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ABSTRACT

The Raton Mesa coal region of Colorado is an 1100 sq mi area in the western portion of the Raton Basin. Coal rank data, desorption of coal samples, structure mapping on the Trinidad Sandstone, isopach mapping of Vermejo coal beds, coal mine methane emission data, and records of oil and gas tests in the region all define a 179 sq mi area containing 1.56 trillion cubic ft of gas in Vermejo coal beds. These Vermejo coals occur in beds up to 14 ft thick; total coal thicknesses in the Vermejo Formation reach a maximum of 30 ft in the 179 sq mi high potential area. These coals contain up to 514 ft^3 of gas per ton of coal and are less than 2000 feet below the surface in the high potential area. Currently, 3 wells are being drilled to test these Vermejo coals.

INTRODUCTION

The Raton Basin is a 150 x 120 mi north-south trending structural basin in southeastern Colorado and northeastern New Mexico (Fig. 1). The Walsenburg and Trinidad Coal Fields of the Raton Mesa coal region occupy 1100 sq mi in the 5000 sq mi Colorado portion of the basin.

Methane has been reported in the region's coal mines since commercial coal mining began in the 1870's. Coal core holes, oil and gas holes, and water wells currently being drilled show methane associated with the coals. Petroleum explorationists have tested the gas production potential of certain coal beds. Analyses show the methane to be of pipeline quality. However, underground coal mine operators go to great expense to vent the potentially explosive gas. The methane is thus both a potential resource and a potential hazard.

The purpose of this study is to locate the gassiest coals in the region, determine why they are gassy, and estimate the amount of gas they contain. Therefore, this report lists the gas contents of coal core samples, presents structure and isopach maps, and describes the geography, geology, and production of coal, oil and gas in the region.

GEOGRAPHY

Physiography

The Raton Basin lies at the western edge of the Great Plains physiographic province. It is bounded by the Sangre de Cristo Mountains to the west, the Wet Mountains and Apishapa Uplift to the north and northeast, and the Sierra Grande-Las Animas Arch to the east and southeast.

The Raton Mesa coal region is coincident with the Park Plateau and lies in the west central part of the basin. The Colorado portion of the coal region covers approximately 1,100 sq mi in Las Animas and Huerfano Counties; it is bounded by a strike valley to the west, Huerfano Park to the north, 500-1,000 ft cliffs to the east and a 40 mi New Mexico border to the south (Fig. 1). Elevations in the coal region increase from 7,000

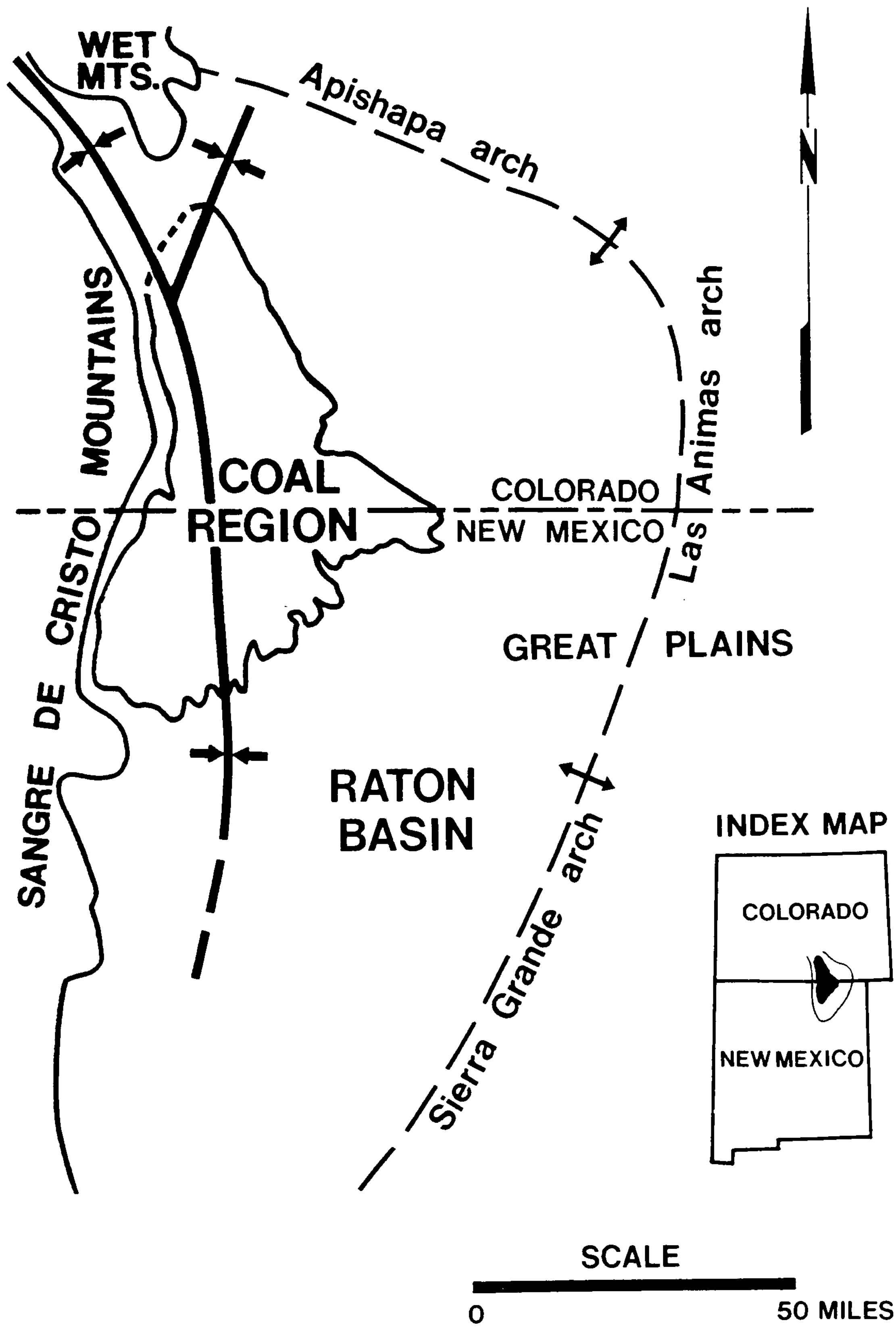


Figure 1. The Raton Basin of Colorado and New Mexico (after Johnson and Wood, 1956, p. 28).

ft in the east to 9,000 ft in the west; the highest point is West Spanish Peak at 13,623 ft (see Fig. 2, topographic map).

Drainage

The four major streams in the basin flow east into the Arkansas River drainage system. The Purgatoire (the largest), the Huerfano, and the Cuchara Rivers all have their sources in the Sangre de Cristo Mountains. The Apishapa River originates on the southwest slope of West Spanish Peak (Fig. 2).

These rivers separate the various terrains of the coal region. In the south, v-shaped valleys branch off the Purgatoire and form very dissected highlands. In the central part of the region, the Cuchara separates the flat-topped hills of an old pediment surface on its southern bank from the low hills on its northern bank which extend to the northern part of the coal region.

Population and Land Use

The three largest towns of the region lie where the major streams descend from the plateau of the coal field onto the Great Plains. Trinidad (population 9,901--1970 census) is on the Purgatoire, Walsenburg (population 4,329--1970 census) on the Cuchara, and Aguilar (population 669--1970 census) on the Apishapa. Smaller farming towns occur along the streams atop the plateau.

Cattle and sheep are the major agricultural products of the area. Irrigated farms along the major stream valleys produce alfalfa and other grains. Dry farms in upland fields produce timothy, millet, rye, and beans. Apples and plums are produced in the valleys where precipitation is greater. Lumber is harvested in the mountains. Major land use divisions are shown in Figure 3.

The most important mineral product of the region is coal. 870,346 tons of coal were produced in 1979 (Blake, 1980, p. 28-29). Sand and gravel, clay, and building stone, have also been produced in the region; however, only sand and gravel (worth $27,614) were produced during 1978 in Las Animas and Huerfano Counties (Blake, 1979, p. 16, 18). Small amounts of silver, gold, and uranium were mined in the past (Jurie and Gerhard, 1969).

Climate

The climate of the coal region is elevation dependent. The mountains experience colder temperatures than the plains and are subhumid. The plains are semiarid. Most precipitation occurs as thundershowers from April through September although June is usually dry. Nevertheless, snow often blankets the area in winter; as much as ninety-nine inches have fallen in La Veta in one year.

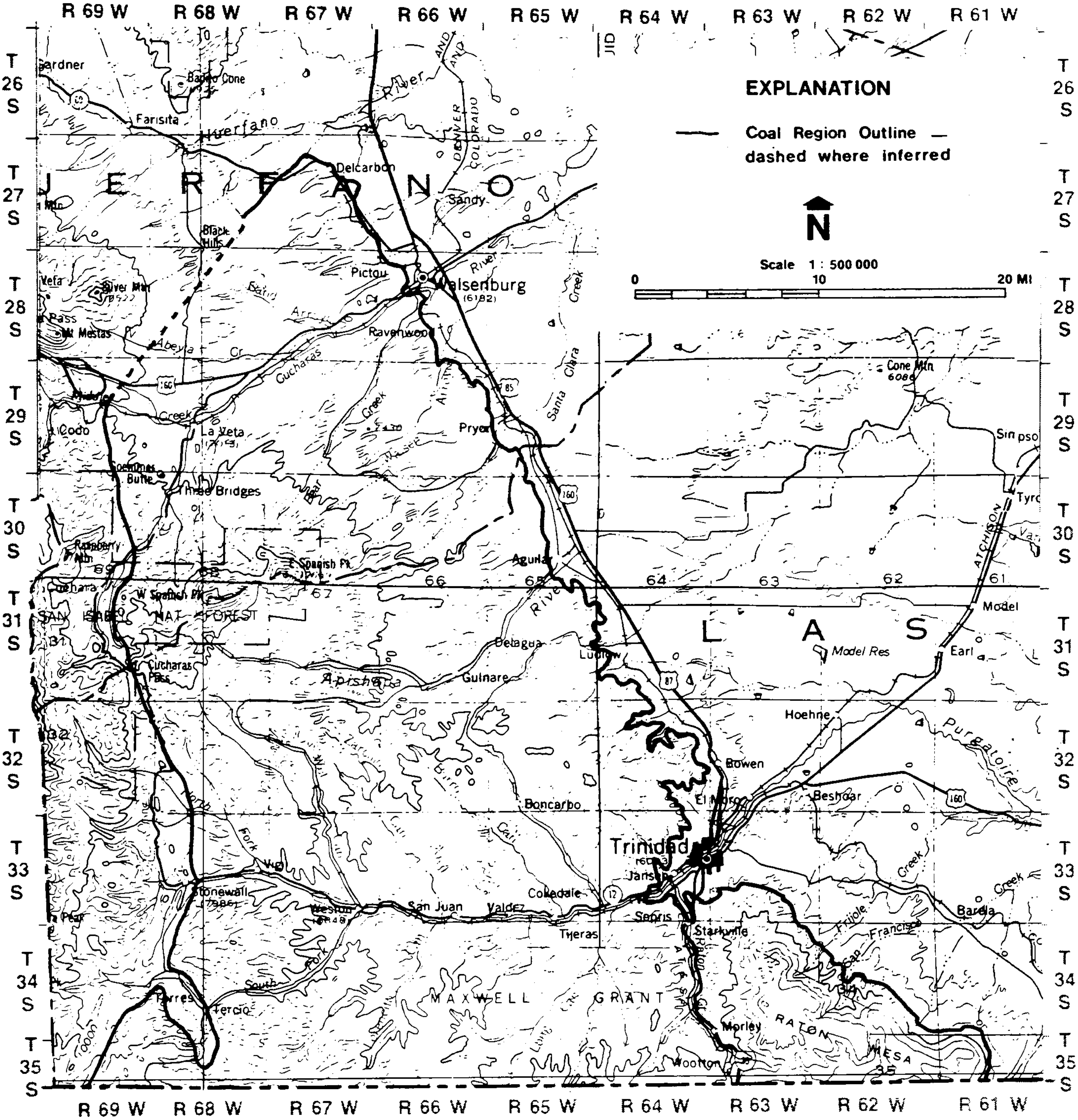


Figure 2. Topographic map of the Raton Mesa coal region, Colorado (after U.S. Geological Survey, 1969).

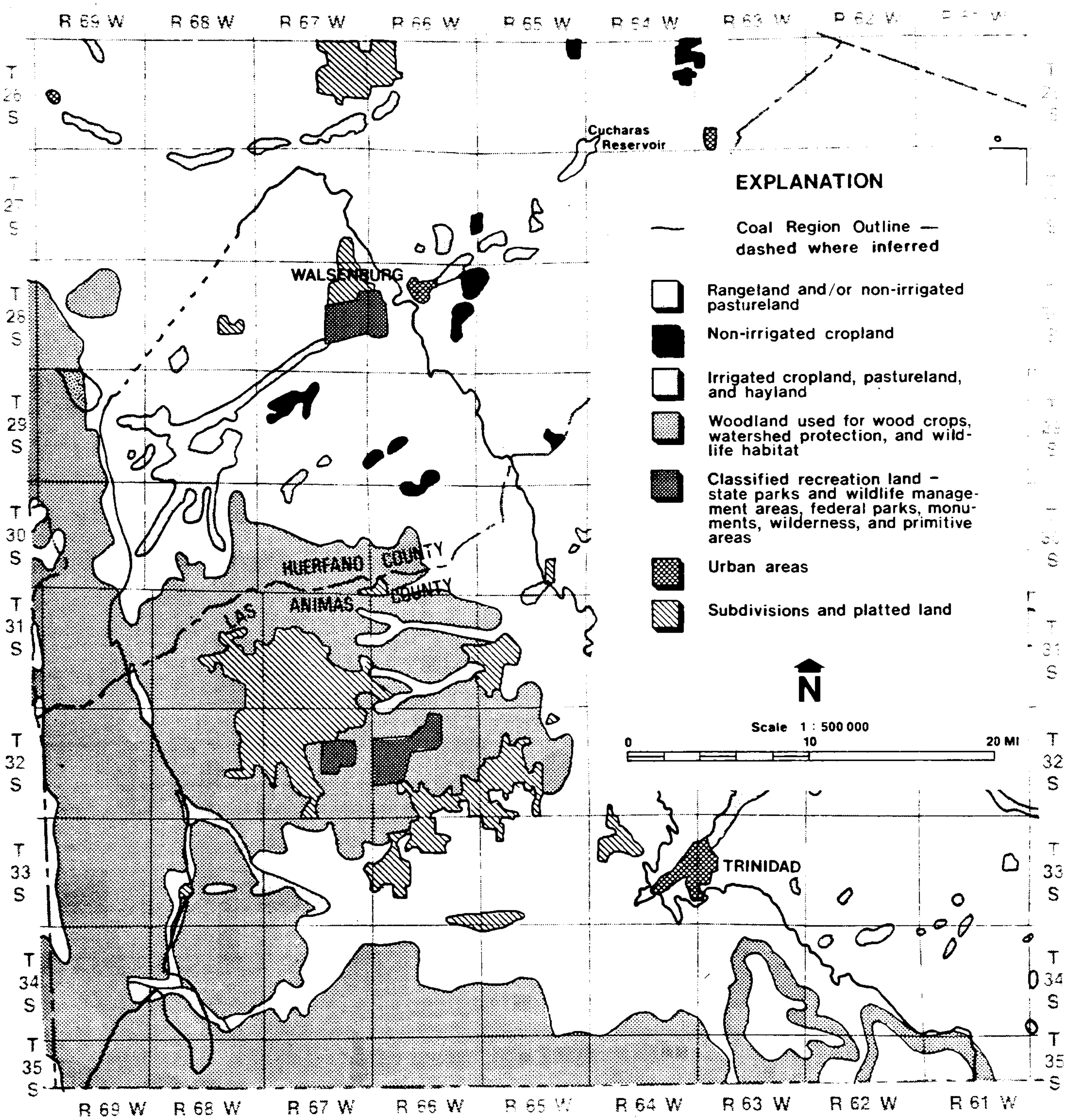


Figure 3. Land use map of the Raton Mesa coal region, Colorado (after Colorado Land Use Commission, 1974).

Winds are generally from the west; wind velocity is highest in the afternoons. Table I contains temperature and precipitation data from the weather stations within the coal region as reported to the Colorado Climatologist, Colorado State University.

TABLE I. Climate Data

Station	Temperatures				Precipitation	Snowfall
	Record Lowest (°F)	Record Highest (°F)	Average January (°F)	Average July (°F)	Mean Annual (in.)	Mean Annual (in.)
Trinidad	-32.0	97.0	33.0	72.1	13.2	42.0
Trinidad FAA	-32.0	102.0	31.7	74.1	11.9	39.0
Walsenburg Power Plant	-36.0	100.0	34.0	71.9	15.1	80.0
North Lake	-36.0	88.0	26.0	59.8	20.6	91.0
La Veta	-25.0	97.0	31.8	69.0	16.75	98.9

Vegetation

Ross B. Johnson divides the coal region into four vegetation zones (1961, p. 136-137). Eighty percent of the coal region is in the foothills vegetation zone of open coniferous forests and grasslands; piñons and junipers are the dominant conifers, blue grama and buffalo grass the dominant grasses. The eighteen percent of the coal region in the mountain vegetation zone is covered with ponderosa pine, Douglas fir, and aspen. Two percent of the region, from 11,000-11,500 ft, is in the subalpine zone of dense coniferous forests. One percent (above timberline on the Spanish Peaks) is in the alpine zone where scattered patches of short grasses are the only vegetation.

Access

The coal region can be reached by Interstate 25, and the state roads and railways shown in Figure 4. The nearest commercial flights land in Pueblo to the north. A 2 to 10 in. Colorado Interstate Gas pipeline from the east serves Trinidad; from Trinidad a City of Walsenburg line runs north to Walsenburg and an 8 in. Raton Natural Gas Co. line runs south to Raton, New Mexico (refer to Fig. 4).

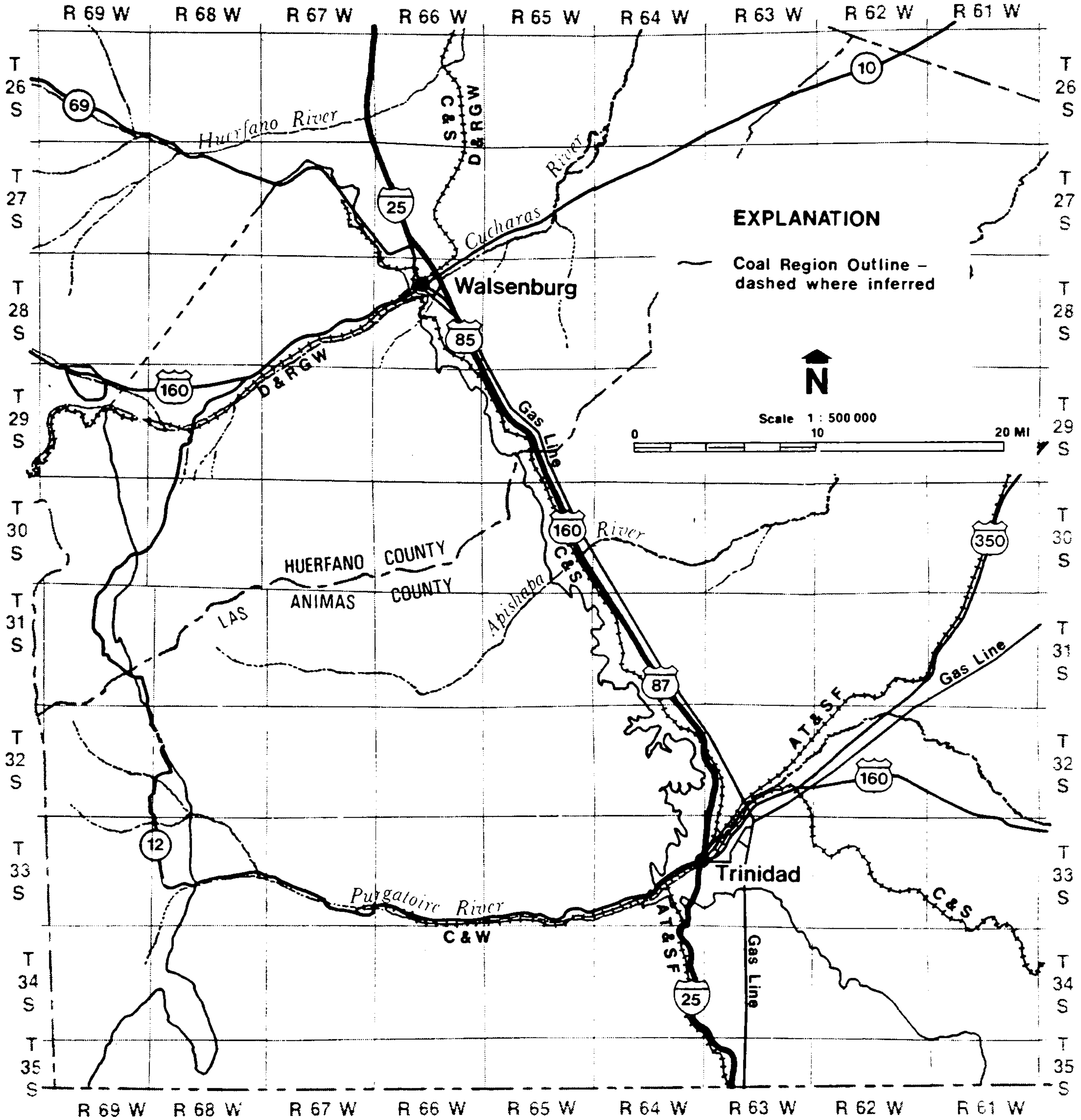


Figure 4. Highway map of the Raton Mesa coal region, Colorado (after Colorado Department of Highways, 1976).

STRATIGRAPHY

The formations present in the Raton Mesa coal region range from Precambrian to Recent in age and are listed on the stratigraphic chart (Fig. 5). The total sediment thickness is 15,000-25,000 ft on the west side of the region and 10,000 ft on the east. Late Paleozoic and early Mesozoic strata form an eastward thinning wedge 12,000-20,000 ft thick in the west to 7,000 ft thick in the east. Overlying late Cretaceous strata are approximately 3,000 ft thick. The stratigraphic section, Plate 1, shows these relationships. Figure 6 is a simplified geologic map of the coal region.

During much of Cretaceous time, the coal region was under a vast Cretaceous sea extending from the Gulf of Mexico to Canada (Fig. 7). The uppermost Cretaceous strata and the Tertiary strata record the northeastward regression of the Cretaceous sea and rise of the Rocky Mountains during the Laramide revolution. The late Cretaceous to Tertiary strata which bear upon the coal bed methane potential of the region are described below. Figure 8 is a type log of these formations.

Pierre Shale

The Pierre Shale is a Cretaceous marine shale, first described in 1862 by F. B. Meek and V. F. Hayden at Old Fort Pierre, South Dakota (Mitchell, Greene, and Gould, 1956, p. 134). The Pierre Shale occurs throughout the Great Plains and is 1,600-2,300 ft thick in the study area. The easily weathered shale floors the narrow valley west of the coal region and the broad plains to the east (see Fig. 6).

The main body of the Pierre is a dark gray to black, noncalcareous, bentonitic, fissile shale 1,300-2,300 ft thick. It contains a few thin limestone lenses and septarian concretions. This part of the formation was deposited in a neritic environment and represents the maximum transgression of the Cretaceous sea. Fossils found in the interval include: Ostrea pellucida M. and H., Inoceramus vanuxemi M. and H.; Cucullaea sp. Lucina sp.; Volutoderma sp.; and Scaphites nodosus Owen var. (Richardson, 1908, p. 385).

The upper 200-300 ft of the Pierre is buff to gray, fine to medium grained shaly sandstones interbedded with gray to black, silty and sandy shales. This highly burrowed zone was deposited in a prodelta environment; Inoceramus sagensis Owen, I. cripsi var. barabini Morton, I. vanucemi M. and H. Baculites ovatus Say, B. Compressus Say, Ostrea sp. (Richardson, 1908, p. 385) and Anomia sp. (Manzolillo, 1976, p. 13) have been found in this zone. This upper Pierre Shale zone forms a gradual transition with the overlying and intertonguing Trinidad Sandstone (Fig. 8); the top of the Pierre is usually placed at the bottom of the lowest prominent sandstone or siltstone bed in the overlying Trindad Sandstone.

GEOLOGIC AGE		FORMATION	THICKNESS (feet)	LITHOLOGY	OIL	AND GAS SHOWS
QUATERNARY		Recent	0 -30	Alluvium; basalt flows		
TERTIARY	MIOCENE	Devils Hole	25 -1300	Water - laid tuff volcanic conglomerate		
TERTIARY	Oligocene	Farisita	0 -1200	Arkosic conglomerate		
TERTIARY	EOCENE	Huerfano	0 -2000	Variegated shale, conglomeratic sandstone		
TERTIARY	EOCENE	Cuchara	0 -5000	Massive red conglomeratic sandstone with thin variegated shale		
TERTIARY	PALEOCENE	Poison Canyon	0 -2500	Coarse arkosic sandstone and conglomerates with thin shales		✱
MESOZOIC	LATE CRETACEOUS	Raton	0 -1700	Thin coalbeds, sandstone, basal conglomerate, shale	●	✱
MESOZOIC	LATE CRETACEOUS	Vermejo	0 -550	Sandstone, shale, coal		✱
MESOZOIC	LATE CRETACEOUS	Trinidad Sandstone	0 -300	Fine-grained beach sand	●	✱
MESOZOIC	LATE CRETACEOUS	Pierre Shale	1600 -2300	Grey marine shale, sandy shale, sandstone	●	✱
MESOZOIC	LATE CRETACEOUS	Niobrara	560 -630	Marine shale, limestone	●	✱
MESOZOIC	LATE CRETACEOUS	Carlile Shale	165 -235	Dark grey marine shale		✱
MESOZOIC	LATE CRETACEOUS	Greenhorn Limestone	38 -80	Thin bedded limestone		
MESOZOIC	EARLY CRETACEOUS	Graneros Shale	185 -385	Dark grey marine shale	●	✱
MESOZOIC	EARLY CRETACEOUS	Dakota Sandstone	100 -150	Grey massive sandstone	●	✱
MESOZOIC	EARLY CRETACEOUS	Purgatoire	100 -150	Continental shale, sandstone	●	✱
MESOZOIC	JURASSIC	Morrison	100 -600	Continental sandstone, shale	●	
MESOZOIC	JURASSIC	Ralston, Todilto		Marine sediments, gypsum		
MESOZOIC	JURASSIC	Entrada		Beach sandstone	●	
MESOZOIC	TRIASSIC	Johnson Gap	10 -700	Limestone conglomerates		
MESOZOIC	TRIASSIC	Dockum Group of formations	0 -1200	Red sandstone, calcareous shales, thin limestones		
PALEOZOIC	PERMIAN	Bernal	<150	Continential sediments		
PALEOZOIC	PERMIAN	Glorieta	0 -200	Marine sandstones		
PALEOZOIC	PERMIAN	Yeso	0 -250	Red silt, shale, sandstone		
PALEOZOIC	PENNSYLVANIAN	Sangre de Cristo	250 -5400	Variegated shales, arkose, conglomerates, thin marine limestones	●	
	PRECAMBRIAN	Precambrian	Basement rocks	Crystalline, igneous, and metamorphic		

Figure 5. Stratigraphic chart of the Raton Mesa coal region, Colorado (after Bench, 1979).

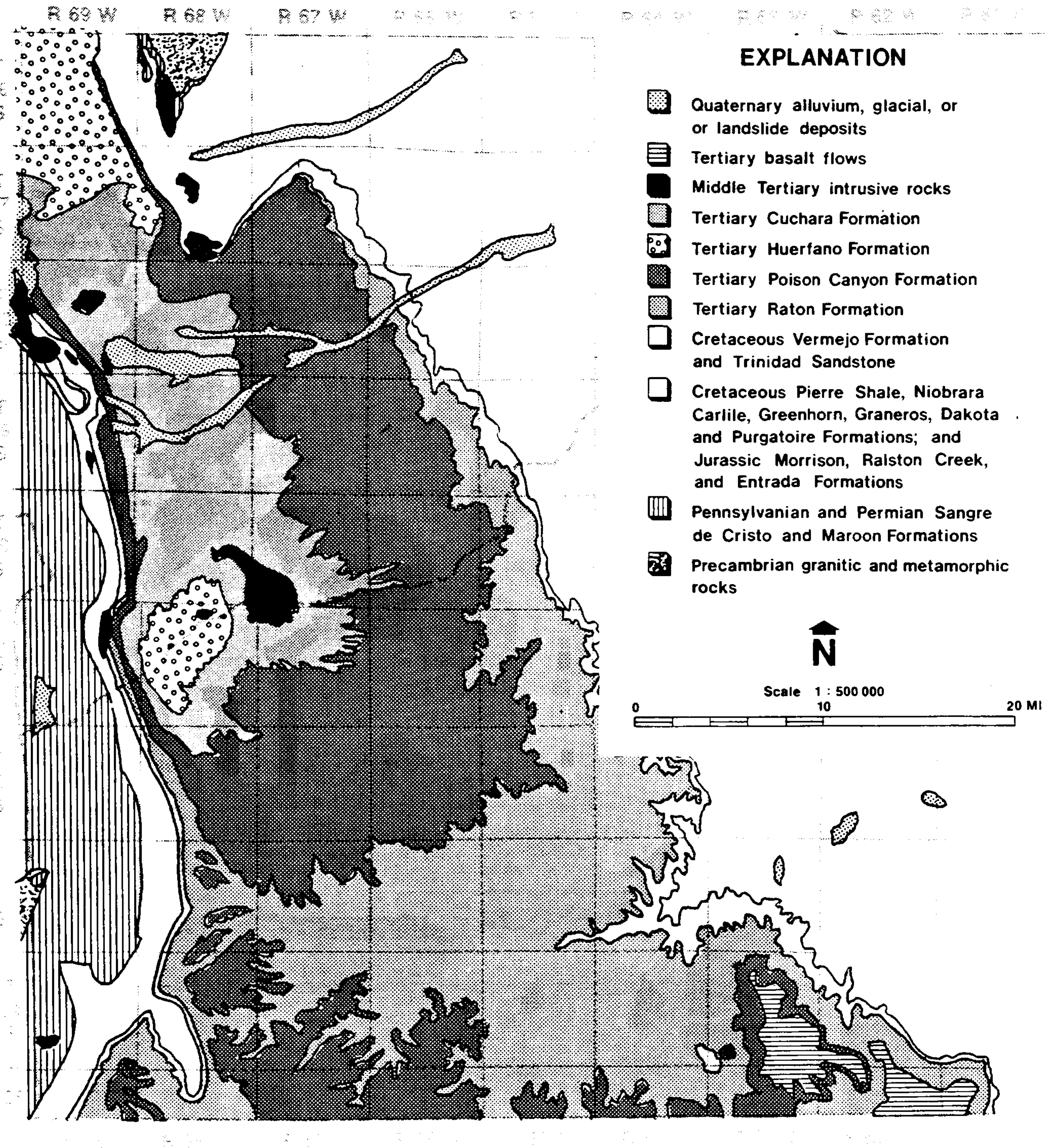


Figure 6. Geologic map of the Raton Mesa coal region, Colorado (after Tweto, 1979).

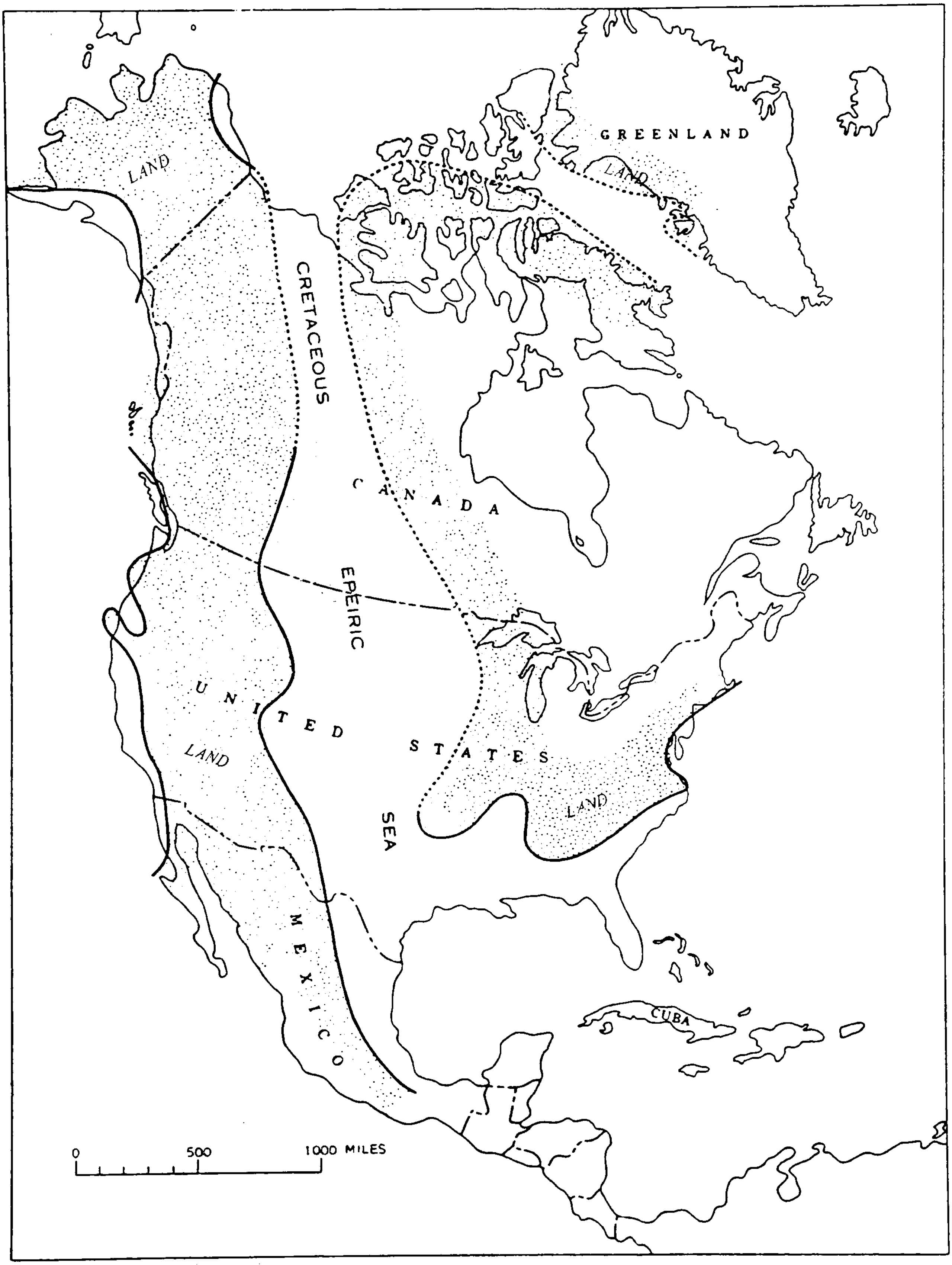


Figure 7. Location of the Cretaceous sea in North America (after Gill and Cobban, 1966, p. A44).

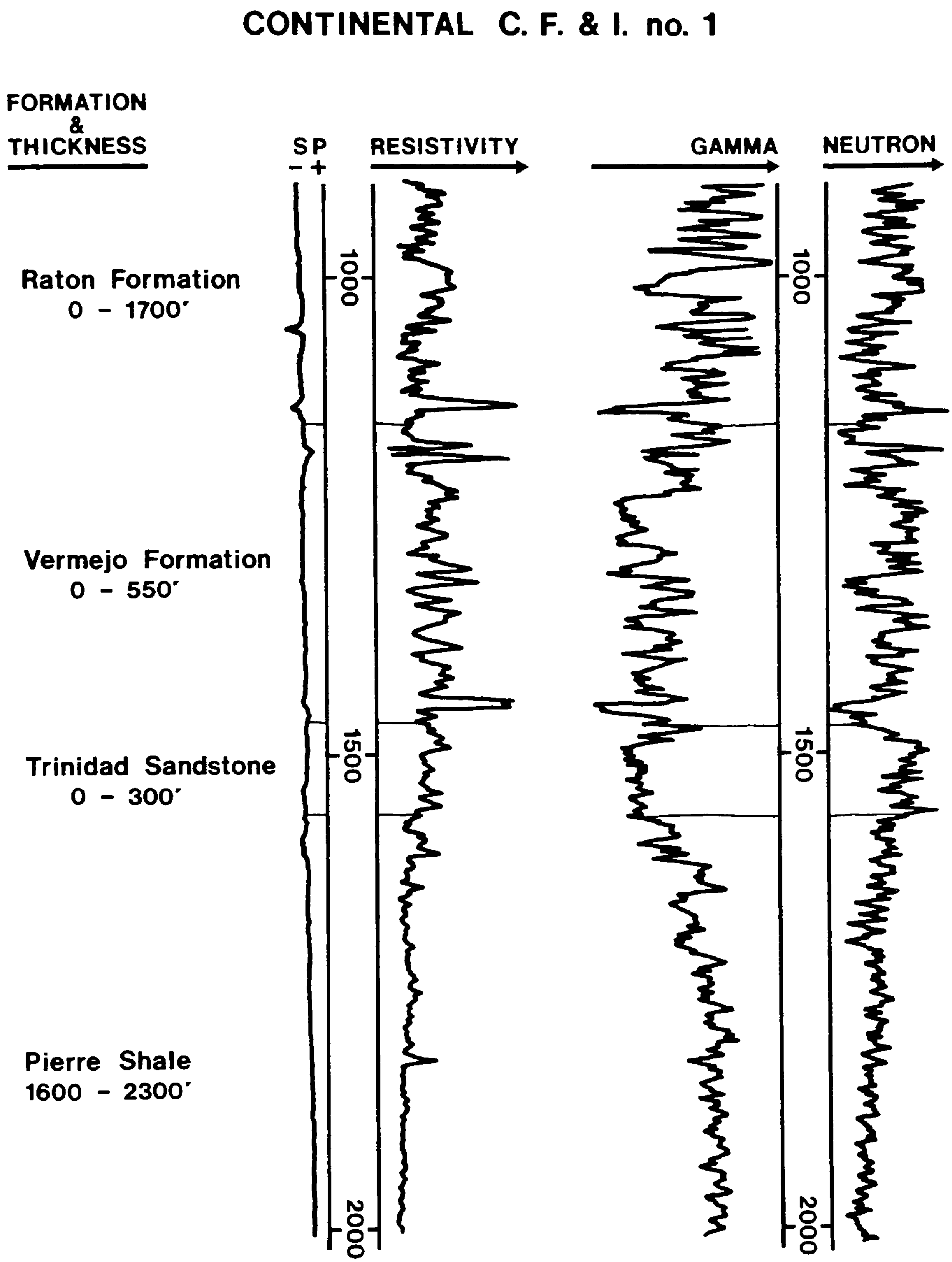


Figure 8. Type log of the coal bearing Vermejo Formation and associated formations, Raton Mesa coal region, Colorado.

Trinidad Sandstone

The Trinidad Sandstone, which lies just below the coal-bearing formations, serves as a marker bed in the coal region; it is the shallowest unit that can be extensively mapped from subsurface data with any agreement among authors. This 0-300 ft thick ledge-forming sandstone (Fig. 9) whose exposure outlines the coal region is roughly correlatable with the Pictured Cliffs Sandstone in the San Juan Basin of southwestern Colorado and the Fox Hills Sandstone of the Denver Basin to the north. Plate 2, Map A is an isopach map of the formation and Plate 2, Map B a structure map.

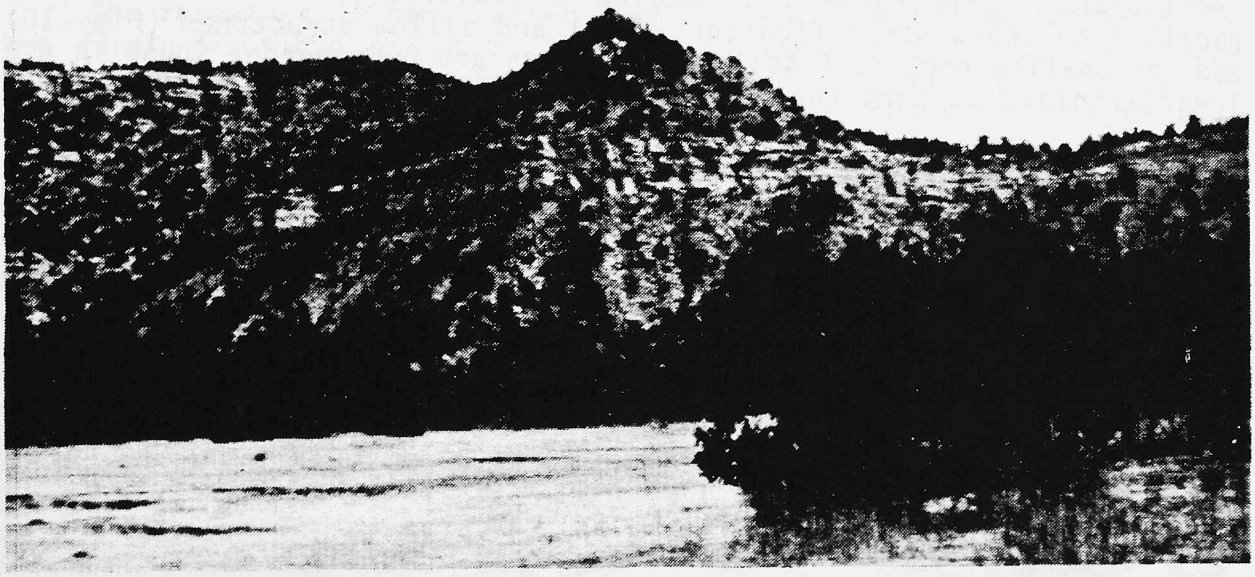


Figure 9. Outcrop of formations in the coal zone on the eastern boundary of the Raton Mesa coal region. The grassy valley floor and lower half of the hill is the Pierre Shale; the cliff forming sandstone in the middle of the hill is the Trinidad Sandstone. A Raton Formation sandstone caps the hill; the boundary between the Raton and Vermejo Formations lies somewhere on the tree covered slope above the Trinidad Sandstone.

R. C. Hills first described the Trinidad Sandstone in 1899 at Trinidad, Colorado (Hills, 1899). Lee (1917, p. 48) later modified Hills' interpretation by placing the alternating sandstones and shales just below the massive sandstone in what is now called the upper zone of the Pierre. The Trinidad is a light gray to buff, locally arkosic sandstone with a few thin beds of tan or gray silty shales. The buff color is due to limonite staining, the gray to carbonized plant fragments. The sand grains are quartz with minor amounts of weathered feldspar, mica, and ferromagnesium minerals; these grains are cemented by clay, calcium carbonate, or silica. Fossils found in the Trinidad are Ophiomorpha, Skolithos, Halymenites, Asterosoma, Diplocraterion, Arenicolites, and Rosselia (Manzolillo, 1976, p. 16).

Early workers considered the Trinidad to be a beach sand formed along the western margin of the northeasterly retreating Cretaceous sea; this interpretation appears to be supported by the northwesterly trending isopach contours in Plate 2, Map A. However, recent workers, Billingsley (1978) and Monzolillo (1976), divide the Trinidad Sandstone into an upper fluvial zone and a lower delta front sandstone.

According to Billingsley and Manzolillo, the lower Trinidad is a coarsening upward, very fine to fine grained quartz sandstone. It usually exhibits tabular bedding, although locally beds are irregular and lenticular. Beds range from medium to massive in size and exhibit parallel to cross stratification. Ball and pillow structures (Fig. 10) and the shallow neritic fossils Halymenites and Ophiomorpha found in the lower Trinidad support the lower delta front depositional model.

Figure 10. Ball and pillow structures in the Trinidad Sandstone--a penecontemporaneous deformation feature formed when the underlying shale is squeezed around the sandstone structures during slumping on steep depositional slopes in a delta front environment.

The upper Trinidad is a fining upward, medium to fine grained sandstone. It is more porous and permeable than the lower; Matusczak (1969, p. 120) reported a maximum porosity of 21 percent and a permeability of more than 200 md in this zone. Billingsley and Manzolillo interpret it as a salt marsh estuarine or distributary channel facies due to: 1) its lack of burrowing, 2) scour contact and high angle cross stratification, 3) fine to medium grain size, 4) subaqueous shrinkage cracks, 5) lag deposits, 6) indistinct bedding, and 7) upward decrease in grain size. The upper Trinidad intertongues with and is overlain by the coal-bearing Vermejo Formation.

Vermejo Formation

The Vermejo Formation is a 0-550 ft thick formation deposited in a delta plain environment during the Late Cretaceous. Map C of Plate 2 is an isopach of the formation.

The Vermejo forms gentle slopes or valley floors between sandstones of the underlying Trinidad and overlying Raton Formations. It is exposed mainly along the borders of the coal region as shown in the geologic map, Figure 6.

The formation is named after Vermejo Park, New Mexico, where W. T. Lee first described it in 1913 (Mitchell and others, 1956, p. 135). Harbour and Dixon (1959, p. 456) describe the formation as 60% shale, 30% sandstone, and 10% coal. These component rocks are shown on the type log, Figure 11, and described below.

<u>Shales</u> - gray, dark gray, and nearly black; carbonaceous and silty

<u>Siltstones</u> - buff, gray, and dark gray; poorly sorted; argillaceous

<u>Sandstones</u> - buff, gray, and gray-green; slightly arkosic; fine grained; grains mostly quartz with weathered feldspar, mica, and ferromagnesium minerals; clay and calcium carbonate cement; occurs in thin to massive beds.

<u>Coals</u> - black; friable; bright luster; platy cleavage; cubic or prismatic cleat; some break with conchoidal fractures; composed of vitrain with lesser durain and fusain; high-volatile A to anthracite in rank (where coked); moderately clean with impurities of pyrite, quartz grain, melanterite, limonite, and resin; beds lenticular and irregular in thickness but extending up to several miles in outcrop, maximum bed thickness of 14 ft; partings of bony coal, carbonaceous shale, siltstone, and fine grained sandstone. Map D of Plate 2 is a net coal isopach of the Vermejo Formation. Coals included in this isopach are 2 ft or greater in thickness.

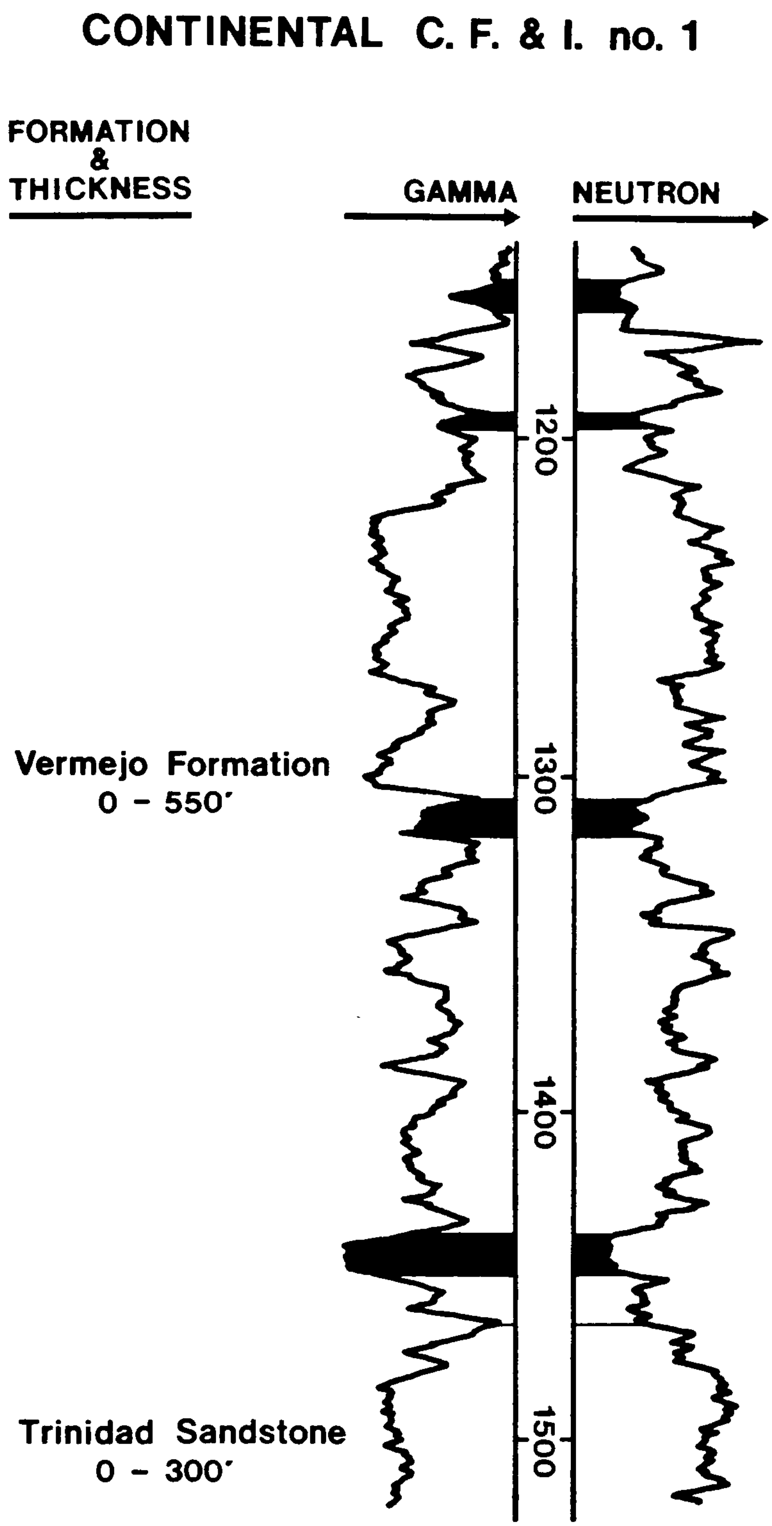


Figure 11. A type log of the Vermejo showing several coalbeds in black.

Raton Formation

The Raton Formation is a 0-1,700 ft thick continental formation of Late Cretaceous and Paleocene age, first described by F. V. Hayden in 1869 near Raton, New Mexico (Mitchell and others, 1956, p. 134). This floodplain formation is composed of sandstones, silty shales, and a basal conglomerate. Although the Raton Formation overlies and intertongues with the Vermejo Formation, the base of the conglomerate is usually picked as the contact of the two formations.

The Raton Formation is exposed over much of the coal region (Fig. 6). The sandstones and the basal conglomerate usually form resistant benches in outcrop; the shales form lowlands. Descriptions of the component lithologies are given below.

Sandstones - light gray to buff; very fine to medium grained, coarse grained locally; subangular to subrounded grains; well to poorly sorted; grains mostly quartz with some white weathered feldspar, ferromagnesium minerals, and rock fragments; clay and calcium carbonate cement; occurs in thin to massive beds with thicker beds usually cross-stratified and lenticular.

Shales - gray to black, mostly plastic and non-fissile; vary from pure claystone to siltstone and carbonaceous shale; most beds thicker than sandstones.

Conglomerate - 0-250 ft thick at base of formation; color varies locally among gray, purple gray, olive green, and buff; dominantly chert pebbles in the east side of coal region, quartzite, granite and gneiss pebbles on the west side with quartz granules and chert granules throughout; pebbles subangular to well rounded; usually well cemented by silica; distinct cross bedding.

Coals - black; friable; cubic or prismatic cleat; some break with poorly developed conchoidal fracture; mostly vitrain with some durain and fusain; high-volatile C to low-volatile in rank; occurs throughout the formation in beds up to 12 ft thick which are more lenticular in shape and irregular in thickness than the Vermejo coals; partings of fine grained sandstone, bony coal, siltstone, carbonaceous shale and tonstein.

Poison Canyon Formation

The Poison Canyon Formation is a 0-2,500 ft thick Paleocene age formation first described by R. C. Hills in 1891 at Poison Canyon in Huerfano County, Colorado (Mitchell and others, 1956, p. 134). It unconformably overlies the Raton, Vermejo, Trinidad, and Pierre Formations in the north and intertongues with the Raton Formation in the south.

Arkosic sandstones, conglomerates, thick shales, and minor coals deposited in a piedmont environment make up the formation. Its contact with the Raton Formation is at the base of the lowest sandstone containing unweathered feldspar grains. The Poison Canyon is exposed over much of the coal region, and like the previously described formations in this semiarid area, the sandstones are cliff-formers and shales slope-formers. Descriptions of the lithologies follows.

Sandstones - buff to red; arkosic; composition similar to Raton sandstones except contain unweathered grains of pink feldspar; coarse to medium grained; some beds lenticular and cross laminated; often thick to massively bedded.

Conglomerates - buff, gray, and olive, weathered outcrops stained light red; contains granite, gneiss, and quartzite pebbles up to 3 or 4 in. in diameter and boulders up to 4 ft in diameter.

Shales - yellow, buff, light gray, or tan; micaceous; commonly silty or sandy; contain very little carbonaceous material; internal bedding obscure.

Coals - rare, 1-1.7 ft lignite beds; dull, friable, soft, commonly dirty, mostly durain with less fusain and vitrain, cubic cleat, conchoidal or irregular fracture.

IGNEOUS ROCKS

Igneous rocks cut all the formations described above. Stocks, laccoliths, sole injections, flows, plugs, dikes and sills emplaced during Tertiary and Quaternary time, occur throughout the coal region. The composition of the rocks varies from basic to silicic.

Prominent stocks include: 1) the granodiorite and syenodiorite porphyritic Spanish Peaks in the west central part of the coal field, 2) the syenodiorite porphyritic Dike Mountain northwest of La Veta, and 3) the three granite porphyritic White Peaks southwest of La Veta. The syenodiorite porphyritic Black Hills in the north and granitic cored Morley Dome south of Trinidad are prominent laccoliths. Goemer Butte is a dark gray latite plug near La Veta.

Hundreds of dikes 2-60 ft thick and up to 100 ft high radiate from the Spanish Peaks (Fig. 12) and Dike Mountain and fill east-west joints throughout the coal region. These dikes often form nearly vertical walls and contain polygonal jointing; they indurate and bleach the surrounding rock and coke the coals they dissect (Fig. 13).

Dike fed sills, inches to 300 ft thick, are also common. They range from gabbroic to rhyolitic in composition and can extend over several square miles. The sills often replace or upgrade coal.

Basaltic flows, most extensive south of Trinidad, form the Raton Mesas. These Mesas and the more prominent of the igneous features mentioned above are shown in the geologic map, Figure 6.

STRUCTURE

The Raton Basin is a north-south trending, structural and sedimentary basin. The axis of this asymmetric basin is west of the geographic basin center (Fig. 14).

The western limb of the basin dips steeply at 20-90°, the eastern limb dips gently at 2-10°, and the interior is almost horizontal. The Ancestral Rocky Mountains orogeny of Pennsylvanian time created the basin; the basin was rejuvenated during the Late Cretaceous-Early Tertiary Laramide orogeny.

The main basinal syncline in Colorado is bisected (see Fig. 14) by the Greenhorn Anticline (a south plunging nose extending off the Wet Mountains to the north). The La Veta Syncline to the west extends from Weston to Huerfano Park. This syncline is asymmetrical in form with less than a thousand ft of structural relief on the east limb and several thousand ft of structural relief on the steeper western limb. The Delcarbon Syncline veers northeastward from the La Veta Syncline and dies out against the junction of the Apishapa Arch and Wet Mountains. This syncline is shallower and more symmetrical than the La Veta Syncline.

As shown in Figure 1, anticlines bound the basin. The Sangre de Cristo Mountains to the west and the Wet Mountains to the north are both Late Cretaceous asymmetric anticlines with exposed Precambrian crystalline cores; they are bounded by faults on the side facing the basin. The Apishapa Uplift on the northeast and the Las Animas-Sierra Grande Uplifts to the east and southeast are lower and broader anticlinal uplifts. The Apishapa Uplift is surfaced by Triassic to Recent rocks, the Las Animas-Sierra Grande Uplift by Cretaceous rocks.

Within the coal region in the interior of the basin are several minor anticlines (Fig. 14) all having eroded crests of Pierre Shale. The Tercio Anticline, in the southwest corner of the coal region, is 5 1/2 x 2 mi in size with a surface closure of 1,700 ft. The Ojo Anticline, in the

Figure 12. A resistant vertical dike radiating from the Spanish Peaks in the background (photograph by Donna L. Boreck).

Figure 13. A dike intersecting a coal bed; the coal at the point of the hammer has been coked (photograph by Steven M. Goolsby).

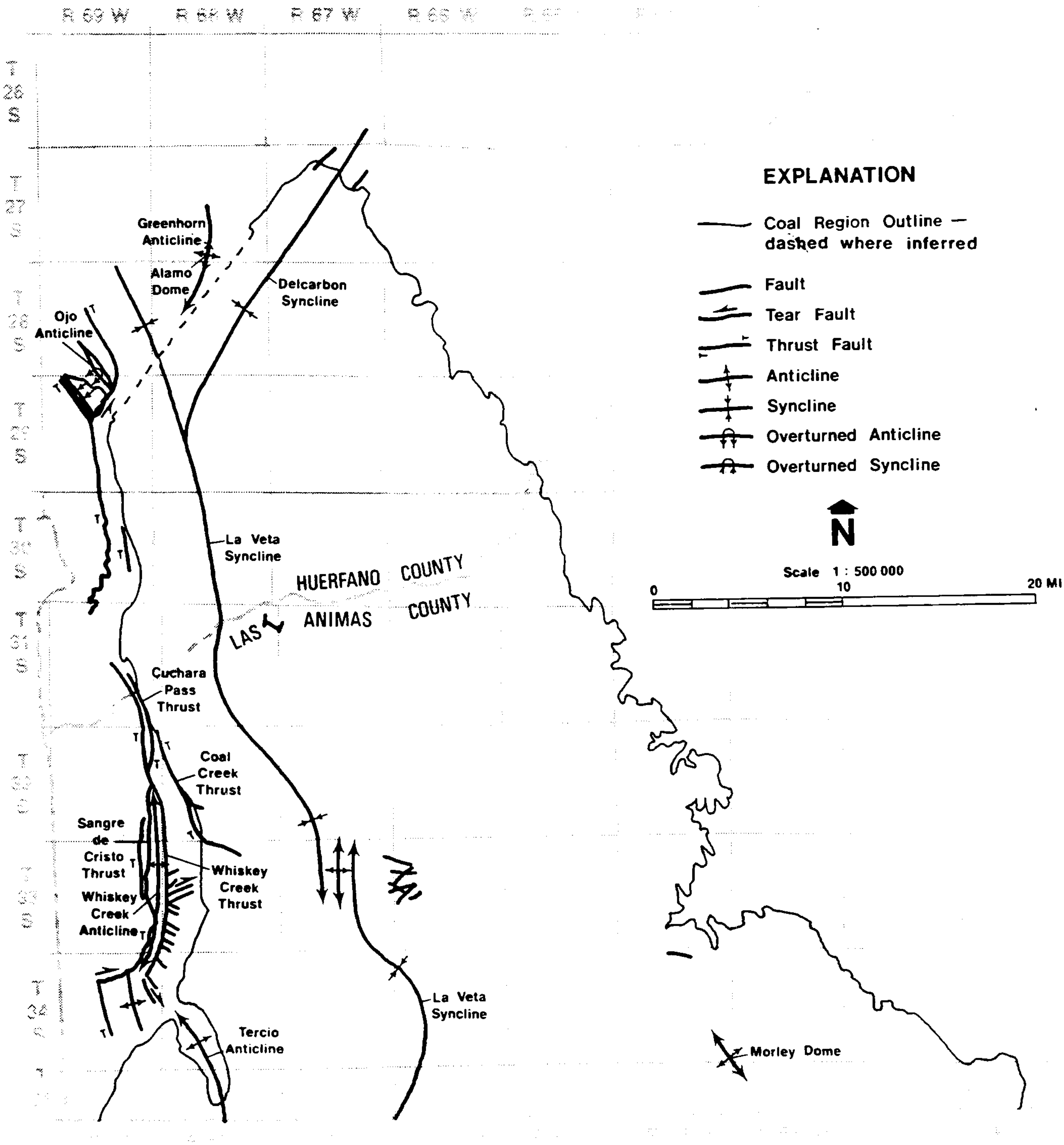


Figure 14. A tectonic map of the Raton Mesa coal region, Colorado.

northwest part of the coal region, is 25 mi long (Creely & Saterdal, 1956, p. 68). The circular Alamo Dome, on the southwest plunge of the Greenhorn Anticline, has a diameter of approximately 3 mi and a closure of at least 400 ft (Creely & Saterdal); at its crest are the Black Hills laccoliths.

Both normal and reverse faults occur in this region. Normal faults are not widespread, but occur in "isolated groups" (Johnson, 1961, p. 152) and have displacements usually less than 50 ft. Listed below are some of these fault locations and references.

1) Tercio Anticline Tps.33 & 34S.-R.68W.	Terry, 1956, p. 66-67
2) Ojo Anticline T.29S.,R.69W.	Creely & Saterdal, 1956, p. 68-69
3) Delcarbon Syncline	Johnson, 1961, p. 152
4) D.H. USGS 78-1	Danilchik, 1978, p. 3
5) between Sarcilla & Wet Canyons & in Frisco Canyon	Wood, Johnson and Dixon, 1957, p. 152
6) northeast of Weston	Johnson, 1961, p. 152
7) Rouse, Midway, Berwind Mines	Richardson, 1908, p. 413
8) between the 2 Spanish Peaks	Johnson, 1961, p. 146

Long north-south trending thrust faults lie mainly to the west of the coal region and "involve the coal bearing and younger formations only locally" (Johnson, 1961, p. 130). The Sangre de Cristo, Whiskey Creek, Cuchara Pass, and Coal Creek Faults are several of the more prominent thrusts (see Fig. 14).

OIL AND GAS PRODUCTION

The four fields capable of production in the Raton Basin are shown in Figure 15. Model Dome has produced helium from the Permian Lyons Formation (refer to Fig. 5). Sheep Mountain contains "a large deposit of CO_2" (Renfro, 1979, p. 51) trapped in the Cretaceous Dakota Sandstone; Arco Oil and Gas Company is considering pipelining this gas to west Texas for use in enhanced oil recovery. Gardner (a one well oil field) produced 2,348 barrels of oil, and 2.25 MMCF (million cubic feet)of gas from the Codell Sandstone during the period 1975-1979. Garcia gas field produced 15,561 MMCF of gas from fractured Pierre Shale from 1934 until 1943 when it was abandoned; this field is currently the target of renewed exploration.

None of the above fields are within the coal region of the Raton Basin. Structures tested within the coal region itself include the Alamo Dome, the Ojo Anticline, the Morley Dome, and the Tercio Anticline. Wells in each have exhibited shows (Fig. 16) but not commercial production rates.

Potential source rocks (organic rich marine shales and coal) exist in contact with potential marine and fluvial reservoir rocks. Moreover, the presence of high-volatile C to low-volatile coals indicates the rocks of the area are mature enough to have generated oil and gas (see Dolly and Meisner, 1977). However, a drilling density in the coal region of only one well per 50 sq mi (Dolly and Meisner, 1977, p. 247) leaves much of the area untested.

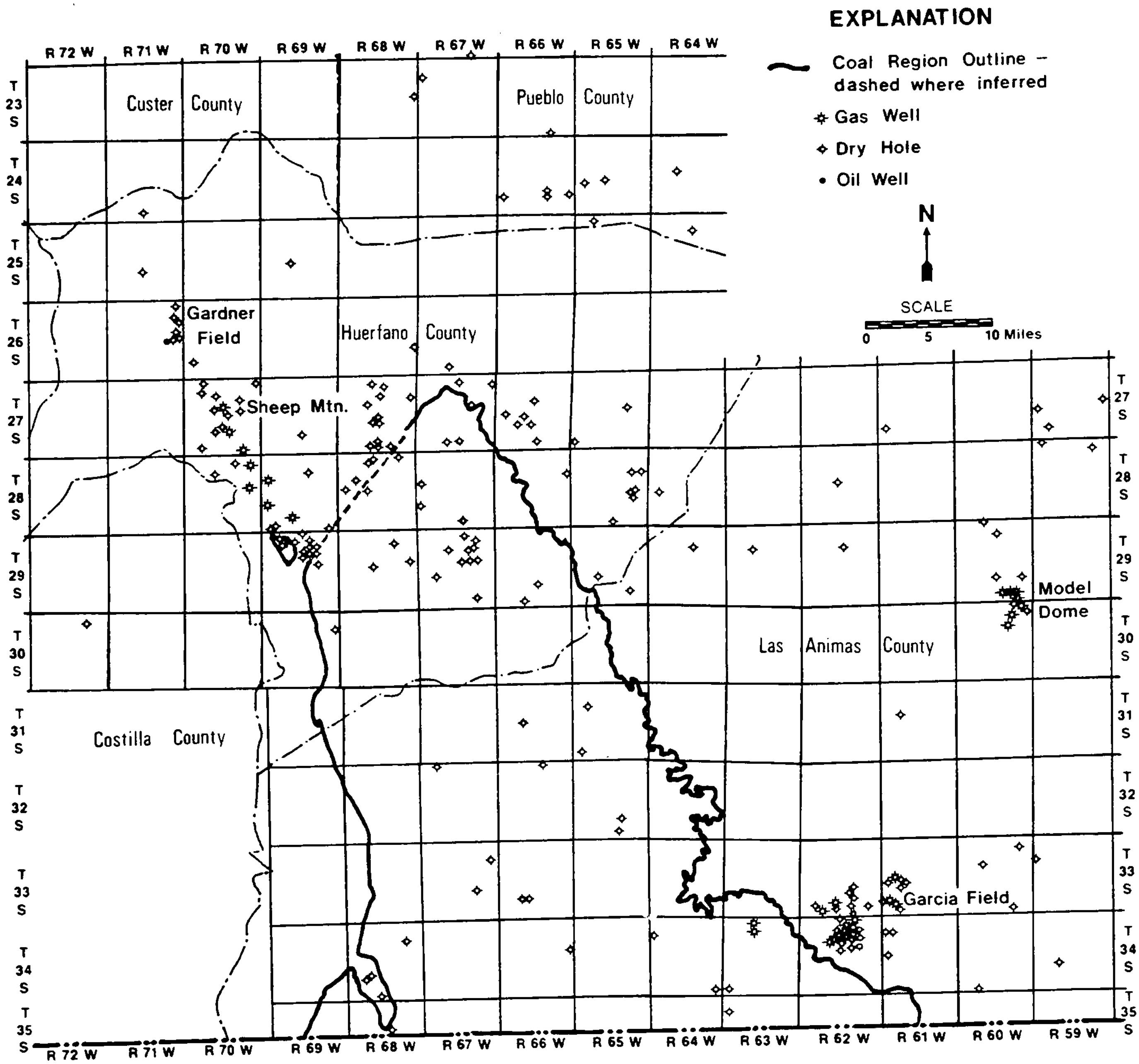


Figure 15. Map showing the location of oil and gas wells and dry holes in the Raton basin. The four oil or gas fields that have been named are also shown.

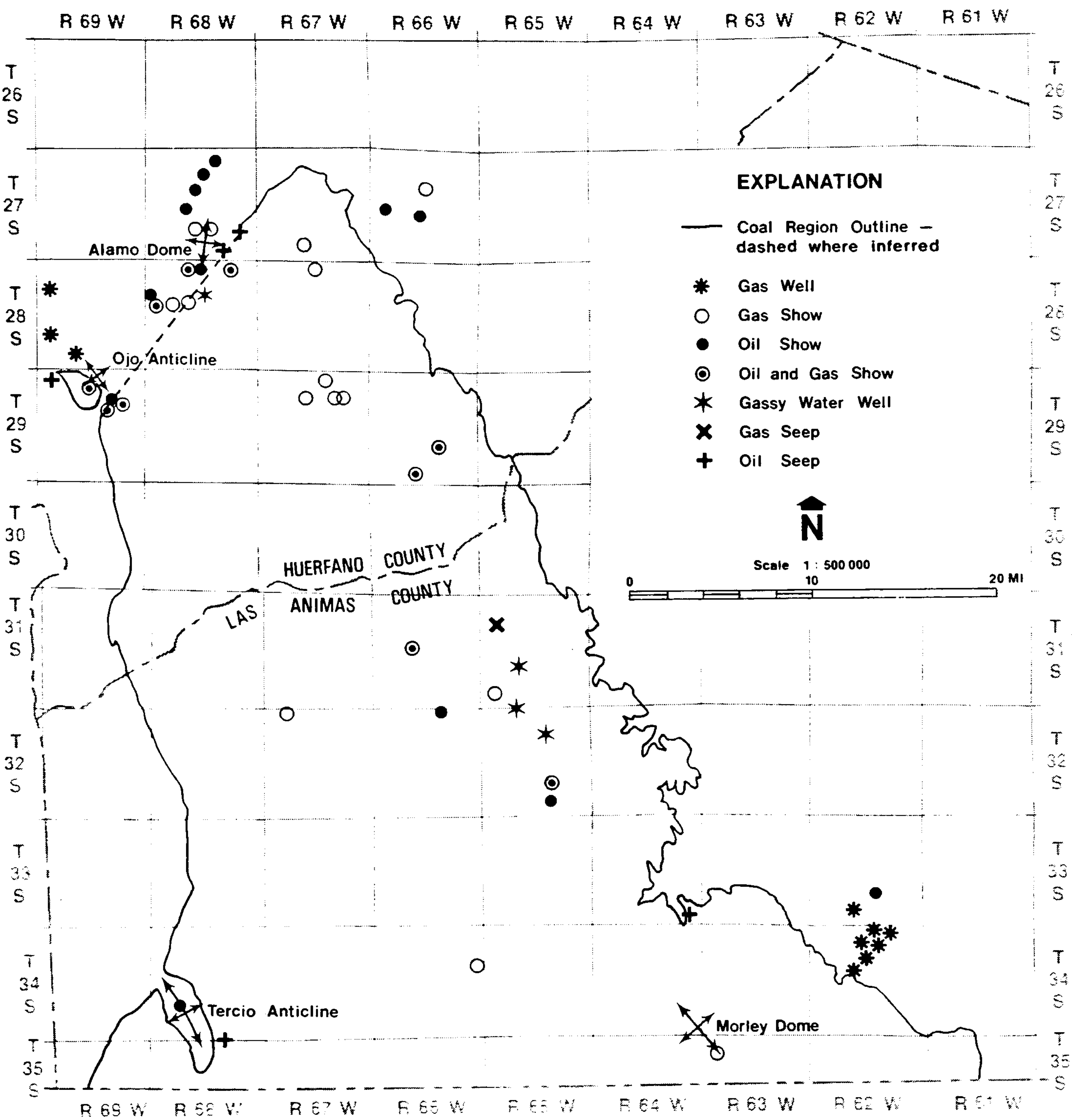


Figure 16. Oil and gas shows in the Raton Mesa coal region, Colorado.

Traps suggested by various authors include: 1) coals and methane charged channel sands in the Vermejo and Raton Formations, 2) stratigraphic traps in the more porous and permeable zones of the Trinidad Sandstone and hydrodynamic entrapment of gas in the Trinidad Sandstone at basin center, 3) entrapment of gas in the Vermejo, Trinidad and Raton Formations where they are truncated by the unconformity on the northwestern side of the basin, 4) fracture traps in the Pierre and Niobrara Shales, and 5) traps formed by the eastward facies changes and pinching out of the Trinidad Sandstone, Dakota Sandstone, and Pennsylvanian strata.

Problems that have hindered exploration and production to date include: 1) low formation permeabilities, 2) subnormal formation pressures, 3) formation damage in reservoirs containing swelling clays, 4) the lack, until recently, of logging programs capable of detecting porosity and hydrocarbon saturation in clay filled reservoirs.

COAL RESOURCES AND PRODUCTION

The commercial coal of the coal region is contained in the Raton and Vermejo Formations in coal beds up to 14 ft thick. However, the beds are discontinuous and can seldom be traced more than a few miles. Hence almost every mined bed bears a different name and coal zones prove more useful for correlation purposes than coal bed names. Figures 17 and 18 show the variety of coal bed names per coal zone.

The coal region in Colorado has historically been divided into two fields named after the major town in each--the Trinidad Coal Field and the Walsenburg Coal Field. Trinidad Field coals are generally of coking quality while Walsenburg Field coals are generally steam coals. The Huerfano-Las Animas County line is usually taken as the boundary between these fields although coal quality actually increases gradually from north to south (Fig. 19).

Cumulative production from the region as of January 1, 1980 was 251,659,807 short tons (updated from Boreck, 1979, p. 48). Production during 1979 was 870,346 short tons (Blake, 1980, p. 28, 29). Remaining reserves as of January 1, 1980 were 668.55 million tons (updated from Boreck, 1979, p. 48).

At least 371 mines have operated in the region (Boreck, 1979, p. 48); 9 mines are currently licensed - 1 in the Walsenburg Field and 5 in the Trinidad Field. Figure 20 gives the locations of existing and historical mines. Table 2 gives the 1979 production of the operating mines, as reported in Blake (1980, p. 28, 29).

RATON MESA REGION - RATON FORMATION

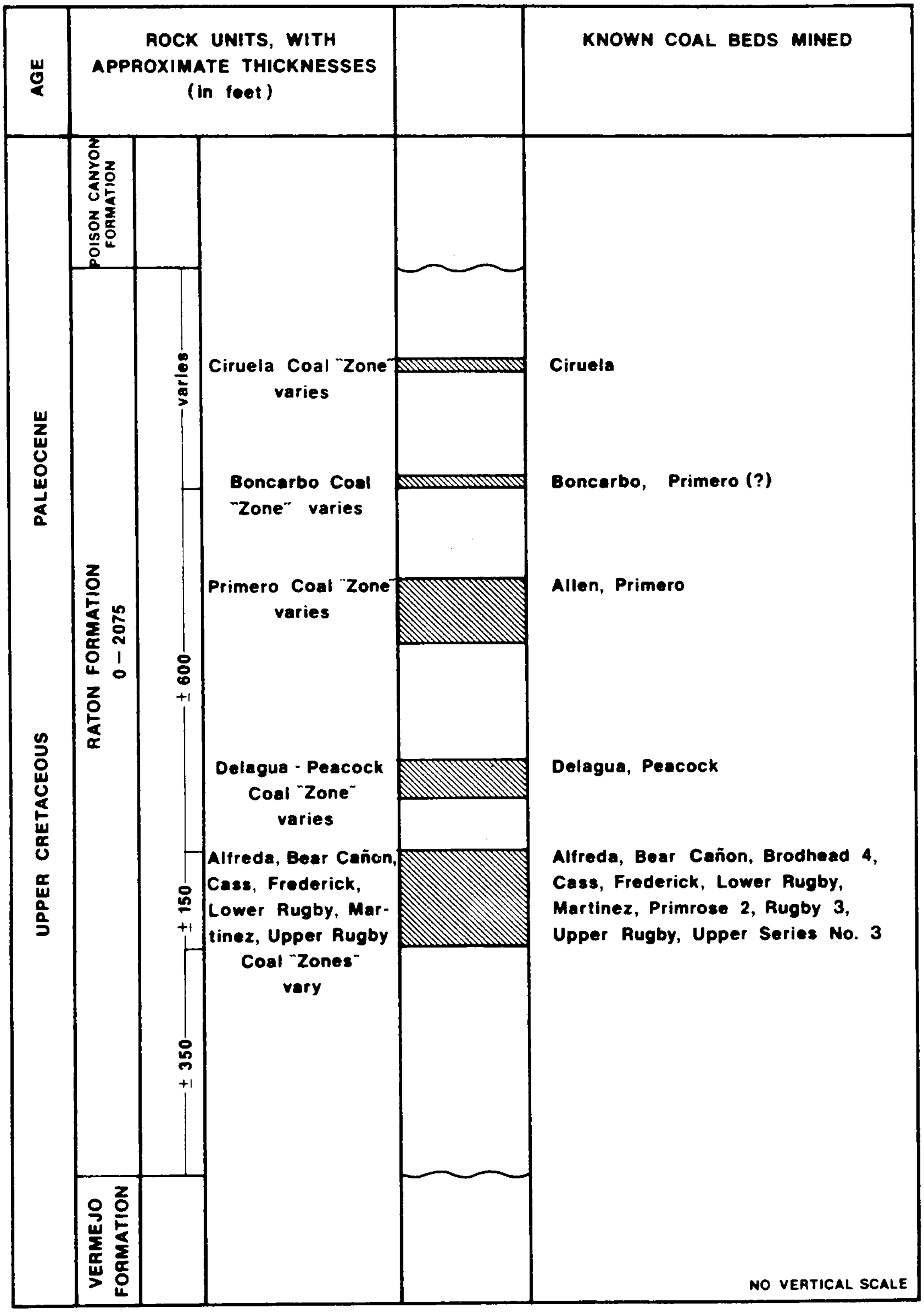


Figure 17. Generalized columnar section of the coal bearing rocks in the Raton Formation, Raton Mesa coal region, Colorado. Shaded areas are the general locations of the coal zones (from Boreck and Murray, 1979, p. 50).

RATON MESA REGION - VERMEJO FORMATION

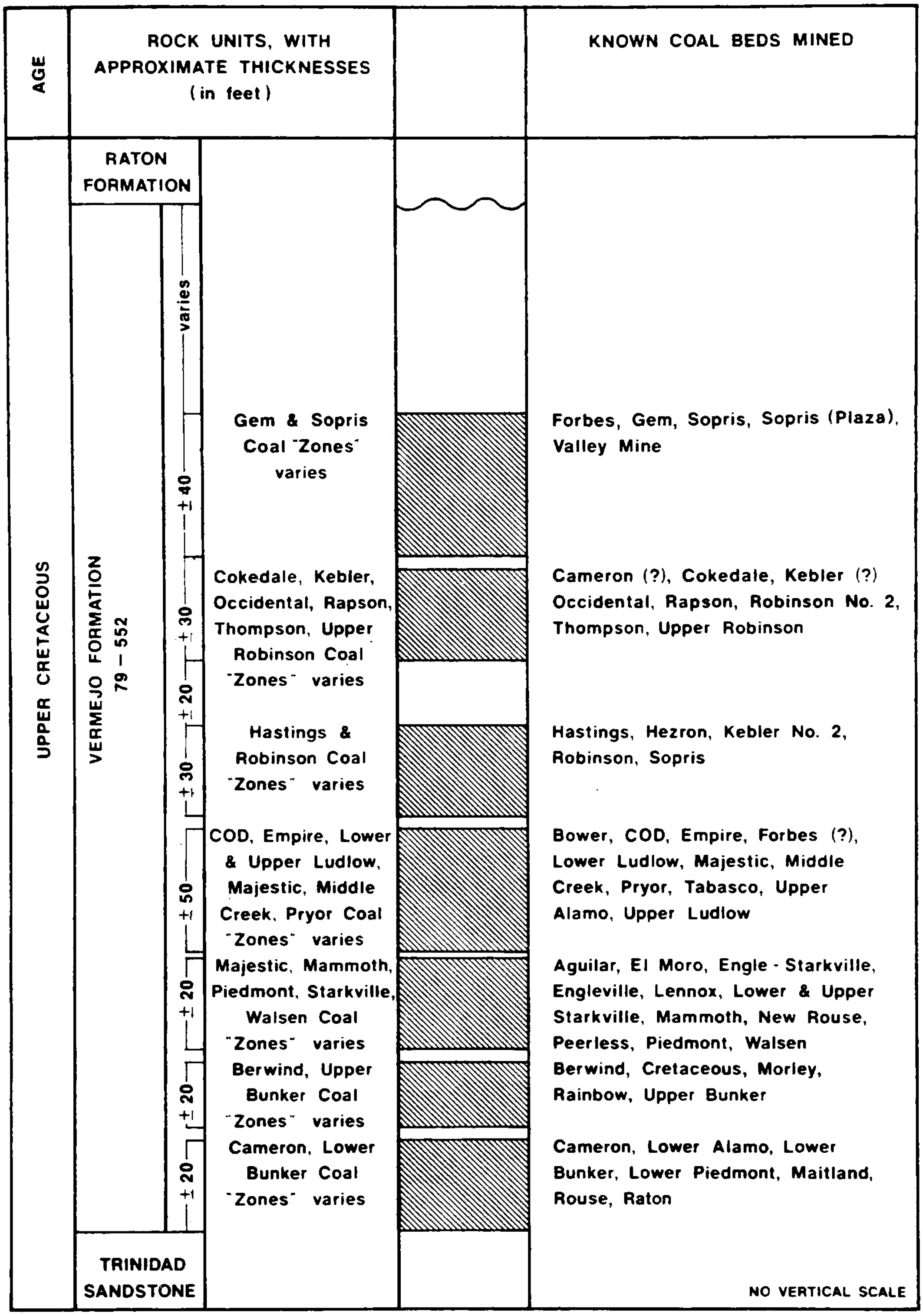


Figure 18. Generalized columnar section of the coal bearing rocks in the Vermejo Formation, Raton Mesa coal region, Colorado. Shaded areas are the general locations of the coal zones (from Boreck and Murray, 1979, p. 49).

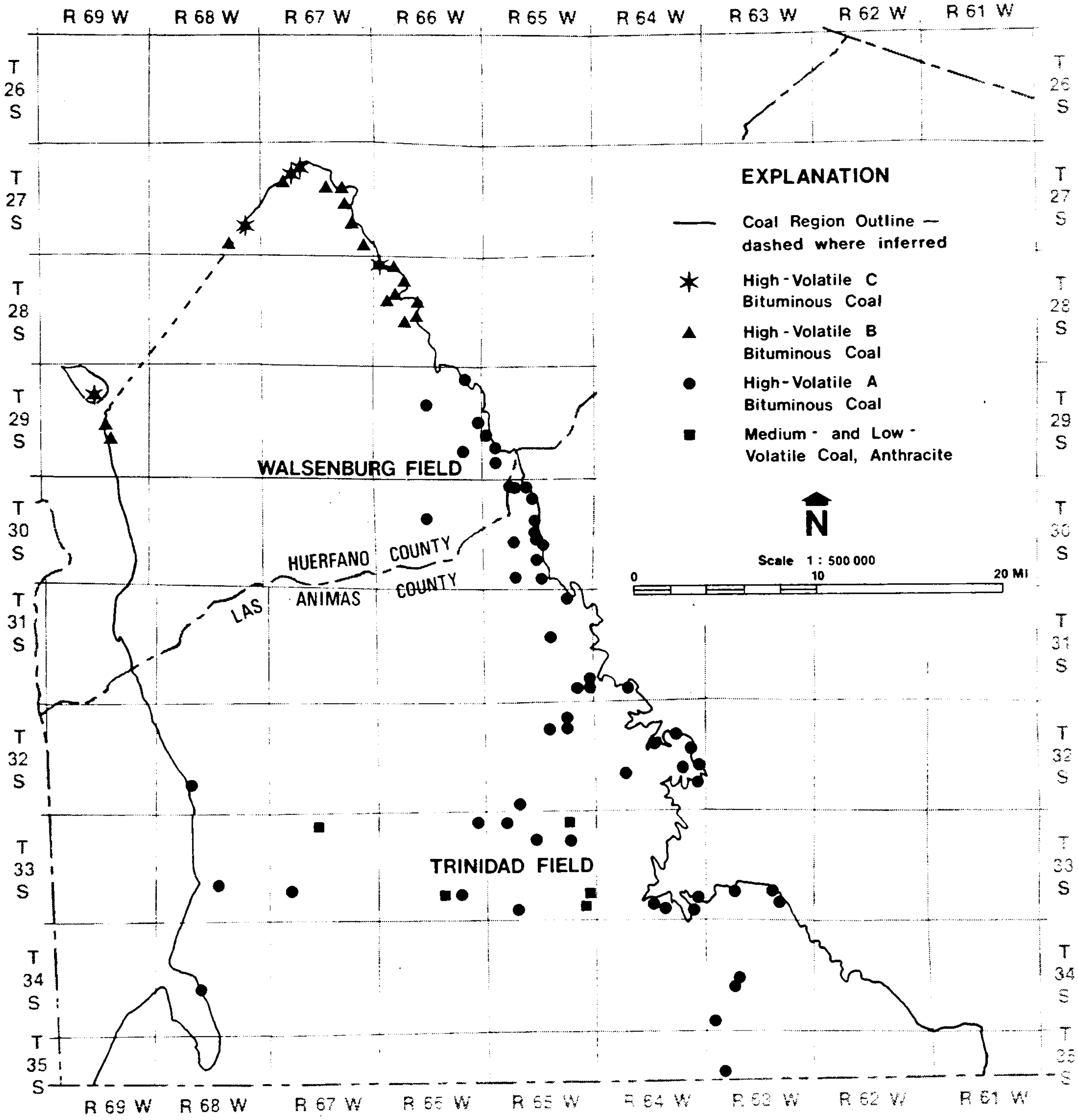


Figure 19. Coal rank map of the Raton Mesa coal region, Colorado (after Goolsby, 1979, plate 1).

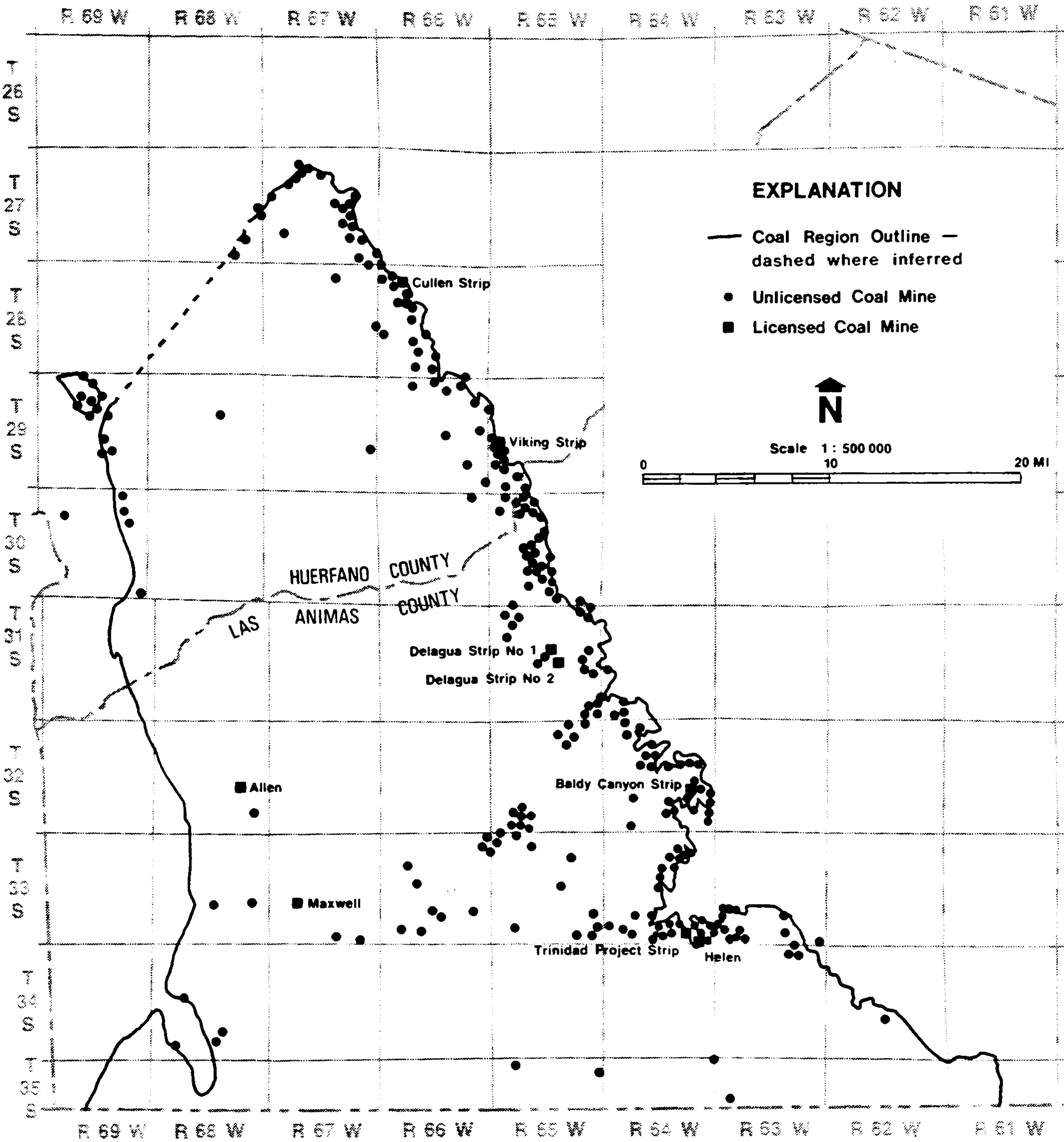


Figure 20. Coal mines in the Raton Mesa coal region, Colorado.

TABLE II. 1979 Coal Production

County & Mine	Company or Operator	No. Men (Average)	Total Days	Tonnage
HUERFANO				
Cullen Strip	Cullen Construction Company	-	-	-
Viking Strip	Thyssen Mining Construction Company	8	170	49,682
TOTALS - 2		8	170	49,682
LAS ANIMAS				
Allen	CF&I Steel Corporation	505	263	634,686
Baldy Canyon Strip	National Energy Resources, Inc.	5	145	2,587
Delagua Strip No. 1	Delagua Coal Company	-	-	-
Delagua Strip No. 2	Delagua Coal Company	5	290	39,000
Helen	Animas Coal Company, Inc.	7	354	18,993
Maxwell	CF&I Steel Corporation	88	255	125,398
Trinidad Project Strip	National Energy Resources, Inc.	-	-	-
TOTALS - 7		610	1,307	820,664

COAL BED METHANE

Project History

Coal has been mined commercially in the Colorado portion of the Raton Basin since 1870 (Pillmore, 1969, p. 126). Reports of methane gas occurrences in the coal mines date back to the same period. Oil and gas exploration in the region began late in the last century. Explorationists encountered methane gas as they drilled through coal zones; they even tested some coal beds. Today coal mines, coal core holes, and oil and gas tests are still encountering large amounts of coal-derived methane. If the amount and source of this gas could be better defined, possible coal mining hazards could be predicted and an untapped gas source utilized.

In 1975, the U.S. Bureau of Mines provided the Colorado Geological Survey with a grant to gather data on the methane potential of the coal beds of Colorado. During this grant, Survey geologists located historically gassy mines and recorded methane emission rates from operating mines (refer to Fender and Murray, 1978). In addition, Survey geologists began using the U.S. Bureau of Mines "direct method" of desorbing (or measuring the gas emitted by) fresh coal core samples to determine the total gas content of a coal.

Today, this research continues under two grants - a U.S. Department of Energy Grant entitled "Evaluation of the Methane Potential of Unmined/Unminable Coalbeds in Colorado" and a Colorado Oil and Gas Conservation Commission grant entitled "Conservation of Methane from Mined/Minable Gaseous Coal Beds".

Specific instances of methane occurence in Raton Mesa region coals include the following examples:

1) Hollis Fender and D. K. Murray (1978) recorded 37 coal mines with reported occurrences of gas. These mines are shown in Figure 21.

2) The Allen Coal Mine (Fig. 22) emitted an average of 410 MCFD of methane during the period of 1974-1976; the mine produced 1,790,759 tons of coal during that period.

3) The Maxwell Mine (Fig. 22) emitted an average of 377 MCFD during 1979; it produced 125,398 tons of coal that year.

4) The Energetics Healy No. 13-8 in sec. 8, T. 31 S., R. 65 W. (Fig. 22), reported background gas of 100% methane throughout the coal interval.

5) Filon Exploration Corporation's No. 1 Zeles Hope, at sec. 31, T. 31 S., R. 65 W. (Fig. 22), recovered some burnable gas after fracturing a 5 ft Raton Formation coal.

6) In the Continental Oil Company Colorado Fuel and Iron Corporation No. 1, sec. 13, T. 34 S., R. 66 W. (Fig. 22), a 12 ft Vermejo coal bed was drill stem tested. The tool was open for 1 hr and 45 min and couldn't be shut in; however, there was a good blow for the entire test and 100 ft of mud was recovered.

7) Thirty eight completed "direct method" tests on coal core samples indicate methane in the coal of up to 16.06 cm^3/g (cubic centimeters of gas per gram of coal) or 514 ft^3/ton (cubic feet of gas per ton of coal) (see Table III).

"Direct Method" Test

Description

In the Bureau of Mines direct desorption method, a sample of coal approximately 1,000 g in weight is obtained from a conventional core and is sealed in a desorption cannister (usually made of plastic or aluminum)

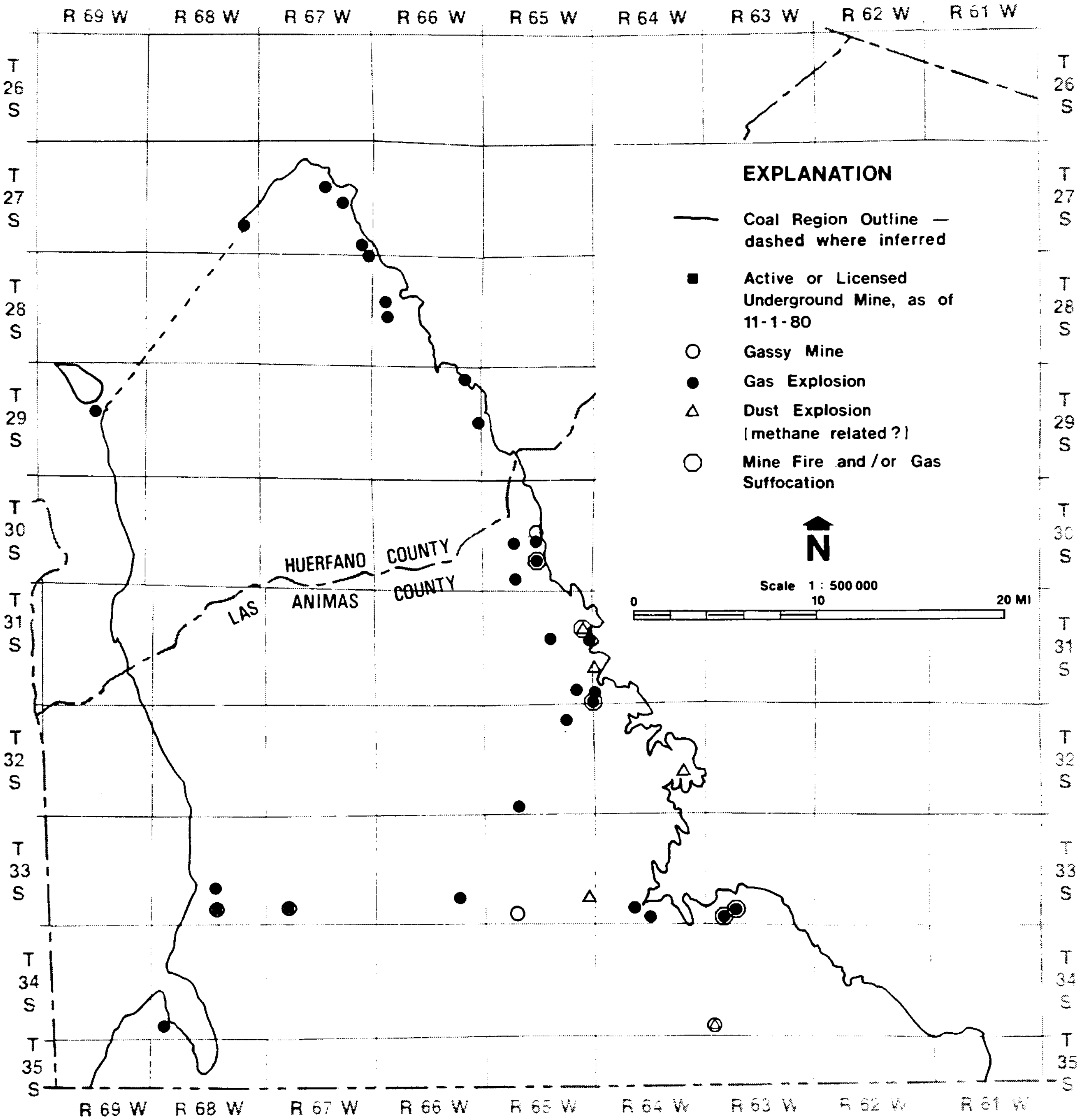


Figure 21. Coal mines with reported gas occurrences in the Raton Mesa coal region, Colorado (after Fender and Murray, 1979, plate 1).

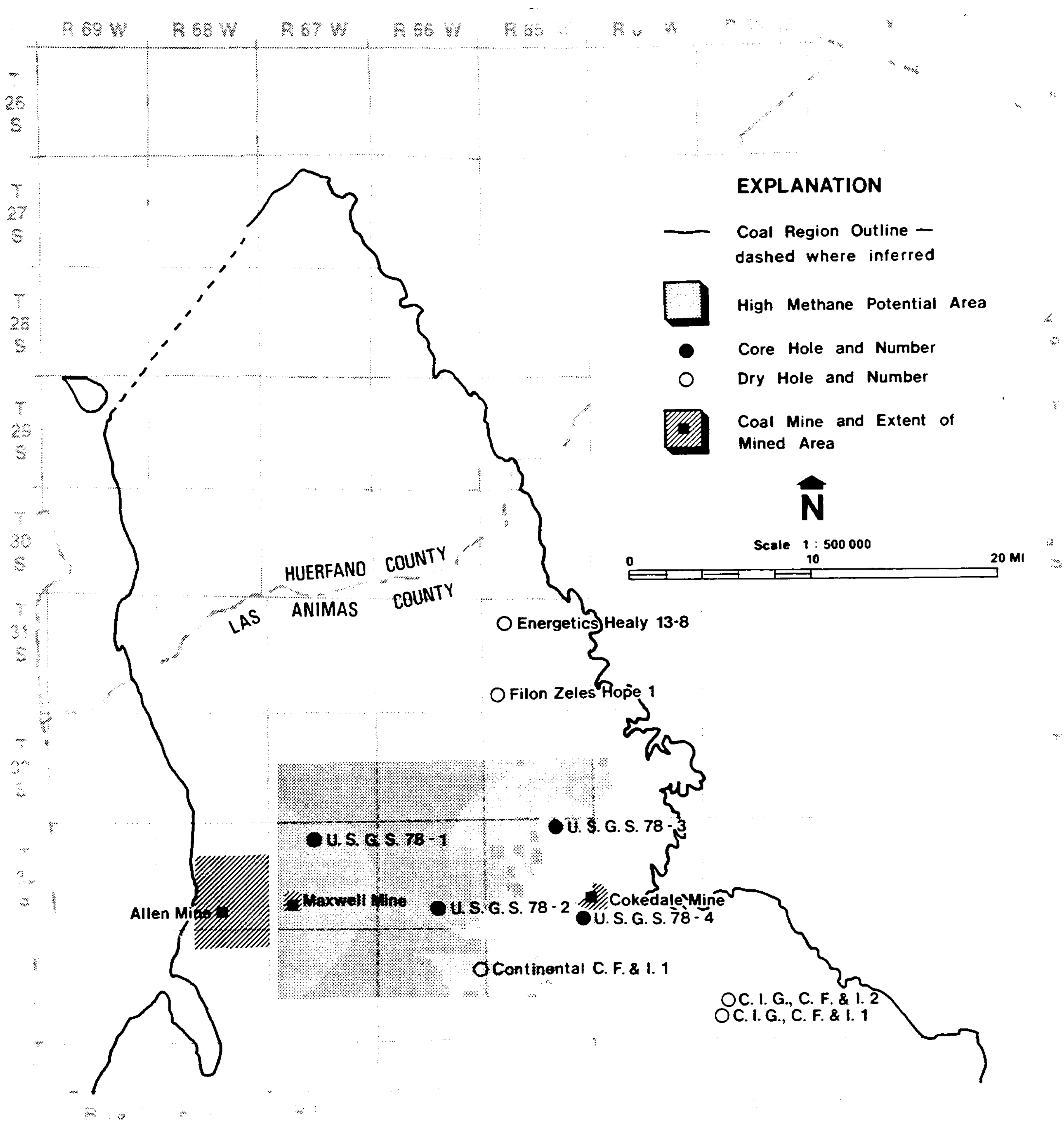


Figure 22. High methane potential area in the Raton Mesa coal region, Colorado.

TABLE III. DESORPTION RESULTS

TEST NO.	FORMATION	DEPTH TO BED (ft)	BED THICKNESS (ft)	SAMPLE WEIGHT (g)	DESORBED GAS (cm^3)	LOST GAS (cm^3)	RESIDUAL GAS (cm^3/g)	TOTAL GAS (cm^3/g)	TOTAL GAS (ft^3/ton)	% METHANE IN GAS (air free)	HEATING VALUE OF GAS (Btu/ft^3)	COAL ANALYSIS (as received-basis) FIXED CARBON%	VOLATILE Matter %	ASH %	MOISTURE %	SULFUR %	HEATING VALUE (Btu/lb)	APPARENT RANK OF COAL
								TRINIDAD FIELD										
1	Raton	810.0	2.0	2319	3086	370	0.10	1.59	51	66.78	698	16.5	7.3	74.2	2.0	1.4	2444	sh[2]
2	Raton	828.0	.45	1098	755	130	0.00	0.81	26	--	--	7.1	10.6	78.9	3.4	1.6	1708	hvCb[3]
3	Raton	1053.5	.4	2308	4731	480	0.00	2.26	72	91.75	925	15.7	14.5	66.3	3.5	.4	3888	hvBb[4]
4	Raton	1063.1	2.0	1710	9441	850	0.01	6.03	193	83.34	841	25.5	16.0	56.4	2.1	.5	5733	mvb[5]
5	Vermejo	1691.2	4	1600	14255	3400	0.04	11.07	354	46.14	465	62.4	25.2	11.7	.6	.7	13517	mvb
6	Vermejo	1792.0	3	1724	18098	8300	0.06	15.37	492	97.16	980	63.1	20.9	15.7	.3	.6	12955	mvb
7	Raton	309.2	2	1461	3390	170	0.16	2.60	83	--	--	48.6	14.3	36.2	.9	.5	9305	lvb[6]
8	Raton	482.2	1.5	1057	2031	890	0.00	2.76	88	--	--	42.1	21.6	35.2	1.1	.5	9595	mvb
9	Raton	499.7	2	767	2719	1110	0.00	4.99	160	--	--	55.6	24.9	19.0	.5	.5	12267	mvb
10	Vermejo	729.4	3	1768	10176	3300	0.33	7.95	254	98.98	997	46.8	23.4	28.9	.9	.6	10757	mvb
11	Vermejo	100.5	2	808	158	170	0.30	0.71	23	--	--	41.5	18.7	39.0	.8	.3	9056	mvb
12	Vermejo	167.9	3	553	1057	800	0.20	3.56	114	--	--	47.6	21.9	29.6	.9	2.5	10507	mvb
13	Vermejo	715.6	2	876	88	--	1.35	1.45	46	--	--	52.8	35.0	11.3	.9	.7	13332	hvAb[7]
14	Vermejo	810.0	5.5	1051	74	115	0.00	0.18	6	--	--	50.2	28.2	20.7	.9	.7	11598	hvAb
15	Vermejo	812.5		1657	56	65	0.00	0.07	2	--	--	53.0	30.5	15.6	.9	.7	12623	hvAb
16	Vermejo	857.5	1.2	1107	4409	280	0.60	4.84	155	81.62	822	52.5	34.3	12.2	1.0	.7	13259	hvAb
17	Vermejo	869.5	2.4	1661	6589	360	0.40	4.58	147	81.49	821	51.0	31.1	16.9	1.0	1.0	12344	hvAb
18	Vermejo	875.0	.5	1223	3183	100	0.50	3.20	102	--	--	38.5	28.5	31.0	2.0	.9	10108	hvAb
19	Vermejo	868.0	2.1	1035	505	70	0.60	1.16	37	--	--	24.1	18.6	55.6	1.7	.4	6177	hvAb
20	Vermejo	872.5	.5	1122	220	10	0.14	0.40	13	--	--	30.5	26.0	42.5	1.0	.5	8352	hvAb
21	Vermejo	961.7	4.65	753	260	130	0.61	1.13	36	--	--	51.2	29.5	18.3	1.0	.7	12076	hvAb
22	Vermejo	963.9		1014	270	70	0.69	1.03	33	--	--	49.0	29.3	20.8	.8	.7	11710	hvAb
23	Vermejo	1005.5	.45	1152	745	130	0.44	1.20	38	--	--	50.6	35.8	12.9	.7	.6	13118	hvAb
24	Vermejo	1012.8	1.6	796	445	170	1.90	2.70	86	--	--	56.7	29.8	12.3	1.2	.7	13067	hvAb
25	Vermejo	1029.1		809	320	90	1.20	1.71	55	--	--	53.0	29.0	17.3	.7	.9	12338	hvAb
26	Vermejo	1030.0	3.2	938	335	160	1.11	1.64	52	--	--	47.3	30.7	21.3	.7	.8	11737	hvAb
27	Vermejo	1030.0		478	847	200	0.65	2.84	91	--	--	45.0	27.9	25.9	1.2	.7	10914	hvAb
28	Vermejo	1192.1	2.6	1286	13430	7100	0.10	16.06	514	93.7	949[1]	60.2	19.7	19.3	.8	.5	12417	mvb
29	Raton	223.8	2.8	485	195	470	0.00	1.58	51	--	--	46.8	41.2	10.5	1.5	.7	13223	hvAb
30	Raton	343.0	3	702	1640	120	0.30	2.8	90	--	--	52.0	33.2	12.9	1.9	.6	12665	hvAb
								WALSENBURG FIELD										
31	Vermejo	111.0	4.0	1049	51	75	0.36	0.93	30	--	--	44.4	37.0	11.1	7.5	.7	12971	hvCb
32	Vermejo	155.0	6.0	1211	82	241	0.41	1.08	35	--	--	43.8	36.4	13.0	6.8	.6	12943	hvCb
33	Raton	674.7	2.7	315	185	300	0.10	1.60	53	--	--	50.5	34.4	14.0	1.1	.5	12524	hvAb
34	Raton	896.0	4.0	352	157	370	0.00	1.50	48	--	--	55.3	35.8	7.8	1.1	.6	13676	hvAb
35	Vermejo	1136.7	5.6	549	134	550	0.80	2.05	66	--	--	50.1	32.8	16.0	1.1	.6	12228	hvAb
36	Vermejo	1006.6	3.9	369	32	300	0.00	0.90	29	--	--	54.2	36.2	8.2	1.4	.6	13328	hvAb
37	Vermejo	1012.6	4.5	584	54	30	0.00	0.14	5	--	--	50.1	34.6	13.9	1.4	.6	12484	hvAb
38	Vermejo	1073.5	1.6	257	48	90	0.00	0.54	17	--	--	51.8	38.0	9.0	1.2	1.4	13253	hvAb

1 4.6% nitrogen and air contamination; heating value probably higher
2 shale
3 High-volatile C bituminous coal
4 high-volatile B bituminous coal
5 medium-volatile bituminous coal
6 low-volatile bituminous coal
7 high-volatile A bituminous coal

immediately after the core has been removed from the core barrel. The gas emmitted by the coal is measured daily (by water displacement in an inverted graduated cylinder [Fig. 23]) until emission (desorption) ceases.

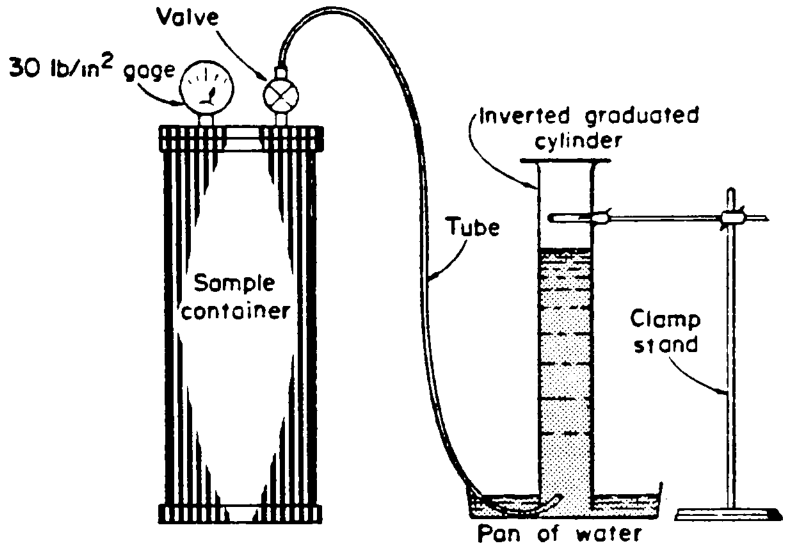


Figure 23. Methane desorption equipment (after McCulloch and others, 1975, p. 4).

The gas lost from the coal between the time it was first penetrated by the core bit and the time it was encapsulated in the cannister is estimated using a "back calculation" method. After desorption, the residual gas in the coal is measured (by the same water displacement method) after the coal is crushed in a sealed ball mill at the U.S. Bureau of Mines' Pittsburgh (Bruceton) facility. The estimated lost gas, plus the measured desorbed and residual gas, are added to give the total in-place gas content (in cm^3/g or ft^3/ton) of the coal bed. (Refer to McCulloch and others, for a more complete description of this method.)

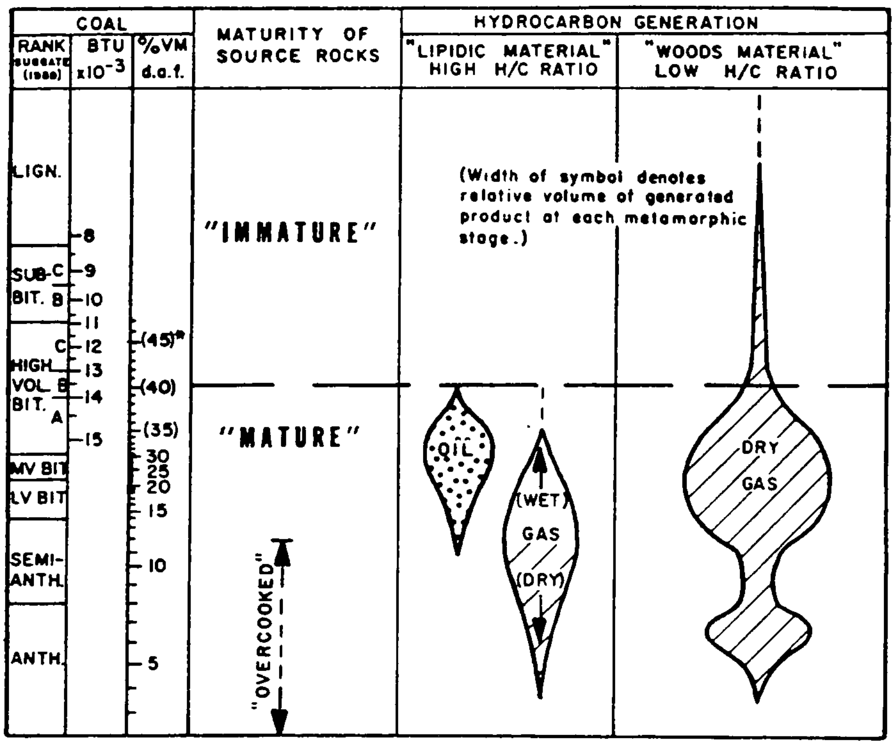
After completion of the residual gas measurements, the samples are sent to the Department of Energy's Pittsburgh laboratory for proximate, ultimate, and related analyses and to the U.S. Geological Survey in Denver for geochemical (including trace-element) analyses. In certain cases, a sample of coal is saved from residual crushing for petrographic analyses. In addition, if the samples emit sufficient gas during the initial days of desorption, a gas sample can be taken from the desorption cannister for hydrocarbon analysis and/or carbon isotope analysis.

Results

As mentioned above, the Colorado Geological Survey has completed 38 "direct method" tests on coal samples from the Raton Mesa coal region. Total gas contents of the 30 Trinidad Field samples range from 0.07 cm^3/g (2 ft^3/ton) to 16.06 cm^3/g (514 ft^3/ton) as shown in Table III. Total gas contents from the 8 Walsenburg Field samples range from 0.14 cm^3/g (5 ft^3/ton) to 2.05 cm^3/g (66 ft^3/ton) (Table III). Methane contents of the 8 gas samples analyzed ranged from 46.14% to 98.98%; heating values ranged from 465-997 Btu/ft^3 (see Table III).

Observations

As can be seen from the Hood diagram (Fig. 24), gas generation increases as rank increases; in addition, the greatest amount of gas is generated when a coal is medium-volatile in rank. However, plotting medium-volatile gas contents vs. depth as in Fig. 25 shows the generated gas is not necessarily retained; the in-place gas content in medium-volatile coals increases with increasing overburden depth. Therefore, it is not surprising that the gassiest samples in the region (nos. 4, 5, 6, 10, and 28, Table III) are of medium-volatile rank and were taken from a depth of 1,000 ft or greater.



After Vassoyevich, et al (1970) and Hood, et al (1975), in part.
*% VOLATILE MATTER IN PARENTHESIS IS SUITABLE ONLY FOR HUMIC, VITRINITIC COALS.

Figure 24. Coal rank related to hydrocarbon generation (from Dolly and Meissner, 1977, p. 261).

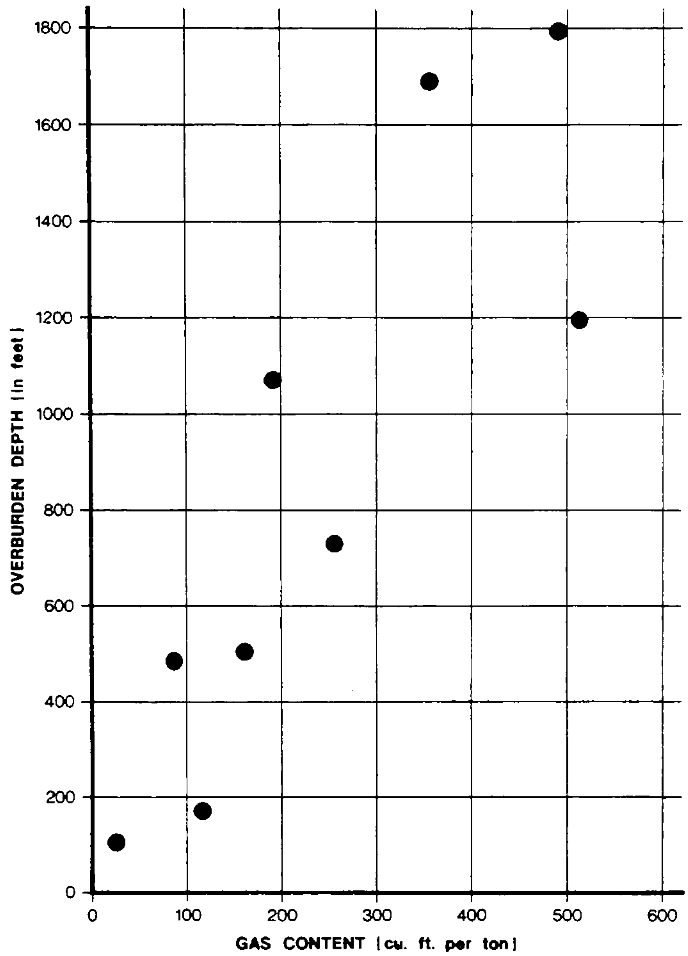


Figure 25. Graph of gas content versus depth for nine medium-volatile coal samples from the Trinidad Coal Field, Raton Mesa coal region, Colorado.

High Potential Area

Desorption tests indicate the highest methane potential area in the coal region is in the Trinidad Coal Field bordering the Purgatoire River (Fig. 22). Overburden depth, coal rank, mine emissions and gas shows in oil and gas tests can provide tentative boundaries to the high potential area. The eastern boundary is the 1000 ft overburden contour on top of the Trinidad Sandstone (the base of the coal bearing interval); U.S.G.S. DH 3 & 4 show that there are shallow gas bearing medium-volatile coals east of this line (see sample nos. 10-12) and there is a medium-volatile coal sample at Cokedale, Colorado. The western boundary is a north-south line half way between the Allen and Maxwell Mines; based on the U.S. Bureau of Mines method of relating mine methane emissions to coal gas content, the Maxwell contains coal of 122-183 ft^3/ton and the Allen coal of 28-42 ft^3/ton (see Appendix A). The southern boundary is the east-west line approximately half way between the Continental CF&I well mentioned earlier and the Colorado Interstate Gas CF&I holes 1 & 2 which contained only moderately gassy high-volatile A coals from the surface to the Trinidad Sandstone (nos. 13-27, Table III). The northern boundary is drawn in an east-west direction through the middle of T. 32 S., R. 65, 66, and 67 W.; just south of this township (Fig. 19) Vermejo coals are medium-volatile and gas bearing, while north of the township (Fig. 19) they are high-volatile with lower gas contents. These boundaries enclose an area of approximately 179 sq mi.

Resource Estimates

Multiplying the area of high methane potential by the coal thicknesses in that area will provide a volume of coal that has a high gas content. This volume multiplied by an average gas content of 404 ft^3/ton yields an in place gas content of 1.56 trillion cubic feet of gas in the Vermejo coals of the outlined high potential area (see Appendix

However, there is presently no way to predict what percentage of the total in place gas is recoverable. The City of Trinidad is presently drilling for coal bed methane in sec. 32. T. 33 S., R. 66 W. The City's wells will be the first complete test of coal gas producibility in the region.

CONCLUSIONS

The geologic evidence presented in this paper indicates the coals of the Raton Mesa coal region contain a large amount of gas--1.56 trillion cubic ft in the Vermejo coals of the high potential area alone.

However, many questions must be answered before it can be concluded that this gas is a true resource. The percentage of the gas that is recoverable can only be determined by production. The best methods of fracturing and completion in the sensitive coal bed reservoirs must be determined. The U.S. Bureau of Mines, the U.S. Department of Energy, and many private companies are presently attempting to answer these questions. Furthermore, geophysical logs to detect the presence of gas in coal beds do not yet exist. And, of course, site specific questions such as the location of pipelines, gas ownership, and the market for the gas must be addressed.

Nevertheless, coal bed gas reservoirs are easily found using coal rank, depth, and desorption data that can be obtained at little cost during drilling for coal reserve information or oil or gas targets. It is hoped that these potential coal reservoirs will be considered in all ongoing exploration so that coal gas reservoirs can be quickly exploited when the economics justify such development.

Disclaimer

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However, any opinions, findings, conclusions, or recommendations expressed herein are those of the author and do not necessarily reflect the views of DOE."

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APPENDIX A. GAS CONTENT FROM MINE EMISSIONS

Mine	Coal Production* (tons)	Average Methane Emissions**
Maxwell	125,398 in 1979	376,550 ft^3/day
Allen	1,790,759 from 1974-76	410,000 ft^3/day

Maxwell

125,398 tons/year - 365 days/year = 343.6 tons/day

376,550 ft^3/day - 343.6 tons/day = 1095.9 ft^3/ton

Allen

1,790,759 tons - 3 years   365 days/year = 1635.4 tons/day

410,000 ft^3/day - 1635.4 tons/day = 250.7 ft^3/ton

However, these methane emissions could be coming from strata adjacent to the coals and the ribs, pillars, and gob areas of the mines. For six mines where the U.S. Bureau of Mines compared the mine emission versus the direct method gas content, it was found that the mine gas content calculated from mine emission data (as above) was six to nine times as great as the actual measured gas content of a coal sample (Kissell and others, 1973, p. 8). Therefore, the figures below are probably closer to the true gas content of the coal.

Maxwell

1095.9 ft^3/ton - 6 = 183 ft^3/ton

1095.9 ft^3/ton - 9 = 122 ft^3/ton

Allen

250.7 ft^3/ton - 6 = 42 ft^3/ton

250.7 ft^3/ton - 9 = 28 ft^3/ton

*from the Colorado Division of Mines records
**from William Turner, Mine Safety and Health Administration

APPENDIX B. RESOURCE ESTIMATE

To provide a resource estimate for the high potential area, the total isopach map of Vermejo coals[1] (Plate 2, Map D) was overlain with the outline of the high potential area (Fig. 22). The area of the four regions shown below was then measured using a planimeter. The thickness of these areas in feet was estimated from the isopach map and the coal volume was calculated as shown below.

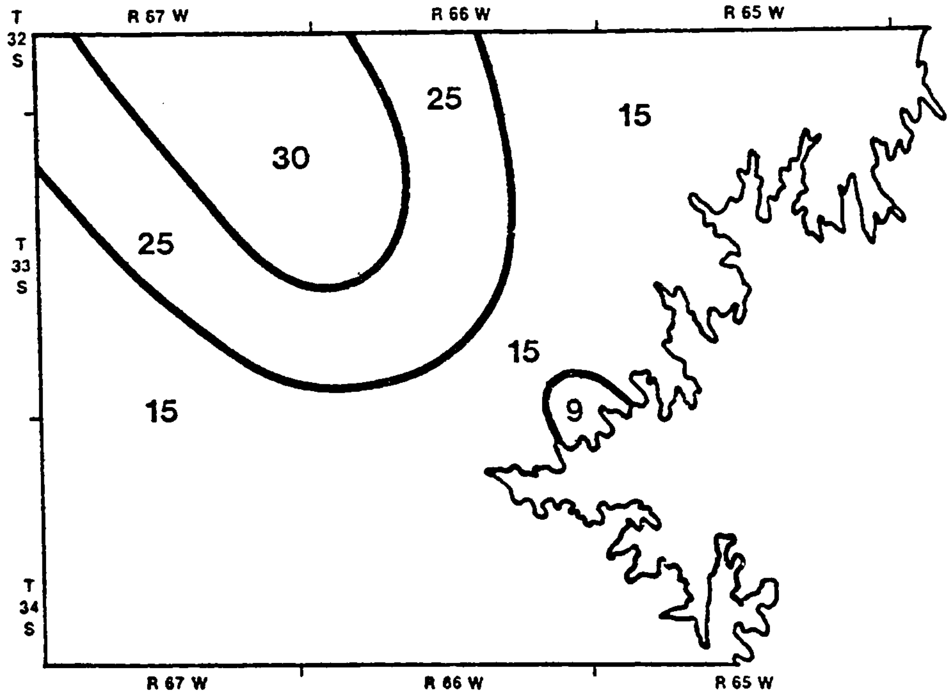

Figure B-1. Resource estimate map. The numbers represent average coal thicknesses (in ft) of each area.

thickness (ft) x area (mi^2) x 640 acres/mi^2 = acre feet

30	x	22	x	640	=	422,400
25	x	35	x	640	=	560,000
9	x	2.4	x	640	=	13,824
15	x	120	x	640	=	1,152,000
Totals		179.4 mi^2				2,148,224 acre feet

The Vermejo coals in this area are bituminous (Fig. 19) and according to Landis (1959, p. 134),there are about 1800 tons in an acre foot of bituminous coal.

The average gas content measured for Vermejo coals in this area is 404 ft^3/ton (averaging nos. 5, 6, 10, and 28 Table III).[2]

2,148,224 acre feet x 1800 tons/acre foot x 404 ft^3/ton = 1.56 trillion cubic feet of gas.

[1]Only Vermejo coals are considered in this estimate since they are the most continuous, deepest, highest ranking and gassiest coals in the area.

[2]These measurements have not been adjusted to standard cubic feet.

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BY CAROL MORGANS TREMAIN

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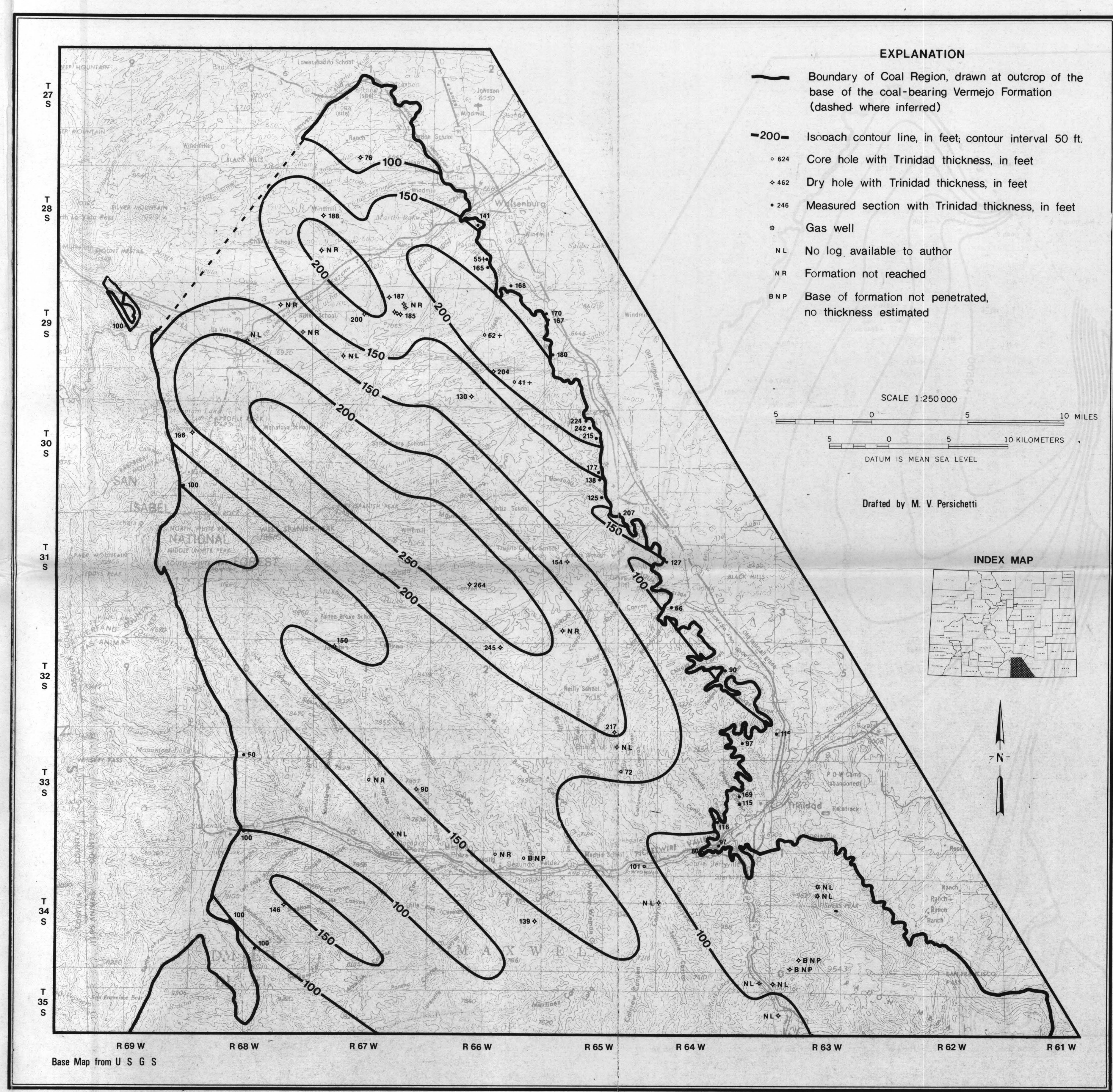
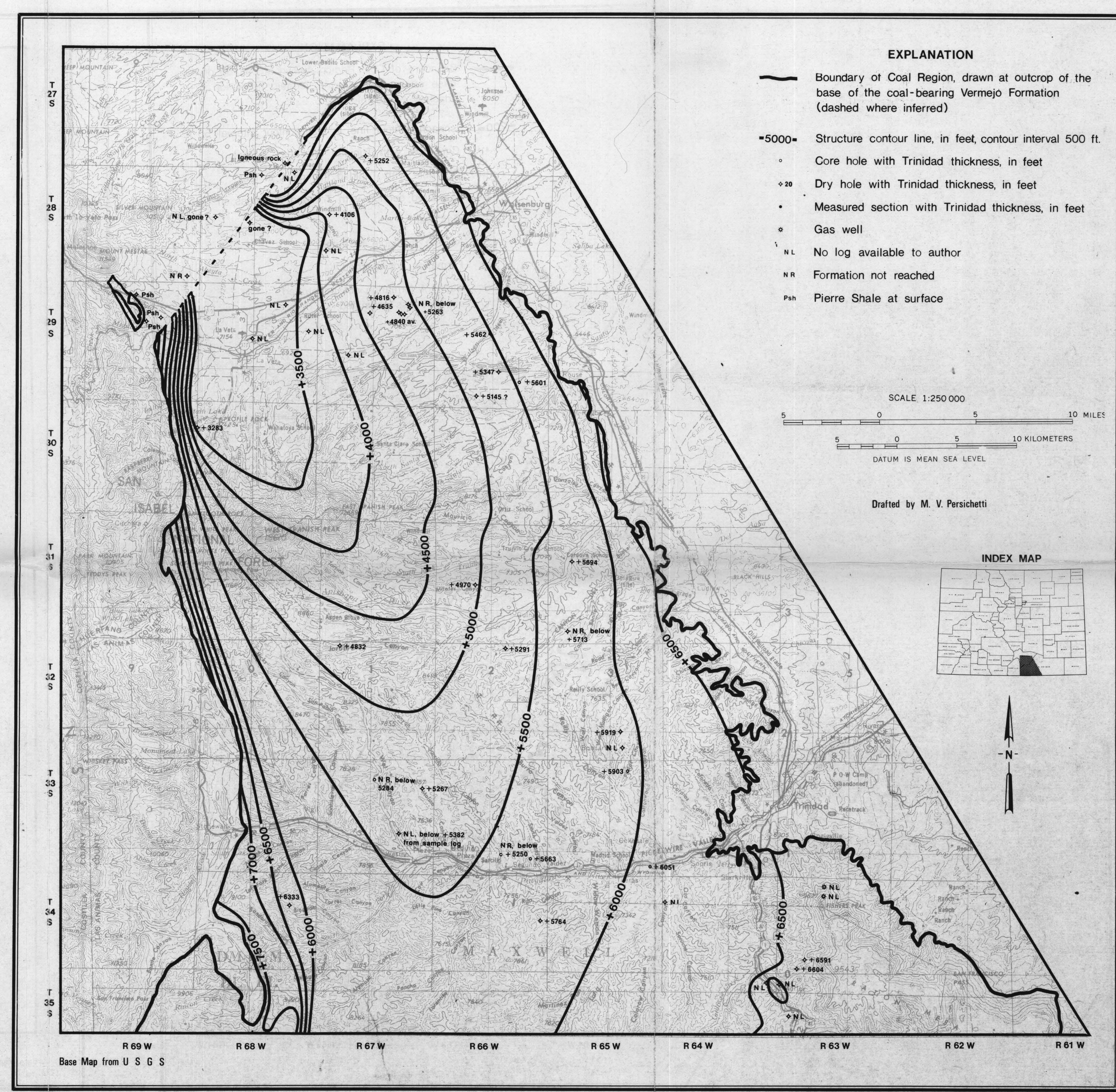
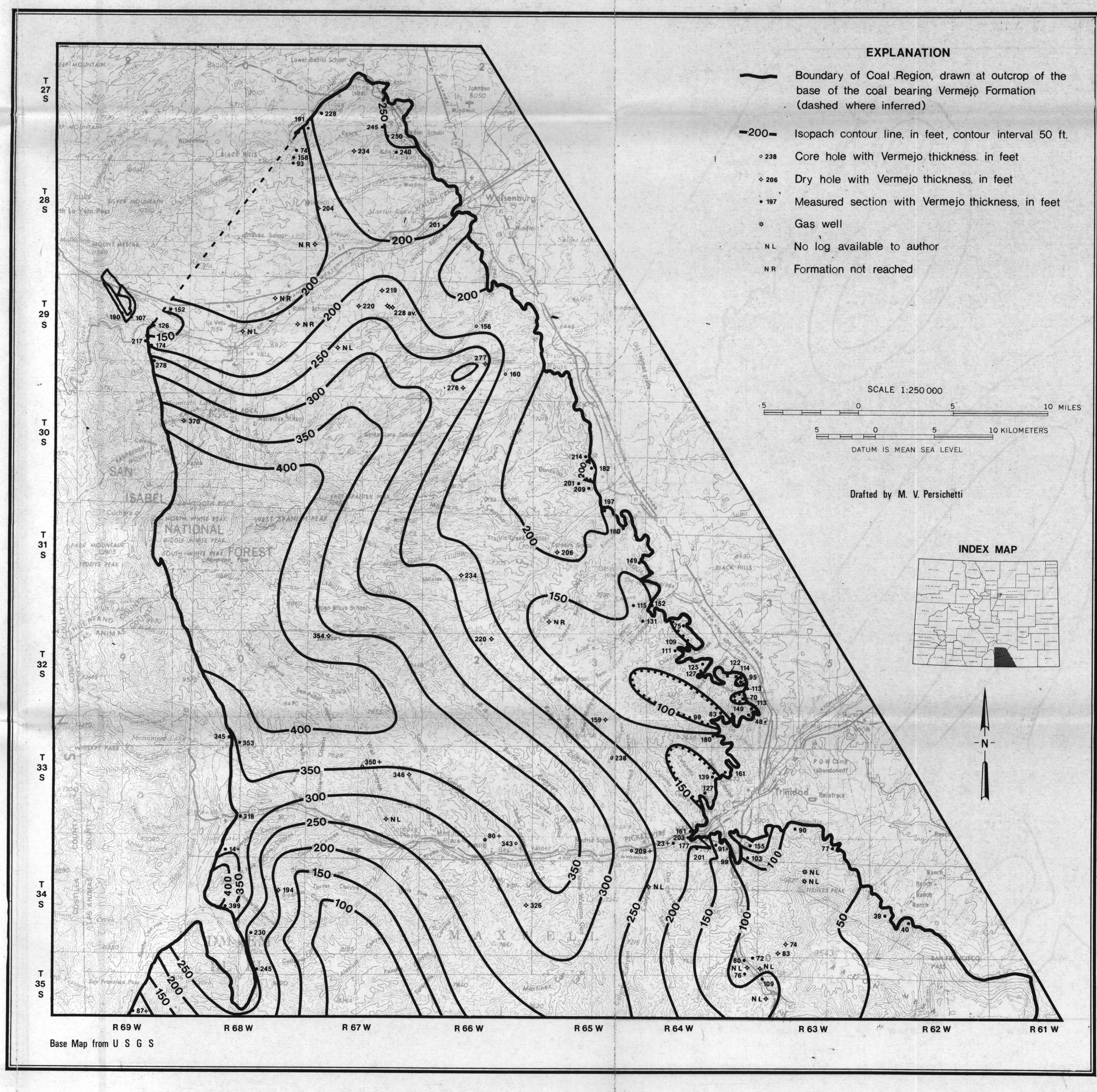
PLATE 2 OF 2



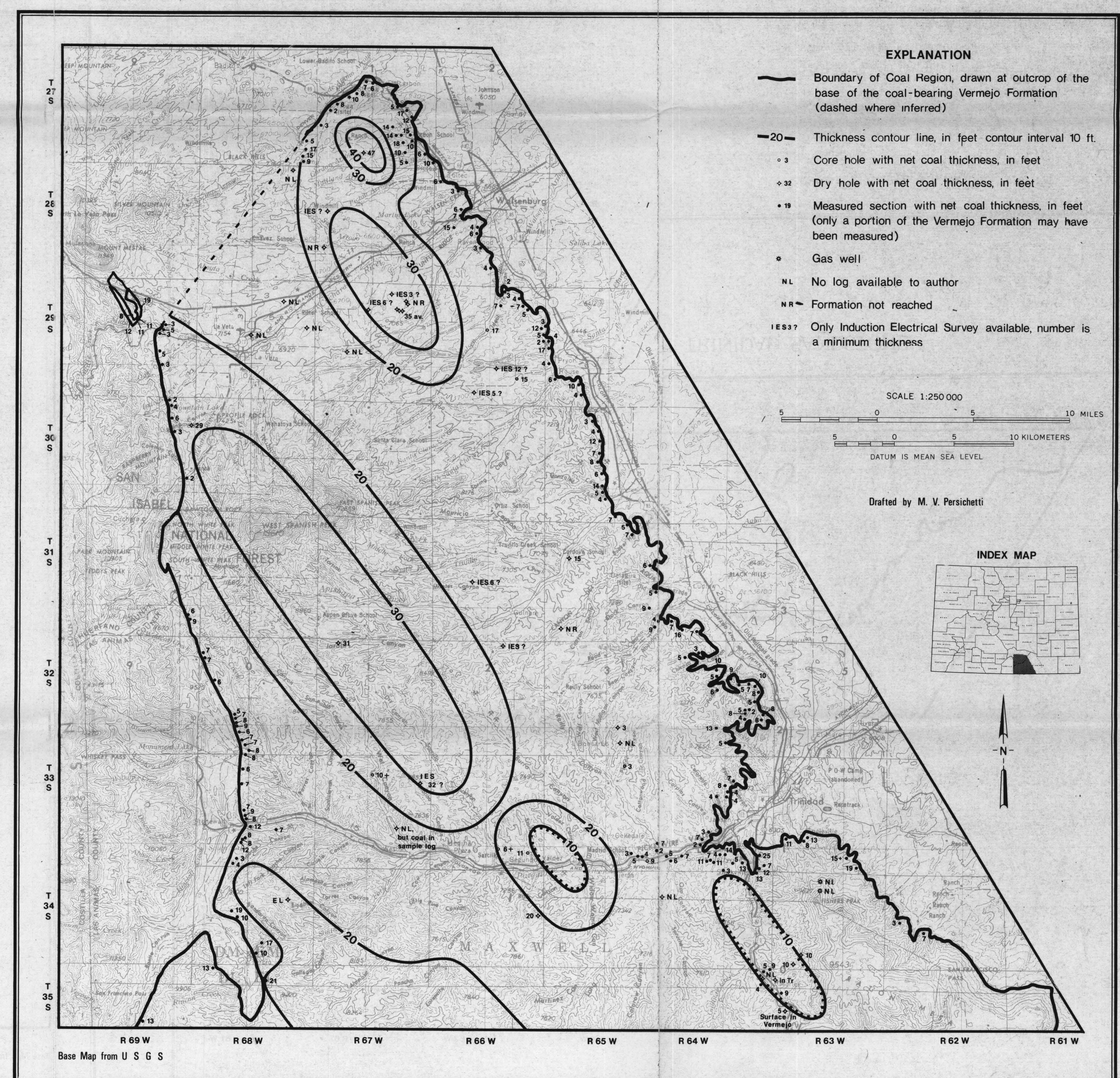
MAP A - ISOPACH MAP OF THE TRINIDAD SANDSTONE



MAP B - STRUCTURE MAP ON TOP OF THE TRINIDAD SANDSTONE



MAP C - ISOPACH MAP OF THE VERMEJO FORMATION



MAP D - NET COAL THICKNESS MAP OF THE VERMEJO FORMATION COALS