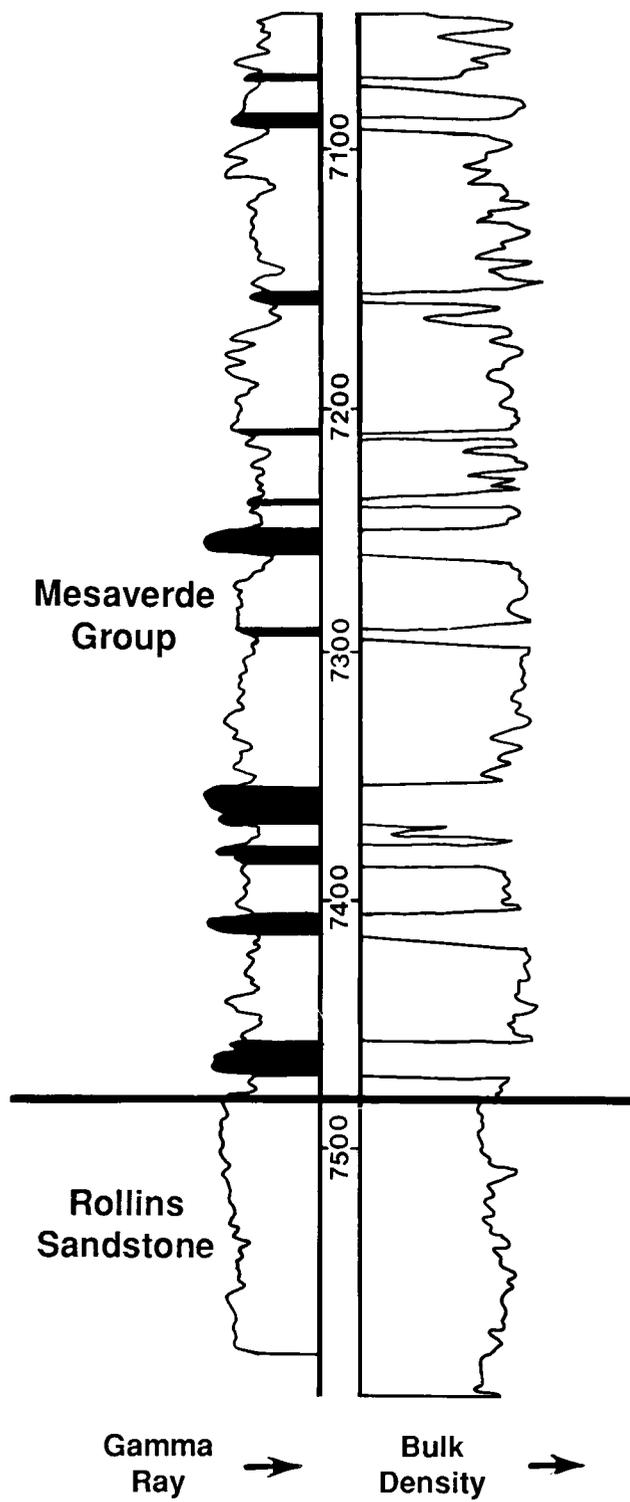


Figure 22. Type log showing Lower Mesaverde coals in the southern Piceance Basin.

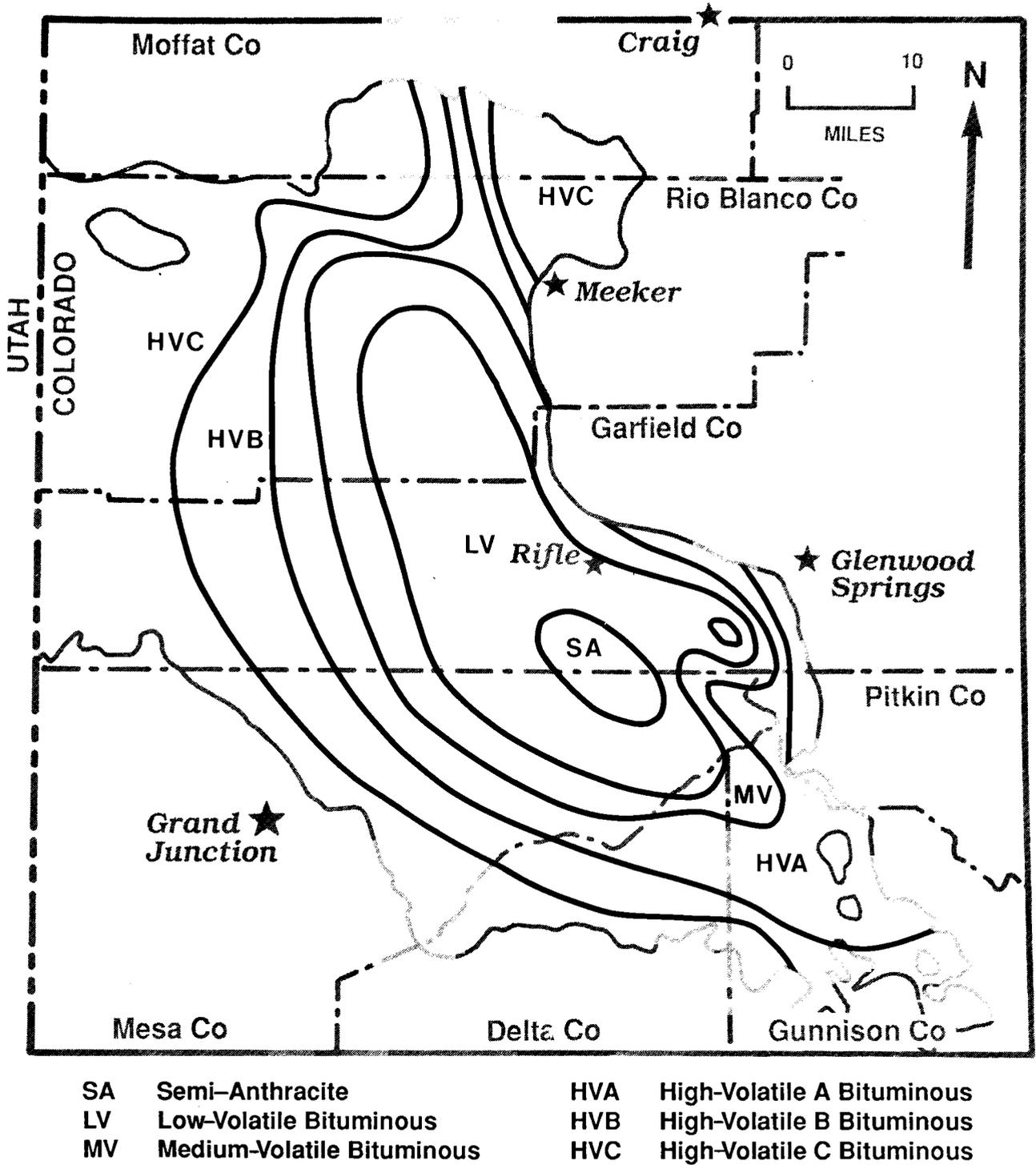


Figure 23. Coal rank map of the Piceance Basin, Colorado (after McFall et al., 1986).

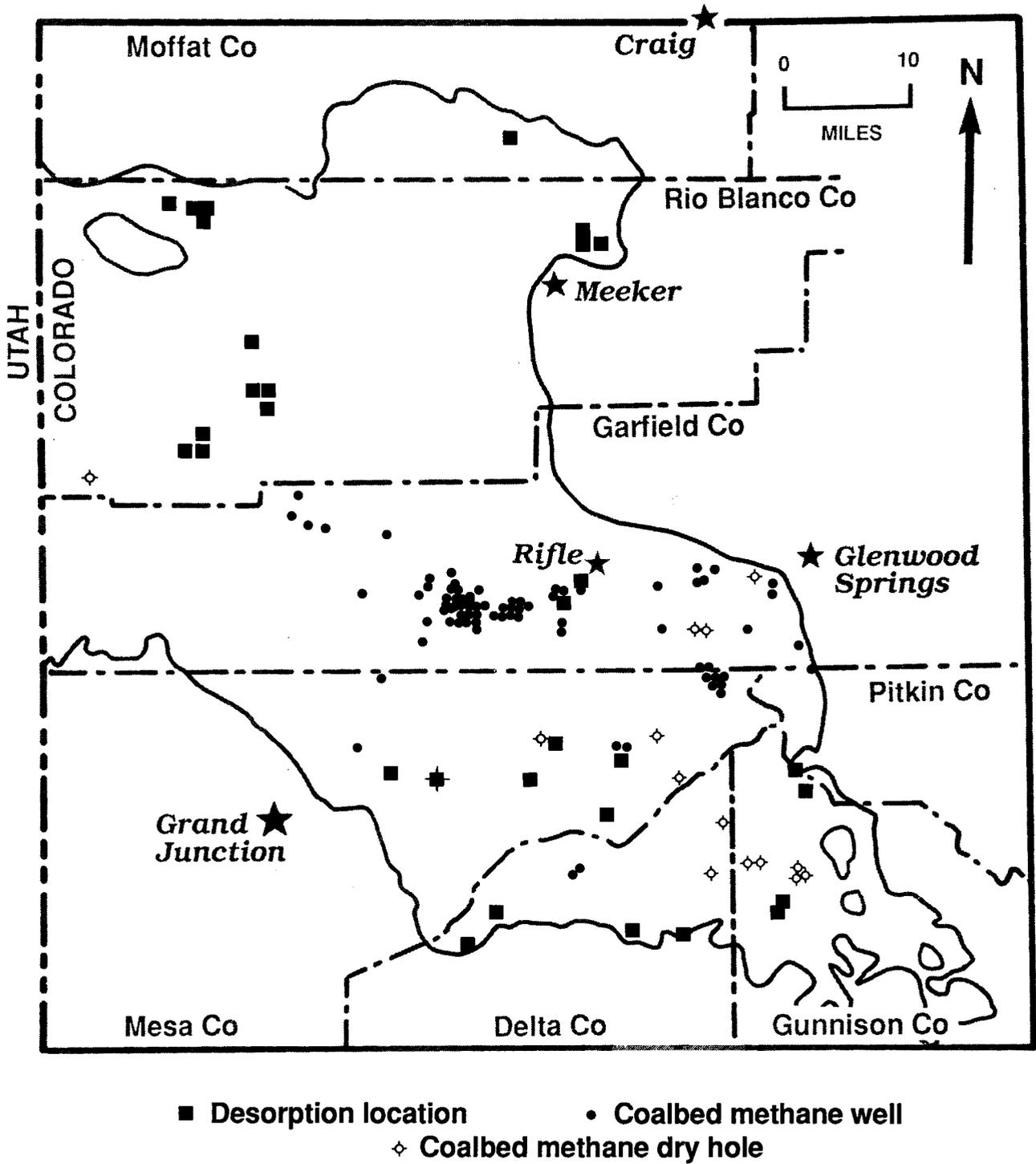


Figure 24. Coalbed methane wells and desorption locations in the Piceance Basin, Colorado.

SAND WASH BASIN

The Sand Wash Basin of northwestern Colorado is part of the Greater Green River Coal Region. The basin is separated from the Washakie Basin of Wyoming by the Cherokee Ridge along the Wyoming/Colorado border (figure 25). The Sand Wash Basin produces more coal than any other region in Colorado, over seven million tons in 1989.

Coal in the Sand Wash Basin is found in the Eocene Wasatch, the Cretaceous to Paleocene Fort Union, the Cretaceous Lance, and the Cretaceous Williams Fork and Iles Formations (Mesaverde Group) (figure 26). The thickest and most continuous coals are found in the Mesaverde (figure 27) and Fort Union (figure 28). Mesaverde coals have a net total thickness of anywhere from 18 to 136 feet with individual coal beds up to 30 feet thick. Fort Union coals have a net thickness of anywhere from zero to 114 feet, with individual beds up to 50 feet thick.

Fort Union coals near the surface are subbituminous B and C in rank and are the lowest rank coals being tested for coalbed methane in Colorado. To date there is no publicly available gas content data for Ft.

Union coals. The older Mesaverde coals are higher in rank, high-volatile C bituminous at the surface to high-volatile A bituminous at 4600 feet in the subsurface. There are published gas contents from three locations in the Mesaverde Formation. High-volatile C coals from depths of 300 to 1300 feet have gas contents of only zero to 16 cubic feet per ton. High-volatile B to high-volatile A coals from depths of 3600 to 4700 feet have gas contents of 120 to 376 cubic feet per ton.

There is little data available on actual coal bed methane production in the Sand Wash Basin. There are approximately 20 wells which are all shut in or dewatering in Fort Union and Mesaverde coals. The Fort Union coalbed methane wells are found in the northern part of the basin and the Mesaverde coalbed methane wells in the south near Craig (figure 29). Well depths are intermediate compared to the other Colorado basins, approximately 2000 to 7000 feet. One test result of five MCFD and 930 BWD was reported from a 5800 foot Meridian well completed in Mesaverde coals.

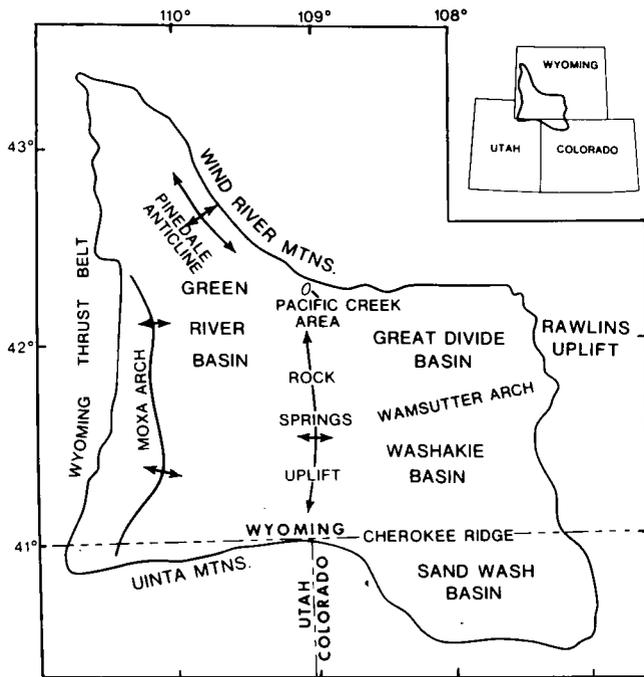


Figure 25. Greater Green River Coal Region (after Pawlewicz et al., 1986).

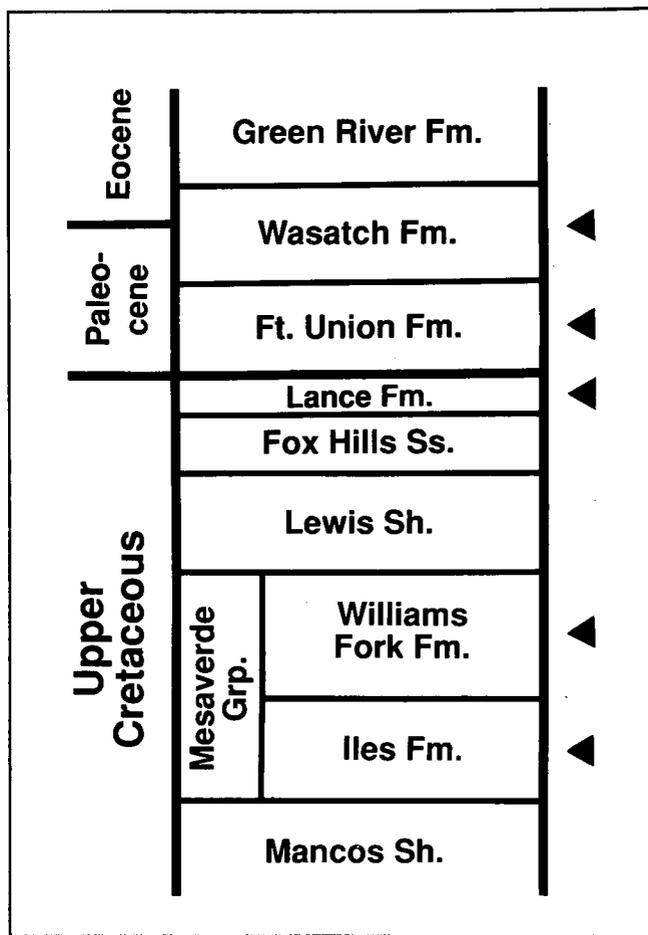


Figure 26. Coal-bearing interval in the Sand Wash Basin, Colorado. Formations containing coal are indicated by arrows.

**Energy Reserves Van Dorn No. 1
Sec. 29, T. 1 N., R. 90 W.**

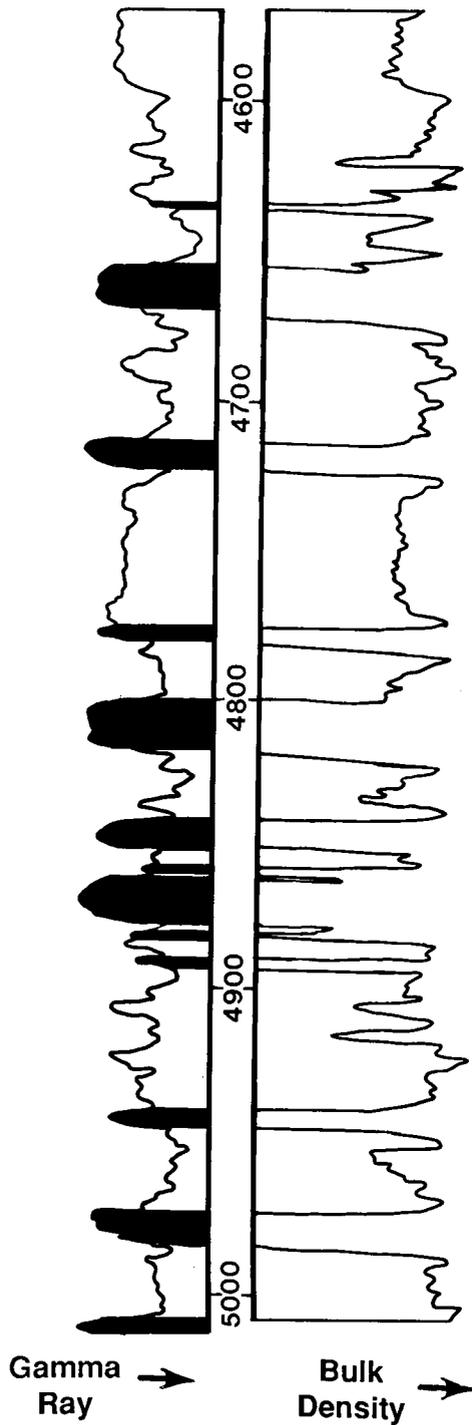


Figure 27. Type log of Mesaverde coals in the Sand Wash Basin.

**Sunmark 1-34 Mar-Win Little
Sec. 34, T. 10 N., R. 93 W.**

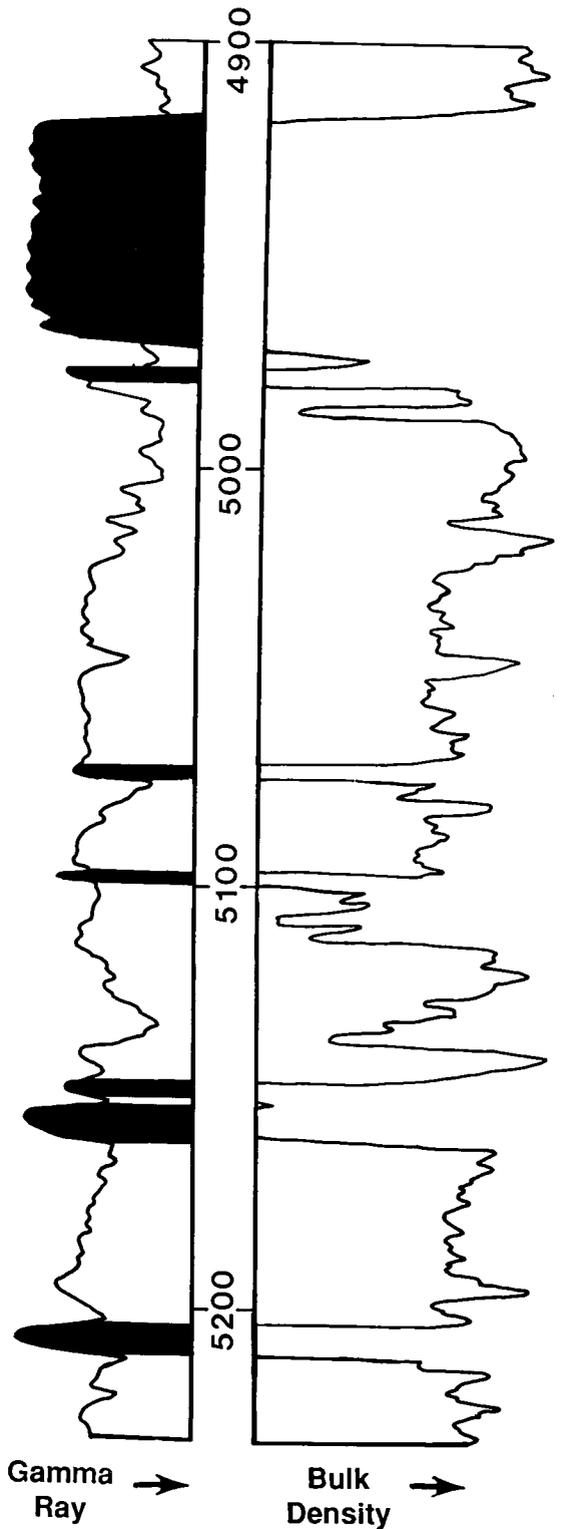


Figure 28. Type log of Fort Union coals in the Sand Wash Basin.

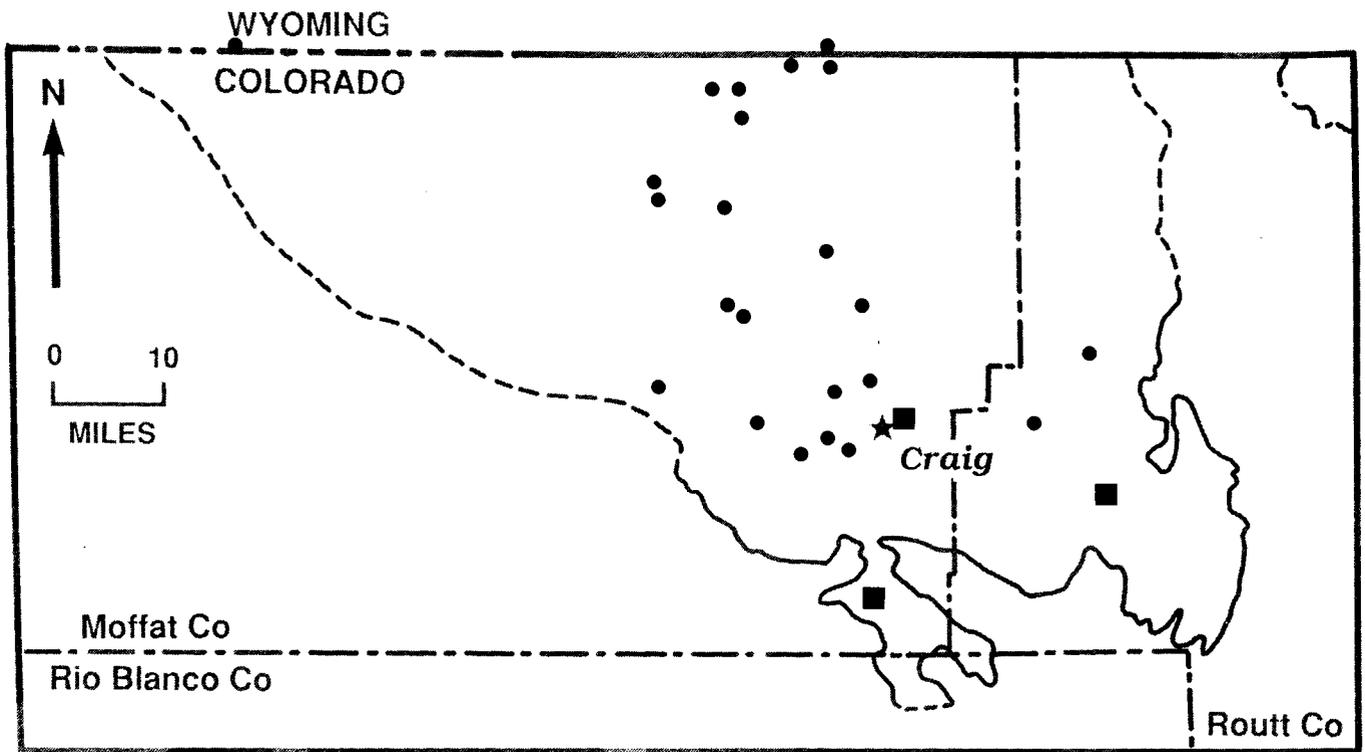


Figure 29. Coalbed methane wells and desorption locations in the Sand Wash Basin.

CONCLUSIONS

The geology in all four of the coal basins is similar (table 1). The coals are Cretaceous to Paleocene in age and were deposited in fluvial or coastal environments. They are discontinuous as compared to eastern U.S. coal beds. High rank and/or thick coals which are actual or potential coalbed methane reservoirs occur in parts of all four of these basins (table 2). The coals in the Raton Basin are relatively thin but these coals are also high rank, close to the surface, and contain the highest quality gas (up to 98 percent methane) of all the basins.

The gas contents in the deeper areas of the basins are all high, approaching 400-500 cf/t. In addition, there are significant estimated methane resources in all of the basins (table 3).

All four basins are currently being tested. Highest initial production test rates seen

to date are from the San Juan and Piceance Basins; these basins also have the most wells (table 4). The San Juan Basin, due to a fortunate coincidence of thick, shallow, gassy coals and existing pipeline networks and markets, has seen the greatest development with 550 wells. Total shut-in and producing wells in the state number over 700, and there are many more permitted locations not yet drilled. In 1989 the State of Colorado produced 13 billion cubic feet of coalbed methane from the Piceance and San Juan Basins. This was only five percent of the total gas production in Colorado for that year (table 5), but with the addition of many new wells in these two basins and the connection of wells in the Raton and Sand Wash, this percentage could double in 1990.

Table 1. Coal-bearing formations and depositional environments.

<u>BASIN</u>	<u>FORMATIONS</u>	<u>AGE</u>	<u>DEPOSITIONAL ENVIRONMENT</u>
Raton	<u>Raton*</u>	Cret./Paleocene	Fluvial
	<u>Vermejo</u>	Cretaceous	Coastal-Fluvial
San Juan	<u>Fruitland</u>	Cretaceous	Coastal-Fluvial
	Menefee	Cretaceous	Coastal-Fluvial
	Dakota	Cretaceous	Fluvial
Piceance	<u>Mesaverde</u>	Cretaceous	Coastal-Fluvial
Sand Wash	Wasatch	Paleo./Eocene	Fluvial
	<u>Ft. Union</u>	Paleocene	Fluvial
	Lance	Cretaceous	Fluvial
	<u>Mesaverde</u>	Cretaceous	Coastal-Fluvial

* Major methane producing formations are underlined.

Table 2. Coal thickness and rank.

BASIN	FORMATIONS	BED THICKNESS (MAX)	TOTAL COAL THICKNESS (MAX)	RANK
Raton	<u>Raton*</u>	<u>12</u>	<u>30</u>	<u>HVC-LV</u>
	<u>Vermejo</u>	<u>14</u>	<u>30</u>	<u>HVC-LV</u>
San Juan	<u>Fruitland</u>	<u>50-80</u>	<u>110-140</u>	<u>SUB B-LV</u>
	Menefee	10	35-60	HVC-LV
	Dakota	9-13	27	HVC-A (Outcrop)
Piceance	<u>Mesaverde</u>	<u>50</u>	<u>120-200</u>	<u>HVC-SA</u>
Sand Wash	Wasatch	THIN	—	—
	<u>Ft. Union</u>	<u>50</u>	<u>114</u>	<u>SUB C—SUB B</u>
	Lance	13	29	SUB C—SUB B
	<u>Mesaverde</u>	<u>36</u>	<u>136</u>	<u>SUB B—HVA</u>

* Major methane producing formations are underlined.

Table 3. Gas content and estimated resources.

BASIN	NO. OF LOCATIONS	GAS CONTENT (CF/T)	ESTIMATED IN-PLACE RESOURCE (TCF)
Raton	17	515-569	8-18 (CO & NM)
San Juan	7	479-609	Kf* Kmf** 50 22-34 (CO & NM)
Piceance	31	438-569	77-84
Sand Wash	3	376	12+

* Kf Fruitland Formation
** Kmf Menefee Formation

Table 4. Well tests and depths.

BASIN	WELL NO.		TEST		WELL DEPTHS
	PR & SI	D & A	MCFD	BWD	
Raton	49	16	239	0-1262	1000-4600
San Juan	550	?	20-3842	0-2145	1500-4100
Piceance	91	15	14-1500	0-2500	2250-8900
Sand Wash	21	—	0-5	81-2250	1831-6833

Table 5. Colorado coalbed methane summary data.

Number of wells (9/90)	700+
Production (1/90)	~13 BCF
Percent of Total Colorado Gas Production	5%

REFERENCES CITED

- Ayers, W. B., Jr., and Ambrose, W. A., 1990, Geologic controls on the occurrence of coalbed methane, Fruitland Formation, San Juan Basin, in *Geologic evaluation of critical production parameters for coalbed methane resource, Part 1, San Juan Basin*, Gas Research Institute Annual Report GRI-90/0014.1, p. 9-69.
- Boreck, D. L., and Murray, D. K., 1979, Colorado coal reserves depletion data and coal mine summaries: Colorado Geological Survey Open-File Report 79-1, 65 p.
- Crouse, P. C., 1989, Coal seam methane is one of the hotter current plays: *World Oil*, November 1989, p. 47-50.
- Dolly E. D., and Meissner, F. F., 1977, Geology and gas exploration potential, Upper Cretaceous and Lower Tertiary strata, northern Raton Basin, Colorado, in *Exploration frontiers of the Colorado and southern Rockies*: Rocky Mountain Association of Geologists, p. 247-270.
- Energy Information Administration, 1990, U.S. crude oil, natural gas, and natural gas liquids reserves, 1989 Annual Report, DOE/EIA-0216(89), 109 p.
- Fender, H. B. and Murray, D. K., 1978, Data accumulation of the coal beds of Colorado, final report: Colorado Geological Survey Open-File Report 78-2, 25 p.
- Gas Research Institute, 1989, Basin activities—Raton Basin, Colorado and New Mexico, in *Quarterly Review of Methane from Coal Seams Technology*, 54 p.
- Gas Research Institute, 1989, Coalbed Methane Workshop, Pittsburgh, Pennsylvania, February 6 and 7, 1989.
- Gill, J. R., and Cobban, W. A., 1966, The Red-bird section of the Upper Cretaceous Pierre Shale in Wyoming: U.S. Geological Survey Professional Paper 393-A, p. A44.
- Johnson R. B., and Wood, G. H., Jr., 1956, Stratigraphy of Upper Cretaceous and Tertiary rocks of Raton Basin, Colorado and New Mexico, in *Guidebook to the geology of the Raton Basin, Colorado*: Rocky Mountain Association of Geologists, p. 28-34.
- Kelso, B. S., Goolsby, S. M., and Tremain, C. M., 1980, Deep coalbed methane potential of the San Juan River Coal Region, southwestern Colorado: Colorado Geological Survey Open-File Report 80-2, 56 p.
- Kelso, B. S., Wicks, D. E., and Kuuskraa, V. A., 1988, A geologic assessment of natural gas from coal seams in the Fruitland Formation, San Juan Basin: Chicago, Gas Research Institute Topical Report GRI 88/034, 54 p.
- McCulloch, C. M., Levine, J. R., Kissell, F. M., and Deul, Maurice, 1975, Measuring the methane content of bituminous coal beds: U.S. Bureau of Mines Report of Investigations 8043, 22 p.
- McFall, K. S., Wicks, D. E., Kuuskraa, V. A., and Sedwick, K. B., 1986, A geologic assessment of natural gas from coal seams in the Piceance Basin Colorado: Gas Research Institute Topical Report GRI 87/0060, 73 p.
- Pawlewicz, J. J., Lickus., M. R., Law, B. E., Dickenson, W. W., and Barclay, C. S. V., 1986, Thermal maturity map showing subsurface elevation of 0.8 percent

vitronite reflectance in the Greater Green River Basin of Wyoming, Colorado, and Utah: U S. Geological Survey Map MF-1890, scale 1:500,000.

Tremain, C. M., 1980, The coal bed methane potential of the Raton Mesa Coal Region, Raton Basin, Colorado: Colorado Geological Survey Open-File Report 80-4, 48 p.